SECOND EDITION

RENEWABLE ENERGY in Europe

Markets, trends and technologies








EREC

Renewable Energy in Europe

Renewable Energy in Europe

Markets, Trends and Technologies

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Intelligent Energy Europe

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Preface

Renewable Energy in Europe presents an overview of the latest political, technological, financial and economic information on renewable energy technologies in the fields of heating and cooling, electricity and biofuels for transport. The book provides insights and gives ideas about how to best reach the binding 2020 target of at least 20 per cent renewable energy from final energy consumption, as outlined in the Directive on the promotion of the use of energy from Renewable Energy Sources (RES) that came into force in 2009. If properly implemented, this Directive will become the most ambitious piece of legislation on renewable energy in the world.

In order to reach the binding overall 20 per cent target outlined in the RES Directive, the development of all existing renewable energy sources as well as a balanced and integrated mix of deployment in the sectors of heating and cooling, electricity and transport is needed. This book, *Renewable Energy in Europe*, is targeted towards policy makers at all levels, European, national, local and global. It gives clear, objective and reliable information on the role and potential of RES in the fields of heating and cooling, electricity and biofuels for transport as well as on the policy requirements to exploit the full potential of renewable energy in these three areas.

During recent years, the European Union (EU) has put considerable effort into creating a favourable political framework for RES, thereby contributing to the security of energy supply and to climate protection as well as to strengthening the EU RES industry, one of the fastest growing sectors in Europe, which in 2009 employed more than 450,000 people and generated an annual turnover surpassing €45 billion.

In order to keep the leadership of the European RES industry, a strong home market with stable framework conditions is necessary. To ensure this, a rapid transposition into national law of the RES Directive is crucial. The European Union needs to continue to play a leading role in the field of renewable energy and be a vital driver towards a remodeling of our energy system based on RES and energy efficiency.

Investment decisions in new energy generating capacity taken today will have an impact on Europe's energy mix for the next 40 years. Europe should lead the way with a clear commitment to a 100 per cent renewable energy future by 2050. This is not only technologically feasible, but also the only really sustainable alternative both in economic, security of supply and environmental terms. The analysis of investment patterns in new electricity generating capacity confirm that renewable energy technologies accounted for 61 per cent of new power generating capacity in 2009 (mainly wind and photovoltaic), an increase on the 2008 share of 57 per cent. Europe is on a promising track, however we need to continue and speed up the needed transformation of our energy system through continuous and stable commitments and policy frameworks, particularly in these economically challenging times. Especially in times of financial turmoil it becomes clear that the promotion of RES is the most successful programme for a sustainable economic recovery.

The end of 2009 was marked by the disappointing outcome of Copenhagen (COP15). COP15 did not keep up with the aspirations that an agreement would be found on a much needed ambitious new international climate treaty, thereby providing the necessary boundary conditions to limit dangerous climate change and promoting existing solutions such as renewable energy. An ever growing number of people are convinced that we cannot wait for a new international agreement and that action is needed straight away. More and more individuals, communities, cities and regions continue to invest in energy efficiency and RES. The much needed Energy[R]evolution needs to happen, if not top-down, then bottom-up.

Europe cannot achieve the necessary change alone; it needs to lead the world by example and remain a strong advocate for renewable energy in the global arena. This publication, which is co-funded by the Competitiveness and Innovation Programme (CIP) of the European Commission, provides an encompassing overview of the benefits of renewable energy use in the sectors of heating and cooling and electricity and transport. It provides a synthesis of the state-of-the art of renewable energy deployment in these sectors and gives a concise outlook of what is needed to help renewable energy sources unfold their full potential and how to best integrate them in order to shape a sustainable energy system for the EU.

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This book has been compiled by the European Renewable Energy Council (EREC), based in Brussels, as part of the IEE-funded project SUPPORT_ERS (www.support-ers.eu). EREC's members are:

- AEBIOM (European Biomass Association)
- EGEC (European Geothermal Energy Council)
- EPIA (European Photovoltaic Industry Association)
- ESHA (European Small Hydropower Association)
- EREF (European Renewable Energies Federation)
- ESTELA (European Solar Thermal Electricity Association)
- ESTIF (European Solar Thermal Industry Federation)
- EUBIA (European Biomass Industry Association)
- EU-OEA (European Ocean Energy Association)
- EUREC Agency (European Association of Renewable Energy Research Centers)
- EWEA (European Wind Energy Association)

and the publication also involved close collaboration with EBB (European Biodiesel Board) and eBIO (European Bioethanol Fuel Association).

The SUPPORT_ERS project aims at 'Optimising Support Schemes for Renewable Energy Sources for Electricity Generation, Heating and Cooling'. It contributes to the reduction of administrative barriers for the use of Renewable Energy Sources (RES) in the new EU member states and candidate countries, shows political decision makers in the new EU member states and candidate countries options to support RES-Heat, and increases the awareness of regional stakeholders for the benefits of RES. The consortium consists of 11 partners: Austrian Energy Agency, Austria; Climate Alliance; Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Germany; Energy Efficiency Agency, Bulgaria; Energy Institute Hrvoje Pozar, Croatia; European Renewable Energy Council; Federal Ministry of the Environment, Nature Conservation and Nuclear Safety, Germany; Institutul de Studii si Proiectari Energetice, Romania; Institute for the Diversification and Saving of Energy (IDAE), Spain; Ministry of Economic Affairs and Communications, Estonia; Ministry of the Environment, Latvia; Slovak Innovation and Energy Agency, Slovakia. The partners

involved in the project are ministries and national energy agencies with a direct link to RES policy processes. Furthermore, a network of municipalities and a European interest group are involved in order to ensure the link to the regional level and to the European RES industry. SUPPORT_ERS helps to optimize support mechanisms to speed up RES market development and to intensify the cooperation among political decision makers and policy consultants in energy agencies to meet the ambitious RES targets of 2020. The 30-month project started in November 2007.

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Part I

Introduction

1

Integration of Renewable Energy Sources

INTRODUCTION

Renewable energies will inevitably dominate the world's energy supply system in the long run. The reason is both very simple and imperative: there is no alternative. Mankind cannot base its life on the consumption of finite energy resources indefinitely. Today, the world's energy supply is largely based on fossil fuels. These sources of energy will not last forever and have proven to be one of the main causes of our environmental problems. Environmental impacts of energy use are not new but they are increasingly well known. As links between energy use and global environmental problems such as climate change are widely acknowledged, reliance on renewable energy is not only possible, desirable and necessary, it is an imperative. The earth receives solar energy as radiation from the sun, in a quantity far exceeding mankind's use. By heating the planet, the sun generates wind. Wind creates waves. The sun also powers the evapotranspiration cycle, which allows generation of power by water in hydro schemes – currently the largest source of renewable electricity in use today. Plants photosynthesize, which is essentially a chemical storage of solar energy, creating a wide range of so-called biomass products ranging from wood fuel to rapeseed, which can be used for the production of heat, electricity and liquid fuels. Interactions between the sun and the moon produce tidal flows that can be intercepted and used to produce electricity. Renewable energy sources are based on the natural and interconnected flows of energy of our planet earth.

Though humans have been tapping into most renewable energy sources (wood, solar, wind, geothermal and water) for thousands of years for their needs, so far only a tiny fraction of the technical and economic potential of renewable energy has been captured and exploited. Yet, with existing and proven technologies, renewable energies offer safe, reliable, clean, local and increasingly cost-effective alternatives for all our energy needs. The Renewable Energy Sector has become a driving force for a sustainable economy in the 21st century. Investments in renewable energy and energy efficiency will lead the way out of the economic crisis that Europe and the world at large are facing today. Confronted not only with an economic crisis but also with the challenge posed by climate change, as well as increasing import dependency and rising fossil fuel prices, it is a matter of urgency that we come up with a solution now and for future generations on how to conserve economic and social livelihoods and maintain a balanced ecological system. By promoting renewable energy technologies, we are able to tackle both the security of energy supply and climate change, while at the same time creating a future-oriented sustainable economy. Today the sector is already providing more than 450,000 jobs and has an annual turnover exceeding €45 billion. Combined with improvements in energy efficiency and the rational use of energy, renewable energy sources can provide everything fossil fuels currently offer in terms of energy services such as heating and cooling, electricity and also transport fuel. However, as current energy prices do not incorporate any external costs, the energy market is still distorted and the deployment of renewable energy sources depends on the appropriate framework conditions in place.

20 PER CENT RES BY 2020: THE EU'S RES POLICY FRAMEWORK

In March 2007, the heads of states and governments of the 27 EU member states adopted a binding target of 20 per cent renewable energy from final energy consumption by 2020. Combined with the commitment to increase energy efficiency by 20 per cent until 2020 and to reduce greenhouse gas emissions by at least 20 per cent within the same period (or respectively 30 per cent in case of a new international agreement), Europe's political leaders paved the way for a more sustainable energy future for the European Union and for future generations. In January 2008, the European Commission presented a draft directive on the promotion of the use of energy from Renewable Energy Sources (RES) which contains a series of elements to create the necessary legislative framework for making 20 per cent renewable energy become a reality. The Directive sets the legislative framework that should ensure the increase of the 8.5 per cent renewable energy share of final energy consumption in 2005 to 20 per cent in 2020 and, if properly transposed into national law, will become the most ambitious piece of legislation on renewable energy in the world. The RES Directive (DIRECTIVE 2009/28/EC) (EC, 2009) was approved by the European Parliament in December 2008, by the Council at the end of March 2009, published in the Official Journal in June 2009 and will then need to be transposed in national law. By June 2010, member states will need to submit national action plans on how they foresee reaching their binding national target. In order to reach the binding overall 20 per cent target outlined in the RES Directive, the development of all existing renewable energy sources and a balanced mix of the deployment in the sectors of heating and cooling, electricity and transport are needed.

Electricity from renewable energy sources

The European Union aims to have 21 per cent of its electricity coming from renewable energy sources by 2010. This target has been formulated in the Directive 2001/77/EC on the promotion of renewable electricity. While some member states such as Germany, Spain and Denmark are well on track to reaching their targets, others are far behind. The Renewable Energy Framework Directive needs to maintain and strengthen the existing legislative frameworks for renewable electricity. It needs to establish minimum requirements for the removal of administrative barriers, including streamlined procedures such as one-step authorization. Issues such as priority grid access and a more balanced sharing of the costs related to grid connection need to be addressed.

Heating and cooling from renewable energy sources

As far as the heating and cooling sector is concerned, the directive finally closes the legislative gap which has existed up until now for this sector. Until recently, Renewable Heating and Cooling (RES-H+C) has received little political attention and in most EU member states there is not yet a comprehensive approach to support RES-H+C. This is particularly striking in view of the fact that nearly half of the EU's final energy consumption is used for the generation of heat, making the RES-heating sector a sleeping giant.

Biofuels for transport

The EU's biofuels policy kicked off in 2003 with the first biofuel directive, which set indicative targets to promote the use of renewable fuels in the transport sector. For 2010 the target was set at 5.75 per cent by energy content. As the experience with the existing biofuels directive shows, fuel distributors only use biofuels if there is a financial incentive or because they are forced to use them. Therefore the renewable energy directive introduces a binding target of 10 per cent renewable energy in transport by 2020. However, only sustainably produced biofuels are allowed to count towards the target and the directive proposes a comprehensive sustainability scheme.

THE RES DIRECTIVE

The RES Directive:

- **Sets mandatory national targets for renewable energy shares of final energy consumption in 2020, (including a 10 per cent renewables in transport target)**: these are calculated on the basis of the 2005 share of each country plus both a flat-rate increase of 5.5 per cent per member state as well as a GDP-weighted additional increase to come up with the numbers as outlined in the table below:

Table 1.1 Mandatory national targets set out in the directive (2005 and 2020)

	Share of energy from renewable sources in final consumption of energy, 2005	Target for share of energy from renewable sources in final consumption of energy, 2020
Belgium	2.2%	13%
Bulgaria	9.4%	16%
The Czech Republic	6.1%	13%
Denmark	17.0%	30%
Germany	5.8%	18%
Estonia	18.0%	25%
Ireland	3.1%	16%
Greece	6.9%	18%
Spain	8.7%	20%
France	10.3%	23%
Italy	5.2%	17%
Cyprus	2.9%	13%
Latvia	34.9%	42%
Lithuania	15.0%	23%
Luxembourg	0.9%	11%
Hungary	4.3%	13%
Malta	0.0%	10%
The Netherlands	2.4%	14%
Austria	23.3%	34%
Poland	7.2%	15%
Portugal	20.5%	31%
Romania	17.8%	24%
Slovenia	16.0%	25%
The Slovak Republic	6.7%	14%
Finland	28.5%	38%
Sweden	39.8%	49%
United Kingdom	1.3%	15%

Source: EREC (2008)

- **Sets interim targets**: the directive sets interim targets per country for 2011/12, 2013/14, 2015/16 and 2017/18 as a percentage share of their 2020 target. These interim targets are crucial for monitoring the progress of renewable energy development in a member state, although they are unfortunately only of indicative nature.
- **Requires national action plans from member states stating how they intend to reach their targets**: member states shall adopt national action plans which set out their targets for the shares of energy from renewable sources in transport, electricity, and heating and cooling in 2020 and adequate measures to achieve these targets. Member states shall notify their national action plans to the Commission for examination by June 2010 at the latest. These plans should provide for two things: to give member states the flexibility to decide for themselves how they want to meet their national targets, but at the same time to create investor security and help to mobilize private capital by setting clear goals and mechanisms on the national level. National action plans should include detailed mandatory outlines and targets for the different renewable energy sectors (heating/cooling, electricity and transport fuels), which show the way ahead on the national level. In addition, support measures to meet the national targets must be outlined.
- **Requires reduction of administrative and regulatory barriers to the growth of renewable energy, improvements in information and training and in renewables' access to the grid**: administrative barriers are still a major problem for renewable energy development and need to be removed. There are a number of non-cost related options to be integrated for any member state in its regulatory framework in order to really push renewable energies. This is reflected in planning regulation and administrative procedures. The Directive provides important provisions to remove further administrative and regulatory barriers which must be put in practice to pave the way for a quick and large-scale RES deployment. Infrastructure development and priority access for renewables to the grid are key for a large-scale penetration of renewables. This should not only apply to electricity networks but also to district heating networks sourced by renewable and gas pipelines for the increased use of biogas. For information and training, the directive requests member states to introduce a certification of installers by accredited training programmes.
- **Creates a sustainability regime for biofuels**: the binding nature of the 10 per cent target has triggered the very important debate on sustainability criteria and a certification scheme. This scheme will serve as an example for biofuel production standards globally. The industry is committed to strict but practical sustainability standards that apply for domestic production as well as imports that will eventually be applied to all energy sources be it biomass, food or fossil fuels.

RES INDUSTRY ROADMAP TO 2020

In January 2004 for the first time EREC called for a binding 20 per cent renewable energy target by 2020. In November 2008, EREC together with its members drew an EU technology roadmap outlining how the EU renewable energy industry foresees reaching the 20 per cent renewable energy consumption target. The estimates given by the renewable energy industry are based on a feasible annual growth scenario for the different technologies. Some renewable energy sectors have developed much more ambitious projections showing that the European renewable energy industry could deliver much more than 20 per cent.

Contribution of renewables to electricity consumption for EU-27 by 2020

Under the present state of market progress and the political support given to electricity generation from Renewable Energy Sources, the current target for RES-Electricity for 2010 can be met. The overall target can be reached with a higher contribution by some of the more successful technologies. Table 1.2 outlines the new targets for 2020 with the expected annual growth rates and the necessary growth rate to increase the share of RES-Electricity significantly.

Table 1.2 Renewable electricity installed capacity projections[1]

Type of energy	2002 Eurostat	2006 Eurostat	Annual growth rate 2002–2006	Projection 2010	Annual growth rate 2006–2010	Projection 2020	Annual growth rate 2010–2020
Wind	23.1GW	47.7GW	19.9	80GW	13.8	180gW	8.5
Hydro	105.5GW	106.1GW	0.2	111GW	1.1	120GW	0.8
Photo-voltaic	0.35GWp	3.2GWp	73.9	18GWp	54.0	150GWp	23.6
Biomass	10.1GWe	22.3GWe	21.9	30GWp	7.7	50GWe	5.2
Geo-thermal	0.68GW	0.7GW	0.7	1GW	9.3	4GW	14.9
Solar thermal elect.	–	–	–	1GW	–	15GW	31.1
Ocean	–	–	–	0.5GW	–	2.5GW	17.5

Source: EREC (2008)

If the projected growth rates were achieved, renewable energies would significantly increase their share in electricity production. The estimations in Table 1.3 are based on the rather moderate growth rate projections.

Depending on the development of the total electricity generation, renewable energies will be able to contribute between 33 per cent and 40 per cent of total electricity production. Assuming that the EU will fulfil its ambitious energy efficiency roadmap, 40 per cent of renewables in electricity production by 2020 is realistic.

Contribution of renewables to heat consumption for the EU-27 by 2020

The lack of a favourable political framework in Europe for the renewable heating and cooling sector up until now has prevented higher market penetration. With the creation of such a political framework the expectations can be raised and the contribution of RES-heating is especially significant in the biomass sector. But geothermal and solar thermal energy will also be able to increase their shares significantly.

Table 1.3 Contribution of renewables to electricity consumption

	2005 Eurostat TWh	2006 Eurostat TWh	2010 Projections TWh	2020 Targets TWh
Wind	70.5	82.0	176	477
Hydro[2]	346.9	357.2	360	384
Photovoltaic	1.5	2.5	20	180
Biomass	80.0	89.9	135	250
Geothermal	5.4	5.6	10	31
Solar thermal elect.	–	–	2	43
Ocean	–	–	1	5
TOTAL RES	504.3	537.2	704	1370
Total Gross Electricity Generation EU-27	3320.4	3361.5		
(Trends to 2030–Baseline)[3]			3568	4078
(Combined RES and EE)[4]				3391
	15.2%	16.0%	19.7%	33.6–40.4%

Source: EREC (2008)

Table 1.4 Renewable heat consumption projections

Type of energy	2002 Eurostat Mtoe	2006 Eurostat Mtoe	AGR 2002–2006	Projection 2010 Mtoe	AGR 2006–2010	Projection 2020 Mtoe	AGR 2010–2020
Biomass[5]	51.2	60.0	4.0%	75	5.7%	120[6]	4.8%
Solar thermal	0.51	0.77	10.8%	1.5	18.1%	12[7]	23.1%
Geothermal	0.59	0.68[8]	3.6%	3[9]		7[9]	8.8%

Source: EREC (2008)

If the projected growth rates were achieved renewable energies would significantly increase their share in heating production. The estimations below are based on rather moderate growth rate projections and 25 per cent in 2020 seems to be possible.

Table 1.5 Contribution of renewables to heat consumption (2006–2020)

	2005 Eurostat Mtoe	2006 Eurostat Mtoe	2010 Projections Mtoe	2020 Projections Mtoe
Biomass[5]	57.5	60.0	75	120[6]
Solar thermal	0.68	0.77	1.5	12[7]
Geothermal	0.63	0.68	3	7
TOTAL RES HEAT	58.8	61.45	79.5	139
Total Heat Generation EU-27	579.2	570.1		
(Trends to 2030)[10]			583.5	606
(Combined RES and EE)[11]				541
Share of RES	10.2%	10.8%	13.6%	22.9–25.7%

Source: EREC (2008)

Contribution of biofuels to transport fuel consumption for the EU-27 by 2020

The EU depends heavily on imported energy to run its economy. In the transport sector there is barely any diversification of energy sources: crude oil fuels more than 98 per cent of the EU's transport sector. Biofuels have a major role to play both in improving energy security and tackling climate change, which are the core objectives of the EU's biofuels policy. The current biofuels directive sets an indicative target of 5.75 per cent in 2010. In 2007 the EU consumed between 2.5 per cent and 3 per cent of biofuels for road transport. Given the fact that the European biofuels industry experienced strong double-digit annual growth rates during the past several years Europe is well on track to reach the 5.75 per cent. With the 10 per cent binding target for the transport sector the renewable energy directive sends a clear signal to investors and confirms the EU's strong commitment to renewable transport fuels.

Table 1.6 Biofuels production projections

Type of energy	2002 Eurostat Mtoe	2006 Eurostat Mtoe	AGR 2002–2006	Projection 2010 Mtoe	AGR 2006–2010	Projection 2020 Mtoe	AGR 2010–2020
Transportation biofuels	1.05	5.38	50.5%	16	31.0%	34	7.8%

Source: EREC (2008)

The renewable energy directive will set an important framework for the future growth of the industry and will pave the way for a stable investment climate. New technologies and applications of biofuels will be developed and marketed up to 2020. With this stimulation of the industry, further coordinated development of biofuels throughout the EU and the possibility of significantly reducing the oil dependence in the transport sector over the next years, the European biofuels industry is committed to reach 10 per cent biofuels by 2020.

Table1.7 Contribution of renewables to transport fuel consumption

	2005 Eurostat Mtoe	2006 Eurostat Mtoe	Projection 2010 Mtoe	Projection 2020 Mtoe
Transportation biofuels	3.13	5.38	16	34.0
Gasoline and oil consumption	297.2	300.4		
(Trends to 2030–Baseline)[12]			317.3	349.5
(Combined RES and EE)[13]				323.9
Biofuels' Share %	1.05	1.79	5.0	9.7–10.5

Source: EREC (2008)

Contribution of RES to final energy consumption

Given the present state of market progress and strong political support, the European renewable energy industry is convinced it can reach and exceed the 20 per cent renewable energy share in final energy consumption by 2020. The estimates by the renewable energy industry are based on a moderate annual growth scenario for the different technologies. Strong energy efficiency measures have to be taken to stabilize energy consumption between 2010 and 2020.

Table 1.8 Contribution of RES to total final energy consumption (Mtoe)

Type of energy	2005 Eurostat	%	2006 Eurostat	%	Projection 2010	%	Targets 2020	%
Final Energy Consumption[14]	1211.5		1214.8					
(Trends to 2030)[15]					1272		1378	
(Combined RES and EE)[16]							1266	
Wind	6.06	0.50	7.05	0.58	15.13	1.19	41	3.0–3.2
Hydro[17]	29.82	2.46	30.71	2.53	30.95	2.43	33	2.4–2.6
Photovoltaic	0.13	0.01	0.22	0.02	1.72	0.14	15.5	1.1–1.2
Biomass	67.51	5.57	73.11	6.02	102.60	8.07	175.5	12.7–13.9
Geothermal	1.10	0.09	1.16	0.10	3.86	0.30	9.4	0.7
Solar Thermal	0.68	0.06	0.77	0.06	1.5	0.12	12	0.9–1.0
Solar Thermal elect.		0		0		0.16	0.02	2.2 0.2
Ocean	0		0		0.08	0.01	0.4	0.03
Total RES	105.3	8.69	113.02	9.30	156.0	12.3	289	20.9–22.8

Source: EREC (2008)

EREC and its members assume that a 20 per cent share of renewable energy of final energy consumption by 2020 is a realistic target for the EU under the condition that certain policy developments will occur and a continuation of the existing policy instruments are ensured. The individual sector projections are based on moderate estimates; some of the sectors forecast much higher figures for their sectors by 2020. A development of all existing renewable energy sources and a balanced mix of the deployment in the sectors of heating and cooling, electricity and transport guarantees the start of a real sustainable energy mix for Europe. Table 1.9 gives an overview of the resulting contribution of renewable energy in the electricity, heating and cooling and transport sectors towards attaining the overall 20 per cent target.

INTEGRATION OF RENEWABLE ENERGY SOURCES

The rapid deployment of renewable energy technologies, and their even greater deployment in the near future, raises challenges and opportunities regarding their integration into energy supply systems. Energy systems are needed to meet the demands for a broad range of services (household, commerce, industry and transportation). Energy systems include an energy supply sector and the end-use technology to provide the aforementioned energy services.

Table 1.9 Contribution of RES to total final energy consumption by sector (Mtoe)

Type of energy	2005 Eurostat	%	2006 Eurostat	%	Projections 2010	%	Targets 2020	%
Final Energy Consumption[14]	1211.5		1214.8					
(Trends to 2030)[15]					1272		1378	
(Combined RES and EE)[16]							1266	
Electricity	43.36	3.6	46.19	3.8	60.5	4.8	116	8.4–9.2
Heating and Cooling	58.81	4.8	61.45	5.0	79.5	6.2	139	10.1–11
Transport biofuels	3.13	0.3	5.38	0.5	16.0	1.3	34	2.5–2.7
Total RES	105.3	8.7	113.02	9.3	156.0	12.3	289	20.9–22.8

Source: EREC (2008)

Electricity sector

In the EU, the existing electricity supply system is mainly composed of large power units, mostly fossil-fuelled and centrally controlled, with average capacities of hundreds of megawatts. RES are geographically widely distributed and, if embedded in distribution networks, are often closer to the customers. Locating renewable energy and other generators downstream in the distribution network is known as 'distributed generation'. Distributed generation involves the use of small, modular electricity conversion units sited close to the point of consumption. Distributed energy generation, close to the end-consumer, differs fundamentally from the traditional model of an energy system consisting of large power stations generating centrally controlled power. The approach is completely new, replacing the concept of economy of scale using large units by economy of numbers (using many small units). Far from being a threat, distributed generation based on renewable energy offers numerous opportunities. It can:

- reduce the transmission and distribution losses as well as their cost;
- provide customers with continuity and reliability of supply;
- stimulate competition in supply, adjusting process via market forces;
- be implemented in a short time owing to the modular nature of renewable energy technologies.

Transport sector

In the transport sector, the use of renewable energies in the form of biofuels is becoming a market reality. However, the integration of renewables requires the adaptation of an infrastructure which has grown over a century of development based exclusively on fossil fuels. Besides the gradual substitution of the vehicles in circulation, it is necessary to develop a new supply chain for the production and distribution of sustainable transport fuels. This will require substantial investment. However, the development of the fossil-fuel-based transport system also required investments that were historically subsidized by the public sector in many countries.

Electric cars will also play a more prominent role in the future. Charging electric vehicles from the grid at the current stage, however, is not carbon neutral since the electricity mix in many countries is still largely composed of fossil fuels. The rapid deployment of renewable electricity generation is a pre-condition for a sustainable extension of the use of electric cars.

Heating and cooling

In the heating sector, the full integration of renewable energies also requires an adaptation of historical infrastructures. This process is particularly important because, in many parts of Europe, it is already possible for new buildings to be completely independent from fossil fuels or electricity for their heating needs. This can be achieved by using state-of-the-art renewable heating and cooling applications which are combined with energy efficiency measures and demand-side management. A substantial economic restriction to the integration of renewable heating (solar thermal, biomass, geothermal) is caused by the long lifetime of buildings. The installation of renewable heating systems is much more cost-effective during the construction of a building or when the overall heating system is being refurbished. This means that there is a short window of opportunity for cost-effective integration of renewable heating. If this occasion is lost, for decades that building will remain dependent on fossil fuels or electricity for its heating. For this reason, it is essential that all possible measures are taken to ensure that the available renewable heating sources are installed in all new buildings. It is also necessary to promote the use of renewable heating at the time of the modernization of the conventional heating system. Renewable heating sources can also be used for cooling purposes. An increasing number of 'well-working' systems are being installed, mainly based on solar thermal and geothermal energy. The growing demand for cooling is having a dramatic impact on the electricity systems in Europe, with several countries reaching peak electricity demand in summer instead of winter. This problem can be mitigated by supporting the development and commercialization of renewable cooling technologies. The choices of millions of citizens in their homes and offices are crucial to the future integration of renewable energies. Raising awareness among the general public and in the specific training of the professional groups involved (heating installers, building engineers, architects, building managers etc.) are therefore very important.

RESEARCH PRIORITIES

In order to develop renewable energy sources to their full potential, further research activities are needed:

- Different technologies have been developed in order to produce electricity from renewable energy sources (wind, biomass, hydro, solar photovoltaic, geothermal, concentrated solar power, marine energy). These technologies are at a different stage of development, but all require some further research and development (R&D) with a view to reducing their cost and facilitating their integration into the grid.
- Biomass, solar thermal and geothermal energy are current renewable energies used for heating and cooling in buildings where technical research advances can be made. In order to increase the adoption of renewable energy technologies in buildings, research should also be addressed towards improving building technologies, including passive solar design and energy efficiency.
- Different options are available for the production of renewable-based fuels for transport applications: renewable electricity to be used in electrical vehicles; renewable hydrogen to be used either in internal combustion engines or in fuel cells;

biofuels (both in the liquid and gaseous status) which can be used with the existing infrastructures. In order to increase the use of renewable energy in transport applications, research is needed not only to improve the fuel production process (feedstock production and conversion into a usable fuel), but also to create the requested infrastructure for the uptake of renewable-based fuels.

Finally, some cross-cutting issues need to be tackled in order to enable faster development of renewable energy technologies in all end-user sectors:

- Research infrastructures (especially laboratory infrastructures): the approach to European funding of energy infrastructures should be extended to allow the integration of European experimental facilities in order to overcome fragmentation.
- There is a lack of finance for demonstration activities of new and improved renewable energy technologies. More demonstration is necessary to bridge the gap between concept and implementation.
- In the heating and cooling sector in particular, public funds need to be increased to carry out the necessary research. This sector contributes to about 40 per cent of the overall energy demand in Europe but the utilization of renewable energy technologies remains low at present.
- Lack of qualified and skilled workers (engineers, installers): more effort is required to encourage young people to go into these fields. This includes not only specific curricula for renewable energy as a course topic in itself, but more focus on renewable energy topics being included in electrical engineering, mechanical engineering, physics and other traditional technical studies. This is essential to meet the rapidly growing need for skilled personnel in the booming renewable energy industry.

NOTES

1 These figures are based on integrated growth rate projections. EPIA (European Photovoltaic Industry Association) believes that the Photovoltaic figures could be much higher if the development of the industry continued at the same rate as previous years. EPIA estimates that in 2020 350GWp of Photovoltaics could be installed. EUBIA (European Biomass Industry Association) believes that the installed capacity for electricity generation from biomass could be in the order of 70GW by b2020 if certain conditions are met, such as higher promotion of co-firing through incentives for utilities and for biomass production. ESTELA (European Solar Thermal Electricity Association) foresees the installed capacity of Solar Thermal Electricity in the range of 30GW by 2020. As far as the geothermal sector is concerned, it must be noted that the Eurostat figure for 2006 does not take all geothermal technologies into account, thus affecting the entire calculation of the respective growth rates.

2 Normalized according to the formula proposed in the RES Directive.

3 European Energy and Transport: trends to 2030 – update 2007, 2008, European Commission Directorate General for Energy and Transport.

4 European energy and transport: scenarios on energy efficiency and renewables, 2006, European Commission Directorate General for Energy and Transport.

5 Biomass for heat and heat derived from co-generation and district heating.

6 AEBIOM (European Biomass Association) believes that a target of 147Mtoe is achievable by 2020 for biomass for heat and derived heat.

7 Based on the assumption that 1m^2 of solar thermal collector area per EU inhabitant is achievable by 2020. ESTIF's target is 21Mtoe of solar thermal energy in 2020.
8 Includes only district heating.
9 Includes all applications including shallow geothermal heat pumps.
10 European Energy and Transport: trends to 2030 – update 2007, 2008, European Commission Directorate General for Energy and Transport.
11 European energy and transport: Scenarios on energy efficiency and renewables, 2006, European Commission Directorate General for Energy and Transport.
12 European Energy and Transport: trends to 2030 – update 2007, 2008, European Commission Directorate General for Energy and Transport.
13 European energy and transport: Scenarios on energy efficiency and renewables, 2006, European Commission Directorate General for Energy and Transport.
14 Including electricity and steam transmission/distribution losses and own consumption.
15 European Energy and Transport: trends to 2030 – update 2007, 2008, European Commission Directorate General for Energy and Transport.
16 European energy and transport: Scenarios on energy efficiency and renewables, 2006, European Commission Directorate General for Energy and Transport.
17 Normalized according to the formula proposed in the RES directive.

Part II

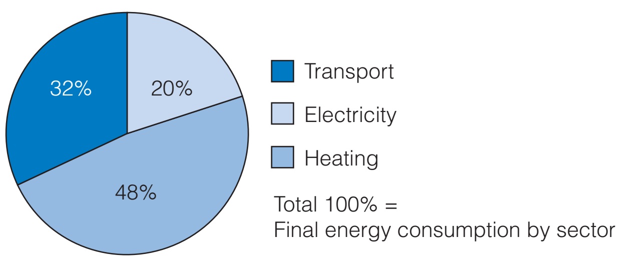
RES Heating and Cooling

Part II

Introduction

Heating alone is responsible for almost half of the EU's final energy consumption, and renewable energy sources like solar thermal, biomass and geothermal energy can make a huge contribution, resulting in substantial savings of gas, oil and electricity, and in greenhouse gas emission reductions. Renewable heating is the heat provided from renewable energy sources, including solar thermal, biomass heat and geothermal energy. Renewable cooling is the renewable fraction of the cooling provided through thermally driven cooling machines based on solar and/or biomass energy, as well as the renewable fraction of cooling obtained directly from the ground or the sea water. The use of heat from co-generation devices and of waste heat from industrial processes is considered renewable if the original energy source is renewable (sustainable biomass or geothermal energy). Fossil fuel-based co-generation or waste heat of fossil origin are not renewable, though their use is certainly desirable within a strategy for energy efficiency. Until recently, Renewable Heating and Cooling (RES-H&C) has received little political attention and in most EU member states there is not yet a comprehensive approach to support RES-H&C. This is particularly striking in view of the fact that around 48 per cent of the EU's final energy consumption is used for the generation of heat, compared to 32 per cent for transport and 20 per cent for electricity, making the heating sector a neglected giant.

The recently adopted Renewable Energy Framework Directive, for the first time in history, puts a focus on heat generation from renewable energy sources. The Directive has finally closed the legislative gap which currently exists for this sector. The renewable energy industry very much welcomes the dispositions in the current RES directive for heating and cooling, particularly the obligation for minimum levels of energy from renewable energy sources in new and refurbished buildings. In its



Source: Eurostat, elaborated by EREC

Figure II.1 Final energy consumption by sector in the EU

Renewable Energy Roadmap, EREC estimates a share of 25 per cent of RES-H of total heat demand in Europe by the year 2020, thereby contributing significantly to reaching the overall binding 20 per cent renewable energy target. The following chapter outlines the current state of market development of the different RES heating and cooling technologies available.

2

Solar Thermal

STATE-OF-THE-ART TECHNOLOGY

Solar thermal systems are based on a simple principle known for centuries: the sun heats water contained in a dark vessel, solar radiation is then transformed into useful heat. In the 1970s, boosted by the first oil crisis, solar thermal systems started to be used more frequently. After more than 30 years of technological and market development, solar thermal technologies on the market now are efficient and highly reliable, providing solar energy for a wide range of applications such as domestic hot water and space heating in residential and commercial buildings, support to district heating, solar assisted cooling, industrial process heat, desalination and swimming pools. The solar thermal technologies replace conventional sources of heat, mainly fossil fuels or electricity. The enormous growth potential of solar thermal is key to moving the heating and cooling sector towards sustainability and to reducing the impact of the growing demand for energy imports on the economy and on the environment.

Technological benefits

The solar thermal technology provides many benefits, such as:

- reducing the dependency on imported fuels;
- improving the diversity of energy supply;
- saving scarce natural resources;
- saving CO_2 emissions at very low costs;
- curbing urban air pollution;
- creating local jobs and stimulating the local economy;
- solar thermal is a proven and reliable technology;
- solar thermal is immediately available – all over Europe;
- owners of systems save substantially on their heating bills.

Solar collectors are designed to concentrate sunlight on a thermal medium flowing in small pipes within the collector and to release as little heat as possible into the atmosphere. In some cases, the collector directly heats the water that is to be used. Flat-plate collectors are the most common in Europe, though more expensive evacuated tube collectors can produce higher temperatures and often have a higher annual energy yield. Solar collectors convert 25–50 per cent of the solar radiation they receive into useful heat. Unglazed collectors are mainly used for heating water in swimming pools. The solar system is part of the circuit used to filter the pool water that is directly heated when flowing through the collector, so no heat exchanger is needed. These systems are cheap, easy to install and very effective. Domestic hot water is the most common application of solar thermal technology. Such systems consist of a solar thermal collector, a water tank and a 'solar loop' connecting all the components. Normally, the solar heat is stored directly in the domestic hot water tank, but there are also systems that store the heat in a buffer tank. The solar loop, which removes the heat from the collector via water, works either by using a thermo-siphon (natural circulation) mechanism, or by 'forced circulation' using a pump. In most cases, solar thermal energy must be backed up by other sources of energy (such as heat from biomass, gas or electricity). The back-up heater is normally integrated into the upper part of the water tank. The collectors on the roof heat the transfer medium (a fluid); the control unit monitors the temperature difference between the collector and lower part of the tank, and, when appropriate, a pump is activated to bring fluid into the tank. Through a heat exchanger, the solar heat is released into the water in the tank. From this point, the system is the same as a normal domestic hot water system. Solar thermal can be used in a similar way to support space heating. As long as there is enough demand the full solar yield is used, thus reducing or eliminating the need for a back-up heat unit (whether biomass, gas, electricity or oil).

Technological applications

Domestic hot water and space heating

Most of the energy consumption of households is linked to two basic needs: hot water and central heating. To meet them we need low temperatures in the range of 40–60°C that can be easily supplied from the sun avoiding an unnecessary waste of oil, gas or electricity. Even the simplest solar thermal systems can provide a large part of domestic hot water needs. With more initial investment, nearly 100 per cent of the hot water demand and a substantial share of space heating can be provided with solar energy. Natural flow systems work without any need for pumps or control stations; they are widely used in southern Europe. Forced circulation systems are more complex and can also provide space heating. These so called 'solar combi' systems are more common in central and northern Europe.

Figure 2.1 Solar heating and biomass plant, 5500 m^2, Falkenberg, Sweden
Source: ARCON Solvarme

Solar assisted cooling

A growing number of cooling projects shows the huge potential for solar assisted cooling. Thermally-driven chillers use thermal energy to produce cold and/or dehumidified air. When backed up by biomass boilers, 100 per cent renewable cooling systems are possible. Solar cooling is being introduced into the market and substantial cost reductions are expected in the next few years, through technological development and economies of scale. A typical solar cooling system also provides central heating and hot water and is often called 'solar combi+' system (a solar combi-system stands for space heating and domestic hot water, a solar combi+ system includes a cooling system in addition to this).

The demand for hot water is relatively stable throughout the year and can be covered completely by solar energy. The demand for central heating is higher in winter when solar energy is less available. Ordinary solar thermal systems cover only a part of the central heating demand, with the remainder covered by a back-up system. Cooling demand in summer typically correlates with high solar irradiation. Solar energy can easily provide more than half of the energy required for cooling, the remainder being provided by the same back-up system used in winter for heating. This will be a key answer to the problems created by the growth of cooling demand in many European countries.

Industrial process heat

Solar thermal can also provide the heat needed in many industrial processes. Ordinary solar collectors typically provide temperatures around 60–100°C that are suitable for many applications such as food processing, water desalination, industrial washing processes etc.: a significant share of the industrial heat demand. Medium temperature collectors for higher temperatures have been demonstrated, but further research and development is needed to standardize them and to reduce their costs. Process heat applications are still very rare, but there is a large potential for growth in this area, as solar thermal becomes more cost competitive and awareness of decision-makers increases.

Swimming pools

Inexpensive unglazed collectors are an ideal solution to achieving a longer bathing season without energy consumption. With glazed collectors, high solar fractions can also be achieved beyond the summer and solar energy can be used for both space heating and clean, hot water.

Cost and prices

Current and expected costs and prices

Table 2.1 shows a range of prices for heat generated by a solar thermal system, compared with the current price of gas and electricity for the end user and the price projected for 2030. Inflation is not taken into consideration.

The costs of solar heat include all taxes, installation and maintenance. The spread is wide, because the total costs vary greatly, depending on factors such as:

- quality of products and installation;
- ease of installation;
- available solar radiation (latitude, number of sunny hours, orientation and tilting of the collectors);

Table 2.1 Comparative overview of solar thermal costs for today and 2030

	Cost in c€ per kWh			
	Today		2030	
	Central Europe	Southern Europe	Central Europe	Southern Europe
Solar thermal	7–16	5–12	3–6	2–4
Natural gas	8.5–29		17–58	
Electricity	7–33		14–66	

Source: ESTTP (2008)

- ambient temperature; and
- patterns of use determining the heat load.

By 2030, it is assumed that technological progress and economies of scale will lead to around a 60 per cent reduction in costs. Over the last decade, investment cost reductions of around 20 per cent have been observed for each 50 per cent increase in the total installed capacity of solar water heaters. Combi-systems in particular have benefited from these cost reductions and have increased their market share. Further R&D investment can help to drive these costs down further. Cost reductions are expected to stem from:

- direct building integration (facade and roof) of collectors;
- improved manufacturing processes;
- new advanced materials, such as polymers for collectors.

Furthermore, cost reduction potential can be seen in increasing productivity by the mass production of standardized (kit) systems, which reduce the need for on-site installation and maintenance works.

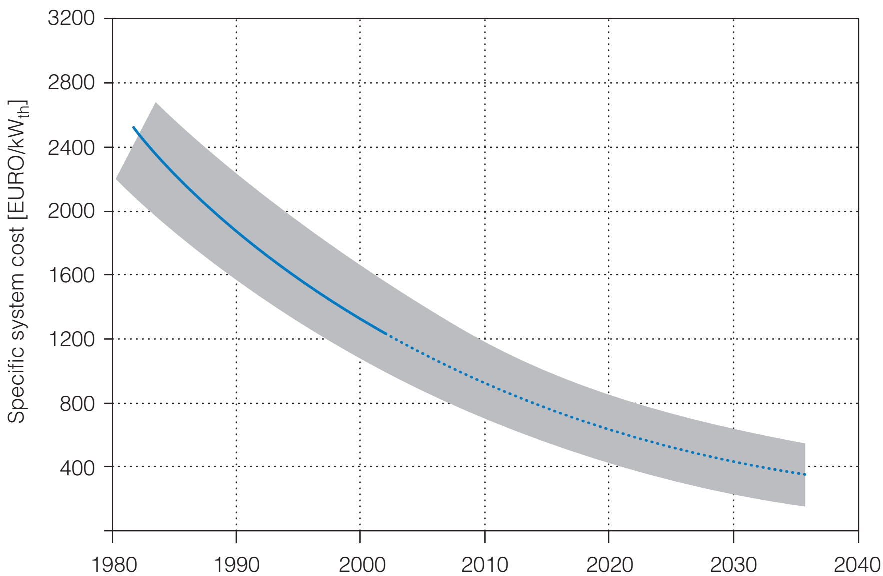


Figure 2.2 Development of specific costs and installed capacity for small solar thermal systems (forced circulation) in central Europe
Source: Institute for Thermodynamics and Thermal Engineering (ITW), University of Stuttgart

BOX 2.1 REACHING THE CRITICAL MASS FOR ECONOMIES OF SCALE

Today solar thermal is one of the most cost effective sources of renewable energy. People in the leading solar thermal countries benefit from higher solar value for money because reaching a critical mass of the market allows for high quality at better prices. The potential for further economies of scale is substantial: at local and national level, in the areas of marketing, distribution, design and installation of the systems; at European and global level, in the production of hardware, where automation for large volumes is still in its beginnings.

EXAMPLE: SOLAR KEYMARK QUALITY CERTIFICATION OF SOLAR THERMAL SYSTEMS

Modern solar thermal technologies are reliable, efficient and absolutely safe. The solar thermal industry has a high interest in delivering high quality products to further enhance the positive image of the technology. Public authorities that support solar thermal want to ensure that the products comply with the relevant norms. The Keymark for solar thermal products assists users to select quality solar collectors and systems. This 'Solar Keymark' is the result of a voluntary certification scheme supported by the European Solar Thermal Industry Federation. The Solar Keymark certifies reliable quality and performance information based on European standards. The user can be sure that the products sold are equal to those tested, as the latter are taken randomly from the production line by inspectors from accredited test institutes. Furthermore, the Keymark requires the existence of a quality management system comparable to ISO 9000.

Advanced applications, such as solar cooling and air conditioning, industrial applications and desalination/water treatment, are in the early stages of development, with only a few hundred first generation systems in operation. Considerable cost reductions can be achieved if R&D efforts are increased over the next few years.

MARKET

Installed capacity and market development in the EU and market segments

The European solar thermal market is developing dynamically. At the end of 2008, the total capacity in operation in the EU-27 + CH reached 19.1GWth (27 million m^2 of collector area). In 2008 more than 3.3 GWth of solar thermal capacity (4.76 million m^2 of collector area) was newly installed in Europe, against 2.1 GWth of solar thermal capacity (2.9 million m^2 of collector area) in 2007. Around 2 million European families already directly benefit from solar thermal energy, as do other frequent users such as hotels, sport centres, office buildings etc.

Beyond policy support, which is discussed in other parts of this book, the main drivers of these high growth rates are:

- growing awareness for solar energy, at least in some countries;
- increasing prices of conventional energies;
- growing concern over the security of supply of imported fuels;
- the unmistakable and visible signs of climate change.

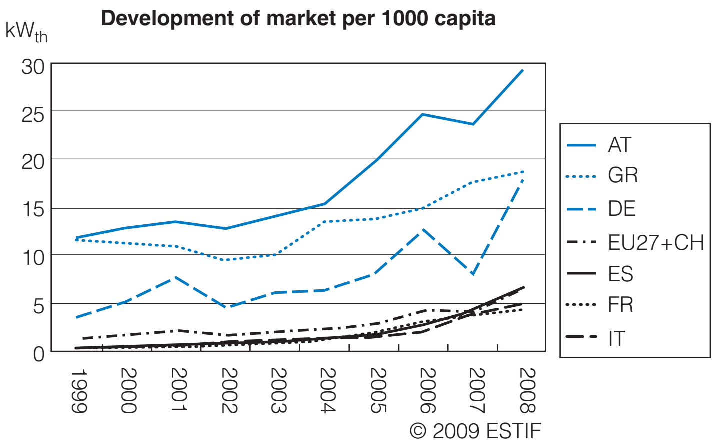


Figure 2.3 Development of solar thermal market per capita 1998–2008
Source: ESTIF (2009)

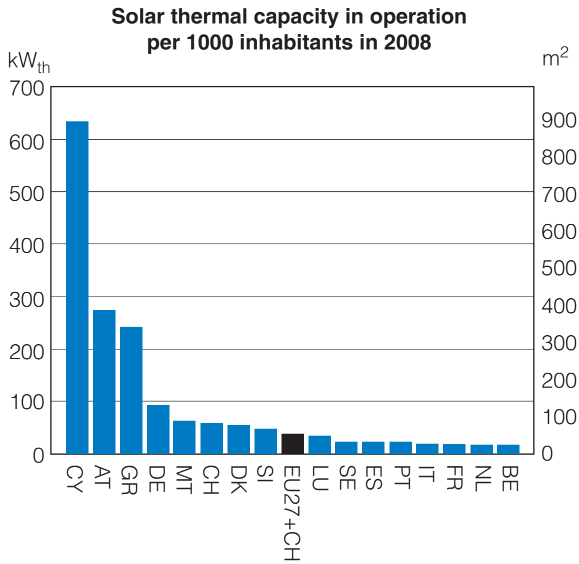


Figure 2.4 European solar thermal capacity per capita 2008
Source: ESTIF (2009)

At the same time, the solar thermal industry has improved its products and services and is widening its distribution networks. However, this growth is driven by a few leading countries, whereas most countries have yet to start serious market development. More than 80 per cent of the EU market is concentrated in just six countries: Germany, Greece, Austria, Spain, France and Italy. The capacity in operation per capita (kWth / 1000 inhabitants) ranges from 623 in Cyprus to 273 in Austria, to less than 25 in high-potential countries like Italy, France and Spain. If the whole of the EU had the same level per head as Austria today, the annual market would be over 20 millions m^2 with a capacity in operation of 136GWth. This would provide more than 94TWh of solar thermal energy, replacing substantial amounts of oil, gas and electricity. And even Austria has a long way to go to fully exploit its technical potential for solar thermal.

Figure 2.5 Residential building block in Denmark with flat-plate collectors on the roof
Source: BATEC Solvarme

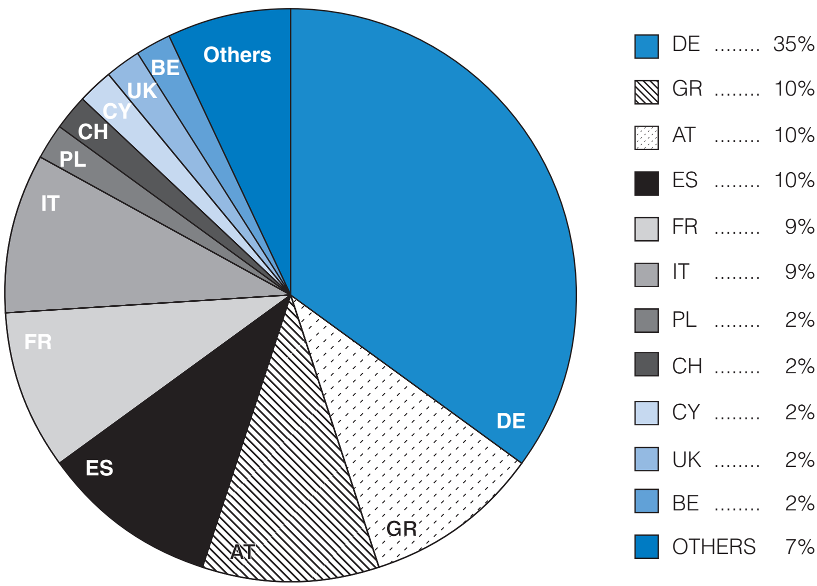


Figure 2.6 Shares of the European solar thermal market
Source: ESTIF (2009)

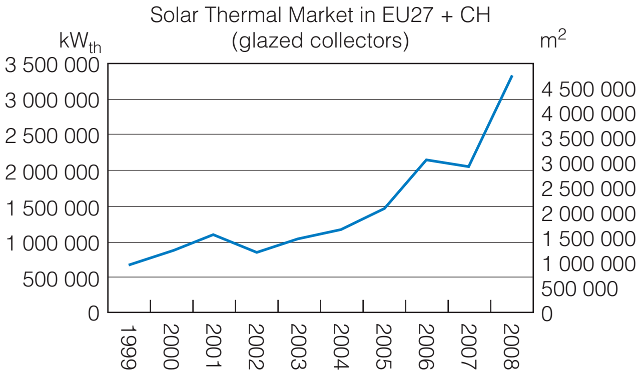


Figure 2.7 Solar thermal market in EU-27 + CH
Source: ESTIF (2009)

Market segments

Approximately 90 per cent of the solar thermal market volume in the EU has so far been in the small residential sector. In Austria, 15 per cent of detached houses are already equipped with a solar system. The market share of solar-combi systems, providing both domestic hot water and central heating, has recently grown to almost 40 per cent. In this segment solar thermal has meanwhile become a standard product, installed in millions of households in Europe, but mostly in only three countries (Austria, Germany and Greece).

Figure 2.8 Residential building in Austria with flat-plate collectors
Source: Gasokol

In large residential, tertiary and industrial buildings solar thermal can be particularly convenient, especially where there is a relatively constant heat demand. This is often the case in large residential buildings, hotels, elderly or student houses, hospitals, sport centres, shopping centres etc. These kinds of buildings usually offer optimal conditions for the use of solar thermal energy, including cooling. There is already a broad technical experience with these larger systems and in Spain they are the dominant system type. In many other countries, however, the level of market penetration is still very low, mainly due to social, legal and economic factors.

Industry

Building up a dynamic industry

What started in the 1970s as garage businesses is now an established international industry. With an annual turnover of around €3 billion, the solar thermal sector employs more than 40,000 people in Europe.

A number of major players from 'neighbouring' sectors have entered the market. At the same time, several solar thermal companies are diversifying into other RES such as biomass heating or solar photovoltaics. The large majority of systems sold in Europe are manufactured within the EU or its Mediterranean neighbours. Imports from Asia are limited mainly to components such as evacuated glass tubes. For European manufacturers, exports outside the EU are becoming a growing market. The main selling point is their high quality and reliability. The industry is in a phase of dynamic growth. Production lines are constantly being expanded. Employment in the European solar thermal sector has already reached 40,000 full time jobs. As in all industrial sectors, manufacturing will be more exposed to global competition as the market develops. However, for solar thermal, nearly half of the jobs are in retail, installation and maintenance.

Figure 2.9 Large (custom-built) flat-plate collector being lifted/installed on roof in Germany
Source: ARCON Solvarme

Innovation and jobs

This work is necessarily local, and creates jobs mainly in small and medium sized enterprises, directly in the regions where the solar thermal market is developing. For the time being, solar thermal is used together with a source of back-up heating. Therefore, solar thermal does not replace another industry's products, but really adds new demand and jobs. This higher initial investment pays off for the investor by reducing the conventional fuel bill over the lifetime of the system. For society it is even better: solar thermal replaces imported oil and gas with local labour! With solar thermal going into the mainstream, employment in the sector at EU level will reach half a million full-time jobs within the next few decades.

Training and education

Training and education are key to achieving a wider adoption of solar thermal energy. Of course, it is necessary to increase the awareness of end-consumers of solar thermal. However, a decisive role in the market is played by professional groups such as architects, planners and installers, who are the interface between end-consumers and industry. These professionals often determine, or have a strong influence on, the end-consumers' choice about heating systems. Usually, the standard education and

Figure 2.10 Production of vacuum tube collectors in Europe
Source: Ritter Solar

> **BOX 2.2** EXAMPLE: QUALISOL SCHEME IN FRANCE
>
> Qualisol is a professional qualification scheme required for the installation of solar systems. Many regional support programmes have linked their financial incentives to the installation of solar thermal systems by certified Qualisol installers.

training of these professionals does not include solar thermal technologies. Unfortunately, this is still the case for the current training patterns in many countries.

European industrial leadership

European industry is the worldwide technological leader in solar thermal. High efficiency collectors use highly selective absorber coating, which absorb more solar irradiation and emit less infra-red radiation. This increases the overall solar thermal energy production. These coatings are available mainly from a small number of European manufacturers who export their coated material to collector manufacturers worldwide. Europe is also leading in research and manufacturing of high quality heat tanks. In solar cooling, European researchers and companies have a clear technological lead. Beyond system design and high quality collectors, the key challenge for wide market introduction of solar cooling lies in the development of smaller and more cost effective thermally-driven cooling machines. More recently, products have been developed that can also be used in small residential buildings, opening new market segments for solar cooling. Most of these new machines have been developed in Europe and various new companies have been founded to bring them into the market.

Preparing for global competition

A glance at the growing competition for scarce resources in the global energy markets is enough to understand that solar thermal will be used almost everywhere possible during the 21st century. Europe is in a good position and has the chance to be the main beneficiary of this new global business field. In most renewables, Europe is leading both in technology and in the market volume. However, the latter is not the case for solar thermal, where the Chinese market is seven times bigger than the whole EU market. Given the price levels, European manufacturers cannot easily compete in markets like China, India and Turkey. If the EU does not catch up soon with a substantial growth in the domestic market, the European industry will face a hard task in maintaining its technological leadership. Beyond market growth, maintaining the technological lead requires a joint effort to define and implement the research strategy to answer the energy needs of tomorrow's world. Industry and research, private investors and public authorities cooperate within the frame of European Technology Platform on Renewable Heating and Cooling in the European Solar Thermal Technology Panel (ESTTP), to pave the way for solar energy to be the sole source of domestic hot water, central heating and cooling and a major contributor to low temperature industrial heating in the next decades: the goal is to identify the research issues and lay the foundations to solve them. As in all industrial sectors, manufacturing will be more exposed to global competition as the market develops. However, for solar thermal, nearly half of the jobs are in retail, installation and maintenance. This work is necessarily local and creates jobs mainly in small and medium-sized enterprises, directly in the regions where the solar thermal market is developing.

Policy instruments to support solar thermal

A positive and stable support framework should be designed to reach the ST ambitious target:

- binding regulations: requiring the use of solar thermal are recommended for new buildings and major refurbishments;
- financial incentives: can speed up the introduction of solar thermal in existing buildings;
- flanking measures, such as awareness raising, training of professionals and R&D funding, are important for the long-term success of the solar thermal markets.

Solar building codes

The current trend in several European countries and regions is well justified by the manifold benefits of solar building codes, which allow for the gradual preparation of the building stock in anticipation of the inevitable future scarcity of fossil fuels. Among other benefits, solar building codes create a minimal critical mass in the solar market and bring about economies of scale that also benefit the voluntary market in the majority of buildings that are not subject to the obligation. Moreover, solar building codes help solve the owner-tenant dilemma (owners are sometimes reluctant to invest in a solar thermal system since they do not benefit directly from the energy savings) and send a strong signal to the users and to all professionals involved in the construction and heating sectors. However, solar building codes fundamentally change the way the solar thermal market functions. Within solar building codes, proper quality assurance measures must be foreseen, including quality parameters for the products, installation and maintenance, as well as a clear inspection and sanctioning regime. Without these measures, it is likely that some construction companies will install the cheapest products, thus producing less solar yield than desired. This could reduce the acceptance of the regulation and possibly of the solar technology in general. Solar building codes are regulations requiring that a minimum share of the heating demand is covered by solar energy. Most refer only to the domestic hot water demand and prescribe a minimal solar share ranging from 30–70 per cent. They usually apply to new buildings, those undergoing major renovation and sometimes in the case of the replacement of the heating system. Often they are in fact renewable heat obligations, as the legal requirement can also be fulfilled with other renewable heating sources. In June 2008, Germany enacted a renewable heating law, which prescribes a minimal share of 15–50 per cent of the total heating consumption of new buildings (including central heating) to be covered by RES. A decade ago, the idea of making the use of solar or RES compulsory sounded radical and politically unfeasible in most parts of the world. Currently, solar building codes have been adopted or are being discussed in a number of countries, regions and municipalities in Europe and beyond. Climate change and security of energy supply have become top political priorities. Together with energy efficiency, renewables are the only sustainable answer to both problems. Within the RES policy debate, the heating and cooling sector are now fully integrated in the European agenda, after having been neglected for over a decade. The solar industry has grown and a new generation of highly reliable products is on the market. Solar building codes are probably the single most powerful instrument for promoting the use of renewables in new buildings. However, they do not cover a large part of the potential uses of solar thermal, such as central heating and cooling, industrial processes and water desalination.

Fiscal incentives

Financial Incentive Schemes (FIS) include any public policy giving a financial advantage to those who install a solar thermal system or use solar thermal energy. For example:

- direct grants (e.g. German Market Stimulation Programme, MSP);
- tax reductions (e.g. income tax break in France);
- loans at reduced rates;
- green heat or energy efficiency certificates.

FIS in the form of direct grants have played an important role in the development of the leading solar thermal markets in Europe (Germany, Austria and Greece). And in the fastest growing solar thermal market (France), a reduction in income tax has significantly accelerated the existing market growth since 2005. The analysis of case studies from different EU member states has clearly shown that it is not so much the type of incentive but the concrete design and implementation – including flanking measures such as raising awareness or training professionals – that makes a FIS succeed or fail. The single most important success factor for the long-term stimulation of a solar thermal market through a FIS has been continuity: with short-term programmes or insufficient budgets, FIS have failed to create healthy market structures, which are the basis for continuous growth.

Reducing administrative barriers

As for administrative barriers, the general principle should be established that the use of solar collectors is allowed without the need for any special authorization, except for a precisely defined and limited number of buildings of special historical interest. Moreover, it is necessary to make the rules solar friendly for the right of use of the roofs in large buildings with many residential or tertiary units.

Flanking measures

Along with raising awareness, training professionals and R&D funding are important for the long-term success of the solar thermal markets. In Austria, 2006 was the year of the consolidation of solar campaigns in some Austrian provinces, which forced awareness of solar thermal on the population. These campaigns were backed by the national solar programme 'klima:aktiv solarwärme'. Solar brochures for home owners, housing associations and hotels were widely distributed, and a highly frequented solar hotline and website and hundreds of press releases helped to bring information about solar thermal to many people.

Key countries and success stories

Germany

Germany is in leading position in total ST installed capacity in Europe. To date, more than 5 per cent of German households use solar thermal energy and over 1.2 million solar thermal systems are already installed on German roofs. The total installed solar energy output in Germany at the end of 2008 amounted to some 7,765,800MWth, 11,094,000m^2. Over the course of the next five years the German Solar Industry Association (BSW-Solar) expects over €10 billion to be invested in new solar energy systems in Germany for the generation of hot water and an increasing share of floor heating too. Medium-sized enterprises and craftsmen in particular will benefit from this market development.

Figure 2.11 House with flat-plate collectors on the roof in Germany
Source: VELUX

There are approximately 5000 German solar thermal energy companies and craftsmen, employing over 20,000 people. In 2008 sales of €1.2 billion were recorded. Solar thermal energy plants are technically advanced, environmentally friendly and protect the climate. In addition, they improve supply security because they reduce dependency upon oil and gas imports. For this reason, in comparison to current oil and gas prices, the German government encourages their use through a grant under the so-called Market Incentive Programme. In order to accelerate distribution in future, further systematic expansion programmes are to be set up in the near term. In addition to

BOX 2.3 THE GERMAN MARKET STIMULATION PROGRAMME

Germany has become one of the EU leaders on solar thermal thanks to its 'Programme to stimulate measures for using renewable energy sources', in short 'Market Stimulation Programme' (MSP). In the MSP, solar thermal systems are supported through a financial incentive of €60 per m^2 of collector area for systems which are used for heating domestic hot water, and €105 per m^2 of collector area for systems which also support central heating (so called combi-systems), or which are issued to heat industrial processes or thermally driven cooling machines. Additional incentives are offered for enlargements of existing systems and especially for 'innovative' systems. Those entitled to apply include, amongst others, private individuals, small and medium-sized companies, municipalities and registered associations. Over 90 per cent of the solar thermal systems installed in Germany receive incentives through the MSP.

BOX 2.4 SUCCESS STORY: SOLAR THERMAL IN UPPER AUSTRIA

Upper Austria is the most successful region for solar thermal penetration in Austria. One out of four solar thermal systems in Austria has been installed in this province so far. For almost 30 years, solar systems have benefited from financial incentives, based on a balanced network of long-term thinking from regional politicians, active solar companies and the regional energy agency *OÖ Energiesparverband* as the driving force and mediator. Subsidies have been given for the new house market as well as for the renovation market. The financing scheme is enacted and administered by the regional government of Upper Austria. *OÖ Energiesparverband* is in charge of energy consultation for private and commercial customers and for monitoring the financing scheme. Based on this monitoring, changes to the financing scheme (subsidy level) have been suggested to the government by the energy agency. Private home owners, housing associations, installers and solar companies have clearly benefited from the financing scheme, because it has led to the only continuously growing solar market among Austrian provinces so far. The official aim of the government of Upper Austria was to increase the total installed collector area to 1 million m^2 by 2010. This target was reached in May 2009 and the the province has now over 0.7m^2 collector area per inhabitant, making them the region with the highest solar thermal installed capacity per capita in the world. Their target is now to reach a total installed capacity of 2.1 GWth (3 million m^2) by 2020. Certainly the lesson to be learned from Upper Austria is that long term establishment of a continuously growing solar market needs stable conditions in terms of uninterrupted subsidy, awareness campaigns and training activities for installers and a stable communication network of public authority and private companies to secure stable conditions.[2]

smaller, decentralized plants, new opportunities are presented by district heating networks, into which large-scale solar collector arrays can feed solar thermal energy. In Germany a great deal of work is already being done on projects of this type. Some of these are also capable of using large seasonal heat tanks, storing the solar thermal energy generated in the summer for use during the winter months.[1]

Austria

Austria remains the Continental-European leader in solar thermal. In Europe, only Cyprus has a higher capacity in operation per inhabitant than the 273kWth per 1000 capita in Austria. A new and very positive trend is the substantially increasing number of larger collective systems. While in the past demand was almost exclusively in the one- to two-family house sector, nowadays more and more multi-family houses (or blocks of flats) are equipped with solar thermal systems. Fifteen per cent of detached houses in Austria already use solar thermal. The annual turnover generated in connection with solar thermal systems in Austria amounted to €590million in 2008 (€385 million in 2007) including swimming pool absorbers and export activities. Growth of 25 per cent was reached in the Austrian market in 2008, while exports increased by 62 per cent. Overall, 243MWth of new capacity was added in 2008 (347,703m^2). In 2008 around 7400 people were employed in the solar thermal sector in Austria (around 6,500 in 2007) including producers, and installers. Of the 1.6 million m^2 total production in Austria, four fifths are exported to more than 20 countries: two-thirds to Germany, 10 per cent to Italy and less than 10 per cent to France and Spain.

France

The French market increased a further 17.6 per cent in 2008, compared to the previous year. 271,600 new kWth were installed, reaching 1,136,870kWth in operation at the end of 2008. The simplicity of the tax rebate introduced in 2005 has significantly contributed to the success of this incentive scheme. Investment in a solar thermal system is tax deductible either from both income tax and corporate tax. This type of scheme has been used in France since 2005 with excellent results and has led to an acceleration of the already significant market growth. In 2005 the market more than doubled compared with the previous year. In the past, tax reductions were also successfully applied in Greece.

BOX 2.5 SUCCESSFUL SUPPORT THROUGH TAX INCENTIVES IN FRANCE

In France, the very successful scheme, introduced in 2005, shows that the positive effects of a tax reduction can be substantial and outweigh any disadvantage: the tax reduction/return removes the need to apply for a grant before purchasing a solar thermal system. This drastically reduces the procedure for receiving the FIS and removes the waiting period between the application for a grant and its approval. Incentive programmes like the French 'plan soleil' could be the beginning of a boom for national industries when accompanied by qualification programmes to educate craftsmen in the professional installation of solar thermal systems like the French 'Qualisol' qualification programme, to train fitters in the installation of solar thermal systems. This programme was started by the French governmental energy agency, ADEME, in January 2006. According to the French Solar Industry Association Enerplan, the sector has during this time developed into a professional economic sector 'with over 10,000 qualified fitters'.

Figure 2.12 Spanish house with thermo-siphon system on the roof
Source: Solahart

Spain

The total ST capacity in operation at the end of 2008 in Spain was 988MWth, and Spain is one of the most dynamic markets in Europe. In 2008, the market for newly installed systems increased by 58 per cent to reach 304MWth.

BOX 2.6 SPANISH TECHNICAL BUILDINGS CODE: ADVANCED SOLAR LEGISLATION

In March 2006, Spain became one of the countries with the most advanced solar legislation in the world. On 17 March 2006, the Spanish government approved the new Technical Buildings Code (Código Técnico de la Edificación, CTE), the most significant reform of the Spanish building sector for decades. The new CTE built on the success of the municipal solar ordinances. The CTE includes the following main areas: security of the buildings structure, fire safety, other safety and health issues, sustainability and energy efficiency of the buildings. The latter part ('Documento Básico HE – Ahorro de Energía') goes far beyond the minimal level of implementation of the EC Directive on the Energy Performance of Buildings and includes an obligation to cover 30–70 per cent of the domestic hot water (DHW) demand with solar thermal energy. The solar thermal part applies to all new buildings and to those undergoing a renovation. It applies to any kind of buildings, irrespective of their use. Some exceptions are defined in the law; mainly in the case of buildings that either satisfy their DHW demand by other renewables or by co-generation, or for shaded buildings.

EXAMPLE: BARCELONA – THE PIONEER OF SOLAR REGULATION IN EUROPE

The city of Barcelona has been the pioneer for solar regulations in Europe. The first Solar Building Code entered into force in 2000 and required that a certain share of the domestic hot water demand in larger residential buildings was covered by solar thermal in new buildings and those undergoing major renovation. The implementation led to a strong increase in the use of solar thermal, thereby also stimulating the voluntary market in non-obliged buildings. The regulation enjoyed wide support among decision-makers and the public. Therefore, the revision approved in 2006 broadened the definition of obliged buildings and improved the procedures, architectural integration and quality requirements.

Greece

For over 30 years, the Greek solar thermal market has been dominated by thermosiphon systems. But that could well change in the future: the local solar suppliers have begun to market combi-systems. A few companies have been successful with large-scale installations for hotels. And the first solar-based air-conditioning systems have been manufactured. In 2008 there was 2708MWth (3,868,000m^2) solar thermal capacity in operation. With 208,600kWth (298,000m^2) newly installed in 2008, they were representing a market growth for the period 2007/2008 of 5 per cent. More than 3000 people are employed in the Greek solar thermal sector with a turnover of more than €250 million.

BOX 2.7 A MATURE MARKET BUT STILL WITH HIGH POTENTIAL

Greece is an excellent example, because it was the first EU country to reach significant ST sales volume. In the 1980s, market development was boosted by public support in the form of strong awareness-raising campaigns, including television advertisements and financial incentives. The latter were gradually phased out. Since 2003 there have been no financial incentive schemes in Greece except for very small ones targeted at special market niches. In spite of the withdrawal of financial incentives, in 2004 Greece had a level of sales per capita around 30 times higher than Portugal and southern Italy and yet all three of these countries have similar climatic and economic conditions. The Greek example shows the true result of a long term, well-implemented FIS for ST: once a certain critical mass is reached, the market continues to grow without further public support. Nevertheless, the potential for solar thermal energy in Greece is a long way from being fully exploited. Within a positive framework of support for the full exploitation of solar potential, the Greek market should grow by a factor of five to ten times over the next two decades.

TOMORROW

The European Solar Thermal Technology Platform was launched in 2006. The solar thermal industry and research institutions developed a common vision for the use of solar thermal up to 2030 and published at the end of 2008 a Strategic Research Agenda (available for download at www.esttp.org).

The Strategic Research Agenda describes the research that is essential to expand the application field of solar thermal technologies, so that in the long term 50 per cent of the thermal heat demand in the EU can be met. To reach this goal, a new generation of solar thermal technologies need to be developed for new application areas. The main new applications are: solar combi-systems using compact seasonal storage, higher temperature collectors for industrial applications and solar cooling. The main research challenges are to develop compact long-term efficient heat storage and cheaper materials for solar systems. The storage technology should make it possible to store heat from the summer for use in winter cost-effectively. New materials are needed because the current materials have a limited supply and could potentially be replaced with cheaper options.

In order to face all these research and technological challenges, the ESTTP has been enlarged into a European Technology Platform on Renewable Heating and Cooling (RHC Platform) which now includes not only solar thermal but also a whole range of renewable energy technologies for heating and cooling i.e. biomass and geothermal.

Targets for 2020 and beyond

The European Solar Thermal Industry Federation (ESTIF) published in 2009 a Study on the 'Potential of Solar Thermal in Europe' that examines the growth that can come from the solar thermal heating and cooling sector. Detailed surveys were conducted in five representative countries (Austria, Denmark, Germany, Poland and Spain) and the figures were then extrapolated to the 27 EU countries. Under the most ambitious scenario, which includes substantial financial and political support mechanisms, energy

Figure 2.13 House with vacuum tube collectors installed on the facade
Source: Ritter Solar

efficiency measures as well as intensive research and development activities, solar thermal would make up 6.3 per cent of the European Union's 20 per cent renewable energy target, representing an annual sector growth rate of 26 per cent. This would represent 0.8m^2 of installed capacity per capita and 9 per cent of the low temperature heat demand in Europe by 2020.

With a suitable support framework it will be possible to reach 0.8m^2 of collector area (0.56kWth) for every European in 2020, equivalent to a total capacity in operation of 271.6GWth in the EU. In the residential sector alone about 2 million EU families have already installed this amount of solar capacity. To reach this target, solar will be widely used for both cooling and to process heat, though the majority of this capacity will still supply domestic hot water and central heating. The average yearly growth rate of the EU market necessary to reach this target is 27 per cent – less than the rate achieved in 2008 and the 2004–2008 average.

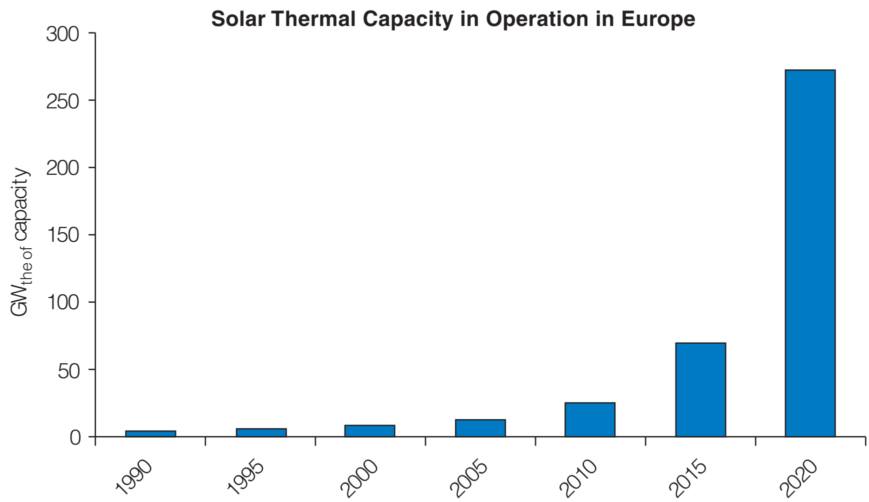


Figure 2.14 Solar thermal capacity in Europe
Source: ESTIF (2008)

Figure 2.15 Collector field on the roof of a commercial building.
Source: ZEN-International

Technological long-term potential

By overcoming a series of technological barriers, which are being analysed in detail in the Strategic Research Agenda, it will be possible to achieve the introduction, at competitive costs, into the wider market of advanced ST applications such as:

- solar active buildings, covering 100 per cent of their thermal energy with solar and in some cases providing heat to neighbours;

- high solar fraction central heating for building renovations;
- wide use of solar for domestic cooling;
- wide use of solar for heat intensive services and industrial-process heat, including desalination and water treatment.

These are the key elements of the ESTTP Vision, Deployment Roadmap and Strategic Research Agenda. By implementing them, the potential for economically viable ST usage can be substantially expanded. The long-term potential of solar thermal (2050) is to provide about 50 per cent of the EU's low temperature heat demand.

NOTES

1 Source: ESTIF and Bundesverband Solarwirtschaft (BSW-Solar), available at www.renewables-made-in-germany.com/en/solar-thermal/.
2 Source: Austria Solar.

3

Biomass

Different conversion paths exist to transform biomass to heat, electricity, liquid fuels or biogas. The most important are shown in the following table.

As biomass for heating and electricity are often interconnected, many of the general considerations that follow concern both technologies.

Table 3.1 Main conversion paths from biomass to heat

Raw Material	Conversion process	End product
	Combustion	Heat
	Combustion and steam process	
	ORC process (doesn't use water but another organic material)	Electricity and heat
Biomass	Stirling Engine	
	Thermal gasification and gas engine	Electricity and heat
	Thermal gasification and Fischer-Tropsch process	Electricity and heat
	Alcoholic fermentation	Ethanol
	Transesterification	Biodiesel
	Anaerobic fermentation	Biogas

Source: AEBIOM

STATE-OF-THE-ART TECHNOLOGY

Biomass includes a broad variety of raw materials such as wood, agricultural crops, by-products of wood processing, agricultural and forest industries, manure and the organic matter of waste streams. Bioenergy is a final energy in the form of heat, electricity and biofuels produced from biomass using various technologies and technological systems. In 2006 RES represented 9 per cent of the final energy consumption in Europe and biomass represented two-thirds of the whole RES production – 89Mtoe. Biomass represents two-thirds of the distribution of RES in 2006.

The main biomass production route is heat as 97.6 per cent (61Mtoe) of renewable heat comes from biomass.

Biomass resources can be classified according to the supply sector as shown in Table 3.2.

The energy available in biomass may be used either by directly as in combustion, or by initial upgrading into more valuable and useful fuels such as charcoal, liquid fuels, producer gas or biogas. Thus, biomass conversion technologies can be separated into four basic categories:

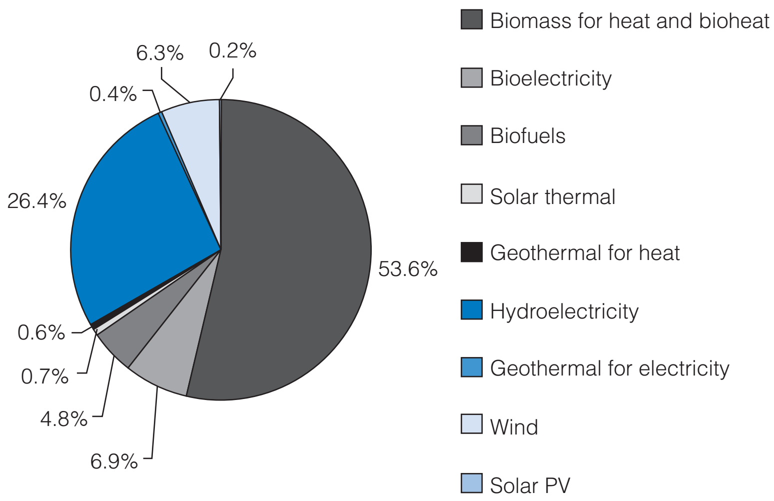


Figure 3.1 RES distribution per sector
Source: Eurostat

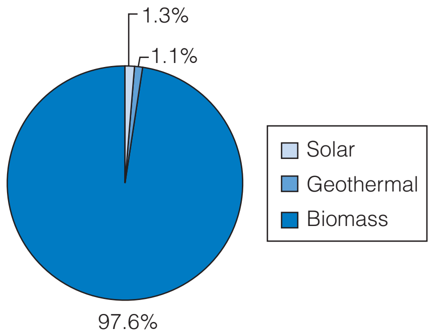


Figure 3.2 Biomass fraction of heat production
Source: Eurostat

1. direct combustion;
2. thermo-chemical conversion processes (pyrolysis, gasification);
3. biochemical processes (anaerobic digestion, fermentation);
4. physico-chemical (the route to biodiesel).

Technological benefits

Biomass is widely available and represents a local, clean and renewable resource. Biomass needs to be produced, recovered and supplied to the plant which adds an additional cost to this renewable energy as compared to other RES. Nevertheless, biomass can be stored in large quantities and, therefore, produced on demand. Furthermore, the use of biomass has many additional advantages.

Table 3.2 Biomass resources

Supply sector	Type	Example
Forestry	Wood from forest	Wood logs, wood chips, wood chips from residues including those coming from fellings, thinning operations (tops, branches and stumps)
	Dedicated forestry	Short rotation plantations (e.g. willow, poplar and eucalyptus)
	Forestry by-products	Wood processing industry by-products such as chips, bark, sawdust, shavings, black liquor and refined wood such as pellets, briquettes, wood powder, charcoal, etc.
Agriculture	Dry lignocellulosic energy crops	Fast growing crops (e.g. miscanthus, reed canary grass and giant reed)
		Oil seeds for biodiesel (e.g. rape seed and sunflower)
	Oil, sugar and starch energy crops	Sugar crops for ethanol (e.g. sugar cane and sweet sorghum)
		Starch crops for ethanol (e.g. maize and wheat)
	Agricultural by-products	Straw, prunings from vineyards and fruit trees, rice husks, crushed grapes, olive kernels etc.
	Livestock waste	Wet and dry manure
Waste	Dry lignocellulosic	Residues from parks, roadside and gardens (e.g. prunings and grass)
	Contaminated waste	Demolition wood
		Organic fraction of municipal solid waste
		Biodegradable landfilled waste and landfill gas
		Sewage sludge

Source: AEBIOM&EUBIA

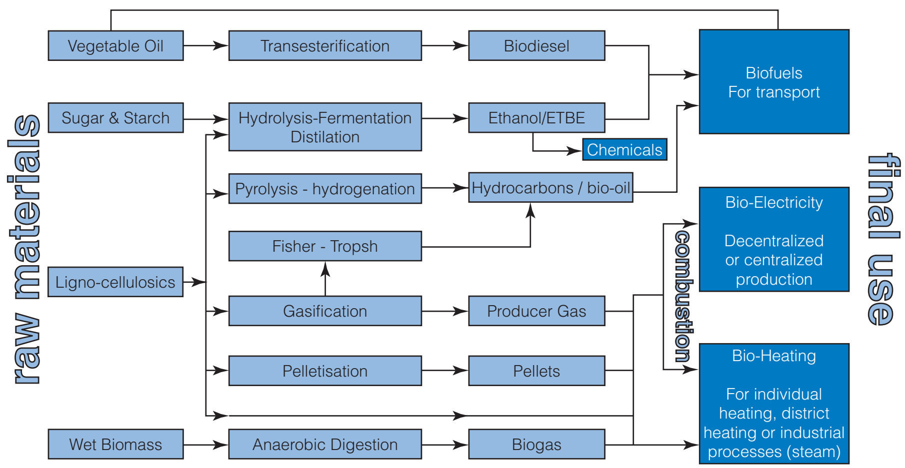


Figure 3.3 Biomass fuels conversion to bioenergy
Source: EUBIA

Political and economic advantages

- guarantees local energy supply and therefore economic and political independency;
- creates jobs, especially in rural areas thus strengthening local economy;

- modern competitive biomass technologies and know-how offer opportunities for technology transfer and exports;
- provides marginal agricultural areas or surplus areas with new development opportunities.

Biomass fuels-related advantages

- widespread availability in Europe;
- biomass has the capacity to penetrate every energy sector: heating, power and transport;
- biomass resources show a considerable potential in the long term, if residues are properly used and dedicated energy crops are grown;
- generally low fuel cost relative to fossil fuels;
- can create and promote markets for refined biomass that can be easily stored, transported and used for heating.

Environmental

- CO_2 mitigation and other emission reductions (SOx, etc.);
- make valuable use of agro-industrial and forestry residues, avoiding the cost of their disposal as waste;
- bioenergy makes valuable use of some wastes, avoiding their pollution and cost of disposal;
- biomass fuels are generally bio-degradable and non toxic, which is important when accidents occur.

Some barriers exist which impede bioenergy expansion:

- physical characteristics of biomass are quite different;
- lack of small capacity efficient units for co-generation using solid biomass;
- costs of bioenergy technologies and resources and especially cost from changing fossil fuel based systems to renewable ones;
- competitiveness strongly depends on the amount of externalities included in the cost calculations;
- resource potentials and distributions;
- difficulties in mobilizing biomass resources;
- local land-use and environmental aspects in the developing countries;
- administrative and legislative bottlenecks;
- if not refined (pellets/briquettes) biomass is biologically unstable.

To overcome these barriers it would be necessary to:

- improve support mechanisms and remove existing legislative and administrative barriers;
- ensure that the biomass sources are mobilized;
- improve the cost-effectiveness of conversion/utilization technologies;
- develop and implement modern, integrated bioenergy systems (multicrops, multiproducts);
- develop dedicated energy crops' productivity;
- establish bioenergy markets and develop bioenergy logistics (transport and delivery of bioenergy resources and products);
- consider the value of the environmental benefits for society, e.g. on carbon balance.

Technological applications

Biomass to bio-heat

The different forms in which biomass is available, such as solid or wet biomass, vegetable oil or sugar, can be transformed into bio-heat (other than renewable electricity and biofuels) through a range of conversion routes – thermal, chemical or biological – and be used for various purposes. Combustion of wood for heat production is the main route for bioenergy. However, several systems can be considered depending on size. Small-scale heating systems for households would typically use wood logs or pellets; medium-scale appliances would typically involve burning woodchips in grate boilers, while large-scale boilers would be able to burn a larger variety of fuels including wood waste and refused-derived fuels.

Biomass fuels

Wood logs

Traditional wood logs are mainly used by households (in stoves and boilers) in rural areas. Production technology of wood logs has remained the same over the decades: trees are manually cut into logs using a chainsaw. The wood harvester technology, however, has developed further. The harvesters cut the timber together with firewood in one operation. Also integrated machines for cross-cutting, splitting and loading logs can be seen as an innovation. Nevertheless, they are only cost-efficient for industrial wood logs production. The accumulative felling head is adapted for forest thinnings to cut and bundle several young trees at once in a standing position without having to lay them on the ground. This increases the harvesting capacity as well as harvesting efficiency due to a lesser manoeuvre moves.

Briquettes

Briquettes are refined raw material for bioenergy production. Residues, such as sawdust and shavings, ram and screw extrudes, are used to produce briquettes. After the additional grinding and drying of the raw material (moisture content has to be less

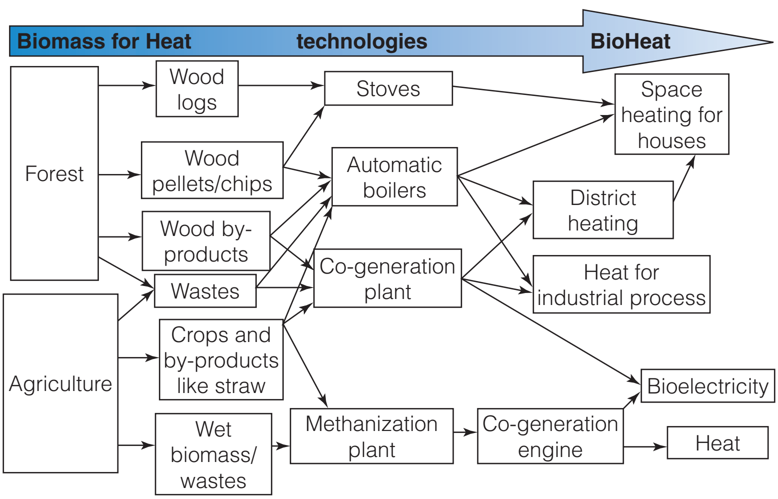


Figure 3.4 Biomass to bio-heat
Source: AEBIOM

than 12–14 per cent), these technologies press the residues into 30–100mm size briquettes. The density of briquettes made by screw press is higher and this technology makes less noise than the ram extruder, although energy cost of pressing is also higher.

Wood chips

Wood chips can be made from a broad variety of raw material such as wood residues – logging residues, small trees from forest thinning operations, stumps and roots, wood waste (old furniture) – or dedicated energy crops such as miscanthus, willow, poplar, reed canary grass etc. Wood chips are mainly used in a large-scale plant for this. Depending on the size of the chipping operations, harvesting and transporting the chips to the plants (usually to produce heat for the district heating plants or combined heat and electricity) can be done in several ways. Chips production can be divided into several procedures: harvesting, chipping, crushing and transportation. Efficient transportation is a key element as this is connected to the highest cost of the process (especially if forest residues are harvested). For this reason it is very important to ensure good logistical planning and high technology navigation systems.

Pellets

Wood pellets are a convenient and clean fuel produced from saw dust and wood shavings compressed under high pressure. In recent years, in some places, log wood from thinning is also used to produce pellets. At present pellets are successfully used for heat production on a small scale (stoves and boilers) but also in a large scale for district heating or in co-generation plants. The large heating plants usually use pellets together with wood chips, bricks etc. However, pellets are especially suitable in small heating systems (stoves and boilers) due to their automatic heating process, easy storage as they do not degrade, relatively low cost and a very low amount of ash and other emissions released. Domestic households account for about 27 per cent of total energy consumption. The heat market related to domestic households can be best addressed by using pellets as this fuel is as convenient to use as fossil fuels. Due to their high energy content and the convenient delivery and storage feature, pellets are an ideal fuel for replacing heating oil or gas. They are, besides biomass district heating, a key technology for increasing biomass use in Europe and thus replacing fossil fuel, natural gas or electricity in the heating sector.

Table 3.3 Key characteristics of pellets

Heating value	4.8 kWh/kg pellets or 0.41toe/t pellets or 2t pellets = 1000l heating oil
Water content	below 10%
Ash content	below 0.5%
Density	0.65 t/m³

The production of pellets from solid biomass is a technology which transforms biomass to an energy carrier efficiently. Biomass is milled, dried and densified. The result is a homogeneous solid fuel with a much higher energy density. State-of-the-art technology of pellet production can achieve overall conversion losses both for drying, milling and densification that are lower than 10 per cent. Excess heat from the production is recycled and used for drying the raw material for new pellets.

Biogas

Biogas is produced from organic matter under anaerobic conditions in nature (swamps), in landfills or in anaerobic digestion facilities (fermenters). In an airtight digester, various anaerobic micro-organisms produce biogas from silage, liquid manure, leftover food, waste or other fuels in a four-stage process. The bacteria break down complex fatty acids, carbohydrates and protein chains until only methane, carbon dioxide and water remain. The raw biogas generated during this process is composed of 50–60 per cent of CH_4, which can be used for energy production. Raw materials that cannot be digested or converted by micro-organisms remain in the form of fermentation residues and are used as fertilizers in agriculture. Biogas can either be used to fuel a gas engine, which is coupled with a generator to produce electricity and heat or – after upgrading to pure biomethane – in natural gas grids or in filling stations as transportation fuel for gas vehicles.

Straw and other agricultural by-products

Crop residues (cobs, stems, leaves, in particularly straw and other plant matter) left in agricultural fields after harvest could potentially be used for solid biofuels production. Due to high energy content, straw is one of the best crop residues for solid biofuels. Its energy content is 17–18MJ per kg of dry matter. However, straw has several disadvantages: it has a higher ash content and a low ash melting temperature; in order to improve its bulk density, straw is generally baled before transportation; straw burning requires a specific technology; to be suitable for heat and electricity, production straw should not have a high content of moisture, preferably no more than 20 per cent as the moisture reduces the boiler efficiency. Also straw colour and chemistry should be considered before burning as it indicates the quality of the straw. Other types of agricultural by-products can also be used to produce heat, such as prunings from vineyards and fruit trees, rice husks, crushed grape, olive kernels etc. Nevertheless, this fuel is more difficult to use and therefore there is a need to improve such technologies.

Waste

Waste for energy can take several forms such as the biodegradable fraction of Municipal Solid Waste (MSW), sewage sludge and other forms of organic material especially from the food industry. In some legislative documents, typical by-products of agriculture or forestry such as straw, bark or chips are considered as waste. These products are not waste but typical by-products of the normal production chains. Waste is an increasing source for energy production. The determination of the renewable fraction of MSW creates difficulties. In some countries this renewable fraction is estimated, in others the total incineration of waste is seen as renewable. Renewable organic waste is the term used to describe those wastes that are readily biodegradable or easily broken-down with the assistance of micro-organisms. Organic wastes consist of materials that contain molecules based on carbon coming from the atmosphere via green plants. This includes food waste and green waste. The European Committee of Standardization (CEN) has prepared 30 technical specifications on solid biofuels.[1] The standards can be used as tools to enable both efficient trading of biofuels and good understanding between sellers and buyers, as well as in communication with equipment manufacturers. These technical specifications are pre-standards, which are in force for three years after publishing. At the moment, they do not invalidate national standards. After a three-year period it will be decided whether these technical specifications will be

Countries	2006 Heat plants only	2006 CHP plants	2006 Total heat	2007* Heat plants only	2007* CHP plants	2007* Total heat
Royaume-Uni/UK	61.9	–	61.9	61.9	–	61.9
France/*France*	44.4	5.8	50.2	47.4	5.8	53.2
Italie/*Italy*	–	38.6	38.6	–	40.9	40.9
Pologne/*Poland*	6.0	28.1	34.2	6.0	28.1	34.2
Rép tchèque/*Czech Rep*	10.0	13.9	23.9	9.6	14.3	23.9
Danemark/*Denmark*	3.7	17.1	20.9	4.7	18.8	23.6
Allemagne/*Germany*	8.7	14.5	23.2	8.7	14.5	23.2
Finlande/*Finland*	2.5	19.7	22.1	2.5	19.7	22.1
Suéde/*Sweden*	4.7	11.7	16.4	4.7	11.7	16.4
Espagne/*Spain*	14.7	–	14.7	14.7	–	14.7
Belgique/*Belgium*	1.0	12.9	13.9	1.6	12.6	14.2
Autriche/*Austria*	4.7	4.2	8.9	4.3	4.2	8.5
Luxembourg/*Luxembourg*	–	4.4	4.4	–	5.0	5.0
Grèce/*Greece*	–	2.9	2.9	–	3.5	3.5
Irlande/*Ireland*	1.5	2.6	4.0	1.5	1.9	3.4
Slvaquie/*Slovakia*	2.3	0.9	3.2	2.3	0.9	3.2
Hongrie/*Hungary*	–	2.6	2.6	–	2.6	2.6
Estonie/*Estonia*	0.1	0.9	1.0	0.1	0.9	1.0
Pays Bass/*The Netherlands*	–	1.0	1.0	–	1.0	1.0
Lituanie/*Lithuania*	–	0.3	0.3	–	0.3	0.3
Chypre/*Cyprus*	–	0.02	0.0	–47.4	0.0	0.0
UE/*EU*	**166.2**	**182.1**	**348.3**	**170.1**	**186.8**	**356.9**

*Estimate

SOURCE: EIROBSERV/ER 2008

Figure 3.5 Gross heat production from biogas in the EU in 2006 and 2007I (in Ktoe)
Source: EurObserv'Er

updated to European norms. The upgrading work started in the autumn of 2006 and will be carried out until 2010. In the meantime, there are various possibilities (via international biomass conferences, articles etc.) for standard users to comment and further improve the European standards.

Combustion

Combustion is the main process for producing heat from biomass. It is a CO_2 neutral process as the carbon in biomass is captured by the plant via photosynthesis from the atmosphere and is delivered back to the atmosphere anyway – by combustion or organic decay.

Table 3.4 CO_2 emissions during combustion causing an increased CO_2 content in the atmosphere

Energy carrier	NCV	CO_2 emissions in relation to the NCV (kg/kWh)
Hard coal	7.43 kWh/kg	0.338
Brown coal	5.28 kWh/kg	0.382
Heating oil	9.79 kWh/l	0.269
Natural gas	10.00 kWh/m³	0.199
Wood at 20% moisture content	4.00 kWh/kg	0 kg /kWh

Source: AEBIOM

Many different combustion technologies can be used to burn biomass fuels:

- **Pulverized combustion**: the biomass fuel is transformed into powder – homogeneous fuel and burned for heat production. In this way, this technology can reach a high temperature mostly for industrial processes. It is normally used in co-firing (coal) power plants and rarely in 100% biomass fuelled plants.
- **Grate combustion technologies (grate furnaces)**: are mostly used for medium and low capacity technologies. There are different types of grate furnaces such as fixed grate or moving grates. The capacity of the furnace, automatization level and the fuels to be burned defines the choice of the most suitable furnace.
- **Combustion in fluidized bed**: the biomass fuel is burnt in a hot bed of fuel particles. The air is injected into the bed and the fuel particles start to suspend in the air flow. Different low quality fuels such as high-ash fuels and agricultural biomass residue can be used whilst at the same time reducing nitrogen oxide (NOx) emissions and increasing heat transfer. Also, low operating temperatures (below 972° C) can be used by these combustors.
- **Fuel gasification (and later combustion)**: is a thermochemical process that converts biomass into a combustible gas – syngas. This gas contains 70 – 80 percent of the energy originally present in the biomass feedstock, and about 10 – 25 percent of the primary fuel mass is a residue charcoal. After the syngas is cleaned, it can be burned directly for space heat or drying, or it can be burned in a boiler to produce steam. Higher quality syngas after it is converted into methanol can be used for the transport sector. If combined with a gas turbine or fuel cell, the gasifier can produce electricity.

  Gasification technology is at the early stage of development. Due to the high cost of equipment, this technology is not widely used.

Two general technologies for biomass combustion are mainly used in Europe. Particle size, ash and water content of the fuel are very important in determining the right technology. Large plants are usually able to handle multiple fuels and quality variations. This helps to secure continuous fuel availability, but also requires a more complex combustion process. The combustion in fixed-bed is the traditional and rather inexpensive technology applied to small scales (<20MW) and it generally requires a certain fuel (e.g. dry wood chips). The construction period and costs can be reduced due to a standardized design. The fluidized bed boiler (stationary or circulating) is a more sophisticated approach suitable for the 10–600MW capacity range. It offers the advantage of handling various fuels with different water contents simultaneously and accomplishes a more complete combustion than a fixed bed, which results in higher yields and lower exhaust emissions. The disadvantages are high investment and operating costs. Biomass is also used in co-firing in order to make existing plants (normally coal) more environmentally friendly.

Stoves

In rural and densely wooded areas stoves fuelled by wood logs have long been the main source of heating for family homes. Due to their limited heat distribution throughout the house, as well as the need for a supply of warm water, stoves usually got replaced by boiler systems using wood logs, split logs, briquettes or even pellets as fuel. Nevertheless, in Europe there are still ovens in use and many people have a woodburner (normally with a glass front) in their living room in order to create a special atmosphere. Used as a supplementary heat source ovens can also significantly reduce heating costs, if wood is cheap (e.g. own production) and prices for non-renewables like oil and gas are high. Wood stoves typically offer a performance of 2–10kW.

Boilers

Boiler technology is available for a wide capacity range and different forms of biomass. The thermal energy created by the burning process heats up water that is either distributed via pipes to customers in district heating networks or directly used for heating and warm water in a single family home. Boilers generally start at 10kW for small family homes and reach 300kW–5MW for district heating. Bigger plants (>5MW) usually co-generate both heat and electricity (combined heat and power, CHP) and reach up to several hundred MW. Small boilers are stocked manually if using log wood or sticky wood residues (for family or multi-family houses or blocks of flats) and automatically if wood pellets or wood chips are used. Heating plants run on wood chips, briquettes, various residues from the wood industry (bark, saw dust cutter chips), straw or miscanthus.

District heating

'District heating or cooling' can be defined as the distribution of thermal energy in the form of steam, hot water or chilled liquids from a central source of production through a network to multiple buildings, for the use of space or process heating or cooling.[2] The core element of a district heating system is usually a co-generation plant (also called combined heat and power, CHP) or a heat-only boiler station. The difference between the two systems is that, in a co-generation plant, heat and electricity are generated simultaneously, whereas in heat-only boiler stations – as the name suggests – only heat is generated. A district heating system works like a domestic central heating system, only on a larger scale. Water is heated at the scheme's energy centre

BOX 3.1 A NEW TECHNOLOGY: THE PELLET CONDENSING BOILER

The principle is the same as a gas condensing boiler. The combustion gases comprise energy which is recovered in the form of steam. The vapour existing in those gases is condensed and allows energy recovery, usually 10–15 per cent of the lower calorific value. The temperature of the smoke varies between 130°C and 145°C in the standard pellet boiler without a condensing system and is around 70°C in a boiler with a condensing system. The efficiency of such a boiler can reach more than 100 per cent.

and circulated through an underground pipe network to customers. A heating pipe will run from the energy centre into a building/home where it is connected to the internal circulation system. District heating supply is reliable due to professional operation and continuous monitoring of heat production and distribution. Solid biomass used for district heating includes wood chips, residues from forests or wood processing, purpose-grown energy crops (poplar, willow, eucalyptus etc.), agricultural crop and animal residues, and the biogenic fraction of MSW.[3]

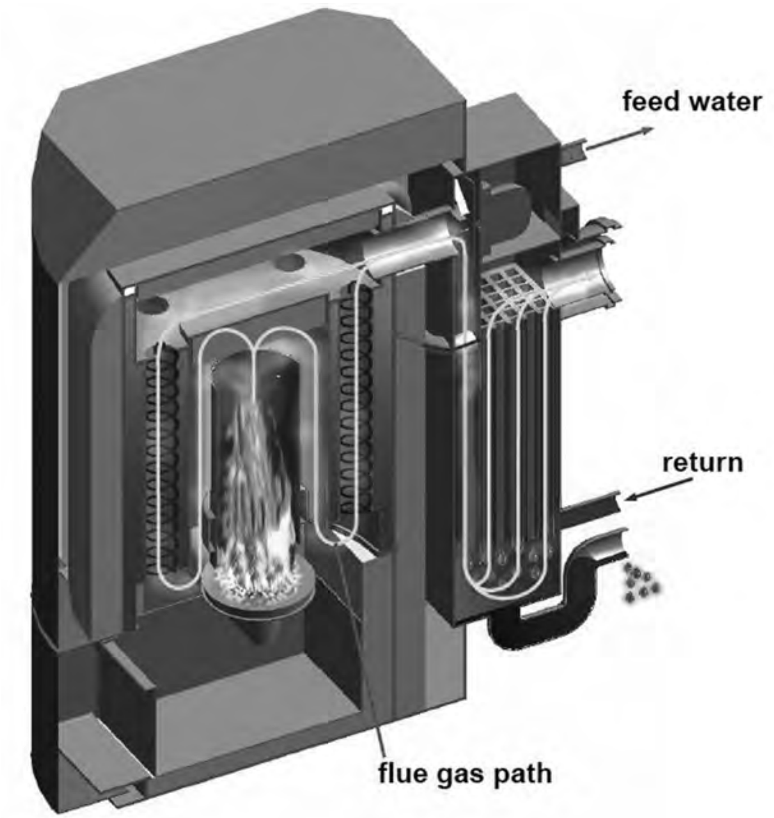


Figure 3.6 Pellet boiler with integrated flue gas condensation (efficiency 103%, nominal capacities 8, 10, 15 and 20 kW)
Source: OkoFEN

Cost and prices

Bioenergy costs mainly depend on biomass fuel costs. Biomass fuels' costs vary greatly between EU member states but the price remains stable compared to fossil fuels.

MARKET

Installed capacity and market development in the EU and market segments

Pellet use in Europe is currently focused on a small number of member states including Sweden, Denmark, the Netherlands, Belgium, Germany, Austria and Italy. Only in these countries have pellets been able to achieve a significant market penetration so far. In a number of other member states markets are still in an early stage of development with very low market penetration but signs of dynamic growth. Experiences in existing markets show that pellet utilization can grow extremely fast, if the proper frame conditions exist. In Italy for example the market of pellet stoves grew within 10 years from virtually zero to over 250,000 stoves sold per year. In Austria the market share of pellet heating systems grew within 10 years to over 12 per cent of all new sold boilers for residential heating.

RETAIL PRICES 6/2005	Forest residues	Ind. by-products	Firewood logs	Chopped firewood	Ref. wood fuels	Other biomass	Light fuel oil	Natural gas	Coal
Austria	N.A	3.86	5.56	4.44	8.61	N.A	16.65	7.39	12.68
Belgium	N.A	N.A	3.90	N.A	10.00	N.A	11.97	N.A	N.A
Czech Rep.	2.79	2.41	5.51	7.25	1.57	2.10	23.11	8.26	1.29
Denmark	4.48	3.73	10.90	N.A	9.21	3.91	22.50	20.80	20.80
Estonia	N.A	1.48	1.43	N.A	N.A	N.A	9.34	2.71	3.31
Finland	N.A	N.A	8.33	12.39	7.21	N.A	21.10	N.A	N.A
France	7.13	N.A	5.10	N.A	10.03	2.59	15.07	10.80	15.03
Germany	2.87	1.23	5.31	N.A	10.03	3.45	13.20	12.45	9.23
Greece	N.A	0.71	8.39	8.82	22.65	27.53	13.76	12.03	N.A
Hungary	N.A	N.A	4.80	5.02	6.41	N.A	19.43	5.84	3.88
Ireland	3.77	2.07	23.18	N.A	16.70	N.A	15.04	13.89	12.59
Latvia	N.A	1.03	0.81	1.29	4.50	N.A	20.68	3.59	1.75
Netherlands	N.A	N.A	N.A	N.A	16.00	N.A	16.48	15.77	N.A
Poland	N.A	N.A	2.50	N.A	5.58	N.A	13.51	8.03	3.49
Portugal	2.78	1.08	3.61	3.61	6.80	N.A	N.A	16.58	N.A
Slovakia	N.A	1.17	1.55	2.62	5.38	N.A	9.01	7.92	4.49
Spain	N.A	N.A	15.80	15.89	12.93	3.31	18.16	N.A	N.A
Sweden	4.09	3.38	5.10	6.22	12.72	4.17	26.99	22.89	N.A
United Kingdom	N.A	N.A	N.A	N.A	N.A	N.A	N.A	7.53	N.A
AVERAGE	3.99	2.02	6.58	6.76	10.01	6.72	16.82	11.03	8.05

Figure 3.7 Reported retail prices in June 2005 without VAT
Source: Alakangas E., Heikkinen A., Lensu T., Vesterinen P. (March 2007) 'Biomass fuel trade in Europe – Summary Report VTT-R-03508-07', EUBIONET II project, VTT

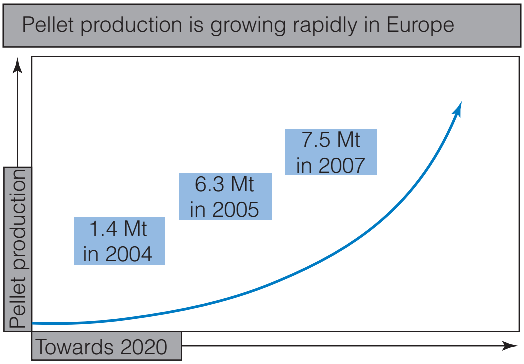


Figure 3.8 Pellet production in Europe towards 2020
Source: European Biomass Association (2008)

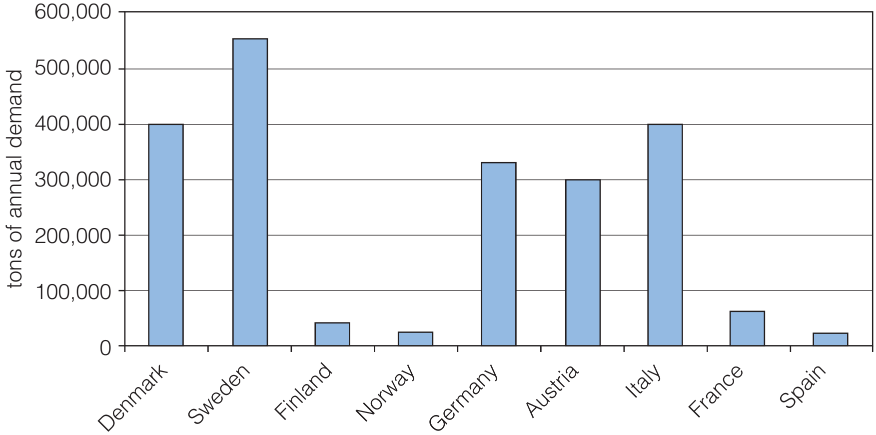


Figure 3.9 European markets for residential heating systems
Source: proPellets (2009)

Three different types of pellet markets have developed in Europe. First, pellet markets that are dominated by their utilization in power plants – this is the case for Belgium and the Netherlands. The UK could become another large power plant market for pellets. A second group of markets combines large-scale and small- to medium-scale use – this is the case in Sweden and Denmark. In the third type of market pellets are predominately used for heating in residential or commercial buildings. Within this last sector again stove markets can be distinguished from markets where pellets are used also in boilers or commercial applications. Typical stove markets are Italy or the USA. In these markets pellets are only distributed in bags. In Austria and Germany pellets are predominately used in residential and commercial boilers for heating. In these countries bulk delivery is the norm.

The fact that only a few countries are currently using pellets extensively is due to dedicated policies supporting market development. It is a common experience that new energy technologies cannot penetrate existing markets without significant political support. Existing barriers are usually too high and competition from fossil fuel industries too strong to allow strictly market driven diffusion. The district heating

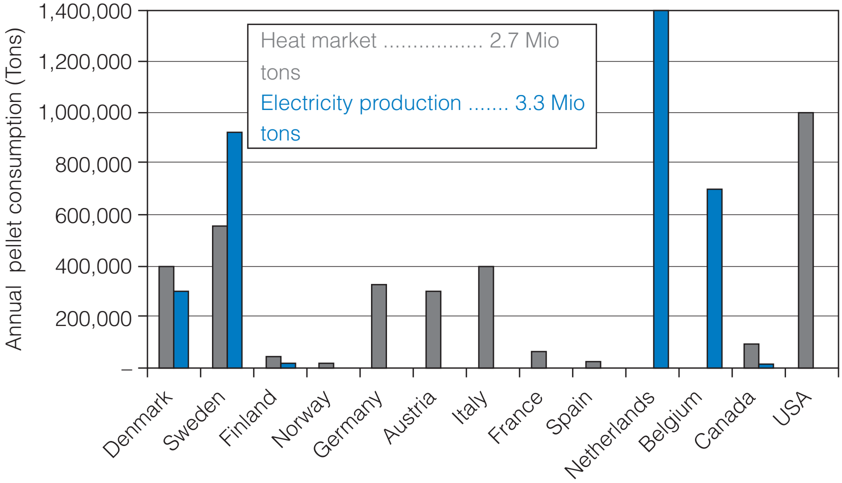


Figure 3.10 Comparison of international pellet markets (2006)
Source: proPellets (2009)

sector traditionally fired by conventional fossil fuels has a prevalent position in central, eastern and northern European countries. CHP and the community responsibility for urban heating developed according to the planning decrees in central and eastern Europe were the two main factors in the historical development of the district heating sector in that region.[4] Although the use of biomass for heat has a number of advantages compared to other forms of utilization, the growth in the past in the EU has not been satisfactory. The use of renewable systems for heating and cooling has received relatively little attention compared with renewable electricity. In the case of biomass, the focus of EU policy instruments to boost the biomass use has been targeted more towards bio-electricity and liquid biofuels; the subject of biomass for heat was frequently neglected in EU energy policy, which explains the limited investment of the renewable energy source in district heating systems in EU member states.

Industry

Biomass industry for heat is vast and includes manufacturers of biomass plants (for heat or co-generation), boilers, stoves, biomass harvesting technology, biomass fuels producers (pellets, wood chips etc) and traders. Biomass industry also includes the providers of biomass fuels such as farmers or forest owners. The biomass industry is the most developed in those countries where there is the highest amount of biomass resources: Sweden, Finland, Austria, Denmark, Germany and France. Sweden, with its policy of fossil fuels taxation, has especially developed the district heating market (or co-generation) with companies such as Söderenergi AB, Göteborg Energi AB and Ena Energi Ab. Finland is well known for their efficient forest residues harvesting technology, and production of heat and power in co-generation plants with companies such as VAPO. Austrian support for small-scale heating systems has helped to successfully develop the small-scale biomass applications such as pellets and wood chip boilers and stoves. There are a number of companies involved in the small-scale industry such as: ÖkoFEN, KWB, KÖB, Fröling, Windhager etc. Pellet industry is very strong in Austria with proPellets association representing not only Austrian but also the

European pellet industry. The manufacturers of small heating technologies have succeeded in attaining high efficiencies with their boilers/stoves, reaching more than 90 per cent or even more than 100 per cent efficiency (condensing technology) and very low fine-dust emission levels that are very important for this sector. These automatic apparatus demand very little maintenance and can be coupled with a solar thermal system to have 100 per cent RES-H. The pellet industry is becoming important not only in Austria and in Sweden, Italy and Germany, but also worldwide as this fuel, because of its characteristics, is easily imported or exported especially via large ports such as Rotterdam. Germany has a number of various technologies ranging from small- to large-scale heating and co-generation systems with companies like Seeger and Green Stream Network, or companies that try to use an increasing amount of biomass fuels for energy production such as Gee Energy. France, however, is mostly using traditional wood to heat their houses. A huge potential for biomass industry lies in eastern countries of the EU such as Czech Republic, Romania, Bulgaria, Baltic States etc., as these countries have huge resources of biomass fuels and a high dependency on imported fossil energy. During the last decade the biomass for heat industry has largely expanded in these countries. Nevertheless, only a small part of bioenergy resources was used.

Policy instruments to support the technology

With the adoption of the EU 'directive on the promotion of energy from renewable sources' (RES directive) in December 2008, heating and cooling will be directly promoted. In the past, a few European directives and several EC political initiatives indirectly promoted heating and co-generation from renewable energy sources. The RES directive promotes biomass for heating by requesting member states to include the heating and cooling sector within the national renewable energy targets that member states have to submit by June 2010. Heat will play a major role in meeting the 20 per cent RES target by 2020 as the heating and cooling sector consumes about 50 per cent of final energy in the EU, which is almost as much as transport and electricity combined. Integrating biomass heating technologies in buildings for H&C is also promoted with minimum requirements of renewable energy in buildings in the RES directive and requirements to tackle the administrative burdens (permitting procedures), by establishing support mechanisms for heat in the National Action Plans. Member states are encouraged to integrate biomass technology (such as the use of pellet boilers and stoves) in buildings as well as to promote the use of district heating and cooling produced using a significant share of biomass. Under the proposal recast of the 'Buildings Directive' (Energy Performance of Buildings Directive) 2009, which is currently under first reading in the EU, the setting of minimum obligations for RES in buildings will be revised. There are mainly two types of support mechanisms to promote the renewable heating and cooling: obligations and fiscal measures. In Europe, three main instruments have been mostly used to promote the RES-H at a national level: investment incentives, tax breaks for the renewable fuel or investments and low interest loans. These instruments are often combined with local and regional policies. Germany and Austria used investment incentives for biomass-fuelled heating systems, which resulted in quite a high biomass heat share within their national energy consumption. Sweden has long been using the CO_2 taxation policy which penalizes polluters and makes biomass fuels more competitive. Sweden, mainly by using biomass resources, has reached the highest share of RES in the EU, with almost 31 per cent (in 2007).

Obligations

Consumption obligations require the use of minimum share of RES. Usually the regulation obligates every building owner who installs a new heating system or who replaces an existing one to meet a minimum requirement of the annual central and water heating using RES. The buildings that are connected to the district heating are exempt from this obligation, although network operators and heat suppliers must meet the minimum RES requirements. Quota or price regulations are another type of obligation that requires the energy traders to buy or sell a certain amount of RES (quota model) or provides an additional remuneration for the producers of renewable heat (bonus model). The latter is used in most of EU countries for electricity production and is called feed-in-tariffs. In Germany a bonus model is defined in the German Renewable Energy Sources Act. However, when producing RES-E the surplus goes into the grid whereas heat is mainly produced in individual houses. Therefore, a special organization was created to deal with bonus claims of thousands of beneficiaries producing heat in their houses. These claims are financed by the energy tax of producers and importers of fossil fuels.

Fiscal instruments

Amongst fiscal support instruments, we can distinguish:

- tax related incentives: creating a new tax for fossil fuels or establishing tax breaks for RES (exemption or reduction of VAT, tax subsidies etc.);
- subsidies: possibly governmental grants for RES using the tax revenue or subsidies under the state supervision with a revenue specifically raised for this purpose;
- certificates: CO_2 or energy production/consumption related.

In order to develop the bio-heat market in Europe, there is a need to make the biomass fuels competitive with fossil fuels. Tax on fossil fuels, as in Sweden, would help to keep the fossil fuels prices high. Some EU member states have implemented a reduced rate on wood fuels leading to a favourable competitive position in Austria, Belgium, Germany, France (wood logs) and the UK. The European Directive 2003/96 establishes a minimum taxation for fossil fuels-based systems (€21/1000 litres), however, this minimum taxation is too low knowing that the €25 average is more than €100/1000 litres. Tax exemptions (or reduction to minimum levels) for RES is unfortunately not the case in many EU countries. One of the main barriers to switching from fossil fuels-based systems to RES ones is the high capital cost. While biomass fuels are usually cheaper, the investment cost becomes the only reason not to switch to renewables, which can be overcome via subsidies as a part of the investments.

Certificates

This fiscal instrument is related to the amount of energy produced or CO_2 saved, for which energy producers receive a certificate which results in a higher income for them. For example, Walloon region in Belgium established a system of green certificates, where one certificate is allocated for each 456kg of avoided CO_2 which means that 1MWh of electricity produced from biomass sources generates 0.86 green certificates (not 1 green certificate as for other RES, because the preparation of biomass fuels requires 23kg CO_2/MWh fuel). The calculation of greenhouse gas emissions counts the heat produced as well; therefore, heat becomes important even though this system does not apply to the heat production plants only. This system makes no distinction for the technology used and is a strong incentive for co-generation plants. However, waste has more advantages within this system (no CO_2 emissions are allocated to waste) as compared to energy crops which already cost more to produce. In Italy, contrary to the Walloon system, a white certificates system counts the primary energy saved rather than produced. It is a marketable document that testifies an energy saving as there is an obligation to achieve a minimum energy saving. The buyer of this certificate can later prove the fulfilment of minimum energy saving. The aim is to save 2.9Mtoe by 2009.

National policy instruments to support pellets

Contrary to fossil fuels, the market of which largely depends on geopolitical conditions, the pellet demand/supply depends mostly on national framework conditions. In most cases biofuels are cheaper than fossil fuels but they can become more expensive if the country decides, for example, to apply a reduced VAT rate on electricity and natural gas instead of supporting bioenergy. At a national level two important instruments to promote or slow down the use of biomass for heat can be distinguished: regulations and financial incentives. Regulations such as the 'Federal Building Code and Federal land Utilization Ordinance' in Germany or the 'Permit Procedure' in Sweden limit the bio-heat development, whereas regulations such as the 'Wood Fuel programme' in France or the 'Energy Saving Ordinance' in Germany have a positive impact on biomass development for heat. The pellet market largely depends on the financial incentives the country decides to implement.

Key countries and success stories

France: Tax credit for sustainable development

As of 2005, the Finance Law has introduced a tax credit for sustainable development and rational use of energy. The aim of this law was to favour high efficiency equipment and the use of RES. The system applies from the beginning of 2005 to the end of 2009. Biomass equipment for heating is eligible for a tax credit of up to 50 per cent. However, minimum efficiency of 65 per cent is required and the equipments have to meet certain technical standards.

Germany: Market incentive programme (MAP)

The main steering instrument for the whole RES-H market in Germany is the Programme to Promote Renewable Energies (Market Incentive Programme) which supports biomass heating systems as well as electricity facilities and biogas plants. The main focus, however, is on the small-scale heating systems in the heat sector. The MAP came into force in September 1999. Every year the German government decides upon the budget of the MAP for the following year as well as the regulations behind it, with the aim of stretching the budget. The programme supports RES-H systems with grants, long-term and low-interest loans and/or partial release of debts and had a budget of €180 million in 2005 and 2006, €213 million in 2007, €350 million in 2008 and €500 million in 2009. The programme's budget is funded from part of the revenues of the taxation of electricity produced with RES and depends in its extent on the annual budget negotiations of the German government. The programme is very successful, although its budget is limited. The budget is usually spent a long time before the year ends, creating an insecure basis for investments and a negative impact on security of demand.

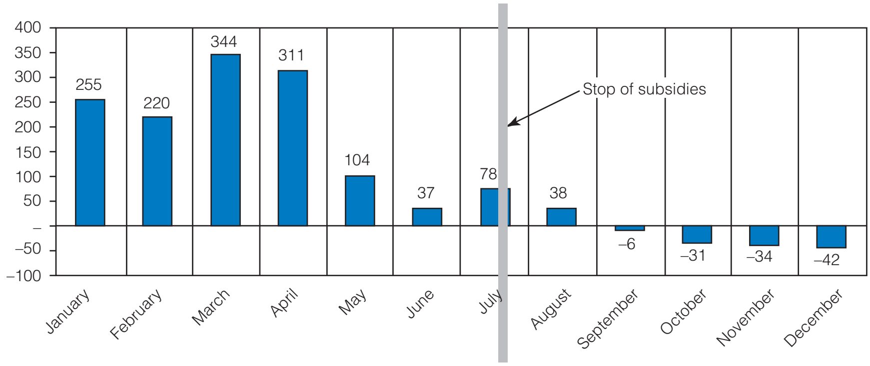


Figure 3.11 Impact of removal of subsidies on boiler sales in Germany 2006
Source: OkoFEN

As for small-scale pellet heating systems, the MAP supports automatically operated wood pellet systems in a range of 8–100kWth with a grant of €60 per kW and from €1000 for systems that reached an efficiency of at least 90 per cent in 2007. In addition an innovation bonus was introduced in the same year: systems which meet particularly challenging environmental requirements (e.g. secondary measures for emission reduction) get double the basic grant. Administrative burdens are lowered to get the basic grant – it is already possible to invest without having applied for the support in advance. However, in order to get the innovation bonus one has to apply in advance and can only start installing the RES systems after approval.

Scandinavia

Biomass heating is mainly used in countries with good resource availability and particularly where district heating systems are already used, mainly in Sweden, Austria, Finland, Denmark and Norway.[5]

The Swedish district heating sector during the last 25 years is an example of the promotion of biomass in district heating and moreover shows that this is a possible and convenient method for introducing biomass for central heating in heat dense urban areas. CO_2 emissions for Swedish urban areas are 63–87 per cent lower than the

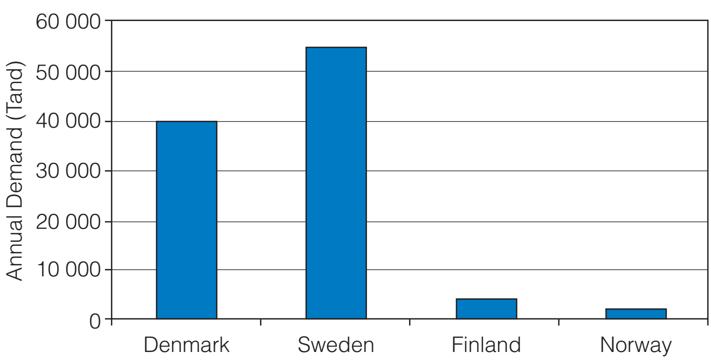


Figure 3.12 Annual demand of biomass heating in the Scandinavia area
Source: proPellets (2009)

European average use of fuel and oil, and natural gas for heating. Sweden is a real example that district heating with biomass is a viable method for reduction of CO_2 emissions and increasing share of RES-H.[6]

TOMORROW

Technology targets by 2020 and beyond

The European RES Directive sets the target of 20 per cent RES by 2020. In 2005 bioenergy contributed to 66 per cent of all renewables and it will still contribute very significantly in 2020. Biomass for heat and derived heat from biomass (heat from district heating and co-generation plants) is by far the main RES in Europe with 60Mtoe in 2006. Pellets will significantly contribute to the renewable contribution by 2020.

To reach the 2020 target AEBIOM estimates that 147.5Mtoe biomass should be used in the heat sector (including derived heat). Pellets are still playing a minor role but taking into account the experience of a few leading countries and provided a biomass heat policy is implemented, pellets use is growing much faster than traditional technologies. Therefore it can be estimated that the use of pellets for heating purposes in the residential, services and industrial sectors might reach 50Mt in 2020, corresponding to 22Mtoe. Demand will also increase for power production and the future development in this sector depends on political decisions. It might reach an additional 20 to 30Mt pellets or more if current polices stay in place, which corresponds to 10Mtoe of biomass and about one-third bio-electricity if converted in a coal fired power plant. It should be noted that targets are nowadays calculated as percentages of the final energy consumption, what favours very much heat and co-generation compared to sole electricity production.

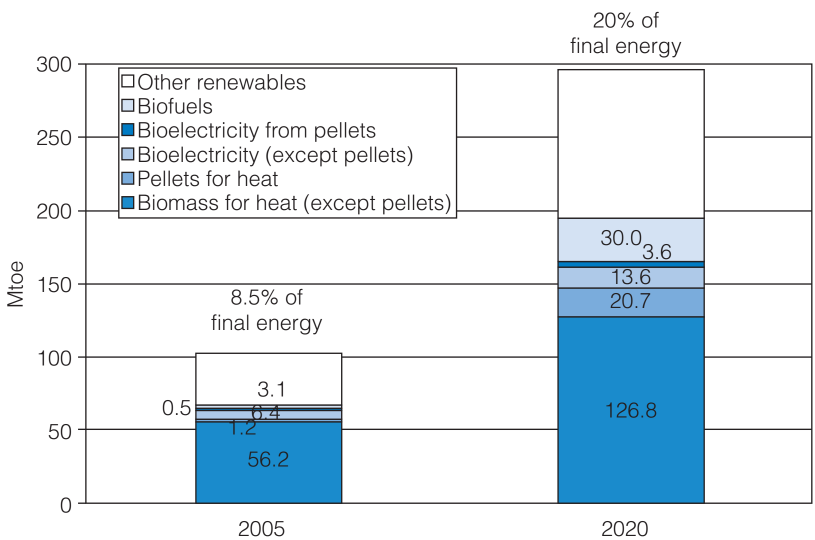


Figure 3.13 Biomass targets by 2020
Source: AEBIOM

Technological long term potential

The overall potential of biomass for energy in Europe is much bigger than its present use, but this potential has to be developed by activities at local, regional, national and international level.

Table 3.5 Potential of biomass fuels

	2004 [Mtoe]	2020* [Mtoe]
Forest based biomass	61.5 (85%)	75.0
Agriculture based industry	3.5 (5%)	97.0
Waste	7.3 (10%)	23.0
Imports	–	25.0
Total	72.3	220

* AEBIOM estimates
Source: AEBIOM

So far forest based biomass is the main biomass fuels provider with the maximum forest fuels potential of 543 million m^3 (94.6Mtoe) in the EU, which covers logging residues that make up 251 million m^3 (43.73Mtoe).[7] Logging residues have the highest potential to increase the forestry fuels used for bioenergy production, however an appropriate logistics system has to be developed so that these residues could be cost-effective for bioenergy use. By-products of wood processing industries will also play an important role. For example, refined fuel pellets accounts for 6.6Mtoe (in 2005 and 7.5Mtoe in 2007) of which 3.3Mtoe are used for electricity and 3Mtoe for heat production. Pellets had a 3 per cent share of bioenergy production in 2005. Nevertheless, the pellets-potential by 2020 is much higher and can reach 14 per cent bioenergy production with 25Mt pellets (10Mtoe) used for bio-electricity and 50Mt (21Mtoe) for heat production. Nevertheless, the agricultural sector has the greatest potential and could become the most important energy supplier by 2020. Out of numerous biomass fuels, dedicated energy crops such as willows, poplars, miscanthus, reed canary grass etc. for heating and electricity production have enormous potential to increase biomass use. So far, there are only about 60,000ha of land planted with such crops whereas 2.5 million ha of land are planted with traditional energy crops. These dedicated energy crops can significantly increase the yield per hectare. Biogas also has a huge potential. This is another biomass source for heat and electricity production but also deployment in the transport sector, as in Sweden. The production of biogas reached 7Mtoe in 2008. Considering the available resources such as manure, organic wastes and by-products as well as crop residues, the theoretical biogas potential can reach 60Mtoe by 2020 (if we use 5 per cent of agricultural land and all available manure). Nevertheless, the realistic potential would more likely be 30Mtoe with 2.5 per cent of agricultural land used and half of the available manure utilized. At present there are about 114 million ha of arable land in Europe. If 5 per cent of this land is used for energy crops a cautious yield of 10 tons of solid dry matter per hectare could provide 22.8Mtoe of energy if combusted completely, or 18.2Mtoe if converted into biogas. As not all biomass compounds (especially lignin) can be digested, a general conversion efficiency of 80 per cent is assumed. According to the European Environmental Agency, if all the theoretical potential estimated in their 2006 study was realized, around 10.5 per cent of Europe's gross energy consumption (9.5 per cent of final energy demand) in 2020 could be met with biomass alone (compared to 4.5 per cent of gross energy demand in 2005). In 2030, 16 per cent of the EU-27 gross energy demand would be met by bioenergy. Bioenergy would meet 18.1 per cent of European demand for heat, 12.5 per cent of electricity demand and 5.4 per cent of transport fuel demand (corresponding to 7 per cent of the diesel and gasoline demand in road transport). Further, if additional priorities and investments were implemented to increase the use of heat from combined heat and power systems, the CHP scenario indicates that overall GHG emissions reductions would increase (454 million tonnes in 2020, 695 million tonnes in 2030), and the bioenergy share of heat would increase to 23 per cent in 2030.

New EU member states offer favourable conditions for a rapid increase of the share of RES-H, because they have well developed district heating systems. So far they use mainly fossil fuels in this district heating net to produce heat. A switch from fossil fuels to biomass in the district heating systems of these countries, which technologically is very easy to achieve, would help to solve several problems. These countries could increase their share of RES rapidly and thus reduce their CO_2 emissions, they would decrease their dependency on imports at rising fuel prices and they could offer their citizens in the future a heating supply at lower prices than using fossil fuels. It seems of utmost importance to encourage these member states to choose this, supported by European funds.

The potential for pellets production is very large. It ranges from wood residues, wood from forest thinnings and short rotation coppicing to the use of agricultural residues, which also can be used to produce pellets. This wide range of feedstock allows that up to 2020 a target for pellet production of 60 to 80 million tons seems achievable. At the moment (2008) more than 440 pellet plants in Europe produce about 7.5 million tons of pellets per year and secure a reliable supply. The number of plants is increasing continually due to the dynamic market development. District heating and cooling have the potential to play an important and decisive role in the

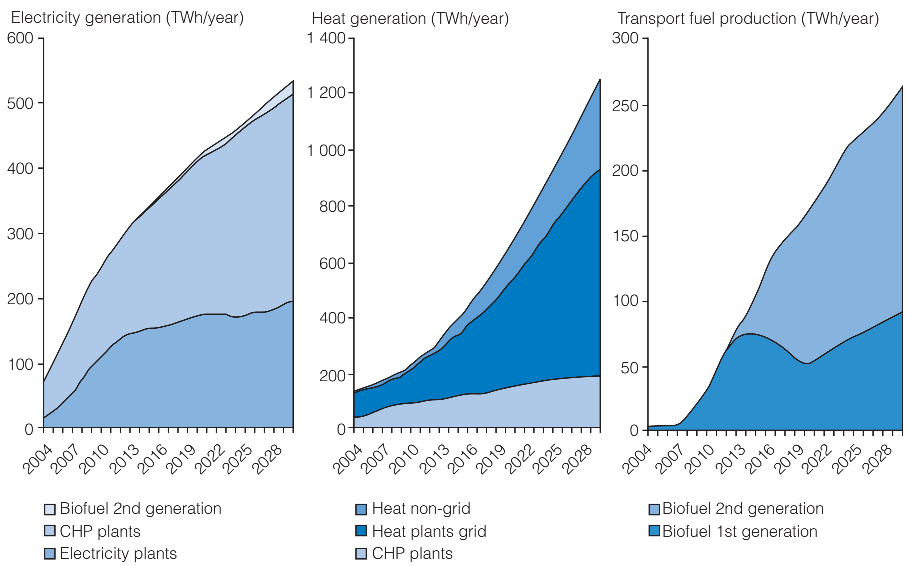


Figure 3.14 Biuenergy allocation EU-25
Source: EEA 2006

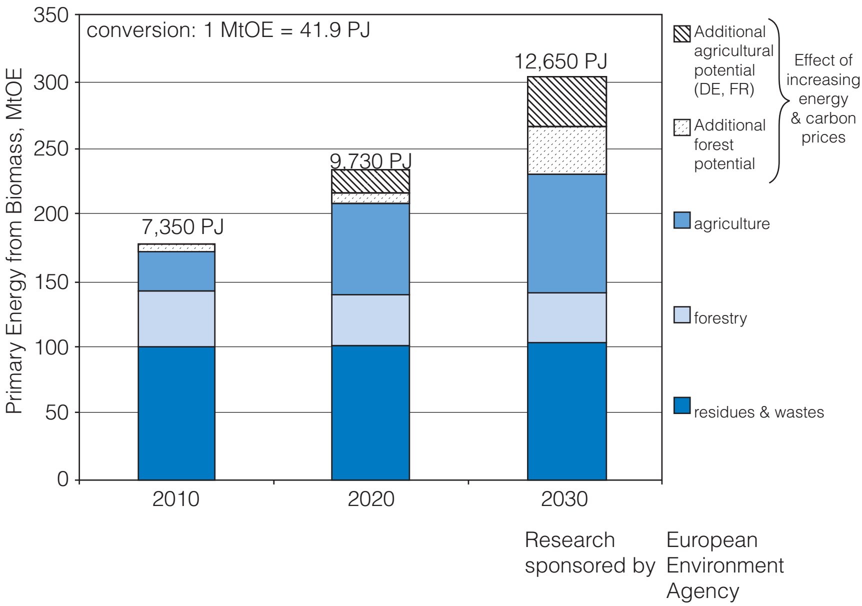


Figure 3.15 Bioenergy potential EU-25
Source: EEA 2006

European energy market by 2020. By integrating renewable energy sources in district heating systems and replacing fossil fuels, the heating sector will increase its share of RES and reduce CO_2 emissions. Where a good biomass resource, solar thermal or geothermal source exists, heating technologies can also often be more cost effective than those using fossil fuel in EU. The EU needs to be more ambitious and more specific on the potential of integrating biomass in district heating systems in member states. In particular the EU needs to raise awareness of the success stories of Scandinavia to the new member states so that they can learn from the good practices of the northern European countries.

NOTES

1 More details can be found at www.eubionet.net, last accessed July 2009.
2 IEA, 2007.
3 EuroHeat & Power, 2007.
4 IEA, 2007.
5 EuroHeat & Power, 2007a. Werner, S (2007a) 'Sweden: District Heat and Cogeneration in Sweden', English Edition, Vol 4, IV, EuroHeat and Power, Germany
6 Pirkko Vesterinen, Eija Alakangas & Terhi Lensu, Technical Research Centre of Finland (VTT).
7 Pirkko Vesterinen, Eija Alakangas & Terhi Lensu, VTT.

4

Geothermal Heating and Cooling

The term 'geothermal energy' refers to the energy stored in form of heat beneath the earth's surface.It has been used since antique times for heating and for about 100 years also for electricity generation. The earth can offer a heat source (30°C-80°C) for direct uses: District heating, applications in agriculture… The earth offers also a steady and incredibly large heat source, heat sink and heat storage medium for thermal energetic uses, like for the geothermal heat pump. A steady underground temperature was first scientifically proven in 1778 in deep vaults beneath the Observatoire in Paris. It took until the middle of the 20th century before this steady heat reservoir was first used by a ground-source heat pump. Geothermal energy is also used for electricity generation. The first attempt at generating electricity from geothermal steam was made at Larderello, Italy in 1904. The success of this experiment indicated the industrial value of geothermal energy and marked the beginning of a form of exploitation that was to develop significantly from then on. After World War II, many countries were attracted by geothermal energy, considering it to be economically competitive with other forms of energy. It did not have to be imported and, in some cases, it was the only energy source available locally.[1]

STATE-OF-THE-ART TECHNOLOGY

Until now we have used just a marginal part of the underground heat reservoir potential. Today geothermal energy is used for electricity, for district heating and for heating (and cooling) of individual buildings, including offices, shops, small residential houses, etc. Given the fact that our earth is full of energy, any temperature level underground can be used directly for geothermal energy, for instance with deep boreholes or with a heat pump. Meanwhile a number of new and innovative applications of geothermal energy have been developed, and some of those have already been demonstrated (e.g. snow-melting, desalination and so on).

Technological benefits

The main benefits of geothermal energy derive from the fact it is:

- a renewable energy source: the heat from the earth is inexhaustibly delivering heat and power 24 hours a day throughout the year, available all over the world, with minimal land use, and contributing to the reduction of Greenhouse Gas (GHG) emissions;
- a safe and controlled technology: independent of the season, climatic conditions and day time; proven and controlled technically; used from ancient times for heating and cooling (H&C) and for more than 100 years for electricity;

- energy adaptable with high performance: this is an answer to all energy needs (electric power, heating, cooling, hot water and energy storage); it can be modulated according to the type of resources, to the size and nature of equipments, and to meet demand; it has an extensive global distribution that makes it accessible to both developing and developed countries;
- an economically sustainable energy: it is indigenous, thus creating independency from external supply/demand effects and fluctuations in exchange rates; it helps saving on overseas expenditures; it allows 'local' fossil resources such as soil, coal and natural gas to be saved with long-term durability of installations which are not sensitive to conventional energy prices.

Furthermore, geothermal energy can help to improve the competitiveness of industries, at least in the long run, and can have a positive impact on regional development and employment. Geothermal energy also has several benefits to society, including positive externalities of private investments; reduction of CO_2 and other emissions; security of energy supply; local economic development; contribution to the creation of economies of scale and thus to cost reductions in the medium and long term. By saving conventional fuels, geothermal systems have lower running costs, although investment costs are usually higher than in conventional heating systems. With rising oil, gas and electricity prices, the timeframe for a positive return on investment is becoming shorter. In many cases, it is already well below the average lifetime of the equipment.

Technological applications

Geothermal energy is an ideal answer to the different energy needs: electricity, heating and cooling, domestic hot water and thermal energy storage. Geothermal H&C can be applied in four areas: geothermal heat pumps, geothermal energy storage, direct uses and district heating. Heat can be obtained from geothermal energy in two distinct ways:

1. The first makes use of geothermal heat pumps at very low energy. The low temperature in the ground is increased to a useful temperature by using a heat pump. It can also be changed artificially by storage of heat or cold
2. The second consists of directly exploiting the ground water of the deeper substratum, the temperature of which varies between 25°C and 150°C: low and medium energy. Direct applications are in agriculture (drying, fish-breeding), industrial process and balneology. It can also supply energy to a district heating or a combined heat and power installation.

Geothermal heat pump (GHP) and applications

Shallow geothermal systems harness the ground heat from the soil surface down to a depth of about 400–500m, in areas without specific geothermal anomalies. Hence the temperature level of these systems is, depending upon climatic conditions of the site, around 5–25°C. With these temperatures, no direct use is possible. The low temperature in the ground has to be brought to a higher level and this is done through a heat pump.

The ground temperature is steady all through the year. A GHP (also called Ground Source Heat Pump, GSHP) has three main components:

1 a ground site, to get heat into or out of the ground;
2 a heat pump (HP), to convert that heat to a suitable temperature level;
3 a building site, transferring heat or cold into the rooms of a dwelling.

An HP is a device which allows transport of heat from a lower level to a higher one, by using external energy (e.g. to drive a compressor). The amount of external energy input, be it electric power or heat, has to be kept as low as possible to make the HP ecologically and economically desirable.

The ground system links the HP to underground and allows for extraction of heat from the ground or injection of heat into the ground. The vertical systems represent nearly 80 per cent of the installations in the EU. A GHP can not only be used for heating, but also for cooling purposes.

There is a wide range of applications for GHP. Also, geothermal applications can be present everywhere and any time for H&C. The maximum delivery temperatures typically are in the order of 50–55°C (with new development looking for increased values) and in cooling mode around 6–7°C.

Another GHP application is snow-melting and de-icing: geothermally heated outside surfaces are typically based on hydronic heat exchanger installations in the pavement. This technology can be used favourably to heat walkways, roads, railway platforms, airport runways, etc.

Geothermal Energy Storage (GES) and applications

The low temperature in the ground can also be changed artificially by storage of heat or cold, creating a geothermal energy system storage (or Underground Thermal

Figure 4.1 Small heat pump for single family house
Source: BBT Thermotechnik

Figure 4.2 Large heat pump in an office building
Source: EGEC 2008d

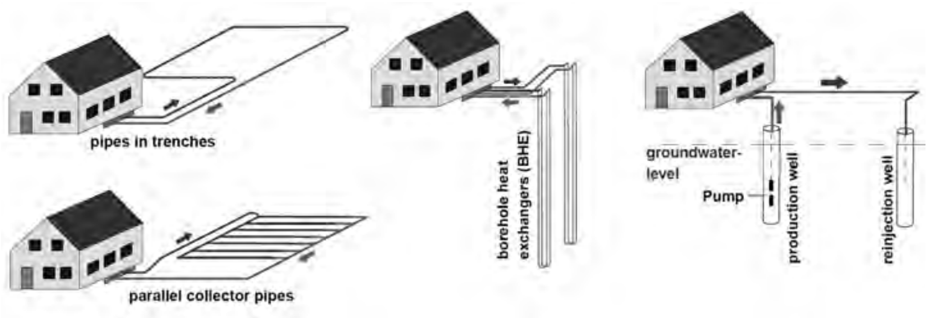


Figure 4.3 Types of GHP used: Closed systems – horizontal collectors (left), borehole heat exchangers (centre) and open system (right) – and groundwater wells
Source: EGEC

Energy Storage, UTES). The highest storage temperature achieved in GES is around 90°C; the lowest (for cooling) is about 5°C. The heat sources for heat storage can be various, however, waste heat or solar heat are typical. For cold storage, the cold ambient air in winter time or during night is the cold source. We distinguish two systems which are the open and the closed circuits:

- **Borehole Thermal Energy Storage (BTES)**: while in a GHP system a heat pump is used, the ground itself is heated or cooled in a GES system. The system uses boreholes and pipes to store H&C. The BTES does not need a ground water flow. It provides a medium thermal conductivity and can answer to high specific heat;

Figure 4.4 Small residential house
Source: Ochsner

Figure 4.5 Its GHP system
Source: Ochsner

Figure 4.6 Large office complex

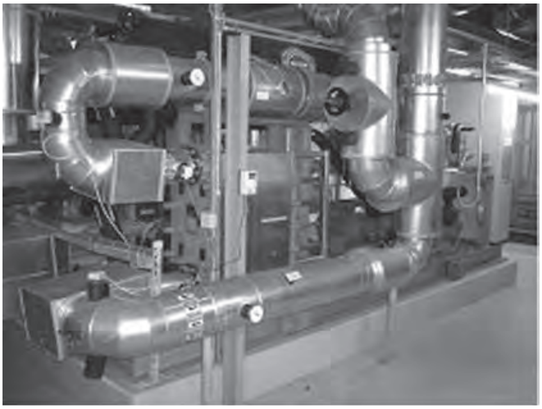


Figure 4.7 Its GHP system
Source: EGEC 2008d

- **Aquifer Thermal Energy Storage (ATES)**: here, the ground water is used as a heat carrier. We need a high porosity and low or no groundwater flow. We are in the presence of medium to high hydraulic conductivity and transmissivity.

One of the main advantages of the BHE-store is the possibility to extend the store by adding further boreholes in relation to the growth of the building area. The range of applications is as large as for GHP: buildings, through a small district heating network (see Figures 4.11 and 4.12); offices (the most prominent example for ATES being the H&C system of the Reichstag in Berlin) and the industry (see Figures 4.13 and 4.14).

Figure 4.8 Supermarket in Austria
Source: Ochsner

Figure 4.9 Its GHP system
Source: Ochsner

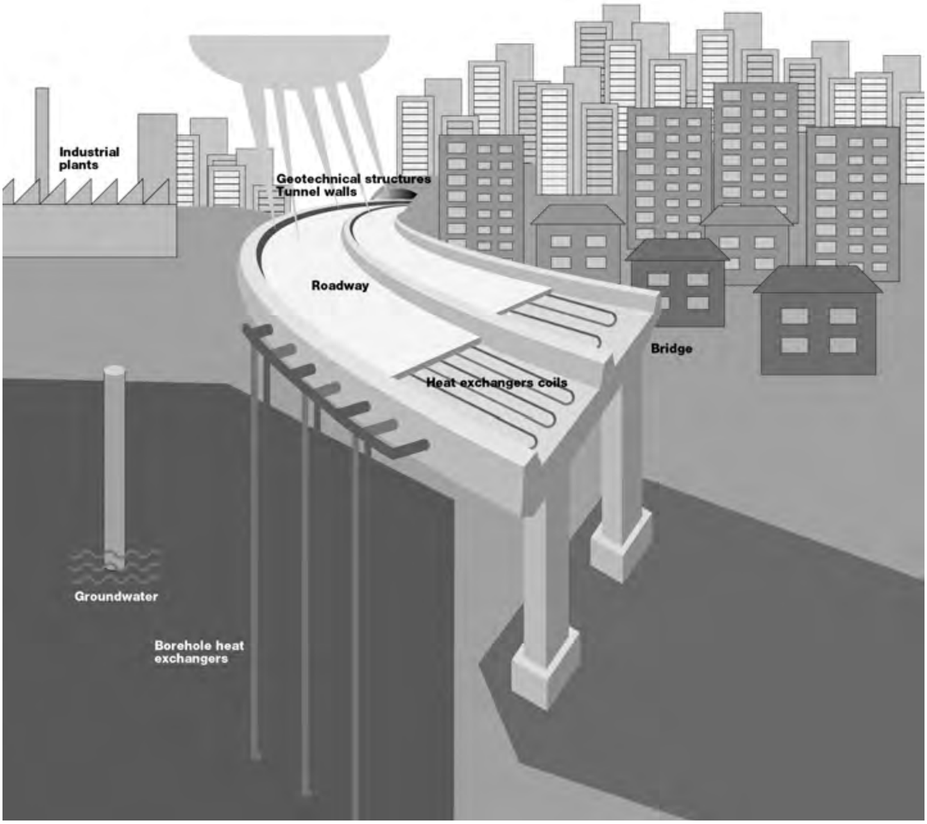


Figure 4.10 Structure of a GHP system for snow-melting and de-icing
Source: Polydynamics

Figure 4.11 Borehole Thermal Energy Storage (BTES) in Neckarsulm, Germany
Source: EGEC, 2008

Figure 4.12 Solar collectors and buffer storage for small DH network with BTES
Source: EGEC

Figure 4.13 ATES for Prins van Oranje Hall at Utrecht fairgrounds, The Netherlands
Source: EGEC, 2008

Direct applications

Deep geothermal energy can be used mainly in geological basins (France, Germany, Italy, Hungary, Poland, etc.), for district heating, for agricultural uses such as greenhouses, for aquaculture (and also for power). The preferred method is the use of thermal water through well doublets, but recently deep borehole heat exchangers have also been demonstrated.

Figure 4.14 Test well for ATES at an industrial site (ITT Flygt, Emmaboda, Sweden)
Source: EGEC

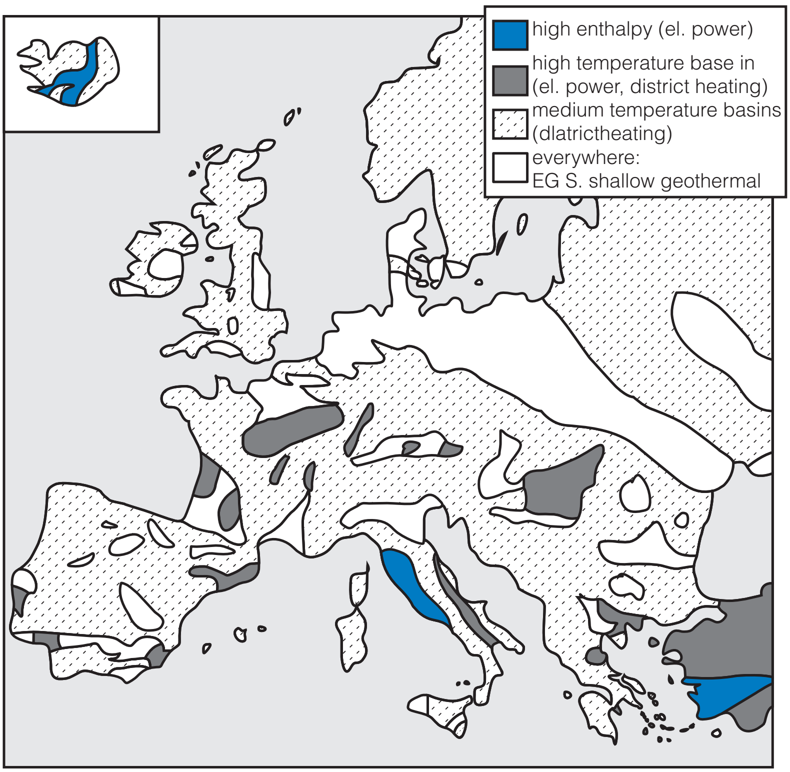


Figure 4.15 Geothermal areas in Europe
Source: EGEC

The major areas of direct use are central heating and cooling including district heating (DH), agribusiness applications, aquaculture, industrial processes, swimming, bathing and balneology. The majority of this energy use is for district heating and bathing.

Deep Geothermal heat has a wide range of applications:

- **Space conditioning**: this refers to heating and cooling of rooms. Space heating with geothermal energy has a wide-spread application, not only for individual residences but also for large buildings and industry. The heating is achieved by passing geothermal water through three major types of heating convectors: forced air (forced convection systems); natural air flow using hot water or finned tube radiators (natural convection systems) and radiant panels.
- **Sanitary warm water**: preparation of sanitary hot or warm water is an important energy consumer for residences, hotels, restaurants, industry and tertiary sector projects. Geothermal energy is the convenient heat provider for these systems as it is continual all year and it can also be used in combination with space heating.
- **Agribusiness applications**: agriculture and aquaculture applications are particularly attractive because they normally require heating at the temperature abundantly matched by geothermal resources. Use of waste heat or the cascading of geothermal energy also have excellent possibilities.
- **Industrial applications**: the actual uses of geothermal energy into industrial processes applications are relatively few. Drying and dehydration of agricultural products are one of the most important and prospective moderate-temperature uses of geothermal energy. Geothermal H&C is used in many ways such as drying, process heating, evaporation, distillation, washing, chemical extraction for food processing, chemical recovery and so on. A fairly wide range of European applications are represented, including heap leaching of precious metals, vegetable dehydration, grain and lumber drying, pulp and paper processing, diatomaceous earth processing, fish processing and drying, chemical recovery and

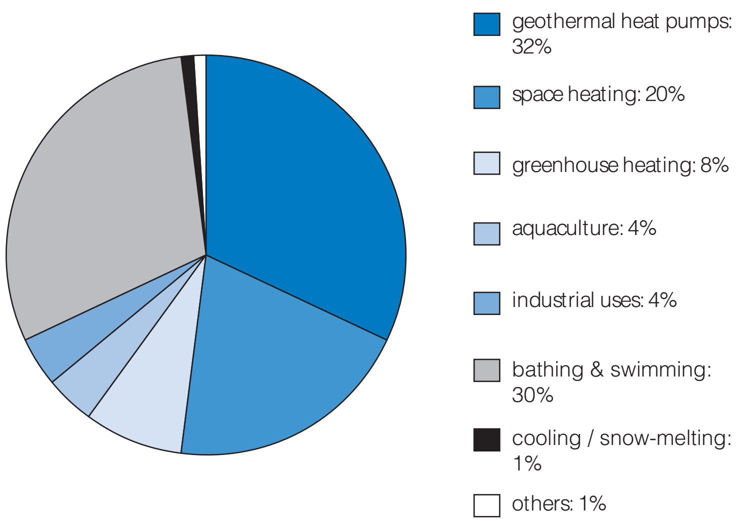


Figure 4.16 Use of geothermal energy for heating purposes
Source: EGEC

waste water treatment. Industrial applications largely require the use of steam, or superheated water, while agricultural users may use lower temperature geothermal fluids.

- **Desalination**: a fairly new application of geothermal energy is the desalination of sea water. Geothermal energy is a source of RES and the oceans are a major alternative source of water. Desalination is very energy-intensive. Low enthalpy geothermal energy (t> 60°C) can effectively drive a sea or brackish water desalination unit in order to produce fresh water for drinking and/or irrigation. At sites where drinking water is scarce and geothermal resources of 60–100°C can be developed, it is appropriate to use geothermal desalination.
- **Balneology**: people have been using geothermal water and mineral waters for bathing and health purposes for many thousands of years. Geothermal energy is regularly used in new balneology centres everywhere, where possible (that is, provided we dispose of thermo-mineral water and we know its chemical composition and temperature) and economically justified.
- **District heating** (DH): originates from a central location and supplies hot water or steam through a network of pipes to individual dwellings or blocks of buildings. The heating is used for central heating and cooling, domestic hot water, agribusiness applications and industrial-processes heat. A geothermal well field is the primary

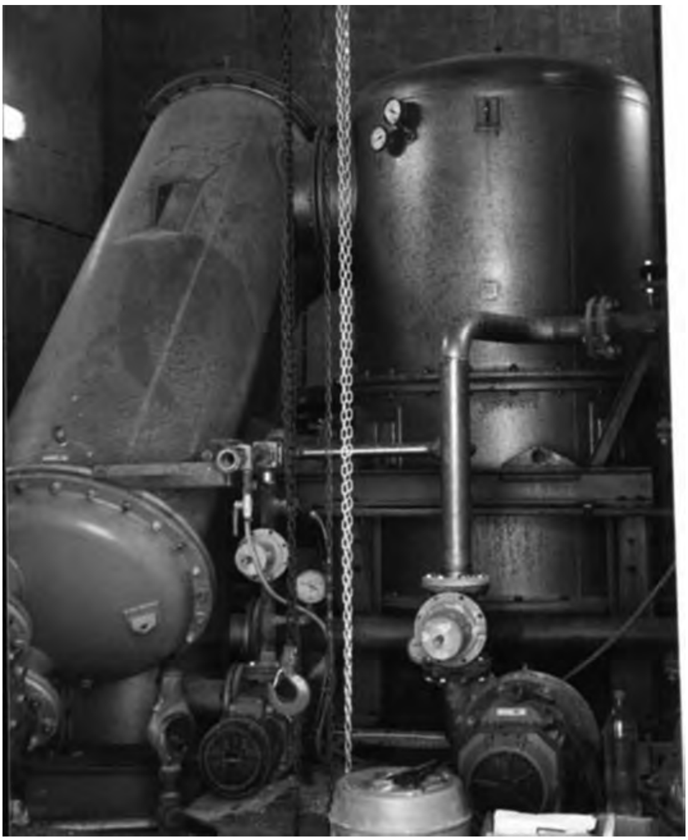


Figure 4.17 Kimolos desalination unit
Source: CRES/EGEC (2008)

source of heating, however depending on the temperature, the district may use a hybrid system.

The location of geothermal DH sites is shown in the following map.

Costs and prices

The final economy of a geothermal project depends on a wide range of influencing factors, beginning with the important influence of regulatory aspects, exploration and

Figure 4.18 Location of geothermal DH sites in Europe
Source: EGEC

investigation for resource identification, complexion and exploitation, alternative conversion technologies (district heating, space heating etc). The three main influencing factors are the investment, the operation and maintenance (O&M) and the development costs. This calculation has to take into account all steps of the life cycle of the geothermal system. The investment costs of a geothermal project can be separated into two main categories:

1. field costs, including surface exploration, drilling, field development and reservoir management;
2. plant costs, including machinery, equipment, design, engineering and civil works.

The specific breakdown of field and plant investment costs is strictly dependent on site-specific conditions and the type of application, particularly with direct use of heat.

The shallow geothermal systems cost is site dependent due to a series of factors: a changing geology; the presence or the absence of water in the rocks; the depth of the water table; the space at the surface to have proper spacing between the wells or the verticals probes; the distance of the plant from the better-adapted driller to perform a correct job and so on. For GSHP systems, the approach is quite different, because the power of each well is also site dependent, but not in the same range. It is possible to drill a GSHP everywhere, and the cost varies little from one location to another. Nevertheless, the cost of a GSHP is influenced by the geological cross-section and by the presence of water in the ground.

For DH systems, investment costs can be broken down into:

- well costs (drilling and well equipment costs): they vary considerably between countries depending on the resource, geological conditions and the market for drilling. The drilling cost is a more and more important factor influencing the costs of production;
- geothermal plant costs, in other words investments related to exploiting the geothermal fluid (including the building): they are determined by the site-specific characteristics of the resource and the local heat demand, as well as the pattern of heat consumption. The installed capacity should have a high load factor related to the climatic conditions of the region;
- heat distribution network costs: they strongly depend on whether a former network exists or not.

O&M costs are an important part of the energy costs of a geothermal project:

- operation costs are mainly connected to the electricity consumption of different pumps. Particular attention should be paid to the optimization of pump running costs in direct use projects, where they rarely have continual use with full power;
- maintenance costs are related to all equipment and materials used in the project. Taking into account the problems with scaling, corrosion, distribution pipes and armature, they are normally higher than in the systems using fossil fuels. In order to be precise in economic evaluations, they should be carefully identified in advance, based on the previous experience of similar running projects;
- good prediction of personnel costs is also a very important issue, relating both the quality of the project exploitation and its economy. As mentioned earlier, part of these costs is related to the investment. In any case, it is not always necessary to

employ numerous staff, although highly specialized personnel are required at times, who are able to cover multidisciplinary 'know-how' needs for proper plant operation. Costs for continuous improvement of knowledge should also be calculated.

The general characteristics of geothermal DH systems are high investment costs and low operating cost. With an average plant life of approximately 35 years and a long compensation period, the investments are profitable. Profitability is also important from an environmental point of view, in terms of imported fuel saved, and for the stimulus to the local business and employment the technology provides. Costs depend on site-specific local conditions (including climatic conditions and users), and will vary according to distribution infrastructures (mainly the pipeline distribution network). The payback time therefore varies following these different criteria and the type of investor. In most countries, the local authorities are the DH operators and they can accept and work on longer repayment periods.

Cost variations for geothermal heat generation are in the following ranges:

- investment costs vary from 0.2 to 1.2 million per MW;
- production costs vary from €5– €45 million per MW.

Deep geothermal technologies are the most cost-competitive for heating applications. Shallow geothermal technologies applied for both heating in winter and cooling in summer can be cost-competitive when evaluated on a life cycle cost basis.

In January 2009, EGEC published a geothermal research agenda fixing the research priorities for all geothermal technologies until 2030, in order to decrease costs:

- by 5 per cent for geothermal district heating, thus reaching €40 per MWh;
- by 10 per cent for geothermal heat pumps, thus reaching €50 per MWh.

Table 4.1 Summary of targeted costs

Heating and Cooling	Costs 2007 Range (€/MWh)	Average (€/MWh)	Costs reduction by 2030 (% 2005 costs)
Deep geothermal 2–40 7.2 +11			
Geothermal District Heating	40–80	50	-5
Shallow geothermal Heating only	10.8–320	19	-9
Shallow Heating and Cooling	7.2–270	61	-8

Note: The figures for deep and shallow geothermal are from the IEA report 2007: Renewables for heating & cooling. The data on District Heating are EGEC projections for geothermal DH in Europe.
Source: IEA, 2007

MARKET

The number of geothermal HP has increased steadily over the years and the technology is well understood. In some countries they have begun to become a routine option when planning the heating system in residential houses. The direct use of geothermal energy for H&C is ancient and largely proven, but not all the potential is explored and used in Europe. Heat supply from geothermal energy in Europe is primarily done by using hot water from deep aquifers for district heating, etc., or in a large number of small- to medium-shallow geothermal plants. Shallow geothermal also supports the use of solar energy for heating, through underground storage of solar heat from summer to winter, and offers many other opportunities of long-term thermal energy storage.

In total, only a minuscule portion of the potential of geothermal energy is as yet explored and in use in Europe. The market situation is very different in the various countries and for the different geothermal technologies, according to natural resources and influenced by political issues.

Shallow geothermal

Market penetration of geothermal HP is still modest throughout Europe, with the exception of Sweden, Switzerland and Germany. There is still ample opportunity for further market growth and the technological prospects endorse this expectation.

The use of GHP for commercial applications can yield economic and environmental advantages. In particular, in cases where H&C is required the ground can act as a heat source and a sink thus becoming a kind of seasonal buffer storage. In several countries a market-driven economy exists for shallow geothermal systems,. This will be further boosted by the expected oil price development. Geothermal (ground-source) heat pumps have the largest installed capacity, accounting for about 70 per cent of the Europe-wide use and capacity. The installed capacity is 9000MWth for GSHP of the almost 12000MWth for total geothermal heat capacity in 2008. Almost all of the installations are located in north and central Europe. The size of individual units ranges from about 5kWth for residential use to large units of over 150kWth for commercial and institutional installations. In Europe, most units are sized for the heating load and are often designed to provide the base load, with peaking covered by fossil fuel in larger installations. As a result, these units may operate from 2000 to 6000 full-load hours per year (capacity factor of 0.23 to 0.68). Sweden, Germany and Austria are the leading countries in terms of the market for geothermal heat pumps in the EU.

A transition is underway of Ground Source Heat Pump (GSHP) technology into some new areas:

- southern Europe and the Mediterranean, with an emphasis on cooling and heating;
- eastern and south-eastern Europe, where the demand for more comfort in houses is growing slowly together with the number of people who can afford it;
- in the UK and Ireland interest is growing and some prestigious plants have been built. The number of systems is rising, although the technology typically used is under some US-influence.

Deep geothermal

The largest geothermal district heating systems within Europe can be found in the Paris area in France, with Austria, Germany, Hungary, Italy, Poland, Slovakia and others showing a substantial number of interesting geothermal district heating systems. In most countries, geothermal district heating needs some investment support and reduced interest loans as possible solutions to becoming economically interesting. Cascade uses (district heating, industry, agriculture and others) improve economy, but they are usually very difficult to achieve due to business obstacles and distances, for instance. The main financial obstacle in geothermal heating plants is the heat distribution network. For heat distribution, Eastern European countries may have an advantage due to existing networks. Some distortions that impact certain national markets should be mentioned. Competition from conventional sources (in particular natural gas) even uses dumping prices to keep costumers. On the other hand, projects in some countries are affected by inadequate mining laws, high taxes, fees and royalties. These expenses are too high compared to the annual heat sales, even in the biggest plants. There appears to be great potential for the development of low- to moderate-enthalpy geothermal direct use across the world. Future developments in this direction will occur under the following conditions:

- co-located resources and uses;
- sites with high heat and cooling load;
- food and grain dehydration;
- greenhouses in colder climates;
- aquaculture in warm climates;
- GHP for H&C.

Installed capacity and market development in the EU and market segment

In 2008 a total of approximately 3Mtoe was supplied by geothermal heating alone within the EU-27 and more than 1Mtoe in other European countries. At the end of 2008, the installed thermal capacity (including heat pumps) amounted to more than 12,000MWth. The geothermal sector has already outgrown the EU White Paper objectives outlined for 2010 (which were less ambitious and did not account for the great success of geothermal heat pumps and of the geothermal potential in new member states).

Geothermal HP

The EU is one of the main regions in the world to have developed this technology. At the end of 2008, their number was estimated at nearly 900,000 units, representing an installed capacity in the order of 7700MWth. During the year 2008, the geothermal heat pump market exceeded the benchmark of 100,000 units being sold for the third consecutive time. Sweden has the largest installed capacity of the EU with nearly one geothermal heat pump out of two being installed there. At the end of 2008, Sweden had more 320,000 units for a capacity in the region of 2900MWth. The 2008 market increased with 25,000 thermal heat pumps sold (in other words, an additional 260MWth). With a market two times smaller, Germany is the second ranking EU country with more than 150,000 units installed at the end of 2008. The German market is currently rising rapidly with 35,000 geothermal heat pumps being sold as opposed to 27,000 units in 2007. This dynamism made it possible for Germany to get ahead of France.

Industry

Different categories of professionals intervene in the design and installation of geothermal H&C systems. A large number of professionals from various industries are involved in the geothermal sector, including engineers, consultants and service firms and energy agencies, for the design; manufacturers of equipment (heat pumps, pipes, BHE, etc.), drillers, installers and civil workers, for the installation. Shallow geothermal installers and heat pump installers are differentiated. The drilling companies are a major actor. Drillers working in the geothermal sector are Small & Medium Enterprises (SMEs) who are specialists in this area, or larger companies having a special-

	2007		2008	
	Number	Capacity (MWth)	*Number*	Capacity (MWth)
Sweden	298 049	2 682,0	320 687	2 909,0
Germany	115 813	1 273,9	150 263	1 652,9
France	102 456	1 127,0	121 886	1 340,7
Finland	38 912	827,9	46 412	857,9
Austria	40 549	454,1	48 641	544,8
Netherlands	15 230	392,0	19 310	508,0
Poland	10 000	133,0	11 000	180,0
Ireland	7 578	124,0	9 673	157,0
Italy	7 500	150,0	7 500	150,0
Czech Republic	6 965	112,0	9 168	147,0
United Kingdom	5 350	69.6	10 350	134,6
Denmark	11 250	123,8	11 250	123,8
Belgium	8 200	98,4	9 500	114,0
Estonia	3 913	50,1	4 874	63,0
Hungary	350	15,0	350	15,0
Slovenia	720	6,4	1 125	12,2
Lithuania	200	4,3	200	4,3
Romania	40	2,0	40	2,0
Greece	194	1,9	194	1,9
Slovakia	8	1,4	8	1,4
Bulgaria	19	0,3	19	0,3
Latvia	10	0,2	10	0,2
Portugal	1	0,21	1	0,2
Total EU 27	**673 307**	**7 649.5**	**782 461**	**8 920.2**

Figure 4.19 Total quantities and installed capacity of geothermal heat pumps in the EU at the end of 2007 and at the end of 2008
Source: Eurobserv'ER, 2007

ization in other fields, such as water, foundation engineering, prospection, etc. The heat pump industry is a dynamic sector of the geothermal energy industry. The Geothermal H&C industry also comprises other components manufacturers (pipes, borehole heat exchangers etc.) and civil engineering companies for the plant. Geothermal DH is operated by municipalities, private companies or in public private partnership (PPP). The European industry of geothermal energy for heating and air conditioning has created many jobs. According to EGEC they constitute approximately 30,000 full time equivalent jobs. The European association estimates that this number should rise to 50,000 in 2010 and to 100,000 in 2020.

Policy instruments to support the technology

The promotion of geothermal energy at a European level was, until now, only considered for electricity. Geothermal heating and cooling received little political attention, in spite of its considerable potential. The following are the main instruments used to achieve a sustainable growth of geothermal heat.

Financial incentives

There is a wide variety of economic instruments in Europe which either support or inhibit the enhanced use of geothermal energy in Europe. There are countries where the financial burden of a fiscal nature (in other words, mining royalties, sewage penalties, groundwater use fees and environmental taxes) are multiple, which breaches

BOX 4.1 BEST PRACTICES FOR FIS

Geothermal energy needs best practices for financial incentives:

- long-term financial incentives;
- measures not announced before they are available;
- any technical parameter linked to the eligibility for an FIS should be strictly oriented to European standards and certifications;
- administrative procedures should be as simple as possible;
- innovative applications should benefit from specific discounts.

general taxation law. The key lesson is that financial incentives (FIS) can play an important role in promoting geothermal H&C, if they are well designed, carefully managed and accompanied by appropriate flanking measures. If they are not, their positive effect is limited and they can be even counter-productive in the medium and long term. The key positive effects of well-designed and managed financial incentive schemes are a reduction of the upfront investment costs and the positive psychological effect to the potential users derived from the signals given by the public authority

Regulations and administrative barriers

Legislation relevant to geothermal energy use reveals great differences in the legal basis. Governmental policies to support geothermal development so far only focus on power generation. Serious efforts are needed to harmonize legislation and to simplify procedures as well as to establish and implement strong policies to boost geothermal heating and cooling. The legislative and regulatory framework for geothermal energy is very diverse within the EU member states and in some cases this is a real barrier to geothermal energy use. Furthermore, there are countries with barriers of a fiscal nature (in other words, mining royalties, sewage penalties, groundwater use fees and environmental taxes), of licensing and so forth.

The main burdens within the EU in particular are:

- royalties: countries affected are, for instance, France, Hungary and Romania (where royalties represent 2 per cent of the turnover), Poland and Slovenia;
- groundwater exploitation/sewage fees, which are applicable in most countries.

Building codes and planning laws can have significant effects, either positive or negative, on the uptake of renewable heating technologies. A problem that can arise through renewable energies regulations is that if certain technologies are required exclusively, this limits the possibility to choose and adapt to a certain building, location and/or climate.

In general, simple and fair application and licensing procedures will help significantly in the development of geothermal heat.

Standards

They already exist in a few countries for shallow geothermal systems (e.g. VDI 4640 and DIN 8901 in Germany). Also some CEN standards on heat pumps cover some geothermal aspects (e.g. EN 15450). In general, components of geothermal systems have to comply with existing standards (e.g. pumps, compressors, heat pumps, pipes, controls, etc.). These standards have been developed or are under development within the relevant technology areas. Specific standards for the geothermal systems will mainly have to deal with exploration, design and installation. This requires both common standards for the whole EU and specific regional aspects according to climate, geology and the traditions of the building sector. Experience, for example with the development of EN 15450, shows this need for opening up to regional practices and circumstances. Past experience proved that the geothermal sector has to be included earlier into standards that are developed from the perspective of certain heating technologies (a very positive example, initiated from inside the geothermal sector already in 1994, is VDI 4640). It is expected that there will be an increasing need for standards first on the shallow geothermal technology and then on the deeper and larger systems (district heating).

Flanking measures

Three important flanking measures are awareness raising, training, and R&D and demonstration projects:

1 Raising awareness: the creation of public knowledge and the understanding of geothermal energy technologies and related benefits is of particular relevance for private consumers as well as professional groups concerned. A well-designed campaign on geothermal technologies, targeted to a broad audience and including training courses for professional groups, could help develop potential and existing markets. The public sector could give priority to renewable heating and cooling installations as part of the procurement policy particularly when it comes to newly constructed buildings or buildings undergoing renovation.
2 Training: the lack of knowledge about geothermal technologies from architects, planners and installers currently limits a broad penetration of renewables in the heating and cooling markets. This knowledge would ensure high quality design and installation of the geothermal systems.
3 R&D and demonstration projects: two-thirds of the costs related to geothermal plants are associated with drilling the wells. Great advances are possible in drilling technology, for exploration and preliminary resource assessment. R&D support is required both for geothermal district heating and for shallow geothermal systems/geothermal heat pumps.

A number of new and innovative applications of geothermal energy have been developed and some of those have already been demonstrated. The most promising topics are desalination, absorption cooling, industrial applications, snow-melting and road de-icing.

Key countries and success stories

In the EU, applications linked to direct uses of heat are the most developed: 18 countries out of the 27 use low- and medium-enthalpy geothermal energy. In EU-27, the direct uses of geothermal heat in 2008 (excluding geothermal heat pumps) represented an installed capacity of ca. 4000MWth. Hungary is the largest user of geothermal energy with an installed capacity of about 750MWth in 2008. The main uses of geothermal energy are for the heating of baths and swimming pools, the heating of greenhouses and district heating networks. Italy, which also uses medium-enthalpy deposits for thermal applications, is ranked second in the classification with a capacity in the region of 500MWth, a few megawatts more than in 2005. The main uses in Italy are, by order of importance: heating of baths and swimming pools, heating of buildings via district heating networks, heating of greenhouses, breeding of fish and industrial uses. France is the third largest user with an installed capacity in the region of 307MWth in 2008. Growth prospects are very good in France. Slovakia also ranks well in the EU classification with a capacity of 186.3MWth, including 118.3MWth for heating baths and swimming pools, 31.8MWth for heating greenhouses, 31.6MWth for heating networks and 4.6MWth for fish breeding.

Way to success in Sweden: Geothermal heat pumps

Sweden is by far the most developed geothermal heat pump market in Europe. The market in Sweden has shown a strong increase every year during the last decade. Sweden, accounting for 40 per cent of all installed ground source heat pumps in 2007, is still the leading country in Europe. Due to the escalating price of oil and electricity in conjunction with an increase of energy related taxes, the competitiveness for geothermal HP has improved significantly. The technology is now fully recognized both by consumers and decision-makers. For many years it has been the number one choice for retrofitting as well as for new construction of single family houses. The rapid market growth for geothermal heat pumps is the most important reason behind the fact that Sweden has reduced the use of heating oil by more than 50 per cent during the last 15 years. Today more than 320,000 geothermal heat pumps supply Swedish homes. The Swedish geothermal heat pump market is now self-sustaining and has reached maturity in the segment of single family houses. Commercial and multi-family buildings (or blocks of flats) are still dominated by district heating, but offer a great opportunity for large ground source heat pump systems. These are the two housing segments that continuously grow, even though the numbers are still low. Due to the high rate of replacements during the last couple of years, the sales of ground source heat pumps is estimated to have reached a peak in 2007. The market is expected to stabilize at an annual sales volume in the range of 30,000–35,000 units.

Success story in Germany: Geothermal heating and cooling

The German GHP market is still growing whereas Sweden is already thought to have reached maturity, thus leading to the conclusion that the German market will become the most important market in the years to come. This belief is strengthened by the fact that the German market is growing on its own merits in contrast to, for example, the French market that is currently profiting from a generous subsidy scheme. The German geothermal heat pump market first started to develop after the first oil crisis in the 1970s. The high price of heating oil and gas, which were dominating the heating sector, made it interesting to look for substitutes. The market reached an early peak in 1981 before it started to drop and come to almost a complete stop in 1987. Although several reasons were behind this decline, two main causes were detected: the sudden fall of oil prices and a poor perception of the technology. At this early stage of market development, ground source heat pumps had roughly 50 per cent of the heat pump market. At the beginning of the 1990s electric utilities and federal, as well as local, governments initiated the development of ground source heat pump systems and support schemes. These actions in combination with the foundation of the German geothermal association (GtV) and an overall energy price increase led to a slow but stable recovery of the market. Some barriers still exist in areas where the local authorities are reluctant to give permission for ground source collectors, but they might be overcome through environmentally benign secondary refrigerants and better under-

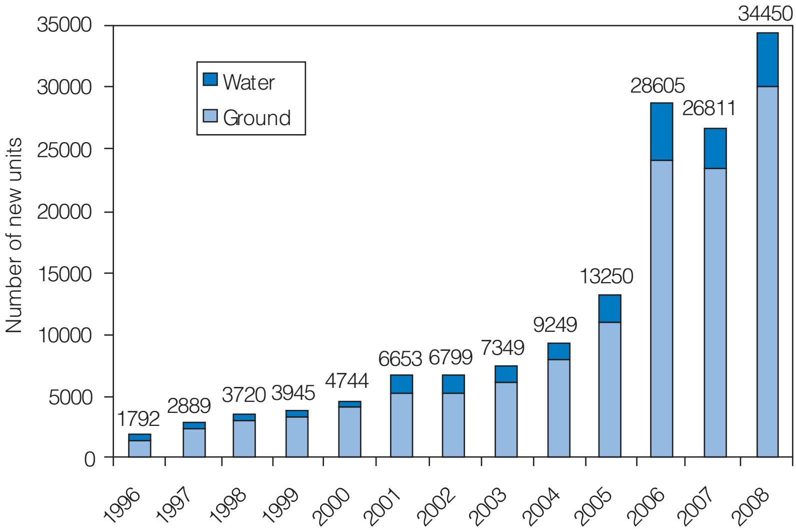


Figure 4.20 Geothermal heat pump sales in Germany 1996–2008
Source: Elaboration by GtV-BV based on data from Bundesverband Wärme pumpe (BWP)

standing among the authorities. The long winter of 2006, further increases of energy prices and the considerable media attention to climate change resulted in 120 per cent growth of sales in the heat pump market.

Support for the district heating plants through the Market Stimulation Programme has been available since 1999. In the first version the rules for application allowed for virtually no requests, however, the new guidelines introduced in 2005 have removed these obstacles and the first new plants with support from the scheme are now producing heat (in the Munich area). Support is also available to remove another barrier to geothermal district heating: the cost of establishing a distribution network. The support is granted through special loans by KfW and is suitable for large installations run by utility companies (for private house owners, the direct support as described in the heat pump section is more appropriate). There is still a problem with the scheme for plants producing both district heat and electricity, with the owner having to decide whether to use support for either heat or power. Support for heat is small, and the amount of power in such combined plants is only a fraction, so a combination of both would be highly desirable. A future revision should remove this obstacle too. In general, the Market Stimulation Programme for deep geothermal plants shows how an inappropriate measure can be converted into a very helpful tool.

France: Geothermal district heating

France is the third largest deep geothermal user with an installed capacity in the region of 307MWth in 2008. The principal low enthalpy use in France is for heating homes in the large Parisian and Aquitaine sedimentary basins. France also uses geothermal energy for fish farming, heating baths and swimming pools, as well as for heating greenhouses. Growth prospects are very good in France. The Ministry of Industry's Heat Pluriannual Programming of Investments (PPI) provides a contribution of 500ktoe by 2015 for heat coming from geothermal energy (except for geothermal heat pumps). This is nearly three times that currently in existence. To promote rapid development, ADEME finances aid for the extension of existing networks according to the number of avoided tons of CO_2 (€400 per ton of CO_2). In the Île-de-France region, the Regional Council adds aid of between €150 and €350 per ton of CO_2 according to the size of the project. The incentives are for District Heating (GDH): the State supports 40 per cent of CI costs for the extension of existing GDH grid/facilities.

TOMORROW

Technology targets by 2020 and beyond

In total, only a tiny portion of the potential of geothermal energy has yet been explored or exploited in Europe. Targets for geothermal energy have been defined but can only be achieved if all stakeholders, institutions, market players, financial institutions, agencies and policy-makers join forces.

Table 4.2 Targets for EU-27

Heating & Cooling EU-27	2007	2010	2020
Geothermal Heat Pumps (MWth)	5700	11,500	30,000
Geothermal Direct uses (MWth)	4100	4500	9000
Total Installed Capacity (MWth)	9800	16,000	39,000
Heat and Cold Production (Mtoe)	2.6	4.3	10.5

Source: EGEC (2009a)

The outlook for geothermal H&C production, today and in the future, seems extremely positive. In 2008, a total of more than 2.5Mtoe had been supplied by geothermal heating alone. At the end of 2008, the thermal capacity amounted to 12000MWth. These figures do not define the limits of the enormous economic potential of geothermal resources that could be exploited through new and improved technologies. Geothermal direct-use applications, such as heating homes, agricultural and industrial uses, aqua-

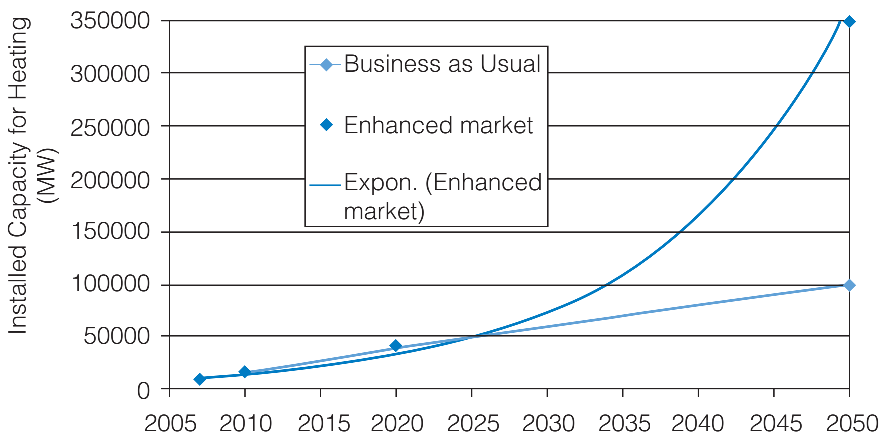


Figure 4.21 Installed capacity for heating up to 2050
Source: EGEC

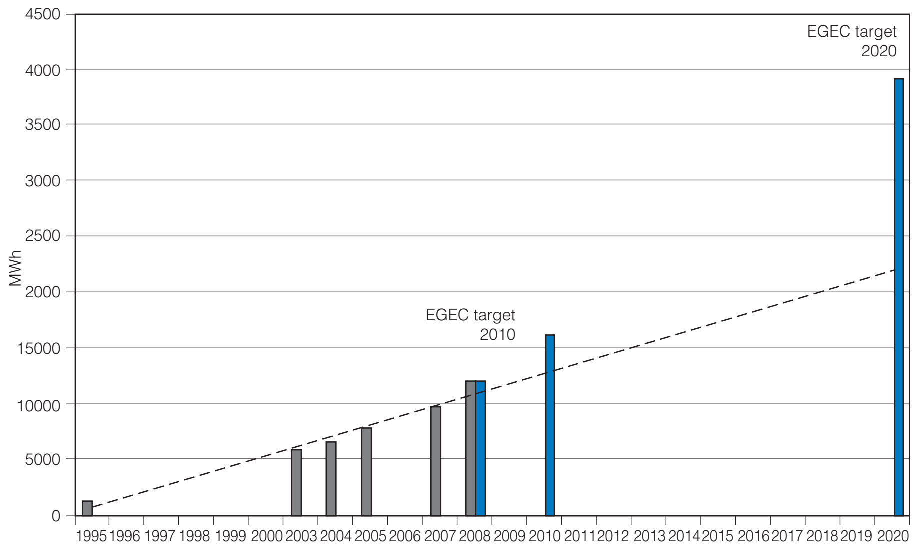


Figure 4.22 Heat production in EU-27 up to 2020
Source: EGEC

culture and balneology are able to produce at least as much energy as geothermal electricity production, if not more.

The rapid development of geothermal heat pumps shows the relevance of shallow geothermal energy resources that, once regularly neglected, need to be taken more into account in any energy development scenario. An increase in the use of geothermal potential, an improvement in plant efficiency as well as a decrease in installation and operational costs are of utmost importance for EGEC in order to reach its tremendous targets; research and technical development is also required in the geothermal sector to achieve the targets. Technological evolution can be expected in geothermal H&C to increase the usable geothermal potential, improve plant efficiency and decrease installation and operational costs. Moreover, the Enhanced Geothermal Systems (EGS) with combined heat and power plants will bring a large heat production. Its rapid deployment after 2030 will give geothermal an essential role for a 100 per cent renewable heating and cooling in the EU.

The future development of the geothermal heating and cooling sector is bound to achieve:

- improved site assessment (including GIS-systems), exploration and installation, including for shallow systems, and the dissemination of successful approaches from some countries to the whole EU;
- further increase of efficiency of ground source heat pumps, optimized system concepts, application of advanced control systems, improved components and materials (compressors, refrigerants, pipes, etc.);
- construction of new district heating networks and optimization of existing networks and plants, in particular in east/south-eastern Europe and Turkey;
- increased application and innovative concepts for geothermal energy in agriculture, aquaculture, industrial drying processes, etc.;

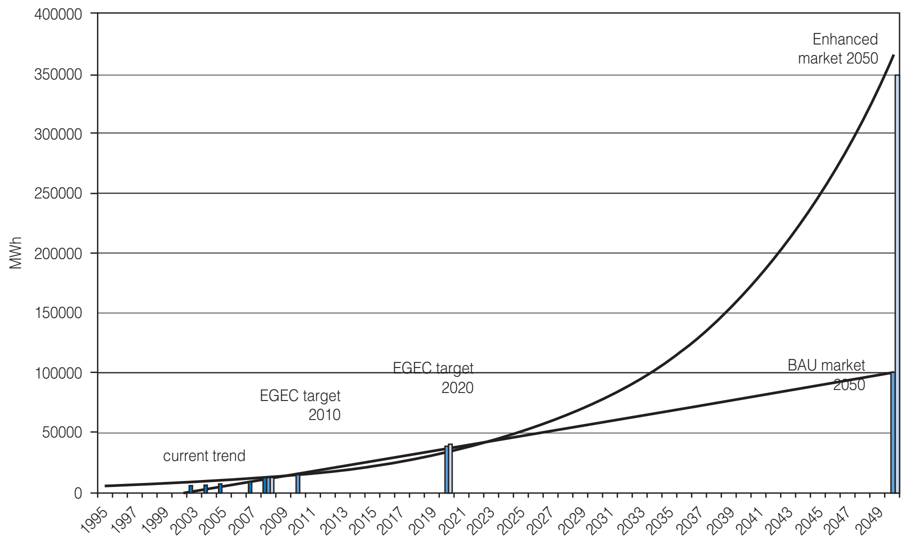


Figure 4.23 EGEC targets by 2050
Source: EGEC

- demonstration of new applications such as de-icing and snow-melting on roads, airport runways, etc., sea-water desalination and geothermal absorption cooling.

Non-technical development is also paramount, including administrative and legal clarity, suitable infrastructure in the form of machines and skilled labour, information to the public, etc. Market potential for industrial applications as yet constitutes the smallest portion of geothermal direct use. The industrial sector, at least in theory, offers a very attractive target for geothermal use. Industrial processes operated at high load factor relative to other geothermal applications, offer a concentrated load at a single location and in some cases are characterized by energy as a significant portion of production cost. Together these qualities suggest attractive conditions for geothermal application. The single remaining large application, food dehydration, has been very successful with large facilities currently operating in Greece and France, among others. Thanks to the intensive work of the FAO CNRE network for geothermal energy use in agriculture during the 1980s, agriculture has been one of the economy sectors where the direct application of geothermal energy has undergone quite rapid development. As mentioned above, R&D support is required both for geothermal district heating and for shallow geothermal systems/geothermal heat pumps.

Technological long term potential

The geothermal H&C sector could reach 150Mtoe by 2050. To achieve these targets, the priorities for geothermal energy are:

- geothermal district heating and cooling;
- shallow geothermal and geothermal heat pumps;
- geothermal heat from co-generation plants (EGS and binary);
- miscellaneous: innovative concepts (agriculture, drying etc.), desalination, absorption cooling, storage of heat or cold and advanced controlled systems.

Geothermal energy already makes an important contribution to the energy sector. In recent years, significant advances have been achieved with engineered geothermal systems. However, only a minuscule portion of the potential of geothermal energy is as yet explored and in use in Europe. Geothermal heating and cooling has a far wider potential than most typical applications today. While the heating of the built environment (central heating, domestic hot water) will continue to be the most important market segment, other applications will grow to significant market shares. Projections with regard to heat production are very positive. As far as low-energy applications are concerned, an annual capacity increase of 150MWth, which corresponds to the current rate, will make it possible to reach 4500MWth in 2010 and 9000MWth in 2020. If the sector for geothermal heat pumps keeps growing at the rate of about 15 per cent per year up to 2010, it could achieve a cumulative capacity of 13,000MWth and reach 33,000MWth in 2020. The White Paper (1997) foresees a geothermal contribution of 5000MWth at the end of 2010, equally divided between deep and shallow geothermal. New projections (16,000MWth by 2010) exceed this forecast, but with a different breakdown: 75 per cent for geothermal heat pumps and 25 per cent for direct uses. The current dynamism of the geothermal sector is in phase with the objectives of the European Commission's Sustainable Energy Europe Campaign 2005–2008. These objectives call for 250,000 new geothermal heat pump installations, 15 new electrical power plants and 10 new low- and medium-temperature installations between 2005 and 2008. At the end of 2008, installed thermal capacity in the EU totalled 12,000MWth. Geothermal sector growth is on the right track for reaching the White Paper objectives outlined for 2010.

NOTES

1 See also Chapter 11.

Part III

RES Electricity

Part III

Introduction

Electricity from wind power, hydro, geothermal and biomass is already a market reality. Photovoltaics (PV) are already cost-effective in some markets worldwide, while tidal and wave power, as well as concentrated solar power, will need further research and development before their full commercial potential can be realized. Under the present state of market progress and the political support given to electricity generation from Renewable Energy Sources, the current EU target for RES-Electricity for 2010 (21 per cent of RES-electricity) can be met. It is expected that renewable energy technologies will be able to contribute between 33 per cent and 40 per cent of total electricity production by 2020. The following chapters provide an overview of the market state and further development perspectives of the different renewable energy generating technologies.

Table III.1 Contribution of renewables to electricity consumption

	2005 Eurostat TWh	2006 Eurostat TWh	2010 Projections TWh	2020 Targets TWh
Wind	70.5	82.0	176	477
Hydro[2]	346.9	357.2	360	384
Photovoltaic	1.5	2.5	20	180
Biomass	80.0	89.9	135	250
Geothermal	5.4	5.6	10	31
Solar thermal elect.	–	–	2	43
Ocean	–	–	1	5
TOTAL RES	504.3	537.2	704	1370
Total Gross Electricity Generation EU-27	3320.4	3361.5		
(Trends to 2030–Baseline)[3]			3568	4078
(Combined RES and EE)[4]				3391
	15.2%	16.0%	19.7%	33.6–40.4%

Source: EREC (2008)

5

Wind[1]

Humanity first learnt to harvest the natural power of the wind in the early civilizations of ancient Iran. Four sails were attached to a vertical shaft inside a chamber, into which the wind could pass and escape, causing the sails to rotate and turn two flat stones that crushed the grain placed between them. Windmills have taken many forms in their evolution from these simple milling devices, through the complex mechanical windmills of industrial-age Europe, to the ultra high-tech wind turbines of today. Wind turbines generate electricity, as distinct from windmills, which were, like their water-powered counterparts, primarily used for milling grain. At their peak, the number of traditional 'Dutch' windmills in Europe reached 100,000 and constituted an essential part of industry, employment and rural industrial life. Traditional windmills were eventually superseded by newer technologies, such as coal and gas, but today, it is these polluting 'conventional technologies' which are in turn being superseded by wind power – in the form of the efficient, modern wind turbine. In 1939, a 1.25MW wind turbine was installed at Grandpa's Knob in the US state of Vermont. The installation brought together some of the finest scientists and engineers of the time and constituted a landmark in the development of wind technology. Since then, many different designs have been trialled, using different materials and taking very different forms; turbines have been designed with two or three blades, running at various speeds and using varying control technologies. The most common type of wind turbine today is the three-bladed, vertical axis turbine, ranging in size from a few watts (for charging batteries), up to the largest 5MW turbines, generating electricity for thousands of homes.

STATE-OF-THE-ART TECHNOLOGY

Many improvements have taken place since commercialization of wind technology in the early 1980s but the basic architecture of the mainstream design is little changed. The evolution of modern wind turbines is a story of engineering and scientific skill coupled with a strong entrepreneurial spirit. In the last 20 years turbines have increased in size by a factor of 100, from 25kW to 2500kW and up to 7MW, the cost of energy has been reduced by a factor of more than five and the industry has moved from an idealistic fringe activity to mainstream power generation. By the end of 2008, the European wind industry's installed capacity of 65GW accounted for 4 per cent of the EU electricity demand, equivalent to the consumption of 34 million average households. By the end of 2008, global installed wind power capacity passed 120GW.

Figure 5.1 shows the architecture of a wind turbine: generally, this is composed of a foundation, a tower, a nacelle which houses various components at the top of the tower and a rotor consisting of three blades that capture wind energy and help convert it into

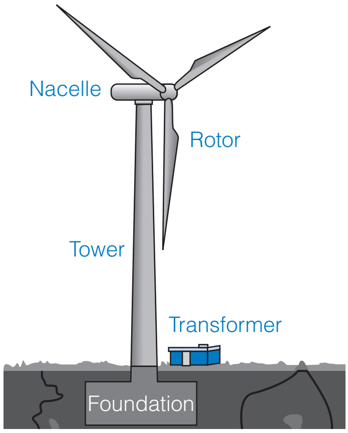


Figure 5.1 Architecture of a wind turbine
Source: Danish Wind Energy Industry Association[2]

electricity. Gearboxes, generators and transformers are also integral to this process. Wind turbines generate high-quality, network-frequency electricity and are often placed in wind farms consisting of several individual turbines. The main design drivers for current onshore wind technology are low-wind and high-wind sites, grid integration, complex terrain, reliability and efficiency. Acoustic and aerodynamic performance, as well as visual impacts, also play a role. In addition, offshore wind farms have their considerations.

Technological benefits

Scientists, engineers and politicians have long known of the benefits of wind power but it is only in the last 25 years that technology and manufacturing have proven what a valuable resource harnessed wind can become. Wind power shares many positive characteristics with other renewable energy sources. As a fuel, wind is free, reliable, local and affordable.

The growing industry creates well-paying direct jobs with much new indirect employment as well. Wind lessens Europe's dependency on increasingly expensive imported fuel. Wind power also has the ability to help Europe become a leader in the fight to halt global warming. Except for a relatively small amount of pollution associated with the manufacturing, installation, operation and maintenance, and eventual decommissioning of the facility, wind power is a clean energy that does not create pollution, CO_2 or other greenhouse gases associated with climate change.

Wind power has also become important because of the EU's binding target of having 20 per cent of its energy portfolio come from renewables by 2020. In 2008, wind power provided 4 per cent of Europe's electricity demand, which avoided the emission of 91million tonnes of CO_2 or was the equivalent of taking 46 million cars off the road. The 8.5GW of wind power capacity installed in the EU in 2008 had an investment value of €11 billion and avoided CO_2 emissions worth €2.3 billion and fuel costs of €6.5 billion annually, assuming an average CO_2 price of €25/t.

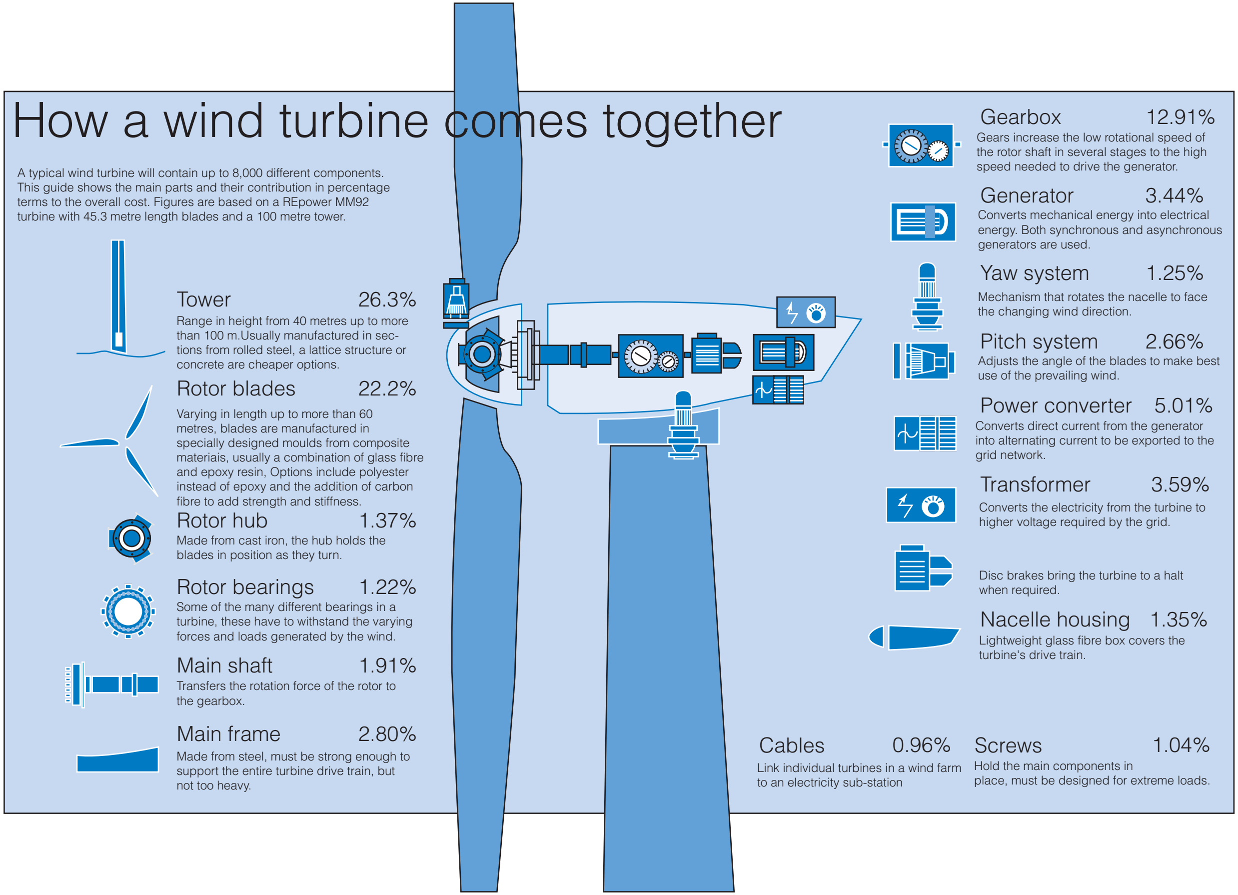


Figure 5.2 How a wind turbine comes together
Source: EWEA (2007a)

Figure 5.3 Winter: Windpark, Tarifa, Cadiz
Source: EWEA

Technological applications

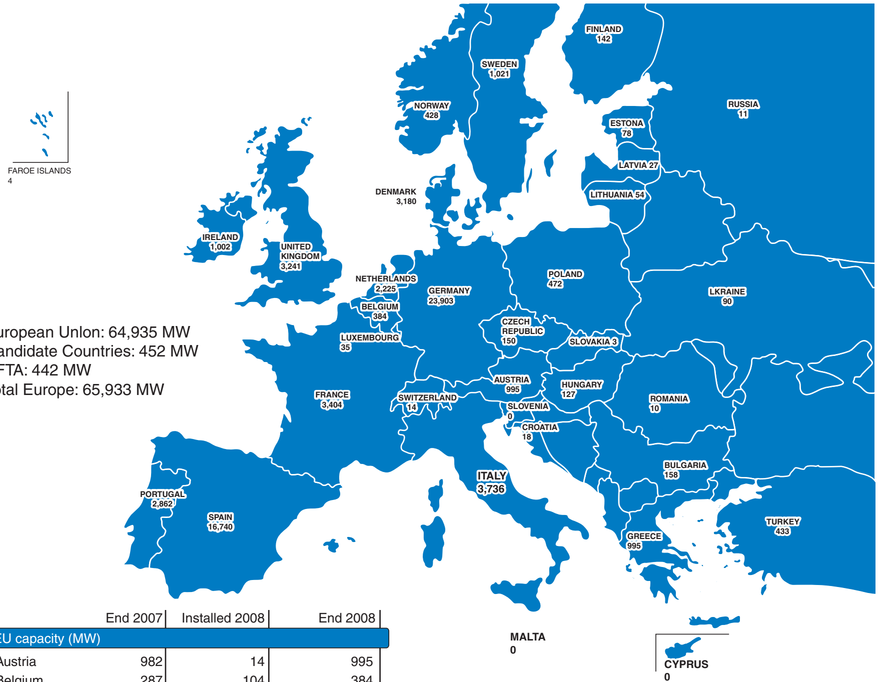
Land-based wind energy

Modern turbine technology is available for sites with low and high wind speeds, in extremely hot or cold climates, and wind farms are capable of high availability throughout the year. Europe has an enormous wind resource. Major areas that have a large wind energy resource include Denmark, northern Germany, Spain, Norway, south-west Sweden, the Netherlands, Belgium, north-west France, the UK and Ireland. Some of the other suitable areas include southern France, Portugal, Italy, the Czech Republic, Austria, Greece and Bulgaria. Before building a wind farm, an in-depth evaluation is required and robust estimates must be provided to support investment and financing decisions. Once the wind speed on the site has been estimated it is then vital to make an accurate and reliable estimate of the resulting energy production from a wind farm which might be built there. Figure 5.4 shows the onshore wind energy resource, according to the European Wind Atlas, published in 1989.

The map shows wind speeds at 50m above ground level, which reflected the height of wind turbines. Since wind speeds increase with height, and because higher wind speeds mean that much more energy can be extracted, the average height of wind turbines has shown a steady increase. Wind speeds experienced by today's commercial technology are therefore higher than those shown in Figure 5.4. The wind speed above which commercial exploitation can take place varies according to specific market conditions and support schemes. Many European countries have exceptional wind-power potential, especially considering rising fuel, carbon and electricity prices and concerns about global warming.

Offshore wind resources

There is also an enormous wind resource in the seas around the coastline of Europe (Figure 5.5).



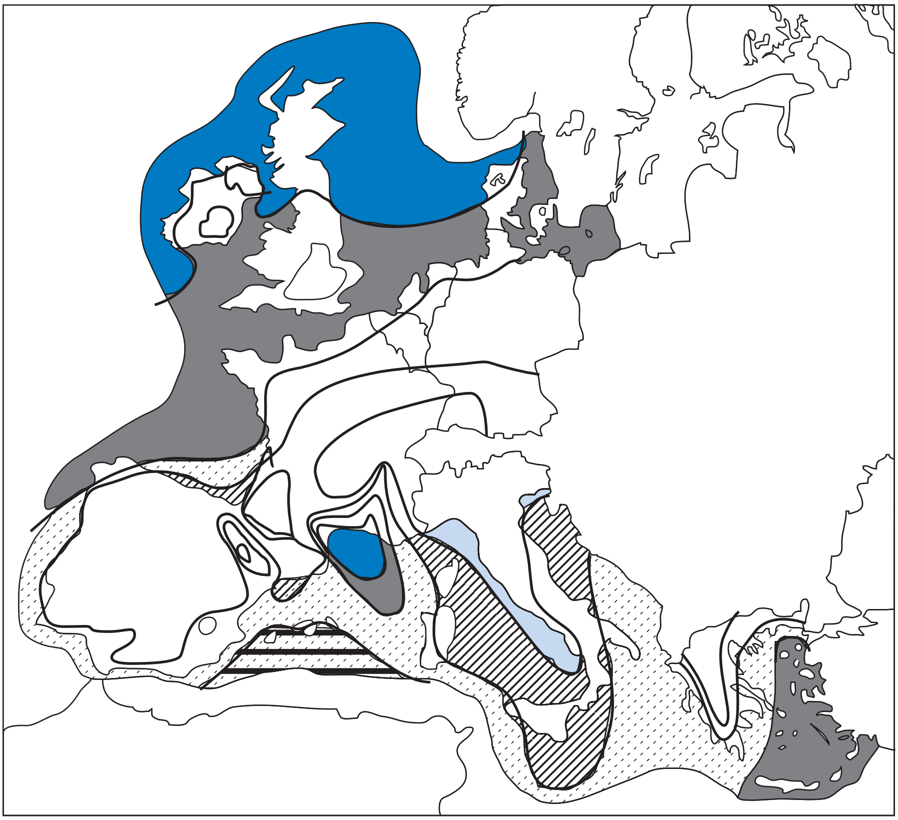
	End 2007	Installed 2008	End 2008
EU capacity (MW)			
Austria	982	14	995
Belgium	287	104	384
Bulgaria	57	101	158
Cyprus	0	0	0
Czech Republic	116	34	150
Denmark	3,125	77	3,180
Estonia	59	20	78
Finland	110	33	143
France	2,454	950	3,404
Germany	22,247	1,665	23,903
Greece	871	114	985
Hungary	65	62	127
Ireland	795	208	1,002
Italy	2,726	1,010	3,736
Latvia	27	0	27
Lithuania	51	3	54
Luxembourg	35	0	35
Malta	0	0	0
Netherlands	1,747	500	2,225
Poland	276	196	472
Portugal	2,150	712	2,862
Romania	8	2	10
Slovakia	5	0	3
Slovenia	0	0	0
Spain	15,131	1,609	16,740
Sweden	788	236	1,021
United kingdom	2,406	836	3,241
Total EU-15	55,854	8,067	63,857
Total EU-12	663	417	1,078
Total EU-27	56,517	8,484	64,935
Of which offshore and near shore	1,114	357	1,471

	End 2007	Installed 2008	End 2008
Candidate Countries (MW)			
Croatia	17	1	18
FYROM*	0	0	0
Turkey	147	286	433
Total	164	287	452
EFTA (MW)			
Iceland	0	0	0
Liechenstein	0	0	0
Norway	326	102	428
Switzerland	12	2	14
Total	338	104	442
Other (MW)			
Faroe Islands	4	0	0
Ukraine	89	1	90
Russia	13	0	11
Total	106	1	105
Total Europe	**57,125**	**8,877**	**65,933**

*FYROM = Former yugoslav Republic of Macedonia
Note: Due to previous-year adjustments, project decommissioning of 70 MW, re-powering and rounding figures up and down, the total for the 2008 end-of-year cumulative capacity is not exactly equivalent to the sum of the 2007 end-of-year total plus the 2008 additions,

Figure 5.4 European Wind Atlas, onshore 1989
Source: European Wind Atlas

A study by consultants Garrad Hassan and Germanischer Lloyd, carried out under the EC's Joule programme 1993–1995, estimated an offshore wind potential in the EU of 3028TWh. Even though Norway and Sweden were not included in the study, this figure far exceeded the total electricity consumption within the EU's 15 members in 1997. The majority of the European offshore resource then was identified in the UK, Denmark and



Wind resources over open sea (more than 10 km off shore) for five standard heights										
	10 m		25 m		50 m		100 m		200 m	
	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}
	> 8.0	> 600	> 85	> 700	> 9.0	> 800	> 10.0	> 1100	> 11.0	> 1500
	7.0-8.0	350-600	7.0-8.5	450-700	8.0-9.0	600-800	8.5-10.0	650-1100	9.5-11.0	900-1500
	6.0-7.0	250-300	6.5-7.5	300-450	7.0-8.0	400-600	7.5-8.5	450-650	8.0-9.5	600-900
	4.5-6.0	100-250	5.0-6.5	150-300	5.5-7.0	200-450	6.0-7.5	250-450	6.5-8.0	300-600
	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 6.0	< 250	< 6.5	< 300

Figure 5.5 European wind resources over open sea
Source: Risø DTU National Laboratory (1989)

France. Using a geographical database, the study assumed that the wind resource could be harnessed to a water depth of 40m and up to 30km from land. A reference wind turbine of 6MW capacity and a 100m diameter rotor was used, with the spacing between turbines set at one kilometre. The study indicates that a lack of wind resource is unlikely to ever be a limiting factor in using wind power to produce electricity. The total available wind resource that is potentially recoverable globally is more than twice as large as the projection for the world's entire electricity demand in 2020.

Cost and prices

Wind turbines

In a European context as well as globally, wind power is being developed rapidly. Within the past 15 years the global installed capacity of wind power has increased from about 2.5GW in 1992 to a little above 94GW at the end of 2007: an annual growth of more than 25 per cent. By the end of 2008, global capacity reached over 120MW. The most important parameters governing wind-power economics are the turbines' electricity production and investment and operating costs. As electricity production is highly dependent on wind conditions, choosing the right site is critical to achieving economic viability. Capital costs of wind energy projects are dominated by the cost of the wind turbine itself ('ex works').[3] Table 5.1 shows a typical cost structure for a 2MW turbine erected in Europe. Thus, an average turbine installed in Europe has a total investment cost of approximately €1.23 million per MW, that is, a 2MW machine costs about €2.5 million including all additional costs for foundation, electrical installation, consultancy, etc. The turbine's share of total cost averages about 76 per cent, while grid-connection accounts for approximately 9 per cent and the foundation for around 7 per cent. The cost of acquiring the site for the turbine varies significantly between projects and therefore the number in Table 5.1 is only to be seen as an example. Other components, such as control systems, account for only a minor share of total costs.

Table 5.1 Cost structure (in €) of a typical 2MW wind turbine based on selected data for European wind turbine installations (2006)

	Investment (1000€/MW)	Share (%)
Turbine (ex works)	928	75.6
Foundation	80	6.5
Electric installation	18	1.5
Grid-connection	109	8.9
Control systems	4	0.3
Consultancy	15	1.2
Land	48	3.9
Financial costs	15	1.2
Road	11	0.9
Total	1227	100

Source: WETF (2009a)

Three major trends have dominated the development of grid-connected wind turbines in recent years:

- the turbines have become larger and taller, thus the average size of turbines sold at the market place has increased substantially;
- the efficiency of the turbines' production has increased steadily;
- in general, the investment costs per kW have decreased (although global demand for the technology has pushed up prices recently).

The annual average wind turbine size has increased significantly over the last 10–15 years, from approximately 200kW in 1990 to 2MW in the UK in 2007, with Germany, Spain and the US lagging only a little behind.

There is quite a difference between some of the countries. In India the average installed size in 2007 was about 1MW, significantly below the level in the UK and Germany, about 2MW and 1.9MW respectively.

In 2008 turbines of 1.5MW or higher had a market share of more than 86 per cent, leaving under 14 per cent for the smaller machines. Turbines with capacities of 2.5MW and up are getting increasingly important, even for on-land sitings. These large turbines had a share of 6 per cent of the market in 2008, compared to only 0.3 per cent at the end of 2003. Also, other costs as a percentage of total costs have generally decreased. In 1989, almost 29 per cent of total investment costs were related to costs other than the turbine itself. By 1997, this share had declined to approximately 20 per cent. The trend towards lower auxiliary costs continues for the last vintage of turbines shown (2000kW), where other costs amount to approximately 18 per cent of total costs. But from 2004 to 2006 other costs rose almost in parallel with the cost of the turbines.

The recent price increases for turbines is a global phenomenon caused by an increasing demand for wind power in many countries and constraints on the supply side, involving both turbine manufacturers and suppliers of wind-turbine components. The rapidly-growing cost of prices paid for raw materials and commodities around the world is also a factor.

Operation and maintenance (O&M)

O&M costs constitute a sizeable share of the total annual costs of a wind turbine. For a new turbine, O&M costs might easily have an average share over the lifetime of the turbine of approximately 20–25 per cent of total levelized cost per kWh produced – as long as the turbine is fairly new the share might constitute 10–15 per cent increasing to at least 20–35 per cent by the end of the turbine's lifetime. Thus O&M costs are increasingly attracting more attention from manufacturers attempting to lower these significantly by developing new turbine designs requiring fewer regular service visits and less down-time.

The cost of energy generated by wind power

The total cost per produced kWh (unit cost) is calculated by discounting and levelizing investment and O&M costs over the lifetime of the turbine, divided by the annual electricity production. The unit cost of generation is thus calculated as an average cost over the turbine's lifetime. In reality, actual costs will be lower than the calculated average at the beginning of the turbine's life, due to low O&M costs, and will increase over the period of turbine use. The turbine's production of power is a very important factor for the cost per generated unit of power. Whether a project is eventually profitable might totally depend on whether it is sited at a good wind location. In this section the cost of wind produced energy will be calculated given a number of basic assumptions. Due to the importance of the turbine's power production this parameter will be treated on a sensitivity basis. Other assumptions include:

- the calculations are performed for a new land-based medium-sized turbine, that is of 1.5–2MW size, which could be erected today;
- investment costs reflect the range given in the section *Development and investment costs of European offshore wind power* (page 101) that is a cost per kW of €1100 to €1400/kW with an average of €1225/kW. These costs are based on data from the International Energy Agency (IEA) stated in 2006 prices;
- operation and maintenance costs are assumed to be €1.45/kWh as an average over the lifetime of the turbine;
- the lifetime of the turbine is set at 20 years, in accordance with most technical design criteria;

- the discount rate is assumed to range within an interval of 5 to 10 per cent per year. In the basic calculations a discount rate of 7.5 per cent per year is used, though a sensitivity analysis of the importance of the above-mentioned interest range is performed;
- the economic analyses are carried out as simple national economic ones. No taxes, depreciation, risk premium etc. are taken into account. Everything is calculated in fixed 2006 prices.

The calculated costs per kWh wind-generated power as a function of the wind regime at the chosen sites are shown in Figure 5.6.[4]

The cost ranges from approximately c€7–10/kWh at sites with low average wind speeds to approximately c€5–6.5/kWh at good coastal positions, with an average of approximately c€7/kWh at a medium wind site. In Europe, good positions are often found on the coast of UK, Ireland, France, Denmark and Norway. Medium-wind areas are mostly found on inland terrain in Germany, France, Spain, Holland, Italy, Sweden, Finland and Denmark. In many cases local conditions significantly influence the average wind speed at the specific site. Approximately 75–80 per cent of total power production costs for a wind turbine are related to capital costs, that is costs for the turbine itself, foundation, electrical equipment and grid-connection etc. Thus a wind turbine is very capital-cost intensive compared with conventional fossil-fuel fired technologies such as a natural gas power plant, where as much as 40–60 per cent of total costs are related to fuel and operation and maintenance costs. For this reason the price of capital (discount or interest rate) is an important factor for the cost of wind-generated power and at the same time it is a factor that varies substantially between individual EU member countries.

Development and investment costs of European offshore wind power

Offshore wind only counts for a small amount of total installed wind-power capacity – just over 2 per cent – and development has mainly taken place in European countries around the North Sea and the Baltic Sea, where by now over 30 projects have been

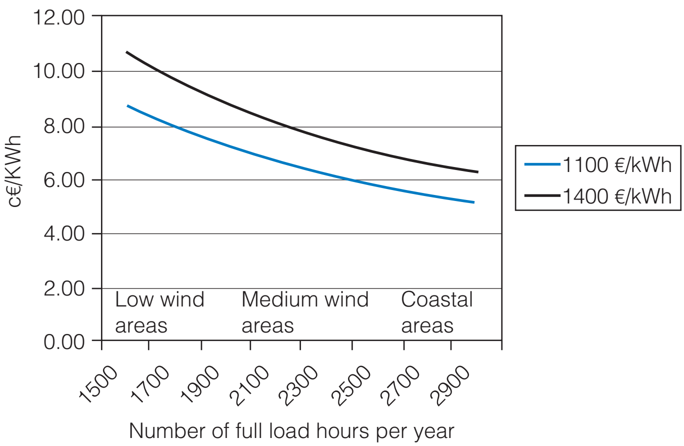


Figure 5.6 Calculated costs per kWh wind-generated power as a function of the wind regime at the chosen site (number of full load hours)
Source: EWEA (2009a)

implemented. By the end of 2008, almost 1471MW of capacity was located offshore in nine EU countries: Belgium, Denmark, Finland, Germany, Ireland, Italy, Netherlands, Sweden and the United Kingdom as shown in Table 5.2.

The overall cost of offshore wind power is still about 50 per cent more expensive to produce than onshore wind. Due to the expected benefits of increased wind and fewer visual impacts from larger turbines, however, several countries have very ambitious goals concerning offshore wind.

Offshore wind farms are installed in large units, often 100–200MW. Higher costs and industrial-capacity problems in the manufacturing stages and the availability of installation vessels causes some delays currently but several projects in the UK, Germany and Denmark should be finished over the coming years.

Table 5.2 Installed offshore capacity in offshore wind countries

Country	Total MW installed by end 2008	Installed MW in 2008
Belgium	30	30
Finland	24	24
Germany	12	5
Denmark	409	0
United Kingdom	591	187
Sweden	133	0
Netherlands	247	120
Ireland	25	0
Italy*	0	0
TOTAL	1471	366

* As of the end of 2008 Italy had one offshore test turbine with a capacity of 0.08 MW, but it was not grid connected.
Source EWEA Pure Power (2009c)

Figure 5.7 Offshore wind power in the Oeresund Chanel Copenhagen 2008
Source: http://energypicturesonline.com

Offshore costs are largely dependent on water depth, distance to the coastline, weather and wave conditions. The most detailed cost information on recent offshore installations comes from the UK where 90MW was added in both 2006 and 2007 and from Sweden with the installation of the 110MW farm at Lillgrunden in 2007. The chosen turbine size for offshore wind farms ranges from 2MW to 3.6MW, with newer wind farms equipped with larger turbines. Also, turbine-farm sizes differ substantially, ranging from Denmark's fairly small Samsø wind farm of 23MW to the UK's planned London Array which will have a rated capacity of 1000MW (Table 5.3).

Table 5.3 Key information on recent offshore wind farms

	In operation	Number of turbines	Turbine size	Capacity MW	Investment cost € million	Investment cost €/W
Middelgrunden (DK)	2001	20	2	40	47	1.17
Horns Rev I (DK)	2002	80	2	160	272	1.7
Samsø (DK)	2003	10	2.3	23	30	1.3
North Hoyle (UK)	2003	30	2	60	121	2.01
Nysted (DK)	2004	72	2.3	165	248	1.5
Scroby Sands (UK)	2004	30	2	60	121	2.05
Kentich Flat (UK)	2005	30	3	90	159	1.76
Barrows (UK)	2006	30	3	90	–	–
Burbo Bank (UK)	2007	24	3.6	90	181	2.01
Lillgrunden (S)	2007	48	2.3	110	197	1.79
Robin Rigg (UK)	2008	60	3	180	492	2.73

Source: EWEA (2009)

The higher capital costs of offshore wind are due to the larger structures and complex logistics of installing the towers. The costs of offshore foundations, construction, installations and grid connection are significantly higher than for onshore. In general, the costs of offshore capacity have increased recently. On average, investment costs for a new offshore wind farm are expected to be in the range of €2.0–€2.2/W for a near-shore, shallow-depth facility.

MARKET

Installed capacity and market development in the EU and market segments

In 2008, more wind power was installed in the EU than any other electricity generating technology, including coal, nuclear and gas. In 2008 36% of all new electricity generating capacity in the EU was wind power. At the end of 2008, wind energy met 4.1 per cent of the EU's electricity demand. Wind power is already the second largest contributor to economic activity and employment in the area of power-plant manufacturing. In 2009, EWEA published new scenarios for the development of wind energy in the EU. Some 82.5GW of wind power capacity is expected to be operating throughout the EU by 2010. Offshore wind energy is expected to reach 3000MW (3.6 per cent of total wind capacity) in 2010 compared to 1471MW (2.2 per cent of total capacity) by the end of 2008. The European Commission's 1997 White Paper on Renewable Sources of Energy set a target for 40,000MW of wind power to be installed in the EU by 2010. That target was reached in 2005, five years ahead of schedule. The overall White Paper target included an increase in electricity production from RES by 338TWh between 1995 and 2010. As EWEA's analysis shows, wind power is expected to produce 179TWh in 2010, thereby meeting 53 per cent of the overall White Paper target. Wind power has experienced dramatic growth over the last few years and in 2008 five EU countries – Denmark, Spain, Portugal, Ireland and Germany – saw more than 5 per cent of their electricity demand covered by wind energy (Figure 5.8).

On 9 March 2007, the European Heads of State unanimously agreed on a binding target of 20 per cent renewable energy by 2020. The 2005 share of RES was approximately 7 per cent of primary energy and 8.5 per cent of final consumption. In January 2008, the EC proposed a new legal framework for renewables in the EU that has led to the 2009 directive on the promotion of energy from RES. This includes a distribution of the 20 per cent target between member states and National Action Plans containing sectoral targets for electricity, heating/cooling and renewables in the transport sector. To meet the 20 per cent target for renewable energy, the EC expects 34 per cent[5] of electricity to come from RES by 2020 (43 per cent of electricity under a 'least cost' scenario)[6] and believes that 'wind could contribute 12 per cent of EU electricity by 2020'. In 2008, approximately 15 per cent of EU electricity demand was covered by renewables, including around 10 per cent large hydro and about 4 per cent wind energy. Excluding large hydropower, for which the realizable European potential has already been reached, the share of renewable electricity in the EU will need to grow five-fold – from 5 per cent to 25 per cent – to reach the electricity target, assuming that electricity demand does not increase. If demand goes up, RES-E will need to grow even more.

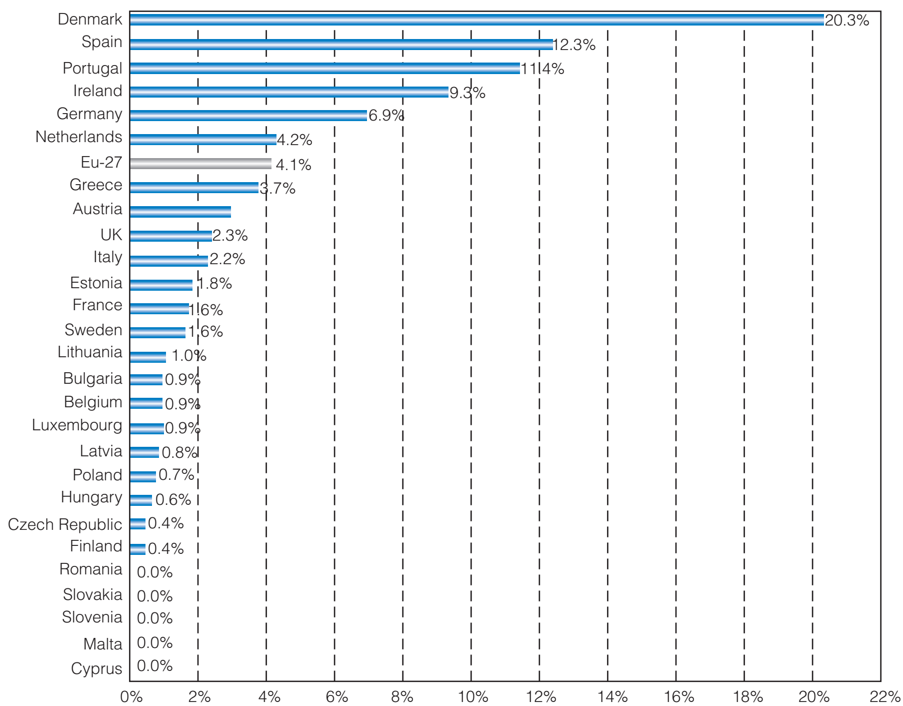


Figure 5.8 Wind power installed in Europe by end of 2008 (cumulative)
Source: EWEA (2009b)

Industry

Wind's spectacular growth as a vehicle for new generation-capacity investment has attracted a broad range of players across the industry value chain. From local site-focused engineering firms, to global vertically-integrated utilities, all have formed part of wind's European growth story. The overall scaling up of the sector has invited large-scale utilities to build sizeable project pipelines with long-term investment plans that indicate their commitment to adding wind into their generation portfolio, while at the same time a market remains for independent players able to contribute development skills, capital, and asset-management experience. Europe's wind energy value chain is seeing dynamic shifts as asset ownership is redistributed, growth is sought in maturing markets and players seek to maximize scale on an increasingly pan-European stage. While utilities build up GW-size portfolios, through their own strategy initiatives or government prompting, independent power producers (IPPs) seek to compete for asset ownership in booming western European markets while development activity continues to shift towards new regions in the east. The proliferation of players looking to develop, own or operate wind plants has pushed competition to a new level, underlining the key elements of local market knowledge, technical expertise and financial capacity as crucial to positioning on the value chain. Even before utilities began adopting wind energy, Europe's vertically-integrated independent power producers (IPPs) aggressively pursued exploiting wind-turbine technology to improve their positioning. Led primarily by Spanish firms connected to large power, construction and industrial companies, the IPP model has evolved in various forms to represent a significant group of players on the value chain. To maximize profitability, utilities have steadily migrated from risk-averse turnkey project acquisitions to greater vertical integration with in-house teams for development and O&M. There are two main types of independent power producers in Europe: integrated IPPs, which have capabilities across the project-development value chain and exploit these for maximum control and returns on their project portfolio, and wind-project buyers, which tend not to play a direct role in the development of wind plants in their portfolio as these firms often tend to be financial investors, rather than energy players. Europe's shifting distribution of wind-power asset ownership clearly illustrates the industry's scaling up and geographic expansion. Wind-power ownership now includes dozens of multinational players owning several GWs of installed capacity. Over the past five years, the most salient trend has been the increased participation of utilities in the industry. Utility share of total wind power installed has increased from 17 per cent in 2002 to 25 per cent in 2007. The biggest jump took place between 2005 and 2006, as the region's top wind utilities saw annual additions of well over 500MW in the case of players making large acquisitions.

Employment

The wind-energy sector has grown exponentially since the end of the 1990s, especially within the EU, and this has had an impact on the employment levels of the regions affected by this process. There are a wide variety of companies whose main field of activity is the deployment of wind energy, either the manufacturing of wind turbines, the measurement of the wind resource, the negotiation of permits, the construction of wind farms or the sale of electricity once the installation is operational. Other companies partially work in wind-related activities, although this does not constitute most of their income: certain sub-component manufacturers, legal services, environmental-impact analysts, educational centres, insurers, banks, etc. These activities must also be grouped under the heading of 'direct employment', but will be difficult to measure, since the companies may not feel identified with the wind-energy sector and the workers devoted to wind-related activities will fluctuate. A third group of companies contains those that produce the raw materials/intermediate goods (copper, lead, steel, bearings and metallic frames) that are needed in later stages by the wind business and companies whose level of activity depends on the amount of wind energy that is produced (e.g. wire manufacturers and energy traders). On a wider scale, wind-energy investments raise the income of a certain region, exerting a positive effect on general consumption that is known by the economic literature as the 'multiplier effect'. The multiplier effect has to be weighted against the resources that are devoted to supporting renewable energies and could have been employed elsewhere. These are the indirect and induced employment effects of wind energy. There is not an official classification of wind-energy companies (those that create direct employment), so the typology that is offered here constitutes a proposal, based on EWEA's expertise. The job profiles vary accordingly:

- **Wind-turbine manufacturers**: these are the producers of wind turbines, including major sub-components (blades, towers, generators, nacelles). Their staff contains scientists in R&D activities and different types of engineers leading the manufacturing and assembly process. The companies also need semi- and non-qualified workers for the production lines, plus the supporting personnel common to an industrial corporation (secretaries, sales managers, etc.).
- **Developers**: these are the companies dealing with the negotiation of all the permits and contracts needed prior to the operation of a wind farm. In some cases, the developers also coordinate the construction process. Developers demand highly-qualified technical staff dealing with the design and development of wind-energy projects and experts in financial and administrative procedures.
- **Construction, repair and O&M companies**: these build the wind farm (road construction, foundations, electrical installations and cabling, etc.); later on, the wind farm has to be inspected, adjusted and eventually repaired. The type of workers needed for building roads or preparing the installation area are much the same as those used for other civil works. However, transporting, erecting, repairing and operating the machines requires specialized training. This is also true for cabling and connecting to the electrical grid as well as inspecting mechanical and hydraulic systems. Health and safety measures have to be tailored to the particularities of wind turbines.
- **Independent power producers or utilities**: they operate the wind farm and sell the electricity either to the final consumer or to a distributor. The staff is very similar to that of other electricity branches, with a high percentage of qualified, technical workers. Large utilities tend to have their own O&M personnel.
- **Consultancies, legal entities, engineering and technical companies**: there is a variety of corporations dedicated to technical activities such as wind measurements, meteorological services, certification of wind turbines, data-management models, testing laboratories, etc. Additionally, some companies are specialized in providing regulatory and market analysis, as well as legal and environmental services: R&D centres, laboratories, universities and training institutions. The R&D activity of the wind-energy business is more intense than in other traditional sectors and that is the main reason behind the dramatic improvement of wind-turbine efficiency during the past 20 years – a modern turbine produces 180 times more electricity and at less

than half the cost per kWh than its equivalent 20 years before (EWEA, 2009d). In turn, an increasing number of universities, vocational and training institutions offer courses dealing with the specificities of the wind energy sector.

- **Financial institutions, insurers**: these entities operate in other economic sectors as well, but have some units devoted to wind energy. The popularity of wind energy means that most banks today are open to negotiating the funding of wind energy projects. Job profiles will combine technical experts with legal advisors and financiers.
- **Energy agencies, energy associations, other**: the heterogeneous category spans activities that are directly linked to the wind-energy sector, at a more modest scale. Job profiles for this kind are difficult to categorize, given the diversity.

A shortage of workers

In the last two to three years, wind energy companies have repeatedly reported an acute shortage of workers, especially within certain fields. An analysis of Eurostat statistics proves that job vacancies have been difficult to cover in all sectors. The rotation of workers is high, both for skilled and non-skilled workers. The scarcity of labour available for wind-energy companies coincides with a general expansion of the European economy, from the end of World War II to the financial crisis which exploded in late 2008. The general pressure provoked by the strong economic growth over a long period of time is complemented by the extraordinary performance of the wind energy sector since the end of the 1990s and its continued relative buoyancy during the 2008-2009 financial crisis. In 2008, the wind energy industry employed 155,000 people directly or indirectly in Europe. If EWEA's wind energy targets are met, the wind energy sector will employ 182,000 people in 2010, 282,000 in 2015 and 446,000 by 2020. (EWEA, 2009c). This has implied a multiplication of job offers in all branches, especially in manufacturing and development activities. A series of interviews with human-resources directors and other senior staff of large companies indicates the shortage is more acute in positions requiring a high degree of experience and responsibility. From a manufacturer's point of view, two major bottlenecks arise: one refers to engineers; the second to O&M and site-management activities. In turn, wind-energy promoters require more project managers than are available. These are the professionals responsible for getting the permits in the country where the wind farm is going to be installed. It requires a combination of specific knowledge of the country and wind-energy expertise that is difficult to get. The bulk of European wind-energy employment is located in Denmark, Germany and Spain. Germany is where more wind-related jobs have been created: about 32,000 directly attributable to wind-energy companies and a similar amount from indirect effects. By the end of 2007, 22,247MW were operational in the country, giving a ratio of 2.8 jobs/MW installed. In Spain, direct employment accounts for more than 16,000 people. When indirect jobs are taken into account, the figure goes up to 54,000. The corresponding ratio is 3.56 jobs/MW. Denmark has over 21,000 employees in the wind-energy sector. This figure may seem high when compared with capacity installed in the country (3125MW in December 2007). In this case, the early adoption of the technology, which has allowed the country to become a world leader in wind energy products, explains the high number of jobs stemming from the sector. The ratio is 6.72 jobs/MW. Other countries where wind-energy activities have a noticeable impact on direct employment are Belgium, Italy, France and the Netherlands, with about 2000 jobs each. In the UK, the figure can be estimated at more than double that. Overall, the European wind-energy sector is responsible for more than 160,000 jobs, approximately half of which are direct positions.

Future employment trends

The 20 per cent renewable-energy target set out in the 2009 EU Renewable Energy Directive will accelerate renewable-energy deployment and, hopefully, open up investment opportunities in countries which, until now, have remained relatively sceptical to the new energy technologies.

According to the European Wind Energy Association (EWEA), the wind-energy sector will account for around 182,000 jobs in 2010 (direct and indirect). By 2020, the total is expected to rise to 446,000 jobs. An EC-supported MITRE study also addressed future job growth in the wind-energy sector. Using two scenarios to estimate new jobs created in the European wind industry, the MITRE study showed there could be up to 282,000 additional jobs by 2010 and up to 368,000 by 2020.

The grid: Wind-energy penetration and integration

Large-scale integration of wind energy has to be seen in the perspective that wind is going to provide a substantial portion of the European electricity demand. Where wind energy covered about 4.1 per cent of the electricity demand in 2008, the EWEA targets for 2020 and 2030 correspond to penetration levels of up to 17 per cent and up to 34.7 per cent respectively. The present levels of wind power connected to electricity systems show it is feasible to integrate wind power to a significant extent. The experience with 65GW wind power installed in Europe shows where areas of high-, medium- and low-penetration levels in different conditions take place and which bottlenecks and challenges occur. Large-scale integration of both onshore and offshore wind raises challenges for the various stakeholders involved, from generation, through transmission and distribution, to power trading and consumers. In order to integrate wind power successfully, a number of issues have to be addressed: design and operation of the power system; grid infrastructure and connection issues; market redesign issues; and institutional issues. Wind energy is a technology of variable output and needs to be considered as one aspect of a variable, dynamic electricity system. The term 'wind-power penetration' indicates the fraction of the gross (annual) electricity consumption that is covered by wind energy. At modest penetration levels, the variability of wind is dwarfed by the normal variations of the load. Wind cannot be analysed in isolation from the other parts of the electricity system. The size and flexibility of the power system are crucial aspects determining the system's capability of accommodating a high amount of wind power.

The variability of the wind-energy resource needs to be examined in the wider context of the power system, rather than at the individual wind-farm or wind-turbine level. The wind does not blow continuously at a particular site, yet there is little overall impact if the wind stops blowing somewhere – it is always blowing somewhere else. It is important to note that wind-power is not the only energy resource responsible for necessary grid upgrades. Indeed, there needs to be a real, free market for electricity and the corresponding infrastructure to handle physical trading.

The impacts of wind power in the electricity system are very much dependent on the level of wind-power penetration, the size of the grid and the generation mix of electricity in the system.

In order to integrate wind power efficiently at higher levels of penetration, and more generally adapt to the new context of variable supply and storage capabilities, changes

Figure 5.9 Wind cannot be analysed in isolation from rest of the power system.
Source: EWEA/Winter (2008)

are necessary in the methods of operating various parts of the power system, such as generators and transmission systems. Electricity networks can be split into two major subsections: the transmission network and the distribution network. The transmission network consists of high-voltage power lines designed to transfer bulk power from major generators to areas of demand. In general, the higher the voltage the larger the transfer capacity. Only the very largest customers are connected to the transmission network. Distribution networks are usually below 100kV and their purpose is to distribute power from the transmission network to the customers. At present, little generation is connected to distribution networks, but it is growing rapidly. Market conditions, technology and the environment create fundamental changes and challenges for European transmission and distribution networks. One of the major drivers is the emerging internal electricity market in Europe, which requires an adequate transportation capacity between regions and member states to enable effective competition and trade. Therefore, enhancing the grid's suitability for increased transnational electricity transportation is in the interests of both the wind industry and the internal electricity market. In addition, the specific nature of RES, including wind energy, as distributed and variable output-generation sources, require specific infrastructure investments and the implementation of new technology and grid-management concepts. In the case of wind power, transportation of substantial amounts of power from offshore wind farms to load centres necessitates the development of Europe-wide offshore grids and possibly trans-European overlay grids. Compared to onshore facilities, offshore wind farms will have large power capacities with sizes comparable to conventional power plants. Modern transmission technologies operating at high and extra-high voltage levels will be required in order to transmit large levels of power over longer distances. Introducing significant amounts of power from RES, including wind, into the electrical system entails a series of economic impacts. Looking at the power-system level, two main factors determine the integration costs: balancing needs and grid infrastructure. The additional balancing cost in a power system arises from the inherent variable nature of power flows generated by renewable sources, requiring changes in the configuration, scheduling and operation of other generators to deal with unpredicted deviations between supply and demand. There is sufficient evidence available from national studies to make a good estimate of such costs. In the case of wind energy, they are fairly low in comparison with the generation costs and with the overall balancing costs of the power system. Network upgrade costs are necessary for a number of reasons. Additional transmission lines and capacity need to be provided to reach and connect present and future wind-farm sites and to transport power flows in the transmission and distribution networks. These flows result both from an increasing demand and trade of electricity and from the rise of variable energy supply. There is no doubt that the transmission and distribution infrastructure will have to be extended and reinforced in most of the EU countries when large amounts of wind power are connected. While the present grid system is not yet used to its full capacity, the need for extending and reinforcing the existing grid infrastructure is critical. Changes in generation and load at one point in the grid can cause changes throughout the system, which may lead to power congestion. In the context of a strategic EU-wide policy for long-term, large-scale grid integration, a fundamental ownership unbundling between generation and transmission is indispensable. A proper definition of the interfaces between the wind-power plant itself (including the 'internal grid' and the corresponding electrical equipment) and the 'external' grid infrastructure (new grid connection and extension/reinforcement of the existing grid) needs to be discussed, especially for remote wind farms and offshore wind energy. This does not necessarily mean that the additional grid-tariff components, due to wind power connection and grid extension/reinforcement, must be paid by local/regional customers only. These costs should be socialized within a 'grid-infrastructure' component at national, or even EU, level. Of course, appropriate accounting rules would need to be established for grid operators.

Policy instruments to support the technology

All power producers would like to have a long-term power purchasing agreement, which guarantees the ability to sell the electricity produced at a certain price, either fixed or within an agreed band. For a capital-intensive industry like the wind industry it becomes fundamental.

Many countries have implemented legal frameworks with support mechanisms that create the necessary framework to attract investments in renewable energy technologies, including wind power. This is done by either price-driven mechanisms (feed-in, premium systems) or quantity-driven measures (green certificates). There are other options, such as tenders (used in the past in three EU member states) and fiscal incentives (currently applied in two Nordic countries and as a supplementary instrument in others), which are variations of a feed-in or quota system.

Figure 5.10 A high speed train rushing past wind turbines in France.
Source: EWEA/Malbete

Price-based schemes

In its classic form, the scheme awards priority access to electricity produced from RES, which is paid at a fixed price that is guaranteed over a specified period of time, or until a certain number of kWh have been traded. In certain countries (Spain, Netherlands, Denmark and the Czech Republic) instead of a fixed price, the government puts a cap and a floor above and below the electricity price. The feed-in or premium is periodically updated, so that it can be adjusted to reflect market trends and cost evolution. This system has numerous variants depending on the country, including tariffs that decrease annually, differentiated tariffs depending on the size of the project, wind speed and season. From the investor's point of view, price-based schemes are highly favourable as they entail low risk, even if the margin is smaller than with other options. The main problem arises when legislation unexpectedly changes or when the tariffs are not adjusted to take into account variations in the generation costs. Still, it is the most common mechanism: 18 out of 27 member states currently have a price-based scheme, which covers most of the capacity installed in Europe. This was the case in the initial stages of the wind-power market, when almost all of the capacity was found in Denmark, Germany and Spain and it is still the case today. In 2004, 83 per cent of new wind capacity was installed in countries with feed-in or premium systems; 87 per cent in 2005. Concerning the price per kWh, there is a range of values, but the European Commission has identified, in a report issued in 2008 (EC, EC Staff Working Document on The support of electricity from renewable energy sources COM (2008) 19 final), that the support level in countries with feed-in/premiums is lower than in countries with green certificates (see below). This is naturally linked to the different risk levels faced by the investor.

Quantity-based market schemes

These are based on a mechanism whereby governments require an increasing share of the electricity supply to be based on RES. The obligation is usually directed to electricity suppliers and accompanied by a penalty system in the case of non-compliance.

Electricity customers finance the schemes (like in a price-based mechanism), since they generally absorb the additional costs from suppliers. Under this system, wind project developers are paid a variable premium above the market price of electricity. In reality, wind turbines produce two things: electricity, which is sold in electricity markets, and green certificates, which are sold in a market for fulfilling the political obligation to supply renewable energy. The green certificates are currently applied in Belgium, Italy, Poland, Sweden and the UK. While theoretically attractive, they face a risk that can be substantially higher than in the case of feed-in or premium systems, because the certificate prices are not guaranteed and may demonstrate significant volatility, especially in the initial stages of the market. These facts were recently highlighted by the Commission staff working document 'The support of electricity from renewable energy sources' in which it asserts that 'quota systems achieve a rather low effectiveness at comparably higher profit margins. It should be mentioned that quota systems are relatively new instruments, and there is at present little knowledge of how certificate prices will develop over time.'

More generally, the stability of the legal framework is crucial. Countries where the support mechanisms vary frequently, will be less attractive to developers and thus will require higher risk premiums.

In the same way, the establishment of RES-E targets can help reduce the perceived risk to the investor and thus the price of wind electricity, as they constitute a signal of political willingness.

Key countries and success stories

It is now apparent that over the last 25 years wind energy in Europe has been a highly successful venture for companies associated with the industry, for politicians wanting to introduce a larger portion of RES into the pan-European energy portfolio and for the beleaguered environment. Of all the 27 EU nations, Germany and Spain were clearly the leaders in total installed capacity at the end of 2008. Germany's total reached 29,903MW while Spain had 16,740MW. Four other countries each had a total of more than 3000MW: Denmark (3180MW), Italy (3736MW), France (3404MW) and the UK (3241MW).

TOMORROW

Technology targets by 2020 and beyond

EWEA predicts there will be 80GW of installed capacity in the EU by 2010, with 3.5GW offshore.

Much of the development over the coming two decades depends on the evolution of the offshore market, over which there is currently some uncertainty. EWEA's targets are 230GW in 2020 and 400GW in 2030.

Summary of the wind energy market in the EU-27 in 2008:

- 56GW installed capacity, including 1.08GW offshore;
- 65GW installed capacity: 63.5GW onshore and 1.5GW offshore
- Annual installations of 8.5GW: 8.1GW onshore (95 per cent) and 0.4GW offshore (5 per cent)
- Annual investments of €11 billion: €10.1 onshore and €0.9 billion offshore
- Meeting 4 per cent of EU electricity demand

- 36 per cent of all new electricity generating capacity in the EU (Total 2008: 23.9GW)
- 8 per cent of total electricity generating capacity in the EU (Total end 2008: 801GW)
- Producing 137TWh: 132TWh onshore and 5TWh offshore, equivalent to the consumption of 34 million average EU households
- Avoiding 91Mt CO_2 annually, equal to 27 per cent of the EU-15's Kyoto obligation
- Avoiding €2.3 billion[7] of CO_2 cost annually
- Avoided fuel cost of €6.5 billion.

Summary of the wind industry target for the EU-27 in 2020:

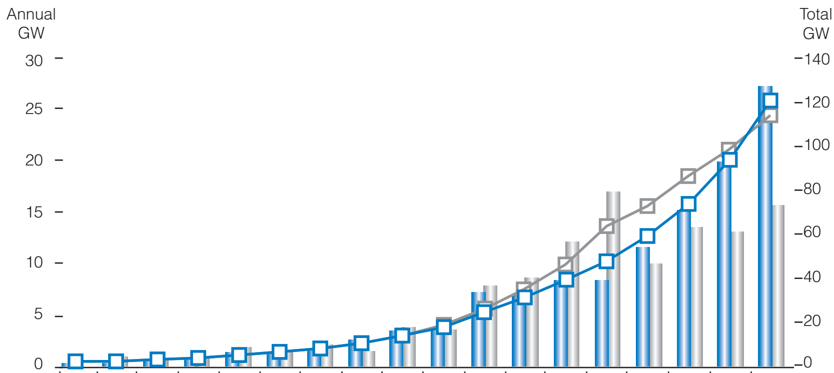
- Summary of wind energy in 2020, according to EWEA 2008 targets
- 230GW installed capacity: 190GW onshore and 40GW offshore
- Annual installations of 24.8GW: 17.9 GW (72 per cent) onshore and 6.9GW offshore (28 per cent)
- Annual investments of €23.5 billion: €14.7 onshore and €8.8 billion offshore
- Meeting 14–17 per cent of EU electricity demand depending on total demand
- 24 per cent of total electricity generating capacity in the EU (Total end 2020: 951GW)
- Producing 582TWh of electricity: 433TWh onshore and 148TWh offshore, equivalent to the consumption of 131 million average EU households
- Avoiding 333Mt CO_2 annually
- Avoided fuel cost of €28 billion (assuming IEA forecast18: fuel cost equivalent to $110/bbl of oil)
- Avoiding €8.3 billion of CO_2 cost annually (assuming €25/t CO_2).

Summary of the wind industry target in EU-27 in 2030:

- 400GW installed capacity: 150GW onshore and 250GW offshore
- Annual installations of 24.2GW: 10.5GW onshore (43 per cent) and 13.7GW offshore (57 per cent)
- Annual investments of €24.8 billion: €8.3 onshore and €16.5 billion offshore
- Meeting 26-34.7 per cent of EU electricity demand depending on total demand
- 38 per cent of total electricity generating capacity in the EU (Total end 2030: 1,061GW)
- Producing 1155TWh of electricity: 592TWh onshore and 563TWh offshore, equivalent to the consumption of 241 million average EU households
- Avoiding 600Mt CO_2 annually
- Avoided fuel cost of €56 billion (assuming IEA forecast: fuel cost equivalent to $122/bbl of oil)
- Avoiding €15 billion of CO_2 cost annually (assuming €25/t CO_2)

Technological long term potential

The wind industry has experienced dramatic growth over the last few years and the development of wind power is no different from the initial development stages of other power sources. Figure 5.11 shows the global development of wind energy (1991–2008) compared with nuclear power (1961–1978).



	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1979
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Annual Wind GW	0.2	0.3	0.5	0.7	1.3	1.3	1.5	2.5	3.4	3.8	7.1	6.9	8.3	8.3	11.5	15.1	19.8	27.1
Annual Nuclear GW	0.0	0.9	0.5	1.0	1.7	1.4	2.1	1.1	3.7	3.5	7.8	8.5	12.0	16.9	9.8	13.5	12.9	15.5
Total Wind GW	2.0	2.3	2.8	3.5	4.8	6.1	7.6	10.2	13.6	17.4	24.4	31.2	39.4	47.6	59.1	74.1	93.8	120.8
Total Nuclear GW	2.9	1.8	2.3	3.2	4.0	6.3	83	0.3	13.0	19.0	26.6	35.3	46.0	64.3	72.7	36.2	98.7	114.2

Figure 5.11 18 years of global wind energy development 1991–2008 compared to the first 18 years of nuclear development
Source: IAEA, EWEA (2009c)

The EC[8] expects a 76 per cent decline in EU oil production between 2000 and 2030. Gas production will fall by 59 per cent and coal by 41 per cent. By 2030, the EU will be importing 95 per cent of its oil, 84 per cent of its gas and 63 per cent of its coal. Europe can go a long way towards an energy supply that is superior to the BAU scenario, offering greater energy independence, lower energy costs, reduced fuel-price risk, improving competitiveness and exporting more technology. Over the coming 25 years, wind energy can play a major role in that development.

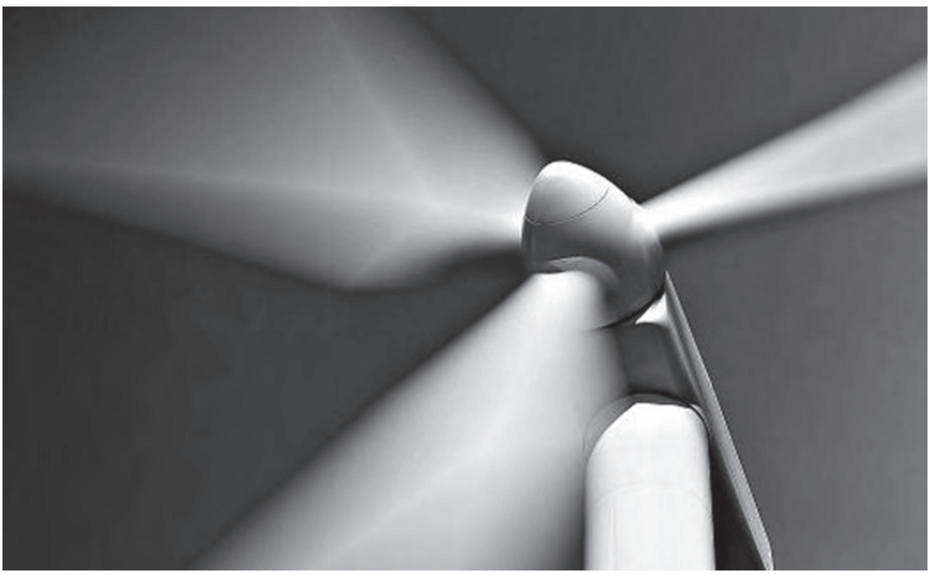


Figure 5.12 Leeming
Source: EWEA/Leeming

NOTES

1 For updates on EWEA statistics please visit www.ewea.org.
2 Available at www.windpower.org (Danish Wind Industry Association, 2008).
3 'Ex works' means that no site work, foundation, or grid connection costs are included. Ex works costs include the turbine as provided by the manufacturer, including the turbine itself, blades, tower and transport to the site.
4 In the figure the number of full load hours is used to represent the wind regime. Full load hours are calculated as the turbine's average annual production divided by its rated power. The higher the number of full load hours, the higher the wind turbine's production at the chosen site.
5 European Commission (2006) 'Renewable Energy Roadmap, COM(2006)848 final', Brussels.
6 European Commission (2006) 'Renewable Energy Roadmap – Impact Assessment', Brussels. SEC (2006)1720.
7 BTM World Market Update 2006, March 2007.
8 European Energy and Transport; Trends to 2030 – update 2007: European Commission May 2008.

6

Photovoltaic

The sun: an energy available for free which can be used in many ways.

There is more than enough solar radiation available around the world to satisfy the demand for solar power systems. The proportion of the sun's rays that reaches the earth's surface can satisfy global energy consumption 10,000 times over.

PHOTOVOLTAIC EFFECT

'Photovoltaic' is a marriage of two words: 'photo' from Greek roots, meaning light and 'voltaic', from 'volt', which is the unit used to measure electric potential at a given point. Photovoltaic (PV) systems use cells to convert solar radiation into electricity. The cell consists of one or two layers of a semi-conducting material. When light shines on the cell it creates an electric field across the layers, causing electricity to flow. The greater the intensity of the light, the greater the flow of electricity is. The most common semi-conductor material used in photovoltaic cells is silicon, an element most commonly found in sand. There is no limitation to its availability as a raw material; silicon is the second most abundant material in the earth's mass. A photovoltaic system therefore does not need bright sunlight in order to operate, it can also generate electricity on cloudy days.

Overview of available photovoltaic technologies

Crystalline silicon cells are made from thin slices cut from a single crystal of silicon (monocrystalline) or from a block of silicon crystals (polycrystalline); their efficiency ranges between 12 per cent and 19 per cent. Thin film modules are constructed by depositing extremely thin layers of photosensitive materials on to a low-cost backing such as glass, stainless steel or plastic. Thin film manufacturing processes result in lower production costs compared to the more material intensive crystalline technology, a price advantage which is currently counterbalanced by substantially lower efficiency rates (from 5 per cent to 13 per cent). Four types of thin film modules (depending on the active material used) are commercially available at the moment:

- Amorphous silicon (a-Si);
- Cadmium telluride (CdTe);
- Copper Indium/gallium, Diselenide/disulphide (CIS, CIGS);
- Multi junction cells (a-Si/m-Si).

Several other types of photovoltaic technologies have been developed, some starting to be commercialized and others still at the research level:

- Some solar cells are designed to operate with concentrated sunlight. These cells are built into concentrating collectors that use a lens to focus the sunlight on to the cells. The main idea is to use very little of the expensive semiconducting PV material while collecting as much sunlight as possible. Efficiencies are in the range of 20 to 30 per cent
- Based on a similar production process to thin film cells, when the active material is deposited in a thin plastic, the cell can be flexible. This opens the range of applications, especially for building integration (roof-tiles) and end-consumer applications.

STATE-OF-THE-ART TECHNOLOGY

Technological benefits

PV power systems offer many unique benefits above and beyond simple energy delivery. PV also brings important social benefits in terms of job creation, energy independence and rural development. Here below we provide a brief description of these 'solar benefits'.

PV fuel is free. The sun is the only resource needed to power solar panels. And the sun will keep shining until the world's end. Also, most photovoltaic cells are made from silicon and silicon is an abundant and non-toxic element (the second most abundant material in the earth's mass).

PV produces no noise, harmful emissions or polluting gases. The burning of natural resources for energy can create smoke, cause acid rain, pollute water and pollute the air. CO_2, a leading greenhouse gas, is also produced. Solar power uses only the power of the sun as its fuel. It creates no harmful by-products and actively contributes in reducing global warming.

PV systems are extremely safe and highly reliable. The estimated lifetime of a PV module is 30 years. Furthermore, the module's performance is very high, providing over 80 per cent of the initial power after 25 years, which makes photovoltaics a very reliable technology in the long-term. In addition, very high quality standards are set at the European level which guarantees that consumers buy reliable products.

PV modules can be recycled and therefore the materials used in the production process (silicon, glass, aluminium, etc.) can be reused. Recycling is not only beneficial for the environment but also for helping to reduce the energy needed to produce those materials and therefore the cost of fabrication.[1]

PV requires virtually no maintenance. Solar modules are almost maintenance-free and offer easy installation.

PV brings electricity to remote rural areas. Solar systems give an added value to rural areas (especially in developing countries where electricity is not available). House lighting, hospital refrigeration systems and water pumping are some of the many applications for off-grid systems.

Telecommunication systems in remote areas are also well-known users of PV systems.

PV will be a key component of future positive energy buildings. Systems can cover roofs and facades, contributing to a reduction in energy that buildings consume. They do not produce noise and can be integrated in very aesthetic ways. European building legislations have been and still are being reviewed to make renewable energies a required energy source in public and residential buildings. This fact is accelerating the development of eco-buildings and positive energy buildings (E+ Buildings) which opens up many opportunities for a better integration of PV systems in the built environment.[2]

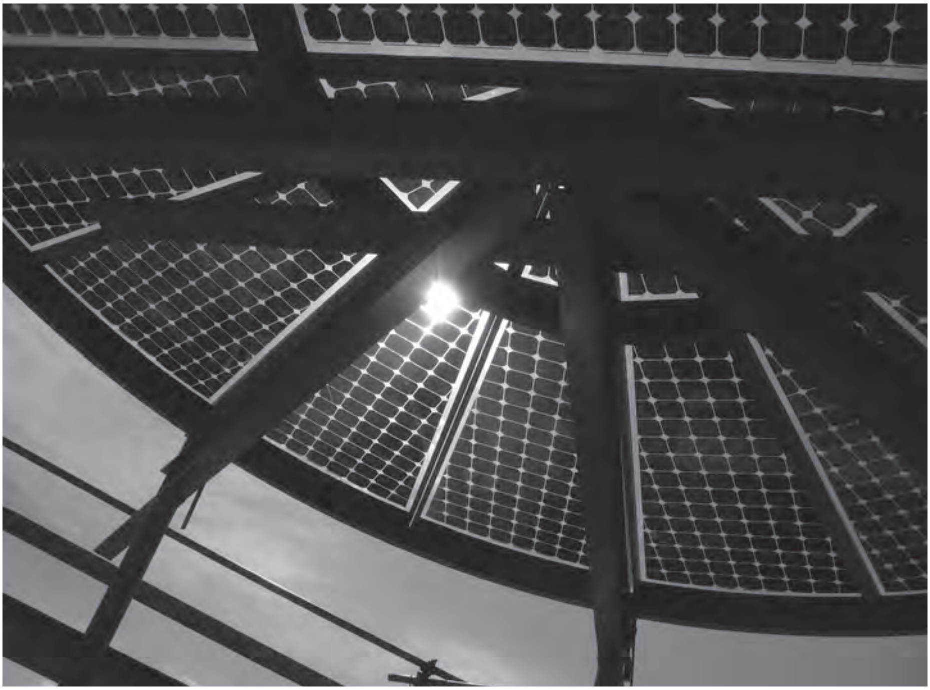


Figure 6.1 Båstad Hotel, Båstad, Sweden
Source: www.ertex-solar.at

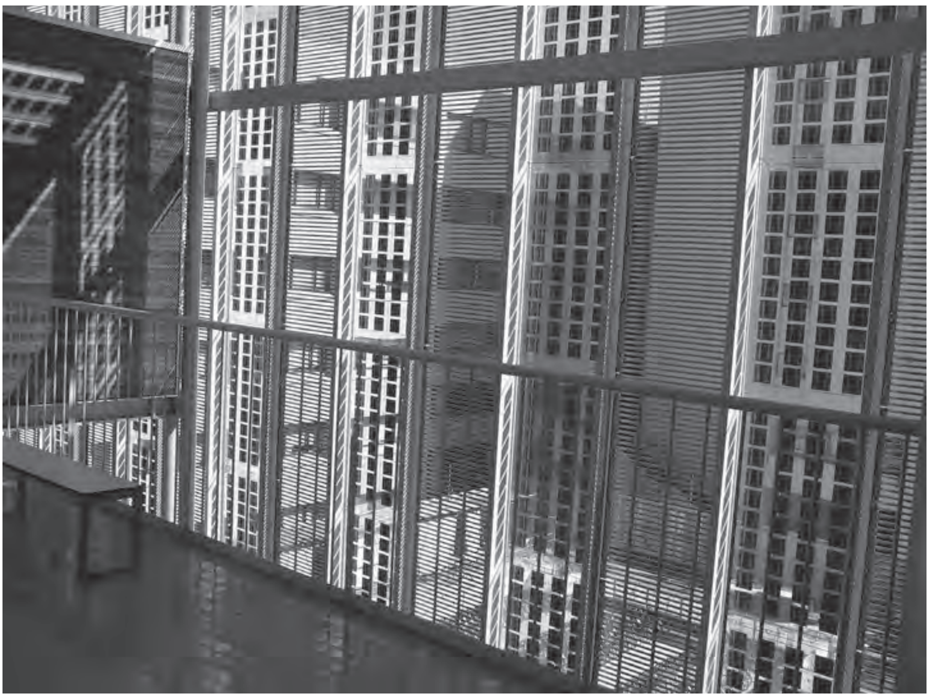


Figure 6.2 Daito Bunka University, Tokyo, Japan
Source: Dr Ingo B. Hagemann[3]

PV energy pay-back time is short and constantly decreasing. This means that the time required for a PV module to produce as much energy as it would need to be manufactured is very short, varying between one-and-a-half to three years.[4] A module, therefore, produces six to 18 times more energy than is needed to manufacture it.

PV creates thousands of local jobs. The PV sector, with an average annual growth of 40 per cent over the past few years, is increasingly contributing to the creation of thousands of jobs in Europe and worldwide.

PV contributes to improving the security of Europe's energy supply. In order to cover 100 per cent of the annual electricity demand in Europe, around 2 per cent of the total land of Europe would need to be covered by PV modules. Therefore, photovoltaics can play an important role in improving the security of Europe's energy supply.

Technological applications

Grid-connected domestic systems

This is the most popular type of solar PV system for homes and businesses in developed areas. Connection to the local electricity network allows any excess power produced to feed the electricity grid and to sell it to the utility. Electricity is then imported from the

Figure 6.3 Herne Hill school, UK
Source: www.solarcentury.com

network when there is no sun. An inverter is used to convert the direct current (DC) power produced by the system to an alternative current (AC) power for running normal electrical equipment.

Figure 6.4 shows how electricity generated by solar cells in roof-mounted PV modules is transformed by an inverter into AC power suitable for export to the grid network. The householder/generator then has two choices: either to sell all the output to the local power utility (if a feed-in tariff is available) or to use the solar electricity to meet demand in the house itself and then sell any surplus to the utility.

Grid-connected power plants

These systems, also grid-connected, produce large quantities of photovoltaic electricity in a single point. The size of these power plants ranges from several hundred kilowatts to several megawatts. Some of these applications are located on large industrial buildings such as airport terminals or railway stations. This type of large application makes use of already available space to produce onsite electricity and compensates a part of the electricity needs of these energy-intensive consumers.

Off-grid systems for rural electrification

Where no mains electricity is available, the system is connected to a battery via a charge controller. An inverter can be used to provide AC power, enabling the use of standard electrical appliances. Typical off-grid applications are used to bring access to electricity to remote areas (mountain huts, developing countries). Rural electrification means either a small solar home system covering basic electricity needs in a single household, or larger solar mini-grids, which provide enough power for several homes.[5]

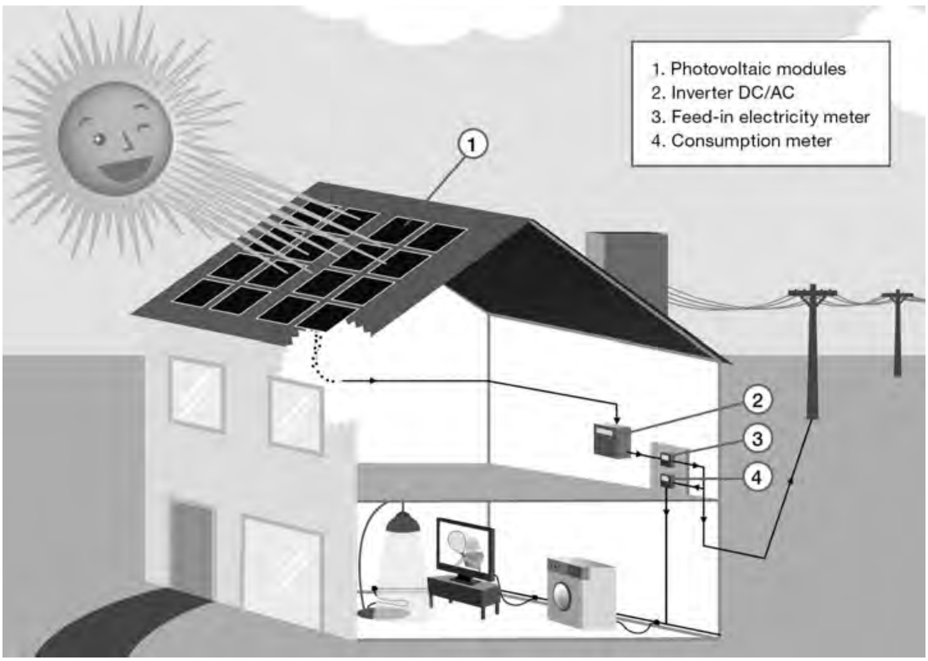


Figure 6.4 How a grid connected domestic system works
Source: EPIA (2008b)

Figure 6.5 Lehrter Bahnhof, Berlin
Source: www.scheutensolar.com

Hybrid systems

A solar system can be combined with another source of power – a biomass generator, a wind turbine or diesel generator – to ensure a consistent supply of electricity. A hybrid system can be grid-connected, stand-alone or grid-support.[6]

Consumer goods

Photovoltaic cells are used in many daily electrical appliances, including watches, calculators, toys, battery chargers, professional sun roofs for automobiles.

Off-grid industrial applications

Uses for solar electricity for remote applications are very frequent in the telecommunications field, especially to link remote rural areas to the rest of the country. Repeater stations for mobile telephones powered by PV or hybrid systems also have a large potential. Other applications include traffic signals, marine navigation aids, security phones, remote lighting, highway signs and waste water treatment plants. These applications are cost competitive today as they enable power to be brought to areas far from electricity mains, avoiding the high cost of installing cabled networks.

Cost and prices

One of the main arguments heard from critics of solar electricity is that its costs are not yet competitive with those of conventional power sources. This is partly true. However, in assessing the competitiveness of photovoltaic power, a number of considerations should be taken into account: the type of PV application (grid-connected, off-grid or consumer goods), what exactly is PV competing with, what are the alternatives and the geographical location, the initial investment costs and expected lifetime of the system. Moreover, the real generation cost should be considered, bearing in mind that conventional sources are heavily subsidized and their 'external' costs, from pollution and other effects, are not accounted for. A lot of progresses have been made in order to reduce the cost of PV modules.

Competitiveness of consumer applications

PV consumer applications do not receive any subsidies and have been on the market for a long time. They have therefore already proved their competitiveness. Consumer applications not only provide improved convenience but they also often replace environmentally hazardous batteries.

Competitiveness of off-grid applications

Off-grid applications are mostly already cost competitive compared to alternative options. PV is generally competing with diesel generators or the potential extension of the public electricity grid. The fuel costs for diesel generators are high, whilst solar energy's 'fuel' is both free and inexhaustible. The high investment costs of installing renewable energy systems are often inappropriately compared to those of conventional energy technologies. In fact, particularly in remote locations, a combination of low operation and maintenance costs, absence of fuel expenses, increased reliability and longer operating lifetimes are all factors which offset initial investment costs. This kind of lifecycle accounting is not regularly used as a basis for comparison. The other main alternative for rural electrification, the extension of the electricity grid, requires a considerable investment. Off-grid applications are, therefore, often the most suitable option for supplying electricity in dispersed communities or at great distances from the grid. However, although lifetime operating costs are much lower for off-grid PV than for other energy sources, initial investment costs can still be a barrier for people with little disposable income.

Competitiveness of grid-connected applications

Grid-connected applications, currently the biggest market segment, are expected to remain so for the foreseeable future. The generation costs of household PV systems are in most cases not yet competitive with residential electricity prices. Electricity prices vary greatly even within the 27 EU countries with 2007 residential prices ranging, according to Eurostat, between 7 and 26c€/kWh (including all taxes). The most recent trend has also been a steady increase. From 2005 to 2007, electricity prices in the EU-27 increased by an average of 16 per cent. At the same time, PV generation costs have been decreasing, a trend expected to accelerate over the coming years. The simplest way to calculate the cost per kWh is to divide the price of the PV system by the number of kWh the system will generate over its lifetime. However, other variables such as financing costs have to be taken into consideration. Table 6.1 includes financing costs (at a 5 per cent interest rate) and a lifetime of 25 years, which is the performance warranty period of many module producers. The figures are based on the expected system prices under the Advanced Scenario (EPIA/Greenpeace, 2008), where strong industrial growth is expected to drive down prices.

The figures in Table 6.1 give PV generation costs for small distributed systems in some of the major cities of the world. They show that by 2020 the cost of solar electricity will have more than halved. This would make it competitive with typical electricity prices paid by end consumer households. One reason is that, whilst PV generation costs are consistently decreasing, general electricity prices are expected to increase. As soon as PV generation costs and residential electricity prices meet, 'Grid

Table 6.1 Expected PV generation costs for roof-top systems at different locations

	Sunshine hours	2007	2010	2020	2030
Berlin	900	€0.44	€0.35	€0.20	€0.13
Paris	1000	€0.39	€0.31	€0.18	€0.12
Washington	1200	€0.33	€0.26	€0.15	€0.10
Hong Kong	1300	€0.30	€0.24	€0.14	€0.09
Sydney/Buenos Aires/ Bombay/Madrid	1400	€0.28	€0.22	€0.13	€0.08
Bangkok	1600	€0.25	€0.20	€0.11	€0.07
Los Angeles/Dubai	1800	€0.22	€0.17	€0.10	€0.07

Source: EPIA/Greenpeace (2008b)

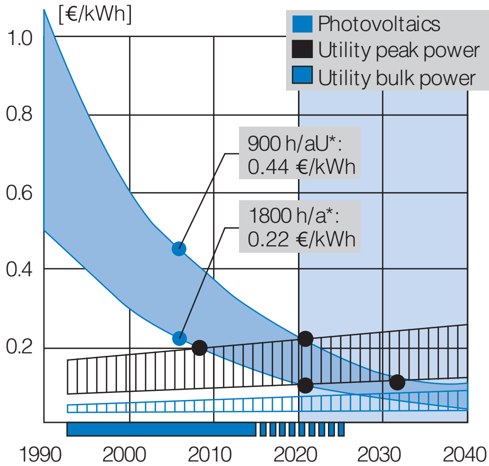
Parity' is achieved. With Grid Parity, every kWh of PV power consumed will save money in comparison to the more expensive power from the grid. EPIA expects that Grid Parity will be probably reached in Italy between 2010 and 2012 where both irradiation and residential electricity prices are high. Grid Parity is then expected to spread steadily towards other countries. Figure 6.6 shows the historical and expected future development of solar electricity costs. The falling curves show the reduction in costs in the geographical area between central Europe, for example northern Germany (upper curve) and the very south of Europe (lower curve). In contrast to the falling costs for solar electricity, the price for conventional electricity is expected to rise. The utility prices for electricity need to be divided into peak power prices (usually applicable around the middle of the day) and bulk power.

Large-scale PV systems are not in competition with residential electricity prices. In the long term, as the costs of PV components decrease, these systems will be able to compete with the generation costs of conventional fossil fuel or nuclear power plants. Large systems also have the advantage that bulk buying of PV modules and other system inputs lowers the price per kW considerably compared to rooftop systems. In some countries with a more liberalized power supply market, electricity prices are more responsive to demand peaks. In California or Japan, for example, electricity prices increase substantially during daytime, especially in the summer, as demand for electricity is highest during that period. Daytime, particularly in the summer, is also the period when the electricity output of PV systems is at its highest. PV therefore serves the market at exactly the point when demand is greatest. During peak times, PV is already competitive in those markets. In many countries, conventional electricity sources such as nuclear power, coal or gas have been heavily subsidized for many years. The financial support (e.g. feed-in tariff) for renewable energy sources such as PV, offered until competitiveness is reached, should therefore be seen as a compensation for the subsidies that have been paid to conventional sources over the past decades.

MARKET

Installed capacity and market development in the EU and market segments

Solar power is booming. By the end of 2008, the cumulative PV power installed of all PV systems around the world had surpassed 14,730MW. This compares with a figure of 962MW in 1998. Installations of PV cells and modules around the world have been growing at an average annual rate of more than 40 per cent since 1998. The market



*h/a: Hours of sun per annum
900 h/a corresponds to northern countries of Europe
1800 h/a corresponds to southern countries of Europe

Note: The blue band indicates that market support programmes will be necessary until about 2020 in some markets.

Figure 6.6 Development of electricity prices and PV generation costs
Source: EPIA/Greenpeace (2008)

value of the solar PV market reached an annual €20–€25 billion in 2008. Competition among the major manufacturers has become increasingly intense, with new players entering the market as the potential for PV opens up.

In 2008, with more than 5.6GWp, the global PV market had more than doubled compared to 2.4GWp in 2007. This impressive progression in 2008 is mainly due to the development of the Spanish market which almost quintupled in one year from 560MWp in 2007 to more than 2511MWp in 2008, representing more than 45 per cent of the global PV market. Besides the development in Spain, other countries continued their progression in 2008. Germany installed around 1.5GWp, the US 342MWp and 230MWp were connected in Japan. Major developments were seen in other countries like Italy (258MWp) and South Korea (274MWp) as well as the emergence of new PV markets such as France (105MWp were installed, 46MW of which were connected in 2008), the Czech Republic (51MWp), Portugal (50MWp) and Belgium (48MWp).

Although growth in recent years has been primarily in the grid-connected sector, the demand side of the international PV market can be clearly divided into four sectors. These market categories, the same as we used before to describe the technology applications and the development of each one, are analysed below.

Goods and services applications

In 2008, this sector accounted for less than 1 per cent of global annual production. As demand for a mobile electricity supply increases, it is likely that the consumer goods market will continue to grow in absolute terms (although its relative share will decrease), especially with the introduction of innovative low-cost solar electricity technologies such as organic solar cells.

Grid-connected systems applications

This market segment is the current motor of the PV boom, with most development taking place in the OECD countries. More and more national governments see PV as

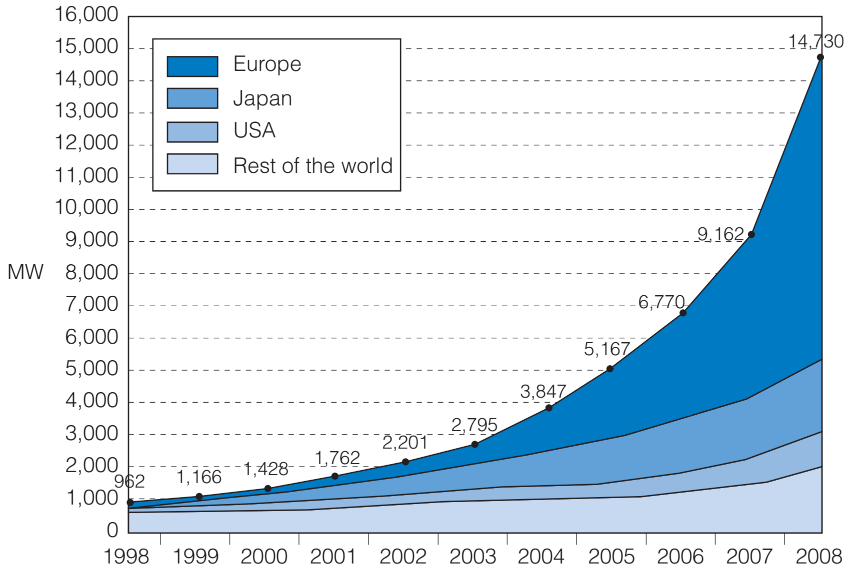
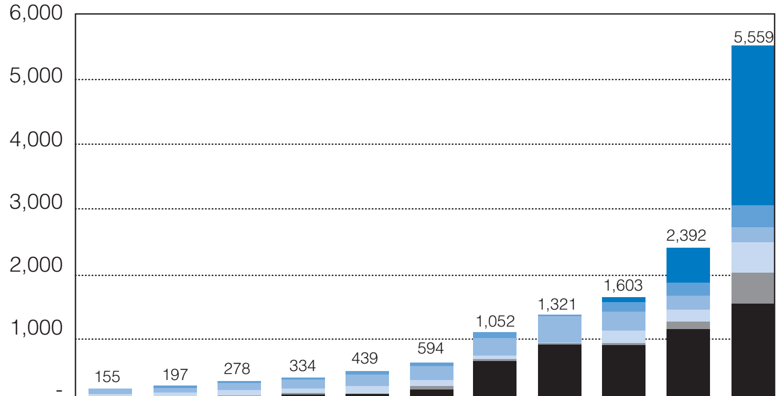


Figure 6.7 Global cumulative PV power installed
Source: EPIA (2009)



MW	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Spain	0	1	-	2	9	10	6	26	88	560	2,511
USA	-	17	22	29	44	63	90	114	145	207	342
Japan	69	72	112	135	185	223	272	290	287	210	230
Rest of the world	68	84	94	75	104	98	53	12	196	207	485
Rest of Europe	8	8	10	16	16	50	30	30	37	108	492
Germany	10	12	40	78	80	150	600	850	850	1,100	1,500
TOTAL	155	197	287	334	493	594	1,052	1,321	1,603	2,392	5,559

Figure 6.8 Regional development of the global annual PV market
Source: EPIA (2009)

an important technology for the future and have already established, or are in the process of establishing, support programmes. Whilst in 1994 only 20 per cent of new PV capacity was grid-connected, this had grown to approximately more than 95 per cent by 2008. A growing number of countries have followed the successful examples of

Germany, Japan and USA, which have all established support programmes for grid connected PV systems. These programmes will continue to provide an impetus for market growth for some years to come – until PV becomes competitive with domestic electricity prices. Another substantial benefit of the grid-connected domestic market is the control which PV systems allow the consumer over their power supply. Not only is electricity generated at the point of demand, avoiding grid losses of electricity, but the consumer is effectively transformed into the operator of his or her own power station. As international power markets steadily liberalize, this is likely to have increasingly important market implications. The full effect will be visible as soon as PV gets close to achieving parity with domestic electricity prices.

Off-grid electrification applications

Apart from its clear social advantages, the economic justification for using PV is through the avoided fuel costs, usually expensive diesel, or by comparison with the cost of extending the grid. For subsistence-level communities the initial stumbling block is often the capital cost of the system. Although numerous rural development programmes have been initiated in developing countries, supported both by multi- and bilateral assistance programmes, the impact has so far been relatively small. However, it is expected that this market segment will capture a substantial part of the global PV market share in the coming decades. In 2008, approximately 2 per cent of global PV installations were dedicated to rural electrification.

Off-grid industrial applications

Apart from avoided fuel costs, for example by totally or partly replacing a diesel engine, industrial PV systems offer high reliability and minimal maintenance. This can dramatically reduce operation and maintenance costs, particularly in very remote or inaccessible locations. The demand for off-grid industrial PV systems is expected to continue to expand over the next decade and beyond, especially in response to the continued growth of the telecommunications industry. Mobile telephone masts and repeater stations offer a particularly large potential, especially in countries with low population densities. Providing communications services to rural areas in developing countries as part of social and economic development packages will also be a major future market opportunity for photovoltaic. About 2 per cent of global PV installations were used for PV off-grid applications in 2008.

Industry

The PV industry is characterized by an impressive growth over the last decade with a Compound Annual Growth Rate (CAGR) of 50 per cent over the period 1999–2008 and rose to an amazing 85 per cent annual growth in 2008 compared to 2007 with around 7.9GW of cell production.

If we look at the regional development over the past three years, we can observe that Japan was cell production leader in 2006 with more than 35 per cent of the global production. In the meantime, the global picture has changed with an extraordinary growth in China with a CAGR over the period 2006–2008 of 160 per cent while Taiwan grew with a CAGR of 132 per cent and Germany 70 per cent over the same period.

At the regional level, 68 per cent of the global solar cell production in 2008 was concentrated in Asia, mainly in China, Japan and Taiwan. Europe comes second with 25 per cent and America accounted for only 5.5 per cent of the global cell production.

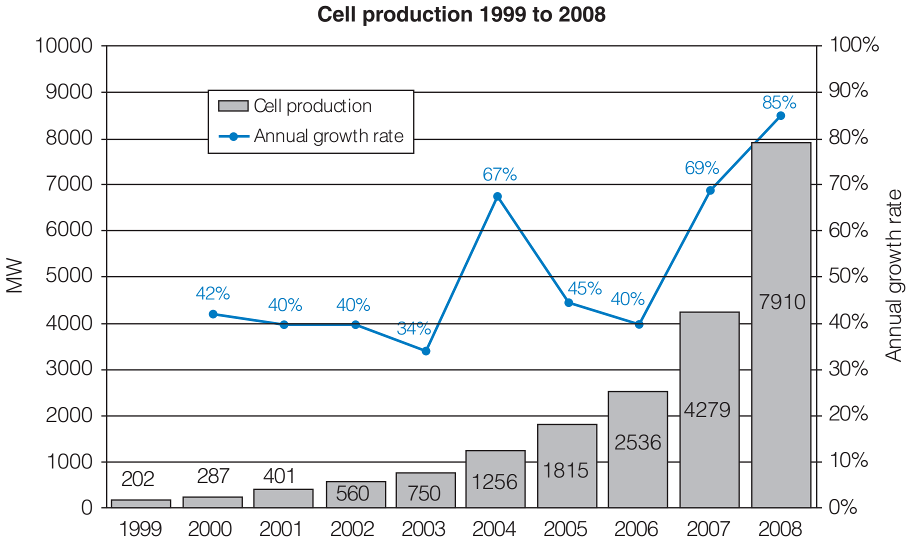


Figure 6.9 Global cell production 1999–2008
Source: EPIA/Photon International (2009)

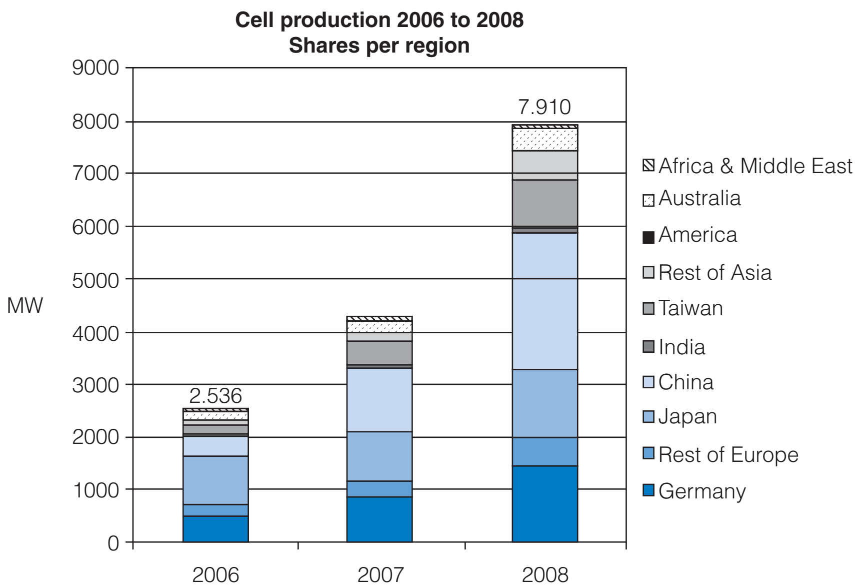


Figure 6.10 Cell production 2006–2008: Shares per region
Source: EPIA/Photon International (2009)

If we look at national level, China was leading the global production with 32.7 per cent, followed by Germany with 18.5 per cent, Japan with 16 per cent and Taiwan with almost 11.6 per cent.

In 2008, the German-based company Q-cells was the world market leader and the only European company in the top ten with a cell production that reached 581.6MW

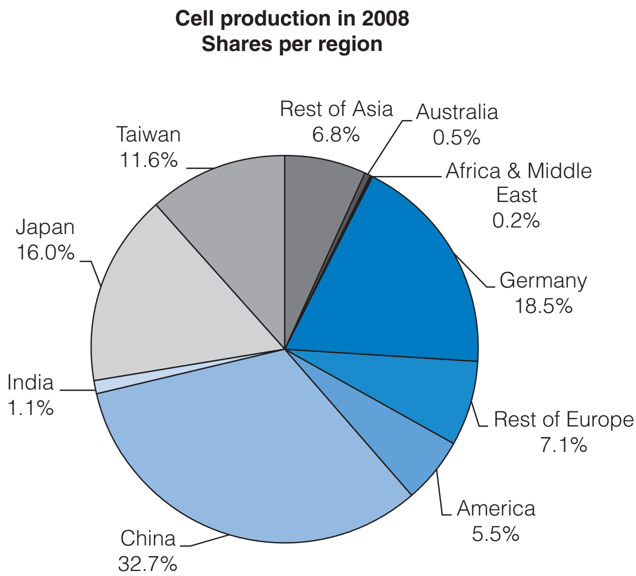


Figure 6.11 Cell production in 2008: Shares per region
Source: EPIA/Photon International (2009)

in 2008 (mainly with wafer silicon based technologies) and 11.6MW from Thin-Film technologies. First Solar was the second world market leader which more than doubled its annual production of Thin-Film modules (cadmium-telluride, CdTe) from 200MW in 2007 to 504MW in 2008 in its different manufacturing plants located in the US, Germany and Malaysia. The third position is held by the China's largest PV company, Suntech, which produced 497.5MW of wafer silicon based solar cells. The last company with a market share higher than 5 per cent in 2008 was Sharp which produced 473MW of wafer-silicon based solar cells, of which a-Si/μ-Si micromorph tandem modules made up an increased share (accounting for 38MW). While there were only a few companies producing solar cells some years ago, there are more than 200 companies producing today, which explains why the share of the top ten countries has declined from 59 per cent in 2006 to 46 per cent in 2008.

An important issue for manufacturers is being able to match the opening of new production capacity with expected demand. Investors need a planning horizon that goes beyond a typical factory's write-off period of five to seven years. Some smaller companies have nonetheless been able to obtain investment from public share ownership, often through one of the increasing number of green investment funds. This is why the relative stability of systems such as the German feed-in tariff has proved crucial to business commitment. In anticipation of a flourishing market, Germany has seen a steady increase in both solar cell and module manufacture from 1995 onwards. Further encouraged by the Renewable Energy Law, annual production of PV cells has increased from 32MW in 2001 to around 1460MW in 2008. The higher up the PV value chain one travels the fewer companies are involved. At the upper end of the chain, silicon production requires substantial know-how and investment, as does the production of wafers. At the level of cell and module producers, on the other hand, where know-how and investment needs are smaller, there are many more players in the market. At the end of the value chain, the installers are often small, locally based businesses.

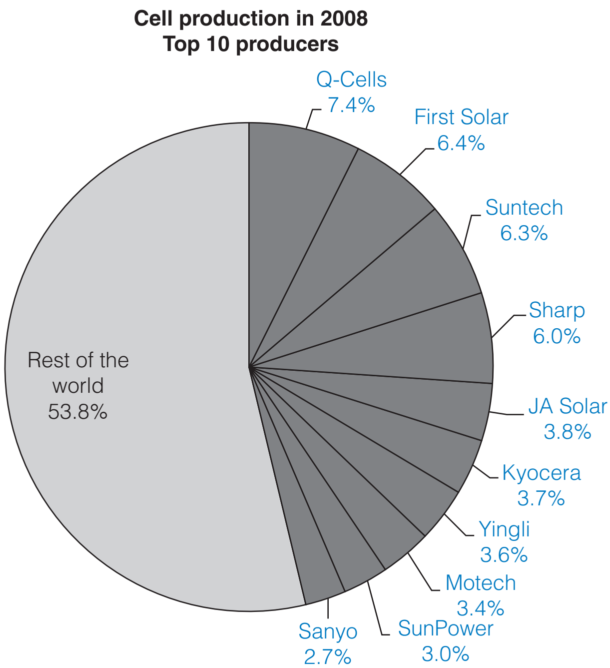


Figure 6.12 Cell production in 2008: Top 10 producers
Source: EPIA/Photon International (2009)

Policy instruments to support the technology

Why support renewable electricity and PV? There is a great need to support renewable electricity in general and Solar Photovoltaic in particular for a number of reasons,. The accumulation of greenhouse gases in the earth's atmosphere is already posing a grave threat to mankind but is expected to get much worse in the coming decades. The global electricity generation portfolio is based on exhaustible and scarce fuels (uranium, gas, coal and petroleum). Global reserves are diminishing fast and fuel prices are increasing drastically, which is seriously damaging the global economy. Therefore even without the problem of climate change, the need for action would nevertheless exist. Vast deployment of renewable electricity is the only answer to increase the security of supply, to ensure EU competitiveness and affordable energy, promote environmental sustainability and to combat climate change. PV is a technology with one of the highest potentials to do all of this. Policy-makers have started to understand the urgency of the situation and several policies to support them are being put in place. This section provides an overview of different support schemes that have been tested over the years at various locations around the world, as well as their characteristics, arguing that a feed-in tariff support scheme is clearly the best solution.

Fixed price systems

Feed-in tariff: in a feed-in tariff scheme, a price for each kWh produced is fixed. The basic idea behind a feed-in tariff is very simple: the producers of solar electricity have the right to feed renewable electricity into the public grid, to receive a tariff per generated kWh, reflecting the benefits of solar electricity compared to electricity generated from fossil fuels or nuclear power and to receive the tariff over a fixed period of time. All three aspects are simple but it took considerable efforts to establish them. For many years, the power utilities did not allow the input of solar electricity into their grid; this continues to be the case in numerous countries to this day.

BOX 6.1 FEED-IN TARIFFS: CORE ELEMENTS

- an efficient tool that has already proved to be successful;
- a temporary mechanism;
- not a burden on taxpayers;
- the driver for further cost reductions and economies of scale;
- ensures high quality PV systems and good performance;
- creates secure conditions for potential investors.

Premium feed-in tariffs: premium feed-in tariffs work similarly to the regular feed-in tariff schemes. The investor is guaranteed to receive a certain price for each kWh produced. However, with a premium feed-in tariff, the tariff consists of two separate payments. The electricity produced is sold to the electricity market at regular market prices. As market prices vary according to demand and supply, any shortfalls are paid to the investor in the form of a premium tariff. In a regular feed-in tariff scheme, investors receive a pre-determined fixed rate.

Investment-based support

Investment subsidies: investment subsidies are a frequently applied form of support for all kinds of goods and services. PV is no exception as grants are a commonly used tool. A specific part of the investment costs (usually a fixed amount per kWp rather than a relative share) is covered by a funding institution. The subsidy is dependent on the rated power capacity (kWp) and not on the annual electricity production (kWh). Compared to other support schemes which focus on annual electricity production, investment grants do not sufficiently motivate investors to invest in highly efficient PV systems.

Tax credits: tax credits are another investment-focused support mechanism. Tax related benefits could be designed in various ways. VAT, income tax, energy tax or other forms of tax could be addressed by policy-makers. Whether an incentive is a cash payment or a tax related benefit does not have much impact on the economic evaluation from an investor's perspective. However, politically there can be a difference depending on who is providing the payment. Tax increases to provide direct subsidies might result in political difficulties.

Bank loans: bank loans with beneficial interest rates can be a very suitable supplementary tool to trigger demand for PV systems. The successfully operating feed-in scheme in Germany is supported by a low interest loan offered by KfW Foerderbank. Up to 100 per cent of the investment (maximum €50,000) can be subject to a low-interest loan for private customers. The KfW payback period can be as long as the feed-in tariff programme (20 years). Similar programmes are provided for commercial investors.

Quota systems: The government fixes the quota

Quota systems can be designed in a variety of different ways. The main principle is that the government compels producers, providers or consumers of electricity to have a certain share of renewable electricity in their mix. Quota systems are also known under 'Quota Obligation' or 'Renewable Portfolio Standard' (USA). While the quota is imposed, the price is set through competition between different project developers and also different technologies. A quota system does not need to be combined with other support tools. However, quota obligations are commonly combined with tendering and tradable green certificates.

Tendering: tendering, or competitive bidding, has been used for wind energy in different countries (such as Ireland, the UK and France). Under a tendering scheme, project developers submit projects and indicate the wholesale price they would like to get for the produced electricity. The company with the lowest production costs will be able to ask for the lowest price and will finally get the order. The project developer enters into a contract which guarantees that the electricity will be bought over a defined period of time (power purchase agreement). The difference between the current market price and the contracted price in the power purchase agreement represents the value that needs to be financed either by a public promotion fund or a levy on the electricity bill.

Tradable Green Certificates (TGC): tradable green certificates resemble the tendering mechanism. Instead of entering a power purchase agreement, in a TGC scheme, prices are set on a frequent basis. Due to varying prices (values of certificates), investors lose security on their returns on investment. A typical TGC scheme works with a government that sets a usually increasing quota for renewable energy in the supply portfolio; consequently the producers, wholesalers, retailers or consumers (depending on who is obliged) are obliged to supply or consume a certain percentage from renewable electricity sources. For each unit of renewable electricity (e.g. MWh), a certificate, that serves as proof that renewable electricity was delivered to the grid, is generated and issued to the producer. These certificates can be obtained by a supplier that owns generation plants, by buying them from other generation plants or a broker who often acts as an intermediate. In order to enforce the scheme, penalties need to be set if quotas are not reached and their value needs to be considerably higher than the expected value of certificates in order to motivate quota compliance. If penalties are set too low, they might have a price controlling factor. An underlying aim of this support scheme is that the target should be fulfilled in the cheapest way. Technologies with the lowest generation costs will be able to operate under a TGC scheme. This will lead to a homogenous energy portfolio of technologies. Unfortunately, some technologies will be excluded from a TGC scheme while already mature technologies are stimulated. Therefore, a number of technologies will generate windfall profits, meaning that the compensation is higher than their actual generation costs.

Key countries and success stories

Germany

The strong growth in electricity production from renewable energy sources in Germany would have been unthinkable without the Renewable-Energy-Sources-Act (Erneuerbare-Energien-Gesetz, EEG). The legislation came into force in 2000 and was amended in 2004. It is successor to the 1991 Electricity Feed Act (Stromeinspeisungsgesetz, StrEG) which back in the 1990s gave important impetus for the expansion of renewable energy sources, especially wind power.

Legislation

The German Feed-in Law (EEG) has inspired many countries all over the world. This law has been the driver not only for the German PV industry, it has also shown the rest of the world that political commitment can help to achieve environmental goals and lead to industrial development at the same time. In June 2007 the German parliament decided to amend the EEG.

Table 6.2 Feed-in tariff structure for photovoltaics under the EEG

	Rooftop								Ground-mounted installations	
	≤ 30kW		> 30kW		> 100kW > 1000kW			All sizes		
	Degression rate*	ct/kWh	Degression rate*	ct/kWh	Degression rate*	ct/kWh	Degression rate*	ct/kWh	Degression rate*	ct/kWh
2009	8%	43.01	8%	40.91	10%	39.58	25%	33.00	10%	31.94
2010	8%	39.57	8%	37.64	10%	35.62	10%	29.70	10%	28.75
2011	9%	36.01	9%	34.25	9%	32.42	9%	27.03	9%	26.16

*without adjustments to the sliding scale

Source: EPIA (2008b)

Annual digression rates will increase from 2009. If the growth of the PV market (new installations) in a year will be stronger or weaker than the defined growth corridor, the digression in the following year will increase or decrease by one percentage point respectively.

Table 6.3 Growth corridor

Growth corridor	Degression	2009	2010	2011
Upper limit in MWp	Above: +1%	1500	1700	1900
Lower limit in MWp	Below: -1%	100	1100	1200

Source: EPIA (2008b)

For PV systems up to 30kWp, the producers have the possibility to auto consume the electricity they produce. In this case, they receive a premium feed-in tariff of 25.01c€/kWh for 2009 for the self consumed PV electricity. The feed-in tariffs are granted for 20 years. The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) has evaluated precisely the cost of its FiT. They estimate the average EEG surcharge for 2007 around €2.94 per month per household, of which PV represents less than €1 per month per household. They estimate the maximum cost of the EEG for a 3500kWh household to peak around €4 per month by 2015. This would decrease then with the declining rates of EEG remuneration.

German PV market

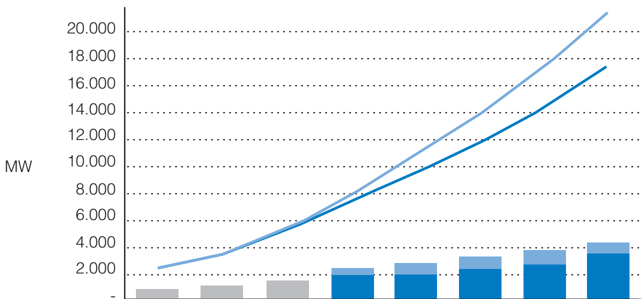
The cumulative installed PV power in Germany increased to 5.3GW by the end of 2008. Annually installed power in 2008 was approximately 1500MW. Germany remained one the leading PV market worldwide just after Spain. More than a third of the global cumulative PV power installed is located in Germany. Although the absolute market figures keep growing in Germany, the market share of Germany in Europe has shrunk during the last year as markets like Spain and Italy finally followed the successful German path. Germany has a diverse mix of PV applications. In 2008, 40 per cent of the German PV systems were installed on residential homes (1–10kW). 50 per cent were installed as commercial roof top systems (10–1000kW) and 10 per cent of the PV systems were installed as very large ground mounted systems. Considering current installation rates, PV will be a major electricity source in Germany within a few years.

Due to the Spanish cap (see section on Spain below) which has been set at 500MWp for 2009, Germany is expected to take back its number one position as the most mature market with a proven FiT scheme, good financing opportunities via Kreditanstalt für Wiederaufbau (KfW), high potential for future development, good availability of skilled PV companies and good awareness of the PV technology. As the degression rates of the feed-in tariffs will be increased by 1 per cent if the German PV market develops to a size larger than 1500MW in 2009, the German market growth will probably slow down in 2010. EPIA estimates that the German market could weigh up to 4GWp annually by 2013 if the present support scheme is maintained, considering that the price of PV systems will decrease accordingly with the FiT degression rates.

Spain

Legislation

The Spanish Royal Decree 436/2004 initiated feed-in-tariffs around €0.41/kWh for PV systems under 100kWp and €0.21/kWh over 100kWp. This Royal decree was amended by the Royal Decree 661/2007 and allowed the Spanish PV market to see an impressive growth in 2007 and especially in 2008. The last Royal Decree 1578/2008 has been in force since 1 January 2009. The new FiT establishes a quarterly 'pre-registration mechanism'. The regulated tariff for each official announcement will be calculated according to the existing demand within the previous announcement, with a decrease in the remuneration if the quarterly cap is totally covered. This mechanism can lead to decrease of the tariff up to 10 per cent per year. Tariffs are still granted for 25 years. The system will be revised in 2012 according to the Renewable Energy Plan 2011–2020 (Plan de Energías Renovables 2011–2020).



		2006	2007	2008	2009E	2010E	2011E	2012E	2013E
Annual market (MW)	Moderate scenario	850	1,100	1,500	2,000	2,000	2,300	2,600	3,000
	Policy-Driven scenario				2,500	2,800	3,200	3,600	4,000
Projected cumulative PV power installed (MW)	Moderate scenario	2,708	3,808	5,308	7,308	9,308	11,608	14,208	17,208
	Policy-Driven scenario				7,808	10,608	13,808	17,408	21,408

Figure 6.13 Historical PV market development in Germany and EPIA projections to 2013
Source: EPIA (2009)

Table 6.4 Feed-in tariff structure under the RD 2008/1578 (tariffs valid for first quarter)

Categories		**Power plant limit size (MW)**	**Tariff 2009 (€/kWh)**	**CAP 2009 (MW)**
Type I – Rooftop	<20kW	2	0,34	27
	>20kW		0,32	240
Type II – Ground-mounted		10	0,32	233 (133+100)
Total CAP				500

Source: EPIA

Spanish PV market

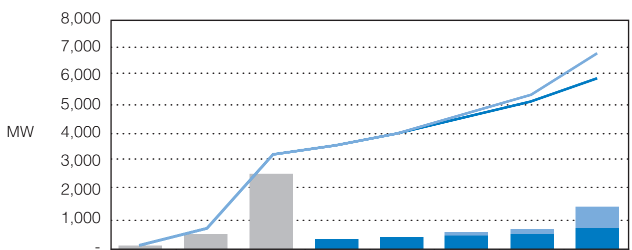
According to the National Energy Commission (Comisión Nacional de Energía), 2605MW was connected to the grid in 2008, reaching a cumulative PV power installed of 3317MW at the end of 2008, of which more than 95 per cent are large-scale ground-mounted systems.

Considering the unexpected growth of the PV market in 2008, the Spanish government has put in place a strict cap which allows only a 500MWp annual market from 2009 to 2011. Considering the quarterly calls for projects, the 2009 market will probably be limited to 375MW. Under the current scheme, EPIA expects little room for market growth in the next five years. Seeing the solar potential in Spain and the high national renewable targets, in the policy-driven scenario EPIA expects a removal of the cap which would allow a GW market by 2013.

Italy

Legislation

Italy introduced a feed in law for RES in July 2005 and the last decree of February 2007 has developed the photovoltaic market. Besides high sun irradiation, Italy offers a very attractive support scheme, mixing net-metering and a well-segmented premium FiT. The main Italian support policy for PV is a premium FiT paid on the



		2006	2007	2008	2009E	2010E	2011E	2012E	2013E
Annual market (MW)	Moderate scenario	88	560	2,511	375	500	500	550	800
	Policy-Driven scenario				375	500	600	650	1,500
Projected cumulative PV power installed (MW)	Moderate scenario	151	712	3,223	3,598	4,098	4,598	5,148	5,948
	Policy-Driven scenario				3,598	4,098	4,698	5,348	6,848

Figure 6.14 Historical PV market development in Spain and EPIA projections to 2013
Source: EPIA (2009)

electricity produced by PV technologies. This FiT is paid by GSE (Gestore dei Servizi Elettrici) and changes according to the plant size and level of building integration.

Table 6.5 Feed-in tariff structure for photovoltaics under the 'Conto Energia' (valid for 2009)

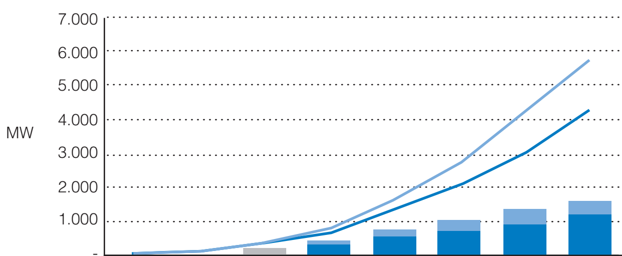
Rated Power	BIPV (€/kWh)	BAPV (€/kWh)	Non integrated (€/kWh)
1–3kWp	0.48	0.43	0.39
>3–20kWp	0.45	0.41	0.37
> 20kWp	0.43	0.39	0.35

Source: EPIA

The incentives are granted for 20 years up to a limit of 1200MWp. The rate suffers a decrease of 2 per cent until 2010 when a new law issued by the Minister of Economic Development will determine new tariffs for PV plants starting work after 2010. In January 2009, the Italian government extended the net-metering ('Scambio sul posto') to PV systems up to 200kW. This means the PV system owner can valorize the electricity he produces himself at the same price as the electricity he consumes traditionally from the grid. If, over a time period, there is an excess of electricity fed into the grid, the PV system owner gets a credit (unlimited in time) for the value of the excess of electricity. This measure is very attractive for the residential, public and commercial sectors.

Italian PV market

With the issue of the new 'Conto Energia' (the Italian Feed-in law) the Italian PV market rose to a cumulative capacity of 350MW at the end of 2008 (of which 258MW were only installed in 2008). Currently the market sectors in Italy are private customers and commercial customers. Of less relevance are agricultural and public costumers. However as many large-sized plants are currently planned in Italy, their share is expected to increase in the future. The strongest market segment in 2010 will be commercial customers realizing medium to large rooftop plants.



		2006	2007	2008	2009E	2010E	2011E	2012E	2013E
Annual market (MW)	Moderate scenario	13	42	258	400	600	750	950	1,250
	Policy-Driven scenario				500	800	1,100	1,200	1,600
Projected cumulative PV power installed (MW)	Moderate scenario	50	92	350	750	1,350	2,100	3,050	4,000
	Policy-Driven scenario				850	1,650	2,750	4,150	5,750

Figure 6.15 Historical PV market development in Italy and EPIA projections to 2013
Source: EPIA (2009)

Under the present FiT scheme valid until the end of 2010, EPIA expects continuous growth in the Italian PV market. In the policy-driven scenario, EPIA expects the Italian PV market to reach the GW level by 2011, assuming that the administrative procedures will be harmonized at regional level, that the net-metering will have a strong impact on the demand for PV systems and that the new FiT will have no cap limitation and will remain consistent with the existing one.

France

Legislation

Since 2004 and the introduction of the 40 per cent tax credit, the French PV market is facing considerable growth. The increase of the tax credit from 40 per cent to 50 per cent in 2005 and to a greater extent the improvement of the feed-in tariff in July 2006 (Arrêté du 10 juillet 2006) allowed a rise in PV installations. The French support scheme is rewarding BIPV installation with a bonus and this bonus is also leading to specialization in the French PV industry. Therefore this bonus can not only be seen as a tool for environmental, but also industrial, policy-making.

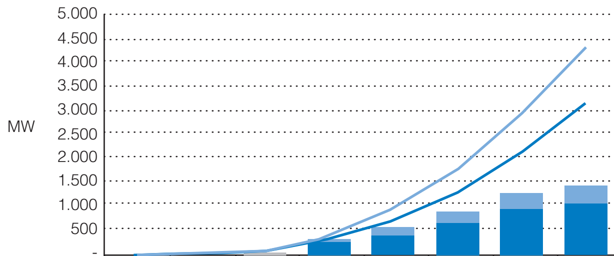
Table 6.6 Feed-in tariff structure for photovoltaics in France (valid for 2009)

	Continental France (€/kWh)	**Overseas regions + Corsica (€/kWh)**
Roof top and ground-mounted	0.32	0.43
BIPV	0.60	0.60

Source: EPIA

French PV market

Due to its favourable BIPV feed-in tariff, the French PV market is dominated today by BIPV applications for residential and commercial applications. In 2008, 105MW were installed but only 46MW were connected to the grid due to long administrative procedures.



		2006	2007	2008	2009E	2010E	2011E	2012E	2013E
Annual market (MW)	Moderate scenario	8	11	46	250	340	600	900	1,000
	Policy-Driven scenario				300	500	850	1,200	1,400
Projected cumulative PV power installed (MW)	Moderate scenario	30	41	87	337	677	1,277	2,177	3,177
	Policy-Driven scenario				387	887	1,737	2,937	4,337

Figure 6.16 Historical PV market development in France and EPIA projections to 2013
Source: EPIA (2009)

EPIA expects all PV systems installed in 2008 to be connected in 2009 and a great majority of the new installed PV power in 2009 to be connected within the year. This is why some PV power installed in 2008 has not been fully integrated into the 2008 figures but will be included in the 2009 figures. In its policy-driven scenario, EPIA expects a simplification of these procedures in 2009 and the introduction of a new tariff for non-BIPV applications on large commercial roofs. Under this scenario, the French PV market would become a leading country in the deployment of solar PV energy in Europe and worldwide.

European PV market outlook

Since 2004, Europe has been leading the global market for PV applications. In 2008, Europe represented over 80 per cent of the global PV market. Among European countries, Germany has been leading the way for several years but Spain took over the number one position worldwide with around 45 per cent of the global market and 56 per cent of the EU market. Numerous countries are developing excellent support schemes for PV, out of which Italy and France are emerging as the new high-potential markets. Some, such as the Czech Republic, Belgium, Bulgaria, Portugal and Greece, are following with promising support schemes.

In its policy-driven forecast for Europe, EPIA expects Germany to remain as the major PV market in Europe with increasing roles from France and Italy. If the cap is removed in Spain, EPIA expects these four countries to represent more than 75 per cent of the European market by 2013.

TOMORROW

Technology targets by 2020 and beyond

Although reliable PV systems are commercially available and widely deployed, further development of PV technology is crucial to enabling PV to become a major source of electricity. R&D is crucial for the advancement of PV. As reported in the Strategic Research Agenda for Photovoltaic Solar Energy Technology, we can summarize in a few points where the R&D efforts have to be pushed forwards. Regarding crystalline photovoltaic, the technology that has dominated the photovoltaic industry since the dawn of the solar PV era, we can refer to six key points:

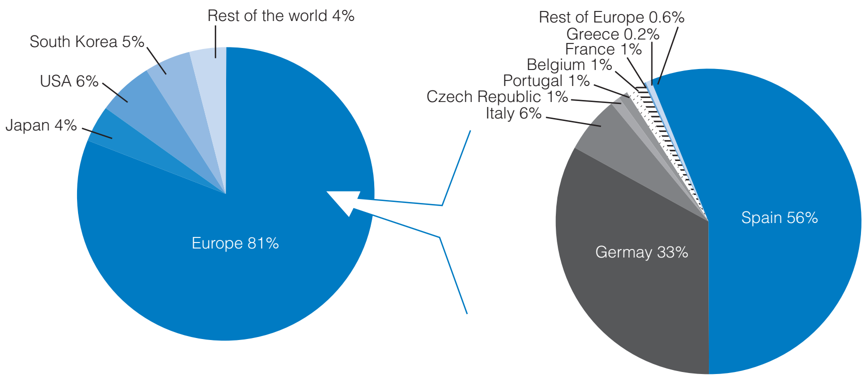


Figure 6.17 Regional distribution of global and European annual PV market in 2008
Source: EPIA

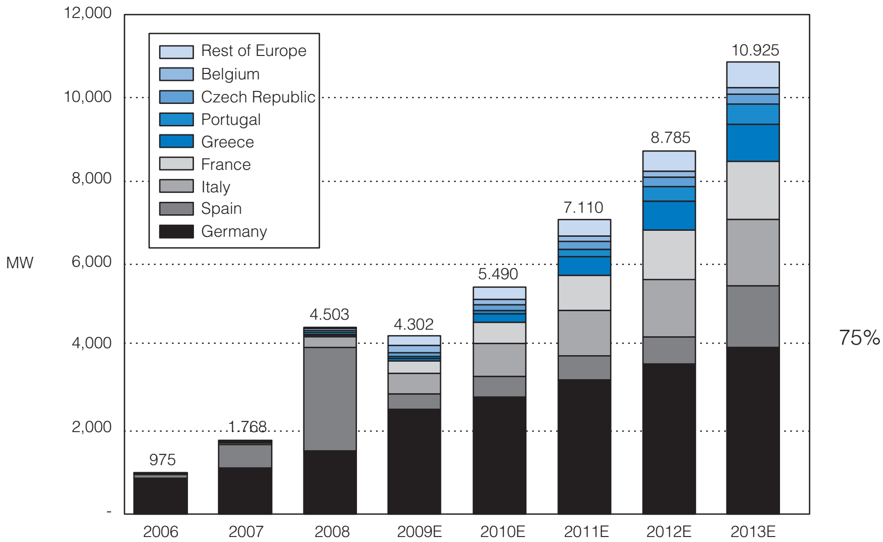


Figure 6.18 European annual PV market outlook until 2013 (policy-driven scenario)
Source: EPIA

1 reducing the specific consumption of silicon and materials in the final module;
2 new and improved silicon feedstock and wafer (or wafer equivalent) manufacturing technologies, that are cost-effective and of high quality;
3 increasing the efficiency of cells and modules and, in the longer-term, using new and integrated concepts;
4 new and improved materials for all parts of the manufacturing chain, including encapsulation;
5 high-throughput, high-yield, integrated industrial processing;
6 finding safe processing techniques with lower environmental impact and reaching longer module life-time.

For Thin Film technology, relatively new and with impressive potential, we can refer to five key points:

1 reliable, cost-effective production equipment;
2 low cost packaging solutions both for rigid and flexible modules;
3 more reliable modules through better quality assurance procedures (advanced module testing and improved assessment of module performance);
4 recycling of materials and old modules;
5 alternatives for scarce chemical elements such as indium, gallium and tellurium.

Moreover, as explained in the costs and prices section, it is clearly an essential goal for the solar industry to ensure that prices fall dramatically over the coming years. Assuming that there are some factors like technological innovations and improvements, increasing of the performance ratio of PV and extension of PV systems' lifetime that will drive further reductions in productions costs, EPIA has laid down specific targets for technological improvements.

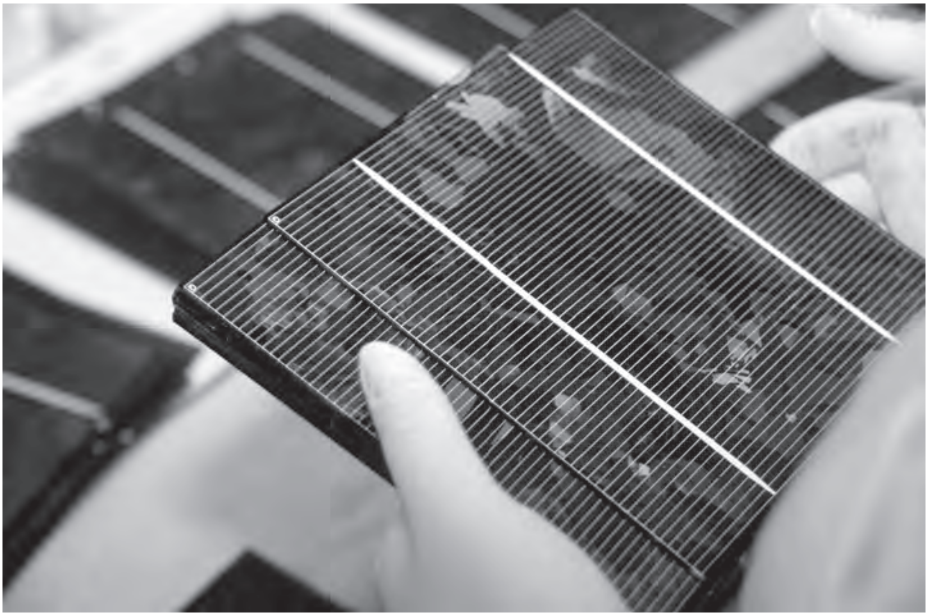


Figure 6.19 Multicrystalline solar cell
Source: Q-Cells

BOX 6.2 EFFICIENCY TARGETS FOR 2020

COMMERCIAL CRYSTALLINE CELLS

- mono-crystalline (Cz) cells to reach average efficiency of 22 per cent (although some commercial cells are already on the range of 19-22 per cent efficiency);
- multi-crystalline (Mz) cells to reach average efficiency of 20 per cent;
- ribbon-sheet cells efficiency to reach 19 per cent efficiency.

COMMERCIAL THIN FILM MODULES

- Amorphous silicon (a-Si) and multi junction micromorph a-Si/μ-si to reach 10–16 per cent respectively;
- cadmium telluride (CdTe) to reach 15–20 per cent;
- copper indium (gallium)-diselenide/disulphide to reach 16–22 per cent.

CONCENTRATED PHOTOVOLTAICS MODULES

- Silicon based and III–V compounds to reach 30 per cent and 35 per cent efficiency respectively.

NOVEL AND EMERGING TECHNOLOGIES

- Advanced inorganic Thin Film, organic solar cells (e.g. Dye solar cells) and thermophotovoltaics to be commercially available with efficiencies over 10 per cent.

Technology long term potential

The cost of producing photovoltaic modules and other system inputs has fallen dramatically since the first PV systems entered the market. Some of the main factors responsible for that decrease have been:

- technological innovations and improvements (increase of efficiency and reduction of material usage);
- increasing the performance ratio of PV;
- extension of PV systems' lifetime;
- economies of scale.

Those factors will drive further reductions in production costs, therefore it is clearly an essential goal for the solar industry to ensure that prices fall dramatically over the coming years. By increasing the efficiency of PV modules, both Thin Film and crystalline, production costs per kWh will fall. At the same time, less and less raw material will be used, especially for crystalline technologies. The ability to produce thinner wafers will reduce silicon consumption and therefore costs, as well as the energy payback time of PV systems. However, the improvement of existing technologies is not the only factor that will drive down production costs. R&D expenditures on PV are growing and delivering promising results for new technologies based on innovative production processes or different raw materials. A good example of significant production cost reduction has been through the development of Thin Film technologies. Similar breakthroughs can be expected from future technologies such as organic cells or nanotechnologies. PV system quality is also a parameter which influences the cost per kWh. The quality of the system is reflected in its performance ratio. This is the ratio of the electricity measured on the AC side of the electricity meter compared to the amount of electricity originally generated by the PV modules. The higher the performance ratio, the lower the losses between the modules and the point at which the system feeds into the grid. The expected range of system performance ratios is between 70 per cent and 85 per cent, but in recent years the trend has been towards the upper part of this range. This means that if losses and malfunctioning of PV systems can be further reduced, the cost per kWh can also be lowered. A further extension of system lifetime will have a positive effect on the generation costs of PV per kWh, as the electricity output will increase. Many producers already give module performance warranties for 25 years: this can therefore be considered as a minimum module lifetime. An extension of the lifetime to 30–35 years is expected by 2020. Another very important driver for PV cost reduction is economies of scale. Larger production volumes will enable the industry to lower the cost per produced unit. Economies of scale can be realized during the purchasing of raw materials through bulk buying, during the production processes, by obtaining more favourable interest rates for financing and by efficient marketing. Whilst only a decade ago cell and module production plants had capacities of just a few MW, today's market leaders have 1GW capacity plants within their reach. Photovoltaic investment cost is decreasing year after year because of the learning curve and there are many economies of scale within the PV industry. This curve showed that the price of PV modules reduces by 20 per cent each time installed capacity is doubled (experience learning curve). The more we install PV, the less it costs. As most of the cost of PV is the investment, the photovoltaic electricity generation cost is decreasing almost proportionally. At the same time, the price of electricity is rapidly increasing worldwide, very much depending on fossil fuel prices. At a certain point, the decreasing price of photovoltaic electricity will equal the increasing price of retail electricity and Grid Parity point will be reached.

The European Photovoltaic Industry Association redefined in September 2008 its industry objectives in the light of recent technology progress and the context of rising energy prices. The industry unanimously agreed that photovoltaic energy could provide up to 12 per cent of European electricity demand by 2020. The evolution of solar photovoltaic technology will be quicker than previously announced. Based on the concept of Grid Parity (when photovoltaic generation costs are equal or lower to than the retail electricity price), EPIA has shown that the addressable market for PV within the EU-27 will represent about 60 per cent of the final EU electricity demand in 2020. This is mainly due to the rising electricity prices in the different European countries and the decreasing cost of PV according to its 20 per cent experience curve factor – the price of photovoltaics is reduced by 20 per cent each time there is doubling of the cumulative installed capacity. Countries like Italy with high irradiation and high electricity prices are expected to reach Grid Parity in 2010. Grid Parity will be reached in Germany in 2015 and will progressively extend to most other EU countries by 2020.

In order to reach this target, the PV industry does not expect any major technological change but rather a continuous technology improvement. The acceleration of cost reduction will be achieved by economy of scale due to an accelerated PV deployment. The PV industry committed itself to make the necessary investments (CAGR 40 per cent) in order to achieve the necessary price degression. It is absolutely vital to point out that this ambitious goal can only be achieved if in most of the 27 EU member states appropriate support programmes – ideally in form of a well structured feed-in law with appropriate degression – are in place for the next few years until pure economics are driving this sector. Achieving up to 12 per cent of European electricity demand in 2020 will place photovoltaics as a major source of electricity supply within the EU, which means that the photovoltaic installed capacity will reach 390GWp generating 420TWh annually. Under such a scenario, the target of 20 per cent renewables in the European end energy mix by 2020 may be exceeded, especially when taking into account the contribution from other renewable energy sources.

NOTES

1 More information is available on the following website: www.pvcycle.org, last accessed November 2009.
2 More information is available at www.pvsunrise.eu, last accessed November 2009.
3 More information available at www.gipv.de, last accessed November 2009.
4 Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities, IEA PVPS Task 10, May 2006.
5 More information is available on www.ruralelec.org, last accessed November 2009.
6 More information is available on www.ruralelec.org, last accessed November 2009.

7

Concentrated Solar Power

STATE-OF-THE-ART TECHNOLOGY

Solar Thermal Electricity, also known as Concentrated Solar Power (CSP) technology, is produced using concentrating solar radiation technologies. It provides clean and reliable power in units ranging from 10kW to 300MW. The first commercial solar thermal power plants were built in the 1980s and in 2009 more than 600MW are commercially operated in the world. In Europe around 1,700MW of solar thermal power plants are either recently operating or under construction. The installed capacity in Europe is expected to be of 2GW by 2012 and potentially 30GW by 2020. The technical potential in Europe in the long run can be estimated at least at 20 times that figure within reasonable generation costs. At different stages of technical development, there are four main CSP technologies to produce solar thermal electricity: parabolic trough plants, central receiver plants, Dish-Stirling systems and linear Fresnel systems. Each technology will progress thanks to a favourable policy framework and to its capacity to reduce generation costs and satisfy the specific needs of the power market.

Technological benefits

Solar thermal power plants are mainly located in extremely dry areas that are uncultivated, not used for agriculture. Commercial activity within these areas will directly and indirectly benefit local communities. Direct benefits include the collection of taxes and the creation of new jobs; indirect benefits are an increase in local services to support the new jobs created. The plants require skilled labour for construction, maintenance and operation. The types of jobs initially created would probably be technical or construction, but opportunities for manufacturing and services jobs may also develop as facilities evolve. The calculation of the new jobs created is based on current industry practices to assess the number and type of jobs that will result from the enactment of renewable energy programmes in recent years. For solar thermal power plants, every 100MW installed will provide 400 man/year equivalent manufacturing jobs, 600 man/year contracting and installation and 60 man/year in Operation & Maintenance (O&M). A community can benefit indirectly from economic development, in other words through an increasing demand in local services commodities. It is widely accepted that for each construction job, four service jobs are created in support. Once construction is completed, O&M will also require local services. Furthermore, the creation of these jobs will allow for the development of a permanent educational system (schools, vocational training institutes, etc.) to continuously train skilled manpower (technicians, engineers, developers etc.).

Technological applications

Parabolic trough plants

Parabolic trough plants use line-concentrating parabolic trough collectors which reflect the solar radiation into an absorber tube. Synthetic oil circulates through the tubes and is heated up to approximately 400°C. Parabolic trough collectors are the most commonly used thermal electricity technology in the market. Their track record began in the 1980s in the USA with a total power installed of about 350MW. New plants have been constructed in the last years, such as the 65MW plant by the Spanish company Acciona in Nevada (USA). In October 2009, more than 30 plants are under construction in Spain which amounts to more than 1500MW and a number of new projects are being developed in the USA. In addition, two plants in Algeria and Morocco of 20MW electrical equivalent power for two solar bottomed combined cycles have been awarded to European companies as a result of an international tender and a 20MW plant is under construction in Egypt. A tender for a 100MW plant is under way in Abu Dhabi as well as additional interest from the Middle East, China and other sunny countries. The current total investment for the aforementioned projects is close to €7000 million.

Plants in operation in Europe:

- Andasol 1 (50MW + 7.5 hour-storage) in Granada, Spain;
- Puertollano (50MW) in Ciudad Real, Spain;
- Alvarado (50MW) in Badajoz, Spain.

Figure 7.1 Parabolic trough plants
Characteristics: 50 to 250MW; proven utility scale technology commercial operation since 1984; preferred technology for new plants in the USA, Spain and North Africa (Morocco, Egypt and Abu Dhabi); more than 30 plants under construction in Spain.
Source: ESTELA (European Solar Thermal Electricity Association)

Central receiver plants

Central receiver plants, also called tower plants, use big mirrors (heliostats) larger than 100m² which are almost flat and track the sun on two axes. The concentrated radiation beam hits a receiver on top of a tower. The working fluid temperature depends on the type of fluid which is used to collect the energy and is within the range of 500 to 600°C. The PS 10 and PS 20 plants in Seville are the only power plants of this kind in operation today. Their nominal power output is 10MW and 20MW and they

Figure 7.2 Central Receiver Plant
Characteristics: 10 to 50MW; demo plants built in the 1980s; first commercial 10MW and 20MW plants in operation in Spain and another one under construction (17MW + 15hr storage); larger projects announced in the USA.
Source: Abengoa Solar (Solucar PS10)

are designed with a northern heliostat field and saturated steam as working fluid in the receiver. The storage system is only designed to cope with transient situations. Another 17MW plant, Gemasolar, is under construction. It is located in the province of Seville, with a circular field type equipped with a molten salt receiver and a storage capacity of 15 hours. The size of these plants might be limited by the maximum distance of the last row of heliostats from the tower. At this time, it is premature to attempt to establish reliable cost/power ratios for this technology as the number of operational or ongoing projects is small, but it will not be very different from the parabolic trough plants. The land use is slightly less effective in the case of solar tower plants. On the other hand this technology does not require a flat land surface like a parabolic trough plant. A further advantage is the potential increase of the overall conversion efficiency (up to 20 per cent) that can be achieved by raising the working fluid temperature. The commercial confidence in this technology is growing as more operational plants are being built and consequently it will improve in the near future. Hybridization is feasible, but no commercial projects have been built so far.

Plants in operation in Europe:

- Solucar P10 and PS20 (10MW + 20MW) in Sevilla, Spain.

Dish-Stirling systems

The Dish-Stirling System consists of a solar concentrator in a dish structure that supports an array of curved glass mirrors. The parabolic dish tracks the sun throughout the day and concentrates the radiation onto the heat absorption unit of a Stirling engine. The focused solar thermal energy is then converted to grid-quality electricity. The conversion process involves a closed cycle, high-efficiency solar Stirling engine

Figure 7.3 Dish-Stirling Systems
Characteristics: 10 to 25kW per unit (modular); several small case installations in operation; utility-scale installations slated for construction in 2010; applications appropriate for both utility-scale projects and stand-alone distributed energy projects.
Source: SunCatcher, Randy Montoya and Sandia National Laboratories

using an internal working fluid (usually Hydrogen or Helium) that is recycled through the engine. The working fluid is heated and pressurized by the solar receiver, which in turn powers the Stirling engine.

The Dish-Stirling Systems have decades of recorded operating history and are flexible in terms of size and scale of deployment. Owing to their modular design, they are capable of small-scale distributed power output, and are suitable for large, utility-scale projects with thousands of dishes arranged in a solar park (two plants in the US totaling over 1.4GW are slated for construction in 2010).

This technology uses no water in the power conversion process (either for steam generation or cooling) and the only water needed is for the washing of the mirrors. Dish-Stirling technologies are furthermore attractive due to their high efficiency and modular design, which gives the systems several key advantages, including a higher degree of slope tolerance and site flexibility, meaning that it does not require flat land, a fact that significantly reduces grading costs and environmental impact; high overall availability due to the fact that there is no singular point of failure and scheduled maintenance on the dishes can occur on individual units while the others continue to generate power; and a low-cost of manufacture and deployment as a result of high-throughput automotive style production and assembly.

Linear Fresnel Systems

Linear Fresnel collectors are line focusing systems like parabolic troughs with a similar power generation technology. The difference with parabolic troughs is the fixed absorber position above a field of horizontally mounted flat mirror stripes, collectively or individually tracked to the sun.

Figure 7.4 Linear Fresnel collector
Characteristics: Current demo projects up to 6MW; larger plants under development (up to 150MW)
Source: ESTELA (European Solar Thermal Electricity Association)

Fresnel technology, which is now being tested under actual operating conditions, is comparatively simple to manufacture, build and operate. The reflectors, which collect and focus the sun's rays, are completely flat and, arranged in a linear pattern, they form long, moveable rows of mirrors. The parallel mirrors focus the radiated energy from the sun onto a pipe, positioned eight metres above the mirrors. Water flows through this absorber pipe, which is heated to temperatures of up to 450 degrees centigrade. This produces steam (as in a conventional power plant), which is converted into electrical energy in a steam turbine. Fresnel collectors are innovative in that they are not sensitive to wind and require a smaller area of land than other solar collectors.

Apart from the generation of solar power, the area below the mirrors can be used in a variety of ways. In desert-like environments the shaded area under the mirror fields, where the sun irradiation is reduced by over 80%, could be used for storage, parking, office buildings (with reduced cooling costs) or even green house agriculture.

So far in Europe no fully commercial plant based on the Fresnel principle is being developed. Demonstration plants with a capacity of several MW are being built in Europe and the USA to evaluate and prove electricity generation costs, to gain operation experience and commercial confidence.

Cost and prices

The investment per kW installed is estimated at €5000, which is the mean value between the cost of plants with 7-hour storage (€6000/kW) and the cost of plants that only have a small operational storage (€4000/kW). The table below shows how thermal electricity sales price will continuously decrease as more and more plants will be operating. Until May 2009 the sales price in Spain, where the direct normal irradiation (DNI) is around 2100kWh/m^2, was fixed at 27c€/kWh by the feed-in tariff scheme. In the Middle East and North Africa (MENA), where DNI is higher (2600kWh/m^2), the sales price of thermal electricity can be lower. This estimation is based on an average annual decrease of 3 to 5 per cent in the sales price of thermal electricity.

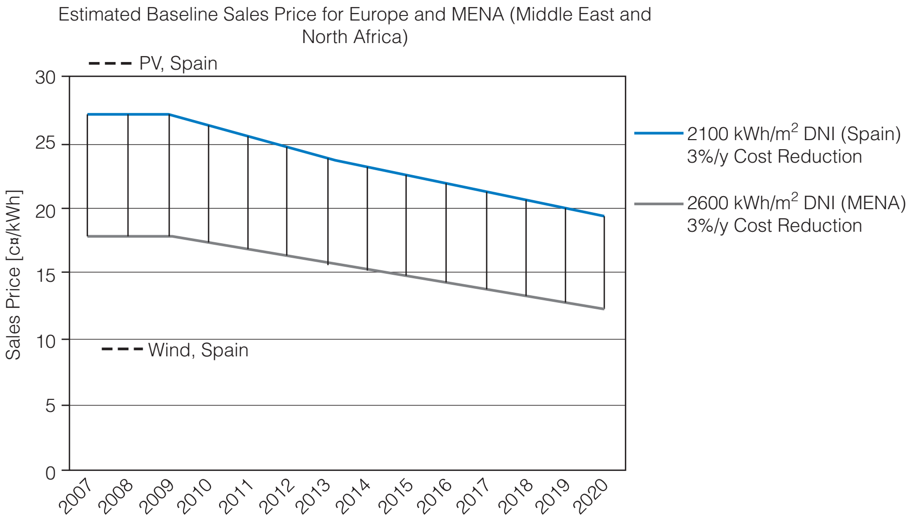


Figure 7.5 Estimated baseline sales price for Europe and MENA (Middle East and North Africa)
Source: ESTELA (European Solar Thermal Electricity Association), April 2009. Design ACG Brussels.

MARKET

CSP has the largest potential and the most suitable characteristics to convert solar radiation into electricity. Solar thermo-electric power plants are fully dispatchable, perfectly meet the demand curve and can additionally provide other fluent renewable conversion technologies (such as wind) with the necessary back up.

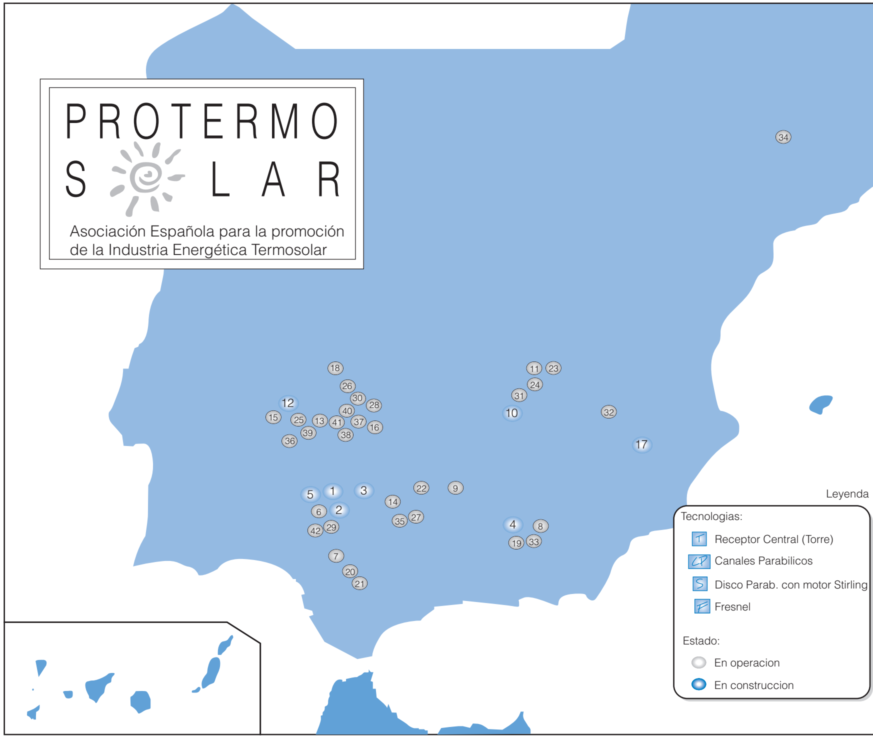
Installed capacity and market development

In the early 1980s parabolic trough solar power plant technology was largely proven with parallel programmes of the International Energy Agency in Almería (Spain) and the Sandia National Laboratories in Albuquerque (USA). From 1985 to 1989 nine commercial power plants called SEGS were installed in the Mojave Desert, California (USA) with a total installed power close to 400MW. These plants are still in operation with a very positive track record for 20 years. During the 1990s the lack of effective supporting systems stopped the deployment and further implementation of this technology until new requirements in some states of the USA and the new feed-in tariff system in Spain provided great business opportunities. Yet, since 2000, several test loops of real size parabolic trough collectors have been installed in different testing facilities in the USA and Spain in order to provide financial institutions with technical evidence in terms of feasibility and performance. R&D programmes are being carried out in several countries (Germany, Spain, Italy, USA, etc.) in order to improve the performance and reduce the cost of these plants. The first parabolic trough of this new generation was constructed in Nevada, USA and it began operating in June 2007. It has been generating 64MW of electricity regularly since then. Another approach was the implementation of a central receiver at the top of a tower with a surrounding heliostat field with mirrors. It was first tested in the early 1980s in several European countries as well as in Japan and the USA. The first commercial 10MW power plant has been operating in Seville (Spain) since mid-2007 with excellent results. The first European parabolic troughs plant with 7.5 hour storage

(Andasol 1) has been operating successfully in Granada, Spain since the end of 2008. Fresnel type reflective trough collectors and Stirling motors mounted on parabolic dishes are also promising technologies. There are several examples of significantly large installations in Europe and the USA with proven results.

Industry

The European industry is the world leader in the CSP sector. All the CSP plants (of a relevant size) that are under construction or have been operating since 2005 were built by European companies. Spain is currently the biggest market in the world with a total investment exceeding €7,000 million. Spanish companies (Abengoa, ACS, Acciona, Sener, Iberdrola) and German ones (FlagSol:Solar Millennium, MAN Ferrostaal) are leading on the system design and engineering, procurement and construction (EPC) of CSP plants. In the solar field Schott, Flabeg, Rioglass and Saint-Gobain are the main suppliers of specific components. Siemens, MAN and Alstom are the favoured turbine suppliers for current projects, far ahead of American companies. The other components are also mainly supplied by European companies. The CSP industry presently employs more than 20,000 people in Europe. There is a huge increase expected with the implementation of the Mediterranean Solar Plan and the new projects that have been announced in the USA and other parts of the world. However, international competition is strengthening, mainly in the USA and Israel, as well as China and India for some components. The following facts demonstrate the involvement and the amount of financial risk on solar thermo-electric projects which is being assumed at an international level by the private sector. More than 30 plants of 50MW each (parabolic trough collector type) and a 17MW plant (central receiver type) are under construction in Spain. Two of them are expected to be connected to the grid this year. The total investment for these projects is exceeding €7 billion. These projects have been financed mainly through a purely commercial financial scheme, after having passed the corresponding detailed due diligence (technical and economical) processes. Project finance structures have been achieved in similar contractual terms to those of wind farms. The total applications requesting connecting points into the grid in Spain amounts to more than 12,000MW, according to recent information from REE (Red Eléctrica Española, the Spanish national electricity company). Since May 2007 all the new applicants have deposited a guarantee of €20,000/MW along with their request. Although the Spanish feed-in tariff system motivated many Spanish companies and gave them the will to participate in solar thermal electricity projects, there are also companies from other countries (Germany, Portugal, France, USA, etc.) that are operating in Spain, either as promoters or as suppliers of goods and services. Fifteen companies of the IBEX 35 (the Spanish Stock Market) are currently participating in solar thermal electricity projects (in Spain and abroad), either as promoters or as suppliers of financial services. The manufacturers of the specific components for the plants (parabolic mirrors and collector tubes) have recently built new factories and are currently increasing their capacities exponentially. There are a significant number of open tenders and approved projects for utilities and other organizations to build solar thermal electricity plants with a total power amount of more than 1000MW in countries all around the world. Two solar plants, conceived to provide additional energy to the steam part of combined cycle plants, are under construction in Algeria and Morocco. New generation plants, both in operation and under constructions, are located mainly in Europe (Spain), in the USA and in the MENA (Middle East and North Africa) countries.



Id	Central	Emplazamiento	Tec.	Potencia	Estado
1	PS10	Sanlucar la Mayor (Sevilla)	T	11 MW	En operación
2	Aznalcollar TH	Sanlucar la Mayor (Sevilla)	S	0.08 MW	En operación
3	ESI	(Sevilla)	S	0.01 MW	En operación
4	Andasol 1	Aldeire-LaCalahorra (Granada)	CP	50 MW	En operación
5	PS20	Sanlucar la Mayor (Sevilla)	T	20MW	En operación
6	Solnova 1, 3 y 4	Sanlucar la Mayor (Sevilla)	CP	3 50 MW	En construcción
7	Lebrija	Lebrija (Sevilla)	CP	50 MW	En construcción
8	Andasol 2	Aldeire-LaCalahorra (Granada)	CP	50 MW	En construcción
9	Palma del Rio I y II	Palma del Rio (Cordoba)	CP	2 50 MW	En construcción
10	Puetollano	Puertollano (Ciudad Real)	CP	50 MW	En operación
11	Manchasol 1 y 2	Alcazar de San Juan (Ciudad Real)	CP	2 50 MW	En construcción
12	Alvarado	Alvarado (Badajoz)	CP	50 MW	En operación
13	Extresol 1, 2 y 3	Torre de Miguel Sesmero (Badajoz)	CP	3 50 MW	En construcción
14	Gemasolar	Fuentes de Andalucia (Sevilla)	T	17 MW	En construcción
15	La Florida	Alvarado (badajoz)	CP	50 MW	En construcción
16	La Dehesa	La Garrovilla (Badajoz)	CP	50 MW	En construcción
17	PE1	TM de Calasparra (Murcia)	F	1,4 MW	En operación
18	Majadas	Majadas de Tietar (Caceres)	CP	50 MW	En construcción
19	Andasol 3	Aldeire-LaCalahorra (Granada)	CP	50 MW	En construcción
20	Vallesol50	San Jose del Valle (Cadiz)	CP	50 MW	En construcción
21	Arcosol50	San Jose del Valle (Cadiz)	CP	50 MW	En construcción
22	Helioenergy 1 y 2	Ecija (Sevilla)	CP	2 50 MW	En construcción
23	ASTE 1a	Ade San Juan (Ciudad Real)	CP	50 MW	En construcción
24	ASTE 1b	Ade San Juan (Ciudad Real)	CP	50 MW	En construcción
25	ASTEXOL 2	Badajoz	CP	50 MW	En construcción
26	Solaben 2 y 3	Logrosan (Caceres)	CP	2 50 MW	En construcción
27	Arenales PS	Moron de la Frontera (Sevilla)	CP	50 MW	En construcción
28	Serrezuela Solar II	Talarrubias (Badajoz)	CP	50 MW	En construcción
29	El Reboso II	La Puebla del Rio (Sevilla)	CP	50 MW	En construcción
30	Termosol I y II	Navalvillar de Pela (Badajoz)	CP	2 50 MW	En construcción
31	Helios I y II	Ciudad Real	CP	2 50 MW	En construcción
32	Renovalia	Albacete	S	1 MW	En construcción
33	Andasol 4	Aldeire-LaCalahorra (Granada)	CP	50 MW	En construcción
34	Termosolar Borges	Borges Blanques (Lerida)	CP	25 MW	En construcción
35	Moron	Moron de la Frontera (Sevilla)	CP	50 MW	En construcción
36	Olivenza 1	Olivenza (badajoz)	CP	50 MW	En construcción
37	Medellin	Medellin (badajoz)	CP	50 MW	En construcción
38	Valdetorres	Valdetorres (Badajoz)	CP	50 MW	En construcción
39	Badajoz 2	Talavera la Real (Badajoz)	CP	50 MW	En construcción
40	Santa Amalia	Santa Amalia (Badajoz)	CP	50 MW	En construcción
41	Torresfresneda	Torrefresneda (Badajoz)	CP	50 MW	En construcción
42	La Puebla 2	La Puebla del Rio (Sevilla)		50 MW	En construcción

Figure 7.6 Location of concentrating solar power plants in Spain
Source: Protermosolar (www.protermosolar.com)

Market perspectives for CSP plants

Electricity generated by CSP plants is dispatchable and its dispatchability can be enhanced by new technologies and/or hybrid concepts using other renewable or conventional fuels. They allow the grid to accommodate more non-dispatchable renewable sources. Dual applications might bring important benefits in some specific areas (electricity and water desalination). Generation costs remain high and the conversion cycle water needed for cooling has to be reduced. The costs will be brought down by innovation in systems and components, improvement of production technology, increase of the overall efficiency, enlargement of operation hours, bigger power blocks, decrease in the O&M costs, learning curve in construction and economies of scale.

Policy instruments to support the technology

Public promotion and support schemes by means of direct investment, tariff increase (feed-in) or by means of mandatory targets are still deemed necessary. The Spanish case provides a good example of an effective legal framework: until May 2009 there was a 27c€/kWh feed-in tariff scheme for plants up to 50MW and the possibility of using 15 per cent natural gas, or in hybridisation with 50 per cent biomass to improve the dispatchability. In May 2009, the legal framework in Spain was changed and there are now two different kinds of incentives to support STE. The first one is a fixed feed-in tariff, the amount of which is the same for all programming periods and depends on the type of installation and the installed power (regarding STE plants: 28,7603c€/kWh during the first 25 years of operation of the plant and 23,0080c€ beyond this period). The second one consists of a premium which is an additional amount added to the market price or to the price freely negotiated by the owner (or representative) of the plant. In the case of STE production, the amount of the premium varies, depending on the market price (the upper limit is: 36,7252c€/kWh and the lower limit is 27,1228c€). The holders of the installations are free to choose one of these two options; so far all the operating plants prefer the second option.

The cost of the energy produced is directly related to the available solar radiation resource, which has to be taken into account when defining the feed-in tariff scheme. The solar thermal electricity industry believes that, in the short and medium term, the European Union should install demand-pulling instruments and promote support mechanisms such as feed-in laws, the most powerful incentives to boost the solar thermal electricity generation. In the medium term, the European transmission grid should be opened to solar electricity from North Africa and this power importation should be secured by implementing demand-pulling instruments and regional agreements in the framework of the Union for the Mediterranean.

Key countries and success stories

Some of the Spanish 50MW power plants under construction have been designed to produce not only nominal power during sunny hours but also to store energy, allowing the plant to produce an additional 7.5 hours of nominal power after sunset, which dramatically improves the integration of the solar thermal electricity plant into the grid. Molten salts are normally used as storage fluid in a hot-and-cold two-tank concept (Andasol 1 in Granada, Spain is already using this technology). The maximum power output of a single plant is theoretically not limited by any physical constraint and power levels of some hundred MW with a unique power group are being designed.

The commonly seen 50MW figure in all of the ongoing Spanish plants is the limit fixed by Spanish legislation and by no means a technical limit. The expectations on the reduction of the kWh generating costs are based upon the efficiency increase in higher working fluid temperature, a more efficient use of the generation group by means of storage, new concepts for the collectors design and/or the contribution of the other primary sources (gas or biomass) and size optimization, and also upon market evolution, without artificial administrative barriers (such as the 50MW limit in Spain). The maximum nominal efficiency of these plants is currently about 16 per cent and it is limited by the working fluid temperature. R&D activities are being carried out in order to find more efficient fluids such as direct steam generation or molten salts. These technologies are not commercially available today, but there are many ongoing development initiatives which are expected to be commercially available shortly. Europe is the world leader in these technology development initiatives, carried out by R&D institutions and industry, with the support of the EU R&TD Framework Programmes. In Spain, an area of 3000km^2 devoted to CSP plants (75GW) could produce 250TWh/year, almost the equivalent of the annual electricity of the whole peninsula.

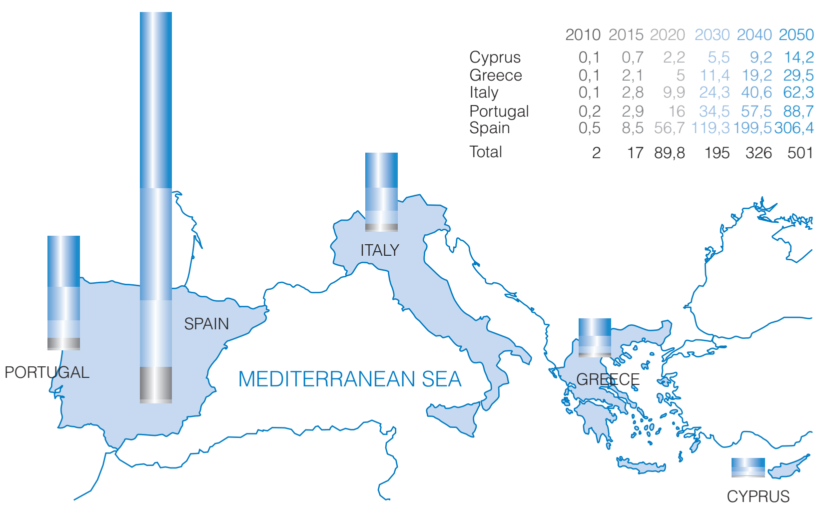
TOMORROW

Technology targets by 2020 and beyond

The emerging industry of solar thermal electricity has strong European roots. It is growing mainly due to the technical and economic success of the first projects and to the stable green pricing or support mechanisms that bridge the initial gap in electricity costs (feed-in tariffs). Future growth will depend on a successful cost reduction and a strong effort in R&D to optimize the potential for technical improvement. In the long term, new markets and market opportunities will appear, as for instance the generation of solar thermal electricity in the south Mediterranean area and its transmission to other parts of Europe. The potential for research and innovation is still of key importance for solar thermal power technologies. R&D is needed to develop and test new materials, components and system development (coatings, storage, direct steam/molten salt systems, adapted steam generators, beam down). Further research is also needed to improve transmission and the energy grid. The European Union should continue to fund demonstration plants to push forward new technologies. This is of utmost importance, as only proven technologies are bankable. The great dynamism, high potential, operational reliability and current production capacity of the European industry as well as the good dispatchability characteristics of this sector, make solar thermo-electric generation a strategic resource for planning the 2020 European electricity scheme. By 2010 there will be more than 500MW connected to the grid, and the short-term potential for European Mediterranean countries is estimated at 30,000MW that could contribute, if the necessary measures are taken, to the EU 20 per cent target in the year 2020. A much larger contribution could be obtained in the longer-term and/or if the potentials of the northern African countries are developed. Solar thermal electricity generation is highly predictable, and can be coupled with thermal storage or hybridization, with gas or biomass, enabling stable national or European electricity networks. Solar thermo-electric plants have favourable inertial response as well as the capability for primary, secondary and tertiary electrical regulation in both senses, up and down. Solar thermal electricity plants can meet the demand at any time, day and night, and can supply electricity at peak hours if they are anticipated. Furthermore these plants can easily meet the demand curve and contribute to the electrical system's stability through the input of substantial amounts of other less dispatchable renewable resources in the electrical systems.

Technological long term potential

European countries, in particular Germany and Spain, have the world leadership in this technology, as shown not only by the number of plants under construction in Spain, but also by the ownership and construction of new plants in the USA, and the international tendering of plants in northern Africa and the Middle East that is awarded to European companies. Furthermore, the number of R&D activities promoted and developed by research centres and by the industry are also key indicators. There are factories in many EU countries for components manufacturing. The European solar plant constructing industry and engineering are world references for parabolic mirrors, absorber tubes, collector structures, heliostats, steam turbines, alternators, transformers and other components. Dramatic changes are to be introduced in the present energy systems to mitigate their negative impact on the environment and the world's climate. The World's 'Sun Belt' which extends from latitudes 35° north to 35° south, receives several thousand times the global energy needed: a resource which is currently not exploited. A large part of this enormous energy could be harnessed through solar thermal electricity technologies, conveyed and used in a sustainable way. The European solar thermal electricity industry is perfectly prepared to lead the development of these technologies worldwide. To remain the world leader is the challenge for the coming years.



	2010	2015	2020	2030	2040	2050
Cyprus	0,1	0,7	2,2	5,5	9,2	14,2
Greece	0,1	2,1	5	11,4	19,2	29,5
Italy	0,1	2,8	9,9	24,3	40,6	62,3
Portugal	0,2	2,9	16	34,5	57,5	88,7
Spain	0,5	8,5	56,7	119,3	199,5	306,4
Total	2	17	89,8	195	326	501

Figure 7.7 Power generation of solar thermal electricity plants in Europe 2010-2050 (TWh/year)
Source: ESTELA (European Solar Thermal Electricity Association) 2009

8

Bioenergy

STATE-OF-THE-ART TECHNOLOGY

Electricity can be produced from solid or wet biomass, through several conversion routes, using chemical, thermal or biological processes.

Biomass resources used for this purpose can come from forestry, agriculture, industry or waste sectors as summarized below:

- forest residues (wood blocks, wood chips);
- short rotation forestry (e.g. willow, poplar and eucalyptus);
- herbaceous ligno-cellulosic crops (e.g. miscanthus);

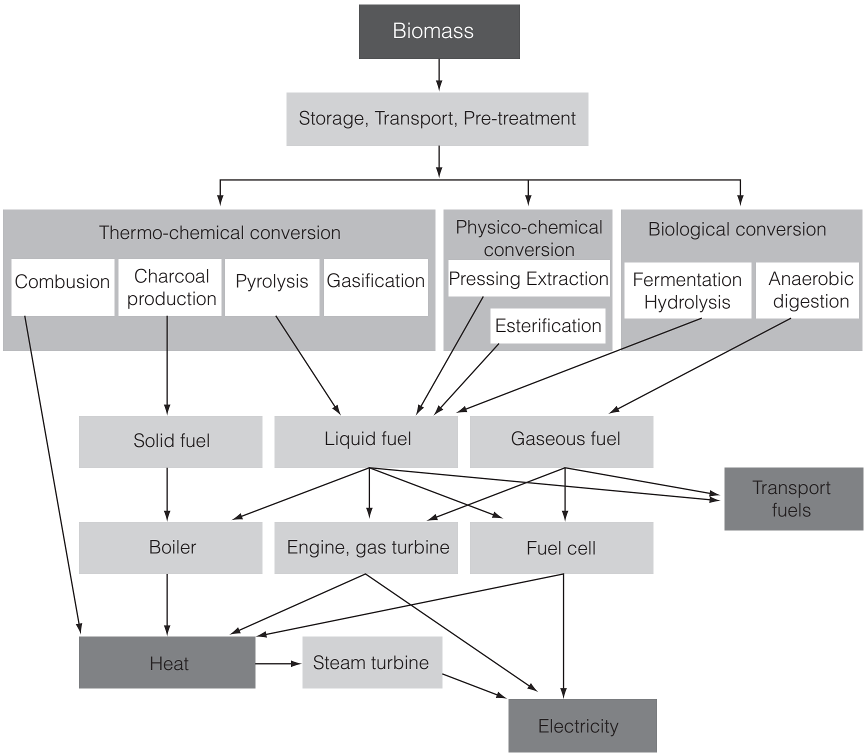


Figure 8.1 Conversion processes to bioenergy
Source: Adaptation from EUBIA (2007)

- agricultural by-products and residues (e.g. straw, animal manure, etc.);
- industrial residues (for instance, from the food and the paper industries);
- wood wastes (wood processing waste, construction residues);
- organic fraction of municipal solid waste and refuse sewage sludge.

Technological benefits

The main benefits of using biomass for electricity are:

- widespread availability;
- contribution to security of supply;
- can usually be stored in large amounts – and as a consequence, bioenergy can be produced when needed;
- creation of stable jobs, especially in rural areas;
- good opportunities to export developing technologies and know-how;
- carbon dioxide (CO_2) mitigation and other emission reduction (for instance Sox);
- high potential in the long term, if residues are properly valorized and dedicated energy crops are grown;
- valuable use of some wastes, avoiding their pollution and cost of disposal;
- increased efficiency of energy conversion and use and thus large cost savings.

Technological applications

Biomass-electricity conversion technologies can be separated into three basic categories: thermo-chemical conversion processes (combustion, Char, pyrolysis and gasification), physical-chemical conversion and biological processes (anaerobic digestion).

Thermo-chemical conversion processes

Thermo-chemical processes are used to convert the original bioenergy feedstock into more convenient energy carriers, such as producer gas, oil or methanol etc., under controlled temperatures and oxygen levels. These products can therefore be used in internal combustion engines and gas turbines as they have higher energy densities – and lower transport costs – or more predictable and convenient combustion characteristics, compared to the original biomass. Despite development which dates back to the 18th century, the commercial implementation of biomass gasification is still problematic. Very few processes have yet proved economically viable, although the technology has progressed steadily.

Gasification

Fuel gasification (and later combustion) is a thermo-chemical process that converts biomass into a combustible gas: the syngas. This gas contains carbon monoxide, hydrogen, water in a vapour form, carbon dioxide, tar and ashes. The low gas fuel is usually gasified to produce clean fuel for specific needs. This gas contains 70–80 per cent of the energy originally present in the biomass feedstock. It can be burned directly for central heating or drying, or it can be burned in a boiler to produce steam and, therefore, electricity. Higher quality syngas, after it has been converted into methanol, can be used for transport sector. If combined with a gas turbine or fuel cell, the gasifier can produce electricity. Products of gasification can also be used in heat or CHP applications. The producer gas is mostly intended for immediate use on site and the gasification unit is an integral part of the heat or power generating plant. In a small unit, the gas is mostly used in a combustion engine and, in a larger unit, in a gas turbine or combined cycle plant.

Direct combustion

One of the first technologies man used for his energy needs was burning wood and other solid biomass. Nowadays, the devices mainly used for direct combustion of solid biomass fuels range from small domestic stoves (1 to 10kW) to the largest boilers used in power and co-generation (CHP) plants (>5MW).

Firing in boilers or heat applications

Firing the raw gas in boilers or heat applications such as kilns after removal of dust and particulates is the simplest application since the gas is kept hot and the tar problem is avoided. This market is one where all types of gasifiers can compete. There are no moving parts and thus very low tar content is not essential if the wall temperature of the gas pipe system can be maintained above the level where tars condense.

Co-generation

There are four broad categories of co-generation application:

1. small-scale co-generation schemes, usually designed to meet electricity and central and water heating requirements in buildings, most based on spark ignition reciprocating engines;
2. large-scale co-generation schemes, usually associated with steam production for industrial and large buildings heating applications based on compression ignition reciprocating engines, steam turbines or gas turbines;
3. large-scale district heating infrastructure based around a power station or waste incinerator with heat recovery supplying a local heating network demand;
4. co-generation schemes fuelled by renewable energy sources, which may be on any scale.

In the last 15 years, significant technological progress has been made to enable engine and turbine technology to be widely implemented and to promote more decentralized forms of co-generation and power generation. Cost-effectiveness and decreasing emissions have often been the result. There are an increasing number of varied applications in industry and residential areas for heating and cooling.

Co-firing with coal and natural gas

Co-firing applications are perhaps the most efficient and interesting at present for an accelerated market penetration as the overall costs are relatively low due to the modest adaptation of existing coal fired power plants. In addition, co-firing has the advantage over co-combustion, where the biomass fuels are mixed with coal before or during the combustion process so that the biomass residual ash is not mixed with the coal ash, which already has a market as a construction material. Also the technical risks are low as the gas used is hot and therefore there is no tar problem. In reburning applications (when the fuel gas is introduced almost at the top of the coal boiler) it has been shown that the environmental performance of the power station is significantly improved, in addition to the benefit of replacing the fossil fuels with renewable biomass fuels. As with coal, fuel gas produced by biomass gasification can be co-fired with natural gas either directly in turbines, boilers or duct burners, or as reburning fuel. This could significantly enlarge the market options for biomass gasification. Calculations show a substantial increase in flame temperature and lower heating value by adding 25 per cent methane to gasifier fuel gas.

Charcoal production

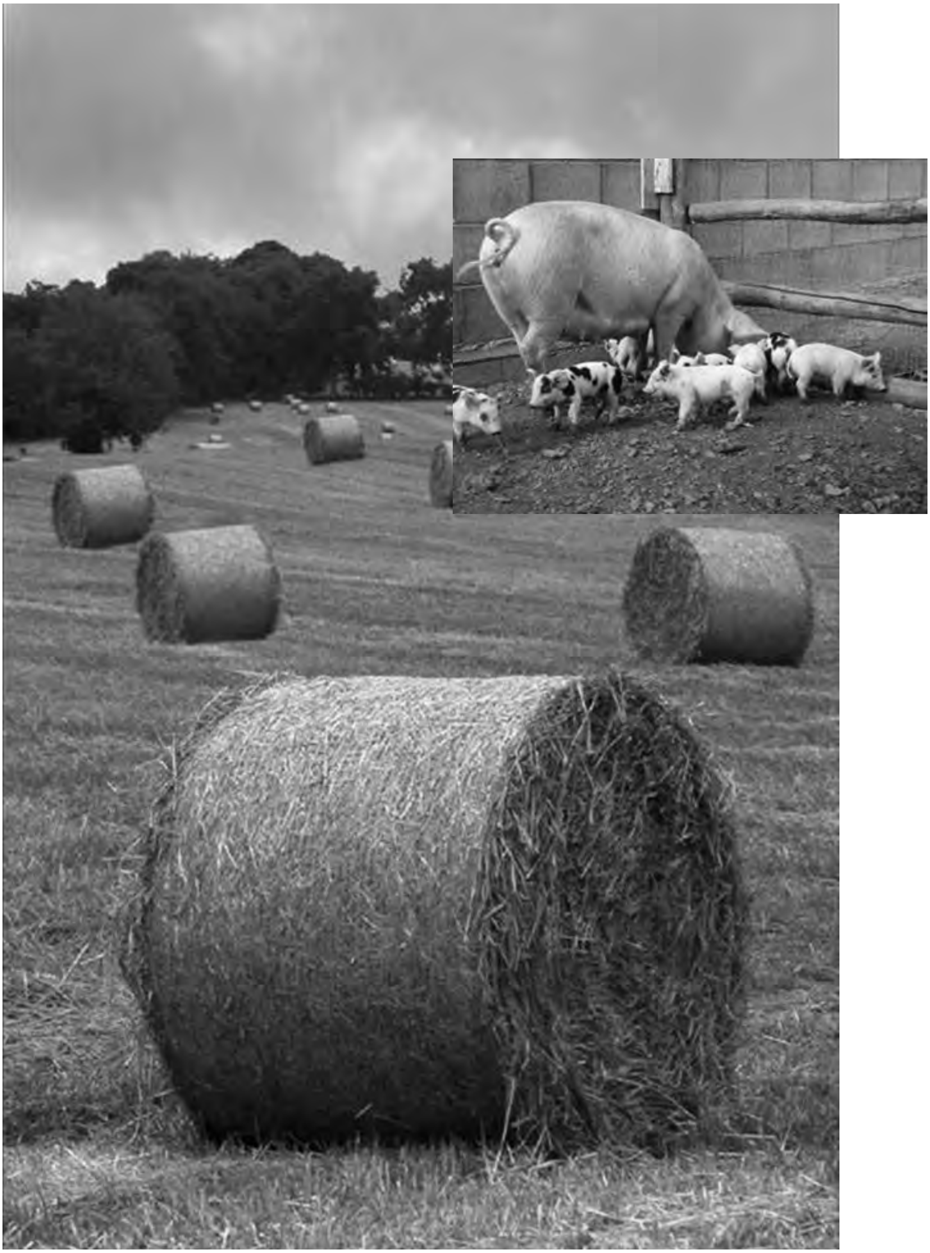
Charcoal is the blackish residue consisting of impure carbon obtained by removing water and other volatile constituents from animal and vegetation substances. Charcoal is usually produced by slow pyrolysis: the heating of wood, sugar, bone char, or other substances in the absence of oxygen. Firewood and charcoal for cooking and heating is widely used. For several hundred millions of people, it is already impossible to get a sufficient supply of firewood because of the ruinous exploitation of forests. Here the modern charcoal technology high-grade energy recovery systems can find a new outlet. Tapping the vast renewable biomass and waste reserves of the world, the charcoal industry can make one of its most important contributions to mankind by helping to provide for the energy needs of the future, especially in all developing countries.

Pyrolisis

Pyrolysis is medium temperature (400–600°C) material decomposition that occurs in the complete absence of an oxidizing agent, such as air or oxygen, or with a limited supply so as to prevent combustion. Products are solid (charcoal), liquid (the so-called bio-oil) and gaseous. Slow pyrolysis produces a large amount of solid products. Modern fast (flash) pyrolysis at moderate temperature provides up to 80wt percentage bio-oil. High temperature is required to obtain maximum gas production. During the process known as gasification this conversion is carried out through partial oxidation (in other words, more oxidizing agent than for pyrolysis but less than for complete combustion) of a carbonaceous feedstock such as biomass or coal. Until now, pyrolysis of biomass has been used for the production of charcoal for industrial or household markets. Refined bio-oil has so far only been commercialized for production of food additives. The bio-oil could also be used for the extraction of other special chemicals and the bio-oil as such could find a market as a long term substitute for petroleum products. However, bio-oil has some properties that trigger additional costs. It is unstable, acidic and corrosive which means that more expensive materials must be used in the burner nozzles and the entire fuel system. The bio-oil calorific value (typically ranging 17–20GJ/ton) is lower than conventional fuel oil (approximately 40GJ/ton) which leads to increased costs for transportation and storage. The viscosity of the oil increases during storage, therefore storage time should only be a few months or less. Whether or not the bio-oil is competitive with petroleum fuel oil depends on the feedstock costs and local fossil fuel oil price.

Biological Conversion Processes

Anaerobic digestion (AD) is a biochemical process that produces the so-called biogas through the bacterial breakdown of organic materials in the absence of oxygen. Biogas is a gas principally composed of methane and carbon dioxide and constitutes a sizeable and renewable form of energy. Natural gas also contains (higher quality) methane than other combustible hydrocarbons. Nevertheless, this is a non renewable fossil fuel. AD provides the possibility of producing renewable energy from organic wastes in decentralized sites, producing a methane rich biogas from manure (human and animal) and crop residues. Apart from supplying renewable energy, AD plants have other positive effects including the strengthening of closed loop recycling management systems, reducing emissions from manure storage and producing a valuable organic fertilizer.



Figures 8.2 and 8.3 Crop residues and animal manure for the production of a methane rich biogas
Source: EUBIA (2007)

It can also create new sources of income for farmers, although currently less than 1 per cent of the potential benefits from AD is being used. Reasons for this include obstacles such as high investment, the legislative framework and the lack of economic incentives for potential investors. For biogas the most efficient way of integrating the biogas into the entire European energy sector is by upgrading the biogas to natural gas quality and injecting it in the natural gas grid.

Table 8.1 Overview of costs of production of biomass resources

Country	Wages* €h-1	Fertilizer Prices** N €(10-2Kg)	P2O5	K2O	Land Costs*** VS €ha-1 yr-1	S	MS
Austria	15.08	54	49	18	274	209	143
Belgium	16.51	54	49	36	203	197	191
Bulgaria	0.77	18	21	21	72	50	28
Cyprus	6.64	57	51	40	178	135	92
Czech Republic	3.87	23	12	17	72	50	28
Denmark	31.37	54	49	29	359	346	334
Estonia	3.8	29	24	17	72	50	27
Finland	16.73	54	49	33	164	113	62
France	9.52	56	51	37	137	132	127
Germany	14.13	45	51	35	267	258	248
Greece	4.61	44	49	33	512	389	266
Hungary	3.77	43	20	20	65	45	25
Italy	14.38	57	49	38	309	232	155
Ireland	17.72	54	49	33	196	189	182
Latvia	2.04	28	20	14	14	9	5
Lithuania	2.40	28	28	21	14	10	5
Luxembourg	13.99	53	49	34	174	168	162
Malta	5.38	54	49	33	178	135	92
The Netherlands	18.96	54	49	41	409	392	375
Norway	20.12	54	51	43	353	341	328
Poland	3.06	18	20	20	72	50	28
Portugal	4.76	46	49	34	178	135	92
Romania	1.09	18	21	21	72	50	27
Spain	14.38	28	20	20	180	137	94
Slovakia	3.06	28	20	20	14	10	5
Slovenia	7.81	47	47	30	14	10	5
Sweden	12.66	54	49	33	110	76	42
Switzerland	17.35	54	51	35	270	205	141
Ukraine	0.43	18	21	21	72	50	27
United Kingdom	14.42	68	47	32	208	201	194
Average WEC	15.10	52	49	35	246	212	177
Average CEEC	2.92	27	24	21	50	35	19

* All data obtained from the LABORSTA (2006) database (International Labour Organisation, Department of Statistics online Database available at http://laborsta.ilo.org, accessed June 2006). Hourly wages are as presented. If only monthly wages were stated an average of 160 working hours per month is assumed in order to calculate hourly wages. Wages stated are for labour in the agriculture, hunting and forestry sector.

** Fertilizer prices are obtained from EUROSTAT (2006) data. For Bulgaria, Romania and Ukraine the price level of Poland is assumed since no data for these countries has been found. For Switzerland the price level of Austria is used. For Norway the price level of Sweden is used.

*** For Bulgaria, Estonia, Romania and Ukraine the price level of Poland is assumed. For Cyprus, Malta and Portugal the price level of Spain is assumed. For Latvia the price level of Lithuania is assumed. For Switzerland the price level of Austria is assumed.

WEC = West European Country (old EU 15 member states); CEEC = Central and Eastern European country (new EU member states)

Source: Copernicus Institute (2008)

Cost and prices

The cost for production of each biomass resource is quite difficult to evaluate and varies greatly from one region to another because of its link with agro-environmental factors. For the analysis of agricultural bioenergy crop production, four main costs have to be considered: land, labour, fertilizers and capital. Three of those (capital, labour, land) can be hectare based. The cost overview (see Table 8.1) is based on LABORSTA (2006) and EUROSTAT (2006) data. For some countries only scarce data were available and therefore reference was made for them to comparable countries, as indicated in the notes of Table 8.1. Three fertilizer market prices are presented for Nitrogen (N), Phosphor (P2O5) and Potassium (K2O). Three land quality land prices are shown for very suitable (VS), Suitable (S) and Moderately Suitable (MS) land.

Forestry residues costs

The costs of forest biomass are mainly due to the transport distance from the forest collection site to the plant. The plant size also has an influence.

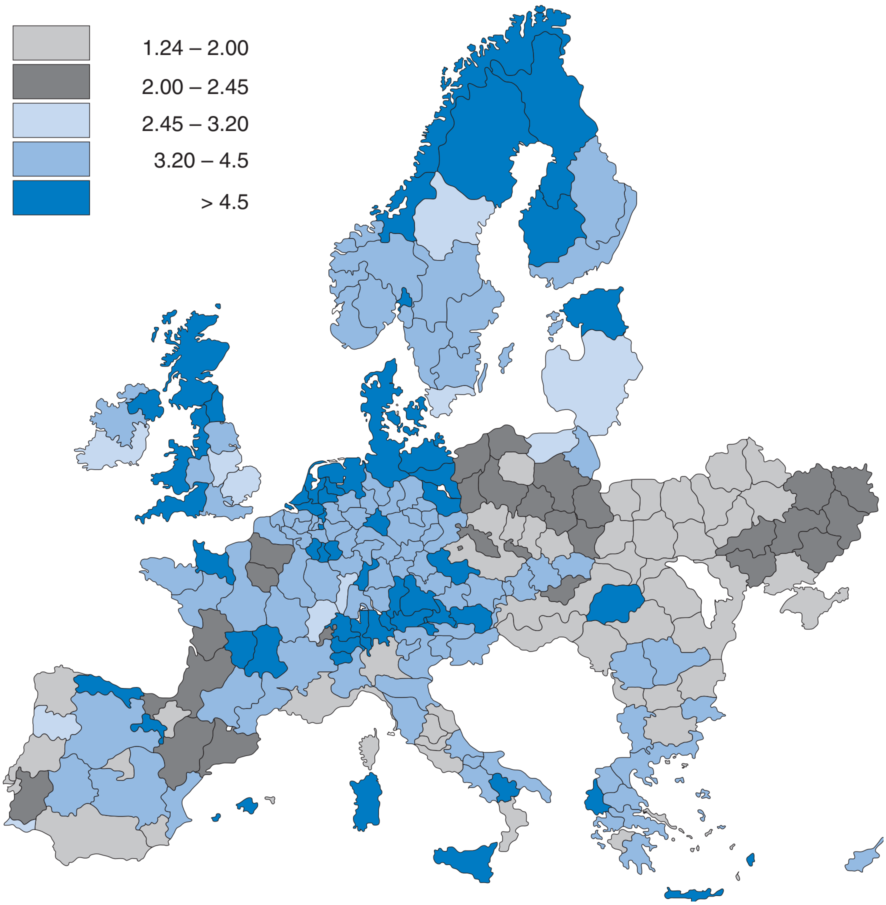


Figure 8.4 Spatial cost distribution for woody crops in 2005 (€/GJ-1)
Source: REFUEL Project 2008

Agricultural residues costs

The production costs for agricultural residues stem from collection on the field, field transport and transport to an intermediate or end use site. Due to the fact that agricultural residues are considered as by-products there is no real cost of production to be considered.

Table 8.2 Cost for agricultural residues

Country	€/GJ	Country	€/GJ
Austria	4.9	Lithuania	1.1
Belgium	3.9	Luxembourg	3.9
Bulgaria	1.1	The Netherlands	3.9
Czech Republic	1.1	Norway	3.5
Denmark	3.5	Poland	1.1
Estonia	1.1	Portugal	0.0
Finland	2.4	Romania	1.1
France	3.8	Spain	1.4
Germany	3.4	Slovakia	1.1
Greece	1.5	Slovenia	1.5
Hungary	1.1	Sweden	3.5
Italy	2.0	Switzerland	3.4
Ireland	6.5	United Kingdom	2.2
Latvia	1.1		

Source: VIEWLS – Deurwaarder (2004)

Table 8.3 Capital costs and efficiencies of principal bio-electricity and competing conversion technologies

Technology	Capital cost in 2002 (EUR/kWe)	Capital cost in 2020 (EUR/kWe)	Electrical efficiency (%)	Cost of electricity in 2020 ** (EUR/MWh)
Existing coal – co-firing	250	250	35–40	24–47
Existing coal and natural gas combined cycle – parallel firing	700	600	35–40	34–59
Grate / fluid bed boiler + steam turbine* biomass fuel	1500–2500	1500–2500	20–40	57–140
Gasification + diesel engine or gas turbine – (50kWe – 30 MWth)*	1500–2500	1000–2000	20–30	50–120
Gasification + combined cycle – (30 – 100MWe)	5000–6000	1500–2500	40–50	53–100
Wet biomass digestion + engine or turbine	2000–5000	2000–5000	25–35	52–130
Landfill gas + engine or turbine	1000–1200	1000	25–35	26
Pulverized coal – 500MWe	1300	1300	35–40	48–50
Natural gas combined cycle – 500MWe	500	500	50–55	23–35

* Larger scale systems will be characterized by the lowest cost and higher efficiency in the value ranges.
** 15% discount rate; biomass fuel cost between €7.2 and €14.4/MWh except for digestion and landfill gas plants where fuel cost assumed to be zero; coal cost €5.8/MWh; natural gas cost €5.4–€10.8/MWh. The cost is calculated for electricity supply only and co-generation could reduce the electricity cost significantly.
Source: Bauen et al, 2003 from EUB2 Market

MARKET

Installed capacity and market development in the EU and market segments

Europe is assisting in an expansion of biomass use for power and CHP generation. Austria, Germany, the United Kingdom, Denmark, Finland and Sweden are leading this process, mostly producing bio-electricity from wood residues and MGW in co-generation plants. A large part of these yields come from power plants belonging to the lumber and wood pulp (paper and chipboard panels) industry. Waste products, such as black liqueurs, wood waste, bark or sawdust, are also treated internally in large-scale power plants in CHP operation, which can use biomass alone, or mix it with other fuels. As well as producing electricity, heat and steam necessary for industrial processes, they generate surplus electricity that can be sold to the grid. Thanks to incentive schemes recently granted in those countries (guaranteed feed-in tariffs, call for tender procedures and green certificates) new power plants have been implemented using biomass over the last few years. EurObserv'Er states a slow down in solid biomass electricity growth in 2007 (+4.4 per cent with respect to 2006, in other words, an additional 2.1TWh) after their strong growth in the previous two years (+11.4 per cent between 2004 and 2005 and +13 per cent between 2005 and 2006). CHP (combined heat and power) systems remain the principle technology used to produce electricity from solid biomass, representing three-quarters (76.8 per cent) of total electrical production in 2007. See Table 8.4 for an overview of gross electricity production in 2006 and 2007 and Figure 8.5 for the overview of the development of the bio-electricity sector compared to other renewables up to 2007.

Table 8.4 Gross electricity production from solid biomass in the European Union in 2006 and 2007

Country	2006			2007*		
	Electricity plants only	CHP plants	Total electricity	Electricity plants only	CHP plants	Total electricity
Finland	1532	9007	10538	1164	8647	9811
Sweden	0	7503	7503	0	8538	8538
Germany	0	7225	7225	0	7390	7390
United Kingdom	3324	0	3324	2920	0	2920
Austria	1020	1533	2554	1154	1734	2888
Italy	1513	979	2492	1666	815	2482
Poland	0	1851	1851	0	2360	2360
The Netherlands	699	1141	1840	735	1235	1970
Denmark	0	1778	1778	0	1829	1829
Belgium	1079	327	1406	1287	513	1799
Spain	275	1298	1573	272	1281	1553
Portugal	78	1302	1380	166	1366	1532
France**	444	806	1250	568	822	1390
Hungary	1106	27	1133	1119	28	1147
Czech Republic	288	443	731	372	596	968
Slovakia	0	367	367	0	436	436
Slovenia	2	74	76	0	63	63
Lithuania	0	19	19	0	48	48
Estonia	0	25	25	0	25	25
Ireland	0	8	8	0	13	13
Latvia	0	6	6	0	5	5
Romania	0	4	4	0	4	4
Total	11,361	35,724	47,085	11,423	37,748	49,171

Note: * Estimate. ** Overseas departments not included for France. They represented a production of 541 GWh in 2007 (463 GWh in 2006)
Source: EurObserv'Er (2008)

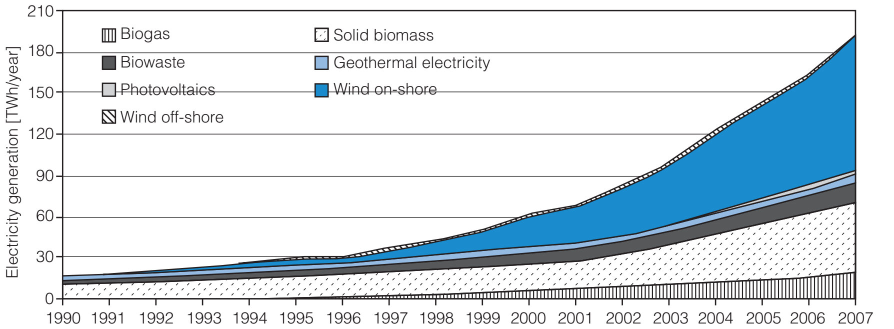


Figure 8.5 Overview of the development of the bioelectricity sector compared to other renewables up to 2007
Source: Held et al (2008)

In the EU both the primary production of biogas and the gross electricity production from biogas increased by almost 18 per cent between 2006 and 2007. The greatest share of this growth was achieved in Germany, and German biogas companies also expanded their business in 2008, despite rising biomass costs. Small-scale electricity production is one of the strong suits of biogas use as this co-generation is very effective with regard to the ratio of heat and power. Technological advances in recent years allow parity in the energy output, corresponding to 1kW electric for every kW.

Industry

Many industries, organizations and research bodies are involved in the biomass for electricity sector, which are scattered and very diverse in size. As a result, there isn't currently a bioenergy community or bioenergy industry in Europe as such. The sector cross cuts the forestry, agricultural, chemical, food, feed, power and heat industries. Therefore to speak of a bioenergy 'industry' is an oxymoron. However, in general to classify this sector, the term 'biopower' industry could be used to define biomass for electricity production. Unstable fuel prices and an increase in energy demand make power generation from biomass more economically competitive than ever before. Combined with the recent EU legislation on promoting energy from renewable sources, the biopower industry has huge growth potential. Biomass for electricity generation will play a vital role in achieving the 20 per cent share of renewable energies by 2020. Both government and industry are already investing strongly in innovation in biomass based power generation and will need to work together to deliver on the long term objectives. Currently under preparation in coordination with the Biofuels Technology Platform and other Biomass Associations, the EU's Bioenergy Industrial Initiative is one such tool to secure the long term objectives if it is run in close cooperation between the EU Commission and industry stakeholders. In the biopower sector, the industry has to take a leading role in the development of innovation in biomass based power technologies and their subsequent deployment. Technological evolution will be important for the future of the industry, but in the meantime it must find avenues to commercial success by using existing technologies. The power industry and utilities need to invest in biopower, as today's investment decisions will define the energy supply of the next generation. Co-firing is the technology with the largest growth potential in the power sector and is the most cost effective method for

	2006	2007
Germany	7446.0	9520.0
United Kingdom	4881.1	5194.7
Italy	1303.7	1381.9
Spain	666.3	668.1
France	522.7	637.7
Netherlands	361.3	497.4
Austria	447.1	492.6
Belgium	278.9	279.4
Denmark	271.2	270.6
Czech Republic	175.8	222.9
Greece	107.9	175.3
Poland	160.1	160.1
Ireland	122.0	118.8
Portugal	32.6	65.4
Slovakia	34.7	48.2
Latvia	35.0	36.9
Luxembourg	32.6	36.6
Sweden	34.7	36.0
Finland	22.3	22.3
Hungary	22.1	22.1
Estonia	14.1	14.1
Lithuania	5.4	6.3
Slovenia	4.0	4.0
Cyprus	0.1	1.4
Total EU	**16981.8**	**19931.9**

* Estimation.

Figure 8.6 Gross electricity production from biogas in the European Union in 2006 and 2007*(GWh)
Source: EurObserv'Er, 2008.

large-scale power generation from biomass, which is particularly relevant for power utilities. Traditional electricity utilities will continue to look at co-firing and 100 per cent biomass fired plants. Due to their small size, dedicated biomass power plants are more expensive than co-firing plants but dedicated biomass plants and dedicated biomass CHP plants are becoming more economically viable. With growing landfills waste-to-energy has become one of the booming sectors in biopower generation. Despite recycling and waste reduction schemes, waste-to-energy is seen as the most viable large-scale alternative to landfills. The Biogas sector will experience growth as traditional gas utilities will need to deploy more renewable generation, and upgrading biogas to natural gas quality and injecting into the natural gas grid is a natural option for gas utilities. In the coming years the economy of scale of upgrading facilities will be met by competition from economy of numbers of installations. It is obvious that the treatment price will be reduced due to the increasing numbers of upgrading facilities installed and also by the economic downscaling of the upgrading facilities fitting to the modular biogas plants existing in countries such as Germany and Austria. Industrialists are more and more interested by the biomass CHP market, while this market is currently much more developed in the very high capacity sector (industrial boilers of the forestry sector). This market's rise in importance is explained by the revalorization of the feed-in tariffs for biomass electricity and by the setting up of green certificate systems backed up by quotas in EU member states. The most critical non-technical barrier to bioenergy is likely to be the availability of resources to ensure long-term continuous large supply at a reasonable cost for the market users. The supply of resources is key for bioenergy. Indeed developing a sustainable supply chain for biomass feedstock for the biopower industry, and indeed biomass for heating purposes is crucial to realizing the long term development potential. Sourcing adequate supplies of feedstock will be the biggest challenge facing the future of the bioenergy industry, as competition for supplies is getting fiercer. Bioenergy is going to commoditize quickly and must make use of all the outputs from its feedstock; going forward 10 or 20 years, there will be a pull on the entire biomass supply chain from a number of sectors – energy, biofuels, and bio-renewable chemicals for example – therefore the industries from the food, agriculture, energy, oil and forestry sectors must come together to a secure and reliable feedstock supply chain and to secure the growth of a future bioenergy industry.

Policy instruments to support the technology

There is significant potential for the development of RES-electricity in the EU, and the use of biomass to produce electricity can substantially contribute to increasing the share of RES in the EU energy mix. EU policy has addressed this sector through policy initiatives, predominantly by setting targets for the promotion of the use of biomass in electricity. For an overview of relevant EU policy which has supported biomass use for electricity please see Table 8.5 opposite.

With the directive for the promotion of energy from renewable sources (RES Directive), adopted by the European Parliament in December 2008 and officially endorsed by the Council in April 2009 (European Commission 2009, Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable source, J OJ l140 of 5.6.2009), significant regulatory measures to promote biomass use for electricity are imminently to become EU law. The overall mandatory EU target of 20 per cent by 2020 and individual national targets provide a necessary stabilizing mechanism for the biomass for electricity market and incentivizes the development of biomass technology in EU member states. The biomass industry is expected to contribute over half of this overall EU target, roughly 12 per cent, through the applications of biomass for energy purposes in transport, electricity and in heating. As far as biomass for electricity is concerned, it is expected to contribute 250TWh/yr by 2020. Under the RES Directive, EU countries are required to take 'the appropriate steps to develop transmission and distribution grid infrastructure, intelligent networks, storage facilities and the electricity system' to help develop renewable electricity (including biomass for electricity). EU countries must also speed up authorization procedures for grid infrastructure and ensure that transmission system operators and distribution system operators guarantee the transmission and distribution of biomass for electricity and provide for either priority access to the grid system – meaning that connected generators of biomass for electricity are sure that they will be able to sell and transmit their electricity – or guaranteed access: ensuring that all electricity from renewable sources sold and supported gets access to the grid. This ensures an easier access for biogas and

Table 8.5 Overview of relevant EU policy which has supported biomass use for electricity

Directive/Communication/ Date Published	Support for the development of Biomass for Electricity
White Paper : Energy For the Future: Renewable Energy Sources of Energy COM(97)599 final [26 November 1997]	The White Paper sets a target for 2010 of 12 % for the share of RE in total EU energy consumption. For biomass, an indicative target of 150Mtoe per year in the EU25 in final energy was set– an increase from 45Mtoe (EU 15) from the 1995 benchmark date for bioenergy use in the EU.
Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal electricity market [27 September 2001]	This directive establishes a framework to increase the share of 'green' electricity from 14% to 22% of gross electricity consumption by 2010, which enabled the promotion of RES-E from solid biomass, biowaste and biogas in member states.
Directive 2004/8/EC on the promotion of co-generation (CHP) based on a useful heat demand in the internal energy market [11 February 2004]	This directive obliges member states to analyse the potential of co-generation in their own country and to provide support mechanisms to encourage the development of the technology in the market.
Communication from the European Commission (COM(2004) 366 final) on the share of renewable energy in the EU [26 May 2004]	Despite the incentives for biomass to be used for electricity, set out by the 2001 Directive, and the 2010 White Paper target, the development of bio-electricity was less important than expected and an additional effort at the EU level was deemed necessary in order to achieve the 2010 target.
Communication from the European Commission (COM (2005) 628 final) Biomass Action Plan (BAP) [7 December 2005]	The BAP recommends an increase in biomass use by 80Mtoe per year, which means an increase of 35Mtoe/yr in the electricity sector more specifically, in order to reach the 2010 target. The Biomass Action Plan sets out 32 key activities for boosting the bioenergy market.
Communication from the European Commission (COM (2006) 302 final) on an EU Forest Action Plan [for 2007–2011] [15 June 2006]	The Forest Action Plan aims to promote the use of forest biomass for energy, particularly by developing the pellet and wood chip markets.
Directive 2009/.../EC for the promotion of energy from renewable sources [RES Directive] [May/June 2009]	The directive sets an overall binding 20% target for RES in the EU by 2020. Also sets mandatory national targets, and improves grid access.

Source: AEBIOM/EUBIA

biomethane to the electricity grids and to the gas pipelines. Prior to the RES Directive, the RES-E Directive set national targets for renewable electricity and led to the establishment of specific feed-in tariffs for electricity from all RES, which includes biomass in most of the EU member states and tradable green certificate schemes in five EU countries. See Table 8.1 for an overview of Primary Support Schemes. According to the International Energy Agency's Deploying Renewables report (2008), the most successful countries in deploying biomass electricity are the Netherlands, Sweden, Belgium and Denmark (for 2000–2005). The case of solid biomass generally shows that different types of incentive schemes can be effective. For example, in Sweden, quota obligation systems have been effective at a moderate cost, while in Belgium, the quota obligation system has encouraged biomass deployment at a high cost. In the Netherlands and in Denmark, feed-in tariff and premium systems are in place.[1] The highest growth in biogas generation for 2000–2005 was in Germany, the United Kingdom and Luxembourg, with Germany and Luxembourg applying a feed-in tariff support scheme and the United Kingdom a quota obligation system with tradable green certificates. Besides the United Kingdom, Italy's quota obligation system has shown some of the highest effectiveness levels, with strong growth in both countries being mainly based on an expansion of landfill gas capacity, thus producing methane which is cheap compared to other biogas feedstocks.

Key countries and success stories

The region of the world that has invested the most in electrical valorization of biomass is western Europe with 38.7 per cent of world biomass electricity. Germany is the second world-leading producer country with 26.1TWh. In 2007 biomass electricity was particularly sustained in central Europe (+73 per cent, in other words an additional 3.2TWh) and western Europe (+15.1 per cent, in other words an additional 11TWh). Western Europe is the region by far the most involved in developing biomass electricity, with an average of +12.3 per cent per year between 1997 and 2007. It represents 55.8 per cent of the increase in production for the period 1997–2007. The strong rise in the price of fossil fuels should keep biomass electricity at high growth levels, notably thanks to development of CHP plants that optimize biomass' energy yield in producing both electricity and heat. Technological progress in terms of biomass gasification could make it possible to accelerate biomass electricity. The advantages of gasification over direct combustion are found in a greater cleanness of combustion (absence of ashes and tars), in the possibility of obtaining higher yields due to higher combustion temperatures and the possibility of valorizing the energy contained in the exhaust gases of gas turbines.

Gothenburg, Sweden

Gothenburg's integrated waste system is one of the best in Europe: it collects, sorts and burns the town's 345,000 tons of annual rubbish thus making electricity and heat as well as reducing landfill to a small fraction of the total waste collected, and cutting emissions by over 200,000t CO_2 per year (25 per cent of the city's CO_2 emissions from energy consumption). Private companies contract waste management services through bids for tenders whereas the local authority is responsible for the collection and treatment of household waste (around 40 per cent of the yearly total amount of waste mainly from business and industries). There are 350 collection points throughout the city. Citizens have to sort and deposit their various kinds of waste, such as glass, metal

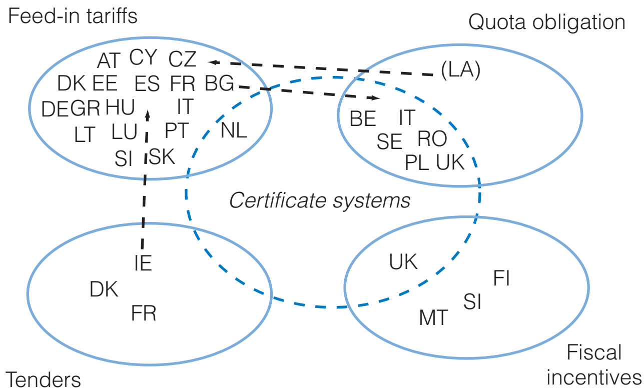


Figure 8.7 Policy instruments adopted in EU member states
Source: Reece (2008)

cans, cardboard, newspapers and batteries. Industry associations are responsible for organizing the contracting of waste management firms to handle the waste. They can opt out of this system provided they set up alternative measures. Waste is only removed by contractors if it has been separated for recycling, meaning 19 per cent of total waste and 33 per cent of household waste is recycled. Thus Gothenburg only needs fossil fuels in winter when the Swedish climate is at its most extreme. Continuous technological advances allowed a total of 1418GWh energy production by waste incineration (1212GWh for heating and 206GWh for electricity) in 2006, at the same time reducing the amount of dust and particulate produced in the burning process. Furthermore, with the 2008 EU legislation on landfills, new rules are applied on both volume and fraction of waste produced so as to boost their reduction. New possibilities are being researched on new organic waste, recycle and reuse exploitations as well as incentive-based schemes.

Güssing, Burgenland, Austria

Güssing (27,977 inhabitants) is an example of how renewable energy technologies can activate the economical situation of a community, also creating employment. The turning point for Güssing arrived in 1991 when policy-makers decided to gain energy independence to alleviate the poor economic situation of the area: with a high unemployment rate and a low density of companies, the district revenues of the area were also suffering because of energy imports. So an energy concept was developed in 1991 mainly based on biomass exploitation, as more than 40 per cent of the district is covered in woodland. EU funded projects allowed the implementation of more than 30 energy plants using various technologies in the district overall. One of the most important projects was a biomass power plant erected in 2001. This new type of power plant was developed to make the production of electricity from organic matter possible in small, decentralized power stations. Through a steam gasification process, the plant produces 2000kW electricity and 4500kW long-distance heating energy using 1760kg of wood per hour. The efficiency reached is 25–28 per cent in electricity and more than 85 per cent if heat production is included. Not only has the city of Güssing now become energy independent, but also it manages to have an overproduction that is being exported, thus contributing to the €13.6 million additional value created in the city. The district is also on its way to energy autarchy. The degree of self-sufficiency is 47 per cent in fuels, 34 per cent in electricity and 71 per cent in heat. The regional added value in the district is €18.6 million. In this process 1000 jobs were created over 15 years and 50 new companies (mainly in the area of renewable energy) were set up. Eco-tourism also contributes to the local GDP. New technologies and applications are being researched in order to improve the results already achieved. To this purpose, in 1999 the Renewable Energy Network (RENET) and, in 2001, the European Centre for Renewable Energy were founded and new projects are being set up, which also include qualifications for technical experts (such as electricians and plumbers) in the solar power sector.

TOMORROW

Technology targets by 2020 and beyond

Although significant progress has been achieved and new improved technologies are being demonstrated, gasification of biomass remains in the developmental stage, with rare exceptions. The reasons are its relatively high cost compared to combustion and the low reliability for long-term operation. The possibility of delivering a clean gas, free of particulates and tars, would turn out to be key progress on the road to a market penetration. Indeed, future market opportunities exist for liquid biofuels production via synthesis gas, however a significant amount of work has still to be done before such plants could be considered by the financial community. Although fast pyrolysis technologies for the production of liquid fuel have been successfully demonstrated on a small scale, and several large pilot plants or demonstration projects are in operation or at an advanced stage of construction, they are still relatively expensive compared with fossil-based energy and thus face economic and other non-technical barriers when trying to penetrate the energy markets. As with biomass gasification, fast pyrolysis will only be able to penetrate energy markets if completely integrated into a biomass system. R&D to develop fast pyrolysis technology should still focus on ensuring the reliability of the processes in the value chain of the development of fast pyrolysis as well as ensuring the high quality of the end product and demonstrating applications for the use of the bio-oil. Cost-effectiveness throughout the process is also a key R&D preoccupation. However, bio-oil production can also be considered as means of biomass pre-treatment for transportation purposes over long distances from several production facilities supplying very large bio-refinery facilities or facilities for the production of synthetic biofuels.

Technological long term potential

Biomass resources and potential are considerable. Estimations vary according to the calculation methodology and the assumptions made (e.g. land use patterns for food production, agricultural management systems, wood demand evolution, production technologies used, natural forest growth etc). It is also common to distinguish several potentials:

- Theoretical potential: the theoretical maximum potential is limited by factors such as the physical or biological barriers that cannot be altered given the current state of science;

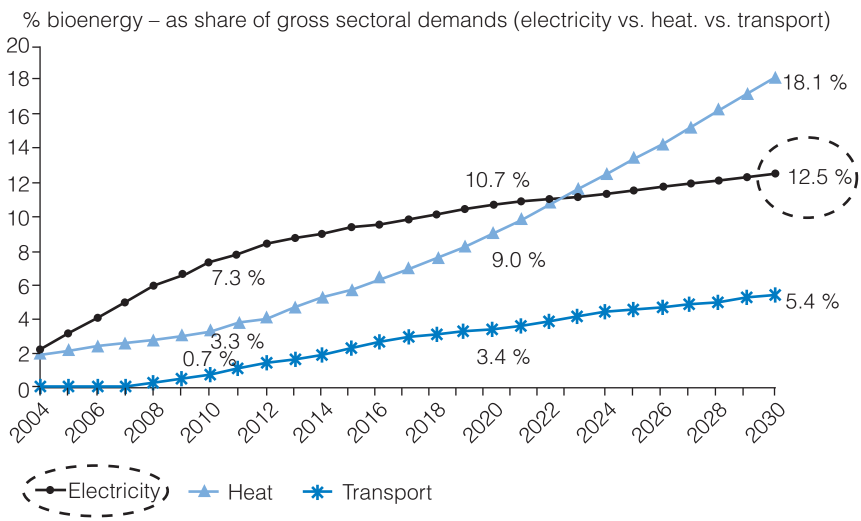


Figure 8.8 How much biopower?
Source: EEA (2008)

- Technical potential: the potential that is limited by the technology used and the natural circumstances;
- Economic potential: the technical potential that can be produced at economically profitable levels;
- Ecological potential: the potential that takes into account ecological criteria, e.g. loss of biodiversity or soil erosion.

The 2008 EEA Report 'Maximising the Environmental benefits of European bioenergy' assessed the environmental impacts of various ways of converting the technical bioenergy potential into electricity, heat and biofuels. It is based on 2006 EEA report 'How much bioenergy can Europe produce without harming the environment', according to which, if the theoretical potential estimated was viable in economic and logistics terms, in 2030 bioenergy would meet 12.5 per cent of electricity demand.

NOTES

1 Leader+ and Interreg IIIa programmes were mainly used, but the Objective 1 status of Burgenland was also very important.

9

Small Hydropower

Approximately 70 per cent of the earth's surface is covered with water, a resource that has been exploited for many centuries. Many tens of thousands of watermills were in regular use across Asia and Europe by the 18th century, mostly for milling grain. They ranged from simple Norse wheels (25,000 of which are still in use in Nepal) to sophisticated waterwheels fitted with speed-governing mechanisms. Challenged by coal-fired steam engines in the 19th century, however, hydropower had to become faster and more efficient. For centuries, civilizations have taken advantage of the power of water. Once used by Greeks to grind wheat into flour, the water wheels of the past have been updated to today's highly efficient turbines that generate electricity by a spin of water. Small hydropower, defined by installed capacity of up to 10MW,[1] is the backbone of electricity production in many countries in the EU.

STATE-OF-THE-ART TECHNOLOGY

Small hydropower (SHP) is based on a simple process: taking advantage of the kinetic energy and pressure freed by falling water of rivers, canals, streams and water networks. The rushing water drives a turbine, which converts the water's pressure and motion into mechanical energy, converted into electricity by a generator. The power of the scheme is proportional to the head (the difference between up- and downstream water levels), the discharge (the quantity of water which goes through the turbines in a given unit of time) and the efficiency of the turbine.

Various types of turbines exist to cope with different levels head and flows. There are two general types of turbines: impulse and reaction. The most commonly used impulse turbine is Pelton and reaction turbines such as Francis and Kaplan.

Technological benefits

Hydropower can be one of the most reliable and cost-effective methods to generate electricity. The concept is designed in a way that it can immediately respond to fluctuations in electricity demand meeting both base-load and peak-load demand. Hydropower's chief advantage is that it provides a steady and secure source of electricity supply. Because it is fuelled by water, it does not pollute the air or produce any other liquid or solid wastes. Other benefits may include water supply during dry summer months and flood control, which are growing in importance with regard to climate change effects. Hydropower is also essential in order to stabilize the European power grid. With more than 17,800 SHP schemes and a total of 40517GWh[2] electricity produced from SHP in the EU-27, the SHP sector plays an important part in meeting

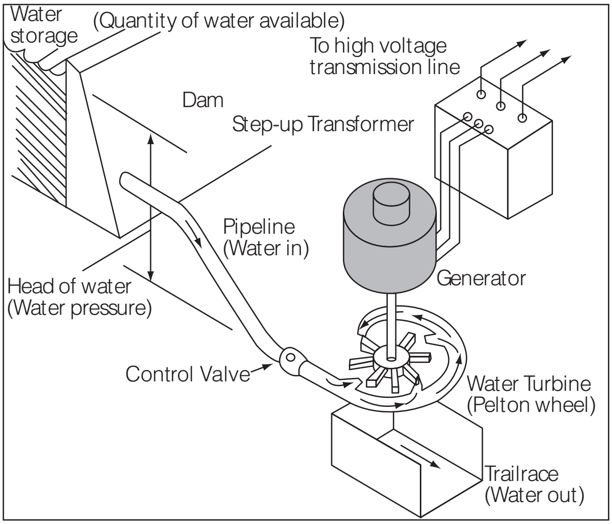


Figure 9.1 Small hydro scheme – how it works
Source: ESHA

Figure 9.2 Setting of a Pelton Turbine
Source: MltyLab, Switzerland

Figure 9.3 Pelton turbine
Source: Andritz Hydro SA

today's urgent need for clean energy. We can summarize hydropower's benefits as follows:

- clean, sustainable and emissions-free source of renewable energy;
- indigenous resource;
- highly efficient (from 70–90 per cent);
- proven and reliable technology;
- relatively low operation and maintenance costs (typical cost ratio 3–5 per cent);
- long lifespan up to 100 years;
- attractive energy pay-back ratio;
- tool for flood prevention and control;
- improves grid stability;
- electricity storage applications;
- technology suitable for rural electrification notably in developing countries.

A well-designed small hydropower system can blend in with its surroundings with no environmental impacts. SHP schemes are mainly run-of-river with little or no reservoir impoundment. SHP is not simply a reduced version of a large hydropower plant, but specific equipment is necessary to meet fundamental requirements with regards to simplicity, high-energy output, environmental measures and maximum reliability. The principal requirements for a project are: discharges; hydraulic head; means of transporting water from the intake to the turbine, such as pipe or millrace; turbine house containing the power generation and regulation equipment; tailrace to return water to its natural course and mechanical or electrical connection to the load to be supplied.

Technological applications

Multipurpose plants

Competition for the use of water has always been strong and climate change is expected to make matters even worse. Multi-use of water resources can reduce this challenge. Multipurpose developments intend to make an optimal use of the community's hydraulic resources, by combining electricity production with other water uses such as irrigation, flood control, recreation and drinking water supply. This means that multiple use of water is connected with small hydropower plant realization. Multipurpose schemes successfully allow compromise among different public interest while such electricity production impacts less on the environment, as the infrastructure is already there with its own impacts, and the turbine integrates itself to the network and recovers the energy formerly lost into pressure breakers.

Examples of multipurpose SHP plants include:

- **Drinking water supply systems**: in recent decades many small hydropower plants have been put into service in drinking water systems, especially in mountain areas, where small turbines have been installed instead of pressure reducing devices to exploit head otherwise dissipated. This way the surplus water pressure can be exploited for energy production giving additional economical benefits.
- **Irrigation channels**: many small hydropower plants have been put into service in irrigation networks or channels, especially in plains where dozens of low head plants exploit the water resource both for irrigation and energy production purposes, supplying energy to the grid or to match electricity demand directly for irrigation (e.g. pumping stations).
- **Flood control and protection**: in many small hydropower plants the river banks near to the diversion works must be rearranged and raised above their normal level. Such an action results in an increase of the water level and consequently of the flow rate which the river can convey during floods. Another way to achieve flood protection is the use of the basin to store part of the water volume during floods, although the available volume of storage in small hydropower plants is usually small compared with the demands of flood protection.
- **Creation of an environmentally friendly recreation area**: as a mitigation measure to be taken in an SHP plant realization, the creation of adjoining environmental areas is often put into effect. These areas contribute to making the SHP plant more easily acceptable from the environmental point of view. Also in some countries there are old, abandoned water-mills that can be upgraded and re-used. In this way, an existent energy potential can be used and hydroelectricity becomes an opportunity to safeguard cultural and historical heritage.
- **Waste water treatment plant**: there are at least two places within a waste water treatment plant to insert a hydropower installation – above the plant and below the plant. For example in alpine regions sometimes there is a central treatment plant down in the valley where the waste water is collected from smaller villages high up in the mountains. The head in such cases is reasonable. A pre-treatment (e.g. trash rack which removes trash from the water to avoid it entering the plant waterways and damaging electromechanical equipment or reducing hydraulic performance) before entering the pressure pipe is necessary. In cases of larger treatment plants the head available downstream between the treatment and the river may be used. No additional cleaning procedures are necessary for the turbine, apart from a traditional screening upstream.

- **Recreation purposes**: in some poundage plants the water level in the basin has to be kept higher than a prefixed level to allow angling or other recreation activities, so that only part of the water volume available can be stored for hydroelectric purposes.
- **Pumped-storage**: pumped storage hydroelectricity is a type of hydroelectric power generation used for load balancing. It allows energy to be stored in such a way that it is possible to release it very quickly when needed. This immediate power generation helps prevent power cuts, thus offering a critical back-up facility during periods of excessive demand on the national grid system. Pumped-storage is also used to level the fluctuating output of intermittent power sources. This application will gain importance in the future when combining with other RES in order to guarantee the energy supply and the grid security.

Cost and prices

Generally, a hydro system requires substantial initial capital investments but has low operating costs. It is considered that the location and site conditions determine 75 per cent of the development costs. Only about 25 per cent of the cost is relatively fixed, being the cost of manufacturing the electromechanical equipment. When creating a financial plan for SHP, the fact that high costs of hydro-technical infrastructure and the project lifetime of SHP are longer than the period of capital return should be taken into consideration. In the case of SHP, a major cost component can be the preparation of project documentation and the feasibility study – this can amount to 50 per cent of the costs. The investment costs of an SHP project depend on: type of SHP (run of river, reservoir); installed power and number of hydro-generators; usable head; capacity of water reservoir and local circumstances (terrain configuration, length and height of any basin embankment, hydrological conditions, costs of land use, etc.). A general SHP project cost level is very difficult to present, because projects are neither uniform nor comparable. Depending on the local environmental conditions, different solutions are used for different locations, hydro-technical constructions, turbines and electrical equipment. Table 9.1 shows the different production and investment cost in the EU.

The percentage contribution of the main costs to the total cost of investment is shown in the Table 9.2.

Table 9.3 shows the prices paid to small hydropower plants in the EU. In some countries the price is not fixed and market rules are applied to the sale of SHP production. This does not favour the development of new schemes, which are easier to exploit under a price system that reduces uncertainty and guarantees cash flow for long enough to satisfy investors.

Other issues to be taken into account are the water fees, cost of administrative procedures and the environmental integration.[3] Fish protection is one of the major problems faced by SHP investors. SHP stations must be equipped with the hydro-technical equipment designed for these purposes, such as fish-passes, fish ladders/lifts, by-pass canals, screen plates and cover bars.

Table 9.1 Investment and production costs of SHP plants in the EU in 2008

Country		Range of investment costs Euro/kW		Average SHP production costs Eurocent/kWh	
Austria	AT	2900	4300	3.6	14.5
Belgium	BE	3700	4960	1.8	
Finland	FI	1750	5400	3	3.5
France	FR	1850	4000	0.5	1.8
Germany	DE	5000	12,000	0.7	1.1
Greece	EL	1000	2000	2.4	4.2
Ireland	IE	1600	5000	0.87	6.34
Italy	IT	2150	4500	10.5	17.4
Netherlands	NL				
Portugal	PT	1800	2500	0.56	0.6
Spain	ES	1000	1500	3.5	7
Sweden	SE	2150	2500	2	4
United Kingdom	UK	6000	8000	7	9
Bulgaria	BG	1000	1500	0.4	0.8
Czech Republic	CZ	1000	6000	1	
Estonia	EE	1000	4000	2	5
Hungary	HU	n/a		n/a	
Latvia	LV	1800	2000	1	
Lithuania	LT	2200	2500	2.5	3
Poland	PL	2200		3	4
Romania	RO	1250		4	
Slovakia	SK	6600	8500	0.6	0.8
Slovenia	SI	1500	3000	n/a	

Source: ESHA

Table 9.2 Investment cost breakdown by percentage

Element of investment	Participation up to (%)
Hydro-technical construction	60
Turbines	25
Building	5
Electrical Equipment	10
Cost of exploitation	0.5

Source: Bobrowicz (2006)

Table 9.3 Prices for SHP generation in some EU member states, 2008

Country	Compensation Scheme	Price for sale to the grid (c€/kWh)
Denmark	Transition period from fixed price to green certificates.	8.48
Germany	Feed-in tariff	7.67 (< 500kW) 6.65 (500kW–5MW)
Ireland	Feed-in tariff	7.2
Italy	From 1 January 2008: Quota + tradable green certificates (GC): the quota should increase by 0.75% each year starting from 2007. The grid authority fixes a cap (upper) price for green certificates every	Old plants: Plants < 1MW: First 250MWh: €136/MWh + GC (12 years) From 251 to 500MWh: €104/MWh + GC (12 years)

Table 9.3 (continued)

Country	Compensation Scheme	Price for sale to the grid (c€/kWh)
	year. Certificates are issued only for: – the first 15 years of operation: plants commissioned after 1 January 2008 – the first 12 years of operation: old plants (commissioned between 1 April 1999 and 31 December 2007)	501–1000MWh: €84/MWh + GC (12 years) 1001–2000MWh: €8/MWh + GC (12 years) Plants > 1MW and < 10MVA: Hourly zonal price (market price) + GC (12 years) New plants (commissioned after 1 January 2008) Plants < 1MW: feed-in tariff 220 €/MWh Plants > 1MW and < 10MVA: market price + GC (15 years)
Portugal	Feed-in tariff	Old tariff 8.5 New tariff 7.0
Finland	Nordpool (common Nordic power market for Finland, Sweden, Denmark and Norway) market plus premium	2.6 (market price) + 0.42 premium if < 1MW + subsidy covering 30% of the investment cost
Sweden	Green certificates: This system started 1 May 2003.	4.9 = 2.3 (certificate level) + 2.6 (Nordpool price,)
United Kingdom	Market price (energy market – NETA) and Renewable Energy Obligation Certificates – ROCs (only available for hydropower up to 20MW when built since 1990 or if built before 1990 and have been refurbished with new turbine runners and control equipment. Hydro plants commissioned since 2000 are also eligible for ROCs	Base price for electrical energy €80/MWh ROC capped price €51/MWh ROC recirculating €24/MWh Levy exemption certificates (LECs) €4.8/MWh
Bulgaria	Combination of feed-in tariffs, tax incentives and purchase obligation. Relatively low levels of incentive make penetration of renewables especially difficult as the current commodity prices for electricity are still relatively low. According to the Energy Act electricity suppliers are obliged to purchase all renewable electricity from generators with production up to 10 MWh. Mandatory purchase of electricity for preferential prices will be applied until the planned system of issuing and trading Green Certificates comes into force.	For SHP €45/MWh (2003–2006) Wind 60 and other RES-E 30 €/MWh
Czech Republic	Feed-in tariffs (since 2002), supported by investment grants Revision and improvement of the tariffs in February 2005. Relatively high feed-in tariffs with 15-year guaranteed support. Producer can choose between a fixed feed-in tariff or a premium tariff (green bonus).	For SHP: Purchase price= Market price + 'Green bonus' Fixed price: €69.6–104/MWh; Two rate tariff: €50–152/MWh 'Green bonus': €21–56/MWh. Wind energy: Fixed: €85/MWh, premium: €70/MWh
Estonia	Feed-in tariff system with purchase obligation. Feed-in tariffs paid for up to	

Table 9.3 (continued)

Country	Compensation Scheme	Price for sale to the grid (c€/kWh)
	7 years for biomass and hydro and up to 12 years for wind and other technologies. All support schemes are scheduled to end in 2015. Together with relatively low feed-in tariffs this makes renewable investments very difficult.	No differentiation among RES-E technologies. Single tariff: €73.4/MWh
Hungary	Feed-in tariff (since January 2003) combined with purchase obligation and tenders for grants. Actions to support RES are not coordinated and political support varies. All this results in high investment risks and low penetration.	For SHP: average 60 (>5MW) and €100/MWh (<5MW).There are also peak and off-peak tariffs. Wind, solar energy: fixed tariff –€100/MWh
Latvia	Quota obligation system (since 2002) combined with feed-in tariffs. Frequent policy changes and the short duration of guaranteed feed-in tariffs result in high investment uncertainty. According to the recent Rules of Cabinet of Ministers (Nr 503 of 2007) RES tariff increased significantly; they are related to the natural gas price.	For SHP commissioned before 2004 there was €99.6/MWh tariff and after 2004 €49.8/MWh. In 2008 this tariff increased to €150/MWh
Lithuania	Relatively modest feed-in tariffs combined with a purchase obligation. In addition good conditions for grid connections and investment programmes Closure of the Ignalina nuclear plant will strongly affect electricity prices and thus the competitive position of renewables as well as renewable support. Investment programmes limited to companies registered in Lithuania. Currently purchase prices for RES-E are under revision (2008). There are plans to move toward a green certificate system (in the period 2010–2021).	For SHP €57.9/MWh guaranteed for 10 years Wind: €63.7/MWh Biomass: €57.9/MWh
Poland	Green power purchase obligation with targets specified until 2010. In addition renewables are exempted from the (small) excise tax.	No differentiation among RES-E technologies. In 2006 market price was 3 €c/kWh + average 6 €c/kWh (green certificate)
Romania	Quota obligation system based on Tradable Green Certificates (TGC). Fixed RES-E quantities established by governmental decision from 2005 to 2012	Hydropower plants below 10MW and commissioned or modernized after 2004 are eligible for TGC. For SHP: 39.3 (Market price) +24 to 42 (TGC)=63.3 to €81.3/MWh For others RES-E power purchase prices are similar.
Slovak Republic	Programme supporting RES and energy efficiency, including feed-in tariffs and tax incentives. Very little support for renewables. The main support programme runs from 2000, but there is no certainty as to the time frame or	For SHP: until 1 January 2005: €56.8/MWh; after 1 January 2005: €68.7/MWh; upgraded SHP (<5MW): €71.6/MWh Wind: €56.8–€74.7MWh; Geothermal: €104.5/MWh

Table 9.3 (continued)

Country	Compensation Scheme	Price for sale to the grid (c€/kWh)
	tariffs. The low support, lack of funding and lack of longer-term certainty make investors very reluctant.	
Slovenia	Feed-in system combined with long-term guaranteed contracts, CO_2 taxation and public funds for environmental investments.Distribution grid operators are obliged by the Energy Act to buy all electricity produced in SHP (and other RES). Price for qualified producers is defined by the government decree. In that case it is composed of a) long-term expected market price, and b) premium. The price is then called 'Unified annual price'. This tariff system is now under revision (2008)	For SHP 'United annual price' is between 61.6 (young plants) and €55.4/MWh (old plants) Premium is between €28.2 (young plants) and €25.4/MWh (old plants) For other RES-E tariffs are similar.

Source: ESHA

MARKET

Installed capacity and market development in the EU and market segments

In terms of capacity, SHP installed capacity accounted for about 12.5GW in the EU-27 in 2006. This amount represents about 9 per cent of the total hydropower installed capacity and around 2 per cent of the total electricity capacity installed in the EU-27 in 2006. The installed capacity of SHP increased only 2.7 per cent between 2000 and 2006 while the total hydro recorded an increase of about 2 per cent. When looking at member states, a large share of this capacity (nearly 12,000MW or about 37,000GWh annually) comes from EU-15. This is demonstrated by the fact that 85.1 per cent of installed small hydropower capacity is concentrated in six member states of the EU-27. These leading six countries are Italy, accounting for about 21 per cent of the total SHP installed capacity in the EU-27, followed by France (17.5 per cent), Spain (15.5 per cent), Germany (14 per cent), Austria (9.4 per cent) and Sweden (7.7 per cent). As for EU-12, the largest capacities are in Romania (3 per cent), Czech Republic (2.4 per cent) and Poland (2.3 per cent). The following graph shows the different installed capacity per member state as well as the different areas for future potential.

Nevertheless, the specific objectives settled in the White Paper and some more generals from the RES-E Directive and the new Energy and Environmental Package for 2020 will most probably not be reached by the SHP sector. The disappointing growth rates of the past years both in terms of production and capacity are just a reflection of the current situation of the sector which has to face many barriers, mainly focused on administrative procedures and in particular the issue of concessions and environmental requirements mainly coming from the implementation of the Water Framework Directive. The identified market segments in which the sector will experience a growth in the future years in the EU are: new load head small hydropower schemes; mini-micro hydropower; upgrading-refurbishment and pump-storage facilities. Current trends in the hydroelectric market are increasingly focusing on small and medium-sized plants. Large projects such as those constructed over the past decades do not need to be changed frequently, but the market is important for this type of equipment especially in growing countries such as

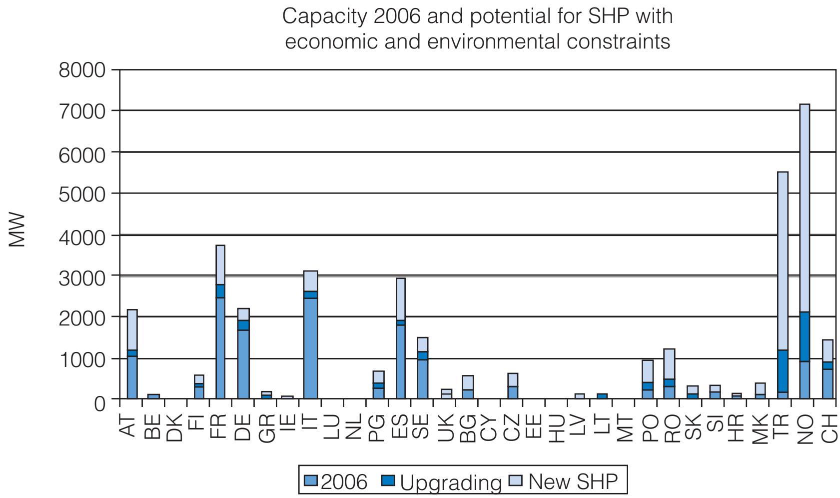


Figure 9.4 SHP capacity and future potential, 2006
Source: ESHA

India, China or Brazil. International aid agencies and financing organizations are again in favour of hydropower. SHP plants also have also great potential: small hydro and medium-size plants meet the electrification needs of remote or peripheral areas, especially in countries or regions with a low-density distribution network. This type of installation is becoming increasingly popular in countries where the hydro potential is already largely used, as is the case for many countries in the EU. Suppliers of equipment for large and medium plants have to face increasingly hard international competition. A direct consequence has been the regroupings and mergers seen over the past decade, mainly in Europe and North America, so that there are few international groups capable of supplying complete equipment for a given development. Looking for new markets, these large industrial groups have often acquired smaller companies, which specialize in SHP, and then employed simplified large-plant techniques (scale reduction). As a general rule, these companies mainly concentrate their activities on plants with an installed capacity higher than 1MW. However, there is a very large number of manufacturers who build small turbines and other equipment and who in theory cover the field below 10MW. The majority of the small and medium plants being built are less than 5MW in capacity. University institutes, on the other hand, perform work that anticipates industrial applications. They are thus players for future markets, rather than actors in the present one.

Industry

The European industry has maintained a leading position in the field of hydropower manufacturing since the technology started to develop 150 years ago. Very little non-European equipment has been installed in European hydropower plants. One important reason for European dominance has been the strong home market. By developing technology and production methods in a fast-growing home market, European manufacturers have, with few exceptions, kept a leading edge compared to manufacturers from other parts of the world. However, although still producing the best technology, the EU hydropower manufacturing industry is experiencing some problems because of the present market situation. Opening up the electricity market to competition has exposed excess production capacity in the system, resulting in a rapid fall in electricity prices as well as the buy-back rates for SHP. The only countries recording a small increase in the number of manufacturers have been those with a stable buy-back system like the feed-in type, or far-sighted systems which give producers economic stability, motivating them to build new plants or refurbish older ones. Several hydro manufacturers are active in SHP in the EU (Table 9.4). Four major multinational companies dominate the market for larger turbines, but the market for 0.5–5 MW/site is more open to smaller companies. European companies have pioneered much of the technical development and in recent years have dominated international contracts for small hydropower equipment and installations.

Table 9.4 EU hydro companies, 2008

COMPANY	COUNTRY
Andritz	Austria
Geppert	Austria
Gugler	Austria
Koessler	Austria
VA TECH	Austria
Willot	Belgium
MAVEL	Czech Republic
Waterpumps WPOY	Finland
Waterpumps Oy	Finland
ESAC Energie	France
Mecamidi	France
THEE	France
ALSTOM Hydro	France/UK
Bernard et Bonnefond	France
MJ2	France
VA Tech/Bouvier Hydro	France
HIS Hydro Engineering	Germany
Ossberger	Germany
Voith Hydro	Germany
Wasserkraft Volk	Germany
Wiegert and Bähr	Germany
WKA Anlagenbau	Germany
Stellba	Germany
Franco Tosi	Italy
IREM	Italy
Orengine	Italy
Turbinenbau Troyer	Italy
Cover	Italy
Tamanini	Italy
Zeco	Italy
Litostroj	Slovenia
Moller Undenas	Sweden
TURAB	Sweden
Waplans Mekaniska Verk	Sweden
Gilbert, Gilkes & Gordon	UK
NHT Engineering	UK
Valley Hydro	UK
Derwent Hydro	UK
Weir Engineering	UK
Segen Hydrogeneration	UK
Newmills Hydro	UK

Source: ESHA

The EU has a multi-disciplinary and highly skilled small hydro industry, which offers the full range of products and services required to develop small hydro projects from initial feasibility and design through to manufacturing, financing and operation. Many EU consultants and manufacturers have a track record in non-EU markets. EU developers have less export experience, but this might increase with the attractive incentives for private participation being offered in emerging markets. Committing sufficient financial and human resources to identifying and evaluating opportunities in remote markets is often a limiting factor for EU small and medium enterprises. The non-EU market[4] still offers good prospects for EU manufacturers, even though financing, as well as differences in business culture, is a serious problem. It would be wise for European manufacturers to make arrangements with export offices and export credit institutions so they can successfully penetrate the non-EU market. Currently, the best markets for European small hydropower manufacturers can be divided into:

- **Markets for new equipment**: these are markets where demand for electricity is growing rapidly or where a change in the electricity production system has been necessary for environmental reasons or to fulfil the requirements of the Kyoto Protocol. In the EU, Germany, Spain and Greece are examples of such countries. The limitations on European expansion in these latter areas include lack of stable financing conditions and difficulties in finding a reliable local company to co-operate with;
- **Markets for servicing, renovation and modernisation**: the best area for EU manufacturers to gain contracts for work on existing plants is still the home market. Today, a considerable number of SHP plants need refurbishment and modernization. Producers are less reluctant to invest in this kind of work because of better buy-back rates.

Latest employment figures show that in 2002 about 2200 people were working directly in the small hydropower sector in the EU. This includes manufacturers (around 1200 employees) and research and consultancy work (around 1000 employees). In addition, there are about 4000 people indirectly involved, including electricity producers. It can therefore be estimated that about 6000 employees are working – directly and indirectly – in the European SHP sector. Future expansion of employment in the small hydropower sector depends on overcoming legal, administrative and environmental constraints on development. We can estimate that the 6000 employees is a realistic figure due to the double effect of cutting personnel production to increase competitiveness, and the increase of highly skilled manpower in engineering and development, because of the future increase of demand in hydropower is considered as a RES. The manufacturers of SHP technology in the EU have a long history. They have developed a highly competitive industry that employs many thousands of people. In order to maintain the competitiveness in the European manufacturing industry it is very important to have an increasing home market and stimulate technical development. It is an old truth that you are only successful in an export market if you can qualify your skill in your home market.

Policy instruments to support the technology

There are no harmonized support mechanisms for small hydropower in the European Union. The principal support instruments for SHP come in the form of investment and production support, fiscal incentives and favourable grid access.

Access to the grid

In the context of the liberalization of the electricity sector, access to the grid is the first and most important step in allowing independent producers to operate effectively in the market. When the costs to connect are unacceptably high, even attractive per-kWh prices are an ineffective measure. The terms for connecting to the grid differ widely in the EU. Some member states deliberately favour SHP developers by paying part of the costs for grid connection, whereas in countries such as Spain and Germany all the costs have to be met by the investor. In other member states, such as Austria and the UK, the connection cost is negotiated between the utility and the developer according to capacity, distance and voltage level. In Belgium, Greece or Portugal, meanwhile, use of the grid is free, though in Italy it is based on a fixed price for plants accepted into a support scheme. In Sweden grid use is not only free but the local grid owner must refund a local producer for any reduction in grid costs resulting from distributed power or a reduced requirement for peak power. For the SHP sector, it is extremely important to provide transparent and fair connection terms with a price structure that reflects the actual costs and avoids any cross subsidies. When appropriate, the subsidy to SHP investors has to be clearly shown. Ideally, the cost of using the grid would vary according to the time used (peak/off-peak hours and seasons), the voltage level and the congestion of the grid. With the contribution of SHP generation, positive or negative, the losses in the grid should also be reflected as much as possible. This would lead to the adoption of a system charge varying according to time and place, with relatively high transaction costs, but clearly indicating efficient use of the grid and other system resources. Specifications for connection to the grid can also be a deterrent to the development of SHP and/or affect the viability of a scheme. Utilities that require unreasonable or unnecessary specifications or conditions (locating the connection point far away from the plant) strongly affect the feasibility of a scheme. In any case, utilities should guarantee a certain quality in their service, therefore asking the independent producer to fulfil certain requirements before being connected to the grid.

Financial incentives

The most widely adopted fiscal incentive is the system of fixed feed-in tariffs, which gives the SHP generators a guaranteed price for their electricity. This is also considered to be the most efficient system as the tariff is set for a number of years, which increases investors' confidence. In some countries green certificates are used as production support but it does not seem to work as well due to price level uncertainty. With SHP, the question is not only about financing new projects but also about financing older schemes in need of refurbishment and modernization. Investment support is appreciated by many investors as it comes in a form of a one-time fixed grant which helps to reduce capital costs. This is, however, usually not available for refurbishment or modernization. A long-term support system is essential for stimulating investments and reinvestments in small hydropower as owners do not usually have similar financial capabilities to large energy companies. Currently some countries are revalorizing their feed-in tariffs, such as Spain, Italy and France, but there are also some that, on the contrary, are questioning their incentive systems, such as Austria, Sweden and Slovenia. The feed-in tariffs are quite well adjusted to generation costs with the Austrian and Portuguese tariffs at the lower end of the cost spectrum. In Finland, the tax measure is unable to cover the costs needed to stimulate investments in new generation capacity. Hence, additional support in the form of feed-in tariffs is currently being considered also in Finland. In the ten newest member states the buyback rate offered to SHP producers varies from the lowest tariff in Bulgaria to the highest in Hungary. Latvia has moved from an ambitious feed-in tariff system to a quota system. Studies show that the indicated buy-back rates are still not enough to attract private investment and to secure investors' confidence. Only Estonia and Poland have introduced additional prices based on the green certificate system. Moreover, other additional support instruments, such as loans at preferential conditions, income tax exemptions (Czech Republic and Lithuania) and reduced VAT (0 per cent in Estonia) are available in some member states. With the new RES Directive the member states will be obliged to define clearer regulatory frameworks and consider the share of SHP in their energy mix to meet their mandatory target.

R&D funding

The key challenges with SHP relate to both economics and ecology. SHP can be successfully developed, as long as it produces electricity at competitive prices and under conditions that respect the environment. In order to increase the profitability of SHP, either the sale price must be increased, or production costs must be reduced. Whereas the first is a political option, the second depends essentially on the technology. Reducing production costs implies firstly reducing construction, operation and maintenance costs, and secondly, there is a general impression that hydro-technology is already mature and fully developed, and it is, consequently, wrongly assumed that the technology cannot be further developed and improved or will be developed or improved without any need for significant institutional support. It is essential to have well-structured and coordinated R&D programmes, in order to continue and increase the development of new machines and construction techniques, with the objective that equipment and new and old plants are environment-friendly, simple, reliable and efficient, in other words to help the technology to become even more environmentally sustainable. Investment in R&D is also important in order to develop and boost innovative SHP solutions.

Flanking measures

In the case of SHP, the participation approach of all stakeholders involved in the development of a future project is crucial since the decisions are taken on a very local level. The dialogue and common understanding with local authorities can ease the process and length of authorization of concessions. Currently in the EU more common and homogeneous measures in terms of authorization processes and concessions procedures have to be developed, as well as a the creation of a legal governing body.

Key countries and success stories

Hydropower is very dependent on a country's geography. This is demonstrated by the fact that 85.1 per cent of installed SHP capacity is concentrated in six MS of the EU-27. These leading six countries are Italy, accounting for about 21 per cent of the total SHP installed capacity in the EU-27, followed by France (17.5 per cent), Spain (15.5 per cent), Germany (14 per cent), Austria (9.4 per cent) and Sweden (7.7 per cent). The largest capacities in the new member states are in Romania (3 per cent), Czech Republic (2.4 per cent) and Poland (2.3 per cent).

Austria

Austria has the highest share (62.1 per cent) of hydro in their power generation mix in the EU. SHP accounts for about 8 per cent of total electricity production in Austria. In

2007 Austria increased its installed capacity of SHP with an additional 76MW, increasing the production by 9.6 per cent to reach 3.6TWh. There are around 2140 SHP, mainly run-of-river, plants in Austria. The average size is from 100kW to 300kW. Additionally about 4000 to 5000 small-scale hydropower plants have not been statistically assessed because they are not connected to the public grid. A typical feature of Austrian small-scale power stations is their decentralized location. They are very often characterized by immediate energy consumption in private and industrial structures. According to estimates of the Austrian Association for the Promotion of Small-Scale Power Stations, the hydropower potential has been exploited, leaving a further 800MW or 4000GWh worthy of further exploitation. Approximately half of this potential justifies exploitation in line with the present state-of-the-art technology. Furthermore, in the past four years Upper Austria has shown increased efforts to modernize SHP plants and to improve their ecological conditions. A package of consulting services and subsidies was established to support the revitalization of SHP plants and to optimize the ecological energy generation based on hydro power. This 'revitalization package' is a unique programme in Austria. It has already led to remarkable success and is considered as the best-practice example all over Austria. There are 587 SHP plants in Upper Austria which feed 645GWh green electricity per year into the public grid. Already 330 SHP operators have been supported with the programme in Upper Austria's energy department.

Italy

Italy is the number one country in the EU when it comes to installed capacity and power production of SHP. The new Legge Finanziaria 2008 introduces simplified administrative procedures for small plants; it strengthens grid connection and dispatching and introduces development procedures for all renewables. For SHP, these changes are especially favourable for installations with capacities lower than 1MW (new Green Certificate system, feed-in tariff for the first 15 years). The Green Certification system shows how, under suitable conditions, marginal small hydro potential can also be successfully exploited from the economic point of view and how the exploitation of already-diverted river stretches is environmentally possible. The objective was to construct two low-head small hydroelectric plants in a sustainable and ecological way while still allowing maximum power generation. Challenging and innovative solutions were needed, however, in order to guarantee environmental integration, technical and economical reliability. The location is along an already-diverted river stretch in Valle d'Aosta in northern Italy. The road for building these sites was very long: the overall duration was over 12 years. This was due to complicated authorization procedures and to the fact that before the Green Certification system came into force it was difficult to finance the plants because of high investment costs and low energy production and revenue.

France

France has the second largest installed small hydropower capacity in the EU with 2060MW connected to the grid at the end of 2007. This also shows an increase in electricity production (+2 per cent with respect to 2006). Hydropower currently represents 12 per cent of total electricity production in France. The awaited feed-in tariff revalorization which took place in March 2007 is especially favourable for installations with capacities lower than 3MV. France has also announced a plan to boost hydropower as part of their goal to increase the share of renewables in its final energy consumption to 23 per cent by 2020. The government wants to increase production capacity by 30 per cent by installing more efficient turbines, by developing small and micro hydro and by developing storage-pumps in order to ensure stable electricity supply. As part of the plan the plant operators will also have to take measures to increase the protection of the aquatic environment. The Very Low Head (eel-friendly) turbine (VLH) concept was designed by hydro specialists to address that specific segment of the hydroelectric market. Low-head hydro has the potential to generate green energy with only a minimal impact on the environment and it is one of the best options for decentralized power generation.

Figure 9.5 VLH (eel-friendly turbine) in working position
Source: ESHA

Romania

Among the new EU member states Romania is the leading SHP country with 325MW installed capacity. In the EU this accounts to a share of 2.77 per cent[5] of installed capacity. In Romania, large hydropower dominates the renewable energy generation with 26 per cent of the electricity production in 2007, SHP being the second largest contributor (with 1.2 per cent of total electricity production). The majority of all SHP plants (80 per cent) in Romania were constructed about 20 years ago. The technically feasible SHP potential in Romania is about 1134MW (4078GWh) and about 20 per cent of the economically feasible capacity has been developed so far. Since the national and local regulations follow European regulations closely, the tendency is towards the development of new green-field projects. The government's promotion scheme for energy produced by SHP in Romania includes feed-in tariffs and green certificates (GC). This means that RES-E can be sold by bilateral contracts at negotiated prices, on Day Ahead Market (the market for energy 24 hours in advance of a given time in any day) or to distribution companies at a regulated price, €36.6/MWh. Green certificates can be sold by bilateral contracts or on the centralized green certificates market with a price of €27–€55/GC. Currently, many formerly state-owned schemes are being privatized. Until 2002 there were no privately owned SHP plants. The largest SHP owner is the state utility HIDROELECTRICA. The state currently plans to sell around 150 of the 220 SHP plants owned by HIDROELECTRICA. During 2004-2008, 97 SHP plants with the installed capacity of 76.09MW (average annual production of 114.12GWh) were privatized; they were acquired by 11 companies. Another 53 are to be privatized and some other 200 SHP are owned by other companies or local communities. Other than HIDROELECTRICA, the Romanian Water National Administration (ANAR), The Romanian Energy Regulatory Authority (ANRE) and the Romanian Power Market Operator (OPCOM) are also main actors of Romanian SHP. In 2008, the Romanian Small Hydropower Association (ROSHA) was established to promote the SHP sector at national and international level.

TOMORROW

Future development will largely depend on the following elements.

- **Reconciling Water Framework Directive (WFD) and RES Directive targets**: this remains a challenge for the further development of SHP. The requirements set by the WFD, which came into force in December 2000, often add cost and slow down SHP development. But at the same time the new RES Directive obliges countries to increase their share of RES production. Thus, it is important that the implementation of the WFD does not oppose the targets of the RES Directive, which is also an environmental directive. As a clean, efficient, emissions-free source of renewable energy, SHP's contribution to security of supply, stability of energy prices and climate change mitigation is considerable. The future of small hydropower will partly depend on these two directives being transposed in a correctly balanced manner.
- **Environmental measures**: European industry and research institutes have responded to growing environmental requirements with innovative solutions, for example, bringing fish-friendly turbines to the market. Much research has been focused on fish, which have been at the centre of environmental concern in hydropower production. New fish protection systems such as fish repulsion systems based on infrasound and various new innovations, eel-friendly turbines for example, have been developed. Other environmentally friendly technologies also include fish-pass

systems, trash rack management systems and multi-purpose schemes combining electricity production with flood control, irrigation channels, waste water treatment and recreational use. Water diversion, which deprives a reach of part of its natural flow, is the key problem concerning the environmental impact of SHP plants. This means that in order to make hydropower production more compatible with natural life of rivers, a minimum flow must be released to ensure the preservation of hydrological continuity of the river and the consequent conservation of natural habitat and ecological life. Efforts are also being made to diminish the impact of power plants on the landscape. Low building structures for river power plants and underground powerhouses for storage power plants are essential in this context. Over the years, construction times have been shortened through the use of modern machinery and methods. Upon completion of the power plant, the former sites are reintegrated into the landscape. A number of techniques have been developed for this purpose: greening of the landscape, which is particularly difficult at high altitudes, has been made possible through engineering biology. Environment and sustainability are of crucial importance for SHP development.

- **Removal of administrative barriers and importance of proactive cooperation at local level**: the principal non-technical problem that constitutes a real obstacle to the development of SHP is the difficulty in obtaining the necessary authorization to build a new site or to refurbish an old one. Apart from the very long time required to process them, procedures vary strongly from one country to another or even from one region to another. Numerous institutional barriers exist. In many countries the main difficulty is in getting the concession to use and divert water from the river (and the renewal of the concession after the concession period). Difficulties in gaining affordable connections to the grid and very long procedures in order to get all permits are also common because hydro operators have to deal with many administrations. In most of the EU member states it has become impossible to get concessions and the process in dealing with the local authorities is a never-ending story. Investors and project developers in the EU are very discouraged with the current situation.

Figure 9.6 Fish by-pass
Source: ESHA

Technology targets by 2020 and beyond

A forecast for 2010 based on the same annual growth level as in 2006 amounts to a total capacity of 12,719MW compared to the figure of 14,000MW advocated by the White Paper, showing that the White Paper target is unlikely to be achieved in the sector. Based on the same linear growth, the installed capacity in 2020 would result in 13,270MW. Figure 9.7 shows how the targets in terms of production are not going to be reached by the SHP sector.

When considering current and future SHP potential in the EU, it has been estimated that a further 68.4TWh/year seems to be technically exploitable according to the Green-X EU project 2007. This potential upgrading may represent 30TWh (TNSHP, 2005) in Europe. Nevertheless, the majority of EU's potential can be found in Romania and Poland, Czech Republic, Slovenia, Bulgaria and Slovakia. Therefore, the highest expectations for further development of SHP are focused in the central and east Europe. In some countries like Bulgaria the installed capacity of SHP is estimated to reach 543MW in 2015 and 696MW by 2020. The small hydro potential in the Czech Republic is about 1115GWh/year.

In Romania the potential reaches 625GWh/year and the future outlook includes upgrading and rehabilitation as one of the main priorities. In Slovakia there is a potential of 1200GWh/year. The RES target for Slovakia planned for 2013 includes 180GWh/year of small hydro. However, as the announcement by the French government about a new plan to increase hydropower production with 7TWh/year by 2020 shows, there is still potential in the 'old' member states. The current economic and political developments with increasing dependency on energy and the volatile gas and electricity prices together with the impact of regulatory changes such as the new RES Directive are likely to speed up SHP development and encourage the remaining economic potential to be boosted. The RES Directive obliges member states to redefine clearer regulatory frameworks and to reconsider their national hydroelectric potential in order to meet the overall 20 per cent RES target by 2020.

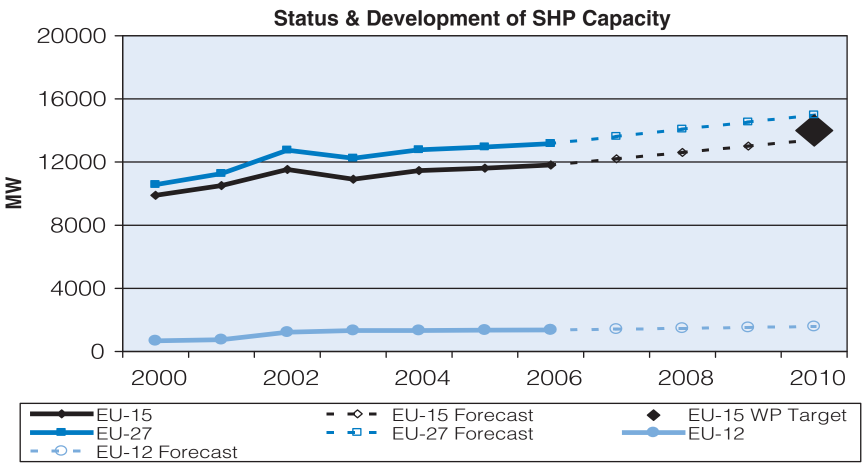


Figure 9.7 Electricity generation 2000-2006 and forecast to 2010 for SHP in EU-15 and EU-27
Source: ESHA

Technological long term potential

Hydropower is a mature technology with a considerable potential still available in most of the EU member states. The following areas show a particular potential for growth:

- new low- and very low-head head small hydropower sites;
- mini and micro hydropower;
- upgrading and refurbishing existing sites;
- development of pumped-storage facilities.

The share of small hydropower in energy consumption not only depends on the political implication of governments to develop this sector but also on the natural resources of the country. In the future, the increased impact of the climate change towards hydropower is twofold:

- the significance of hydropower is likely to increase due to the need for multi-use of water, in other words developing multipurpose plants which enable flood prevention and control, irrigation and water supply during dry periods with electricity generation at the same time;
- mini-hydro schemes in some countries could be vulnerable to shifts in rainfall patterns caused by climate change.

On a global scale, there are new prospects for export and technology transfer for EU manufacturers. The ETS (Emissions Trading Scheme) and CDM (Clean Development Mechanism) markets bring new opportunities for the sector. In fact, approximately 90 per cent of all clean development mechanism projects in China are SHP. The off-grid and stand alone possibilities make SHP very suitable for rural electrification also in difficult circumstances. In the end SHP's main challenge relates to both economy and ecology. SHP can be largely developed only to the extent that it produces electricity at

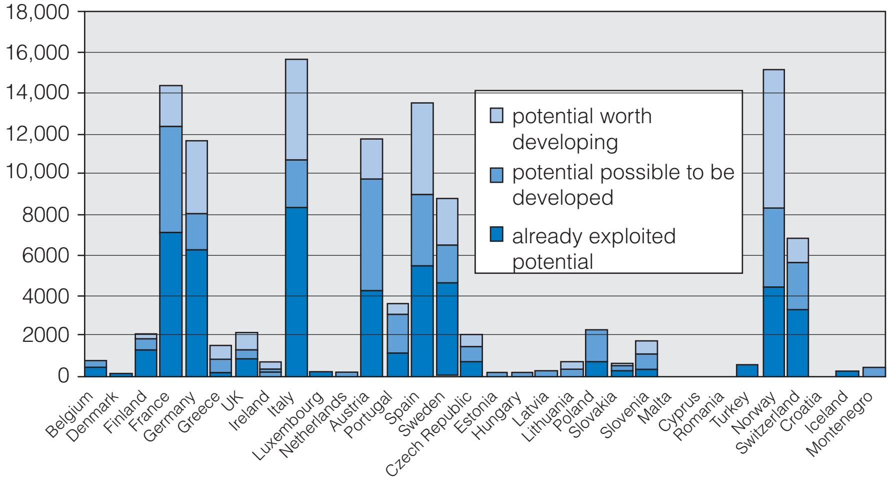


Figure 9.8 SHP potential
Source: ESHA

competitive prices and under conditions that are respectful of the environment. Therefore, a future challenge for the sector is to tackle how untapped potential could be exploited in the most economical and environmentally friendly way.

NOTES

1 There is no international consensus on the definition of SHP. However, 10MW is the generally accepted limit adopted by ESHA and the EC.
2 Eurostat, 2006.
3 It should be mentioned that the implementation of the EU Water Framework Directive (WFD) and the requirements on water quality and ecological status is having a direct impact on the small hydropower sector not only in terms of increasing the cost of the projects by integrating environmental mitigation measures, but also in delaying the authorization for concessions.
4 For example, within Romania's national strategies for energy efficiency and valorization of renewable energy, its targets are to improve energy efficiency and to increase the share of electricity produced from renewable resources in the national gross electricity consumption. Promoting these targets by using less energy or using more environmental friendly energy, contributes to the reduction of pollutant emissions (especially GHG emissions) at the level of Romanian economy, in compliance with the recommendations of the spring 2007 European Council. The share of electricity produced from renewable energy resources in the national gross electricity consumption was about 29 per cent in 2004, close to the target of 33 per cent, by 2010 (according to Governmental Decisions no. 443/2003 and 1535/2003), but almost entirely in large hydropower plants. Therefore, the gap should be bridged primarily by other renewable sources, in order to avoid a heavy reliance on hydro-energy produced in large capacities.
5 In 2006. Source: Eurostat.

10

Ocean Energy

Ocean Energy (OE) involves the generation of electricity from the tides, the waves, the currents, the salinity gradient and the thermal gradient of the sea or the ocean. The ocean is an enormous source of renewable energy with the potential to satisfy an important percentage of the worldwide electricity supply. Globally, the theoretical potential of OE has been estimated at over 100,000TWh per year (as a reference, the world's electricity consumption is around 16,000TWh/year).[1] The global technical resource exploitable with today's technology is estimated to be in the order of 45,000TWh/year for wave energy; tidal current energy is in the order of 2200TWh/year, salinity gradient energy in the order of 20,000TWh/year and Ocean Thermal Energy Conversion (OTEC) in the order of 33,000TWh/year. Conversion of the wave resource alone could supply a substantial part of the electricity demand of several European countries, particularly Ireland, UK, Denmark, Portugal and Spain. The electricity demand on islands in remote areas could entirely be met by converting a small fraction of the available OE resource.

STATE-OF-THE-ART TECHNOLOGY

Unlike other RES, ocean energy is not captured from a single source, but, instead, is stored in a variety of forms: the energy of waves, the kinetic energy of marine and tidal currents, the potential energy of tides and salinity or thermal gradients. As a consequence of this variety, and of the relative youth of the sector, the number of concepts for ocean energy conversion is very large. A first, basic division is grounded on the specific source of energy that the technology is tapping into.

Tidal energy

Tidal energy conversion techniques exploit the natural rise and fall of the level of the oceans caused principally by the interaction of the gravitational fields in the earth-sun-moon system. Some coastlines, particularly estuaries, accentuate this effect creating tidal ranges of up to about 17m. The vertical water movements associated with the rise and fall of the body of water, and horizontal water motions termed currents, accompany the tides. These resources therefore have to be distinguished between tidal range energy (the potential energy from the difference in height – or head – between high and low tides) and tidal current energy (the horizontal movement, in other words the kinetic energy of the water in a tide or marine current).

The energy of tides can be harnessed with barrages, or via 'in-stream devices'.

Tidal barrages

Potential energy associated with tides can be harnessed by building barrages or other forms of engineering constructions across an estuary. Tidal barrages consist of a large, dam-like structure built across the mouth of a bay or an estuary in an area with a large tidal range. As the level of the water changes with the tides, a difference in height develops across the barrage. Water is allowed to flow through the barrage via turbines, which can provide power during the ebb tide (receding), flood tide (allowing water to fill the reservoir via sluice gates) or during both tides. This generation cycle means that, depending on the site, power can be delivered twice or four times per day on a highly predictable basis.

The principle of conversion is very similar to the technology used in traditional hydroelectric power plants. Therefore, tidal barrages represent the oldest and most mature of all OE technologies. In France, the La Rance Barrage has a capacity of 240MW and has been producing 600GWh/year since 1966. Other barrages are currently under discussion in the UK for hundreds of MW of installed power.

Tidal currents

Rather than using a dam structure, tidal current devices are placed directly 'in-stream' and generate energy from the flow of the tidal current. There are a number of different technologies for extracting energy from tidal currents. Many are similar to those used for wind energy conversion, in other words, turbines of horizontal or vertical axis ('cross flow' turbine, as well as others, such as venturis and oscillating foils). Additionally, there are a variety of methods for fixing tidal current devices in place, including seabed anchoring, via a gravity base or driven piles, as well as floating or semi-floating platforms fixed to the sea-bottom via mooring lines. In contrast to atmospheric airflows, the availability of tidal currents can be predicted very accurately, as their motion will be tuned with the local tidal conditions. Because the density of water is some 850 times higher than that of air, the power intensity in water currents is significantly higher than in airflows.

Figure 10.1 La Rance, St. Malo, France (240MW)
Source: International Conference on Ocean Energy (ICOE) (2008)

Figure 10.2 SeaGen, Marine Current Turbines, Strangford Lough, Northern Ireland (1.2MW)
Source: Marine Current Turbines Limited

Marine (ocean) currents

Currents are not generated by tides only, but also by winds, and temperature and salinity differences. The concept for harvesting the kinetic energy from marine, also known as ocean currents, is essentially the same as with tidal currents.

Ocean thermal energy conversion

OTEC uses the heat stored in the oceans to generate electricity. Due to solar heating, the top layer of the water is much warmer than deep ocean water. Where the temperature difference between the warmer, top layer of the ocean and the colder, deep ocean water is about 20°C (36°F), the conditions for OTEC are most favourable. These conditions exist mainly in coastal areas located close to the equator. The amount of energy available in the temperature gradient between hot and cold seawater can be substantially larger than the energy required to pump the cold seawater up from the lower layers of the ocean. The warm water from the surface is used to boil a working fluid (or, in open cycle systems, the seawater itself under low pressure), which is then run through a turbine and condensed using cold seawater pumped up from the depths. Some energy experts claim that once it reaches cost-competitiveness with conventional power technologies, OTEC could produce billions of watts of electrical power.[2]

Figure 10.3 Enermar: Kobold turbines, Messina, Italy (prototype 40kW)
Source: Ponte di Archimede International S.p.A.

Salinity gradient (osmotic energy)

At the mouth of rivers where fresh water mixes with salt water, energy associated with the salinity gradient can be harnessed using pressure-retarded reverse osmosis process and associated conversion technologies. Another system is based on using freshwater upwelling through a turbine immersed in seawater, and one involving electrochemical reactions is also in development.

Waves

The possibility of generating electrical power from the sea has been recognized for many years (the first patent on wave energy conversion was issued as early as 1799 and by 1909 a harbour lighting system in California was powered with a wave energy system). However, significant research and development of wave energy conversion began only rather recently: in fact, although there was a renewed interest in wave energy after the oil crisis of 1973, it subsided again a few years later. Five years ago, especially in Europe, the sector experienced a resurgent interest. Today, wave energy conversion is being investigated in a number of EU countries, major activity is also ongoing outside Europe, mainly in Canada, China, India, Japan, Russia and the USA. Nascent wave energy companies have been very involved in the development of new wave energy converters such as the Pelamis, the Archimedes Wave Swing, AquaBuOY, Oceanlinx, Wave Star, Wave Dragon, etc. A technical classification of the wave systems is based on the take-off system (the system for the conversion of the mechanical work transmitted by the waves, into electricity).

Although over 4000 wave energy conversion techniques have been patented worldwide, the apparent large number of concepts for wave energy converters can be classified according to the basic principles of energy conversion. Several classifications exist; Table 10.1 (page 197) shows but one example:

Figure 10.4 Pelamis, Agoucadoura wave farm, Portugal (2.25MW)
Source: Pelamis Wave Power

Figure 10.5 Wave Star, Nissum Bredning, Denmark (1:10 prototype, full scale 6MW)
Source: Wave Star

Figure 10.6 Wavebob, Galway Bay, Ireland, (1:4 prototype, full scale 2MW)
Source: Wavebob

Figure 10.7 Limpet, Islay, UK (500kW)
Source: Wavegen

Figure 10.8 Azores PICO plant, Portugal (500 kW)
Source: WaveEnergy Centre

Technological benefits

Ocean energy shares with other RES a vast set of strong advantages. Like other renewables, ocean energy:

- is reliable and inexhaustible: the theoretical power of our planet water mass is immense, immediately available and virtually inexhaustible;
- is fairly environmentally benign: like any electrical generating facility, an OE power plant will affect the environment in which it is installed and operates. Although no systematic data is available at this time, desktop studies have been performed on the potential impacts of wave and tidal energy. These assessments, and the follow-on consents for installation of wave and tidal ocean energy conversion devices, provided findings of no significant environmental impacts;
- has zero emissions: OE technologies do not produce any waste, greenhouse gases (including CO_2), liquid or solid emissions;
- job creation and economic development: in addition to the maritime communities directly affected, through its induced needs (construction, transportation, maintenance, control, etc.), Ocean Energy would stimulate a dynamic job market estimated

to be in the order of 10–20 jobs per installed MW in coastal as well as in other regions;[3]

- increases diversity and robustness of electricity energy supply portfolio: through its contribution to increase the level of the offer in the renewable portfolio, OE will provide an important contribution to the future of energy supply;
- is a viable source for remote areas: in remote coastal areas, including small islands, it can help reduce the reliance on auxiliary (diesel) power stations, thus eliminating their emission of greenhouse gases to the atmosphere and reducing the environmental risks associated with the transportation (often by water) of the fuel to the site.

Table 10.1 Power take-off technologies

OWC (Oscillating Water Columns)	These systems are essentially closed, and partially submerged, hollow structures open to the seabed below the water line. The heave motion of the sea surface alternatively pressurizes and depressurizes the air inside the structure generating a reciprocating flow through a turbine installed beneath the roof of the device. OWC devices are categorized by location: onshore, nearshore and offshore.
Overtopping devices	Floating or fixed to the shore that collect the water of incident waves in an elevated reservoir to drive one or more low head turbines.
Heaving devices	Floating or submerged, these are mechanical and/or hydraulic devices that convert up and down motion of the waves into linear or rotational motion to drive electrical generators.
Pitching devices	They consist of a number of floating bodies hinged together across their beams. The relative motions between the floating bodies are used to pump high-pressure fluid through hydraulic motors, which drive electrical generators.
Surging devices	Exploit waves' horizontal particle velocity to drive a deflector or to generate pumping effect of a flexible bag facing the wave front.
Point absorbers	The basic design of a point absorber involves a floating buoy whose mass and buoyancy are selected so that the buoy resonates strongly with the waves. The waves will then cause this buoy to undergo relative movement against a fixed reference; this can be a taught line connected to the seabed, another buoy which is tuned to not oscillate with the waves or a flat damper plate that remains relatively stable.
Mechanical and other	The systems in this category are also used both in point absorber buoys and in other wave energy converter designs. Mechanical power take-off systems have many forms, including worm gears or rack-and-pinion type systems for converting vertical motion into rotation, as well as clutch-flywheel or rectifying systems that convert oscillating rotation into unidirectional rotation. While mechanical systems by definition require a fair number of moving parts, potentially increasing maintenance, they can also offer high conversion efficiencies or allow for simpler generators (rotational instead of linear) to be used. Other systems like magnetohydrodynamics (MHD) are also placed in this category.
Pressurized hydraulic	This is the most frequently used method for power take-off for wave devices, with about 28 surveyed systems using either hydraulic oil in closed loop systems or seawater in open loop configurations. This method of power take-off is suited not only to point absorber buoys but also to a variety of other devices that are based on pitching or horizontal movements, including inverted pendulums and directional absorber floats.
Water turbines	The most frequent application of water turbines for wave energy capture is in overtopping devices, where waves are directed over a wall and into a raised reservoir. Water turbines are used to drain this reservoir, with low-head 'Kaplan' type turbines being the most common choice.

Source: NEEDS project (2008)

However, in addition to this set of shared benefits, ocean energy also has numerous distinctive advantages that make it uniquely appealing:

- it is highly predictable: tides can be predicted with extreme exactitude up to centuries in advance; waves travel over vast distances and their arrival at a certain location can be well predicted from satellite observation and tracking; currents and gradients are a known data. With proper forecasting the variation in ocean energy produced can be integrated more economically into the electrical grid, with consistent advantages in security of supply and stability of the grid;
- it has an extremely high power density: the density of water is several hundred times higher than air, resulting in a lower installed capacity cost;
- it is readily available in proximity to major demand centres: many major demand centres worldwide are located near the shoreline, making OE particularly suitable to them;
- it has a very low visual impact: with few exceptions, OE devices are submerged, semi-submerged or located deep offshore, thus minimizing visual pollution.

Technological applications

Several different concepts and devices have been developed tapping into the different sources of ocean energy. Many of them are in an advanced phase of R&D, through the deployment and testing of large-scale prototypes in real sea conditions; some have reached premarket deployment and many more are scheduled to be installed over the next few years, along with initial arrays of multiple devices. A number of companies are developing commercial-scale projects to deliver and sell electrical power in the next few years. Here, in alphabetical order, is a list of the industry-oriented plans in the most active countries.[4]

Denmark

In Denmark, since 1998 the test site in the fjord of Nissun Bredning has hosted facilities for testing wave power models. The site is mainly operated by Alborg University (Denmark) and currently hosts several scale models such as Wave Dragon and Wave Star. A quater-scale prototype of the Danish Wave Dragon has been functioning reliably for several years. A 7MW demonstration project is currently being built for deployment in Wales and preparations are being made for a 50MW array in Portugal. Another Danish company, Wave Star, has been operating a grid-connected one-tenth scale prototype (Figure 10.5) since 2006. Also during 2009, in collaboration with the utility company Dong Energy, Wave Star will install a first 500kW converter, grid connected to a big offshore wind park 15km into the North Sea.

France

Besides the many research projects currently ongoing in specialized centres such as the IFREMER institute and universities, France has the oldest world tidal barrage system at La Rance (Figure 10.1): the barrage was completed in 1967 and has an installed power of 240MW. It has been working since then, without major interruption, producing an average of 600GWh/year. The national electrical company Électricité de France (EDF) recently closed agreements with the ocean energy developing company Open Hydro to create grid-connected plants exploiting the energy of tidal currents.

Ireland

Ireland has an intense R&D activity that in some cases have reached pre-commercial stage (see, for example, the tidal energy company Open Hydro). In March 2008 the Swedish utility company Vattenfall AB and Wavebob Ltd (Figure 10.6) signed a cooperation agreement covering the development of wave power technology to full-scale commercial level. There is also a common understanding between the two companies to broaden and deepen the cooperation to include studies regarding site selection methodology and development of a large demonstration project of 250MW.

Portugal

Portugal is emerging as one of the most active countries in ocean energy and recently created a 250MW pilot zone with simplified licensing and permits for wave energy and a feed-in tariff scheme to support the development of this new industry. Three Pelamis machines (wave energy) with a total installed power of 2.25MW are currently operational, grid connected, in the commercial wave energy farm in Agouçadoura (Figure10.5). In Spain several regional governments along with industrial partners are committing to ocean energy, the Basque Energy Board (EVE) and the Basque local and regional authorities are setting the €15 million Biscay Marine Energy Platform (BIMEP) in the Biscay gulf, which aims at becoming Europe's most advanced platform for research into electricity generation mechanisms using wave power. Also, Iberdrola, one of the leading private electric utilities in the world, and the Basque Tecnalia Corporación Technológica invested around €4.5 million to develop the OCEANTEC project to put into operation a competitively priced, high-performance wave power device by 2009. The regional governments of Cantabria and Asturias are also looking at wave energy as an important energy potential.

United Kingdom

The UK is extremely active in the ocean energy sector, both at the governmental and institutional level, and at the developing and investment one. The UK recently invested £28 million to build by 2010 a facility called the WaveHub: a 20MW grid-connected wave energy farm in Cornwall enabling pre-commercial testing of wave energy devices on a large scale. It will offer grid-connected berths for 'plug and play' device testing. The UK is also at the forefront of research and development. Since 2003, the European Marine Energy Centre (EMEC) at Orkney provides for full-scale testing for a variety of European wave and tidal devices at grid-connected open sea sites. EMEC verifies device performance, monitors the environment and helps to develop industry standards. Also, the New and Renewable Energy Centre (NaREC), Northumberland, provides testing and research facilities for a range of renewables including marine and is used for initial small-scale prototype testing in sheltered waters. The UK has currently several ongoing installations and industrial projects in ocean energy. With the West Wave project, the German power company E-On plans to build up to seven Pelamis wave energy converters in the Wave Hub offshore facility, 10 miles off Hayle on the north coast of Cornwall (5MW). Also, the UK is extremely active in the domain of tidal current research: Lunar Energy is building a Rotech Tidal Turbine for deployment and has formed a partnership with E-ON to develop a tidal stream power project of up to 8MW in the sea off the west coast of the UK. A 500kW tidal current turbine has been operated by Marine Current Turbines off the southwest coast of the UK and a 1.2MW commercial system has recently been deployed in Ireland. Scotland has an intense research activity on ocean energy (e.g. Wavegen has successfully operated a 500kW shore-based oscillating water column for over five years). The Scottish government has taken significant steps in the support of ocean energy: on 22 January 2008 the Scottish government approved the Siadar wave energy project on the island of Lewis. Npower Renewables will be the operator and Wavegen, the Scottish subsidiary of Voight Siemens Hydro Power Generation, the technology provider. The Siadar project will apply Wavegen's OWC technology to generate electricity from 4MW of installed capacity. Besides its large number of research installations, Northern Ireland is also a well-targeted area for the deployment of pre-commercial development such as the 1.2MW tidal stream rotor in Strangford Lough operated by SeaGen (Figure 10.2).

Both in Europe and internationally, many developers in wave energy are approaching the prototype demonstration stage. In Norway, for example, Wave Energy AS is developing and testing its SSG system; Fred Olsen Ltd is testing a one-third scale model of the FO^3 and working on optimising the design to be tested at the Wavehub in full scale. Outside Europe, a number of developers are deploying large-scale wave energy prototypes, with a view to expanding into the European market in the near future (e.g. Finavera's megawatt-scale AquaBuOY systems in the USA and Canada; Energetech's 1.5MW OWCs in Australia and the USA). Tidal energy is encountering a similar positive international development: various tidal barrages have been built around the globe: 5MW in China, 20MW in Canada and barrages for hundreds of MW have been planned or are under discussion, both in Europe and worldwide. Other technologies are in a less mature stage, but are steadily developing. A few companies developing marine currents systems, such as the Italian ENERMAR (Figure 10.3), and the French Hydro-gen, are developing prototypes. Hydro-gen is expecting to develop 1MW machines by 2010. Saline and thermal gradient plants are still under development. However, the Norwegian company Statkraft and REDstack in the Netherlands announced saline gradient projects and prototypes plants which will be available in the near future.

Cost and prices

Although today a number of developers have advanced to realistic pre-production prototypes, only few are able to provide real costs transcending the R&D dimension. Whilst the basic technology is already present, to achieve an optimal and cost-effective design there is a need for continued demonstration and operating experience in generating grid-connected electricity production. The majority of the developers are SMEs with limited financial resources. Additional and parallel R&D would help to mitigate the substantial technical and non-technical risks. This requires long-term funding for a period of 5–10 years or even longer to allow developers to go from large-scale testing to commercialization. However, assumptions can be made based on a few studies: the cost of energy from initial tidal and wave energy farms has been estimated to be in the range of 15–55c€/kWh; initial stream farms, in the range of 11–22c€/kWh.[5] More specifically, the Carbon Trust has estimated that the current cost of wave electricity is around 33–37c€/kWh.[6] On average, the available studies expect electricity generation costs in the range of 10–25c€/kWh (comparable to photovoltaic) by 2020. In their World Energy assessment, the United Nations and the World Energy Council estimate the potential future energy cost in the same range wind energy.[7] According to the latest research findings, ocean energy will benefit from a very strong learning rate that is estimated to be 10–15 per cent for offshore wave and 5–10 per cent for tidal stream.[8]

MARKET

After several years of research and development, today ocean energy is ready to make a significant contribution to the energy market. However, unlike other RES, ocean energy is still lacking long-term, fixed feed-in tariffs. This is a major hindrance to the development of ocean energy: the right incentives are crucial to making ocean energy much more appealing to the market and will become a major factor in attracting project financing and investment. Thus, in the next few years, market-fuelled incentives will drive further innovation, project financing and investments, thus abating costs and increasing ocean energy competitiveness. In such a scenario, it is estimated that OE will grow well over 200GW of worldwide installed capacity by 2050 (see 'Industry' below).

Installed capacity and market development in EU and market segments

In 2008, the combined installed capacity of deployed OE farms and prototype installations was in the order of 300+ MW (including the 240MW of La Rance's tidal barrage). However, the status of the ocean energy sector is advancing rapidly. OE has developed beyond the research environment to move to large-scale demonstration and commercial projects in real sea conditions, resulting in a high degree of interest in ocean energy both in Europe and worldwide. Today, the OE sector is in a condition comparable to wind energy a few decades ago, and has similar economic potential.

Industry

Although the sector is still taking its first steps into a full commercial dimension, the industry is already looking at it with positive interest . Major industries such as Siemens-Voight, Bosch Rexroth and Rolls Royce have opened research branches dedicated to OE. National electric companies such as Électricité de France (EDF), DONG and Energias de Portugal (EDP) are closing agreements with ocean energy developing companies to create grid-connected OE plants (EDF recently signed an agreement with the Irish Open Hydro for tidal current energy production in France).

Policy instruments to support the technology

OE has the potential to become a major player in the worldwide renewable energy mix in a fairly short amount of time. However, while developers work diligently on technology development, their ability to expand commercially may be significantly hindered unless non-technological barriers are addressed in earnest and industry players have access to the same level of financial support and incentives as other emerging industries. In particular, governments and private investors have the necessary resources to propel OE from the demonstration to the commercial stage in less time that it took the wind industry to mature.

As previously stated, for the OE to take off at its full potential speed, it would be necessary for both the EC and the member states to start providing their support to tackle the non-technological barriers impairing the OE sector and to create a favourable climate for ocean energy:

- **EU Targets**: there is a need for institutional support to OE and, at the same time, for a more realistic approach to setting the cost targets for ocean energy by 2020 and beyond. False expectations will lead to the technology being assessed as a failure regardless of the progress made. An expected cost of €0.10–0.25/kWh is a realistic target by 2020.

- **Incentives**: future development of OE is highly dependent on support schemes. Market driven incentives drive innovation: in the history of new industry creation it is a known fact that artificial market conditions need to be created at the early stage of industry development to create a market pull and to incentivize early adapters. Such a market pull ideally consists of three elements: incentives for investors (investment tax credits), incentives for end-users (investment and production tax credits) and feed-in tariffs that would make high-cost pre-commercial installations attractive to investors and the end-users. A reliable mechanism for feed-in tariffs has proven to stimulate development and investment, and to reduce the high risk for SMEs. Many EU countries have already introduced a feed-in tariff for renewable technologies, especially wind and solar. OE needs the same long-term, predictable and reliable fixed feed-in tariff mechanisms and investor incentives which are applied to other renewable energies. The UK, Ireland and Portugal have introduced a combined tariff/capital grant scheme for OE. An EU-wide mechanism for feed-in tariffs would be a very beneficial start. Assuming a similar support scheme as for solar power (around €500/MWh), it has been estimated that 10,000MW of ocean energy generation could be installed by 2020.
- **Coordinated approach**: there is a need for a coordinated approach; concerted efforts are needed to tackle technological as well as non-technological barriers to allow ocean energy to develop to its full potential. The EC can contribute by providing funding for coordinated research projects.
- **Public support and awareness**: ocean energy is lacking public awareness because it is a developing industry. A public awareness campaign could provide similar benefits as was enjoyed by the wind industry in its early days.
- **Regulatory framework**: permitting, licensing and consenting requirements must be coordinated and simplified. Initial efforts in securing installation permits in a number of countries demonstrated that permitting is expensive, long and intensive. Lack of field data to support environmental analysis makes it much harder to provide permitting authorities with factual information versus desk analysis. Furthermore, there is lack of coordination between permitting authorities, making it much more difficult to obtain the required permits.
- **Infrastructural/grid issues**: ocean energy is a coastal resource. National grids were designed to accommodate central generation, resulting in weak transmission lines available in coastal areas. Except in coastal countries, like Portugal and the southwest region of the UK that have high voltage transmission lines available close to the shore, coastal communities lack sufficient transmission lines and thus the capacity to provide grid access for any significant amount of electricity that can be generated from ocean energy.
- **Support baseline studies**: support baseline studies and follow-up programmes related to environmental impacts are required to establish a better balance between funding of research and demonstration projects.

Key countries and success stories

Seven European countries are today developing ocean energy projects and are providing supporting schemes for ocean energy: Denmark, France, Ireland, Italy, Portugal, Spain and the UK.

Denmark

The Danish government will allocate DKK 25 million (almost €3.4 million) per year in the next four years for pilot projects in renewable energy technologies such as wave power.

A big part of the wave energy technology development is carried out on a private basis. Development of renewable energy in Denmark received national funding from EUDP and EnerginetdK of DKK130 mllion. Among the ongoing wave projects are the Poseidon's organ, the Wave Dragon (full scale expected 7MW), the Wave Star (full scale expected 6MW) (Figure 10.5) and the Waveplane (ready to deploy the first full-scale 100kW prototype).

France

The French Atlantic coast has a favourable wave climate. The wave resource theoretical potential is estimated at 420TWh/year (that is almost the electrical energy consumption in the whole country). In the past wave energy activities in France focused on R&D and were supported by public funding. In 2007 the creation of a grid-connected test site in the Pays de la Loire region (west coast and near Nantes) was announced. The site is expected to be running the first tests by mid 2010 and will be fully instrumented to enable initial demonstration of wave energy devices and also research on marine and oceanographic applications. The programme of the test site is supported by public funding (around €5 million). In 2001, for the first time in France, a feed-in tariff explicitly including wave and tidal energy was introduced (and modified in 2005).

Ireland

In 2006, in the National Ocean Energy Strategy, the Irish government clearly expressed the ambition to make Ireland a world leader for ocean energy technologies, setting forth a four-phase framework to support the development of ocean energy in Ireland. Phase 1 of this programme is currently underway with support provided for research and development activities up to 1:4 scale together with support for third level research activities. Attention is now focused on preparations for the development of a test site and a larger pre-commercial development site. In 2007 the Energy White Paper set an initial goal of 500MW of ocean energy power installed by 2020. Since early 2006, feed-in tariff has become the main tool for promoting RES-E technologies. On 15 January 2008, the Irish government announced a feed-in tariff of €220/MWh for ocean energy.

Italy

Although Italy has a relatively low wave energy climate, it has higher resources in tidal energy. Today, Italy has a €340/MWh FiT for wave energy and has a dynamic activity in national research centres, such as CNR and ENEA. In the private sector, apart from the initiative on current energy in the frame of the ENERMAR project (Figure 10.3), the sector is at an R&D stage.

Portugal

In 2002 the Portuguese authorities announced a support scheme to accelerate wave energy introduction into that country. The basis of the scheme was a special guaranteed feed-in tariff for the sale of electricity to the utility. This was guaranteed at €250/MWh. The introduction created much excitement in the industry but during the time it ran no device developer was even in the position to take it up. In 2007 new higher tariffs for emerging technologies were introduced, including wave energy, which provided the legal basis for government use of public maritime areas for producing electricity from sea-wave power (see Table 10.2).[9]

In 2008, the Portuguese government established a 320 km^2 pilot zone, in central Portugal, with a 250MW capacity, dedicated to testing prototypes and exploitation by pre-commercial and commercial wave farms.[10] Also, in May 2008 the US Secretary of Energy and the Portuguese Minister of Economy and Innovation signed a Memorandum of Understanding to establish a framework for the Signatories' cooperation on the policy, scientific and technical aspects of wave energy generation.

Spain

In 2007 a new Renewable Act explicitly included ocean energy in the form of wave, tides and currents, and regulated electricity production under the Special Regime.[11] Fixed feed-in tariffs provide support for some offshore RES of €69/MWh for 20 years. However, the exact final subsidy for each RES-E technology is a combination of the national FiT (calculated as a percentage of a standard figure, the 'Tarifa Media de Referencia', which is determined annually in the Real Decreto) and the regional support schemes. At a regional level, Andalusia, Asturias, Cantabria, Galicia, Murcia and Basque Country have a recognized OE potential and each one has a specific additional set of energy regulation. In these regions, Greenpeace estimates 84,400MW of electrical power could be installed, based on wave energy, and 296TWh a year could be generated, making it possible to cover 106 per cent of projected peninsular electricity demand in 2050.[12] The Basque Country is on the frontline of ocean energy initiatives and investment. By the end of 2010, the Biscay Marine Energy Platform (BIMEP) aims to create a 20MW infrastructure for the research, demonstration and operation of offshore wave devices, to stimulate the growth of a technological and industrial sector in ocean energy. The BIMEP has an estimated budget of €13–14 million.

United Kingdom

In 2004 BERR (formally DTI) launched the Marine Renewable Deployment Fund (MRDF) at a budget of £50 million. At the core of the measures provided by the fund is the DTI Wave and Tidal-Stream Demonstration Scheme: a £42 million fund to support to the first grid-connected wave and tidal arrays. In 2006, a major review of UK energy policy was carried out. Today the British support system is based on the 'Renewable obligation' (RO) system, and its tradable certificates (ROC). In 2007, the government continued to support research and development of marine energy technologies primarily through the technology programme. The new projects brought the total support for marine energy technology R&D projects through the technology programme and its predecessors to some £30 million since 1999. R&D support for wave and tidal energy is also proposed through the newly established Energy Technologies Institute, which in December 2007 announced a call for expressions of interest to develop a small number of major new development and demonstration projects in marine energy – each to be funded at a level of £5–£10 million. The UK government announced in September 2007 its commitment to study the feasibility of generating electricity from the tidal range of the Severn estuary, which – as the sustainable development commission confirmed – has the potential to generate some 5 per cent of UK electricity from a renewable indigenous resource. In September 2006, the Scottish government published separate proposals that will amend the Scottish Renewables

Obligation so as to provide greater support for wave and tidal-stream technologies. The proposed initial phase of support is for up to 75MW giving support levels of £175/MWh for wave and £105/MWh for tidal-stream. In 2007, the Scottish government announced grants totalling £13 million under a 'Wave and tidal energy support scheme' that has total funding of £8 million. The aim of the scheme is to provide grants to businesses to support the installation and commissioning/deployment of pre-commercial wave and tidal devices at the European Marine energy Centre (EMEC). The scheme will also support components of projects requiring testing at EMEC, e.g. mooring systems, foundation installation systems etc. that will lead to reduced project cost and/or improved operation and maintenance for the industry. The Scottish government approved the Siadar, a large wave energy project on the Scottish island of Lewis. Npower renewables, a UK-subsidiary of RWE Innogy, will be the operator of the planned facility with Wavegen, the Scottish subsidiary of Voith Siemens Hydro Power Generation, the technology partner for the wave power units. In September 2006 the Welsh Assembly announced a £1 million 3-year project to develop a Welsh marine renewable energy strategic framework (MRESF) that will ensure the sustainable development of the marine renewable energy resource contained within the Welsh seas.

Table 10.2 Support schemes in selected countries

Country	FiT	Available OE Support schemes
Denmark	€50–80/MWh	FiT (Fixed and Premium); Incentives (Fiscal and Investment); Tenders
France	€150/MWh	FiT; Tender system for large renewable projects; Incentives (Fiscal and investments); Indirect schemes (Tax on polluting activities)
Ireland	€220/MWh	FiT
Italy	€340/MWh	Quota; TGC; FiT; Incentives and subsidies (fiscal and investments)
Portugal	€260.76/MWh	FiT; direct subsidy payments and tax incentives; Fiscal and financial incentives.
Spain	€69.8–65.1/MWh, €38.4–30.6/MWh reference feed-in premium	FiT
UK		Quota; ROC; TGC

TOMORROW

Technology targets by 2020 and beyond

In December 2008 the three targets for 2020, introduced with a decision by the EU Council of ministers of 9 March 2007, became binding: 20 per cent from renewables by 2020 is an official obligation. This ambitious target is challenging given that to date only 6.5 per cent of EU energy supply comes from renewable energy sources. However, it is essential to meet the target if the EU wants to secure its energy supply and to combat global warming by producing fewer greenhouse gas emissions. Ocean energy can contribute significantly to the energy mix, tackling these two major challenges the EU is facing. Besides this, an increased share of renewables will limit exposure to high fuel prices. Energy importing countries would be able to invest the money in their own economies. In the start-up phase of building the ocean energy industry large capital investments will be required. In order to attract investors and for the start-up companies to develop, a certain high feed-in tariff is required. A tariff of the order of €500MWh (same magnitude as the feed-in tariff for photovoltaic) is required to get development moving. If this tariff is kept constant until 1 per cent of the EU and NMS electricity demand is covered by ocean energy (10,000MW installed), the ocean energy community expects that this could be achieved by year 2020.

Technological long term potential

If the mainly non-technological barriers that hinder the development of the sector are removed, it is expected that in the medium term OE will become one of the most competitive and cost effective forms of generation, constituting a significant portion of the global energy mix, and will enjoy in the next few years a dynamic market penetration, following an analogous curve to on-shore wind energy. The EC-funded NEEDS[13] project for the evaluation of energy policies and future energy systems developed the following global scenario.

Table 10.3 Worldwide ocean energy projections: installed capacity

GW	2007	2010	2020	2025	2030	2040	2050
Very optimistic	0.4	1	20.4	40	61	149	309
Optimistic/Realistic	0.4	1	17	30	44	98	194
Pessimistic	0.4	0.4	4.8	7.4	10	20	40

Source: NEEDS project (2008)

Table 10.4 Worldwide ocean energy projections: generated electricity

TWh	2007	2010	2020	2025	2030	2040	2050
Very optimistic	1	3	70	151	231	593	1281
Optimistic/Realistic	1	3	51	101	152	372	773
Pessimistic	1	1	14	22	30	69	152

Source:NEEDS project (2008)

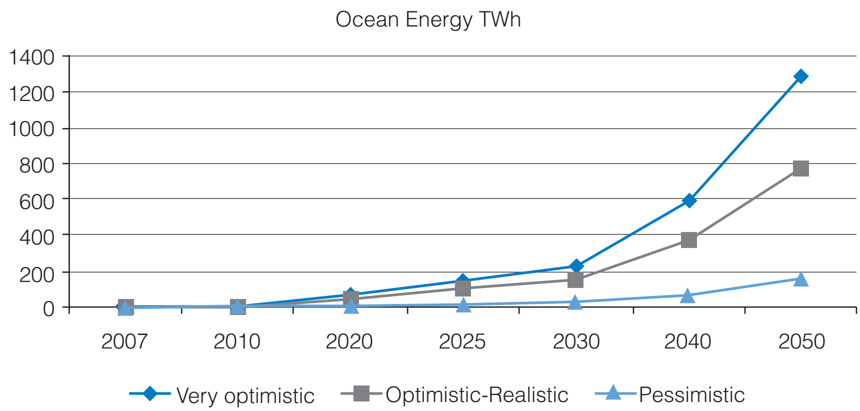


Figure 10.9 Worldwide ocean energy projections: generated electricity

The scenario of ocean energy is changing very quickly. The market is growing fast, with more and more private and public companies investing in the sector and with an increasing number of devices being deployed and grid connected. Thanks to this increased presence in the mix of the renewable energies, public awareness is increasing. OE is emerging from the specialist domain where it has been relegated in the last decades and is acquiring a very concrete role both in the market and in the public understanding of renewable energy sources. The European industry is looking with growing expectation at ocean energy. However, in order to gain momentum, the ocean energy sector needs the same political and economic support that other renewables enjoyed in the past. This should be achieved with two main measures: dedicated financial incentives and the removal of non-technological barriers such as the lack of coastal grid connection and administrative obstacles.

NOTES

1. Assuming 15 per cent utilization factor and 50 per cent capacity factor (Isaacs and Schmitt, 1980).
2. Soerensen and Weinstein, 2008, p.5.
3. Soerensen et al, 2007, p.6.
4. This does not include R&D.
5. Present cost estimates are based on analysis from the NEEDS project, New Energy Externalities Developments for Sustainability (2008).
6. Carbon Trust, UK, 2006.
7. United Nations Development Programme, 2004.
8. Carbon Trust, UK, 2006.
9. Legislação Nacional, Decree-law 225/2007, 31 May 2007, DR 105 - Série I, Emitido Por Ministério da Economia e da Inovação.
10. Decree-law 225/2007 31 May 2007, DRI05-Série I, Emitido por Ministério da Economia e da Inovação.
11. Real Decreto 661/2007 dated 25 May 2007, available at www.boe.es/aeboe/consultas/bases_datos/doc.php?coleccion=iberlex&id=2007/10556
12. Greenpeace, 2005
13. NEEDS Project, 2008.

11

Geothermal Electricity

Geothermal energy is the heat from the earth. Earth's temperature increases with depth, under a gradient of 2–3°C/100m. The total heat flux from the earth's interior provides us with an abundant, non-polluting, almost infinite source of clean and renewable energy.

In the early 1900s, geothermal fluids were already being exploited for their energy content. A chemical industry was set up in Italy during that period, in the area known now as Larderello, to extract boric acid from natural hot water outlets or from purposely drilled shallow boreholes. From years 1910 to 1940 the low pressure steam, in that area of Central Tuscany, was utilized to heat industrial and residential buildings and greenhouses. In 1928, Iceland, another pioneer in the utilization of geothermal energy, began exploiting its abundant geothermal resources (mainly hot waters) for domestic heating. The first attempt to generate electricity from geothermal steam dates back to 1904 at Larderello. The success of this experiment proved the industrial value of geothermal energy and marked the beginning of an exploitation route that has been developed significantly since then. Actually, electricity generation at Larderello was a commercial success. By 1942 the installed geothermoelectric capacity had reached 128MWe. This application, exemplified by Italy, was followed by several

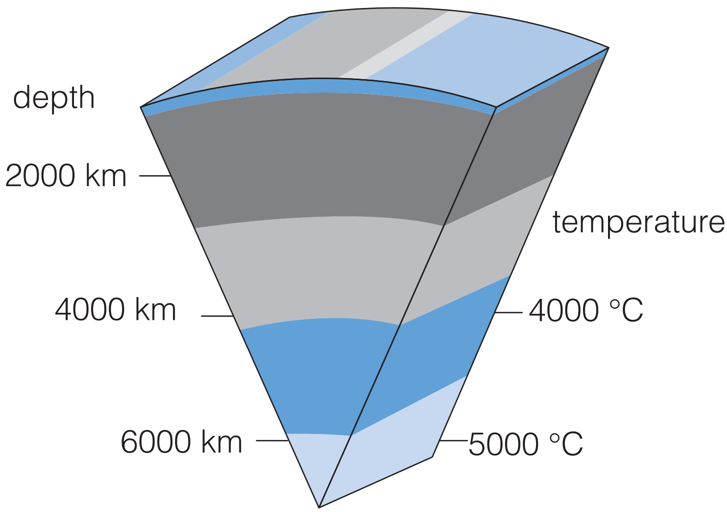


Figure 11.1 Temperatures within the earth
Source: EGEC (2008)

countries. In Japan, the first geothermal wells were drilled in 1919 and, in 1929, at The Geysers, California, in the USA. In 1958, a small geothermal power plant started operating in New Zealand, in 1959 in Mexico, in 1960 in the USA, and in many other countries the following years.

STATE-OF-THE-ART TECHNOLOGY

The underground heat reservoir is inexhaustible, but up until now we used just a marginal part of its potential. The use of the ground temperature is monitored to sustain the geological conditions and thus ensure the viability of the systems. The use of ground water is controlled by reinjection, to have a sustainable circuit.

Schematically, a geothermal system may be described as convective water in the upper earth crust transferring heat in a confined state from a heat source to a heat sink (usually a free surface). Hence, a geothermal system includes three components: a heat source, a reservoir and a heat carrier fluid. The heat source can be either a magmatic intrusion at very high temperature at relatively shallow depths (5–10km) or hot rocks at depth, in the case of low temperature systems. The reservoir consists of hot permeable rocks from which circulating fluids extract heat. The reservoir is generally overlain by impervious cap rocks and connected to a superficial outcropping area subject to meteoric recharge, which replaces, at least in part, the fluids abstracted through spring and/or well discharge. The geothermal fluid is water, usually of meteoric origin, in either liquid or vapour phase depending on its temperature and pressure.

Hot water and steam are extracted by drilling wells into the reservoir thus enabling the exploitation of this clean and sustainable resource. Reliable expertise and engineering skills have been developed in order to achieve relevant reservoir assessments and drilling locations. Once available at production well-heads, geothermal fluids can be used for electric power generation or non-electric (direct use) heating purposes or both (CHP). Power plants need steam to generate electricity; the steam rotates a turbine that activates a generator (alternator), thus producing electricity.

Conventional power plants burn fossil fuels to boil water. Geothermal power plants, instead, use steam produced from geothermal reservoirs, located at several hundred to a few thousand metres below ground. This steam production process does not require any artificial or natural combustion whatsoever, thus avoiding man-induced CO_2 emissions. Three types of geothermal power plants can been distinguished, then: dry steam, flash steam and binary cycle. Largest installed capacities correspond to flash plants (64 per cent); despite their current low ranking (8 per cent) due to smaller plant ratings, binary units raise fast growing interest as they address widespread, low to medium temperature, resource settings. A total of around 500 geothermal units were reported online in 2008. The maximum addresses about 250 binary plants, totalling an 800MWe installed capacity (in other words a unit 3.3MWe plant load). The sizes of flash and dry steam plants average 31MWe and 44MWe respectively.

Technological benefits

Over the last decades a growing concern over environmental issues has been spreading around the world in parallel with a dramatic increase in energy demand. Energy sources are not equally distributed among countries and quite often developing nations cannot afford to buy fossil fuels abroad in order to meet industrial and civil needs. An indigenous and easily exploitable energy source would therefore be needed in many countries around the world to give a boost to local activities and support a self-sustaining economic growth.

Geothermal energy then can represent a viable, local and environmentally friendly solution for many of these countries: it is almost ubiquitously available and its use could allow fossil fuels savings; it involves no burning processes so no man-made emissions will affect the area (any geothermal area is already characterized by gas emissions which escape naturally from the ground, but the clouds over geothermal plants are made only of steam) and no radioactive waste is produced. In other words, geothermal energy is a clean, reliable and base-load energy (as it is available all year), that allows economical savings in terms of fuel imports avoided and can create jobs in local communities.

The development of geothermal energy has always faced different constraints and difficulties mainly due to our limited knowledge of nature that may limit the real possibilities and advantages of this special RES.

Technological applications

Geothermal energy is the perfect answer to different energy needs: electricity, and heating & cooling.

Dry steam and flash power plant

Dry steam power plants use simple steam, which is piped from production wells to the plant, then directed towards turbine blades. The first ever exploited geothermal field is located in Larderello in Italy. Still in operation, it is among the very few dry steam fields recorded worldwide.

Figure 11.2 Larderello: Steam conduits through the valley
Source: EGEC (2008)

Figure 11.3 Larderello: Italian geothermal power plant
Source: EGEC (2008)

Conventional dry steam turbines require fluids of at least 150°C and are available with either atmospheric (backpressure) or condensing exhausts. In the backpressure system, steam is passed through the turbine and vented to the atmosphere. This cycle consumes twice as much steam per produced kWh as a condensing cycle at identical turbine inlet pressure. However, backpressure turbines may prove rewarding as pilot and/or stand-by plants in case of small supplies from remote isolated wells and for generating electricity in the early stages of field development. They become mandatory in the case of high non-condensable gas contents with an excess of 12 per cent in weight in the vapour phase.

55 to 60MWe plant installed capacities are quite common but recently 110MWe plants have been commissioned and are currently operating. Flash steam plants, by far the most common, address water dominated reservoirs and temperatures above 180°C. The hot pressurized water flows up the well until its pressure decreases to the stage it vaporizes, leading to a two-phase water-steam mixture and a vapour lift process. The steam, thus separated from water, is piped to the plant to drive a turbo-alternator. Separated left-over brine and condensed steam are piped back into the source reservoir through an injection process that meet sustainability requirements for waste disposal, heat recovery, pressure maintenance and resources.

Binary cycle power plant

Binary plants (also known as Organic Rankine Cycle, ORC or Kalina) operate usually with waters in a temperature range of 100–180°C. In these plants heat is recovered from the geothermal fluid via a heat exchanger in order to vaporize a low boiling point organic fluid and drive an organic vapour turbine. The heat-depleted geothermal brine is pumped back into the source reservoir, thus securing sustainable resource exploitation.

Since the geothermal and working fluids are kept separated during the process, few if any atmospheric emissions are produced. Adequate working fluid selection may allow the extension of the former temperature range from 180°C to 75°C. Binary processes are emerging as a cost-effective conversion technology for recovering power from water-dominated geothermal fields at temperatures below 180°C. Recently, a

Figure 11.4 Geothermal power plant of Ribeira Grande, Azores, Portugal
Source: EGEC (2008)

new candidate binary process, known as the Kalina cycle, has been developed which displays attractive conversion efficiencies. Its distinctive features address an ammonia-water working fluid mixture and regenerative heating. It takes advantage of the low boiling point of the water-ammonia mixture to allow a significant fraction of it to be vaporized by the excess heat available at the turbine exhaust. Reclamation of low temperature geothermal sources, achievable via binary cycles, can significantly increase the overall exploitation potential worldwide. Small scale geothermal binary plants (<5MWe ratings) can be widely implemented in rural areas and, more generally, respond to an increasingly disseminated human demand.

Binary systems represent a means for upgrading overall plant efficiencies of 'conventional' flash cycles. Contrary to dry steam plants, where the water phase reduces to steam condensates, flash units produce large amounts of separated water and waste heat, which remains lost unless otherwise utilized as heat (central heating/process heat for instance) or as binary power downstream from the flash steam turbine. This power cascading scheme produces low cost energy extras at zero mining costs.

Enhanced Geothermal Systems (EGS)

At places where no natural geothermal resources in the form of steam or hot water exist, the heat of the rock can be used by creating artificial permeability for fluids which extract that heat. Known as 'Hot Dry Rock' technology (HDR), this method has been under development since the 1970s and crucial breakthroughs have been made.

In June 2008, the commissioning and official inauguration of the first EGS power plant at Soultz-sous-Forêts, in the upper Rhine Graben of Northern Alsace, concluded 30 years of EU R&D actions dedicated to heat and power extraction from low permeability/near impervious, deep seated (5km), basement rocks. The system is currently operating with two production wells, equipped with submersible pump sets, and one injection well, achieving all together a 35l/s circulation rate and an installed capacity of 1.5MWel.

North of Soultz, in the upper Rhine Graben, a commercial project completed in a higher grade EGS environment, applying the rock stimulation techniques implemented at Soulz, is now on line. The operating CHP plant exhibits net power and heat outputs amounting to 3MWel and 6MWth respectively.

Since the validity of the concept has been demonstrated, EGS plant ratings should move from 3-10MWel in the early development stages of the technology towards 25 to 50MWe units produced from multiwell (five to ten) clusters, as currently practised in the oil and gas industry.

Hence, the EGS concept aims at dramatically increasing the geopower potential normally expected from conventional “natural” hydrothermal settings. Such an ambitions goal implies that the following prerequisites be fulfilled:

- identify and exploit the natural fracture networks hosted in basement rocks;
- boost their conductivity/connectivity via massive stimulation techniques to favour the creation of large fractured rock volumes and related heat exchange areas;
- complete a heat extraction system based on a multi-production/injection-well array;
- circulate large amounts of water via pumping/lifting/buoyancy into this ‘man made geothermal reservoir‘ to maximize heat and power production;
- achieve adequate heat recovery and system life to secure system sustainability.

Combined heat and power (CHP)

Geothermal CHP is nothing new. As a matter of fact, a low temperature (81°C) geothermal resource has been exploited since the late 1960s at Paratunka in Kamchatka, Russia. Such a temperature cascading use is what geothermal CHP is all about. Actually, heat may be regarded as a by-product of geothermal power production in terms of either waste heat released by the generating units or excess heat from the geothermal source.

Figure 11.5 Altheim CHP: Well-head and pump station
Source: EGEC (2008)

Power generation from medium enthalpy sources (in the 100–150°C temperature range) by using a low boiling point working fluid and an organic vapour turbine (through the already mentioned ORC) can hardly seek any economic viability, unless a heating segment is added to the utilization grid.

Therefore, reclamation of these resources implies a structural synergy, illustrated so far in three geothermal CHP co-generation plants operated in Austria (Altheim and Bad Blumau) and Germany (Neustadt-Glewe) and a fourth that is underway (Unterhachting, Germany). Several other CHP plants are presently under completion in Germany at Isar (Munich), Speyer and Landau. Ideally, one could contemplate the integrated power, heating and (absorption) cooling design displayed in a cascading scheme. The existing technology is currently trending towards increased efficiencies in order to optimize the power segment of CHP plants. In the past, geothermal CHP addressed high enthalpy resource settings, which in Europe are located in Italy, Greece, French DOM/TOM (overseas departments and territories such as Guadeloupe, West Indies), Spain (Canary Islands) and Portugal (Azores archipelago) and in Iceland and Turkey. Implementation of low temperature geothermal CHP binary plants can be contemplated in candidate areas exhibiting the required medium enthalpy temperature patterns. Such areas are encountered in the following regions:

- the Alpine Molasse basins (north and south of the Alps);
- the Pannonian basin of Hungary and border areas of Slovakia, Slovenia, Serbia and Romania;
- areas stretching from the Paris basin (including southern England) throughout Benelux, northern Germany, Denmark and the southern-most parts of Sweden and into Poland and Lithuania, although to a lesser extent.

Graben systems, indeed a distinctive geodynamic attribute, offer attractive CHP issues. Such is the case of:

- the Upper Rhine Graben, targeted by several commissioned German CHP projects;
- the Rhone and Limagne graben structures in France;
- several, smaller but promising, settings identified in the Balkans (Serbia, Macedonia, Bulgaria, northern Greece).

Last but not least, the geothermal CHP spectrum could be significantly widened thanks to a successful achievement of the leading Enhanced Geothermal Systems (EGS) project carried out at Soultz-sous-Forêts, France. This could enable currently 'silent' areas of central, southern and western Europe to access the CHP route. Therefore, geothermal CHP seems to have a good chance of further development.

Costs and prices

Final economy of a geothermal project depends on a wide range of influencing factors, beginning with the important influence of regulatory aspects, exploration and investigation for resource identification, complexion and exploitation and alternative conversion technologies (district heating, space heating, etc.). The three main influencing factors are the investment, the Operation & Maintenance and the development costs.

As a large part of the costs for a geothermal power plant comes from deep drilling, further development of innovative drilling technology is expected. Assuming a global average market growth for geothermal power capacity of 9 per cent per year up to

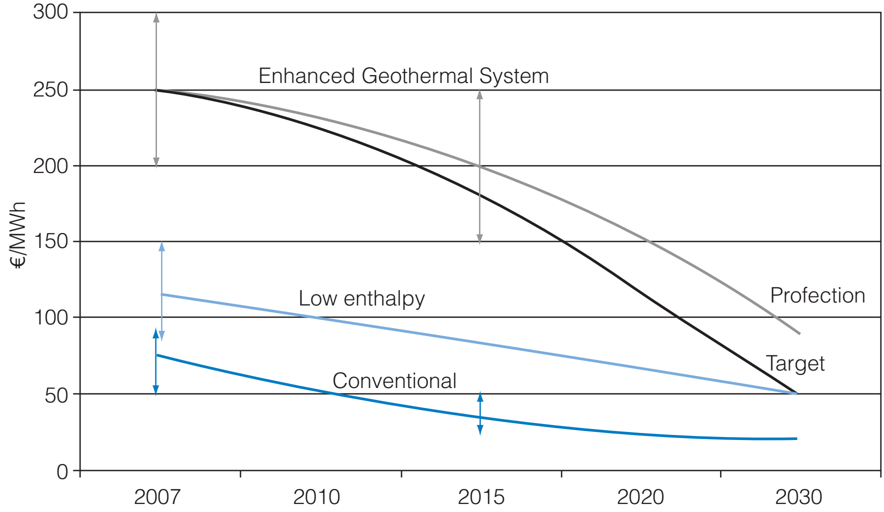


Figure 11.6 Summary of targeted costs
Source: Scientific and Technological References – Energy Technology Indicators (EC progress report 2002).

2020, adjusting to 4 per cent beyond 2030, the result would be a potential cost reduction of 50 per cent by 2050:

- for conventional geothermal power, from 7c€/kWh to around 2c€/kWh;
- for EGS, despite the presently high figures (about 20c€/kWh), electricity production costs – depending on payments for heat supply – are expected to come down to around 5c€/kWh in the long term.

Because of its non-fluctuating supply and a load to the grid operating up to almost 100 per cent of the time, geothermal energy is considered to be a key element in a future supply structure based on renewable sources.

Table 11.1 Summary of targeted costs

Geothermal Electricity	Costs 2007 Range (€/MWh)	Average (€/MWh)	Costs 2030 Average (€/MWh)
Electricity Conventional	50–90	70	20
Low temperature	80–150	115	50
Enhanced Geothermal Systems	200–300	250	70

Source: IEA (2007)

MARKET

As far as geothermal electricity is concerned, the vast majority of eligible resources in Continental Europe at large are concentrated in Italy, Iceland and Turkey; the exploited potential so far represents 0.3 per cent of the whole renewable energy market.

The average growth rate of installed capacities is slowly decreasing: from 4.8 per cent during the decade 1990–2000 to 3.7 per cent and 3.3 per cent for 2000–2010 and 2010–2020 respectively, without accounting for any EGS contribution. Only a relevant supporting policy can achieve the development of new, deeper and/or costly geothermal resources. Another barrier to further exploitation relates to the adequacy of resource to demand: for instance, in areas of high geo-electric potential, such as Iceland and far east Russia there is enough offer and supply. On the other hand, a great increase in direct uses is projected, from 16,000MWth in year 2010 to 39,000MWth in 2020. It is difficult to appraise the impact of new frontier technologies as well as the contribution of EGS issues in the European geothermal scenario. Prospects, in this respect, are very promising and opportunities for extracting heat in non-hydrothermal artificially fractured systems via a closed loop circulation can be quite significant in a long run far-sighted perspective. Geothermal electricity development in Europe stands at 1500–2000MWe in 2010, while for 2020 it can be estimated to match the 4000–6000MWe target.

Table 11.2 Targets for EU-27

Geothermal Electricity EU-27	2007	2010	2020
Electricity conventional (MWe)	815	920	1200
Low temperature (MWe)	15	70	300
Electricity Enhanced Systems (MWe)	–	10	4500
Total Installed Capacity (MWe)	830	1000	6000
Yearly Electricity Production (TWh)	6.5	8	50

Source: EGEC (2009a)

Installed capacity and market development in EU and market segments

There are two major geothermal areas in Italy: Larderello-Travale/Radicondoli and Monte Amiata which achieve 810MWe installed capacity. They represent two neighbouring parts of the same deep seated field, spreading over an area of about 400km^2, which produces superheated steam. In Larderello the exploited area and installed capacity amount to 250km^2 and 562MWe respectively. In Travale/Radicondoli the installed capacity is 160MWe and the exploited area 50km^2. The steam condensates recovered from Travale are reinjected into the core of the Larderello field, via a 20km-long water pipeline. The Monte Amiata area, in northern Latium, includes two water dominated geothermal fields: Piancastagnaio and Bagnore. On both fields a deep resource has been identified under the shallow producing horizons. Weak social acceptance from the local communities is slowing down the full development of the promising, high potential, deep reservoir. Five units are currently in operation, one in Bagnore and four in Piancastagnaio, totalling 8MWe installed capacity. Projects have been commissioned and will be completed in the near future, thus adding a further 100MWe capacity. In Greece, direct drilling and testing assessments have allowed the exploitation of high temperature geothermal resources in the Aegean volcanic island arc, in Milos (Cyclades) and Nisyros (Dodecanese) islands. Electricity generation from a 2MWe rated pilot plant ceased further production due to the strong opposition of the local community and mismanaged communication by the geothermal operator. The country potential in the Aegean archipelagos and, to a lesser extent, in the northern mainland located grabens is estimated at around 200MWe. Otherwise, several low temperature fields are exploited for greenhouse heating and process heat applications on presently limited bases.

In Guadeloupe islands, at Bouillante (France), a small plant of 4.7MWe was built in 1984, meeting 2 per cent of the islands' electricity demand. Its capacity has recently been increased to 15MWe.

In the Sao Miguel Island (Azores, Portugal), 43 per cent of the electrical production is supplied from a high temperature saline brine (230°C at 1200 metres), by three flashed steam plants (23MWe total installed capacity) which have been online since 1980. An additional 12MWe capacity is scheduled in the near future. Recently, almost 10MWe capacity binary power has been produced in Austria and Germany from low temperature geothermal sources. The conversion process, Organic Rankine Cycle (ORC) or Kalina cycle, raises considerable interest as it makes it possible to produce electricity from cooler geothermal sources (typically within the 100-120°C temperature range, exceptionally down to 70-75°C depending upon the availability of a cold water source). Improvements should concentrate on cycle and plant efficiencies alongside cogeneration production. As a result, two development routes are contemplated:

- small plant designs targeted at 1MWe/2MWht CHP capacities, close actually to those implemented already in the EU [(0.5 – 3 MWe) / (1–6MWt)];
- a microgeneration standard for small scale ORC modules.

To the question of how geothermal energy could expand its power market penetration share, the EGS issue is the answer.

Figure 11.7 Unterhaching well testing
Source: EGEC (2008)

Figure 11.8 Soultz enhanced geothermal system (EGS) power plant
Source: EGEC (2008)

Development of these technologies will make it possible to access huge geothermal potential. Among the ongoing EGS projects worldwide, the Soultz European test site has been inaugurated in June 2008. Without EGS contribution, the geo-electricity target expected in 2010 stands at 1800MWe, in other words approximately an increase of 400MWe from now.

Industry

In 2008 the geothermal electrical industry supplied about 2000 direct jobs. This corresponds to around 2 jobs per megawatt (MW) of geothermal power capacity installed. Employment in the industry is at an historic high since power plant construction has been maximal.

In the future, employment is likely to increase much more. More power purchase agreements have been signed for new geothermal power plants. There will be significant growth in the industry in the coming years. The growth in the industry is not only creating new direct power plant jobs, but also creates many equipment manufacturing and construction jobs, and opportunities for indirectly related businesses and support services. The geothermal industry has the potential to stimulate substantial new employment. The EGEC reference scenario for the geothermal industry growth suggests that 9000MW of new power production capacity could be built during the next 15 years. This would correspond to the creation of around 50,000 jobs directly related to power plant construction and manufacturing. Power plant construction as well as operation and maintenance involve the use of numerous goods and services provided from other economic and industrial sectors. Increased demand for those goods and services will result in indirect and induced employment impacts, both locally and Europe-wide.

Construction of a geothermal power plant takes about 17 to 33 months and involves many types of skilled workers. Typically, a majority of the construction and O&M workforce is hired locally. Since the types of construction activities change throughout the project completion, the type of worker involved in these tasks also evolves.

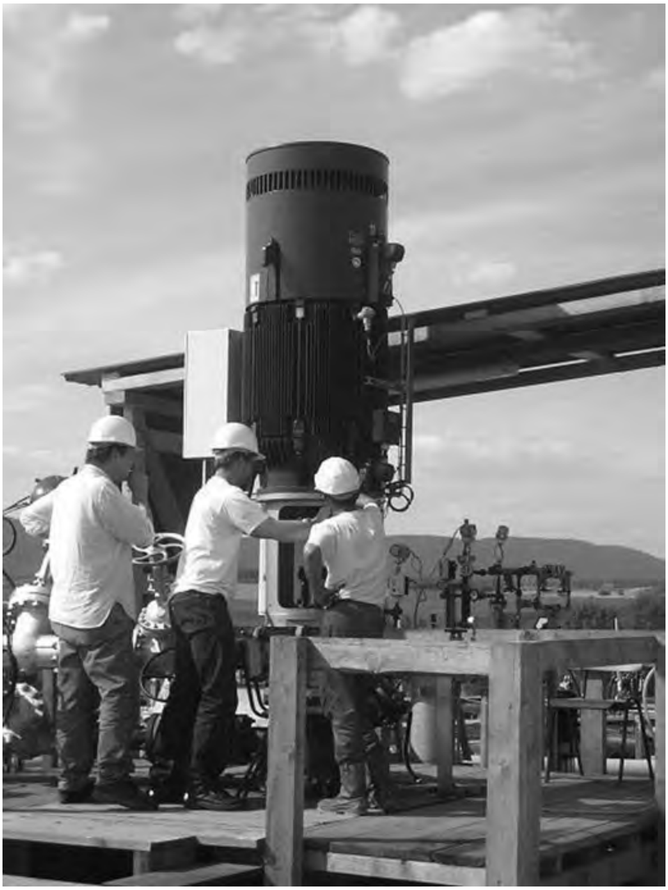


Figure 11.9 Soultz EGS power plant
Source: EGEC (2008)

Policy instruments to support the technology

The newly adopted directive on the promotion of energy from renewable sources (RES Directive) will increase the use of geothermal energy and its contribution towards our technology targets, ultimately supporting the struggle for a sustainable and clean energy future in Europe. This important piece of legislation describes the EU's strategy and objectives, but also requires member states to adopt National Action Plans stating how they intend to reach their own national targets. There is an urgent need for increasing information and awareness on the geothermal sector, essential for reaching the EU target of 20 per cent RES by 2020. This also implies that the European geothermal industry should encourage member states and local authorities to drive the implementation of new geothermal initiatives and, in some cases, implement direct actions for this purpose, aiming at removing existing barriers.

New policy initiatives in this field will need to address the barriers which currently hamper the rapid expansion of geothermal market.

- Although geothermal energy offers much lower operation costs, investment costs are usually higher. In the short term, consistent and reliable support programmes, including programmes which promote innovative financing mechanisms (risk insurance), must help to overcome this barrier. In the mid- and long-term, economies of scale and R&D are expected to significantly decrease investment costs.

- An insufficient database: currently, statistics on the geothermal sector and inventories of geothermal resources in general are weak. The swift establishment of robust market data and reliable statistics that would thus allow for the determination of a baseline, as well as progress monitoring, is essential.
- In many countries and regions in Europe, information and awareness levels, in particular about geothermal energy, are still relatively low. Clear market signals, such as targets and awareness campaigns proactively targeting suppliers (especially installers), can help to overcome this obstacle.
- Any regulatory framework for geothermal energy has to serve the following main purposes: a) securing environmentally friendly use of geothermal energy, in particular concerning the ownership, licensing procedures, etc.; b) regulating competing uses and securing sustainable use of geothermal energy; and c) granting to the investor, as the basis for business plans, a firm right to use geothermal energy in a given area and to a given extent.
- R&D and demonstration projects.

The objectives are to develop enabling technologies for the exploitation of geothermal resources and to prove the sustainability of EGS technology.

Two-thirds of the costs associated with geothermal plants are related to drilling wells. Great advances are possible in drilling technology, such as 'micro-drilling' for exploration and preliminary resource assessment, and laser drilling and fusion drilling for drilling the main borehole.

Figure 11.10 Soultz EGS power plant
Source: EGEC (2008)

The aim is to develop enabling technologies for the exploitation of geothermal resources and to prove the sustainability of EGS technology in representative EU sites. The estimated current cost of electricity generation from the first-generation prototype plants is in the order of €0.15–0.20/kWh. A continued reduction in cost through innovative developments, learning curve effects and co-generation of heat and power should lead to an electricity cost of around €0.05/kWh in 2020.

TOMORROW

The growth in EU-27 installed capacity from geothermal power plants is promising. An increase of about 250MWe in the last seven years (2000–2007) has been achieved. Installed geothermal electricity capacity is approaching 1GWe threshold, 10 per cent of the world installation. Other European countries count for about 0.9Gwe. The economics of electricity production are mainly influenced by drilling costs and resource development.

Binary plant technology is now playing a very important role in Europe. Utilization of lower temperature resources (80°C) can be achieved with binary plant, increasing the overall exploitable potential. In the future, EGS will play a major role.

Technology targets by 2020 and beyond

The gradual introduction of new developments (permeability enhancements, drilling improvements, enhanced geothermal systems, low temperature production and super-critical fluid) will boost the growth rate, thus reaching the EU-27 target of 1.2GWe for 2010 and 6Gwe installed (42TWh/y) in 2020. Some of these new technologies are already proven, like the binary plant (low temperature electricity production) or the EGS, and are currently spreading quickly into the market.

Better technical solutions (reinjection, inhibitors against scaling/corrosion and better knowledge of the field parameters using advanced geophysical surveys) for the power plants will improve their performances and reduce the costs. The EGEC forecasts a decrease from €50–90/MWh to €20/MWh for 'conventional' geothermal power and from €200–300/MWh to €50/MWh for EGS.

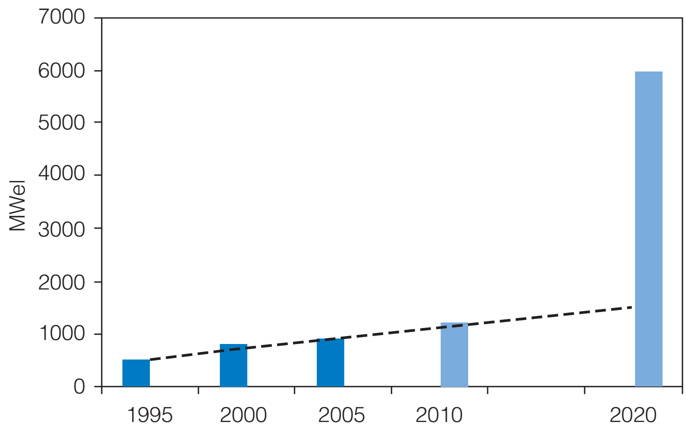


Figure 11.11 EGEC forecasts up to 2020
Source: EGEC (2009a)

Technological long term potential

Estimating the overall worldwide potential is a delicate exercise due to the many uncertainties involved. Nevertheless, it is possible to try an estimation, taking into consideration the economically exploitable zones, making an intense development in the low-medium temperature range, which is the most abundant geothermal resource. The expected value of 70GW is a realistic target for year 2050.

Moreover, including new technologies (permeability enhancements, EGS, Super-critical fluids and magmatic resources), it would be possible to at least double the total world electrical geothermal production by 2050, considering that 40 countries, mostly in Africa, Central and South America and in the Pacific, could be fully powered by geothermal energy (in terms of electricity production). Geothermal Energy is already widely used in the world, for power production, and it could provide electricity anywhere: at places where no natural geothermal resources in form of steam or hot water exist, the heat of the rock will be used by creating artificial permeability for fluids extracting that heat (EGS).

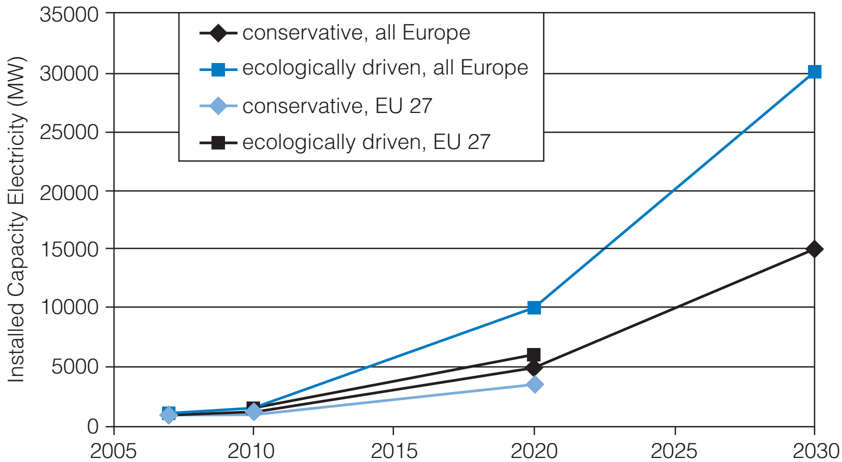


Figure 11.12 Trends up to 2030
Source: EGEC (2009a)

Part IV

Biofuels

12

Bioethanol

The two most commonly used biofuels are bioethanol and biodiesel. At a global scale bioethanol is the preferred biofuel (90 per cent). However, in Europe 75 per cent of the market is biodiesel.

STATE-OF-THE-ART TECHNOLOGY

Bioethanol, also known as alcohol, is a renewable fuel made by fermenting sugars mainly from cereals such as wheat, maize, triticale, rye, barley and from sugar cane or sugar beet. Ethanol production from cereals containing starch takes place in five stages (see Figure 12.1):

1. Milling: in the first step the cereal is mechanically crushed in a milling process in order to release the starch component of the grain;
2. Saccharification: the starch obtained through milling is converted into sugars in the second production step. This is done by heating and by adding water and enzymes, which break the starch up into fermentable sugars. The resulting fluid is called mash;
3. Fermentation: the liquid mash is then treated with yeast, whereby the sugar is converted into CO_2 and ethanol;
4. Distillation and rectification: during this process the ethanol is concentrated and cleaned. Impurities are removed;
5. Dehydration: drying of ethanol to a purity of 99.7 percentage volume.

When bioethanol is produced only using sugar syrup (molasses), a by-product of the sugar refining process, stages 1 and 2 are not needed. However, not all grain starch can be converted to bioethanol because it is bound to other molecular structures. This is known as residual starch. The residual starch content can be as high as 10 per cent of the total starch, with 5 per cent as the average. On the other hand, as the co-product obtained from the dry-mill bioethanol production process, the Distiller's Dried Grain and Solubles (DDGS) contains all the constituents that have not been converted into bioethanol, including all the proteins, fibres and fats, as well as the non-converted starch.

While concerns have been raised about whether first generation biofuels are sustainable, production technology has come a long way since the beginning of biofuels programmes in the 1980s. Driven by cost savings, energy-conscious design has since reduced the energy demand of the process by up to half. Energy efficiency is a proven, cost-effective way of cutting GHG emissions and contributing to sustainability.

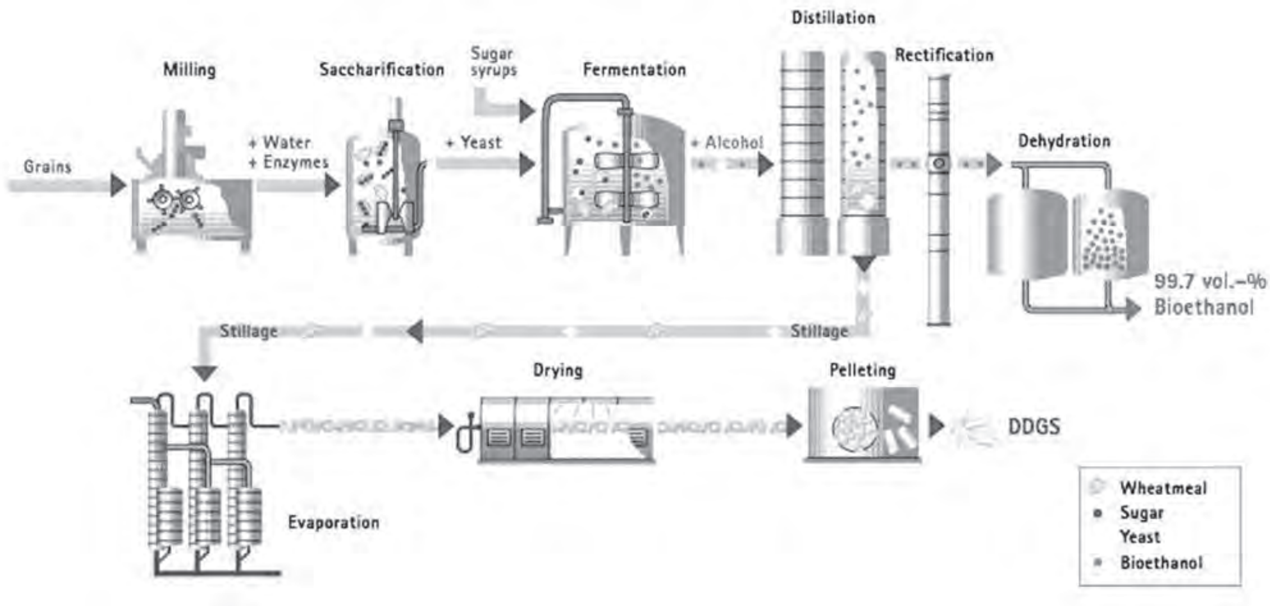


Figure 12.1 Schematic diagram of production process of bioethanol and DDGS from grains and sugar syrup
Source: CropEnergies AG (2008)

Technological benefits

Bioethanol is crucial for a sustainable road transport future. It is both a critical technology for tackling our most intractable greenhouse gas (GHG) problem and it is one of the only technologies we have to address our greatest energy security threat. It also offers a wide range of ancillary benefits:

- **Immediate greenhouse gas savings**: The EU transport sector is performing worst in terms of GHG emissions compared to other sectors. Presently, biofuels are the only way to reduce GHG immediately. A share of 10 per cent biofuels by 2020 would deliver GHG savings of 68 million tonnes CO_2.
- **Increased energy security**: the EU depends heavily on imported energy for running its economy. For the transport sector there is hardly any diversification of energy sources: crude oil fuels 98 per cent of the EU's transport. The 10 per cent share of biofuels by 2020 would reduce crude oil imports by 31 million tonnes of oil equivalent.[2] Moreover, global reserves of oil have been consistently shrinking both in quantity and geographical spread since the 1980s. The smaller the number of reserves the more unstable the supply base becomes and the more difficult it is to expand production to meet the ever-growing needs of an energy hungry world. Biofuels are a vital source of domestic energy production that will help alleviate these problems.
- **Better air quality**: blending ethanol in gasoline dramatically reduces carbon monoxide tailpipe emissions. According to the US National Research Council, carbon monoxide emissions are responsible for as much as 20 per cent of smog formation. Additionally, ethanol-blended fuels reduce tailpipe emissions of volatile organic compounds which readily form ozone in the atmosphere. These reductions more than offset any slight increases of evaporative emissions due to the higher volatility of ethanol-blended fuel. Thus, the use of ethanol plays an important role in smog reduction. Moreover, ethanol reduces tailpipe toxics content by 13 per cent (mass), 21 per cent (potency) and tailpipe fine particulate matter (PM) emissions by 50 per cent[3]:
- **Optimal utilization of arable land**: bioethanol from cereals and sugar beet produces substantial quantities of valuable animal feed. For every tonne of sugar beet or cereals used for ethanol production, on average between one-half and two-thirds will enter the animal feed stream. Also gluten is separated in the process and sold on to the feed market. In addition, a variety of other co-products are also produced, for example, high performance Combined Heat and Power (CHP) electricity generation contributes to energy efficiency and local power supplies. The carbon dioxide produced in the process can be captured and used for a wide variety of purposes, like horticulture production.
- **Benefits to the developing world**: many developing countries have seen their farming industries crushed by competition from the dumping of cheap imports of structural surpluses from the EU and other rich countries. The UN Food and Agriculture Organisation (FAO) has repeatedly stated that the removal of this dumping would play a huge role in reducing hunger and starvation. EU-produced bioethanol offers a way to use cereal surpluses in a less distorting way. In some cases, in developing countries it can help build a domestic agricultural sector vital for increasing local food production and fighting poverty. In those cases, biofuel production is an opportunity for the developing world. It can attract investments in countries which have a surplus of land but lack the necessary infrastructure to make it productive

and thereby create a sustainable source of income. Moreover, new export markets for biofuels will arise and energy security can increase by replacing extremely expensive fossil fuels with locally produced biofuels.

- **Sustainability**: the EU has set an ambitious precedent by introducing strong sustainability criteria for the biofuel production chain. All biofuels used in the EU will have to comply with those criteria, which will serve as a positive example globally. As all EU produced bioethanol uses EU-grown agricultural crops the European producers comply with the most rigorous environmental criteria in terms of land use, water use and biodiversity laid down in the cross-compliance rules, as well as social standards. Eventually a strict sustainability certification for all biomass is needed including food and non-food applications. To create a true level playing field, fossil fuels would also need to go through an equally strict sustainability assessment in the future.

Technological applications

Bioethanol is the principal fuel used as a petrol substitute for road transport vehicles whereas biodiesel (predominantly manufactured from oil seeds) substitutes fossil-derived diesel. Bioethanol can either be blended with gasoline directly or it can be processed into Ethyl tert-butyl ether (ETBE). ETBE is a blending component added to petrol to make it burn cleanly and completely thus enhancing engine perfromance. ETBE contains abot 47 per cent of ethanol and is a major outlet for EU-ethanol production.

Since 1986, EU law has permitted up to 5 per cent bioethanol in petrol and today most of the European petrol fleet can accept a 10 per cent blend. This legally fixed limit will increase to 10 per cent under the recently adopted review of the Fuel Quality Directive (2009/30/EC). Bioethanol can also be used in much higher concentrations in adapted cars such as E85 vehicles that run on a blend of 85 per cent bioethanol and 15 per cent petrol. Pure ethanol also fuels certain types of buses and trucks in Europe.

Cost and prices

Calculating the costs of production is one of the most challenging 'guessing games' in the ethanol industry. Many elements of the cost structure are considered confidential and are therefore not available in the public domain. However, at the same time a detailed knowledge of production cost permits the determination of a minimum market price level at which best practice companies would continue to operate. If at national level, it allows an assessment of the competitiveness of a sector and, as a result, the probability of production expansion or contraction in the medium to long run. Besides the confidentiality issue, there are other limitations which need to be taken into consideration. For example, exchange rate movements, price fluctuations in local energy markets and sudden, seasonal increases in feedstock values all have a, sometimes decisive, influence on the level of production cost. In order to arrive at results which are comparable we have chosen the so-called engineering approach. This guarantees consistency between the results derived for different countries and feedstock. Starting from the detailed and disaggregated listing of the inputs that are used to produce ethanol, one can attach local prices to each of the inputs, to arrive at a relatively realistic cost estimate.

The total cost of producing ethanol can be broken down into three elements:

1 Capital related or fixed costs (depending on the facility's outstanding debt and loan structure);

2 Variable operating costs (labour, maintenance and consumables; energy; etc.);
3 Net feedstock costs (feedstock costs minus co-product credits).

Figure 12.2 shows that invariably, feedstock costs account for the biggest chunk of the total costs. Therefore, the volatility on the feedstock markets decisively influences the profitability of any given ethanol distillery. The graph shows that wheat alcohol producers had been particularly hit by the strong increase in world grain prices in 2007 and 2008. If distillers had not hedged themselves against price movements, they would have been faced with production costs of around \$800–\$850 per m^3 during 2007/08. Of course, in reality, the cost of production is much lower because professionally organized fuel alcohol producers use risk management tools in order to protect themselves against volatile commodity markets. However, such a strategy has its limits. The time-period for which feedstock purchases can be hedged is limited and if there is an extended rally on the feedstock markets, producers will eventually be squeezed. In the EU and other grain alcohol producing countries, the sharp price correction on the world grain market seen in the fourth quarter of 2008 will have come at exactly the right time to avoid such a squeeze.

Going forward, the volatility on the feedstock market will force distillers to pursue strategies that will limit their exposure to price movements. Hedging on the futures markets is one such instrument. However, there are others as well. These include feedstock flexibility and the search for alternative energy sources for the fermentation and distillation process. In Europe, there are a number of plants which can process a variety of feedstocks ranging from various grains to sugar beet and wine alcohol. A second instrument to reduce exposure to commodity markets is the increasing use of biogas and biomass for the production of process energy. Most of the new plants currently being built in Europe are following this strategy which, besides making economic sense, will also help them to meet sustainability criteria set by the EC.

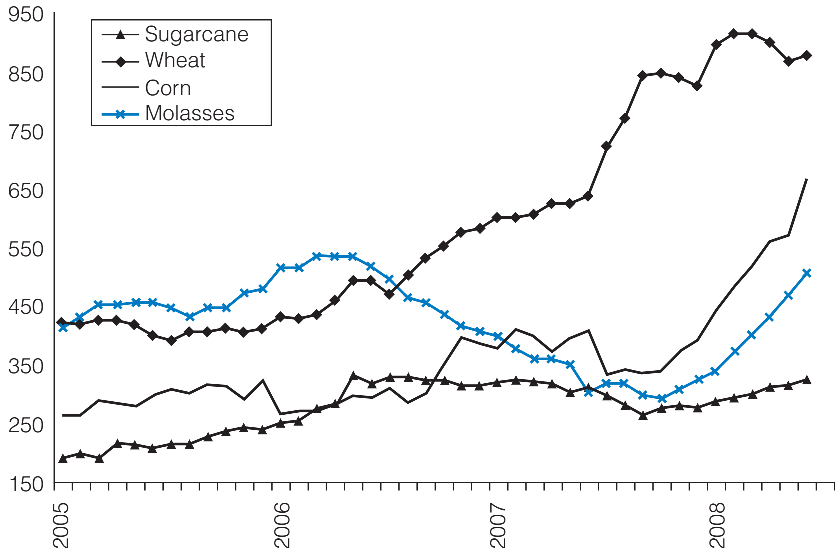


Figure 12.2 World ethanol production costs (\$/cubic metre)
Source: F.O. Licht

MARKET

Europe's fuel ethanol sector was a slow starter. It took almost 10 years to grow production from 60 million litres in 1993 to 528 million litres in 2004. In the two following years (2005 and 2006) annual production experienced double-digit growth rates of 75 per cent as an immediate result of the EU law on biofuels (2003/30/EC). For a number of reasons, 2007 production increased by 'only' 12 per cent. In 2008, however, the EU ethanol market again grew strongly (+58 per cent) to over 2.8 billion litres.

Compared to the US and Brazil, but also to the EU biodiesel sector, the EU fuel alcohol sector is rather small. In 2008 the US produced well over 33 billion litres and Brazil about 24 billion. Total ethanol for fuel production worldwide in 2008 was about 62 billion litres. The top four EU producers of ethanol are France, Germany, Spain and Poland. The top seven consumers are Germany, Sweden, France, Spain, the Netherlands, the UK and Poland. Overall consumption of fuel ethanol in 2008 is approximately 3.5 billion litres, whereas total production was just over 2.8 billion litres. This gap was filled by ethanol from, almost exclusively, Brazil (going to mainly Sweden, the UK and the Netherlands). A final characteristic of the EU market worth mentioning is the substantial and preferred use of ETBE as an octane improver, which uses ethanol as feedstock.

Contrary to the big ethanol producers, the EU is using a variety of crops for ethanol production. Whereas in Brazil only sugar cane is processed and in the US mostly corn, wheat is the preferred feedstock in the EU. Besides other grains such as rye, barley maize and triticale, sugar beet juice is also used in considerable quantities. Also raw alcohol[4] is sometimes upgraded to fuel ethanol. Because of higher grain prices there has been a shift (mainly in Germany) to the greater use of sugar beet juice. Obviously, the change of the Common Market Organisation for Sugar is also contributing to this shift. If we look at the bigger picture of grain use in the EU it becomes immediately clear that bioethanol production is only a marginal consumer of grain (less than 2 per cent gross). Most of Europe's cereals go to the animal feed sector (over 60 per cent). Of this relatively small quantity of cereals for bioethanol production, about one-third goes to the animal feed sector as a high protein animal feed called Dried Distillers Grains and Solubles (DDGS). This by-product is able to replace imported soya meal.

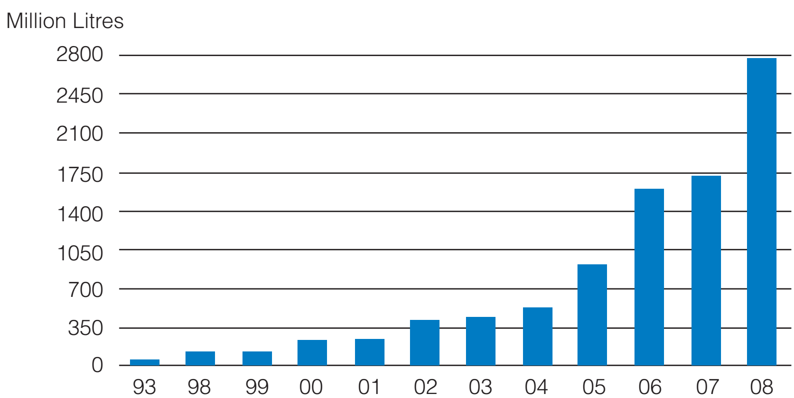


Figure 12.3 EU bioethanol market (1993–2008)
Source: eBIO

Installed capacity and market development in EU and market segments

EU production capacity is rapidly increasing. At the end of 2009 there was an installed capacity of 6.3 billion litres and another 2.1 billion litres under construction. Most of the installed capacity is located in France, followed by Germany and then Spain. In 2011, the EU production capacity should reach approximately 8 billion litres. There is a substantial gap between installed production capacity and what was actually produced in 2008 (2.8 billion litres). This can be explained by a number of reasons, the most important being that some plants came on-stream rather late in 2008 and that at least three plants reduced output or did not produce at all due to high cereal prices. In terms of future production facilities a great number of new plants have been announced in recent years. However, due to the high feedstock prices in mid 2008, the fierce competition with Brazil and the growing hostile media and political climate the biofuel sector is facing, many of these plans have been put on ice. The financial meltdown will also result in slowing down the development of planned projects. The regulatory framework is driving the EU biofuel market development. As long as biofuels are more expensive than fossil fuels, mandates are required to stimulate the market. Whether, under those circumstances, there is a growing market opportunity for the EU ethanol industry depends on the level of imports mainly from Brazil. The EU is faced with growing imports of ethanol (not only for fuel). Imports increased to 1.9 billion litres in 2008 and around 700 million litres thereof were used in the fuel sector. The overwhelming majority (1.5 billion litres) came from Brazil. There are three important reasons for this increase. One is the competitiveness of Brazilian ethanol. Due to strong growth in production capacity and output, which is partly caused by low sugar prices on the world market, the price for Brazilian ethanol was at an all-time low in mid 2007. The second reason is that some EU countries (UK, Netherlands, Sweden and Finland) allow Brazilian imports against much lower imports duties. EU producers are unable to compete with Brazilian ethanol if the duty is lowered to €102/m^3 (one of the imports duties applied). Finally we lack a single import tariff for fuel alcohol in the EU. We have several imports duties on ethanol depending on the nature of the ethanol: if, for example, ethanol is mixed with a chemical, even though there is 90 per cent ethanol in the mixture, it is classified by some customs as a chemical, resulting in a lower duty being applied. One of the consequences of this classification practice is that it is very difficult, if not impossible, to know precisely how much ethanol is imported irrespective of the end-use. To give a clear example: in 2008 Brazil, according to Brazilian export statistics, shipped 1.5 billion litres of ethanol to the EU. According to the EU import statistics there were only 809 million litres imported from Brazil. The difference entered either 'disguised' into the EU or was re-exported to African countries after adding petrol. Having one single import tariff for fuel ethanol would close these loopholes.

Industry

Rural areas of Europe suffer higher than average rates of unemployment and underemployment. Those with jobs receive incomes significantly below the EU average. European biofuel farming and processing means more jobs and increased wealth for rural communities. The European Commission estimates that a 10 per cent market share of home-grown biofuels would lead to a net increase in EU employment of approximately 150,000 jobs.[5] This would lead to an increase in the EU gross domestic product by at least some €25 billion and an increase in GDP of 0.17 per cent.[6]

Policy instruments to support the technology

Under the EU biofuels directive, member states have developed their own support policies to promote the use of biofuels. Directive 2009/28/EC requires member states to set their own national targets in National Action Plans that will have to be notified to the European Commission by June 2010. Currently, some member states use financial incentives such as tax breaks or penalties to make the use of biofuels more attractive. Others simply put in place an obligation. Some member states have combined all three measures. The different national systems also vary with respect to the openness of their markets: some systems result in a closed market with limited access from outside producers, whereas other markets are less restrictive or even very welcoming (see Table 12.1). Finally, some member states have strict conditions on the quality of the fuel.

Table 12.1 Different member states: Different support systems

Policy Instruments

Tax measures	Austria, France, Germany (E85), Sweden, Poland, Hungary, Ireland, Latvia, Spain, UK, Belgium, Italy, Baltic states, Poland
Obligation	Austria, Germany, Baltic states, Netherlands, Czech Republic, Slovakia, Slovenia, Romania, Finland, UK, Italy, Ireland (2009), Hungary (2009), Spain (2009)
Penalty	France, Germany, Italy, Poland, UK

Market Access

Closed	France, Italy, Ireland, Belgium, Spain, Portugal
Relatively open	Austria, Germany, Baltic states, Poland, Sweden (E5), Ireland
Very open	United Kingdom, Netherlands, Sweden (E85), Finland, Czech Republic

Source: eBIO

Key countries and success stories

Germany: Successful mix

The German system is a perfect example of a system which unifies all important support mechanisms and that successfully transformed from pure financial support to obligation. Germany used to base its support mechanism on financial incentives only in the form of a full exemption from the mineral oil tax. However, with growing volumes of biodiesel used in the German market this form of promotion became too costly. Therefore Germany introduced an obligation in January 2007. The government set two separate mandatory targets for biodiesel and bioethanol. The bioethanol target was set at 1.2 per cent in 2007 and increases to 3.6 per cent in 2010. Additionally, the overall share of biofuels as transport fuels (based on total consumption) must be at least 5.25 per cent in 2009 and will increase to 8 per cent in 2015. Fuel suppliers that do not fulfil the targets set will pay a penalty of 60–90 eurocents depending on the biofuel. The quota can be fulfilled either by pure biofuels or blends. All biofuels that serve to fulfil the quota are subject to full taxes. Biofuels that are put in the market on top of the quota can apply for a tax relief or they can count towards the obligation for the following year. In the case of bioethanol, cellulosic ethanol and blends from E-70 to E-90 are exempt from the excise duty. Besides this regulation, only undenatured (unfit for human consumption) ethanol with an alcohol share of at least 99 per cent volume is allowed to enter the German fuel market. This provision guarantees that only those batches of ethanol on which the full import duty (€192/m^3) has been paid can enter the fuel stream . The very generous support scheme before 2007 resulted in Germany being the first EU country to exceed the 2 per cent biofuel target in 2005 and having already a share of 6.35 per cent by 2006 mainly thanks to biodiesel.

Sweden: Strong government support and booming market

Sweden is often referred to as the spearhead of bioethanol fuel use in the EU. The national indicative targets are set at 3 per cent by energy in 2005 and 5.75 per cent in 2010 in line with the existing EU biofuels directive. Despite the fact that there are no mandatory targets to foster the use of biofuels, other support mechanisms fulfil this purpose. A strong financial incentive is given in the form of full exemption of excise duty. This makes the price for renewable fuels very attractive at the pump compared to fossil fuels. Furthermore, since 1 April 2006 Sweden's larger filling stations were obliged to offer a renewable fuel for sale next to petrol and diesel. Initially this was15 per cent of all filling stations (sales volume over 3000m^3) whereas this share should increase to 60 per cent in 2010. The renewable fuel of choice is increasingly E85.[7] Additionally there are several measures to promote successfully the use of clean vehicles[8] such as a CO_2-based vehicle tax, a strict environmental policy for state-owned cars,[9] clean vehicle premium

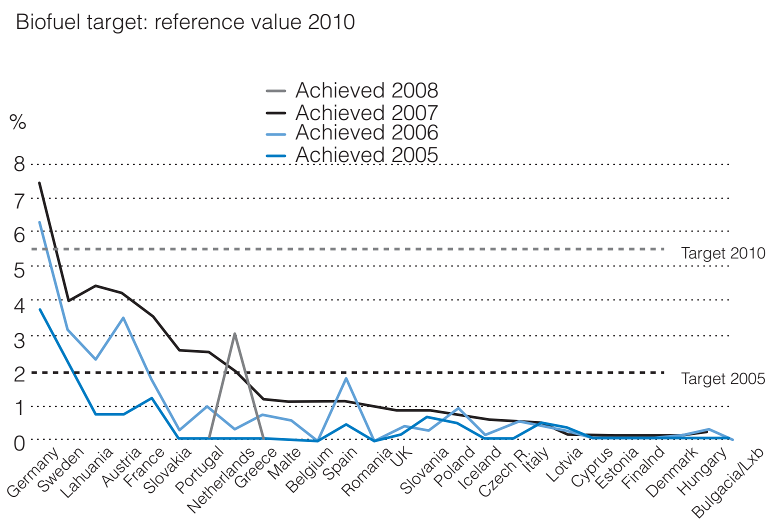


Figure 12.4 Targets and actual achievement in the member states
Source: Member state reports in accordance with Directive 2003/30/EC, available at http://ec.europa.eu/energy/renewables/biofuels/ms_reports_dir_2003_30_en.htm, last accessed 23 November 2009.

for private individuals[10] and exemption of congestion charges. E95 buses are also strongly promoted.

Since most of the measures are based on financial incentives the Swedish policy depends on a high level of subsidies to be sustainable. Also there is no obligation to use biofuels, which means consequently that the price level is crucial. Therefore E85 and E95 are classified as chemical substances so that only comparatively low import duties have to be paid. A high level of imports and a loss of new markets for domestic/EU produced ethanol are the downside.

France: A closed but flourishing market

In France there is no obligation to use biofuels. However, the French government has set an ambitious indicative target of 5.75 per cent by energy content in 2008, 7 per cent by energy content in 2010 and 10 per cent in 2015. Those indicative targets are coupled with a fiscal penalty for blenders if the volume put into the market is less than the yearly national quota. The penalty is set at €450 million for every percentage that is not blended. The core element of the French biofuels policy, which distinguishes the French system from most other EU member states, is the quota system.[11] Different quota for biodiesel, bio-ETBE and ethanol for direct blending purposes were introduced until 2013. During 2006 and 2007 tenders were published for which biofuels producers could apply. Only those biofuels producers who won a certain quota can now sell biofuel to a fuel distributor and only these quota-related batches are eligible for a tax reduction that was set at €0.27 per litre for ethanol in 2008 (in 2007 this was still €0.33). As a result only those biofuels produced as part of the quota are competitive. Producers outside this regime could theoretically access the market, but will in practice never find a buyer. However, the French system is slowly changing. Over the next three years the tax credit will decrease to €0.21 in 2009, €0.18 in 2010 and €0.14 in 2011. In 2012 the tax reduction will cease to exist. To compensate for this reduction in tax break France moved to E10 blends (now E5) as of 2009. This penalty system goes hand in hand with an active promotion of an E85 fuelling network throughout the country. The French E85 or 'superéthanol' has generous tax breaks that currently allow a price of €0.80 to €1 per litre. However, the fact that E85 cars are not considered environmentally friendly does not qualify them for lower road taxes. This hampers the sale of flex-fuel cars.[12] The fact that France has been the number one EU ethanol-producing country in 2008 shows that this system is not unsuccessful in promoting renewable fuels. The system is a closed shop which makes it inaccessible for other European producers. On top of that the French law foresees that the tax reduction can be adjusted every year. History shows a reduction every year since the system has been in operation. The possibility of this yearly adjustment introduces an element of uncertainty.

TOMORROW

Technology targets by 2020 and beyond

Technological research and development is pushed along three lines:

1 Improvement of existing processes;
2 New feedstock and conversion technology to handle it;
3 New utilizations of ethanol beyond transport fuel.

Improvement of existing processes

Optimization of the conversion process

Bioethanol is a price-sensitive product and consequently the industry has always been keen to bring down production cost by process optimization. Major improvements include process simplification by integration of process steps (e.g. integration of saccharification and fermentation), combining bioethanol with production of further products from grains (e.g. gluten from wheat) or so-called biorefinery concepts. New ideas for cellulose ethanol are hybrid installations which are linked to conventional starch or sugar processing units or the utilization of the remaining C5 sugars for different products.

Improving fermentation efficiency

This is especially important: an economically successful and efficient alcohol fermentation process at the same time allows for high yield (achieved through minimum formation of by-products such as lactic acid and glycerol and a low amount of residual sugars and dextrin left in the fermented mash before it enters distillation); high stability and reliability (especially from the biotechnological point of view to minimize plant shutdowns); simple process (minimizes expenses in labour and/or automation) and high productivity (reduces the required fermentation volume).

Raw material basis

One clear target is the broadening of the raw material basis. Additional grain types like rye, barley and sweet sorghum are now taken into account for bioethanol production just as cassava in tropical zones. The EU sugar market reform makes sugar beet available for bioethanol production. A further possible feedstock source is waste starch and residues from gluten extraction. A significant reduction of the raw material costs and the emissions related to the raw material supply is expected by using optimized grain varieties and improved plantation methods.

Reducing energy and water consumption

Energy efficiency is a proven, cost-effective way of cutting greenhouse gas emissions and contributing to sustainability. On the one hand a reduction of energy cost can be gained by process optimization and circulation of process streams (stillage recirculation, increase of alcohol concentration in fermentation). On the other hand a considerable reduction of thermal energy consumption can be obtained from thermal (heat) integration and the application of modern process concepts: multi-effect evaporation units for stillage concentration; evaporation units with mechanical vapour compression; thermal integration of distillation and dehydration thermal integration of distillation and evaporation; multi-pressure systems with split mash and rectification column and thermal integration of stillage drying with evaporation.

These concepts have already been realized in modern plants and are also an option for the reconstruction of existing facilities. Examples for a future improvement potential are the application of mechanical vapour compression in the distillation and DDGS drying under pressure, which opens up a new secondary energy source for other units such as the distillation. Water usage issues are becoming more important. Reducing the water consumption is linked to stillage treatment and the reuse of treated process effluents. Reduction of process water is made possible by recirculation of part of the stillage to the liquefaction process. In addition to reducing the overall water demand of the plant this increases the energy saved. In future the utilization of treated process effluents in utilities, already state-of-the-art for cooling towers in modern plants and even for process purposes, will provide further opportunities.

Energy from biomass

Other aspects of process development include the application of biomass-based energy supply concepts. Under discussion are alternative methods for stillage processing such as incineration and anaerobic treatment. From the energy point of view they have a similar purpose: self-sufficient supply of renewable energy for the plant. Anaerobic gasification is based on established process know-how.

Of intense interest is incineration because of its high potential to further improve the greenhouse gas balance of bioethanol production. The target is that bioethanol plants will be able to cover the complete energy demand with biomass and – similar to sugar cane processing plants in Brazil – supply surplus electricity to the grid.

Alternative concepts for DDGS (a by-product of grain ethanol production) such as incineration for process energy provision or commercialization as animal feed have to be weighed up against each other. After all as much as one-third of the grain used in production can be processed to substitute (imported) soya and thus serve the biggest consumer of grains, which is animal feed.

New feedstock and conversion technology to handle it

Advanced generations of bioethanol fuel offer the prospect of sourcing energy from an even wider range of feedstock. These include non-food crops such as grasses; agricultural residues such as cereal straws and corn stover; industrial, municipal and commercial wastes and processing residues such as brewer's grain, and forest products and residues such as wood and logging residues. Those new pathways will provide even higher greenhouse gas savings. Compared with a conventional feedstock, production of ethanol from new feedstock requires different technological (pre-) treatment:

Biomass enzymatic hydrolysis

Extensive processing to release the sugars in cellulose and hemicellulose account for 30–50 per cent and 20–35 per cent of plant material, respectively. However, the composition of biomass is variable and more complex than starch-based grain feedstock. The right combination of the 'enzymatic cocktail' will be able to attack the cellulose and hemicellulose fractions, releasing sugars for fermentation. Research is being carried out to bring down the substantial costs of enzymes and thus the overall production costs of advanced bioethanol.

A further challenge is efficient co-fermentation of both hexose (six carbon, C6) and pentose (five carbon, C5) sugars to ethanol. None of the yeasts or other microorganisms currently in commercial use can ferment C5 sugars. Research is proceeding to develop organisms that can effectively use both types of sugars in order to maximize ethanol yields per ton of biomass feedstock. Efficient conversion of both types of sugars to ethanol is needed to make the whole process economical.

Thermo-chemical conversion of biomass

First the biomass undergoes a severe heat treatment, then in the presence of a controlled amount of oxygen, a process called gasification takes place. The product gas from gasification is called synthesis gas or syngas. If the process is conducted in the absence of oxygen, the process is called pyrolysis; under certain conditions, this process might yield predominantly a liquid product named bio-oil.

The syngas can be used in a catalytic process for the synthesis of a variety of products. In a Fischer-Tropsch (FT) process, the syngas will be used for the production of transportation fuels like diesel and gasoline, along with other chemicals. The syngas can also be used for the synthesis of methanol, ethanol and other alcohols. These in turn can be used as transportation fuels or as chemical building blocks. The bio-oil can be burned for direct energy production in a combustion process or can be gasified to syngas. Another potential use is the extraction of chemicals.

This biorefinery concept, where biomass is processed into a wide spectrum of marketable products, resembles a petroleum refinery: the feedstock (conventional or advanced) enters the refinery and is, through several processes, converted into a variety of products such as transportation fuels, chemicals, plastics, energy, food and feed. The feedstock is used in the most efficient way thus enhancing economic, social and environmental sustainability.

New utilizations

Bioethanol in fuel cells

One of the newest markets being looked at for bioethanol uses is fuel cells. Electrochemical fuel cells convert the chemical energy of bioethanol directly into electrical energy to provide a clean and highly efficient energy source.

Bioethanol is one of the most ideal fuels for a fuel cell. Besides the fact that it comes from renewable resources, highly purified bioethanol can solve the major problem of membrane contamination and catalyst deactivation within the fuel cell, which limits its life expectancy. Extensive research activities ensure that bioethanol remains among the most desirable fuels for fuel cells, delivering all the benefits that the bioethanol fuel cell technologies promise.

E-diesel

The bioethanol-diesel blend, better known as E-diesel, contains up to 15 per cent bioethanol, diesel fuels and additives. Compared with regular petrol-diesel fuel, E-diesel can significantly reduce particulate matter and toxic emissions and improve cold flow properties. Research is underway to make E-diesel commercially available.

NOTES

1 SEC (2006) 1719, p.27.
2 SEC (2008)85/2, p.124.
3 Gary Z. Whitten (2004).
4 Raw alcohol originates from low quality wine.
5 These numbers were based on an oil price of $48/barrel and therefore considerably underestimate job creation in Europe (SEC, 2006b).
6 SEC (2006a), p.27.
7 In the first six months of 2009 almost 70.8 million litres were consumed for the E85 market, compared to 93.8 in 2008 and 43 million in 2007 (over the same period, January to June). Source: Swedish Petroleum Institute.
8 Clean vehicles mean fuel-efficient cars with maximum 120g/km CO_2 emissions and cars which can use alternative fuels including Flex Fuel Vehicles (FFV). The proportion of new car sales comprising clean vehicles rose from 5 per cent in 2005 to 11 per cent in 2006 and 33 per cent in 2009.

9 Vehicles purchased by the public sector must as a general rule be clean vehicles. From 2007 onwards a minimum 85 per cent of cars purchased or leased by state authorities must be clean vehicles.

10 A private individual buying a new clean car in the period 1 April 2007 to 31 December 2009 will receive a SEK 10,000 (approximately €1057) premium.

11 Up to now only Belgium operates a similar quota system but without a penalty system. The result of this was that Belgian oil companies hardly used biofuels. Therefore the Belgian government introduced in 2009 an obligation to put 4 per cent of ethanol on the market (in relation to the total amount of gasoline put on the market).

12 The French government has announced that as of 2009 FFV cars no longer get a penalty but they are still excluded from receiving a bonus.

13

Biodiesel

Produced from oleaginous plants, animal fats, used vegetable oils or algae, biodiesel is a renewable transport fuel used in diesel-run cars. In Europe, biodiesel can be marketed in 5–7 per cent blends in diesel in normal cars, while in captive fleets for public transportation, biodiesel can be blended from 30–100 per cent with some engine and filter modifications.

The European biodiesel sector has experienced major development during the last five years. Over this period biodiesel has emerged as a reliable solution for renewable transport in Europe. As the tribulations caused by both energy-import dependency and climate change became apparent, policy-makers and investors saw that biodiesel was a low-carbon, renewable and domestically controlled solution to Europe's transport fuel problem. Biodiesel represents a feasible solution for improving the diesel dependency and the overall energy security of supply. An EU mandate in 2003 to deliver 5.75 per cent of all road transport fuels from renewable sources by 2010 gave

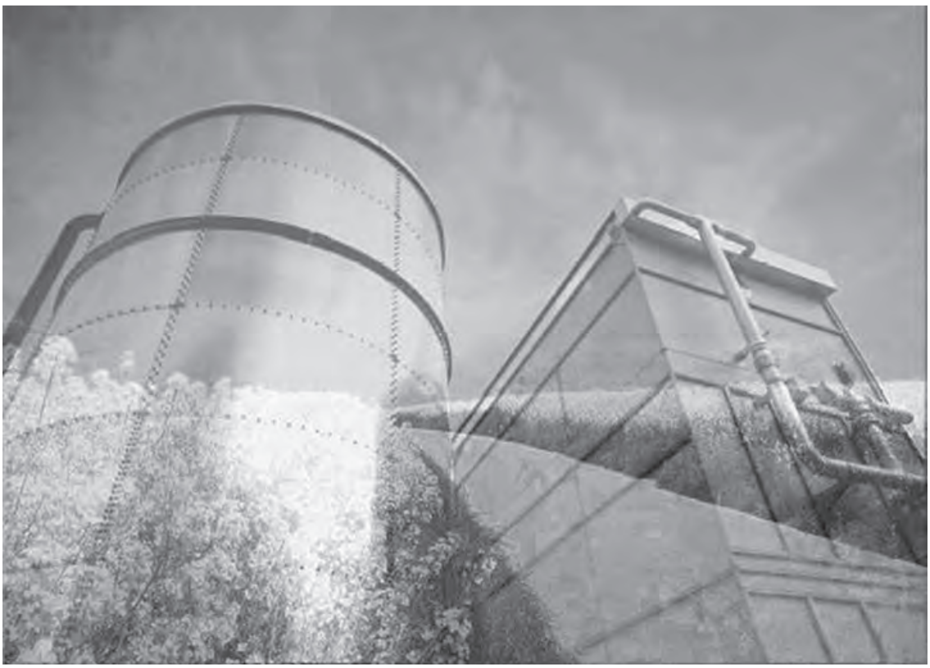


Figure 13.1 Rapeseed field and biodiesel plant
Source: EBB (2008)

the industry the impetus it needed to invest and production increased from 1.5 million tonnes of renewable fuel in 2003 to 5.7 million tonnes per year in 2007. In a year when oil prices have reached record new levels and imports are becoming increasingly isolated and risky, biofuels accounted for the majority of non-OPEC supply growth and, according to Merrill Lynch, the presence of biofuels shielded the global economy from a further increase in crude oil prices of 15 per cent.[1]

STATE-OF-THE-ART TECHNOLOGY

Biodiesel currently produced both in the EU and worldwide is predominantly 'Fatty Acid Methyl Ester' (FAME), derived from recycled or virgin vegetable or animal fats and oils.

The production of biodiesel (FAME) can be summarized as follows:[2]

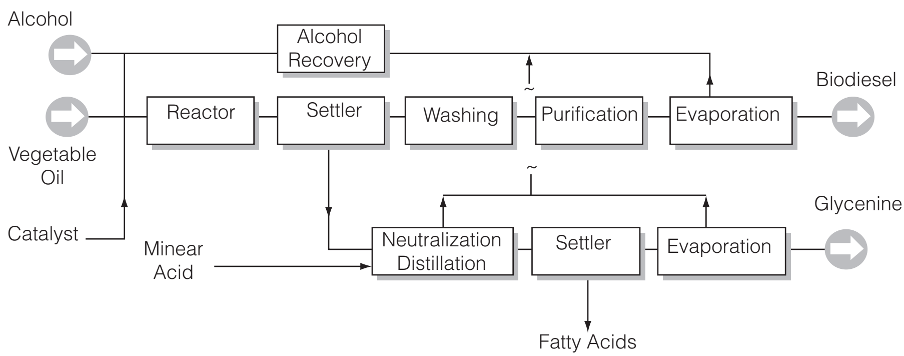


Figure 13.2 Production of biodiesel (FAME)
Source: EBB (2008)

The vegetable oil is turned into biodiesel through a chemical reaction called transesterification, as biodiesel is technically called a Fatty Acid Methyl Ester (FAME). Although the transesterification process is a relatively easy chemical reaction, it is particularly difficult to conduct it properly, which calls for the highest industrial standards to ensure the quality of biodiesel. Today, biodiesel produced or marketed in Europe must meet the specifications of the CEN standard EN 14214.

However, new production pathways have recently been developed, sometimes referred to as 'second' generation biodiesel:

- **Hydro-treated vegetable oils (HVOs)**: new technologies transform HVOs and animal fats into a paraffinic biodiesel, which presents near identical chemical properties with conventional diesel. Although hydro-treated vegetable oils in Europe are produced in free-standing facilities, this process can build on existing oil refinery infrastructures. To avoid any confusion with processes used in the food industry sector, the term 'hydro-treatment' is preferred to 'hydrogenation'.
- **Biomass to liquid (BTL)**: BTL is a multi steps process to produce liquid biofuels from biomass. Contrary to current biodiesel pathways (FAME and hydro-treated vegetable oils and fats), the BTL process aims at using whole plants (biomass), including agricultural and forest residues.

The so-called ‘Fischer-Tropsch’ technology, which is an integral part of the BTL process, is an advanced biofuel conversion technology that comprises gasification of biomass feedstocks, cleaning and conditioning of the produced synthesis gas and subsequent synthesis to liquid (or gaseous) biofuels. Originally, this process was used for the production of liquid fuels from coal (CTL) and natural gas (GTL). The CTL, GTL and BTL production pathways are usually referred to as ‘XTL’ fuels.

Technological benefits

The benefits from the development of biodiesel technology pathways run from the greenhouse gases emission reduction and the promotion of other outcomes for agriculture, to a positive impact on the European deficit in protein meals. Higher blends of 7 per cent and 10 per cent will ensure a further reduction of the increasing European deficit on diesel mainly coming from Russia. And above all the reduction of GHG emissions will be ensured, guaranteeing the decoupling between economic development and emission increase.

The biodiesel sector in Europe has developed high sustainability standards that also meet the cross compliance rules set for European farmers. Sustainability can be defined as a strategy by which communities seek economic development approaches that also benefit the local environment and quality of life. When applied to biodiesel production, sustainability implies a thorough consideration of the agricultural production, of the economic benefit to the local communities involved, while ensuring the protection of the environment. Moreover, not only the local impacts are considered, but also the international/global ones.

The two main pillars of sustainability are GHG balance and certification. As a principle they should be kept separate. While GHG balance focuses more on the methodology used (mathematic hypothesis, modelling), the elements accounted for (direct land use/indirect land use, co-products, etc.) and their emissions values (CO_2, NOx, etc.), certification deals with the implementation and the control system with implications at world level.

There are numerous initiatives to create sustainability standards for the sector:

- national initiatives: (Cramer Criteria, The Netherlands), Renewable Transport Fuel Obligation (RTFO) (UK) and MVO Sustainability Certification Scheme (Germany);
- international initiatives: CEN (European Centre of Normalization), Technical Committee 383 for Sustainability Criteria for Biomass for Energy Purposes (initiated in 2008), RSB (Roundtable on Sustainable Biofuels Switzerland), Forest Stewardship Council (FSC) and World Energy Council WEC 2008.

Consequently the biodiesel pathways developed in Europe are realized with very high concerns for the environment.

Other than the definition of principles and certification schemes, the sustainability paradigm is seeking to highlight best practices in production and consumption and recommendation of best pathways for the future. Several horizontal issues are equally considered as part of the sustainability aspiration, They go from the regulatory framework for Genetic Modified Organisms (GMOs) in the EU-27 and the rest of the world, to the use of forestry and wastes in the production of biofuels. Numerous initiatives have been created aiming at developing standards and certification mechanisms for biofuels and bioenergy in general. There are more than 20 parallel initiatives in the world today that have biofuels sustainability as their goal.

However, sustainability has to be considered in a comprehensive manner and not fragmented by sectors. Biofuels sustainability is just one part of the solution and it is therefore key that all economic actors both upstream and downstream the production chains should engage in delivering sustainable goods and services. Against this background the European biofuels industry has committed itself to actively embrace the two-fold challenge: first, to contribute to the definition of sustainability and certification schemes and second, to deliver highly sustainable products on the markets.

Technological applications

The European production of biodiesel uses as its main raw material locally grown rapeseed, followed by smaller proportions of sunflower, soy and palm oil (the latter being used for between 3–5 per cent of the total EU biodiesel imports (EU Oil and Proteinmeal Industry federation, www.fediol.org/1/index.php). The climate conditions in Europe allow for a wide cultivation of rapeseed for biodiesel production that at the same time meet the requirements for the European harmonized standard for biodiesel, EN14214. Since the production of biodiesel in general is so strongly related to agricultural activities, the European production in particular follows the EU Common Agricultural Policy that governs all environmental standards of agricultural production. Therefore the sustainability of European biodiesel is guaranteed by the cross-compliance rules followed by European farmers and by all social and economical standards of developed economies. Moreover European production of biodiesel does not contribute to deforestation due to management initiatives such as the Roundtable on Sustainable Palm Oil (RSPO) or Roundtable on Sustainable Biofuels (RSB, 2008).[3] Finally, the EU agricultural and trade potential is rising due to productivity increases in the new member states and in neighbouring countries such as Ukraine, which is a major EU trading partner in agricultural products.[4] Many European producers also use recovered vegetable oil and animal fats from food processing as they are readily available waste products and produce a biodiesel with extremely beneficial greenhouse gas savings. Several of the biggest biodiesel producers in Europe are agricultural producers who add value to their oilseed products and processing capacities by converting oil to biodiesel, similarly many are involved in the oleo chemical industry as biodiesel production produces glycerine suitable for the cosmetics and pharmaceutical industries. Biodiesel production also results in increased availability of oilseed cake used for protein in animal feeds.

Cost and prices

Once the sector and the market achieved maturity, the costs of the technology followed a descending trend. The cost per unit (litre) of final product decreased and stabilized once the technologies (mainly production technologies Desmet Balestra and Lurgi) became available worldwide. Nonetheless increasing costs are incurred by the constant research in new technologies and culture pathways. Such activities incur very high costs combined with medium-high risks of project abandonment and require important public or private investments. National governments across Europe and the world have subsidized the sector in order to aid its development and to ensure the commercialization of the products in the initial stages. States have usually covered the price differential between the biodiesel production costs and the diesel equivalent. Biodiesel has grown to commodity status and is being traded worldwide. In the same time

Figure 13.3 Biodiesel plant
Source: EBB (2008)

market-driven standards are currently enabling a significant volume of this trade. So far there is no harmonization of such standards and the three main players (EU, US and Brazil) are working on compatibility aspects between the separate standardization approaches. This will enable further market development and a boost in the traded volumes. Biodiesel prices reflect the different raw materials used and their different cold filter plugging points (CFPP)[5] with lower CFPP levels at a premium. Finally, the volatility of oil markets has an important influence on biodiesel prices and overall international biodiesel trading.

MARKET

The European market for biodiesel is closely related to the diesel one since the renewable transport fuel is meant to physically replace the traditional fossil fuel. Since the trend in the last decades showed a clear tendency towards a 'dieselization' of the European economy, biodiesel, by replacing a growing amount of diesel every year, will play an increasing role in the medium and long run.

However in Europe the demand for diesel specifically has become an important issue as refining capacities are at maximum output and imports from Russia have had to triple in the last three years, making the EU heavily dependent on Russian diesel.

Tackling the diesel deficit problem, the European biodiesel sector can provide a solution by using the already installed capacity, while contributing to a further decrease in the gas emissions from transport.

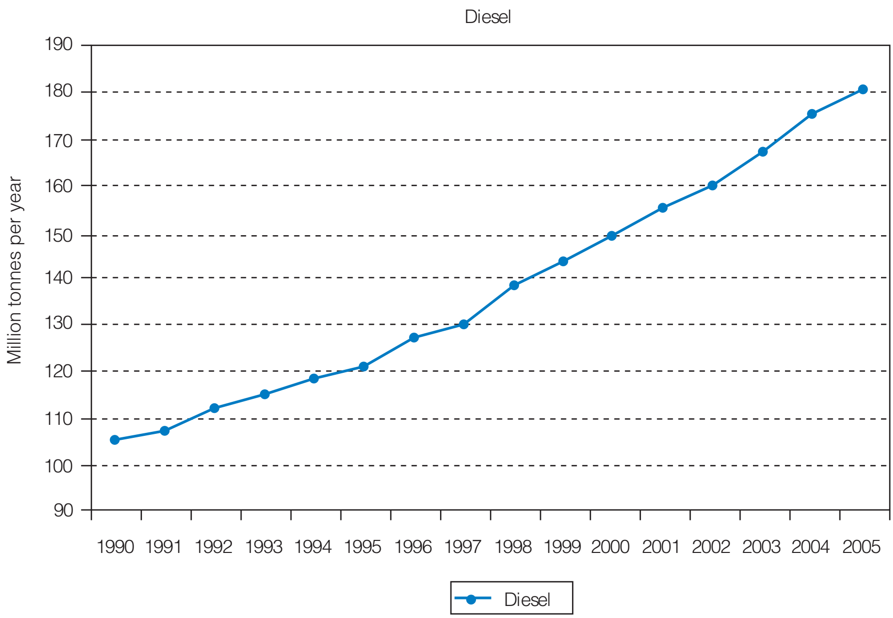


Figure 13.4 Evolution of the diesel demand in the EU
Source: Europia (2007)

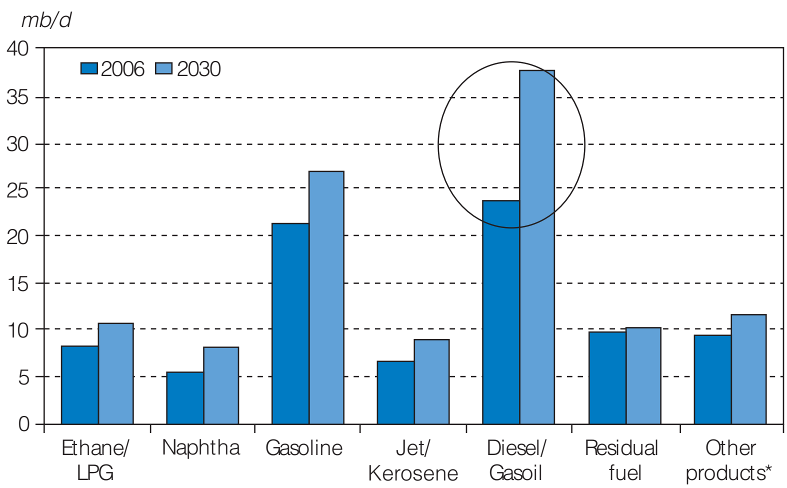


Figure 13.5 Global demand by product
Source: OPEC (2008)

Installed capacity and market development in EU and market segments

Due to a strong political commitment in 2003 and the consequent market response, today the European biodiesel industry is a world leader. Two-thirds of global production comes from European member states, with Germany producing almost half of the EC output. In 2007, production was 5.7 million tonnes per year. In most EU countries biodiesel is blended directly into conventional diesel and sold as normal on petrol station forecourts. The haulage industry benefits from the price

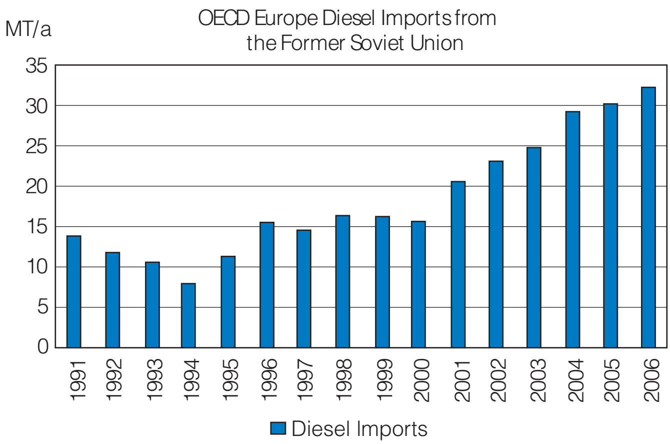


Figure 13.6 OECD Europe diesel imports from the former Soviet Union (FSU)
Source: OECD Statistics

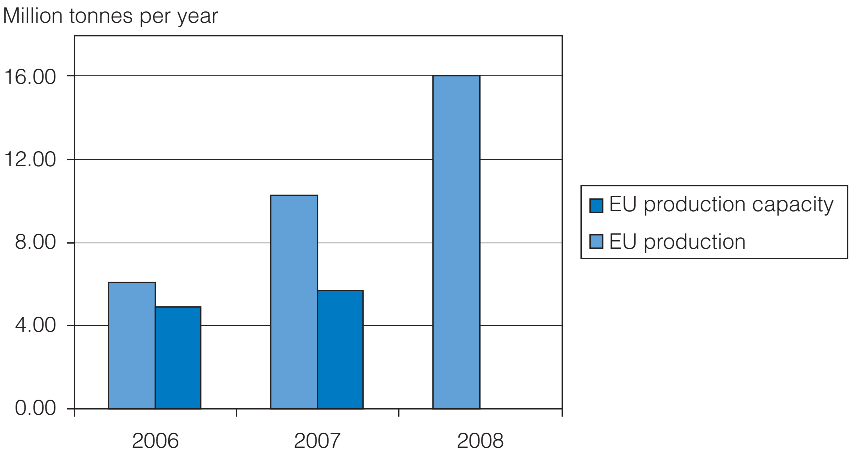


Figure 13.7 EU biodiesel production capacity and biodiesel production
Source: EBB (2008)

advantage and engine cleansing properties of biodiesel and utilizes 30 per cent blends in its trucks. Another market segment is formed by the captive fleets (urban transport city buses) which uses in some cities pure biodiesel as fuel in order to drastically cut pollution. Biodiesel is produced in 26 member states and has installed capacity of 16 million tonnes which would be sufficient to meet the 5.75 per cent target and would already be able to cater for 7.7 per cent of expected diesel demand in 2010.

Industry

With close to 21 million tonnes of installed production capacity in 2009, the EU biodiesel industry stands ready to deliver much higher volumes than it did in 2007 and 2008. In 2008 a total of 214 biodiesel production facilities stand ready to produce up to

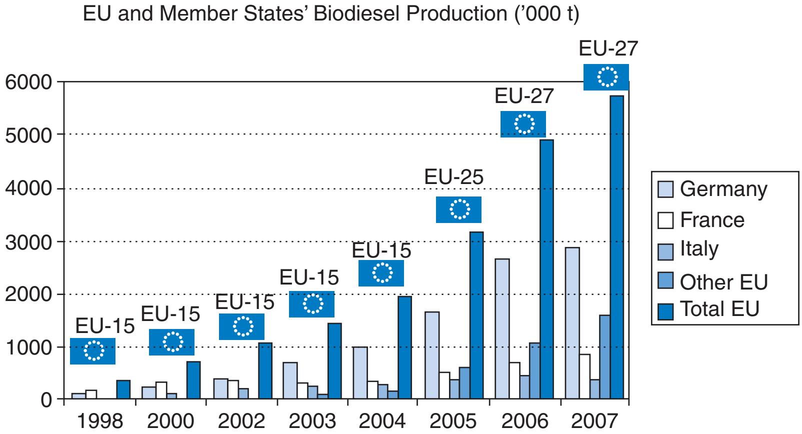


Figure 13.8 EU biodiesel industry today: Historical EU biodiesel production
Source: EBB (2008)

Table 13.1 EU 2007 and 2008 biodiesel production estimates[6] (in thousands of tonnes)

COUNTRY	2008 Production	2007 Production
Austria	213	267
Belgium	277	166
Bulgaria	11	9
Cyprus	9	1
Czech Republic	104	61
Denmark/Sweden	231	148
Estonia	0	0
Finland	85	39
France	1,815	872
Germany	2,819	2,890
Greece	107	100
Hungary	105	7
Ireland	24	3
Italy	595	363
Latvia	30	9
Lithuania	66	26
Luxemburg	0	0
Malta	1	1
Netherlands	101	85
Poland	275	80
Portugal	268	175
Romania	65	36
Slovakia	146	46
Slovenia	9	11
Spain	207	168
UK	192	150
TOTAL	7,755	5,713

*Subject to a margin of error of -/+ 5%

16 million tonnes of biodiesel per year. Production in 2007 was 5.74 million tonnes, reflecting a difficult year (with production growth rates falling by more than 60 per cent compared to 2006 and 2005) due to the presence of subsidized biodiesel imports from the US. In absolute terms the European and international biodiesel production increased; nonetheless biodiesel production rate of growth has decreased by a factor of three due to the unequal competition in the market (mainly the subsidized US product). As a consequence a trade complaint and case are being handled by competition authorities in the EU and US.

Policy instruments to support the technology

The newly adopted directive on the promotion of energy from renewable sources sets renewable fuels to replace 10 per cent of fossil road transportation fuels in total consumption by 2020. At the same time it promotes a set of sustainability criteria for the production of biofuels, which will ensure that they deliver significant greenhouse gas reductions, as well as strict environmental management of plantations and biodiversity protection. Negotiations between the European Commission, the European Parliament and the Council were held during autumn 2008 and spring 2009 in the context of the adoption of the directive and of other legislative initiatives under the generic name of the Climate Change Package.[7] The Commission promoted biofuels for the important role that they have to play in the current and the future renewable transport strategy. All forms of RES are to be supported by the Commission, but so far investors and the transport industry have shown that biodiesel is a concrete option that is already available at the current time. The Energy Taxation Directive 2003/96/EC[8] came into force in 2003, defining both the fiscal structures and the tax levels that member states should impose on energy products and on electricity. From the point of view of the biodiesel industry, one of the most important provisions of Directive 2003/96 is Article 16. This article lays down the possibility for member states to support the biodiesel sector (just like it supports all renewable energy sectors) by applying de-taxation schemes for biofuels production. In 2007, the Commission released a Green Paper[9] meant to pave the way for the revision of the Energy Taxation Directive. The main concept put forward in the Green Paper was that of splitting the tax for energy products into two parts: an energy part (products would be taxed according to their energy content) and an environmental part (a so-called CO_2 'emission tax'). Subsequent to the anticipated changes, the Commission is expected to present a proposal for a new Energy Taxation Directive,[10] a proposal which would define the level of support allowed for the biofuels sector across Europe.

Key countries and success stories

Germany

The biggest European producer of biodiesel, Germany, has built over the years a production capacity of 5.1 million tonnes (EBB, 2008). More than 1900 public filling stations are selling biodiesel in Germany. 2,662,000 tonnes of biodiesel were sold in 2006 and 2,890,000 tonnes in 2007. Germany was and remains by far the biggest market in terms of biodiesel produced in the EU-27. Germany achieved a 3.5 per cent share of biofuels in total fuel consumption in 2005, in energy content. With Sweden, Germany was the only country that achieved a biofuels penetration superior to the 2 per cent target fixed in the Directive 2003/30.

Germany's federal government cabinet decided in October 2008 to reduce biofuels quotas to 5.25% from 6.25% for 2009 and to freeze quotas at 6.25% from 2010 onward.

The Federal Environment Minister announced a 17 per cent target by 2020 which was recently confirmed by the coalition. On 17 January 2007 stakeholders (mineral oil industry, car industry and agriculture) and the Federal Ministry of Agriculture and Federal Ministry of Environment decided to work on a proposal for a roadmap on biofuels.

A roadmap for biofuels and a national sustainability scheme have been two successful initiatives. The GHG calculation methodology for biofuels will take the form of an executive degree to the law on biofuels obligation. A preliminary draft working paper was issued on 21 August 2007 which outlines the following idea: biofuels may only count to the mandatory 'quota' targets when they fulfil the additional criteria:

- attain a certain GHG reduction level;
- the feedstock is supposed to be grown according to sustainability criteria: best farming practices excluding certain land.

Unlike France or Italy, Germany has no production quota (as defined in the form of a Call for Tender). As a result, and considering the price trends for vegetable oil and diesel fuel in past years, Germany invested substantially in new units and German capacity is today the largest in Europe. Germany is also the leader in biodiesel production with more than 2,662,000 tonnes produced in 2006. Mineral oil companies have to fulfil the shares (the quotas are just an indication of how much biofuels would be needed to fulfil the targets, obligations are in energy content of the fuels):

Table 13.2 Quotas to be fulfilled by mineral oil companies in order to reach their targets

Year	Obligation for biodiesel	Approx. Quotas in volume (t) biodiesel	Obligation for bioethanol	Approx. Quotas in volume (t) bioethanol	Global Obligation
2007	4.4%		1.20%		
2008	4.4%		2%		
2009	4.4%	1,498,848	2.8%	2,086,060	6.25%
2010	4.4%	1,590,389	3.6%	2,213,465	6.75%
2011	4.4%	1,719,040	3.6%	2,392,518	7.00%
2012	4.4%	1,840,468	3.6%	2,561,519	7.25%
2013	4.4%	1,958,163	3.6%	2,725,324	7.50%
2014	4.4%	2,072,125	3.6%	2,883,934	7.75%
2015	4.4%	2,170,938	3.6%	3,021,459	8.00%

The biofuels under the quota system should fulfil the following requirements:

- biodiesel should correspond to EN 14214 (version November 2003);
- pure plant oil should correspond to DIN V 51606 (version July 2006);
- bioethanol should contain a 99 per cent volume of alcohol and correspond to ethyl-alcohol under position 2207 10 00 and EN 15376 (version May 2006).

The Energy Tax Act became effective 1 August 2006 and finally provided for a gradual decrease of tax exemption for B100 and vegetable oils (indicated in cents/l in the table below), the factual level of taxation then amounts to that described in the table below (converting energy content to volume and taking into account the shares of biodiesel under the obligation subject to full taxation):

Table 13.3 Tax exemption for B100 and vegetable oils

Year	B100	Vegetable oil (pure plant oil)
2006 / 2007	9 cent /l ~ €90/m³	€0/m³ (full exemption)
2008	13.40 cents/ l ~ €150/m³	8 cents/ l ~ €100/m³
2009	19.70 cents/l ~ €210/m³	16 cents/ l ~ €180/m³
2010	26 cents/l ~ €270/m³	25 cents/ l ~ €260/m³
2011	32.30 cents/ l ~ €330/m³	32 cents/ l ~ €330/m³
From 2012	44.9 cents/ l ~ €450/m³	45 cent/ l ~ €450/m³

The German tax on diesel is €470.40/m³ with less than 10mg/kg sulphur and €485.70/m³ >10mg/kg sulphur. This is the second highest tax after the diesel tax of United Kingdom.

Most of the major mineral oil companies are already blending their diesel with biodiesel. As a result, 40 per cent of the biodiesel marketed in Germany is sold under the form of blends below 5 per cent,[11] although the German car industry has repeatedly expressed its support for the introduction of higher 10 per cent blends on the German market. In general, the market of blends is increasing sharply, although the pure biodiesel market, mainly targeting road hauliers and captive fleets with separate pumps and labelling, should remain an important strategic segment (60 per cent market share in 2005/2006). However, it is anticipated that the increase of taxes on pure biodiesel will considerably hamper the development of the pure biodiesel market. Under the current German legislation blends up to 5 per cent can be sold at service stations, without any labelling requirement. Blends in a percentage higher than 5 per cent can be sold with specific labelling 'containing more than 5 per cent volume of biodiesel' (§7, 10. BImSchV of 24 June 2004). In Germany the minimum standard EN 14214 has to be fulfilled in any case if blended in EN590 or pure (§3 of BImSchV), otherwise the biofuel produced may not count towards the obligation and not be accounted for tax exemption (in which case full taxation will apply). Volkswagen, Audi, Seat and Skoda gave a warranty for B100 (i.e. pure Biodiesel) use in passenger cars. DaimlerChrysler gave a warranty for B100 use in heavy duty vehicles (as buses). Other manufacturers gave a warranty for B100 use in agriculture vehicles.

France

By 2008 the second largest producer in Europe, France, had already installed almost 2 million tonnes of production capacity. For more than 10 years the French government has encouraged the development of biofuels, in directly blending small amounts into conventional fuels. As a result, the biofuels share in transport fuels in 2006 was 1.77 per cent, compared to 1 per cent in 2005. The 2007 biodiesel production amounted to 872,000 tonnes. A substantial increase in both French production and capacities incurred in 2006–2008 in order to meet the additional demand generated by the ambitious government plans. At first, the major outlet for biodiesel has been captive fleets, which can use B30 blends.

The national indicative targets, based on the energy content of transports fuels are:

- 2005: 1.2 per cent;
- 2006: 1.75 per cent;
- 2007: 3.50 per cent;
- 2008: 5.75 per cent;
- 2009: 6.25 per cent;
- 2010: 7 per cent;
- 2015: 10 per cent.

The French legislation provides for a reduced energy tax for certain volume of biofuels marketed in France and distributed via a bidding system on a yearly basis. This system is also opened for non-French companies (currently Italian and German companies hold quota entitlements). Only quantities produced in the framework of the quota are eligible to detaxation.

At the end of 2004 the initial quota of 317,500 tonnes/year was raised by 70,000 tons to reach 387,500 tonnes. In February 2005 the government launched bids for an additional quota of 480,000 tonnes of biodiesel for periods of six years (30,000 for the period 2005–2009, 160,000 for the period 2006–2010 and 290,000 for 2007–2011) and 320,000 tonnes of bioethanol. In practice these new quotas underpin the construction of four new biofuels production units of 200,000 tonnes in 2007, thus tripling France's annual biofuels production capacity to some 1.25 million tonnes, as the government expected.

To sum up, the following quotas for biofuels production have been set since 2004:

Table 13.4 Quotas for biofuel production set since 2004

tonnes	FAME	ETBE*	Ethanol
2004	387,000	99,000	12,000
2005	417,000	130,000	72,000
2006	677,000	169,000	137,000
2007	1,343,000	224,000	337,000
2008	2,478,000	224,000	717,000
2009	2,728,000	224,000	867,000
2010	3,148,000	224,000	867,000

* Only the share of ethanol used to produce ETBE is eligible for detaxation and thus taken into account in the table.

At the end of December 2004 a new law was adopted by the French parliament, creating a new tax on mineral oil (Financial Law of 2005, article 32). The new law amends the French custom code and creates a new tax on polluting activities (the so-called TGAP or 'Ecotaxe') which will cover all fuels (petrol and gas oil) for transport. Some important modifications both of the TGAP rates and of its basis of calculation were introduced in July 2005. This tax will be levied as a percentage calculated on the basis of the pump price of fuels, excluding the VAT. The TGAP rates will be as follows:

Table 13.5 TGAP rates

Year	2005	2006	2007	2008	2009	2010
TGAP	1.2%	1.75%	3.5%	5.75%	6.25%	7%

The percentage of the tax will be reduced by the percentage of biofuels (biodiesel or bioethanol) that will have been introduced in the market by the single operators. The percentage of biofuels is to be measured in terms of energy content.

If France was to raise its existing biofuels usage targets beyond 10 per cent of all fuels, producers would have to boost imports sharply. Currently, 65 per cent of the vegetable oil needed to make biodiesel comes from French rapeseed, 15–20 per cent from domestically grown sunflower and the rest from imported soybean oil or palm oil. It is estimated that 10,000–15,000 tonnes of palm oil and 100,000–150,000 tonnes of soybean oil are used annually for biodiesel production.

TOMORROW

Technology targets by 2020 and beyond

As the international leaders in feedstock and production technology, the European biodiesel industry is engaged in the development of new fuels. Due to efficiency and environmental objectives, research has focused on new feedstock which can be grown on non-agricultural land and which yields a high volume of oil feedstock per acre with minimal fertilizer or energy requirements. The most promising feedstock currently under development are algae and tropical plants such as Jatropha, which grows well in arid land but is labour intensive to harvest. Algae has emerged as an extremely promising crop as it can yield oils for biodiesel at a rate hundreds of times faster than traditional agricultural feedstock like rapeseed or soy; it is also suited to low temperatures so can be used as an aviation fuel.

Biodiesel researchers are developing the most suitable production techniques for algae which can be grown either in open ponds, or in highly controlled photo-bioreactors using waste water and consuming carbon dioxide emissions from factories. Each new technology presents different benefits and problems, but the potential of algae and the highly developed efficiencies and environmental standards of European biodiesel production ensure that the industry will continue to reduce greenhouse gas emissions and allow drivers and policy-makers to keep their cars, with no modification needed to the energy distribution network.

There are projects to develop biodiesel from used cooking oils and animal fats that it is deemed will expand considerably into the next ten years due to the high availability and the overall very good performance in terms of CO_2 emissions reduction (more than 80 per cent compared to the fossil fuels reference).

Other technologies have been developed and are being researched further: biomass to liquid (BTL), pyrolysis,[12] gasification and the transformation of the resulting gas into synthetic fuel through the Fischer-Tropsch process.[13]

Technological long term potential

The ongoing research is concentrated into increasing the yields of the current biodiesel pathways, diversifying the raw material while ensuring a transition towards the new and future developed technologies. Other projects are investigating new feedstock (e.g. mustard seeds, field pennycress and Jatropha, flax, hemp or even waste) whilst new technologies envisaged include bacteria or fungus transformation of cellulose material into biodiesel.

Algae biodiesel and jet fuel applications

While algae biodiesel has the same characteristics as normal fuel, the production process can be also used to capture CO_2 from power stations and other industrial plant (synergy of coal and algae). Algae oil production per acre is extremely high and does not even require agricultural land as it can be grown in the open sea, open ponds or on industrial land in photo-bioreactors. Moreover algae biodiesel production can be combined with wastewater treatment and nutrient recycling, where polluted water (cleaned by algae) acts as a nutrient in their growth. But most important is that algae biodiesel jet fuel represents the best potential answer for the sustainability of the aviation industry.

NOTES

1 Barta, P. (2008) 'As Biofuels Catch On, Next Task Is to Deal With Environmental, Economic Impact', Wall Street Journal, 24 March (quoting Merrill Lynch commodity strategist Francisco Blanch), from the baseline scenario where biofuel production was not developed.
2 The graph provides a sort of 'average' scheme for biodiesel production. It must be specified that the processing of biodiesel can differ from one production unit to the other.
3 It was initiated by the Polytechnic School of Lausanne in 2006.
4 'EU and World cereal market situation', European Commission, Agriculture and Rural Development, July 2009.
5 Cold Filter Plugging Point (CFPP) is the highest temperature, expressed in multiples of 1°C, at which a given volume of fuel fails to pass through a standardized filtration device in a specified time when cooled under certain conditions. This test gives an estimate for the lowest temperature that a fuel will give trouble-free flow in certain fuel systems. This is important as in cold temperate countries; a high cold filter plugging point will clog up vehicle engines more easily.
6 Capacity is the potential per plant production capacity calculated if the plant was able to run at full production rate for a whole year.
7 The Climate Change Package contains:
   - RE-D Directive 2003/30/EC;
   - ETS Directive: amending Directive 2003/87/EC in order to improve and extend the greenhouse gas emission allowance trading system of the Community;
   - Effort Sharing Directive: a decision by member states to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020;
   - CCS directive on the geological storage of carbon dioxide (Carbon Capture and Storage).
8 Directive 2003/96/EC restructuring the Community framework for the taxation of energy products and electricity.
9 Green Paper on Market Based Incentives for environment and other related purposes COM (2007) 140 Final, from 28 March 2007.
10 The timeline is last quarter 2008 to first quarter 2009.

11 Sources: Association of German Biofuel Industry (VDB) and Union for the Promotion of Oil and Protein-bearing Plants (UFOP).
12 Pyrolysis is the chemical decomposition of organic matter by heating in the absence of oxygen.
13 The Fischer-Tropsch process is the conversion of the gas into liquid biofuels.

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PART I INTRODUCTION

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Acronyms

AD	anaerobic digestion
ADEME	French Environment and Energy Management Agency
AEBIOM	European Biomass Association
ATES	Aquifer Thermal Energy Storage
BAP	Biomass Action Plan
BIPV	building integrated photovoltaics
BTES	Borehole Thermal Energy Storage
BTL	biomass to liquid
c€	euro cent
CAGR	compound annual growth rate
CEN	Comité Européen de Normlisation (European Committee for Standardization)
CFPP	cold filter plugging points
CH	Switzerland
CH_4	methane
CHP	Combined Heat and Power
CO_2	carbon dioxide
CSP	Concentrated Solar Power
DC	district cooling
DDGS	Distiller's Dried Grain and Solubles
DH	district heating
DHW	domestic hot water
DNI	direct normal irradiation
eBio	European Bioethanol Fuel Association
EBB	European Biodiesel Board
EC	European Commission
EDF	Electricité de France
EDP	Energias de Portugal
EEA	European Environment Agency
EGEC	European Geothermal Energy Council
EGS	Enhanced Geothermal Systems
EMEC	European Marine Energy Centre
EPC	engineering, procurement and construction
EPIA	European Photovoltaic Industry Association
EREC	European Renewable Energy Council
ESHA	European Small Hydropower Association
ESTELA	European Solar Thermal Electricity Association

ESTIF	European Solar Thermal Industry Federation
ESTTP	European Solar Thermal Technology Panel
ETBE	ethyl tert-butyl ether
ETS	Emissions Trading Scheme
EU-27	The 27 member states of the European Union: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and United Kingdom
EUBIA	European Biomass Industry Association
EU-OEA	European Ocean Energy Association
EUWFD	EU Water Framework Directive
EUREC Agency	European Association of Renewable Energy Research Centres
EWEA	European Wind Energy Association
FAME	fatty acid methyl ester
FAO	Food and Agriculture Organization
FFV	flex fuel vehicles
FIS	financial incentive schemes
FiT	Feed-in Tariff
FSU	former Soviet Union
GDP	gross domestic product
GES	geothermal energy storage
GHG	greenhouse gas
GHP	geothermal heat pump
GIS	geographic information system
GSHP	ground source heat pump
H&C	heating & cooling
ha	hectares
HP	heat pump
HVO	hydro-treated vegetable oil
ICOE	International Conference on Ocean Energy
IEA	International Energy Agency
IPP	Independent Power Producers
ITW	Institute for Thermodynamics and Thermal Engineering
KfW	KfW Bankengruppe
MAP	Market Incentive Programme
MENA	Middle East and North Africa
MJ	mega joule
MRESF	marine renewable energy strategic framework
MS	Member States
MSP	Market Stimulation Programme
MSW	municipal solid waste
NaREC	New and Renewable Energy Centre
NCV	net calorific value
NOx	nitrogen oxides
O&M	operation and maintenance
OE	ocean energy
OECD	Organisation for Economic Co-operation and Development

ORC	Organic Rankine Cycle
OTEC	ocean thermal energy conversion
OWC	oscillating water columns
PPI	Pluriannual Programming of Investments
PPP	Public Private Partnership
PROGRESS	Promotion and Growth of Renewable Energy Sources and Systems
PV	photovoltaic
R&D	research & development
REE	Red Eléctrica Española (Spanish national electricity company)
RES	renewable energy sources
RES H&C	renewable energy sources for heating & cooling
RES-E	renewable energy sources for electricity
RES-H	renewable energy sources for heating
RO	renewable obligations
RSPO	Roundtable on Sustainable Palm Oil
SHP	small hydropower
SME	small to medium enterprises
Sox	sulfur oxides
SRA	Strategic Research Agenda
ST	solar thermal
TGAP	Taxe générale sur les activités polluantes (General tax on polluting activities)
TGC	Tradable Green Certificates
UNDP	United Nations Development Programme
UTES	underground thermal energy storage
VLH	very low head
WFD	water framework directive

PHYSICAL UNITS AND CONVERSION FACTORS

Units

Cal	calorie
kW	kilowatt
kWh	kilowatt-hour
We	watt of electrical power
Wth	watt of thermal power
Wp	watt peak
t	tonne
toe	tons of oil equivalent

Prefixes

M = Mega = 10^6
G = Giga = 10^9
T = Tera = 10^{12}
P = Peta = 10^{15}

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