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# CONTRIBUTION OF RENEWABLES TO ENERGY SECURITY

IEA INFORMATION PAPER

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# Foreword

The environmental benefits of renewable energy are well known. But the contribution that they can make to energy security is less widely recognised. This report aims to redress the balance, showing how in electricity generation, heat supply, and transport, renewables can enhance energy security and suggesting policies that can optimise this contribution.

For those countries where growing dependence on imported gas is a significant energy security issue, renewables can provide alternative, and usually indigenous, sources of electric power as well as displacing electricity demand through direct heat production. Renewables also, usually, increase the diversity of electricity sources, and through local generation, contribute to the flexibility of the system and its resistance to central shocks.

This makes it all the more important to pursue policies for research, development and deployment (RD&D) that can progressively reduce the costs of renewables so that, with appropriate credit for carbon saving, they can be established as technologies of choice.

Attention has focused disproportionately on the issue of the variability of renewable electricity production. This only applies to certain renewables, mainly wind and solar photovoltaics, and its significance depends on a range of factors - the penetration of the renewables concerned, the balance of plant on the system, the wider connectivity of the system, and the flexibility of the demand side. Variability will rarely be a bar to increased renewables deployment. But at high levels of penetration it requires careful analysis and management, and any additional costs that may be required for back-up or system modification must be taken into account.

The direct contribution that renewables can make to domestic or commercial space heating and industrial process heat deserves much more attention than it has so far received. Heat from solar, and geothermal sources, as well as heat pumps, is increasingly cost effective but often falls through the gap between government programmes that promote public awareness and provide incentives for renewable electricity and energy efficiency. We urge that greater focus be given to this topic.

The IEA's World Energy Outlook 2006 concludes that rising oil demand, if left unchecked, would accentuate the consuming countries' vulnerability to a severe supply disruption and resulting price shock. Biofuels for transport represent a key source of diversification from petroleum. Biofuels from grain and beet in temperate regions have a part to play, but they are relatively expensive and their benefits, in terms of energy efficiency and $CO_2$ savings, are variable. Biofuels from sugar cane and other highly productive tropical crops are substantially more competitive and beneficial. But all first generation biofuels ultimately compete with food production for land, water, and other resources. Greater efforts are required to develop and deploy second generation biofuel technologies, such as bio-refineries and ligno-cellulosics, enabling the flexible production of biofuels and other products from non-edible plant materials.

# Executive Summary

***"Ministers and Government Representatives from 154 countries gathered in Bonn, Germany, June 1-4, 2004, for the International Conference for Renewable Energies, acknowledge that renewable energies combined with enhanced energy efficiency, can significantly contribute to sustainable development […] creating new economic opportunities, and enhancing energy security through cooperation and collaboration."***

***Political Declaration, renewables2004 – International Conference for Renewable Energies Bonn 2004***

Providing energy services from a range of sources to meet society's needs should ideally provide secure supplies, be affordable and have minimal impact on the environment. However these three government goals often compete.

Security of energy supply is a major challenge facing both developed and developing economies since prolonged disruptions would cause major economic upheaval. Security risks include the incapacity of an electricity infrastructure system to meet growing load demand; the threat of an attack on centralised power production structures, transmission and distribution grids or gas pipelines; or global oil supply restrictions resulting from political actions. Extreme volatility in oil and gas markets can present a security risk. Overall, the picture is complex: In many circumstances diversifying supply, increasing domestic supply capacity using local energy sources to meet future energy demand growth, and demand reduction can all make positive contributions to energy security.

This paper focuses on the contribution of renewable energy technologies to energy security. It does not consider other options relating to energy security and the environment, such as nuclear energy, coal, including carbon dioxide capture and storage, oil supply and cost predictions, or natural gas distribution. It assesses opportunities presented by renewable energy technologies (RETs)[1] to mitigate risks to energy supply, such as:

- Energy market instabilities;
- Technical system failures; and
- Physical security threats including terrorism and extreme weather events.

The paper recognises that some features of renewable energy systems can, however, also carry security risks if not adequately addressed.

[1] The IEA's definition of renewable energy sources includes energy generated from solar, wind, biomass, the renewable fraction of municipal waste, geothermal sources, hydropower, ocean, tidal and wave resources, and biofuels.

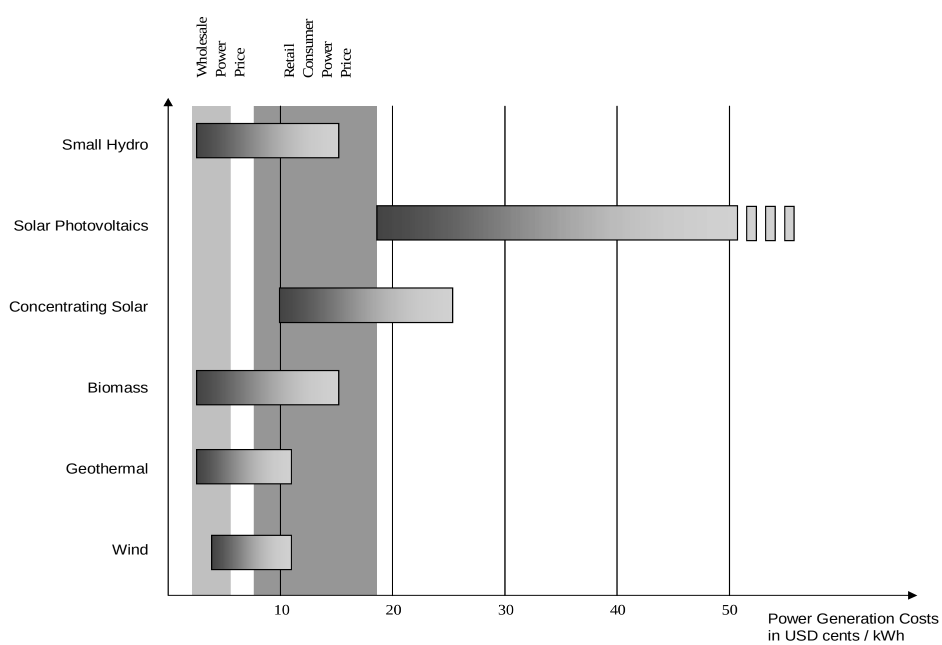
**Energy supply and environmental impacts**

Widely fluctuating oil and gas commodity prices have impacts on world economies, particularly developing countries. Low-income economies that import fossil fuels are particularly vulnerable to price increases which can badly affect their balance of payments and increase their vulnerability (ESMAP, 2005b).

Electricity accounts for around 17% of global final energy demand, low temperature heat 44% (of which traditional biomass used for heating and cooking in developing countries has a significant share), high temperature industrial process heat 10%, and transport fuels 29% (IPCC, 2007).

Renewable energy can contribute to the security of supply of all these energy forms and in addition reduce greenhouse gas (GHG) emissions when displacing fossil fuels. This makes it all the more important to pursue policies for research, development and deployment (RD&D) that can progressively reduce the costs of renewables so that, with appropriate credit for carbon saving, they can be established as technologies of choice (Figure 1).

**Figure 1: Cost-competitiveness of selected renewable power technologies, before credit for carbon savings**




Source: IEA, 2006f

Nevertheless, the implications of renewables for energy supply security differ between the electricity, heat and transport sectors.

***Electricity:*** Introducing a broad portfolio of renewable energy - hydro, geothermal, bioenergy, solar and wind energy - generating plants into the system, and establishing a decentralised power generation system can provide more security, especially where many small to medium generating plants can be located close to the load.

Renewables can reduce geopolitical security risks by contributing to fuel mix diversification. Their risks are different from those of fossil fuel supply risks, and they can reduce the variability of generation costs. In addition, indigenous renewables reduce import dependency. Biomass can be an exception although imported bioenergy feedstocks usually diversify import portfolios.

Some renewable energy technologies (RETs) such as hydro, wind, solar photovoltaics (PV), tidal depend on different natural cycles and are therefore subject to variability on differing timescales. This has to be taken into account in considering security. While large hydro, bioenergy, geothermal resources and concentrating solar power (CSP) plant offer comparable levels of firm capacities to conventional fossil fuel based plant, solar PV applications, wind and possibly small hydro resources (and wave energy resources in the future) are more variable. These characteristics may affect the degree to which some RETs will be able to displace fossil fuel and nuclear generating capacity. At high penetrations these characteristics will pose new challenges in the stability, reliability and operation of electricity grids. The direct effects of an increasing share of variable RETs depend on the balancing options. Options sometimes exist to balance the grid using a mix of RETs with different natural cycles, reducing the need for back-up capacity. For instance, large hydro can complement wind power. In such circumstances, RET installations can therefore be built to meet increasing power demand or replace existing power plants at the end of their life, reducing investment in fossil-fuelled power plants and possibly also in the distribution infrastructure. Nevertheless, appropriate grid management strategies and investments in back-up capacity and demand-side management may be necessary to absorb the large-scale grid integration of variable renewables. The additional costs for grid back-up and/or electricity storage and spinning reserve have to be taken into account (Swider *et al.*, 2006; Meibom *et al.*, 2005)[2].

[2] Flexible measures to absorb the fluctuations in wind power production are required as the grid penetration of wind power increases. Recommended integration measures include the use of electrically operated heat pumps in CHP systems which can provide relatively cheap optional demand (Holttinen *et al*., 2005; Meibom *et al.*, 2005).

RET installations have the advantage of being flexible with regard to the scale of plant size and to the possibility of integrating them either into the transmission or the distribution systems. These characteristics yield positive effects for physical aspects of energy security.

***Heat:*** Deploying renewable heating and cooling technologies can reduce energy security supply risks for the same reasons as in the electricity sector. Many biomass, solar thermal and geothermal heat applications have already reached or are close to competitiveness with heat production from fossil fuels. A major barrier to their market is consumers' lack of awareness of the range of available heating options. Nevertheless, renewable heating (and to a lesser extent cooling) provide energy security benefits as a result of distributed supply and also reduce greenhouse gas (GHG) emissions, and can reduce pressure on electricity transmission systems.

The energy security advantages of renewable heat production can be substantial when large-scale market deployment is achieved. Governments should develop and implement a support framework of enabling policy measures, including market-based financial incentives. These could build upon the lessons learned from support policies for renewable electricity production. Extensive information dissemination programmes to inform the public about viable alternative heating technologies could be beneficial.

***Biofuels*****:** The production of liquid transport fuels from a range of biomass resources is growing. Many governments perceive biofuels as a part solution to the high dependence on imported oil, the need for GHG mitigation and clean air targets, and the increasing costs of foreign exchange expenditure from relatively high gas and oil prices. Biofuels can help reduce supply risks for several reasons. They can be produced at both the large scale (limited by local feedstock resource availability) and small scale (limited by maintaining fuel quality standards and higher costs).

The commercial viability of biofuels depends on future oil and feedstock prices, land use change, and possible technological breakthroughs. Production of bioethanol from sugarcane crops is already commercially viable with oil prices around USD50/bbl. At this price biodiesel from waste oils and animal fats is also competitive but limited in supply volumes. Other biofuels are more costly to produce and cannot compete when oil is below USD70/bbl without some form of support such as agricultural subsidies or excise tax exemption. To maximize the potential for biofuels, RD&D investments should aim to drive down costs. The production of biofuels should be further encouraged in tropical and sub-tropical countries, but only where sustainable land use is practiced without the clearing of forests, stripping of soil nutrients or the contamination and depletion of local water supplies. Competition for biomass feedstock for different uses presents a significant challenge for large-scale expansion of "first generation" biofuel production although growing momentum for the integrated production of food, fibre and energy co-products in "biorefineries" and the development of advanced ligno-cellulosic technologies will likely reduce this concern.

**In summary:** RETs have the potential to contribute to energy security as well as environmental objectives on the national, regional and global levels. While, in many cases, the environmental objectives will be uppermost, governments and industry should also take into account the security benefits of renewables (and occasionally dis-benefits) in framing their policies. In order to bring down costs and achieve market penetration these policies will need to include support funding, incentives to stimulate private investment, government procurement and buy-down actions, facilitation of international collaboration, and removal of barriers to technology use. Providing better access to modern energy services for the poor in non-OECD countries will enhance investor confidence in the sustainability of energy demand growth.

Greater investment in RD&D for renewable energy systems, both by the public and private sectors, will enhance energy security at affordable costs with minimal environmental impact[3]. Good progress in bringing down the cost of energy technologies has been made in recent years but there is a further need to make markets work better, improve technology performance and provide coherent support for renewable energy technologies in ways that safeguard health, safety and the environment.

[3] The IEA has recently published "Renewable Energy: RD&D Priorities – Insights from IEA Technology Programmes" (IEA, 2006f).

# 1. Risks to energy security

The IEA defines energy supply to be "secure" if it is adequate, affordable and reliable. Consumers expect the lights to always come on at the flick of a switch, their buildings to be maintained at a comfortable temperature all year round, and to be able to purchase vehicle fuel or public transport tickets whenever they wish to travel. Electricity, heat, and mobility are usually considered to be amongst the basic necessities of life and therefore should be affordable to all at any time.

The European Commission defines energy security in its Green Paper (EC, 2000) as the "uninterrupted physical availability of energy products on the market, at a price which is affordable for all consumers (private and industrial)".

This study defines energy security risk as being the degree of probability of disruption to energy supply occurring. A forthcoming IEA report on the interactions between energy security and climate change policy uses an analogous definition of energy **insecurity** as "the loss of economic welfare that may occur as a result of a change in the price and availability of energy" (Bohi and Toman, 1996 cited in: IEA, 2007).

Energy security risks can be categorised as:

a) Energy market instabilities caused by unforeseen changes in geopolitical or other external factors, or compounded by fossil fuel resource concentration;

b) Technical failures such as power "outages" (blackouts and brownouts) caused by grid or generation plant malfunction; and

c) Physical security threats such as terrorists, sabotage, theft or piracy, as well as natural disasters (earthquakes, hurricanes, volcanic eruptions, the effects of climate change etc.).

a) *Energy market instability.* Energy supply constraints may occur due to political unrest, conflict, trade embargoes or other countries successfully negotiating for unilateral supply deals. Such supply constraints rarely result in physical supply interruptions thanks to the flexibility of the energy transport, storage, transformation and distribution systems as well as international mechanisms. Nonetheless, they do have consequences for price developments in fossil energy markets - immediately in the case of oil, with a time lag also in natural gas and coal markets.

The impact on energy market volatility of such geopolitical threats is heightened by the uneven global distribution of fossil fuel resources. The world's proven conventional oil and gas reserves are concentrated in a small number of countries. Taken together, members of the Organisation for the Petroleum Exporting Countries (OPEC) countries account for 75%

of global conventional oil reserves. OECD countries only account for 7% while they consume close to 60% of the world total.

Similarly, over half of global proven gas reserves are found in three countries: the Russian Federation (27%), Iran (15%), and Qatar (14%). OECD member countries account for only 8% of the total reserves but consume over 50% of the world total (BP, 2005). The concentration of fossil fuel resources is the most enduring energy security risk (IEA, 2007).

The 2006 World Energy Outlook (WEO) business as usual Reference Scenario projected that oil demand will become increasingly insensitive to price, which reinforces the potential impact of a supply disruption on international oil prices. Transport demand is price-inelastic relative to other energy services. Since its heavy dependence on global oil consumption is projected to rise, oil demand will become less responsive to movements in international oil prices. Thus, prices are expected to fluctuate more than previously in response to short-term demand and supply shifts (IEA, 2006h). The relative weight of the impact of price fluctuations varies according to the robustness of economies and businesses (see section 1.1).

b) *Technical failure.* Faults in energy supply systems caused by accidents or human error may cause a temporary supply interruption. Due to network complexity and the immediate loss in network stability which has to be established system-wide, such failures have particularly sharp and wide-ranging effects if they occur in large interconnected systems as observed during the recent power outages in California, Italy, Germany and elsewhere. The probability and impacts of such events can be reduced by investment and control measures.

c) *Physical actions.* Acts of terrorism, sabotage or piracy – which occur relatively rarely- and natural disasters can affect any part of the energy supply chain including:

- Power stations, sub-stations and transmission lines;
- Oil and gas exploration, extraction and refining installations as well as oil and gas-fired plants, pipelines and storage facilities; and
- Rail or road networks; stations, terminals and ports; or individual planes, shipping tankers, trains or road vehicles.

The effects may be similar to that of technical failures. Large scale actions may cause longer outages, take longer and have deeper impacts and longer-lasting effects on energy markets. The costs of security measures needed to prevent or mitigate them can affect prices, network stability and provision of energy services and may have significant effects over the long term. Oil platform and refinery closures off the south coast of the USA following

Hurricane Katrina in 2005 exemplify the threat to energy supply infrastructure posed by extreme weather events, which climate change models expect to increase.

Highlighting the significance of physical threats to energy security, the G8 stated in its 2006 St. Petersburg Plan of Action that “[r]ecognizing the shared interest of energy producing and consuming countries in promoting global energy security, we, the Leaders of the G8, commit to […] safeguarding critical energy infrastructure […]” (G8, 2006).

## *1.1 Risks for developing countries*

The impact and perception of energy security risks differ across countries. Widely fluctuating oil and gas prices have an impact on world economies, particularly those of developing countries. In many developing countries, consumers’ expectations of reliable energy services are often low and disruptions to energy supply are sometimes considered to be normal. Nonetheless, increasing short term oil and gas price fluctuations are a major threat to meeting the United Nations’ Millennium Development Goals for sustainable development (ESMAP, 2005a and 2005b). Oil importing, low-income economies are particularly vulnerable to price increases which badly affect their balance of payments (ESMAP, 2005b).

One and a half billion people in developing countries have no access to electricity; two and a half billion rely only on biomass for cooking and heating fuels. For them, ensuring continuous energy access is necessary before the security of their energy supplies can be discussed.

Energy access and environmental sustainability are inextricably linked - without access to modern energy services, the unsustainable use of indigenous energy sources in developing countries, such as traditional biomass, often leads to environmental degradation and resource scarcity, which place further pressure on energy supply (Saghir, 2006; Bugaje, 2006; Plas & Abdel-Hamid, 2005). The populations of many, especially small, oil-importing developing economies are faced with insecure, inadequate, barely affordable and unreliable energy supplies that undermine economic development (Saghir, 2006).

## *1.2 Policy responses to energy security risks*

In order to prevent significant impacts from energy insecurity, governments can diversify their energy sources. Of course renewables are not the only option for such diversification. For instance, coal supply has a wide geographic spread. However, coal without carbon capture and storage, is a major $CO_2$ emitter and countries have to take account of the environmental, as well as the security impacts of their policies. The advantage of renewables is that they can address environmental as well as security objectives.

Energy efficiency improvements through demand side management and technological innovation can cost-effectively mitigate the large-scale impact of energy supply disruptions in the electricity and heat sectors, and to a limited degree in the transport sector too. Demand side management and energy efficiency measures can reduce dependence on conventional fuels for the production of electricity, heat and transport fuels. Long-term IEA scenarios to 2050 based on existing and near-commercial technologies (the ETP Accelerated Technology Scenarios) indicate that energy efficiency in the transport, industry and buildings sectors plays a crucial role in significantly reducing oil demand growth as well as $CO_2$ emissions (IEA, 2006e).

As the following analysis shows, increasing the deployment of RETs in the energy mix can help reduce the impact of supply variations and disruptions. For example, in the buildings sector, introducing renewable heating and cooling and distributed power generation should be considered in tandem with energy efficiency measures, as combining both options creates synergies in terms of energy security.

## *1.3 Energy security implications of renewable energy technologies*

Renewable energy sources (RES) are typically indigenous resources and can reduce dependence on energy imports. RES are widely (though unevenly) distributed and their use for electricity generation can minimise both transmission losses and costs when they are located close to the demand load of end-users: so called “distributed” generation[4]. Although relatively high capital costs per unit of capacity installed remain for many RETs - in spite of significant cost reductions as a result of learning experience (IEA, 2006f) - this is offset to some extent by a zero fuel cost over the life of the system so the cost per energy unit generated can be competitive for instance for wind generation on good sites. Bioenergy is the exception, since the biomass fuel cost may represent a significant share of total production cost. However, this varies with the feedstock which can even have a negative cost where disposal of the biomass as a waste product is avoided. The corollary is that electricity or heat supplied using renewable energy is less prone to fuel cost fluctuations than is the case with fossil fuel plants (Janssen, 2002).

With bioenergy applications, over the longer term, feedstock supply itself represents a risk and securing biomass supplies over the longer term poses a challenge. Where the feedstock is produced as a by-product of a process with another primary objective, such as food or fibre production, it will only be available as long as the processing plant continues to operate.

[4] Distributed generation refers both to off-grid and on-grid applications which differ in their capacity requirements due to different load patterns.

Alternatively, in the case of a bioenergy plant that relies on bringing in the feedstock from outside sources, be it local forest residues or foreign imports, a similar supply and price risk will emerge as for purchasing fossil fuels. Negotiating long term contracts for biomass feedstock with suppliers in advance of building the energy conversion plant is one option to reduce feedstock price and supply risks, although few long-term biomass supply contracts exist. Developing a diverse portfolio of feedstock suppliers is a viable risk mitigating alternative. The associated level of risk depends on the distance travelled, the choice of supply chain, such as the Middle East – Europe route, as well as on the biomass feedstock itself. Differing fuel characteristics also engender different levels of transport risk, e.g. a tanker transporting oil or gas constitutes a higher risk (to the environment) than woody biomass transported to biomass plants.

A significant supply risk is the competition for the biomass resource – for energy uses, such as electricity, heat and transport, and for food, fibre and chemical production. Biomass suppliers will sell to the highest bidder. However, bioenergy is unique amongst RETs in that is the only renewable source of hydrocarbon fuel for transport and feedstock for many petrochemicals. Diversifying import origins thanks to biofuels which could be produced from countries that are not oil exporters may still reduce energy security risks.

Similarly, in the medium-term future, imports of renewable electricity, e.g. generated from wind power or CSP, through high-voltage direct current (HDVC)[5] lines could help diversify the origins of energy supply. A recent study shows that, in the case of Europe, the key for increasing the share of renewable energy supply in the European electricity mix is the development of strong interconnection within the EU and its neighbouring countries, including North African and Middle Eastern countries (Czisch, 2004). Interconnection would spread the geographic area of variable electricity sources, thus contributing to smoothing variability. More importantly, it enables European countries to access additional and good quality renewables energy resources from its margins.

[5] This technology is already in place in various applications worldwide in order to either to save power losses on long transmission lines, reduce environmental impacts or connect asynchronous grid areas.

# 2. Current energy use by market segment

Renewable energy systems are diverse, widely available and, in some cases, close to being cost competitive. RET applications based on wind, solar, geothermal and tidal grew 8% annually on average from 1971 to 2004 (IEA, 2006g). Appropriate deployment of renewable energy systems can thus help improve the security of energy supply for electricity, heating/cooling and transport fuels.

The IEA projected in its WEO 2006 Reference Scenario that renewables (including hydro, biomass and waste and other renewables) will only constitute 13.8% of world primary energy demand by 2030. In contrast, in its Alternative Policy Scenario, which assumes the implementation of energy-related policies and measures currently being considered by governments to ensure energy security and reduce energy sector $CO_2$ emissions, this share rises to 16.2% (IEA, 2006h) (though in both instances most of the biomass is traditional supplies).

Large-scale displacement of fossil fuels and traditional biomass by renewable energy is theoretically possible as the resource potential is huge. Nevertheless, the evolution of the economic potential of RETs over the coming decades will depend both on their technological development and on cost in relation to competing conventional energy technologies. Appropriately targeted and stable research, development and demonstration (RD&D), together with incentives for market deployment and climate change policies may influence both factors.

Electricity accounts for around 17% of global final energy demand, low temperature heat 44% (of which traditional biomass used for heating and cooking in developing countries has a significant share), high temperature industrial process heat 10%, and transport fuels 29% (IPCC, 2007).

## *2.1. Electricity production*

In 2004, the share of coal[6] used as fuel for electricity generation in OECD countries was around 38%, natural gas 18%, nuclear 23% and oil 5%, with large hydro representing 13%, combustible renewables and waste 1.4% and other renewables[7] 1.1% (IEA, 2006b). The share of oil-fired plants ranges from less than 5% in OECD Europe and North America (though for individual countries it reached up to 16% as in Italy) up to nearly 10% in the OECD Pacific region where small diesel gensets are more common (*ibid*.).

[6] Includes hard coal, brown coal, peat and coal gases
[7] Other renewables include wind, geothermal, solar, tidal and wave energy.

As oil no longer plays a major role in electricity production in most OECD countries, the security of natural gas supply has gained in significance. The shares of gas-fired power generation were 17% in OECD Europe, 19% in North America and 19% in OECD Asia (*ibid*.). OECD Europe imported 54.8% of its gas in 2004 mainly from the former USSR and Middle East/North Africa (MENA) countries. For the OECD Pacific region import dependence is even more pronounced, with 87.1% of its gas imported from non-OECD countries. OECD North America imported only 13.1%, mainly from Trinidad and Tobago.

Dependence on a small number of gas supplier countries can be an indication of fossil fuel resource concentration which can affect energy security (IEA, 2007). However, as energy markets become liberalised and the distinction between domestic and foreign resources becomes more fluid, import dependence may become a less significant factor (*ibid*.).

The IEA has developed an energy security indicator which complements a physical availability component derived from the notion of import dependence, with a price component based on calculations of market power and concentration (*ibid.*). Modelling results suggest that increasing the role of renewables in electricity generation, which will most likely displace fossil fuel fired generation, reduces both the price and volume (physical availability) components of the energy security index – in other words, an increase in energy security (*ibid*.).

The impact of a disruption in the supply of gas to a power plant depends on its source. Gas-pipeline infrastructure is inflexible, so that a loss of supply through a particular pipeline system cannot always be made good by supplies from other sources (IEA, 2006h).

LNG supply shipped into ports is more flexible in principle as the loss of supply from one producer may be replaced by imports from another. The growing share of LNG in world gas trade should therefore contribute to more flexibility in gas supply. That said, in practice there may be insufficient liquefaction and shipping capacity available to compensate for a large supply disruption. Increasingly, a shortage of gas in one region may therefore affect global gas prices. To mitigate such a supply risk, most LNG is sold under long-term contracts, with rigid clauses, e.g. “take or pay”, covering delivery (*ibid.*). This underlines the special risk structure of gas supplies in comparison to coal where a world market exists in combination with a more flexible transport system on both land and sea.

The current trends in electricity production and the assumptions about the future generation mix are reflected in the WEO Reference Scenario (IEA, 2006h) which assumed a decline of the market share of coal in the OECD, an increase of the market share of gas, and an increase of non-hydro renewables until 2030 (Table 1).

**Table 1: Current market shares and trends in OECD electricity generation for 2004 and WEO Reference Scenario projection for 2030**

| | 2004 Generation (TWh) | Share (%) | 2030 Generation (TWh) | Share (%) | Growth rates (% p.a.) 2004-2030 |
|---|---|---|---|---|---|
| Coal | 3842 | 38 | 5391 | 37 | 1.3 |
| Oil | 527 | 5 | 297 | 2 | -2.2 |
| Gas | 1854 | 18 | 3345 | 23 | 2.3 |
| Nuclear | 2319 | 23 | 2382 | 16 | 0.1 |
| Hydro | 1267 | 13 | 1519 | 11 | 0.7 |
| Combustible renewables and waste | 196 | 2 | 485 | 3 | 3.6 |
| Other renewables | 115 | 1 | 1049 | 8 | 8.9 |

Source: IEA, 2006b and IEA, 2006h

## *2.2. Heat*

Heat production has grown steadily in OECD countries in recent years. In 2004, OECD total gross heat production[8] was approximately 2,721 PJ[9] with direct use of heat from geothermal an additional 160 PJ and solar thermal applications a further 126 PJ[10]. The OECD Europe region represented 82% of OECD gross heat production in 2004, while the OECD North America and OECD Pacific regions supplied 10 and 8% respectively. In comparison, total non-OECD gross heat production amounted to 9,691 PJ. Natural gas contributed the bulk of 2004 gross heat production both in OECD and in non-OECD countries, namely 44% and 57% respectively (IEA, 2006b).

A large amount of waste heat (approximately 75,000 PJ/ year or 1,791 Mtoe/ year) from power plants is not utilised and is dumped as it is either not close to demand or timing of heat demand requirements do not match power generation requirements. Industrial waste

[8] An important caveat is that the IEA statistics include heat sold to third parties only. Auto-production by industry is not included, nor is residential transformation of electricity, natural gas and fuel oil for space heating and other heat uses. The amount of total heat produced is at least two orders of magnitude above commercially sold heat.
[9] IEA, 2006a

heat recovery offers a significant opportunity to reduce energy consumption and emissions and increase productivity. There are several techniques for heat recovery, all based on intercepting the waste gases before they leave the process, extracting some of the heat they contain, and recycling that heat.

## *2.3. Transport*

Biofuels have been identified as a part solution for transport fuels but this may be limited by competing requirements for (mainly land and water) resources. This is particularly the case with first generation technologies based around several existing crops more commonly grown for food. Second generation systems under development using crop and forest residues and non-food crops hold greater promise in terms of scale, but cost reductions remain to be made. Even with aggressive support policies to account for carbon benefits, improved vehicle consumption rates, integrated cropping, uptake of new crop varieties (possibly genetically modified) and more efficient process production processes, biofuels are unlikely to meet more than 4-7% of global transport fuel demand by 2030 (IEA, 2006h). This share depends on future oil prices and availability as well as the rate of uptake of liquid fuels from unconventional oils.

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[10] Nevertheless, non-OECD countries, such as China, Israel, Brazil, India, Cyprus and South Africa, constituted over 50% of global direct use of solar thermal systems in 2004 (IEA SHC, 2006). This figure only includes “active” solar systems; “passive” solar architecture is not accounted for.

# 3. Renewable energy technologies in the energy mix and effects on energy security

The following sections assess the impacts of the different categories of risks for disruption to energy supply security in the electricity, heating and transport sectors. An indicative overview of the relative significance of these risks is presented in Table 2.

## *3.1. Electricity production and the impact of variability*

Renewable energy technologies used to generate electricity are flexible in scale and type of use. They can be exploited locally, used both for centralised and dispersed power generation, and the energy sources used are indigenous. Regional variations in both capacity factors and variability of the available resource exist so that security of renewable energy supply is site specific. The output variability of individual renewable energy sources can be a constraint to reliable and secure supplies but can be minimised by demand variability, especially where this correlates with times of high energy output by RETs; better predictability of their generation output; and the complementarities of different power sources to overall supply .

**Hydropower** is a highly flexible technology from the perspective of power grid operation as the fast response time of hydro reservoirs can meet sudden fluctuations in demand or help compensate for the loss of other power supply options. Hydro reservoirs provide built-in energy storage which assists in the stability of electricity production across the entire power grid. In the case of run-of-river systems with limited storage, hydropower may show strong seasonal variability; prolonged periods of low rainfall in regions where insufficient reservoir capacity exists can have significant effects on power supply predictability.

**Solar photovoltaics (PV)**, whether grid connected, stand alone or building integrated, are exposed to variability as a result of seasonal variation from winter to summer, diurnal variation from dawn to dusk and short-term fluctuations from varying cloud cover. At significant grid penetrations, such possible variations in electricity production have to be compensated for by flexible grids and/or energy storage. Solar PV is not dispatchable in a traditional sense, meaning its output cannot be controlled and scheduled to respond to the variable consumer demand for electricity. However, solar PV electricity supply fits well with demand wherever peak demand occurs during daylight hours and especially where a large part of demand is for air-conditioning.

**Table 2: Relative significance of supply disruption risks from a national and business perspective**

| | Electricity system and infrastructure | | Low temperature heating and cooling | | High temperature heat | | Transport and infrastructure | |
|---|---|---|---|---|---|---|---|---|
| **Nature of risk** | **National** | **Business** | **National** | **Business** | **National** | **Business** | **National** | **Business** |
| Energy market instability | * | * | * | * | * | ** | *** | ** |
| Technical failure | *** | *** | * | ** | * | *** | * | * |
| Physical security threat (including natural disasters) | *** | ** | | | | * | ** | ** |

| | |
|---|---|
| *** | High risk |
| ** | Medium risk |
| * | Low risk |
| **No star** | No perceived risk |

**Concentrating Solar Power (CSP) plants** can provide electricity especially in areas with long and reliable hours of direct sunshine. In these areas peak demand is usually driven by air-conditioning systems and the availability of CSP matches peak and mid-peak demand well – although heat storage and/or fossil fuel back-up may help fully cover the mid-peak demand during a few hours after sunset. Because insolation is available only in the day, CSP can provide base load only if heat storage technologies are integrated. While round-the-clock operation is technically possible industrial heat storage options are currently not economically feasible.

**Wind power** is directly dependent on the cube of the wind speed within the operating range. The wind speeds, at which wind turbines commonly operate, are between 2.5 to 25 m/s. Thus, wind power can become unavailable at times of low wind speeds, but also at times of very high wind speeds when wind turbines need to be shut down in order to avoid damage to equipment. Thus, for entire grid system control areas, power generation will gradually decrease at mean wind speeds higher than 25 m/s. The annual power output of a given turbine varies greatly with location and capacity factors of over 45% are rare[11]. Wind energy is typically variable on time-scales from minutes to hours but can also be seasonal. Geographical distribution across a grid partly compensates for short term fluctuations as is also the case for solar.

**Biomass combustion**, used widely for heat as well as power generation using feedstocks usually from organic waste products, depends on reliable supplies. Seasonal cycles of energy crops or crop residues used for biomass can have effects on the availability of feedstock and thereby affect supply security. Cogeneration plants using sugar bagasse for example often only operate for 6-7 months of the year during the sugar harvesting season. The possibility of storing biomass, however, such as straw bales or wood chips can help to offset other variable power production systems. Using a bioenergy system as back-up to a solar thermal power plant is one example, although mainly for nights as the bioenergy plant response time is not fast. The co-firing of biomass with coal can also partly reduce the risk of supply. Common designs of handling and combustion systems often restrict biomass to less than a 15% share.

Where available, **geothermal power** plants can provide base load capacity as variability is not an issue. Geothermal energy is largely untapped in many areas of the world and is available in many developing economies of South and Central America, Africa and South-East Asia. Near surface geothermal heat is only accessible in limited regions worldwide.

[11] Wind turbines are designed to minimise cost per unit of electricity generated in the wind conditions where the wind turbines are placed. Least cost per generated unit of energy is usually obtained with capacity factors of 25-35%.

Geothermal heat from deeper hot rocks is more widely available but also more costly to extract.

**Ocean energy** is at the development stage and has considerable potential. Tidal power is variable but predictable as are ocean currents. Similarly, wave power outputs are variable, but with non-random patterns; this permits output predictions, albeit with varying degrees of accuracy. The energy available through ocean thermal energy conversion (OTEC) is one or two orders of magnitude higher than other ocean energy options such as wave power, but current systems have very low efficiency.

### 3.1.1 Contribution of renewable energy technologies to electricity production

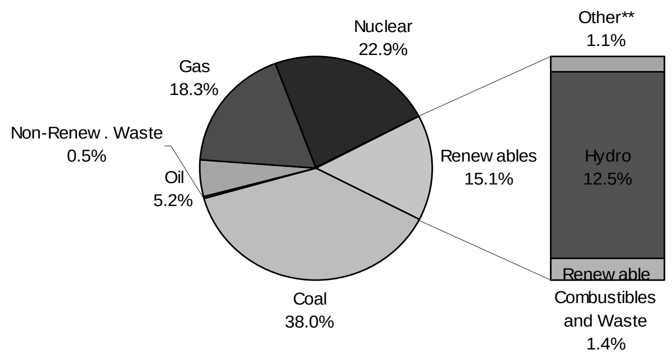
Electricity demand has grown in most OECD member and non OECD countries over the past decades. However, the generation mixes and the corresponding growth of underlying primary fuel use have varied across regions. In the USA and China for example a huge growth of coal-fired power generation has occurred, whereas in Europe the main growth has been from the use of gas. Wind energy generates a significant share of electricity in some European countries and regions, such as Denmark, northern Germany and Spain. Geothermal energy makes a significant contribution to electricity generation in some OECD countries - Iceland and New Zealand – as well as in several non-OECD countries, for example Kenya, Philippines, Indonesia and El Salvador[12]. Overall however, renewable energy has not contributed to a large extent to this growth and its share has remained secondary.

In 2004, 15.1% of total electricity in OECD countries was produced from renewables (excluding generation from pumped storage plants): 12.5% from large hydro, 1.4% from renewable combustibles and waste[13] and 1.1% wind, solar, geothermal etc. (IEA, 2006g) (Figure 2). These shares differ by country depending on the local renewable energy resources, current energy prices and policy support mechanisms in place.

A large increase of non-hydro renewables especially in Europe is expected to achieve a market share of 11% by 2030. This is based on official targets and strong government support policies and measures (IEA, 2006h). In 2005, annual investment in new renewable power capacity increased to USD 38 billion (REN21, 2006), representing about 20% of total additional worldwide investment in power generation[14].

[12] Personal communication, IEA Geothermal Implementing Agreement
[13] This includes solid biomass, renewable municipal waste, biogas and liquid biofuels.
[14] Figures of global power generation investment exclude transmission and distribution investment and fossil fuel supply chains, which might mean the comparison is too favourable to renewable energy.

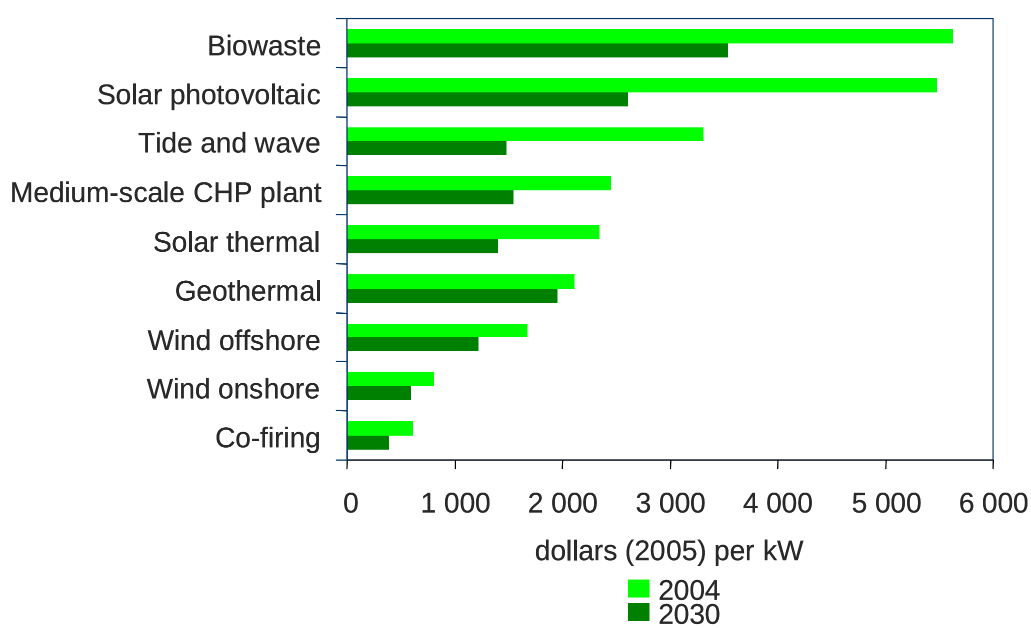
**Figure 2: Renewable shares in OECD electricity production, 2004**




** Other renewables include geothermal, wind and solar. Source: IEA, 2006b

Investment as well as generation costs vary greatly among RETs, with several technologies already approaching competitiveness with conventional power generation technologies at the midpoint of their respective cost ranges. The IEA projects that by 2030 learning effects will have pushed investment and generation costs further down (Figure 3 and Table 3). In a few countries, some prime locations for the deployment of RETs, especially for electricity generation, are already used which may affect the potential for future cost reductions. However, in most countries, renewables offer a large unexploited potential.

**Figure 3: Capital costs for renewables-based technologies, 2004 and projected for 2030**




Source: IEA, 2006h

**Table 3: Costs of electricity generation technologies in OECD countries, 2005 and projected for 2030**[15]

| Technologies based on: | Investment costs (USD per kW), 2005 | Investment costs (USD per kW), 2030 | Typical electricity generation costs[16], 2005 (USD per MWh) | Typical electricity generation costs, 2030 (USD per MWh) |
|---|---|---|---|---|
| Large hydro | 1,500 – 5,500 | 1,500 – 5,500 | 30 – 120 | 30 - 115 |
| Small hydro <10 MW | 1,800 - 6,800 | 1000 - 3000[17] | 60 - 150 | 50 |
| Wind onshore | 900 – 1,100 | 800 – 900 | 30 – 80[10] | 30 – 70 |
| Wind offshore | 1,500 – 2,500 | 1,500 – 1,900 | 70 – 220 | 60 – 180 |
| Geothermal | 1,700 – 5,700 | 1,000 – 2,000 | 30 - 90 | 30 - 80 |
| Solar PV | 5,000 – 8,000[18] | 1,200 – 1,800 | 180 - 540 | 70 - 325 |
| Solar thermal | 2,000 – 2,300 | 1,700 – 1,900 | 105 - 230 | 90 - 190 |
| Biomass | 1,000 – 2,500 | 400 - 1200 | 30 – 100 | 30 – 100 |
| Ocean (current, tidal, wave) | | | 55 - 160 | |
| Coal | 1,000 – 1,200 | 1,000 – 1,250[19] | 20 - 60 | 35 - 40 |
| Coal with CCS[20] | 1,850 – 2,100 | 1,400 – 2,100[12] | 40 - 90 | 45 - 60 |
| Natural gas | 450 – 600 | 400 - 500 | 40 - 60 | 35 - 45 |
| Nuclear | 2,000 – 2,500 | 1,500 – 3,000 | 25 – 75 | 47 - 62[21] |

Source: IEA, 2006e; IEA/NEA, 2005

### 3.1.2 Security effects of grid integration of renewables

**Generation mix**

Given increasing environmental and climate change concerns and efforts to reflect the cost of $CO_2$ emissions in energy markets, renewables are gaining increasing attention. They are increasingly substituting other conventional generation technologies.

This substitution process can be made by dispatching renewable energy plants from the grid or by modifying the load. As an example, in Germany, electricity production from gas is limited to peak load and spinning reserve power. Hence, the displacement of gas out of the

[15] Using 10% discount rate. The actual global range is wider as discount rates, investment cost and fuel prices vary. Wind and solar include grid connection costs, where appropriate.
[16] Total costs include investment, operation and maintenance and fuel costs. For wind and solar PV, the cost also encompasses grid connection costs.
[17] Johanssen *et al*. (2004), Fisher (2006), IEA/NEA (2005), MIT (2003), WEC (2004a, 2004b)
[18] Personal communication, IEA PVPS Implementing Agreement
[19] Projected investment costs for 2030 relate to advanced coal conversion technologies (advanced steam cycles, FBC, IGCC).
[20] CCS stands for carbon dioxide capture and storage
[21] These costs relate to Generation III (advanced boiling water reactor, advanced pressurised water reactor, European pressurised water reactor) and Generation III+ (pebble bed modular reactor and AP1000 a third-generation light water reactor) nuclear reactor types. Generation IV reactors are not expected to be available until around 2030.

generation mix by wind energy is almost negligible to date. This indicates a small improvement in energy security in terms of decreasing gas import dependency.

In the UK, natural gas-fired electricity contributed 40% of total gross electricity production in 2004, so the effect of introducing renewables is very different (IEA, 2006b). Meeting load demand by following the least-cost merit order based on marginal pricing means that the capacity which is more expensive to generate is not dispatched. Gas fired plants manifest a higher share of fuel as part of total in generation costs (USD/GJ) than coal, nuclear or renewables (IEA/NEA, 2005). Consequently, gas plants can be assumed to be the fossil fuel plants with higher marginal costs (although oil-fired plants would be even higher). Switching gas for renewable energy would therefore likely affect gas consumption in the UK more than in Germany. Thus, the effect of RETs on energy security in a mainly gas-fuelled electricity system can be significantly higher.

**Management strategies for variable power generation**

Downstream security refers to the probability of interruptions to the energy supply from the electricity system. Most renewable energy technologies such as hydro, wind, solar, tidal and wave depend on different natural cycles and therefore vary on different time scales. At high levels of grid penetration by RETs the consequences of unmatched demand and supply can pose challenges for grid management. This characteristic may affect how, and the degree to which, RETs can displace fossil fuels and nuclear capacities in power generation. The additional costs for grid back-up and/or electricity storage and spinning reserve have to be taken into account (Swider *et al.*, 2006; Meibom *et al.*, 2005)[22].

Large shares of a single variable resource, such as wind energy, require means to balance the supply with the load. In many countries existing control methods together with back-up capacity available can deal with the ever-changing power demand at penetration levels up to around 20% (GWEC and Greenpeace, 2006). Western Denmark already successfully integrates a 20% share of wind energy into the electricity system, but this ability relies on good inter-connection to the German and Nordic grids for back-up and export. Above this level, some changes may be needed in power systems and their method of operation to ensure system reliability.

In countries with high penetration levels of wind power but few flexible power stations and little hydropower storage for back-up, the question of sufficient operational reserve is critical. Less flexible conventional power stations can be costly back-up as changing their load may

[22] Flexible measures to absorb the fluctuations in wind power production are required as the grid penetration of wind power increases. Recommended integration measures include the use of electrically operated heat pumps in CHP systems which can provide relatively cheap optional demand (Holttinen *et al*., 2005; Meibom *et al.*, 2005).

reduce efficiency and thereby raise costs. Improved wind prediction methods have lowered these risks.

High-impact, low frequency weather events, such as long periods of low wind speeds, need to be evaluated. Statistically, these 'outlier events' (see box) are at the edge of the probability distribution. Experience suggests that capacity reserves will be needed as a consequence of low wind speed events[23]. Such rare events are manageable, although they may affect the installation of large wind capacities disproportionally.

**Example of an "outlier event"**

Hourly wind data collected over a 23 year period (1970-2003) from 66 different locations in the United Kingdom showed that low wind speed events affecting more than half of the UK are present for less than 10% of all hours. The data did not indicate any hours where wind speeds were below 4 m/s throughout the UK. The UK experiences far fewer high speed wind events (average hourly wind speeds above 25 m/s) than low wind speed events, with the UK not having any high speed wind events for over 96% of all hours over the 23 year period (Sinden, 2007). Three year data (2000-2002) in Denmark identified that the longest duration of calm weather with wind generation below 1% of capacity was 58 hours in 2002 and 35 hours in 2000. For Finland and Sweden it was 19 hours and for Norway 9 hours. However, if the wind power production of these four neighbouring countries were combined, there were no totally calm periods in the data (Nørgård *et al*., 2004).

Besides the occurrence of extreme wind conditions, the availability of wind power at different times of the year and different demand levels is a critical aspect. Over the long term, low wind speed events are less likely during periods of high electricity demand than during periods of low electricity demand. The relationship between the extent of high wind speed events – although extremely rare - and electricity demand is more complex. While the impact of high speed wind events is greatest during periods of high electricity demand, such wind events on average affect less than 0.2% of the UK at such times. Moreover, the extent of such events is at its greatest during periods of relatively low electricity demand (Sinden, 2007).

Improved control technologies, more accurate forecasting techniques and increased geographical dispersion of wind farms - ensuring that the wind will generally be harvested somewhere in the network - will all help their effective integration. A balanced portfolio of RES with different natural cycles may also reduce the need for back-up capacity. A good example is a combination of solar and wind energy to satisfy peak demand (the former being more productive during summer, the latter often more productive during winter) with base load provided by geothermal or biomass.

The direct effects in quantitative terms of an increasing share of variable renewables depend on the balancing options and demand-side response techniques. If the possibility exists to

[23] Low wind speed events are defined as average hourly wind speed measurements of less than 4 m/s (the minimum wind speed for electricity generation for many modern wind turbines).

balance the grid using other RETs, these installations can effectively replace existing power plants and consequently reduce investment needs in fossil-fuelled power plants.

Geothermal is not a variable power source, nor is biomass except where the latter depends on seasonal cycles and harvesting periods of dedicated energy crops. These cycles affect biomass production on larger time-scales and, since many forms of biomass can be stored for short to medium time periods, it is therefore more manageable than other renewables. Competing uses of land for energy, food and fibre production can also put constraints on the availability of biomass. The low density of several forms of biomass exposes them to high transportation costs limiting some resources to on-site use for heat and power or distributed generation, resulting, in some cases, in reduced use of power transmission grids. Hydropower is exposed to generation variability depending on the hydrological cycle which provides seasonal rain and runoff from snow melt.

Within the aforementioned characteristics of their natural cycles, then, hydro, biomass, CSP (with heat storage or fossil fuel back-up) and geothermal power technologies can be used for base and peak load production. Consequently, their capacity value is close to one. In the case of CSP, this is due to the matching of its availability with summer peak demand. Bioenergy can also be used for mid load production. Geothermal technology applications are able to operate in a load-following manner, although this is not the optimum operating mode. Therefore, CSP, geothermal and biomass can have direct fuel substitution effects at the mid load level, and thus a high net effect on capacities. This results from the absence of the need for further balancing of capacities. Consequently, bioenergy installations can affect the need for new investments or the use of current power plants. Under the assumption of complete market integration of bioenergy technologies, the effect on other power plants is determined by their marginal costs.

Therefore, geothermal and biomass plants can displace new investments in nuclear, coal or gas plants depending on their various deployments in different countries. Depending on the growth of variable RETs' share in power production, renewables are most likely to displace conventional technologies used for base load generation, namely coal, nuclear and natural gas (IEA, 2007).

Associated costs for variable renewables can be divided into additional balancing costs, requirements for operational and capacity reserves as well as adaptation of transmission and distribution grids.

**Energy technology portfolios**

Adding RETs to the portfolio can reduce the risks of generation failure by adding to the portfolio of technologies in the energy supply mix. In general terms, portfolio theory aims to determine the mix of different financial assets which is the most desirable to hold. In energy terms this seeks to secure a combination of generation plants that reflects the risks and corresponding prices under pre-defined goals and risk targets. In the context of electricity or heat generating options, expected portfolio cost is used, rather than the expected return.

Optimisation seeks to minimise the expected portfolio cost (Awerbuch and Berger, 2003). A diversified portfolio of energy supply options reduces energy security risks, such as fuel price volatility due to resource concentration. It can offer a hedge against future uncertainties – population growth, rate of energy demand growth, speed of new technology development and technology performance.

The drawback of utilising the concept of fuel mix diversity as an indicator of energy security is that it cannot be easily measured or quantified. Basing a portfolio's composition on past price correlations does not adequately reflect energy security concerns, especially where prices are regulated and in the event of price shocks.

Individual energy technologies face different risk structures as a result of differences in capital intensity, fuel dependency and fuels used. Consequently, disruptions in energy markets affect energy sources differently. Energy security risks may show up as physical interruptions that can seriously harm supply of energy services or as sudden price shocks reflecting rising demands, falling supplies or several other factors like political risks. The risk structures of some power generation technologies depend on their degree of variability (Table 4).

Gas-fired power generation is exposed to high fuel cost risk. This implies that a further expansion of gas-based electricity production of 2.5% per year from 2004 to 2030, as assumed in the WEO 2006 Reference Scenario (IEA, 2006h), will probably result in a higher price risk for the generating portfolio. Geothermal, wind and PV do not face a similar risk as they do not rely on a commodity feedstock. Hence, their risk structure is not correlated with the risk of gas or other fossil fuels whose fuel costs depend on overall energy demand. Under the assumption that variable renewable energy technologies can be geographically dispersed and considered as part of a diverse RET portfolio, the costs of these variable technologies are quite stable. Consequently, following the portfolio approach, to deploy renewable energies can result in a reduction of the volatility of generation costs and therefore in a risk reduction to a portfolio of generation technologies.

The problematic definition of an optimal portfolio is determined by the degree of risk aversion, the effect of variability on the economy, and the extent to which mechanisms exist to mitigate risk efficiently. Several factors including demand response, fuel flexibility determine the final value of a risk reduction measure to a portfolio. What value a risk reduction measure can have in monetary terms goes beyond the scope of this study. Nevertheless, the assumption is supported that those renewables not exposed to fuel costs have a positive effect on the risk profile of generation portfolios by reducing the risk of rising fuel costs. This shows the benefits from increased diversification through the inclusion of renewables.

**Projections of future electricity market structures**

The World Energy Outlook 2006 Reference Scenario projected a total investment in global electricity markets of USD 11.3 trillion by 2030, of which USD 6.1 trillion will go to new and upgraded transmission and distribution assets (IEA, 2006h). As RETs gain more significant market shares, some of this investment will benefit the integration of these technologies. Six main areas of structural change directly benefit renewables:

- Increased grid capacity and cross-boarder connections, corresponding to the WEO 2006 projections;
- Balancing/regulating markets that are cost-reflective, transparent and interconnected with gate closure times reflecting the technical and economic needs of the system;
- Enhanced uptake of efficient demand-side response mechanisms.
- Installation of more flexible generating capacity, including hydro-power and biomass, as capacity reserves and increased efforts to reduce costs of novel storage solutions to widen the number of strategic options;
- A mix of different renewable energy technologies, taking advantage of different natural cycles and thus reducing volatility and uncertainty; and
- Improved forecasting and modelling of natural fluctuations and increased utilisation of communication technologies to disseminate this information between grid operators and markets.

The first four are likely to occur as a consequence of continued evolution of electricity markets and electricity grids. Other options might require further policy guidance. Overall, variability should not be regarded as a risk to energy security (dena, 2005). However, the issue needs to be carefully analysed and managed.

### 3.1.3 The physical security advantages of renewable electricity generation

Renewable energy installations vary greatly with regard to the scale of plant size and to the possibility of integrating them either into the transmission or the distribution systems. For example, large hydro plants and the majority of large-scale wind farms (up to 300MW) feed in to the high voltage transmission system, in the same way as conventional power plants.

**Table 4: Qualitative comparison of risks of electricity generation technologies**

| Technology | Plant capacity ranges (MW) | Lead time | Fuel cost as % of total generation costs[24] | Risk of fuel cost fluctuation | Variability | Rapid response rate use to level out peak demand for generation | Regulatory risk |
|---|---|---|---|---|---|---|---|
| **Hydro** | 14 – 32000 | Long | Nil | Nil | Low | Yes | High |
| **Wind power** | 0.5 - 300 | Short | Nil | Nil | High | No | Medium |
| **Photovoltaics** | 0.01 - 10 | Very short | Nil | Nil | High | No, except in hybrid systems and systems with expensive storage components | Low |
| **Geothermal** | 0.1 - 200 | Long | Nil | Nil | No | No | Low |
| **Biomass including CHP** | 10 - 240 | Medium | 60% | Medium[25] | No | No | Low |
| **Fuel cells** | 0.1 - 10 | Very short | 40% | Low | No | Yes | Low |
| **Coal** | 150 - 900 | Long | 35% | Medium | No | Yes | High |
| **CCGT** | 100 - 500 | Short | 75% | High | No | Yes | Low |
| **Nuclear** | 700 - 1600 | Long | 10% | Low | No | No | High |
| **Internal combustion engines** | 0.1 – 60 | Very short | 70% | Medium | No | Yes | Low |

[24] At 10% discount rate - IEA/NEA (2005)
[25] A significant supply risk is the competition for the biomass resource – for energy uses, such as electricity, heat and transport, and for food, fibre and chemical production.

On the other hand, small hydro applications and small wind turbines for self-production are decentralised and much smaller in capacity when compared to traditional power stations. Biomass and geothermal installations typically are 20-100 MW capacities, although plants can be larger with combined heat and power (CHP) opportunities. These smaller installations tend to be widely dispersed and do not show a major security risk in terms of exposure to sabotage or terror attacks. Plant outages for any reason would only affect a small portion of electricity supply. Consequently, there is no need for costly precautionary measures with regard to specific or common security risks.

Centralised power generation is exposed to a larger set of supply security risks relative to distributed generation. An outage of one of these power stations could have significant impacts on the electricity supply in absence of reserve capacities and may therefore imply major costs for society. However, the probability of this risk is limited as electricity systems normally rely on a large number of units and are designed to cope with unplanned outages at individual stations due to technical problems as well as planned outages for maintenance.

Besides the protection of central power stations another burden is the protection of transport infrastructure and storage capacities like pipelines, ships as well as gas terminals etc. Although difficult to assess, the costs involved in securing such infrastructure against piracy and attacks can be substantial. Where these costs are at least partly borne by public funds the security requirements are not internalised in the costs of fossil fuel based electricity production. The risk of physical security risks, such as sabotage, faced by high voltage transmission systems is moderate, as overhead transmission lines are vulnerable to possible attacks. While the short-term economic impacts of power outages would be significant, the attacks would not have long-term effects as the affected high-voltage transmission lines could normally be reinstalled in a fairly short period of time. The extent to which renewables can be regarded as reducing the exposure of an electricity network to terrorist attacks or natural disasters will vary greatly depending on the nature and penetration of the renewables as well as the extent of the system and the characteristics of the other generation sources.

However, in some circumstances, the deployment of renewable energies can have a positive effect in reducing the amounts of transported and used fuels as well as on the need for securing power stations.

### 3.1.4 Summary

1. Depending on electricity market conditions, the effects of a country's renewable energy generation facilities on fossil fuel consumption are determined by the infrastructure and the characteristics of the generation technologies. Consequently, the impacts relating to energy security have to be assessed by technology and by country.

2. Electricity generation from renewables is, in the case of hydro, wind, biomass and geothermal, often already competitive with generation from conventional power stations to the midpoint of the RET cost ranges at current fossil fuel prices. Targeted and adequate RD&D investments can help reduce technology costs by facilitating collective market learning.
3. Renewables can reduce the exposure of power generation to price risk. Price volatility due to fuel cost variations can be reduced which affects the risk structure of generation portfolios. This effect favours renewables and enhances their competitiveness.
4. Renewable electricity systems can contribute to security against terror, sabotage and localised natural disasters as a result of their dispersed structure.
5. Careful analysis is required of the impact of large scale penetration of variable renewables in a power grid. Depending on the balance of capacity available and wider connectivity of the system, investment may be needed in back-up capacity and in policies to enhance demand side response.
6. Depending on the extent to which variable RETs dominate a power network, they are most likely to displace conventional generation technologies used for base load, namely coal, nuclear and natural gas (IEA, 2007).
7. Positive effects of renewables on selected indicators for energy security may include:

   - Diversification of energy sources in energy supply: renewables can contribute to diversification of the portfolio, especially as their risk structure is not related to fossil fuel supply risks, they can reduce the variability of generation costs.

   - Diversification of imports with respect to imported energy sources: as most renewables do not need imported fuels, they can contribute to reduced import dependency. Biomass can be an exception. However, in some countries, using bioenergy provides opportunities for diversifying import portfolios.

## *3.2. Heat production*

Globally, heat is the largest energy end use. Nevertheless, because of the relative absence of policy interest to date compared with electricity and transport fuels and its distributed nature, the energy security implications of heating have not received much attention.

Similar to electricity generation, heat can be provided both through grid- and non-grid connected systems though the transport distance is short. Official government statistics only capture the commercially traded fuel inputs to heat production as well as the commercial sale of heat by contract to a third party use (e.g. residential, commercial or industrial consumers). Thus, while the data on grid-connected and centralised systems, such as district heating, CHP plants and industrial process heating, will be more reliable, heat production in non-grid connected and decentralised systems, such as ground-source heat pumps and domestic solar thermal[26], is not included in official statistics. Therefore, the actual contribution of renewables to heating is understated in official statistics.

### 3.2.1. Contribution of renewable energy technologies to heat production in OECD countries

About 22% of reported world heat production in 2004 was in OECD member countries (IEA, 2006b). Renewables as defined by the IEA represented approximately 18.4% of total gross heat production[27] (including direct use of geothermal and solar heat) in 2004 among OECD countries (IEA, 2006b, 2006f). The deployment of renewable heat production technologies differs among OECD regions. OECD Europe, and the EU-15 in particular, occupies the dominant position in the deployment of commercially available renewable heat, with the region representing all listed commercially traded geothermal and solar heat, 94% of heat from solid biomass and 92.4% of heat from renewable municipal waste.

Among OECD countries, heat derived from biomass technologies overshadows geothermal and solar thermal technologies and represents 65.8% of commercially traded heat produced from renewable sources (IEA, 2006g).

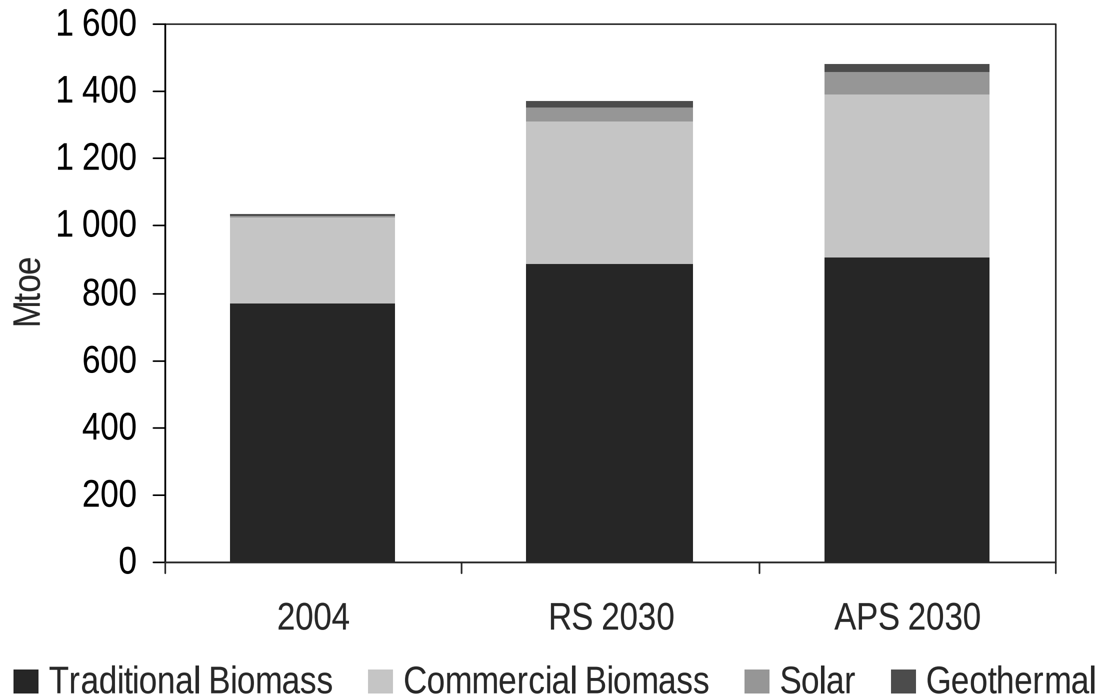
In its WEO 2006 Alternative Policy Scenario (APS), which assumes the implementation of all policies currently under consideration by governments driven by concerns for climate change mitigation and energy supply security, the IEA projected that by 2030 global renewable heat production in the building and industry sectors will have grown by 43% from 2003 (IEA, 2006h). The most substantial growth is projected to derive from commercial biomass followed by solar thermal, while traditional biomass supply stagnates and its relative share in renewable heat production declines.

#### 3.2.1.1 Bioenergy

Biomass, including traditional fuelwood and dung, is the largest contributor to renewable energy heat worldwide. In 2004, biomass supply was 7,034 PJ and represented a 10.4% share of global primary energy supply but only 3% of total OECD primary energy supply based on IEA, 2006g).

[26] i.e. for direct use of RES for heating
[27] An important caveat is that the IEA statistics include heat sold to third parties only. Auto-production by industry is not included, nor is residential transformation of electricity, natural gas and fuel oil for space heating and other heat uses. The amount of total heat produced is at least two orders of magnitude above commercially sold heat.

**Figure 4: Worldwide renewable heat production in industry and buildings in 2004 and projected by 2030**




Note: RS = Reference Scenario; APS = Alternative Policy Scenario

Source: IEA, 2006h

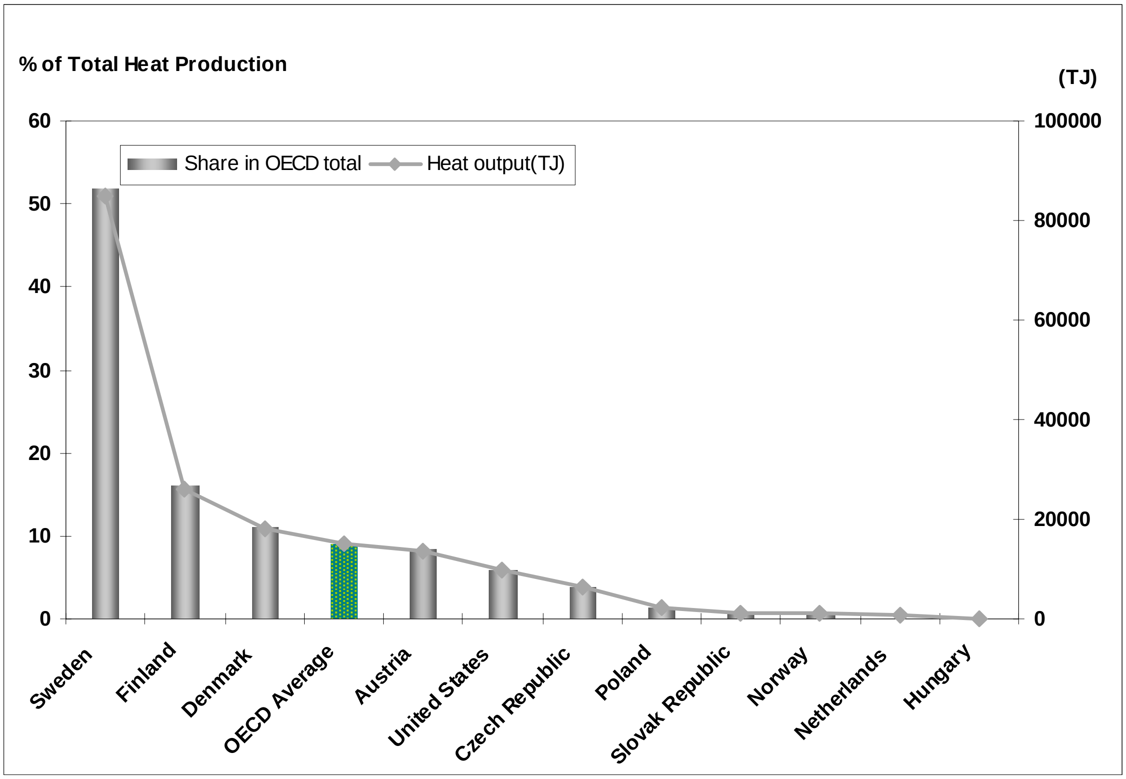
Gross heat production in OECD countries from solid biomass was 164 PJ in 2004, which is 30% of total renewable heat production; 52% was from direct use of solar and geothermal heat. Heat production from renewable municipal waste[28] was 29%.

In 2004, the largest producer of heat from solid biomass in the OECD was Sweden (85 PJ), representing 52% of total OECD heat production from solid biomass (Figure 5). Favourable policy instruments and the dominance of biomass feedstock for district heating systems are major drivers underlying Sweden's significant development of biomass. Other major producers were Finland (26 PJ), Denmark (18 PJ) and Austria (14 PJ).

In Sweden, solid biomass – mainly forest products and residues - met 49% of the supply for district heating systems in 2003, a three times increase since 1990. In Finland, gross heat production from solid biomass increased from 6 PJ in 1995 to 26 PJ in 2004, an average annual growth of more than 17% per year. Heat generation is not taxed in Finland and plants are eligible for investment credits.

[28] Renewable municipal waste excludes the non-renewable waste fraction.

**Figure 5: Solid biomass share in OECD heat production, 2004**




Source: IEA, 2006g

In 2004, heat production from solid biomass in Austria was 14 PJ, up from 1 PJ in 1990. Federal and state policies have been instrumental in stimulating the market for biomass district heating plants for villages since the mid-1980s. These policies have primarily taken the form of implementation management and, as a financial incentive, investment grants. Installation of biomass district heating plants has increased steadily.

The share of commercial heat in total final energy consumption is also relatively high in Denmark at 16% due to Denmark's extensive use of district heating, which was promoted after 1979 through the National Heat Supply Act. It included a national heat plan and the possibility for local governments to mandate connection to the district heat network for new and existing buildings.

In the EC's 1997 White Paper on Renewable Energy Sources biomass represented 68% of the EU's indicative target of doubling its share of renewable energy sources from 6% of gross domestic energy consumption in 1998 to 12% in 2010 (EC, 1997). However, in its more recent Biomass Action Plan, the EC highlighted that despite the existence of mature, straightforward and commercially viable technologies for renewable heating for residential and industrial purposes, the consumption of biomass is growing slowest in the heating sector

(EC, 2005). In its Roadmap for Renewable Energy the European Commission emphasises that biomass is projected to contribute significantly to the suggested target of 20% of primary energy supply by 2020 in all three end-use sectors – power, heating and cooling and transport (EC, 2007b). In the heating and cooling sector, biomass could contribute the bulk of growth towards the doubling of renewable heating and cooling sources' current market share by 2020 through the deployment of high efficiency biomass-fired CHP and efficient residential heating systems (*ibid.*). In order to achieve it is assumed that renewable heating policies are implemented across EU member States, providing sufficient incentives for the deployment of all relevant renewable heating technologies (EC, 2007c).

The IEA Bioenergy Implementing Agreement[29] identifies a lack of demand as the main barrier to a significant growth in the uptake of heat from bioenergy sources (or "bio-heat"). The main reason for the lack of demand is argued to be an absence of targeted policy instruments for renewable heating which would in turn create an enabling market environment and stimulate R&D investment.

#### 3.2.1.2 Geothermal heat

According to the IEA Geothermal Implementing Agreement[30] geothermal resources have been identified in more than 80 countries, with recorded geothermal utilisation in 72 countries to date. At the end of 2004, total geothermal heating in OECD countries was 175 PJ/year including the direct use of geothermal energy.

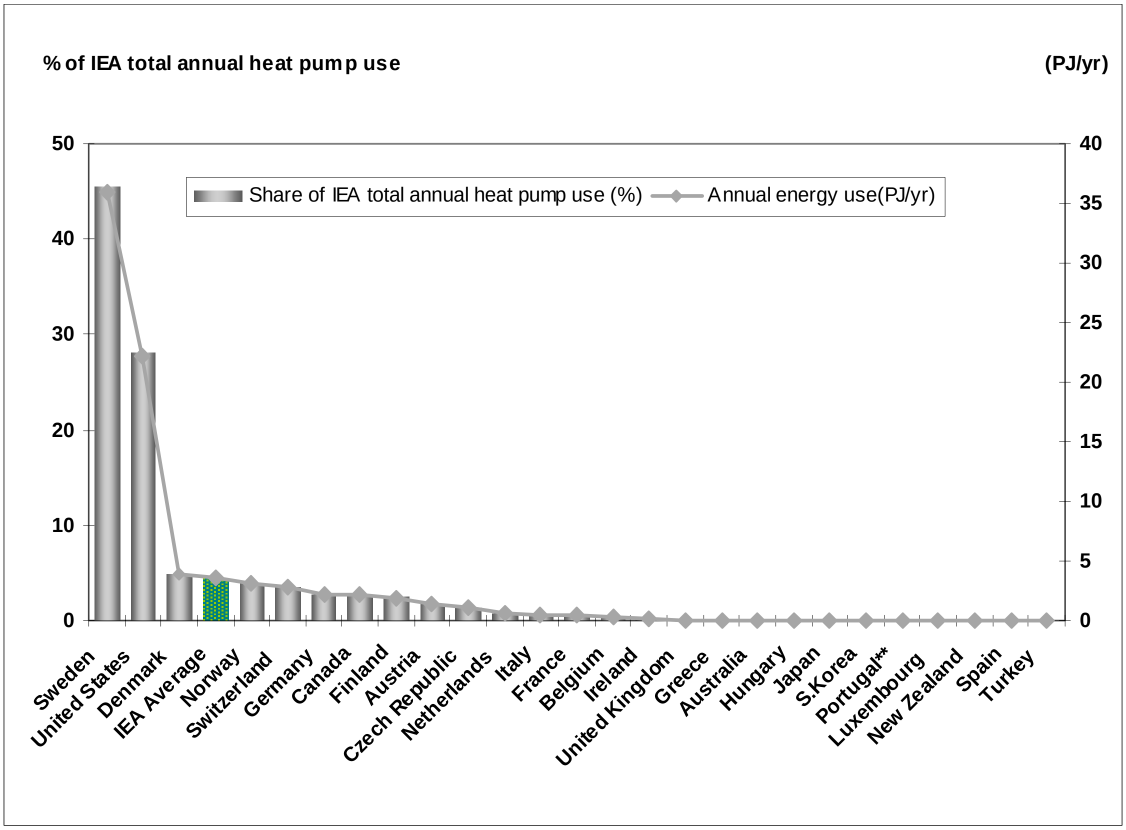
It was reported at the World Geothermal Congress 2005 that total annual worldwide direct use was 273 PJ, which represents an almost 45% increase over 2000 and a compound growth rate of 7.5% per annum. The numbers include all direct uses, for agriculture, industry, and space heating. The growth rate has increased in recent years, despite economic downturns and other factors. In space heating there are centralised systems like district heating networks (in Iceland, a non-IEA member participant in the GIA, geothermal heat supplies 88% of all buildings), and smaller, decentralised ground-source heat pump (GHP) systems. GHP supplied 79 PJ in 2004 (Figure 6) being the greatest contributor to geothermal heating and cooling. They contributed decisively to the growth over time due to the growing awareness of their capabilities, popularity and ability to use them anywhere in the world.

Sweden and the USA contributed 73.4% of total IEA heat production from GHP, with China, Denmark, Switzerland and Norway also major users. Japan has a strong heat pump manufacturing industry but GHPs have still not established a market. In general, there are large discrepancies in GHP usage from country to country; major reasons include the lack of

[29] The website link of the IEA Bioenergy Implementing Agreement is: http://www.ieabioenergy.com
[30] The website link of the IEA Geothermal Implementing Agreement is: http://www.iea-gia.org/

awareness among end users about this relatively new technology as well as the high upfront equipment and drilling/ installation costs relative to other conventional heating applications, which commonly deter domestic users with high implicit discount rates.

**Figure 6: Geothermal heat pump use for heating and cooling in IEA countries, 2004**




Source: Data from Lund *et al.* (2005)

### 3.2.1.3 Solar thermal

Low temperature solar heating covers a broad spectrum of technologies, including solar water heating, active solar space heating, and passive solar heating, all of which have been commercially available for more than 30 years. Medium to high temperature heat for industry is also feasible.

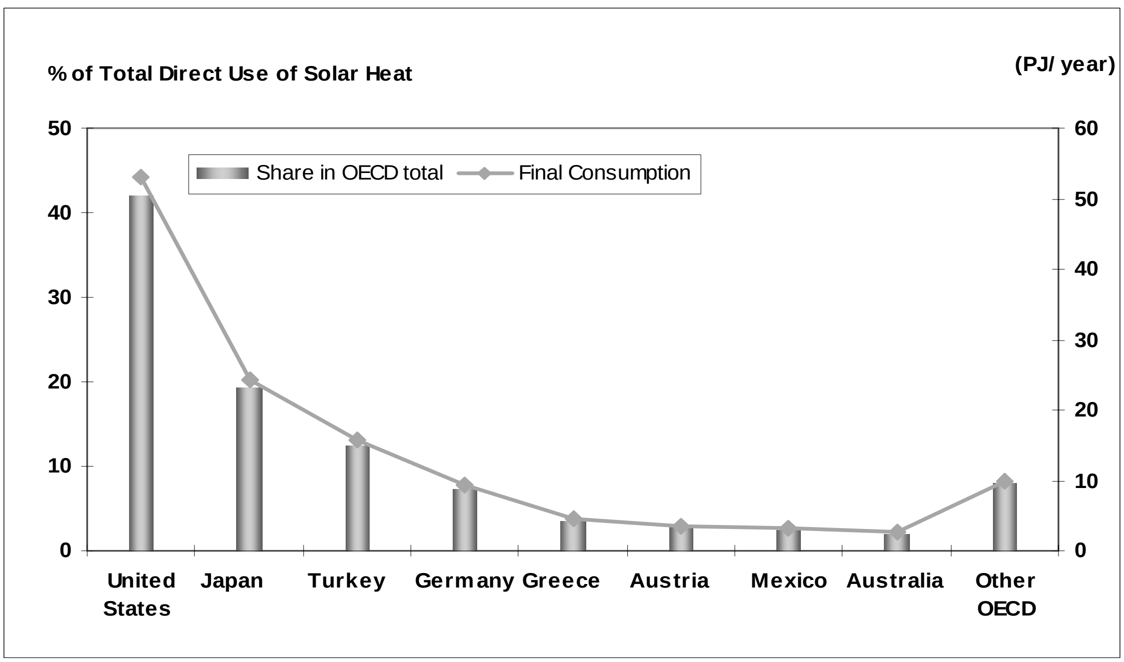
The worldwide contribution of solar heat to the overall energy supply is significant. At the end of 2004 a total of 141 million square meters of collector area, corresponding to an installed capacity of 98.4 $GW_{th}$, had been installed in the 41 recorded countries (Weiss *et al*., 2006)[31]. OECD member countries represented 50% of worldwide installed capacity. Of the total

[31] The 41 countries (all OECD countries except Korea and Iceland plus – in descending order of total installed capacity - China, Israel, Brazil, Taiwan, India, Cyprus, South Africa, Barbados, Slovenia, Malta, Latvia, Lithuania, Estonia) included in this report represent 3.8 billion people or about 58% of the world's population. The collector area installed in these countries is estimated to represent 90% of the solar thermal market worldwide.

worldwide installed capacity, 34 $GW_{th}$ were accounted for by flat-plate and 40.3 $GW_{th}$ for evacuated tube collectors, used to heat water and for space heating and 23.1 $GW_{th}$ for unglazed plastic collectors, used mainly to heat swimming pools. Unglazed air collector capacity was 1.2 $GW_{th}$ installed. This collector type is used for drying agricultural products and to a lesser extent for space heating of houses and other buildings (*ibid.*). In 2004, the highest collector surface area per 1,000 inhabitants was Cyprus with 582 $m^2$, followed by Austria 297 $m^2$, far above the EU average of 33.7 $m^2$ (EurObserv'ER, 2005b).

The worldwide market for glazed solar collectors has greatly increased over the last decade to approximately 10 million $m^2$ installed per year – in 2004, 72% of the growth in new capacity installed occurred in China which represented 45% of the world's total capacity in operation in 2004 (Weiss *et al*., 2006). The largest users of solar water systems among OECD countries were the United States, Japan and Turkey which account for 74% of direct use (Figure 7).

**Figure 7: Direct use of solar heat in OECD countries, 2004**




Source: IEA, 2006g

If one observes the use of solar thermal energy it becomes clear that it greatly varies between the different countries and economic regions. In North America (USA and Canada) swimming pool heating is dominant with an installed capacity of 18.8 $GW_{th}$ of unglazed plastic collectors while in China and Taiwan (44.4 $GW_{th}$), Europe (10.8 $GW_{th}$) and Japan (5.4 $GW_{th}$) plants with flat-plate and evacuated tube collectors mainly used to prepare hot water and for space heating are dominant.

### 3.2.2 The security advantages of renewable heat production

The benefits of heat production based on RES with regard to energy security are similar to those of renewable electricity production (section 3.1.3). The main difference between electricity and heat markets is the lack of tradability for heat as a commodity. Like electricity, heating (services) are required at all scales of consumption. Industrial process heating requires larger-scale equipment, whereas space heating and hot water production in commercial and especially residential buildings can be achieved both with small-scale applications as well as with medium- and large-scale technologies.

#### 3.2.2.1 Technical security advantages

Bio-heat, geothermal and solar thermal applications can satisfy the diverse scales of heating demand due to the modular characteristics of these systems which are based on mature technologies. Bio-heat technologies can be used for medium- and large-scale heating purposes, such as to supply district heating systems in metropolitan areas, as in Sweden, Finland and Denmark, as well as for the small scale space heating of individual buildings, using wood stoves and pellet burners. Geothermal heat is also a significant provider of heat on the small scale of individual homes and buildings via GHPs and on the larger scales through district heating schemes, such as those in Iceland, Turkey, China and France.

In contrast, solar thermal applications are generally used at the domestic level. Most high temperature solar applications for industrial processes have been on a relatively small scale and are mostly experimental in nature. Solar Heating Industrial Processes (SHIP), a new joint task of the IEA SolarPACES and Solar Heating and Cooling Implementing Agreements, is investigating the potential for solar heat in industry.

Domestic solar water heating has energy security benefits in that it reduces households' exposure to risk of supply disruption and any sudden increase in fossil fuel prices as heat is produced on-site. Small-scale domestic renewable heat applications run a lower risk of technical system failures (although in the case of solar thermal not completely eliminated) as they reduce requirements for transmission, distribution and service equipment and are not affected by power losses in transmission lines which can be up to 10% of total generation.

District heating systems based on RES combine both efficiency gains of the economies of scale with the environmental benefits of using renewable heat sources. District heating pipe networks allow end users to consume renewable heat without shouldering the installation cost of individual single building units. Given the more common distributed location of such installations, the risk of physical security threats is low.

Implementation of renewable heating should be considered in tandem with energy efficiency measures since combining both options creates synergies in terms of energy security. The buildings sector represents 40% of the EU's energy requirements. Therefore, environmentally friendly options for decentralised renewable heating options are encouraged alongside a push to improve the energy efficiency of buildings in the EC's Buildings Directive (EC, 2002). Another pertinent EC directive relating to the promotion of end-use efficiency and energy services was promulgated in early 2006 (EC, 2006a), which could also further the diffusion of renewable energy service companies (RESCOs) for both electricity and heat production.

#### 3.2.2.2 Resource potentials

In terms of resource adequacy, the resource potentials for both geothermal and solar thermal technologies are virtually unlimited. Unlike the other energy sources, GHPs can be installed practically everywhere is not restricted by location. In contrast, biomass resources for heat production are limited and compete with both electricity and transport fuel production for feedstock supplies. Biomass supply is considered to be variable to the extent that it depends on climatic conditions and the seasonal cycle of dedicated energy crops.

There are broad ranges for estimated resource potentials for all renewable heat sources. Geothermal enjoys the advantage of being a non-variable resource, as opposed to solar energy. As a consequence of the reduced availability of solar energy during peak heating load times, such as at night and during winter, solar heating systems require either an in-built storage system or a back-up heating system often fuelled by natural gas. This reduces the energy security benefits of solar thermal technologies, relative to geothermal.

Due in part to the relative ease of transporting and storing biomass resources, biomass is the only one of the three renewable heat sources whose diverse feedstock options have market prices.

**Table 5: Key factors in the availability of biomass waste and energy crops**

| **Biomass residues and wastes** | **Dedicated energy crop production** |
|---|---|
| Demand for alternative uses, e.g. as fertilisers or as input for recycled paper | Alternative uses of agricultural land, primarily food production |
| Climate conditions | Climate conditions |
| Legislation concerning waste | Agricultural policy (at the EU level especially the Common Agricultural Policy) |

(Faaij, 2006; Ericsson & Nilsson, 2006)

Disruption may interrupt the supply of biomass feedstocks to CHP and heat-only plants or to wholesalers and retailers of biomass, such as wood chips or pellets, who supply domestic households. Adequate and affordable storage of biomass feedstocks represent a possible physical security target. However, this risk can be assumed to be low as storage facilities are likely to generally be decentralised and reasonably small in size, corresponding to the scale of heat generation. A discussion of the impact of international trade in biomass resources on energy security follows in section 3.2.4.

Heating is currently already the cheapest energy conversion mode for biomass with average costs ranging between USD 0.01-0.05/ kWh (ICEPT, 2002). The dedicated production of energy crops is generally more expensive at least in IEA Europe, than the use of available residues and waste, as land and labour are relatively expensive in developed economies (Faaij, 2006). Upward price pressures due to the increasing influence of international market demand may threaten the future affordability of biomass resources. This would be especially so if dedicated energy crops, which compete with different uses for limited agricultural land, play a dominant role in biomass supply.

#### 3.2.2.3 Affordability

In terms of affordability, solar heat is expected to be cost-competitive with conventional heat technologies (oil, gas and electricity) across Europe by 2015 due to reduced system costs, and sooner if fossil fuel prices remain high. In 2000, the cost of solar thermal heat production was close to EUR130 (USD170)/ MWh for domestic solar hot water systems (Rantil, 2006). Recent IEA research indicates that this is cheaper than electricity in Denmark and the Netherlands, comparable to the cost of electricity in Austria, Germany and Italy, but more expensive than electricity in other OECD countries. It is also more expensive than heat from natural gas in urban areas (Philibert, 2006). By 2030, solar heating is projected to cost USD 65-105/ MWh for solar hot water systems and EUR50-80 (USD130-180)/ MWh for solar combisystems. Large-scale solar thermal applications (above 1 $MW_{th}$), such as district heating and industrial systems, are projected to cost EUR30-50 (USD40-65)/ MWh (Rantil, 2006).

Geothermal heat applications are generally already cost-competitive in terms of investment and heat production costs with most conventional fossil fuel heat technologies, both for low-to-medium temperature applications, including district heating, and for very low temperature applications.

A discussion of the affordability of renewable heat production needs also to consider the costs of externalities, such as supply disruptions, which market prices for energy sources do not yet reflect.

### 3.2.3 Regional dimension of renewable heating – energy security implications

In 2004, fossil fuels accounted for 78.8% of heat production among OECD countries (IEA, 2006b)[32]. Natural gas represented over 50%, with two thirds of natural gas for heat being supplied in OECD Europe where it is the most significant energy source for heat production and accounts for 39.5% of gross heat production (including direct use of geothermal and solar heat) (*ibid.*).

The significance of natural gas in the general energy matrix is growing across developed economies, and especially in Europe. The EU Green Paper on energy security predicts that by 2030 demand for natural gas will have more than doubled since 1990 and will be set to overtake oil as the leading energy source (EC, 2000). Its growing importance means that natural gas presents a significant potential energy security risk due to single source dependence, transit dependence, facility dependence and structural risks (IEA, 2006h). Europe's reliance on natural gas imports is forecast to rise rapidly (by 2030 the dimension of gas imports will represent between two to three times the current volume up to a maximum volume of 500 billion $m^3$).

The WEO 2006 scenarios forecast that the share of gas imports in the region's total gas supply will also increase substantially (IEA, 2006h). The majority of OECD member countries import natural gas supplies via pipelines from a limited number of supplier regions. For OECD Europe it is predominantly Russia, North Africa and the Middle East (Weisser, 2006), so thus becoming increasingly source dependent.

In contrast, the Netherlands, which is the second-largest producer of heat from natural gas after Germany, is currently a major exporter of domestic natural gas reserves. In 2002, 66% of final gas consumption (22.8 Mtoe) was used in the residential and service sectors.

[32] This figure takes into account gross heat production both from combustible fuels as well as direct use of geothermal & solar heat.

**Dominance of natural gas for heating in the Netherlands**

Natural gas has evolved to be the major fuel source in the Netherlands since the 1970s with the discovery and development of domestic natural gas reserves. Natural gas now dominates the heating market with a near-95% market share (IEA, 2004a), and, in 2004, represented 45% of the country's TPES compared to the IEA average of 22% (IEA, 2006d). This is the largest penetration of natural gas among IEA countries. Self-sufficiency is facilitated by large domestic gas reserves (the second largest in IEA Europe) and by the balancing capacity of the large Groningen field which is complemented by the development and exploitation of small fields under the Netherlands' "small fields policy". In 2004, the Dutch government implemented a specific production cap on the Groningen field - replacing the previous indirect cap on national gas production - which should help secure production from smaller fields (IEA, 2006a). In 2005, exports represented 66% of domestic gas production (IEA, 2006d). However, gas imports are rapidly increasing, transported via pipelines (IEA, 2004a) and four planned LNG terminals.

In the medium term, the limited gas import capacity of the Netherlands is likely to become a concern. At present, available contractual capacity at pipeline interconnections is very small. There is a need to expand capacity for imports by new entrants as domestic production declines.

Although residential gas consumption has declined following a national drive for improved domestic energy efficiency (including improved insulation and boiler efficiency), the decline has been hampered in recent years by an increased use of gas for hot water production (*ibid.*).

With the ongoing liberalisation of the Dutch gas market towards the creation of a Northwest European gas market, the explicit link of natural gas prices with oil prices will break down, enabling gas prices to full reflect gas scarcity. Together with concerns about the supply stability of imports, this trend will likely lead to substitution efforts, particularly towards biomass which enjoys an inherent resilience against supply disturbances (Jansen *et al.*, 2004). While large industrial users may be able to switch easily to alternative auto-production capacity, e.g. biomass-fired CHP, most residential and commercial customers will be less able to do so in the short term.

### 3.2.4 Local resources and global trade – implications for energy security

Although heat can not be easily traded or transported beyond short distances, biomass can be. Biomass is the only one of the three renewable heat sources with a fuel input, and consequently has a market price.

In 2003, trade in primary solid biomass contributed only 0.9% of the solid biomass share of TPES while for liquid biofuel trade contributed 3.4% of total consumption (IEA, 2006d). These figures only reflect trade in biomass produced in centralised plants whereas the majority of biomass resources such as biomass residues and their secondary products, e.g. wood pellets and energy crops, are produced in decentralised plants so cross-border trade originating in decentralised plants may not be captured in official government statistics.

The distributed nature of biomass harvesting and production of secondary fuels and the large number of potential trading partners reduces the structural risks that exist in the supply chain for many fossil fuel sources, such as natural gas, which rely on large and inflexible transport infrastructure, such as pipelines. Flexibility of supply, in terms of diversity of suppliers and origin and duration of contract, provides biomass for heat with a distinct security advantage over fossil fuel alternatives.

However, regional and international trade flows and the associated cost and distance of transport also bring negative implications for energy security including potential domestic disruption (short-term logistical or longer-term political) in the exporting country's supply system which may interrupt cross-border trade flows and thus threaten stability of supply. However, this risk can be mitigated by establishing a wide and varied group of suppliers producing a variety of substitutable biomass fuels. A further negative impact is increasing GHG emissions due to longer transport distances as a proportion of life-cycle emissions of biomass. Depending on the future scale of international trade in biofuels, the transport modes used, and on future policy measures to restrict GHG emissions of mobile sources, this may inhibit the growth of biomass resources for heat (and electricity) relative to the use of geothermal and solar energy resources which do not require transportation.

The development of internationally standardised certification for biomass, which is still in its infancy, although national criteria already exist, will support a growth in sustainable biomass imports.

### 3.2.5 Effects of renewable heating on fossil fuel demand

Renewable energy provides a direct hedge against volatile and escalating natural gas prices and it reduces the need to purchase fossil fuels as heat sources, replacing it with fixed-price renewable energy. Diversification of energy sources for heating, in particular increased investments in renewable energy, could help alleviate the threat of high gas prices over the short and long term. By displacing gas-fired generation, increased deployment of renewable energy is expected to reduce demand for fossil fuel energy sources, such as natural gas, for heating and consequently put downward pressure on natural gas prices (Wiser & Bolinger, 2006).

Oil as an industrial and residential heating fuel has been increasingly substituted by gas (and electricity) since the high oil prices of the mid 1970s and early 1980s. In 2004, oil represented 17% of OECD total final consumption in the residential sector and 19% in commercial and public services (IEA, 2006d).

### 3.2.6. Challenges and barriers

#### 3.2.6.1 Biomass: uncertainties regarding future supplies

Among IEA countries, European members are currently the major producers of renewable heat and are likely to remain so up to 2030. The largest biomass potential in the EU-25 (plus Ukraine and Russia) region resides in energy crops, forest residues and industry by-products with crop residues, such as from straw and maize, occupying a secondary role (Ericsson & Nilsson, 2006).

Difficulties exist in forecasting future areas of agricultural land available for energy-crop production over a time frame of several decades (*ibid.*) as other land uses compete with energy-crop cultivation, such as food, fibre and chemical production, environmental protection concerns etc. Factors influencing the future availability of land include food demand, farming practices and agro-climate trends. In general, regional variations are likely to arise or be exacerbated, even if total agricultural production may increase.

Similarly, the future availability of forestry residues and by-products is also difficult to predict as it is a complex function of the implementation of sustainable forest management guidelines combined with climate change effects and rising GHG atmosphere concentrations which are likely to lead to regional variations in forest productivity (*ibid*.).

The EC asserts in its Biomass Action Plan that at least in the short-term (to 2010) there will be no major competition for feedstock as electricity and heating rely mainly on wood and wastes while biofuels rely mainly on agricultural crops (EC, 2005). Furthermore, competition for feedstock may be restrained, as the optimum efficiency of the conversion technologies for electricity, heat and transport fuel production rely on different characteristics of biomass feedstocks.

However, in the medium term, competition for feedstock supply may occur between electricity and heat production; the IEA's 2006 Alternative Policy Scenario projects that by 2030 power generation from bioenergy will more than quadruple to 983 TWh (IEA, 2006h) and, at the same time, it is expected that the majority of bio-heat will continue to be generated in co-generation plants. Demand for bioenergy supplies for transport fuels may also precipitate competition, if biofuel production for transport grows as rapidly as forecast (section 3.3).

#### 3.2.6.2 Balancing electricity & heat production

CHP technologies offer significant advantages with regard to primary energy savings and avoided network losses by using both electricity and heat generated from a single source. These systems recover heat that normally would be wasted in an electricity generator, and utilise it to produce steam, hot water, heating, desiccant dehumidification or cooling. Through the use of CHP systems, the fuel that would otherwise be used to produce heat or steam in a separate unit is saved. However, as the following example highlights, operational decisions can be skewed away from the optimal production choice due to an unfavourable policy framework.

While electricity generation from renewable energy sources is supported in the United Kingdom under the Renewables Obligation (RO), heating from such sources is not. The UK Renewable Energy Association argues that the lack of incentives for renewable heating systems disadvantages biomass which can be used effectively for both electricity and heating production. Despite enjoying the advantage of being non-variable, the use of the UK's biomass resource has not expanded much under the RO because of cheaper, albeit variable, on-shore wind power generation. A study commissioned by the Department of Trade and Industry (DTI) calculated that generation costs in 2004 for stand-alone biomass plant stood at an average of EUR 0.096/ kWh compared to an average EUR 0.058/ kWh for on-shore wind. Biomass co-firing is a lower cost renewable energy technology with average generation costs of EUR 0.039/ kWh (Enviros, 2005). However, financial support for biomass co-firing under the RO is limited and will cease completely by 2016.

If the heat element of biomass output, such as reusing steam in a CHP plant, was valued as the power element is, then the economic feasibility of biomass would change significantly. Without a financial incentive for renewable heat a CHP plant operator's choice between producing electricity and heat will be oriented towards the electricity portion because of the associated revenue from the sale of Renewable Obligation Certificates (ROCs), as well as Climate Change Levy certificates (LECs) in addition to the electricity's wholesale market value. This may lead to non-optimal production choices with respect to efficiency, as steam production with higher process efficiency is neglected.

The demand for renewable heating technologies, such as biomass, geothermal, ground source heating and solar thermal, could be boosted by the introduction of a market-based support mechanism modelled on the Renewables Obligation, such as a Renewable Heat Obligation (RHO), where a quota obligation relative to their fossil fuel sales could be placed on fossil fuel suppliers of heat, which could be met through the surrendering of Heat Obligation Certificates (HOCs) from eligible renewable heat producers.

### 3.2.7. Summary

The technical potential for heat from renewable biomass, geothermal and solar resources is large. The costs of these heat sources vary. Some are already competitive with fossil fuels and others have the potential to become so. However, in many cases, renewable heat generation suffers from not receiving comparable support to renewable electricity or energy efficiency measures. There are also barriers due to lack of awareness of the potential and the lack of trained professionals to tailor installations. Effective political instruments are needed to promote the use of renewables in the heating and cooling sector when it can substitute for the most critical fossil energy resources of oil and gas. Renewable heat production provides the energy security benefits of distributed supply and production and of non-dependence on fossil fuel imports.

In order to utilise and benefit from the energy security advantages of renewable heat sources, renewable heat production must be brought to large-scale market deployment, which it is capable of in terms of resource potential and technological maturity. Therefore, to achieve this, governments should develop and implement a support framework of enabling policy measures, including market-based financial incentives, building on the lessons learned from support policies for renewable electricity production.

## *3.3 Biofuel production for transport*

Today's transport infrastructure is vulnerable due to its major dependence on a single fuel source – oil. Petroleum products provide around 96% of transport fuels and much of the supply is concentrated in a few countries with economic and political problems threatening their stability. Liquefied petroleum gas (LPG), compressed natural gas (CNG), biofuels and electricity provide the remainder.

Trade between oil exporters and highly dependent nations is vulnerable to supply disruptions for a variety of reasons. Many consumers of petroleum and natural gas resources depend to varying but significant degrees on fuels imported from distant, often politically-unstable regions of the world. A disruption in supply could have a severe impact on global oil markets. When in the foreseeable future international shipping trade in oil and LNG expand, the risks of supply disruption may increase (IEA, 2006h; CIEP, 2004).

The size of the global problem is easily expressed. In 2005 around 1215 billion litres (Gl) of gasoline and 1207 Gl of diesel were consumed as transport fuels, equating to 84 Mb of oil equivalent each day. IEA projections in the 2006 WEO Reference Scenario (IEA, 2006h) are for 6.3% per year production growth from 20 Mtoe in 2005 to 54 Mtoe in 2015 and 92 Mtoe by 2030. Growth in the Alternative Policy Scenario would be 8.3% per year, reaching 147 Mtoe in 2030 giving 7% of road transport fuel use (IEA, 2006h).

This understanding of the global position has already led many countries to support the development of their own biofuels industry with supporting policies, regulations and tariffs.

There is now a need for clear government initiatives aimed at fostering the development of an international biofuels industry to begin to meet the growing demands.

Biofuels are defined as liquid and gaseous fuels produced from various forms of biomass and used to displace conventional petroleum fuels used for transport (mainly on land but also for sea and air). Bioethanol, biodiesel, biogas, dimethyl esters and synthetic fuels are included, but fossil fuel derived liquid fuels produced from oil shales, tar sands, coal-to-liquids and gas-to-liquids are not.

The growing oil demand and resultant price increases have led to a sudden worldwide interest in biofuels not seen since the oil price shocks and severe supply disruptions of 1973 and 1979 caused transport fuel prices to rise rapidly. At that time considerable progress was made as a result of large RD&D investments to produce bioethanol and biodiesel. Since then the oil price declined as did interest and R&D funding in biofuels. In the past five years biofuels have gained renewed momentum, partly due to the goal of reducing carbon emissions from transport fuels and more recently due to the drive for energy security and the assumption of higher oil prices. In addition, agricultural policies, and new and improved processing technologies are propelling many governments to enact powerful incentives for the use of biofuels. This in turn is encouraging private investment in numerous biofuel production and processing plants and a growing interest in biomass refineries of the future to produce a number of chemical products, biomaterials as well as biofuels (OECD, 2004).

The implications of the use of biofuels for global security as well as for economic, environmental, and public health need to be further evaluated. Biofuels are relatively convenient to use as low blends in the existing fuels used for the transport vehicle fleet and can be easily integrated into the infrastructure designed for petroleum fuels. Government decisions made in the near future will help determine whether the use of biofuels will have a largely positive impact in the future or not.

As conventional oil prices rise and concerns about long term supplies gain greater traction, the interest in unconventional oils has also risen (see box). There are large quantities of these to be extracted. Canada already supplies 15% of its transport fuels (around 1.6 EJ /yr) from oil sands in Alberta. Heavy oils (orimulsion) mainly in Venezuela and oil shales mainly in the USA are starting to be utilised and even sub-marine methane clathrates are being considered at the R&D stage. In all cases, however, they are more difficult and costly to extract and refine than conventional petroleum products. They also require significant inputs of energy and/or water, and hence have higher GHG intensities in terms of g $CO_2$ emitted per person-km travelled (or per tonne-km for freight).

**Oil reserves and alternatives**

Oil accounted for 34.3% of total primary energy supply in 2004 (IEA, 2006b), consumed in 220 countries. More than 50 countries produce it and 35 are exporters, and it is consumed in 220. The assessment of the volume used to date, remaining reserves, and the amount economically available for extraction has been controversial. Oil data is poor due to non-disclosure of all relevant information by oil producing nations and oil companies. The uncertainties are poorly understood and there is lively debate about the issue of "peak oil" which commonly denotes the point of maximum production worldwide (IEA, 2005).

The IEA's study on "Resources to Reserves" emphasises that the moment of "peak oil" is difficult to forecast because of uncertainties over the respective amounts of resources and reserves (IEA, 2005d), as well as uncertainties about future consumption rates. Estimates of the time of peak conventional oil range from today to 2050 or beyond. The IEA stresses that pinpointing when conventional oil production will peak is less significant than assessing the cost involved (not forgetting to include the cost of $CO_2$ emissions) when making unconventional fossil fuels available or increasing the recovery rates of conventional fossil fuels, as well as the impact of energy efficiency gains. Such mitigation efforts will need a lead time of more than a decade. Therefore, attention to supply, demand and risk management is warranted.

Conventional oil refers to crude oil produced from well bores by primary, secondary or tertiary methods. The known reserves, based on geological and engineering information, can be recovered with reasonable certainty from reservoirs under existing economic and operating conditions. Additional "probable" and "possible" resources do not yet meet the criteria for proven reserves but may do so in future with improved knowledge and extraction techniques, but only if demand exists and market conditions allow. Resource estimates are therefore difficult to make. Unconventional oil shales, tar sands, heavy oils, coal to liquids, coal bed methane (and methane clathrates) require different and more complex extraction and upgrading methods (*ibid*.).

IEA analysis has indicated that 20 trillion barrels of oil equivalent (boe) (115,000 EJ) of the world's endowment of oil and gas remain in the form of both conventional and non-conventional sources (IEA, 2005a). Up to half could be technically recovered, but not necessarily economically depending on the rate of extraction and long term price assumptions. To date around 1.5 trillion boe (8,500 EJ) have been consumed. So the volume of geological resources is not the issue with regard to supply security. More relevant is the rate of development of new extraction and process technologies, future prices, supporting policies, investment levels, and mitigation of the increased carbon emissions.

### 3.3.1 Current role of biofuels worldwide

IEA member countries value biofuels as a means of reducing greenhouse gases, meeting clean air policies and achieving greater energy supply security by reducing foreign oil dependence. Developing countries, on the other hand, also consider biofuels to be a means of stimulating rural development, creating jobs, and saving foreign exchange.

The global production of all types of biofuels for 2005 was estimated to be over 40 billion litres (or 40 Gl). Combined exports were less than 4 Gl, while Brazil already exports over 10% of its production.

Biofuels can be produced at both the large scale (limited by local feedstock resource availability) and small scale (limited by maintaining fuel quality standards and higher costs). In 2005 the world produced 38 Gl of bioethanol (3% of the gasoline volume of 1215 Gl or 2% on an energy basis) and 3.84 Gl of biodiesel (0.3% of the diesel market of 1207 Gl).

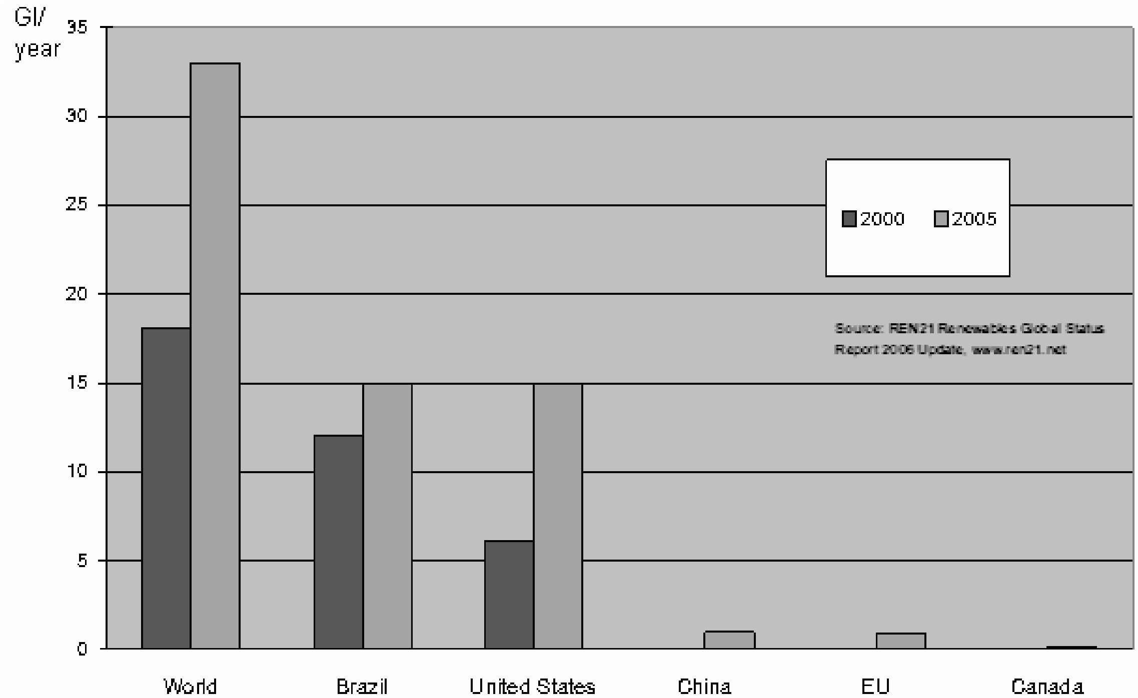
If 2005 total transport fuel demand remained static, and the world were to move towards an E10 target blend (10% ethanol/90% gasoline by volume) for gasoline alone, some 120 Gl of bioethanol would be required annually. For an E3 blend, this would be closer to 40 Gl annually. For biodiesel B10 and B3 blends the volumes of biodiesel required would be approximately 130 Gl and 40 Gl[33].

Brazil, the largest global producer of ethanol (Figure 8), processed around 15 Gl from sugar cane feedstock in 2005 which met 44% of its total national automobile fuel demand. A further 2.5 Gl were exported, being half of the world ethanol trade (although this is mainly for beverages and industrial uses). Production figures for 2006 are expected to be approximately 16 Gl but this depends in part on the competing sugar price as bioethanol competes for the same feedstock. The Brazilian government has mandated for 23% anhydrous ethanol content in gasoline and 40% of all vehicles to utilise high ethanol blends or hydrous E100 by manufacturing more vehicles with flexi-fuel engines (see section 3.3.2).

In the USA, bioethanol production from subsidised corn (maize) crops increased from 4 Gl in 1996 to over 7 Gl in 2002, then doubled again to 15 Gl in 2005 giving overall recent growth at 15-20% per year (Figure 9). It now accounts for 3% of the total US gasoline market due to its high octane value and suitability as a substitute oxygenate replacing methyl tertiary butyl ether (MTBE), which negatively affects the taste and odour of drinking water and may pose health risks, entering US water supplies from road vehicle exhausts. Ethanol is blended into 30% of all retail gasoline.

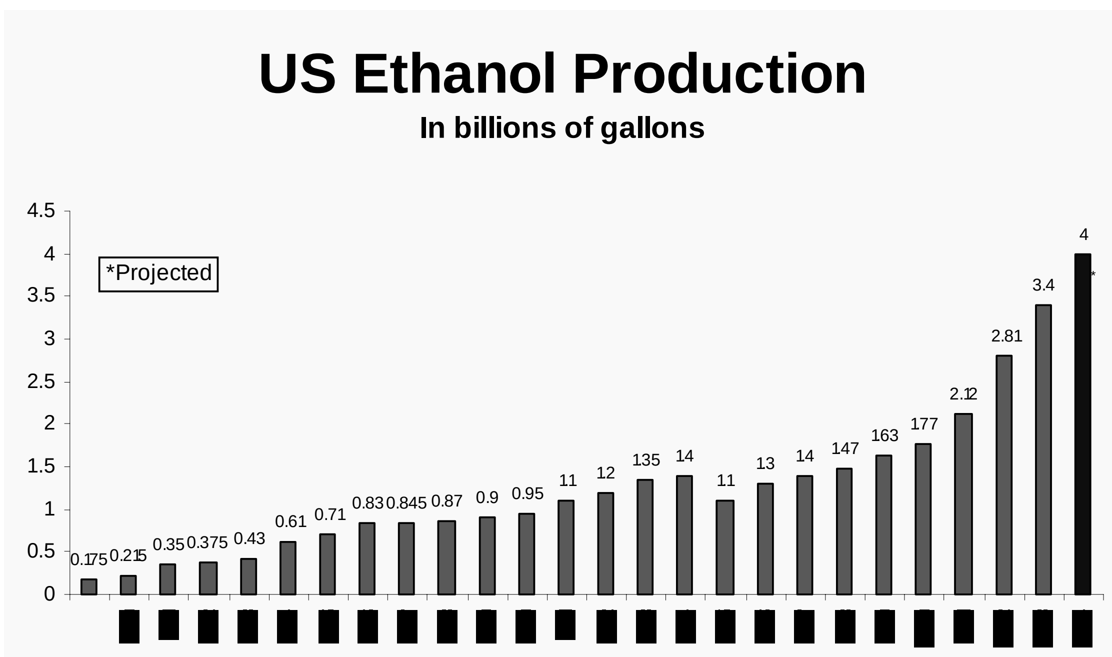
[33] Biodiesel (33.0 MJ/l) has a higher net energy value than ethanol (21.2 MJ/l) on a volume basis, but both are lower than diesel (36.1 MJ/l) and gasoline (33.5 MJ/l).

**Figure 8: Fuel ethanol production, 2000 and 2005 (billion litres/ year)**




Source: REN21, 2006

**Figure 9: Growth of US bioethanol industry from 1980 to 2004**




Source: ACE, 2006a

The US Clean Air Act (1990) has driven industrial growth and, amongst other initiatives, banned the use of MTBE and other toxic and carcinogenic additives into transport fuels. In August 2005, President Bush signed a comprehensive energy bill [34] which included a requirement to nearly double the production of bioethanol from 15 to 28 Gl by 2012. Between 2005 and 2012 this will displace 338 Gl of crude oil and reduce the outflow of US currency largely to foreign oil producers by around USD64 billion (2005 dollars).

In many US states, ethanol use in transport fuel is mandated at 10% (E10). During the past two years in California, major fuel companies have switched to ethanol prior to the 2004 deadline for the phase out of the MTBE additives (ACE, 2006b).

The third highest bioethanol producer is China which produced 5 Gl in 2005 mainly from corn, sugarcane and inedible agricultural products. Growth is reported at 8-10% a year. The Japanese government supported E3 in 2003 and is currently considering 5% biodiesel (B5) and trialling E10 but has no local production. The Ministry of Environment has indicated the possibility of a mandate for 10% in petrol and 15% in diesel for transport use in the longer term. Demand at these levels will result in ethanol usage of approximately 5-7 Gl per year. The Canadian government has stated a plan for 35% of petrol to contain 10% ethanol by 2010. This level would reflect a usage of approximately 1 Gl/year. India has approved an E5 blend with an increase to 10% ethanol anticipated by 2010. Indonesia's current palm oil production is reported at 4 Gl/ year from 17 production facilities with plans to add biodiesel processing plants. Plans are in place to increase the level of production by 5 times to 20 Gl/ year over the next five years. Australia has no mandated consumption at present but major government investments in R&D includes AUD500 million in the Low Emissions Technology Development Fund, which includes biofuel pilot and demonstration plants, and AUD100m in the Renewable Fuels Development Fund. Production subsidies of AUD0.30 per litre are in place for bioethanol and development of a biodiesel plant based on animal fats has just been announced. Import tariffs on ethanol are AUD0.38 per litre which is a deterrent to Brazilian imports (AEL, 2006). Germany was the largest producer of biodiesel in 2005, with 1.92 Gl from oilseed rape being almost half of the world's supply. France, Italy and the USA are other leading producers.

In the short term sugar cane is the most economic source and also most efficient in achieving carbon reductions. Brazil has shown that bioethanol from sugar cane is already competitive with imported transport fuels and also suitable to become a widely tradable commodity.

[34] Energy Policy Act of 2005

**Policies and measures**

National target levels for biofuels total around 2.8% of the 2006 total worldwide transport fuel demand. For example the US aims for 10% growth/year of bioethanol (to 28 Gl) by 2012 and the EU aimed for a 2% market share of motor fuel by 2005 (but only 1.4% was reached by February 2006) and now aims for 5.75% (12 Gl) by 2010 with 10% by 2020 the long term goal. This will require a 35%/ year increase in process plant capacity. Mandatory biofuels targets placed on oil companies exist in 11 countries and other common support policies include excise tax incentives.

Biofuels have recently received considerable publicity due to increased world oil prices, energy security concerns and the drive for GHG emission reductions. However, based on current technologies, costs and policies, only a small proportion of future transport fuel demand during the next 2-3 decades will be met by biofuels. A 5% displacement of gasoline and diesel by biofuels as suggested by various policy debates would reduce global oil consumption of transport by around 1.8 Mbbl/ day (2%) but this would require the current biofuels market to increase 2.4 times. Hence, policies need to focus on market deployment. This could be considered as a possible task by the new IEA Implementing Agreement on Renewable Energy Technology Deployment.

Biofuels can only be fully developed by expanding the range of feedstocks and commercialising any breakthroughs in advanced conversion technologies including bioethanol from ligno-cellulosic feedstocks, Fischer Tropsch synthesis, biotechnical solutions to produce novel biofuels, and development of multi-product bio-refineries. Policies need to speed the transition to second generation technologies which have a high potential but currently cost over USD 0.8/ l, when produced in small scale pilot plants.

The land and water resource bases necessary for biomass production need protecting. Biofuels produced from crops grown in temperate climates remain more expensive, are less effective at reducing emissions, and hence continue to require financial support policies. Land use subsidies need reviewing, possibly transferring support from food and fibre to energy products.

Quota policies that incentivise biofuel production in OECD countries can under some circumstances have limited value, can be costly in terms of carbon emissions avoided, and do not necessarily lead to the development of new and improved technologies. Bioethanol from sugarcane and biodiesel from waste fats and oils remain cost competitive in a high oil price environment in spite of feedstock price increases. Production of these biofuels should be encouraged in countries able to provide economic feedstocks, not only for their own transport fuel supplies but, if in excess, also for export.

### 3.3.2 Fuel standards and engines

Fuel specification standards have been produced in Europe, USA and elsewhere to ensure only biofuels with pre-determined properties are used and hence warranties by vehicle engine manufacturers can be maintained. E85 blends (85% bioethanol, 15% gasoline) can be used to fuel specialist "flex-fuel" engines millions of which already exist, whereas E10 "gasohol" is suitable for most spark ignition engines, though older vehicles may experience minor problems if seals and plastic fuel pipes are not compatible.

Most compression ignition engines will run satisfactorily on 100% biodiesel (B100) or any lower blends with minimal modifications. Exhaust emissions are mostly reduced by using biofuels resulting in improved local air quality particularly in cities. Biodiesel reduces both $SO_x$ and particulates although $NO_x$ can increase by 5-30%. Engine life using biodiesel is increased due to lubricity and low sulphur content. Using gaseous fuels in vehicles is well understood for CNG and LPG fuels but biogas and producer gas are more challenging, especially for dual-engine vehicles.

**Carbon emissions and energy ratios**

Energy ratios (fossil fuel input to biofuels output) are around 1:3 for biodiesel but vary from 1:8 for sugar cane bioethanol down to 1:1.2 (or lower) for corn bioethanol in the USA. Here diesel is used for crop production, drying and transporting the grain, and electricity, natural gas or coal are used to fuel the processing and distillation plant. "Well-to-wheel" analyses have shown that biofuels can range from being close to carbon neutral to producing only a 13% reduction in emissions of GHG per km travelled compared with when using petroleum fuels. It depends on the level of fossil fuel inputs to produce the energy crop (including fertilisers) and used by the processing operations. For sugar cane ethanol most of the energy inputs for heat and power come from bagasse-fired cogeneration plants. Diesel fuel is only used for harvesting and transporting the crop to the processing plant, so high carbon mitigation potential results.

### 3.3.3 Economic feasibility

The commercial viability of biofuels depends on future oil and feedstock prices, land use change, and possible technological breakthroughs. The existing fuel distribution infrastructure can be utilised with minimal modifications. Although the future market potential is uncertain, hundreds of biofuels processing plants are currently planned or under construction, partly due to the higher oil prices making blending biofuels more attractive. WEO 2006 projections of 2030 market potential range from 4% (Reference Scenario) to 7%

(Alternative Policy Scenario) of total transport fuels but these all have a high degree of uncertainty.

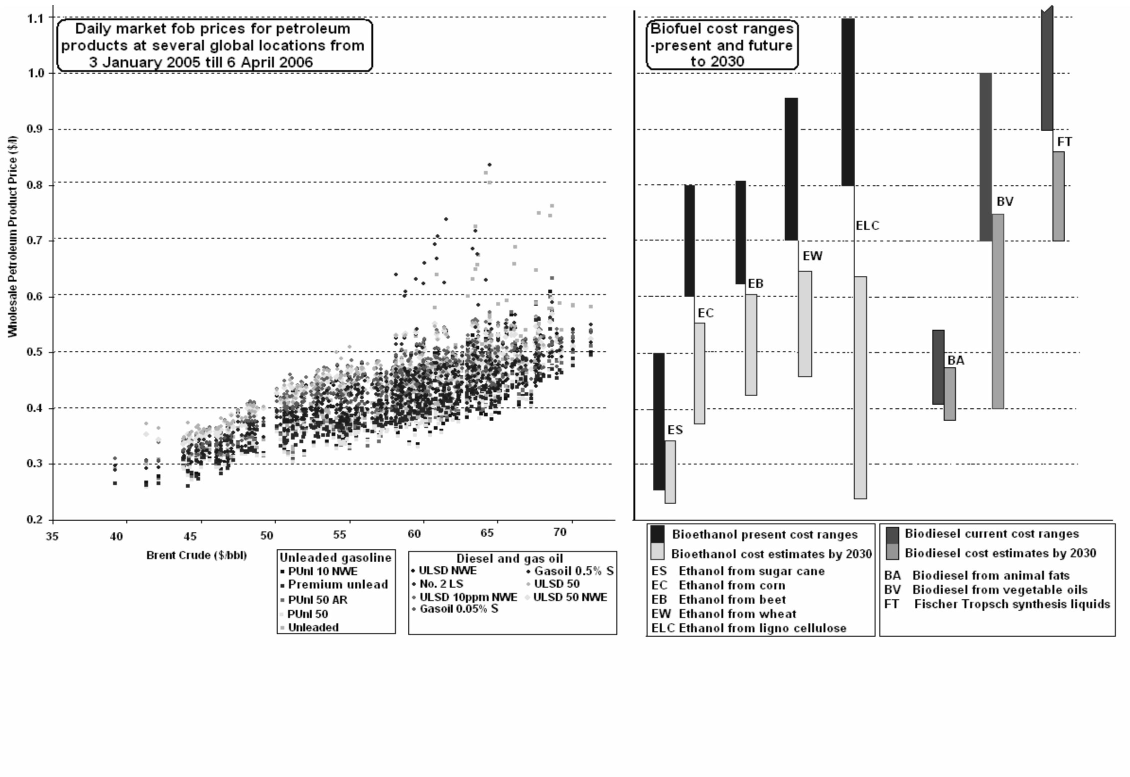
Cost analysis of biofuels need to be in terms of “litre of gasoline equivalent” (lge) since bioethanol has a lower heat value of around 63% that of gasoline, and that of biodiesel is around 91% of diesel. However, the superior properties of biofuels, when they are combusted in an engine, partly offset these lower heat values. Commercial bioethanol production costs currently range from USD0.25/lge (sugarcane, Brazil) to USD0.80/lge (sugar beet, UK) with corn ethanol around USD0.60/lge (USA) and ligno-cellulosic ethanol from pilot scale plants claimed to be between USD0.80 - 1.00/lge. Biodiesel costs range from USD0.42/l (animal fats, New Zealand) to USD0.90/l (oilseed rape, Europe; soybean, USA) with palm oil, Malaysia in between. Development of improved processes and learning experience and plant scale-ups could lower production costs of bioethanol by 2015 to USD0.25-0.65/lge and biodiesel to USD0.40-0.75/lge. It should be noted that in the USA and Europe energy crop gross margins are linked to agricultural subsidies. Excise tax exemptions also distort the biofuels retail price.

A comparison was made between current and future biofuels prices versus gasoline and diesel ex-refinery (fob) prices over a range of crude oil prices over a 16 month period until 31 March 2006 (Figure 10). Ethanol from sugar cane (ES) can compete with oil price around USD40/bbl and biodiesel from animal fats and waste cooking oils (BA) around USD60/bbl (although volumes available are limited). Other biofuels, based on other more expensive feedstocks, will only compete when oil is above USD70/bbl unless the production costs can be significantly reduced by plant scale-up, RD&D investment and learning experience. Alternatively, government interventions through agricultural subsidies, excise tax exemptions, carbon charges and other support measures will be necessary.

However, crop requirements for water and nutrients could be constraints. Deforestation to produce more cropping land to grow energy crops would be a major environmental setback. The extensive worldwide production of biofuel crops may also result in substantial increases in the use of artificial fertilisers and pesticides with consequent high risks of contamination of water supplies.

“Second generation” biofuel technologies will come mainly from cheaper sources of non-edible biomass such as crop and forest residues. Conversion of these ligno-cellulosic materials by hydrolysis to hydrocarbon biofuels has been researched for decades but so far with limited commercial success. Several novel systems endeavouring to produce a range of synthetic fuels and di-methyl esters are under development. Biomass refineries to produce a range of chemical products as well as biofuels are also under investigation.

**Figure 10: A comparison between current and future biofuel production costs (US¢/ l gasoline equivalent) versus gasoline and diesel ex-refinery (fob) prices over a range of crude oil prices over 16 months**




Source: based on IEA, 2006h

Research, development and deployment initiatives will play a crucial role in commercialising these technologies.

Globally, there are a number of drivers underpinning a rapid increase in demand for bioethanol and biodiesel as a transport fuel. These include:

- The lucrative carbon credits market, created to allow nations to fulfil their Kyoto Protocol commitments;
- Mandated requirements on oil companies to retail a share of product as biofuels in the European Union, Japan and elsewhere;
- The growing use of ethanol to replace the environmentally harmful additive MTBE in US gasoline;
- Consumer demand for environmentally acceptable replacements for higher priced, GHG producing fossil fuels; and
- The desire to increase national economic security through a reduced dependence on oil.

In many regions, generous tax breaks are afforded to the bioethanol and biodiesel industry to encourage its growth. Furthermore, the wealth of experience gained in using blends of ethanol and gasoline has given confidence to legislators and ethanol producers to encourage the growth of this industry. Collectively, these drivers are leading to the establishment of an international commodity market in biofuels. This market will likely exceed 100 billion litres per annum by 2010 and 250 billion litres by 2020.

By mid 2006, 34 states and eight nations had implemented mandatory biofuels targets to transport fuel retailers. Such quotas, as described below for the European Union, need to be carefully designed as they could be met by high cost biofuel technologies and with limited carbon dividends. Transport fuel supply security will result if dependence on imported oil can be reduced. However, society will need to determine at what cost it is willing to achieve this supply security.

Trade in biofuels is seen as a key component of this strategy. Currently there is no specific customs classification for biofuels and bioethanol is grouped in with industrial ethanol for EU import duty levies.

The ambitious EU vision for biofuels out to 2030 is that up to 25% of Europe’s transport fuel demand could be met by biofuels using a wide range of biomass feedstocks (Biofuels Research Advisory Council, 2006). In addition European technology may well be used by countries exporting biofuels to Europe. By that time gaseous and liquid fuel demanding spark and compression ignition engines will probably remain the main powertrains in vehicles but engine designs will have evolved to better match the second generation synthetic biofuels. In addition low fuel consuming engines will become common (for example plug-in, hybrid biodiesel vehicles) so that less biofuels will be consumed per km.

This vision will be met only if biomass feedstock supplies can be produced in a sustainable manner and biofuels can be manufactured using innovative processes which are commercially viable. Certainly using the whole harvested plant through an integrated bio-refinery (OECD, 2003) is critical but nutrient cycling and water conservation will be other key elements needed for success.

The 2030 EU target will require a phased development initially aiming at improving existing biofuel production and processing technologies together with reduced fuel consumption in the short term whilst also seeking commercial development and deployment of second generation biofuels in the longer term.

**Case study of the European Union: the Biofuels Directive**

In May 2003, the Council of the European Union promulgated that Member States should ensure that a minimum proportion of biofuels should be placed on their markets (EC, 2003a). To that effect national indicative targets needed to be set. A reference value for these biofuels targets was 2%, calculated on the basis of energy content, of all petrol and diesel for transport purposes placed on their markets by 31 December 2005 and 5.75% by 31 December 2010.

Currently transport accounts for 21% of GHG emissions in the EU and is continuing to rise. Oil is virtually the sole energy source which gives concerns as it is known to be limited in reserves which are restricted to a few world regions. Securing transport fuel supplies for the future requires a wide range of policy initiatives including diversification of sources and technologies and to also reduce import dependency.

Options include encouraging the manufacture and use of more efficient vehicles, upgrading the public transport systems, supporting cycling and walking, avoiding unnecessary trips and gasoline and diesel substitution with biofuels. “The EU is supporting biofuels with the objectives of reducing greenhouse gas emissions, boosting the decarbonisation of transport fuels, diversifying fuel supply sources and developing long-term replacements for fossil fuels” (EC, 2006b). By February 2006 less than 2% of the European liquid transport fuels market was supplied from biofuels and the policy targets are unlikely to be met.

Meeting the Biofuels Directive target of 5.75% (EC, 2003a) would require using between 4 and 13% of the total agricultural land to grow energy crops in the EU (which roughly equates to the set aside area). However, integrating food, fibre and energy production would reduce this area. It would also help meet the GHG reduction targets and develop a new industry.

The Biofuels Directive of 8 May 2003 on the promotion of the use of biofuels and other renewable fuels for transport is to be reviewed by the end of 2006. Emphasis will be placed on its cost effectiveness, level of ambition after 2010, and the assessment and monitoring of the full environmental impacts of biofuels versus security of supply.

A “Biomass Action Plan” was adopted in December 2005 to encourage the uptake of biofuels (EC, 2005). The strategy aims to:

- Further promote biofuels in the EU and developing countries, ensure their production and use is positive for the environment and that economic competitiveness is taken into account;
- Prepare for the large scale uptake of biofuels by reducing their costs through the optimised cultivation of dedicated feedstocks, researching “second generation” biofuels, and supporting market penetration by scaling up demonstration projects and removing non-technical barriers; and
- Explore the opportunities for developing countries to produce feedstock and biofuels and to set out the manner in which the EU could support such an initiative for the development of sustainable biofuel production.

However, the assessment of the Biofuels Directive in the Biofuels Progress Report (EC, 2007a) showed that the 2010 target is unlikely to be achieved with present policies given the disparities between the targets that Member States announced for 2005 and the low shares that many achieved.

To provide clearer and stronger signals for market development, the European Commission in its Roadmap for Renewable Energy of 10 January 2007 proposes legally binding targets for EU member states of at least 10%, calculated on the basis of energy content, by 2020 (EC, 2007b). At the European Council summit on 8-9 March 2007, the member state governments formally endorsed the adoption of a 10% binding minimum target for biofuels and a binding target of a 20% share of renewable energies in overall EU energy consumption by 2020 (European Council, 2007).

### 3.3.5 Summary

Biofuels could become a potential part solution to some of the most challenging issues facing the world, including increasing national and global insecurity, rising oil prices, worsening local and global pollution levels, rising climate instability, and rural and agricultural development in a sustainable manner.

Bioethanol from sugarcane is the leading contender based on Brazil's experience and production should be encouraged elsewhere with technology transfer already going to developing countries such as Fiji, Mozambique, Paraguay, Bolivia, South Africa and other African countries.

The potential for biofuels to meet a significant share of transport fuel demand by 2030 is dependent on the future success of RD&D investment, which will help reduce the production costs, the availability of suitable land, and learning how to optimise the production of integrated multi-products, including bioenergy, from relatively scarce land, water and nutrients,

Energy efficiency improvements and design changes to vehicle engines will be needed at the same time as biofuel research is conducted to ensure engines are compatible with the new fuels. Partnerships between oil companies, engine manufacturers and governments will ensure this occurs. Already, several oil companies have close partnerships with other smaller private sector companies seeking to produce commercially viable second generation biofuels.

# 4 Conclusions

Security of energy supply should be a key objective of governments if they are to meet other objectives relating to economic growth. Following a period of stable and reliable energy supplies since the Second World War (with the exception of the 1970 oil shocks), IEA member countries, and more recently non-member countries, have invested in roads, buildings and infrastructure with the expectation that cheap and readily available energy supplies would continue. Now that a number of threats to the future continuation of conventional energy supplies have been identified, there is growing concern that other energy sources need to be found.

Renewable energy systems are well placed to reduce the risk of energy supply disruptions and the current reliance by many countries on imported fuels. Renewable energy sources are widely distributed and, in many locations, can provide alternative choices for generating electricity, producing heat and manufacturing transport fuels. In addition, significant greenhouse gas reductions and various other co-benefits can be obtained.

The use of renewable energy in itself is not risk free. Supplies vary due to the natural variable availability of many forms and the costs can be relatively high compared with traditional energy supplies. In recent years however the costs for renewables have trended downwards whilst the costs for fossil fuels (including a carbon charge) have increased. Thus renewables have become more competitive and world growth in capacity for wind and solar has been around 20% per year for 10 years or longer.

In order for governments to obtain greater security of energy supply, and to help meet their climate change policy targets, greater uptake of more energy efficient technologies, demand reduction, and adding more renewable energy systems to the national portfolio make good sense.

Good co-ordination and collaboration among IEA member nations and between the public and private sectors is essential if renewable energy technologies are to be successfully developed to help meet the goals of sustainable development and climate change mitigation as well as to reduce the risk of continuing disruptive energy supplies.

There is significant scope for further work on the effects of renewables on energy security. Of particular interest is a detailed quantitative analysis of the impact of RETs on energy security.

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The International Energy Agency (IEA) is an autonomous body which was established in November 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an inter-national energy programme.

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- To promote rational energy policies in a global context through co-operative relations with non-member countries, industry and inter-national organisations.
- To operate a permanent information system on the international oil market.
- To improve the world's energy supply and demand structure by developing alternative energy sources and increasing the efficiency of energy use.
- To assist in the integration of environmental and energy policies.

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