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FINNISH ENERGY INDUSTRIES – ENERGY SCENARIOS AND VISIONS FOR THE FUTURE

Background Report

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CONTENTS

1. INTRODUCTION

This report is a background report of the futures process by the Finnish Energy Industries (Energiateollisuus ry). The aim of the futures process is to formulate energy scenarios for Finland up to the year 2050. The scenarios, including possible images of the future and pathways to these futures, are a result of a series of futures workshops and questionnaires implemented by Turku School of economics, Finland Futures Research Centre. The first futures workshop was arranged in Helsinki 4 of November 2008, followed by a questionnaire sent to all workshop participants and additional energy experts in December 2008, followed by a questionnaire sent to all workshop participants and additional energy experts in December 2008. The futures process continues in 2009 and will be reported separately later on, but it is the general context of this background report, which gathers together information of future prospects in the energy sector and provides seeds for inputs of the participants at different stages at the futures process.

The content of this background report includes an overview of existing international energy-related scenarios and international development in general, a review of different energy resources, potentials and energy technologies. The purpose of this report is firstly to offer input for the participants of the above described futures process, and secondly to provide up-to-date information of available international energy scenarios and available energy solutions to a wider public.

The structure of this background report is as follows: After the Introduction, a set of existing international energy scenarios are described in Chapter 2 titled “Global Megatrends”. This chapter deals also with overviews to development in some major economies in the World; China, India, the United States, European Union and Russia. International climate change negotiations are also presented from the perspective of possible burden sharing approaches because as we all know, the future of the UNFCCC Climate negotiations is open after the first commitment period of the Kyoto Protocol ends in 2012.

Chapter 3 outlines requirements of the Finnish society for the future energy production and consumption. The main focus in this chapter is on domestic energy and climate strategies and related policies, but it is necessary to keep in mind that the Finnish society consists of different types of actors who may have their own energy-related visions and strategies which are not represented at national level which is more or less a political compromise. Moreover, national strategies and policies do not reach as far as 2050.

Chapter 4 presents energy resources, potentials and technologies starting from fossil fuels and ending with energy storage and carbon capture and storage technologies. In between, nuclear energy technologies, several different renewable energy and energy storage technologies are described as possible options for future.

Chapter 5 deals with energy markets – traditionally energy producers have utilised world markets of oil and refined oil products, coal, and other fuels, but the actual energy carriers have been generated, transmitted and distributed by regional monopolies. Electricity and gas markets have been liberalised and opened for competition, and they still face many problems in spite of the experience obtained from two decades. New energy markets may also emerge at different levels from national to global energy systems.

The last chapter focuses on energy transmission and distribution, which is in a central role in the direction where future energy markets will develop. All the themes of the chapters in this background report are related to each other, which sets a real challenge to formulate possible energy futures and pathways to them but also makes the topic an extremely interesting in Finland, a small open economy with limited domestic energy resources.

2. GLOBAL MEGETRENDS

2.1. Review of selected Global Energy Scenarios

In the following, major elements of energy scenarios published by World Energy Council, WEC (2.1.1), International Energy Agency, IEA (2.1.2), Greenpeace (2.1.3), American Council of the United Nations University (2.1.4), United Nations, UN (2.1.5), Shell (2.1.6), Total (2.1.7), and European Renewable Energy Council EREC (2.1.8) will be presented.

2.1.1. World Energy Council: Deciding the Future: Energy Policy Scenarios to 2050

Since 1993 World Energy Council has built energy scenarios to provide insight on the rapidly changing environment in which the energy sector operates. In Energy Policy Scenarios to 2050, the council decided to take a new approach to scenarios, moving away from strictly statistical modelling to an approach that would take account bottom-up regional views of energy future focusing on policies to ensure energy sustainability. Series of 20 workshops were conducted from July 2005 to April 2007 in various regions of the world. Over 400 principals from industry, government, academia, NGOs and trade groups gave their views of how to meet the need for energy that is accessible, available, and acceptable by 2020, 2035 and 2050. These qualitative views of how policies can address future challenges to the delivery of clean energy services in all regions of the World were checked for consistency against a mathematical model of the energy sector. In addition, seven specialist groups provided current data on everything from climate change to power generation, energy price drivers and electricity consumption patterns, transport and finance. (WEC 2007)

According to WEC's Energy Policy Scenarios to 2050 energy supplies must double by 2050 to meet the energy demand of all households worldwide. The main driver to address this challenge is higher energy prices. Higher prices will also propel the developed world towards greater energy efficiency and attract much higher levels of public and private capital investment in infrastructure, research, development and deployment of clean and more efficient technologies. Different levels of government engagement in these and other areas can have different outcomes in the future. Using the metaphors of four well-known animals, the work of the WEC Scenarios group delineates four possible approaches by decision makers to the challenges of delivering future energy in a sustainable and secure way. These four approaches are represented by the lion, the giraffe, the elephant and the leopard. (WEC 2007)

The lion is a highly skilled and social animal that launches its forays after careful planning and in a highly cooperative effort. It represents strong government engagement, together with close cooperation and deep integration of the public and private sectors, domestically and internationally. The giraffe is a highly adaptable and independent creature that thrives in an unstructured environment and sees opportunity at great distances. It describes market-driven actions made with minimal government involvement but a high degree of cooperation and integration of the public and private domains, domestically and cross borders. (WEC 2007)

The elephant is a social animal with good memory that relies mostly on its own well-structured family unit with little cooperation between families. It characterizes government deeply engaged in policymaking, but with little cooperation between nations or integration of the public and private spheres. The leopard is a solitary creature swift to act in isolation. It represents energy responses with little government involvement and little cooperation and integration of the public and private sectors. (WEC 2007)

Below are the graphics of some of the main variants of the scenarios. The first graphic presents the global energy intensity for the four scenarios. The second graphic presents the percent change in primary energy production. The third graphic presents the rise of the greenhouse gas emissions for the four scenarios. (WEC 2007)

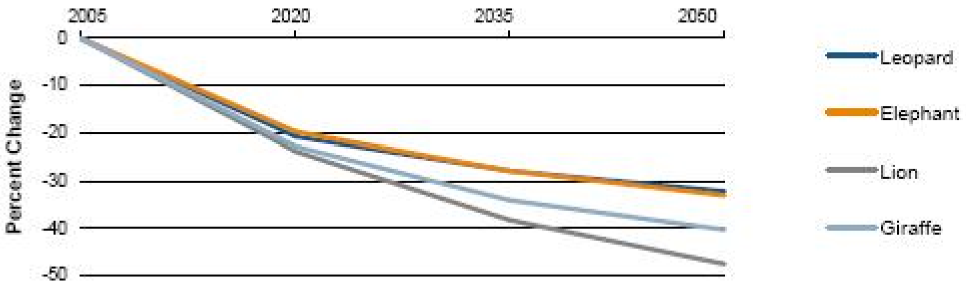


Figure 1. *Percent Change in Global Energy Intensity (E/GDP) for the Four Scenarios from the Mathematical Model Projections (WEC 2007).*

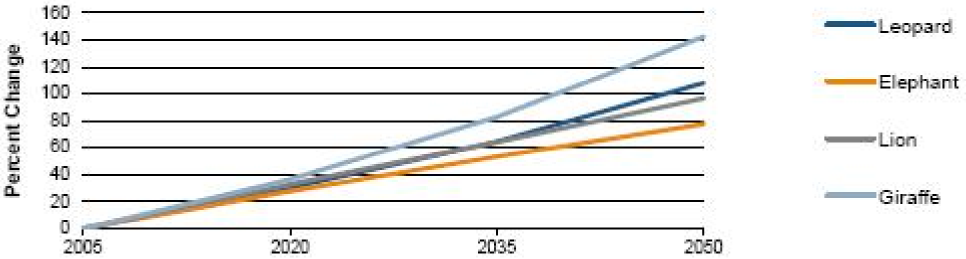


Figure 2. *Percent Change in Primary Energy Production for the Four Scenarios from the Mathematical Model Projections (WEC 2007).*

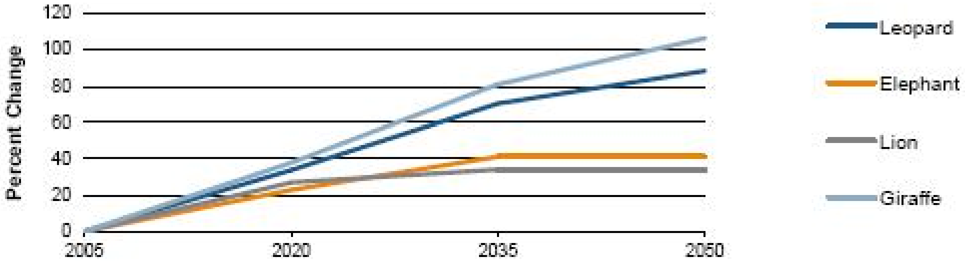


Figure 3. Percent Change in Greenhouse Gas Emissions (as Carbon Dioxide equivalent) for the Four Scenarios from the Mathematical Model Projections (WEC 2007).

2.1.2. IEA: World Energy Outlook 2008

World Energy Outlook (WEO) is an annual publication by International Energy Agency (OECD/IEA) containing medium- to long-term energy projections and analysis. It has been long recognized as the leading source of forward-looking global energy market analysis and has received a number of awards from prestigious organisations around the world.

Key assumptions of the IEA energy scenarios include population growth and growth rate of World GDP, primary drivers of energy demand. According to the report, global population is assumed to grow 1 % per year on average, from an estimated 6.4 billion in 2004 to 8.1 billion 2030. The rate of growth in World GDP is assumed to be 3.4 % per year over the period. (IEA 2006b)

In a Reference Scenario, which provides a baseline vision of how energy markets are likely to evolve without new government measures to alter underlying energy trends, global primary energy demand increases by 53 % between now and 2030. Over 70 % of this increase comes from developing countries, led by China and India. Oil remains its position as a number one primary energy source as the World's oil demand reaches 116 million b/d in 2030 (84 million b/d in 2005). Consequently global carbon-dioxide (CO_2) emissions reach 40 Gt in 2030, a 55 % increase over today's level and China overtakes the United States as the world's biggest emitter of CO_2. These trends would amplify the magnitude of global climate change. (IEA 2006b)

An Alternative Policy Scenario demonstrates that the energy future can be substantially improved if governments around the world implement the policies and measures they are currently considering. In this scenario, global energy demand is reduced by 10 % in 2030 – equivalent to China's entire energy consumption today. Global carbon-dioxide emissions are reduced by 16 % – equivalent to current emissions in the United States and Canada combined – in the same time-frame. In the OECD countries, oil imports and CO_2 emissions peak by 2015 and then begin to fall. Improved efficiency of energy use contributes most to the energy savings. Increased use of nuclear power and renewables also help reduce fossil-fuel demand and emissions. Just a dozen specific policies in key countries account for 40 % of the reduction in global CO_2 emissions. These shifts in energy trends would serve all three of the principal goals of energy policy: greater security, more environmental protection and improved economic efficiency. (IEA 2006b)

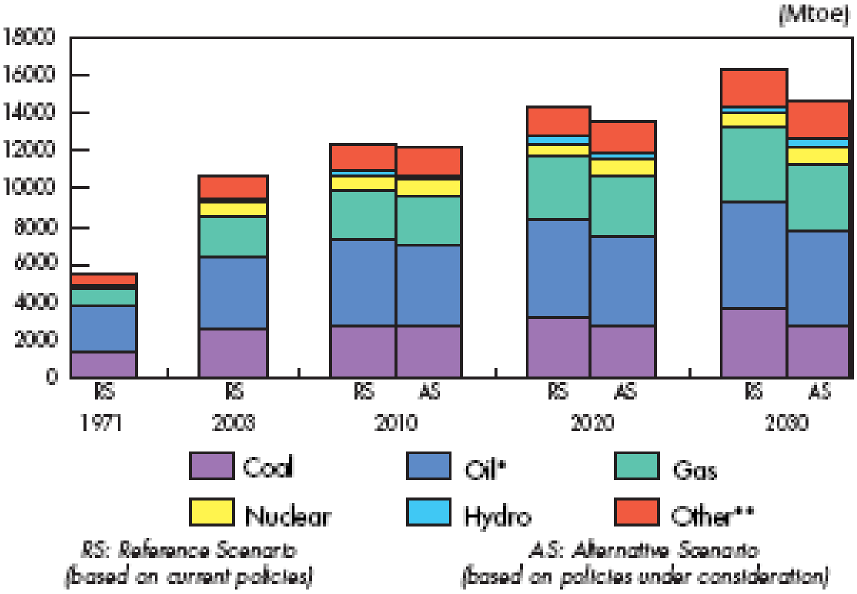
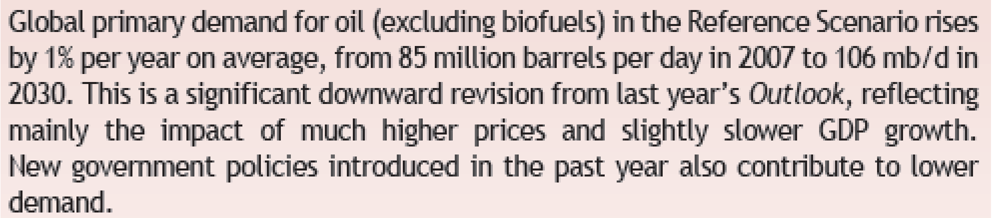


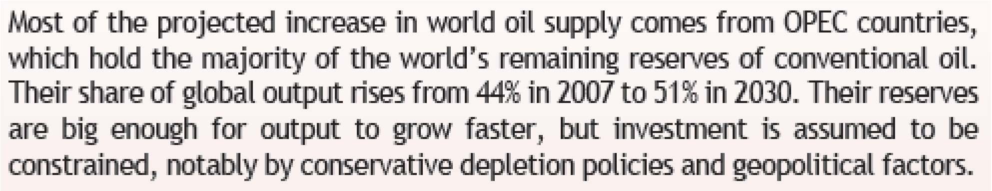
Figure 4. Total Primary Energy Supply by Fuel (IEA 2006a).

The new World Energy Outlook 2008 is based on following assumptions in its reference scenario:



Global primary demand for oil (excluding biofuels) in the Reference Scenario rises by 1% per year on average, from 85 million barrels per day in 2007 to 106 mb/d in 2030. This is a significant downward revision from last year's *Outlook*, reflecting mainly the impact of much higher prices and slightly slower GDP growth. New government policies introduced in the past year also contribute to lower demand.

All the increase in world oil demand comes from non-OECD countries. India sees the fastest growth, averaging 3.9% per year over the *Outlook* period, followed by China, at 3.5%. High as they are, these growth rates are still significantly lower than historic trends. Other emerging Asian economies and the Middle East also see rapid growth. By contrast, demand in all three OECD regions falls, due largely to declining non-transport demand. As a result of these trends, the share of OECD countries in global oil demand drops from 57% in 2007 to 43% in 2030.



Most of the projected increase in world oil supply comes from OPEC countries, which hold the majority of the world's remaining reserves of conventional oil. Their share of global output rises from 44% in 2007 to 51% in 2030. Their reserves are big enough for output to grow faster, but investment is assumed to be constrained, notably by conservative depletion policies and geopolitical factors.

The price of crude oil is estimated to increase slowly up to 2030 stabilizing at the price level of about 120 $/barrel (real 2007 dollars) (IEA 2008).

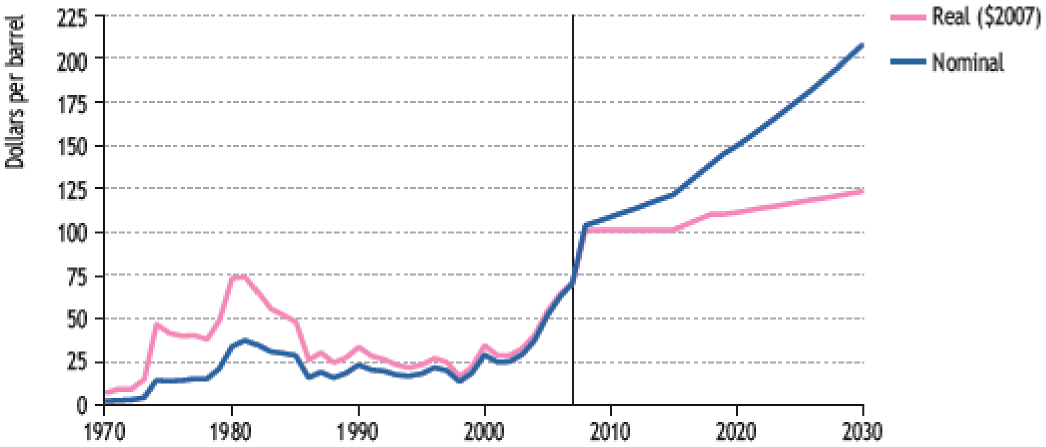


Figure 5. *Average IEA Crude Oil Import Price (annual data) (IEA 2008).*

The world primary energy demand is expected to continue its growth in the reference scenario although the growth is slower than in previous scenarios due to increased price and lower economic growth (IEA 2008).

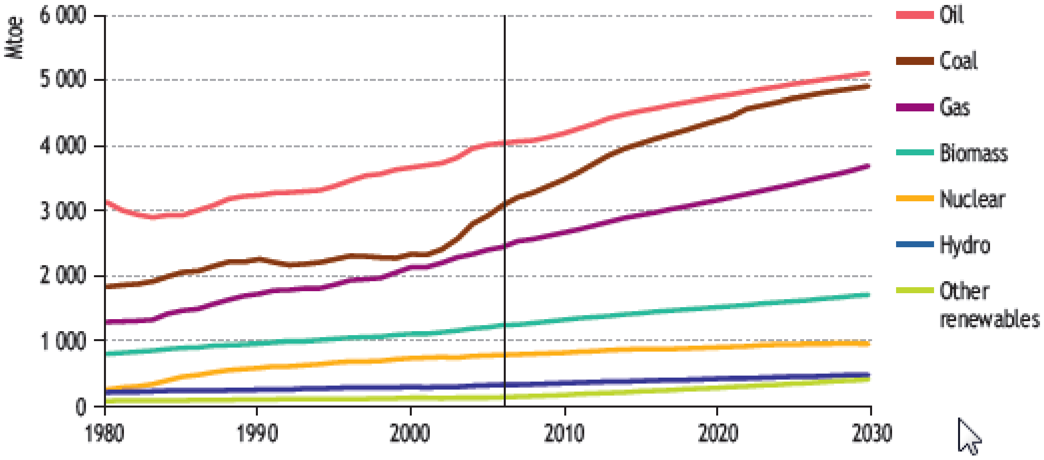


Figure 6. *World Primary Energy Demand by Fuel in the Reference Scenario (IEA 2008).*

Most of the primary energy demand growth comes from non-OECD countries, especially China and India (IEA 2008).

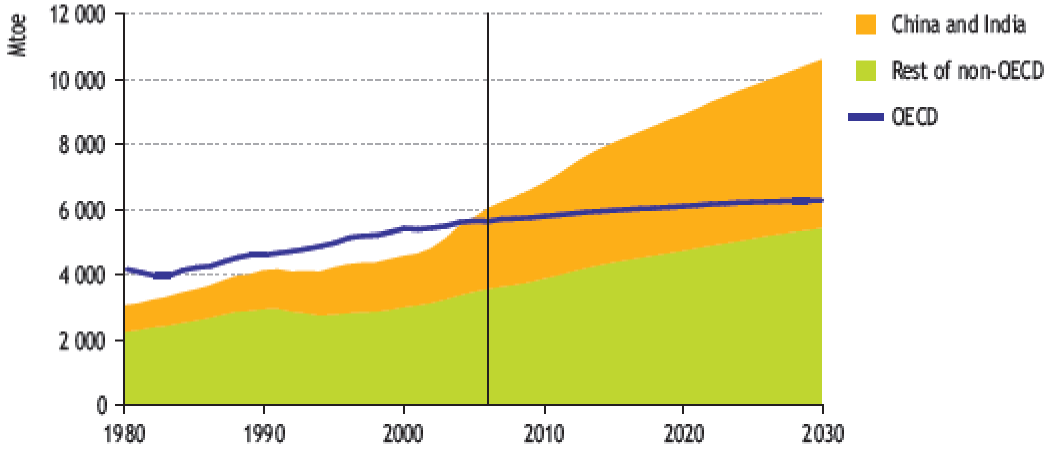
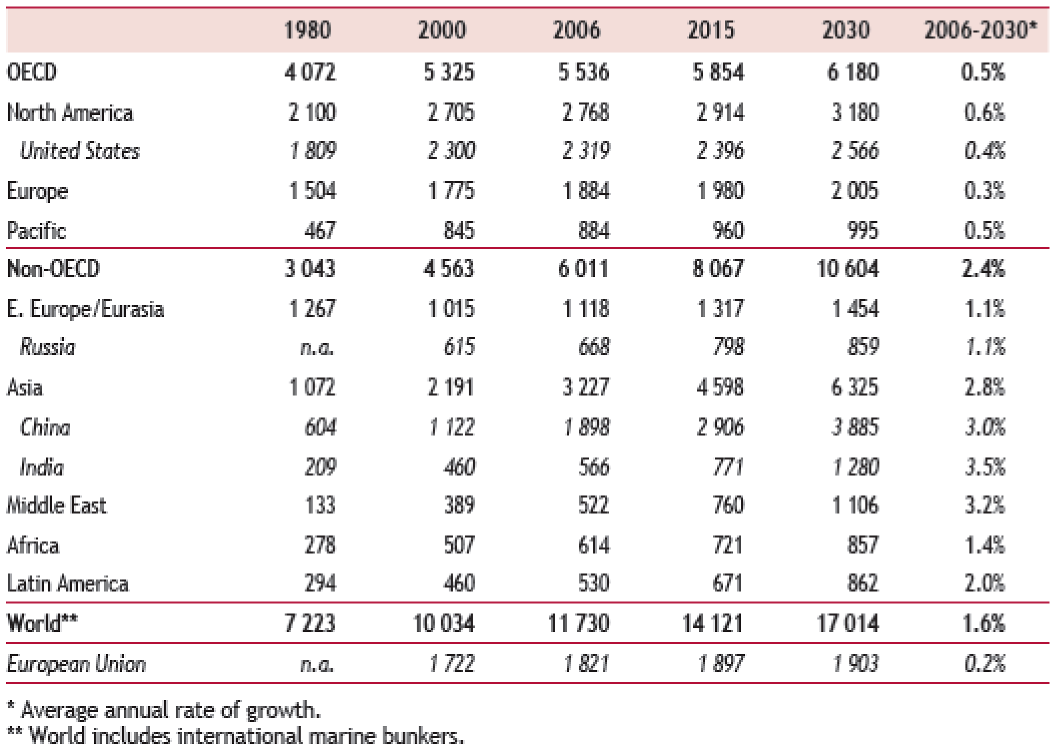


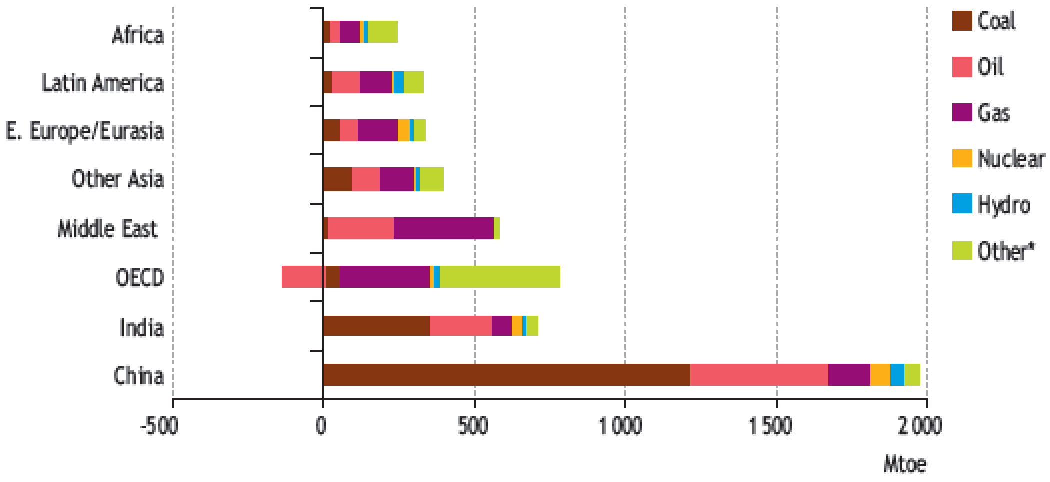
Figure 7. *World Primary Energy Demand by Region in the Reference Scenario (IEA 2008).*

Table 1. *World Primary Energy Demand by Region in the Reference Scenario (Mtoe) (IEA 2008).*



	1980	2000	2006	2015	2030	2006-2030*
OECD	4 072	5 325	5 536	5 854	6 180	0.5%
North America	2 100	2 705	2 768	2 914	3 180	0.6%
United States	*1 809*	*2 300*	*2 319*	*2 396*	*2 566*	*0.4%*
Europe	1 504	1 775	1 884	1 980	2 005	0.3%
Pacific	467	845	884	960	995	0.5%
Non-OECD	3 043	4 563	6 011	8 067	10 604	2.4%
E. Europe/Eurasia	1 267	1 015	1 118	1 317	1 454	1.1%
Russia	*n.a.*	*615*	*668*	*798*	*859*	*1.1%*
Asia	1 072	2 191	3 227	4 598	6 325	2.8%
China	*604*	*1 122*	*1 898*	*2 906*	*3 885*	*3.0%*
India	*209*	*460*	*566*	*771*	*1 280*	*3.5%*
Middle East	133	389	522	760	1 106	3.2%
Africa	278	507	614	721	857	1.4%
Latin America	294	460	530	671	862	2.0%
World**	7 223	10 034	11 730	14 121	17 014	1.6%
European Union	*n.a.*	*1 722*	*1 821*	*1 897*	*1 903*	*0.2%*

* Average annual rate of growth.
** World includes international marine bunkers.

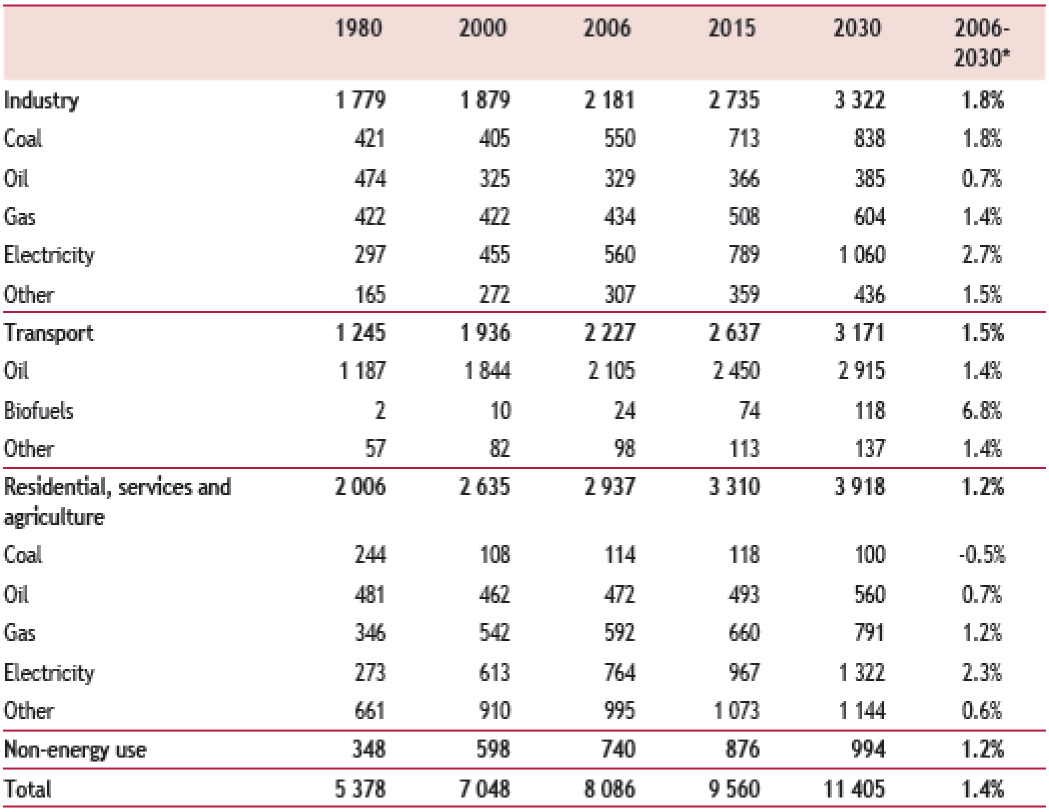


* Other includes biomass and waste, and other renewables.

Figure 8. Incremental Primary Energy Demand by Fuel in the Reference Scenario, 2006–2030 (IEA 2008).

The growth in energy demand is estimated to be quite evenly distributed between industrial, transport and residential demand. IEA does not believe that in the transport sector there will be any major shift to electric vehicles. (IEA 2008.)

Table 1. World Final Energy Consumption by Sector in the Reference Scenario (Mtoe) (IEA 2008).



	1980	2000	2006	2015	2030	2006-2030*
Industry	1 779	1 879	2 181	2 735	3 322	1.8%
Coal	421	405	550	713	838	1.8%
Oil	474	325	329	366	385	0.7%
Gas	422	422	434	508	604	1.4%
Electricity	297	455	560	789	1 060	2.7%
Other	165	272	307	359	436	1.5%
Transport	1 245	1 936	2 227	2 637	3 171	1.5%
Oil	1 187	1 844	2 105	2 450	2 915	1.4%
Biofuels	2	10	24	74	118	6.8%
Other	57	82	98	113	137	1.4%
Residential, services and agriculture	2 006	2 635	2 937	3 310	3 918	1.2%
Coal	244	108	114	118	100	-0.5%
Oil	481	462	472	493	560	0.7%
Gas	346	542	592	660	791	1.2%
Electricity	273	613	764	967	1 322	2.3%
Other	661	910	995	1 073	1 144	0.6%
Non-energy use	348	598	740	876	994	1.2%
Total	5 378	7 048	8 086	9 560	11 405	1.4%

* Average annual rate of growth.

The increase in future fossil fuel production mainly takes place in non-OECD countries (IEA 2008).

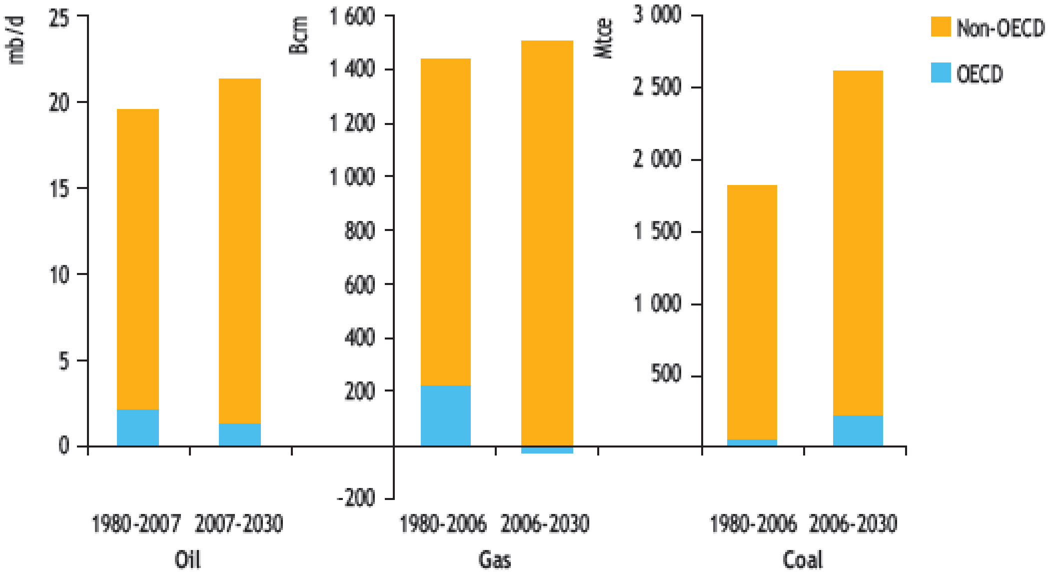


Figure 9. Incremental World Fossil Fuel Production in the Reference Scenario (IEA 2008).

The cumulative investments in energy supply infrastructure will be mainly carried out in developing countries and the largest investments will be in power sector (production, transmission and distribution) (IEA 2008).

Table 2. Cumulative Investment in Energy-supply Infrastructure in the Reference Scenario, 2007–2030 ($ billion in year-2007 dollars) (IEA 2008).

	Coal	Oil	Gas	Power	Total
OECD	165	1 437	2 286	5 708	9 739
North America	87	1 023	1 675	2 645	5 490
Europe	39	304	417	2 259	3 099
Pacific	39	110	195	804	1 149
Non-OECD	521	4 635	3 044	7 897	16 187
E. Europe/Eurasia	53	1 079	859	916	2 913
Russia	*36*	*544*	*653*	*440*	*1 674*
Asia	431	916	682	5 327	7 386
China	*323*	*515*	*234*	*3 099*	*4 186*
India	*70*	*179*	*82*	*1 455*	*1 791*
Middle East	1	997	597	509	2 107
Africa	23	868	608	447	1 949
Latin America	13	775	298	697	1 832
Inter-regional transport	42	225	122	n.a.	389
World	728	6 296	5 452	13 604	26 315

Note: Regional totals include a total of $234 billion investment in biofuels.

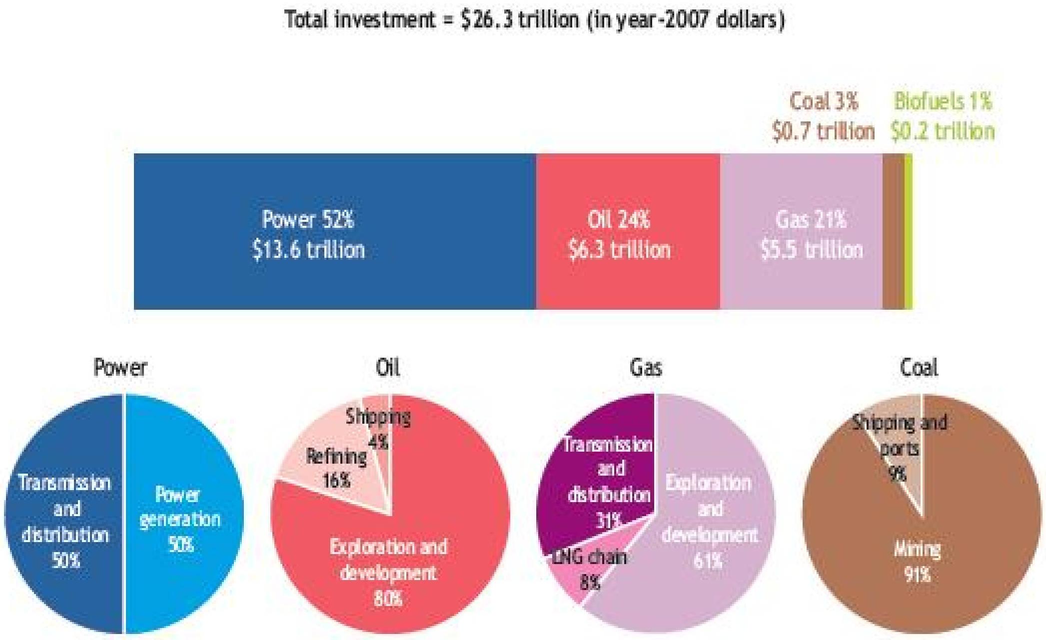


Figure 10. Cumulative Investment in Energy-supply Infrastructure in the Reference Scenario, 2007–2030 (IEA 2008).

Oil

The oil demand is estimated to decrease in OECD countries mainly due to decrease in non-transport sectors. The main increase is estimated to take place in China. (IEA 2008.)

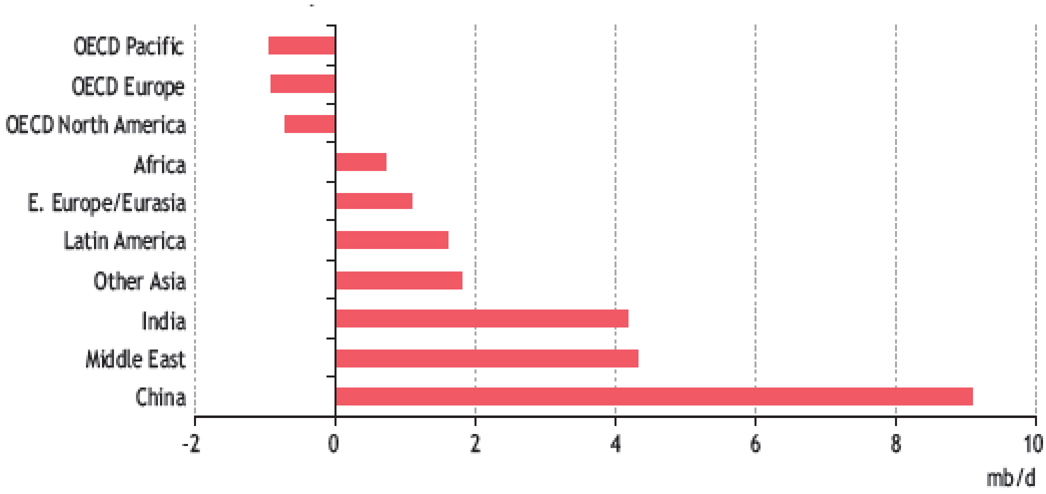


Figure 11. Change in Primary Oil Demand by Region in the Reference Scenario, 2007–2030 (IEA 2008).

The oil demand is estimated to increase mainly in transport sector and especially in non-OECD countries (IEA 2008).

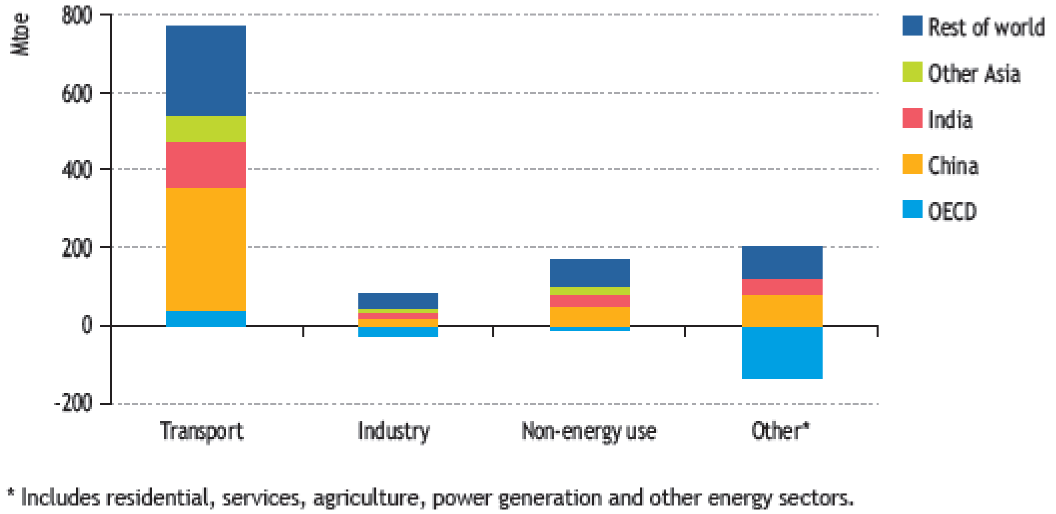


Figure 12. Incremental Oil Demand by Sector in the Reference Scenario, 2006 - 2030 (IEA 2008).

The increase in vehicle fleet is also estimated to be highest in China (IEA 2008).

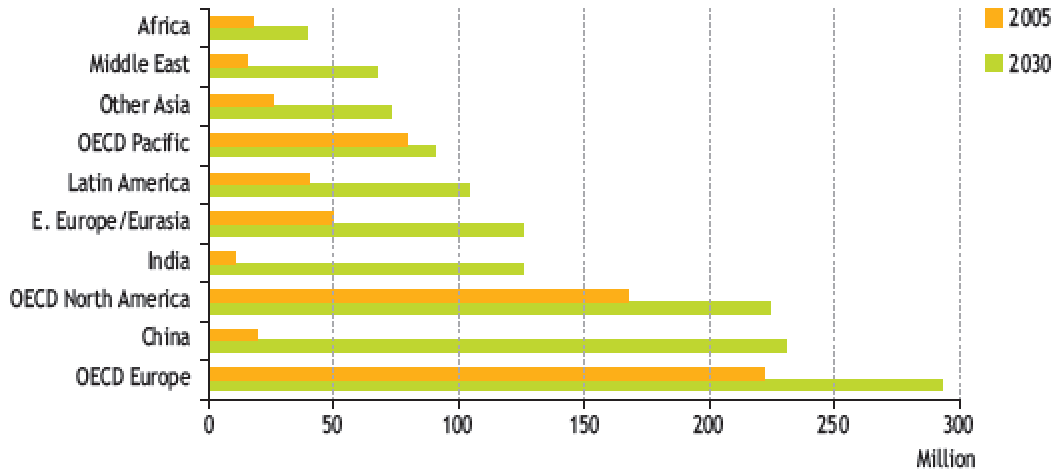
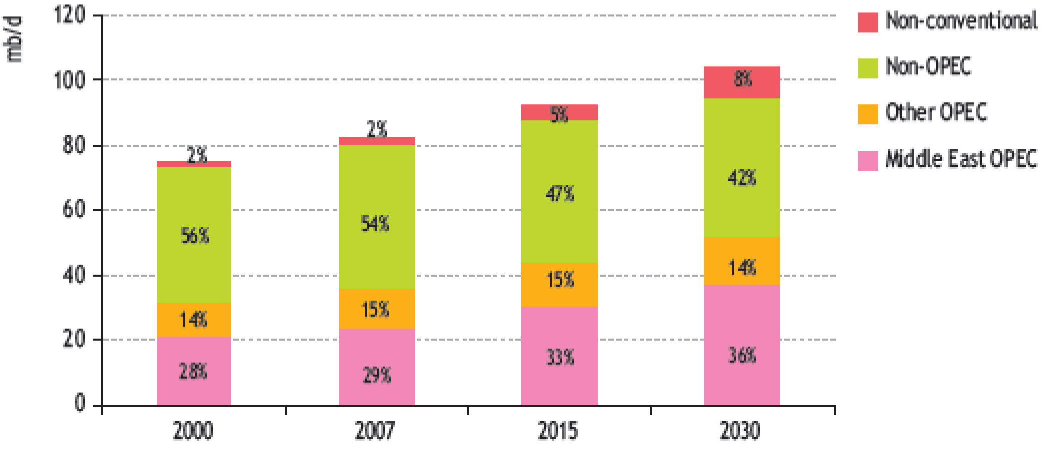


Figure 13. Light-duty Vehicle Stock by Region in the Reference Scenario (IEA 2008).

Middle East is assumed to increase its share in oil production from the present 29 % to 36 % in 2030 due to its large reserves (IEA 2008).



Note: Excludes processing gains. Conventional oil includes crude oil, condensates, natural gas liquids (NGLs) and extra-heavy oil from Venezuela.

Figure 14. World Oil Production by Source in the Reference Scenario (IEA 2008).

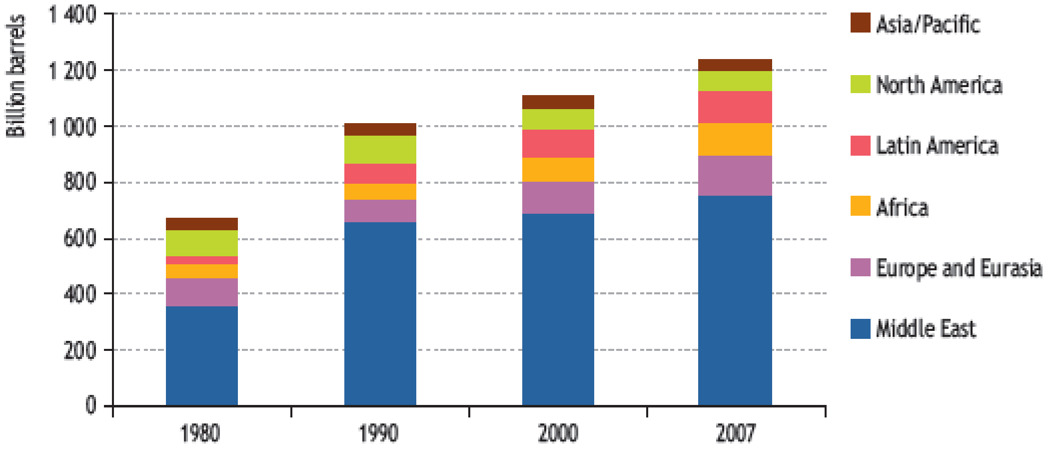
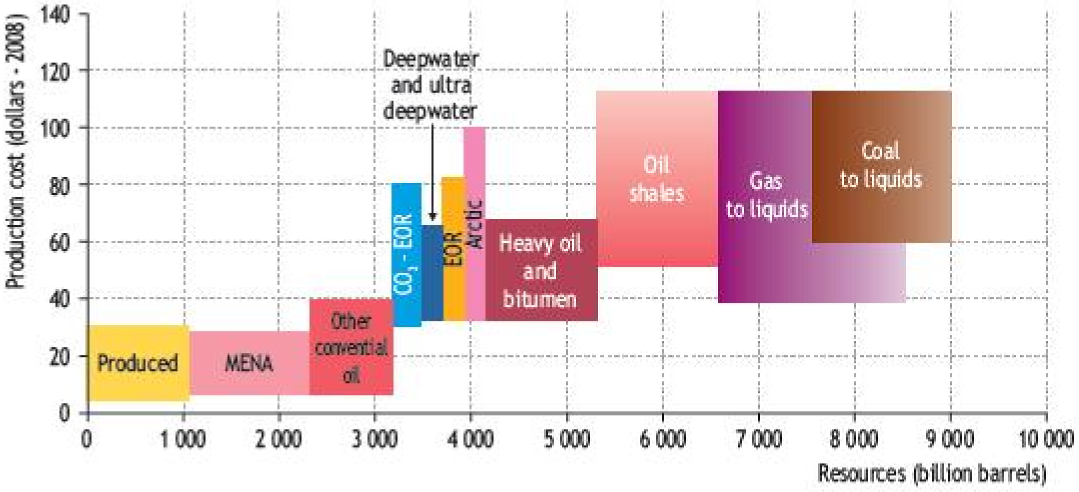


Figure 15. Proven Remaining Oil Reserves by Region, 1980– 2007 (end-year) (IEA 2008).

The production costs of oil depend on the source and technology utilised. The production costs of non-conventional sources are considerably higher than in conventional sources (especially in Middle East) (IEA 2008).



Note: The curve shows the availability of oil resources as a function of the estimated production cost. Cost associated with CO_2 emissions is not included. There is also a significant uncertainty on oil shales production cost as the technology is not yet commercial. MENA is the Middle East and North Africa. The shading and overlapping of the gas-to-liquids and coal-to-liquids segments indicates the range of uncertainty surrounding the size of these resources, with 2.4 trillion shown as a best estimate of the likely total potential for the two combined.

Figure 16. Long-term Oil-supply Cost Curve (IEA 2008).

The main increase in future growth of oil supply is thought to come from sources yet to be developed and those yet to be found. The increase of supply by Enhanced Oil recovery (EOR) technology (e.g. by CO_2 injection) and non-conventional sources is estimated to be minor. (IEA 2008.)

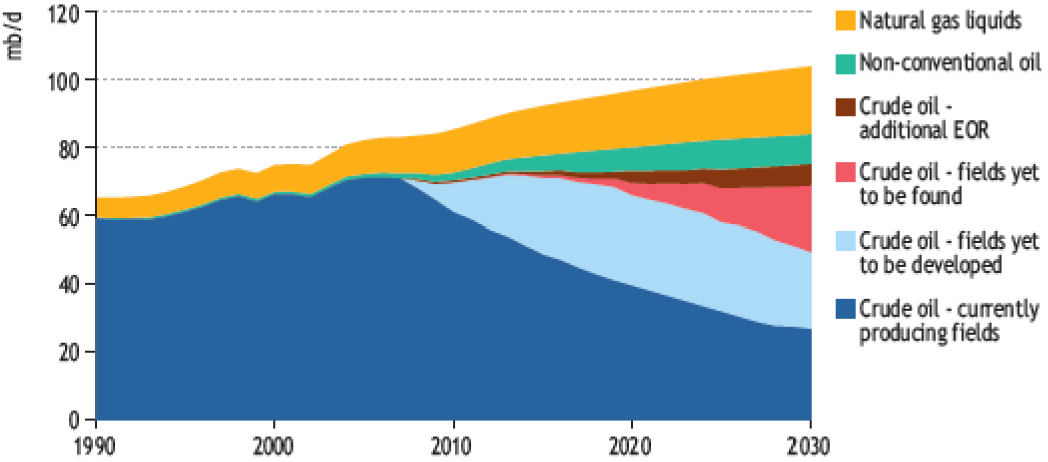


Figure 17. World Oil Production by Source in the Reference Scenario (IEA 2008).

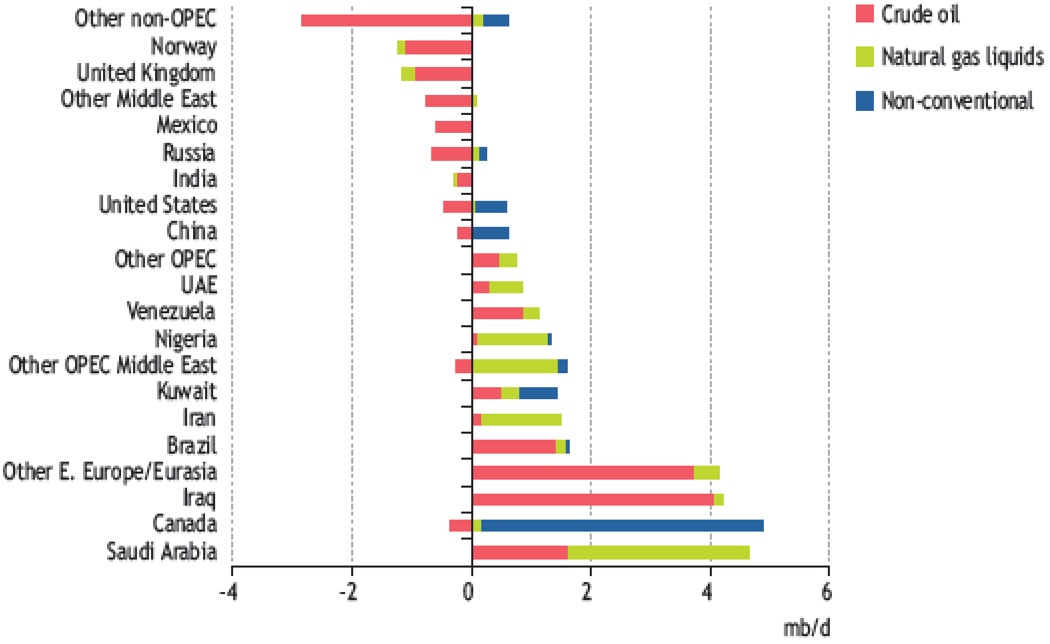


Figure 18. *Change in Oil Production by Country / Region, 2007–2030 (IEA 2008).*

Gas

Natural gas demand is estimated to increase especially in Middle East and Asia and the main sector where gas consumption is increasing is power production. (IEA 2008).

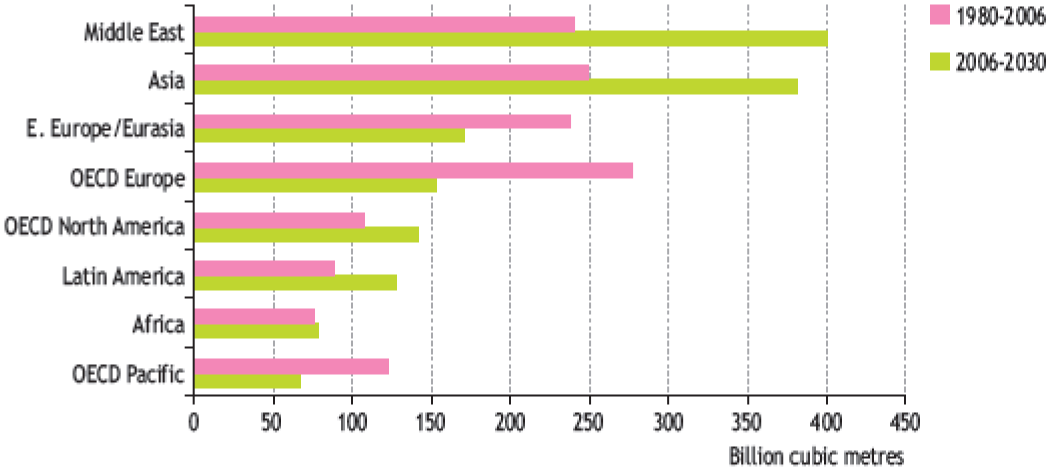


Figure 19. *Increase in Primary Demand for Natural Gas by Region in the Reference Scenario (IEA 2008).*

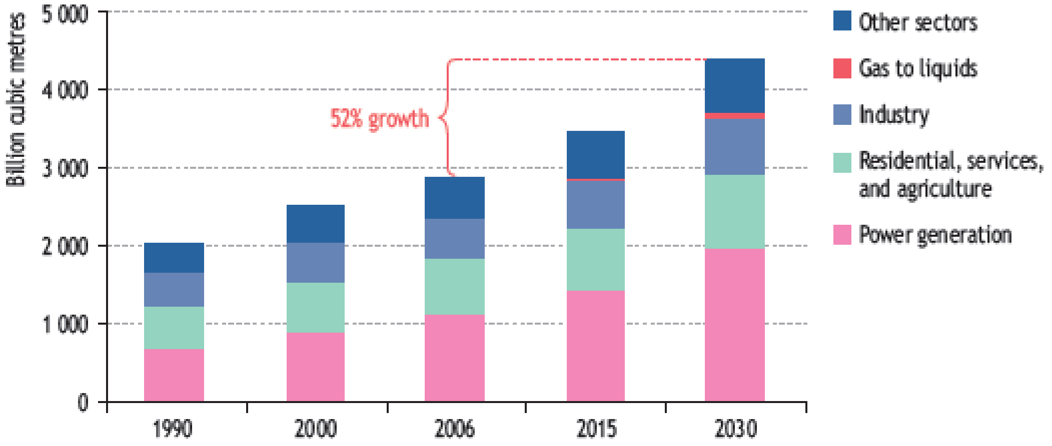


Figure 20. World Primary Natural Gas Demand by Sector in the Reference Scenario (IEA 2008).

Natural gas production is estimated to increase most in Middle East although East Europe/Eurasia is supposed to remain the main production area also in the future (IEA 2008).

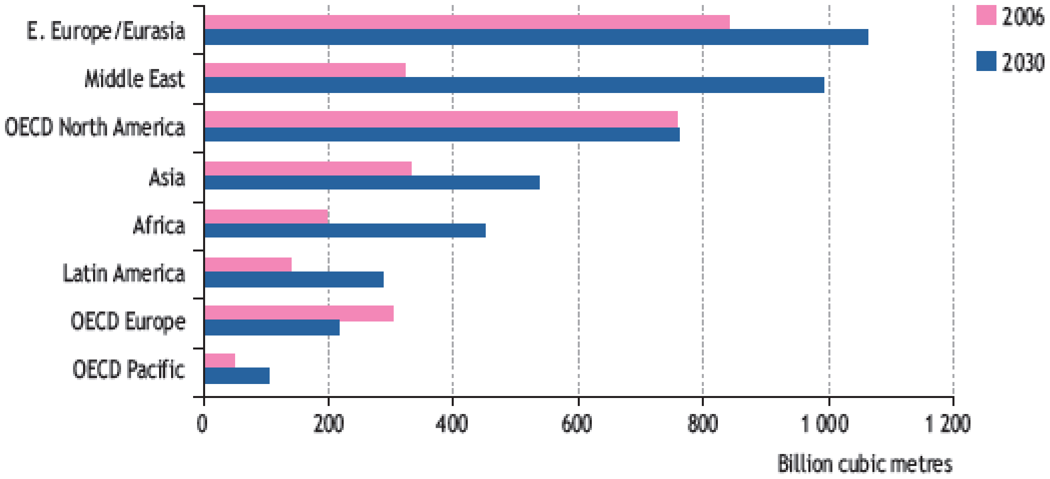


Figure 21. Natural Gas Production by Region in the Reference Scenario (IEA 2008).

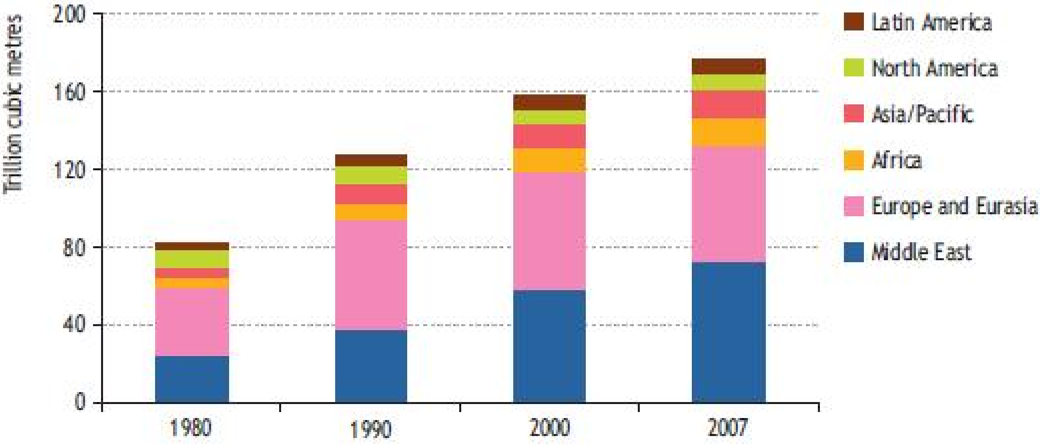
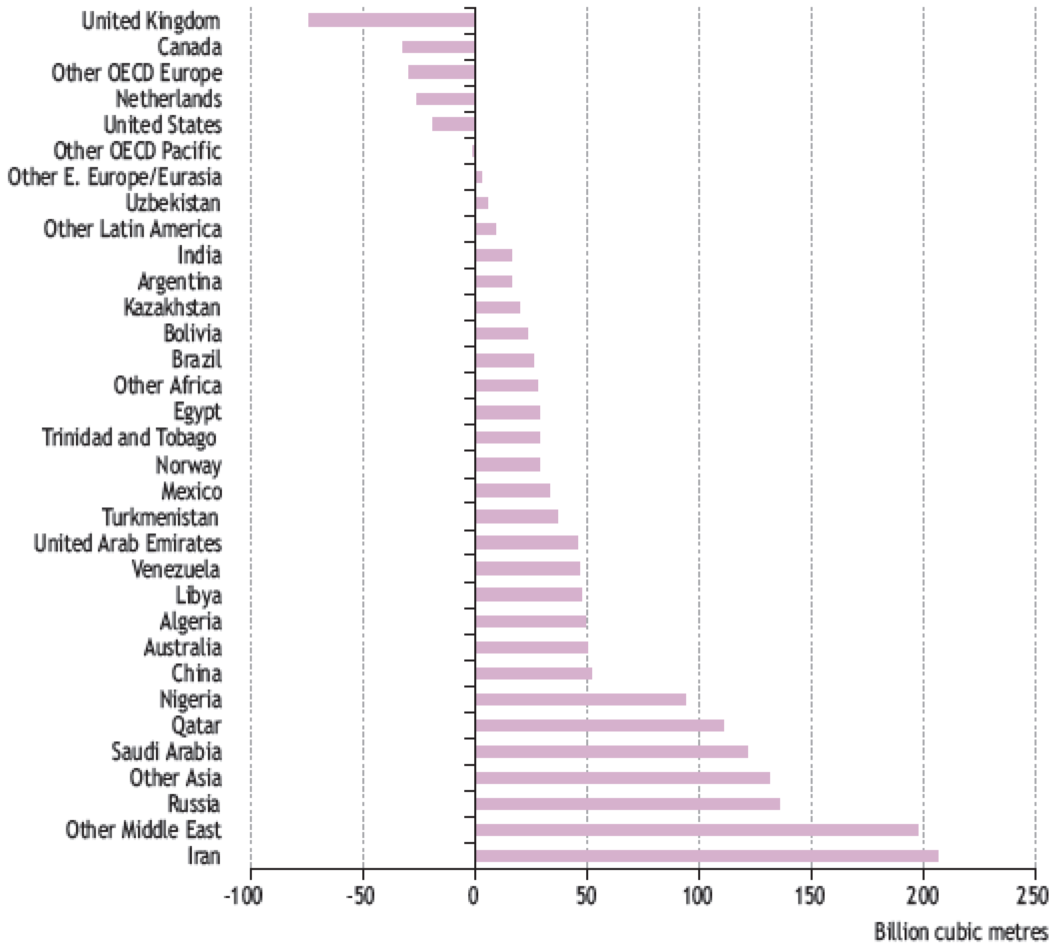


Figure 22. Proven Reserves of Natural Gas (IEA 2008).

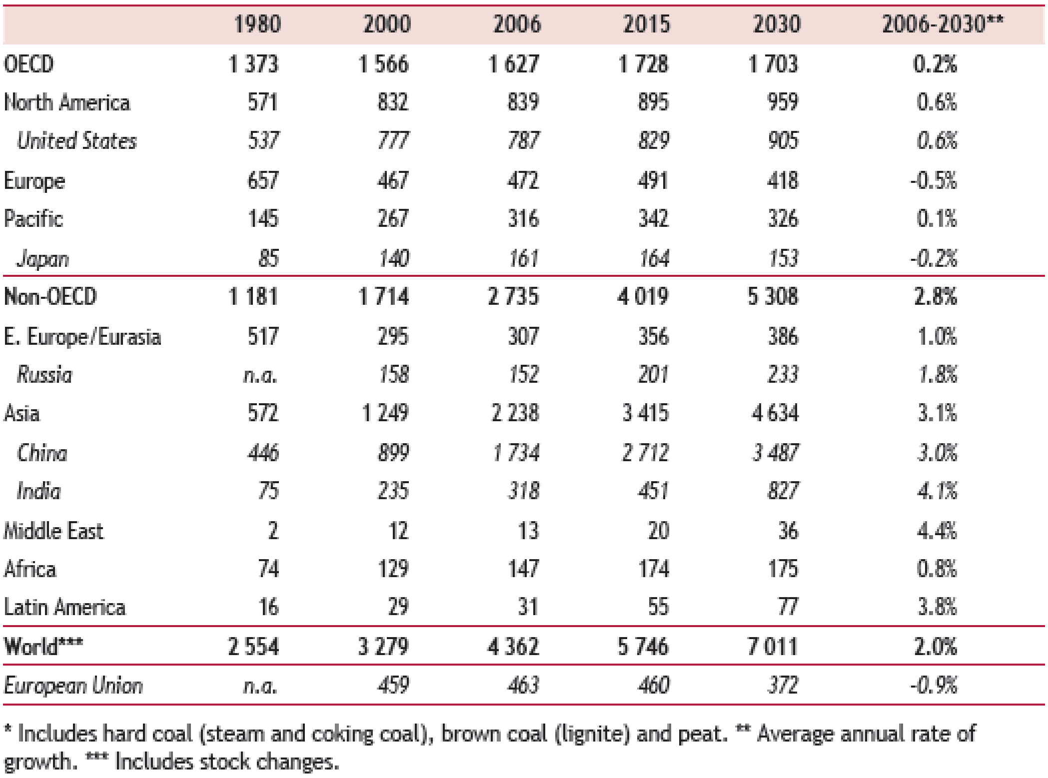


Note: Based on provisional data for 2007.

Figure 23. Change in Natural Gas Production by Country / Region, 2007–2030 (IEA 2008).

Coal

The coal demand is estimated to increase mainly in non-OECD countries, especially in China. The European coal demand is estimated to decrease after 2015 (IEA 2008).



	1980	2000	2006	2015	2030	2006-2030**
OECD	1 373	1 566	1 627	1 728	1 703	0.2%
North America	571	832	839	895	959	0.6%
United States	*537*	*777*	*787*	*829*	*905*	*0.6%*
Europe	657	467	472	491	418	-0.5%
Pacific	145	267	316	342	326	0.1%
Japan	*85*	*140*	*161*	*164*	*153*	*-0.2%*
Non-OECD	1 181	1 714	2 735	4 019	5 308	2.8%
E. Europe/Eurasia	517	295	307	356	386	1.0%
Russia	*n.a.*	*158*	*152*	*201*	*233*	*1.8%*
Asia	572	1 249	2 238	3 415	4 634	3.1%
China	*446*	*899*	*1 734*	*2 712*	*3 487*	*3.0%*
India	*75*	*235*	*318*	*451*	*827*	*4.1%*
Middle East	2	12	13	20	36	4.4%
Africa	74	129	147	174	175	0.8%
Latin America	16	29	31	55	77	3.8%
World***	2 554	3 279	4 362	5 746	7 011	2.0%
European Union	*n.a.*	*459*	*463*	*460*	*372*	*-0.9%*

* Includes hard coal (steam and coking coal), brown coal (lignite) and peat. ** Average annual rate of growth. *** Includes stock changes.

Figure 24. *World Primary Coal* Demand in the Reference Scenario (million tons of coal equivalent) (IEA 2008).*

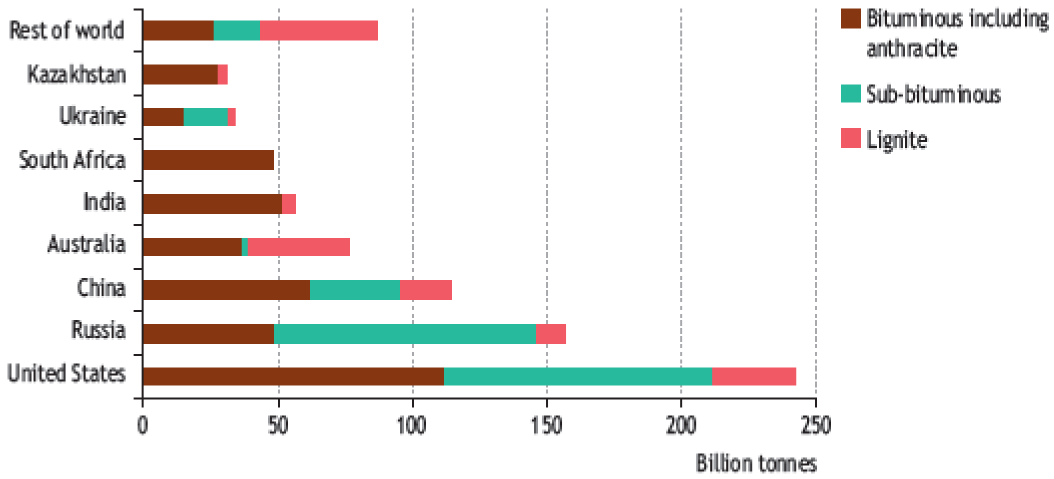


Figure 25. *Proven Coal Reserves in Leading Producing Countries, 2005 (IEA 2008).*

Electricity

Electricity demand is estimated to grow in all world regions. The growth is estimated to be highest in Asia (especially in India and Indonesia) where the per capita consumption figures are still very low. (IEA 2008).

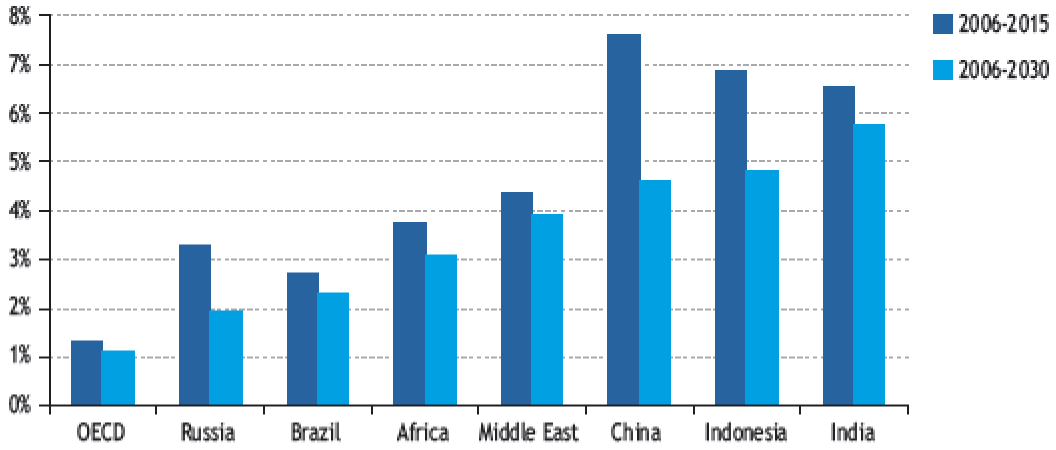


Figure 26. *Electricity Demand Growth Rates by Region in the Reference Scenario (IEA 2008).*

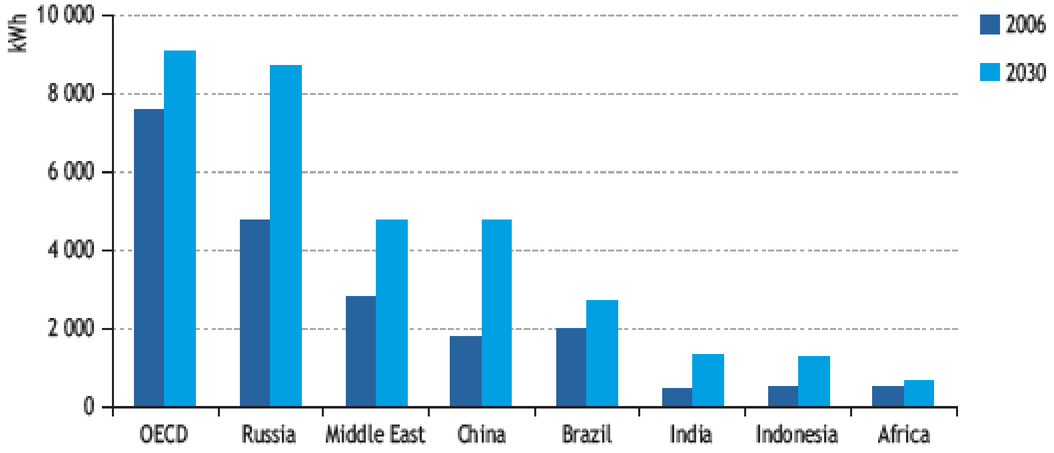


Figure 27. *Per-capita Electricity Demand by Selected Region in the Reference Scenario (IEA 2008).*

Coal is estimated to be the main source in the increased power production. Considerable increase is also estimated to take place in gas, hydro and wind production. (IEA 2008).

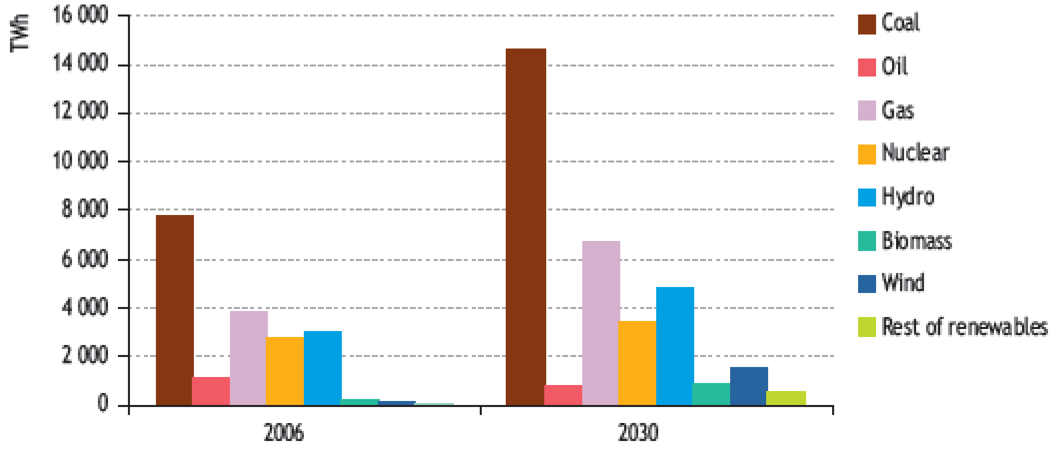
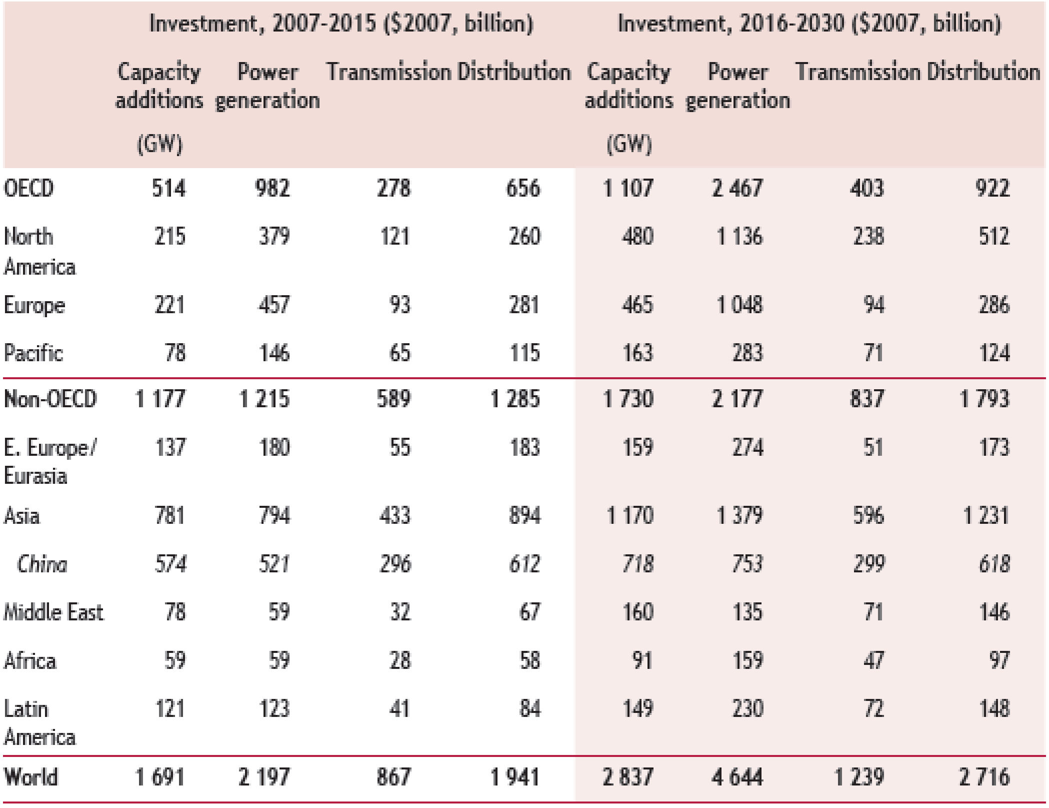


Figure 28. *World Electricity Generation by Fuel in the Reference Scenario (IEA 2008).*

The investment needs in the power sector are huge. In the OECD the investments are estimated to take place mainly in power production, while in the non-OECD countries, especially in Asia, huge needs exist especially in the distribution sector. (IEA 2008).



	Investment, 2007-2015 ($2007, billion)				Investment, 2016-2030 ($2007, billion)			
	Capacity additions (GW)	Power generation	Transmission	Distribution	Capacity additions (GW)	Power generation	Transmission	Distribution
OECD	514	982	278	656	1 107	2 467	403	922
North America	215	379	121	260	480	1 136	238	512
Europe	221	457	93	281	465	1 048	94	286
Pacific	78	146	65	115	163	283	71	124
Non-OECD	1 177	1 215	589	1 285	1 730	2 177	837	1 793
E. Europe/ Eurasia	137	180	55	183	159	274	51	173
Asia	781	794	433	894	1 170	1 379	596	1 231
China	*574*	*521*	*296*	*612*	*718*	*753*	*299*	*618*
Middle East	78	59	32	67	160	135	71	146
Africa	59	59	28	58	91	159	47	97
Latin America	121	123	41	84	149	230	72	148
World	1 691	2 197	867	1 941	2 837	4 644	1 239	2 716

Figure 29. Projected Capacity Additions and Investment Needs in Power Infrastructure in the Reference Scenario (IEA 2008).

The increase in renewables based power generation is mainly estimated to take place in hydro and wind production although later on the biomass and solar based production is also estimated to increase. IEA does not estimate huge increase in solar power production because they do not believe in any major technological breakthrough in solar panel production, but estimate just slow decrease in production costs due to increased automation in production and slight increase in efficiency. (IEA 2008).

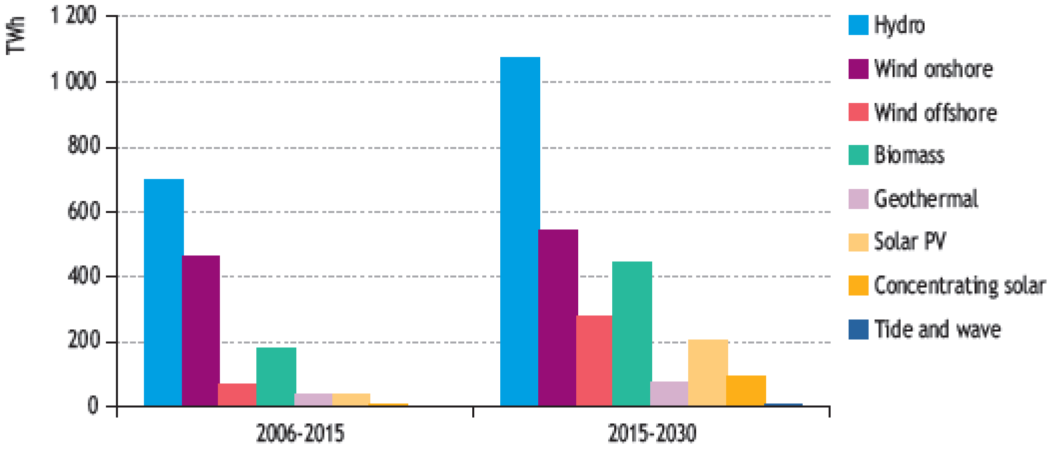


Figure 30. *Increase in World Electricity Generation from Renewables in the Reference Scenario (IEA 2008).*

It is estimated that in OECD the main relative increase in power production after 2015 takes place in nuclear production, but in absolute terms the fossil production and wind production will be most important. Most of the power production investments worldwide are assumed to take place in renewable energy based production. (IEA 2008)

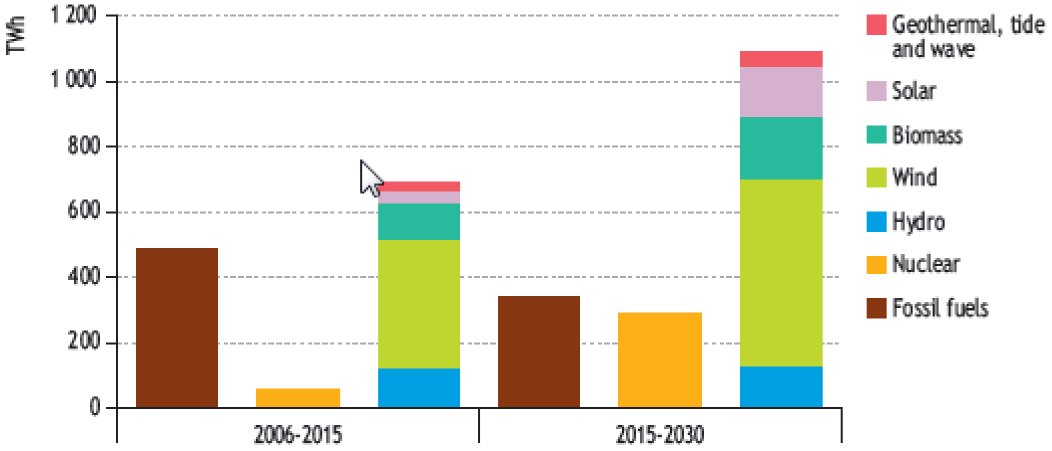


Figure 31. *Increase in OECD Electricity Generation by Source in the Reference Scenario (IEA 2008).*

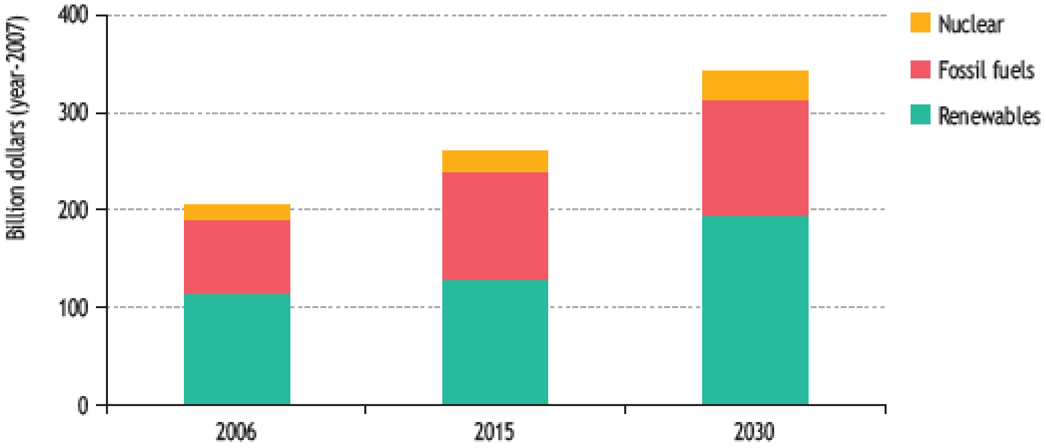


Figure 32. *World Investment in New Power-generation Plants by Fuel in the Reference Scenario (IEA 2008).*

CO_2 emissions

The CO_2 emissions are estimated to grow in the reference scenario. The main increase will come from coal combustion in non-OECD countries. (IEA 2008).

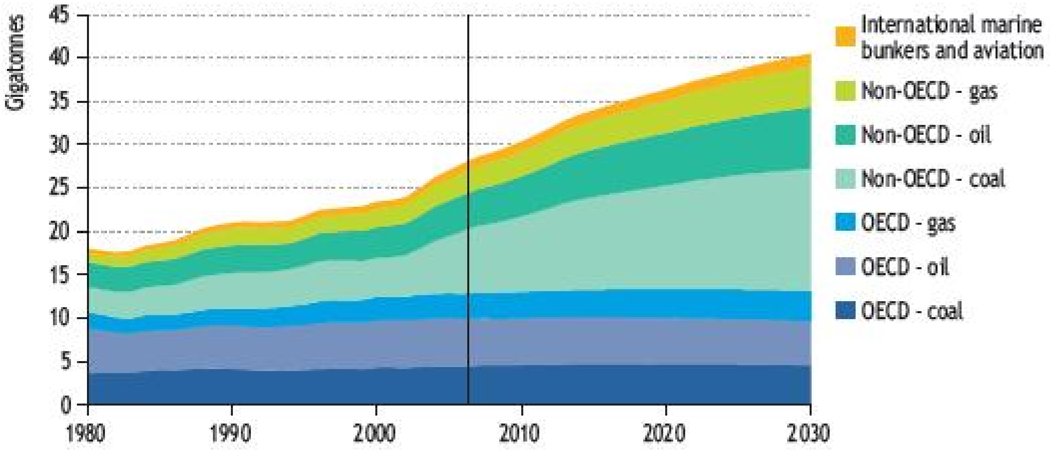


Figure 33. *Energy-related CO_2 Emissions in the Reference Scenario by Fuel and Region (IEA 2008).*

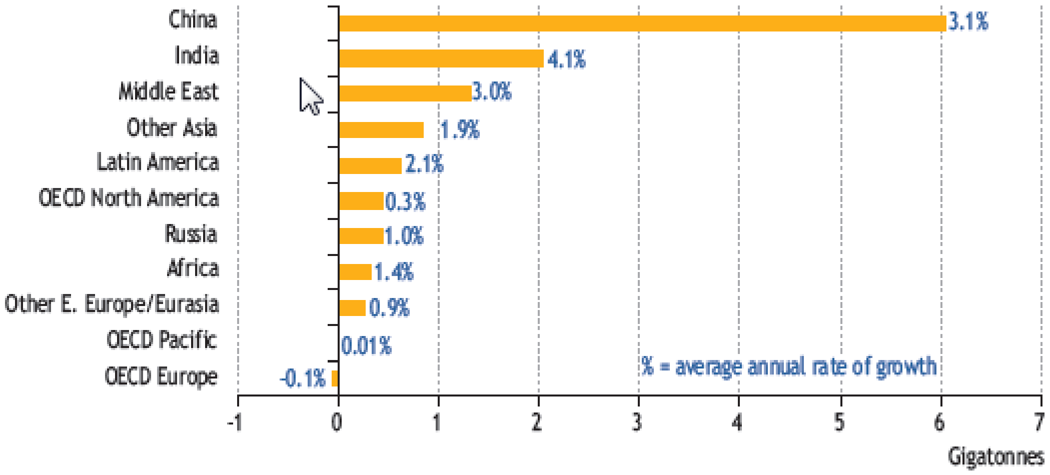
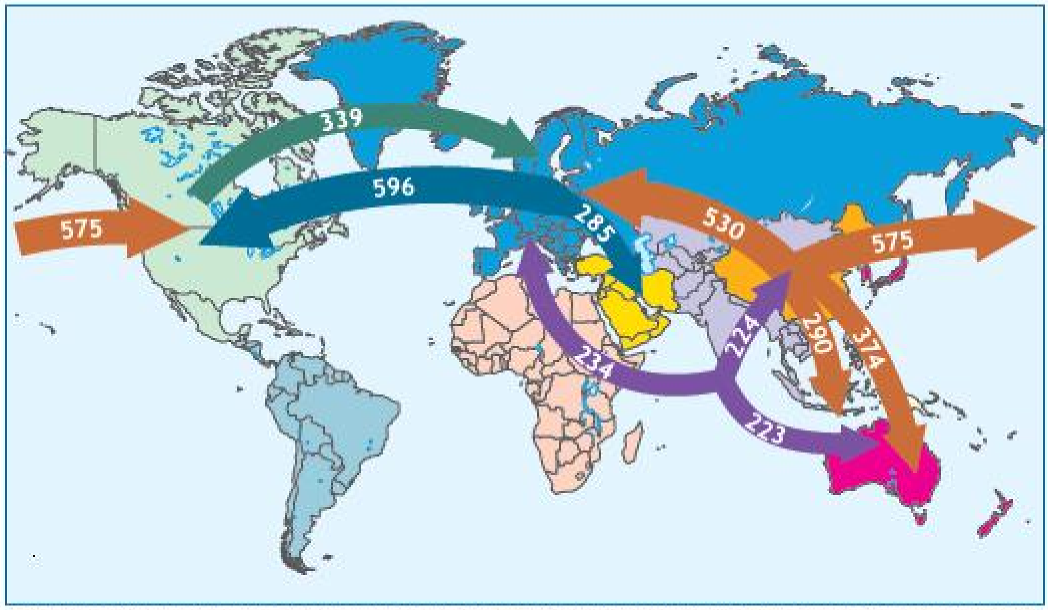


Figure 34. *Incremental Energy-related CO2 Emissions by Country and Region, 2006–2030 (IEA 2008).*

The increase in the CO_2 emissions in China is closely related to the structural change in world economy. China will be producing more goods to be consumed in other parts of the world. Figure 35 shows the inter-regional flows of energy related CO_2 emissions embedded in exports of goods and services in 2006. It can be estimated that the "export" of CO_2 emissions embedded in Chinese products will continue to increase in the future. This phenomenon can also be seen in the Finnish case of exporting embedded CO_2 emissions especially in the pulp and paper and metal products. (IEA 2008).



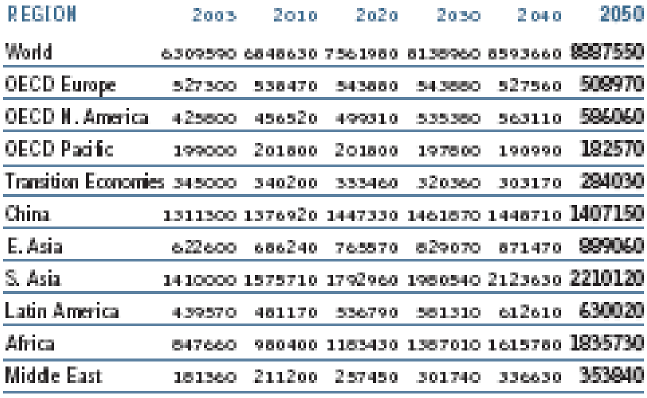
The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

Figure 35. *Ten Largest Inter-regional Flows of Energy-related CO2 Emissions embedded in Exports of Goods and Services, 2006 (Million tonnes) (IEA 2008).*

2.1.3. Greenpeace: The Energy [R]evolution

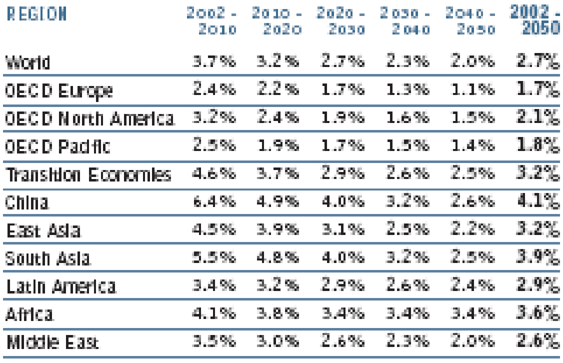
In 2007 Greenpeace published an energy scenario for the year 2050. It was written in collaboration with the European Renewable Energy Council (EREC), specialists from the German Space Agency and scientists and engineers from universities, institutes and the renewable energy industry.

The Energy [R]evolution provides a practical blueprint for how to half global CO_2 emissions, while allowing for an increase in energy consumption by 2050. It demonstrates how a 'business as usual' scenario, based on IEA's World Energy Outlook projections, is not an option for environmental, economic and security of supply reasons. In energy revolution scenario energy demand will be reduced by almost 50 % in 2050 and half of the remaining demand will be covered by renewable energy sources. (Greenpeace & EREC 2007)



REGION	2003	2010	2020	2030	2040	2050
World	6309590	6848630	7561980	8138960	8593660	8887550
OECD Europe	527300	538470	543880	543880	527560	508970
OECD N. America	425800	456520	499310	535380	563110	586060
OECD Pacific	199000	201800	201800	197800	190990	182570
Transition Economies	345000	340200	333460	320360	303170	284030
China	1311300	1376920	1447330	1461870	1448710	1407150
E. Asia	622600	686240	765570	829070	871470	889060
S. Asia	1410000	1575710	1792960	1980540	2123630	2210120
Latin America	439570	481170	536790	581310	612610	630020
Africa	847660	980400	1183430	1387010	1615780	1835730
Middle East	181360	211200	257450	301740	336630	353840

Figure 36. Projection of Global Population Development (Greenpeace & EREC 2007).



REGION	2002 - 2010	2010 - 2020	2020 - 2030	2030 - 2040	2040 - 2050	2002 - 2050
World	3.7%	3.2%	2.7%	2.3%	2.0%	2.7%
OECD Europe	2.4%	2.2%	1.7%	1.3%	1.1%	1.7%
OECD North America	3.2%	2.4%	1.9%	1.6%	1.5%	2.1%
OECD Pacific	2.5%	1.9%	1.7%	1.5%	1.4%	1.8%
Transition Economies	4.6%	3.7%	2.9%	2.6%	2.5%	3.2%
China	6.4%	4.9%	4.0%	3.2%	2.6%	4.1%
East Asia	4.5%	3.9%	3.1%	2.5%	2.2%	3.2%
South Asia	5.5%	4.8%	4.0%	3.2%	2.5%	3.9%
Latin America	3.4%	3.2%	2.9%	2.6%	2.4%	2.9%
Africa	4.1%	3.8%	3.4%	3.4%	3.4%	3.6%
Middle East	3.5%	3.0%	2.6%	2.3%	2.0%	2.6%

Figure 37. Projection of Global GDP Development (Greenpeace & EREC 2007).

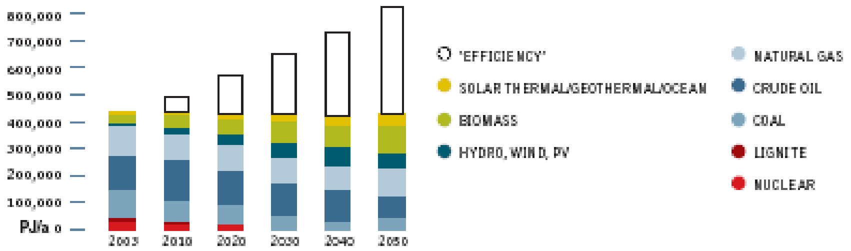


Figure 38. *Development of Primary Energy Consumption under the Energy [R]evolution Scenario ("efficiency" reduction from Reference Scenario) (Greenpeace & EREC 2007).*

Whilst worldwide emissions of CO_2 will almost double under IEA's Reference Scenario, under the energy [R]evolution scenario they will decrease from 23,000 million tonnes in 2003 to 11,500 million tonnes in 2050 (Greenpeace & EREC 2007).

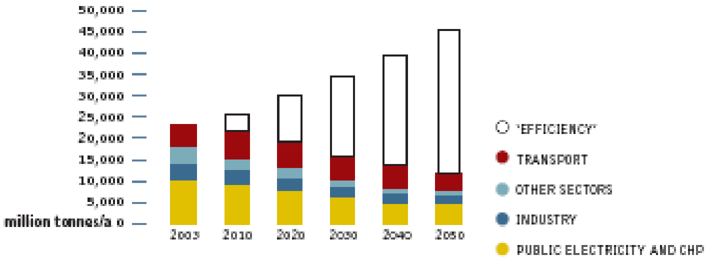


Figure 39. *Development of Global CO2 Emissions under the Energy [R]evolution Scenario (Greenpeace & EREC 2007).*

2.1.4. State of the Future 2007, Global Energy Scenarios 2020

State of the Future is a yearly report published by the American Council of the United Nations University. State of the Future 2007 includes a chapter that represents four energy scenarios for the 2020. They are Business as usual, Environmental backlash, High tech economy and Political turmoil.

Business as usual scenario assumes that the global dynamics of change continue without great surprises or much change in energy sources and consumption patterns, other than those that might be expected as a result of the change dynamics and trends already in place. Economic growth is predicted to be moderate or high until oil prices go so high they might cause recessions and depressions. Environmental backlash scenario assumes that the international environmental movement becomes much more organized; some lobbying for legal actions and new regulations and suing in courts, while others become violent and attack fossil energy industries. Economic growth is predicted to be moderate or high. Oil price fluctuates with environmental actions. (State of the Future 2007)

High tech economy scenario assumes that technological innovations accelerate beyond current expectations, and have impacts in the energy supply mix and consumption patterns, to a similar magnitude as the Internet initiated in the 1990s. Economic growth is high and great efficiencies prevent oil peak prior to 2050. Political turmoil scenario assumes increasing conflicts, wars, and several countries collapsing into failed states, leading to increasing migrations and political instabilities around the world. Economic growth is predicted to be low and depressions are probable. (State of the Future 2007)

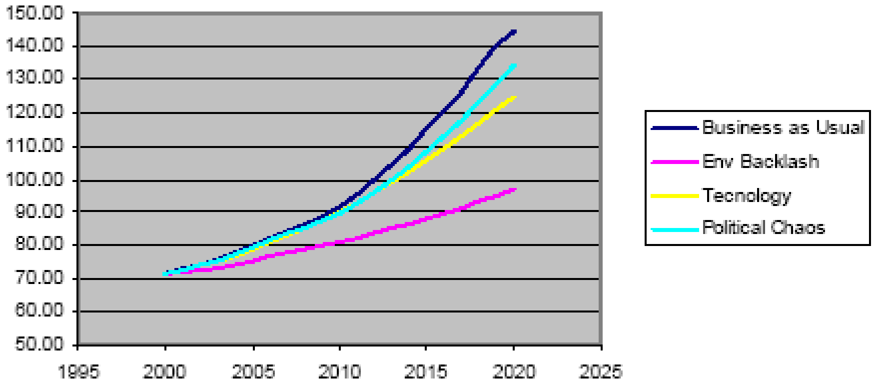


Figure 40. Total Energy Demand (billion barrels OE) (State of the Future 2007).

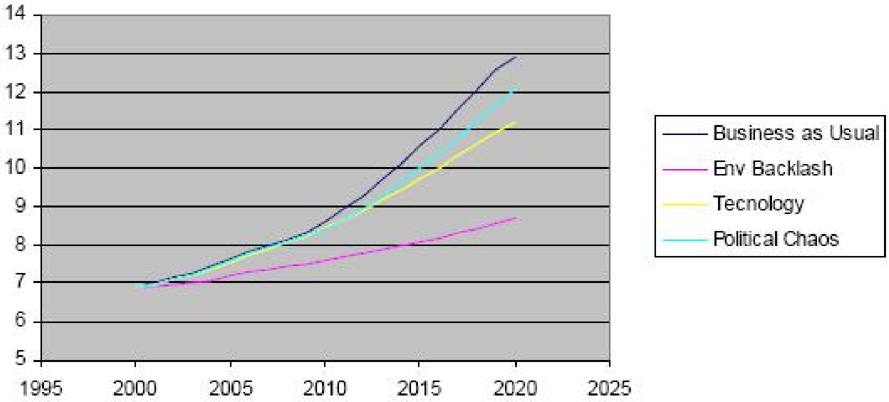


Figure 41. Annual CO2 Emissions from Fossil Fuels (billion tons) (State of the Future 2007).

2.1.5. UN: Global Environmental Outlook

Global Environmental Outlooks are the most comprehensive UN reports on the environment. The United Nations Environment Programme's fourth report was prepared by about 390 experts and reviewed by more than 1 000 others across the world. Four scenarios are constructed in the report. Markets First, Policy First, Security First and Sustainability First explore society's common future up to the year 2050 in terms of the environment and the impact of lifestyle choices and policy responses to address various challenges. They explore how current social, economic and environmental trends may unfold along divergent development paths in the future, and potential impacts for the environment, human well-being and development. (UN 2008)

World population is predicted to be increasing in every scenario. In Security First scenario the population is estimated to be almost 10 billion in 2050 (UN 2008).

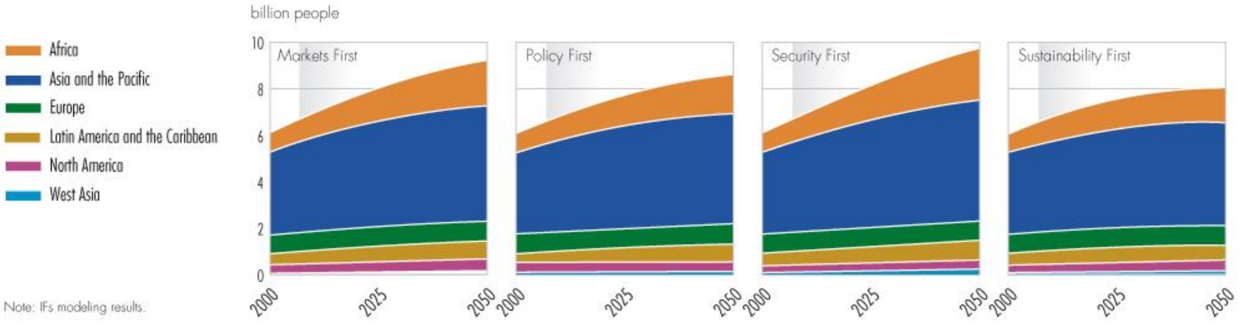


Figure 42. *Population Trends (UN 2008).*

World GDP is expected to increase in all scenarios. The lowest rate is in Security First scenario (UN 2008).

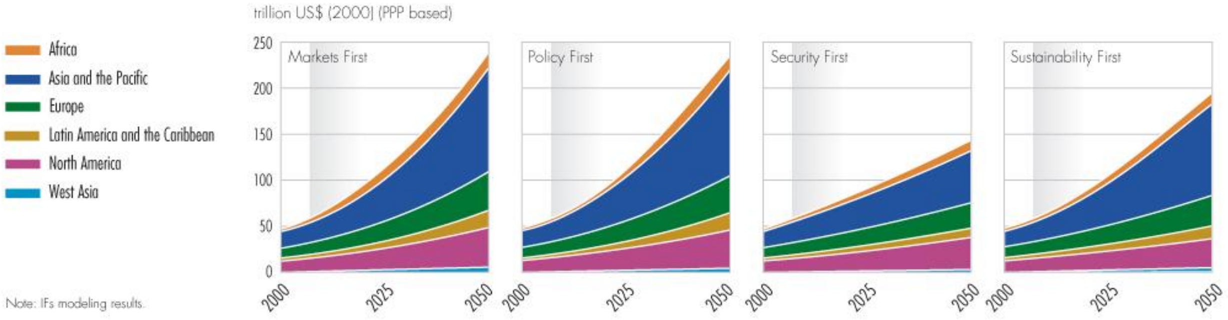
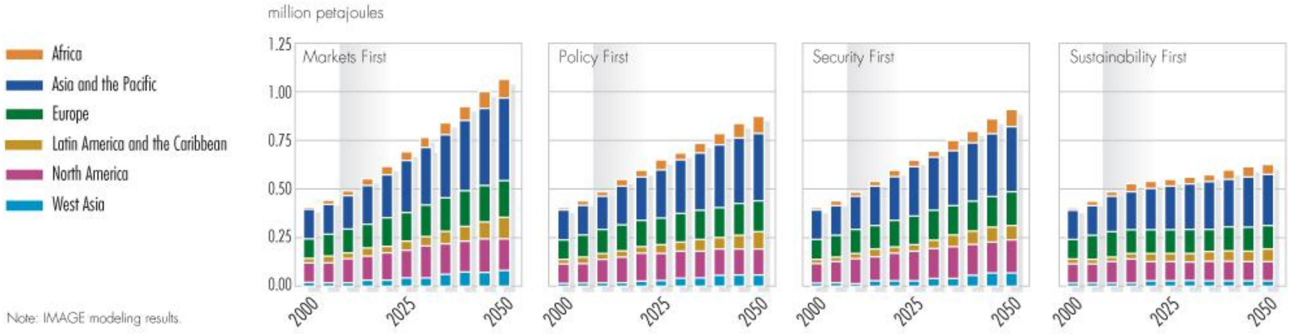


Figure 43. *Gross Domestic Product (UN 2008).*

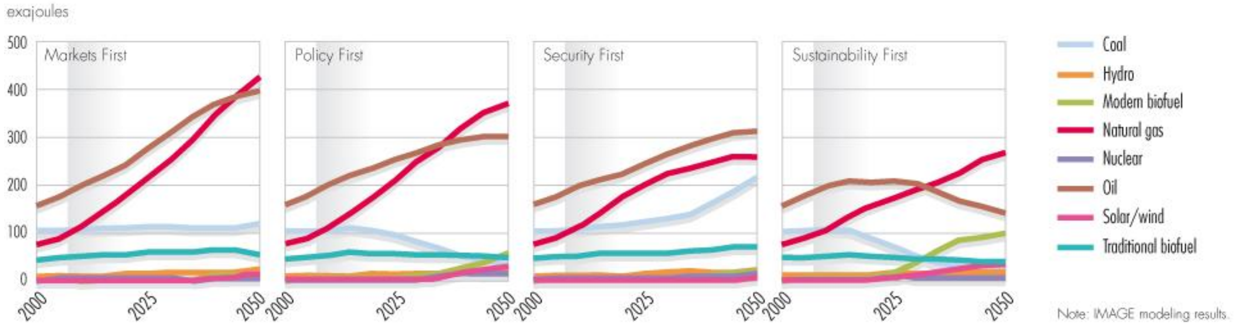
World energy use is expected to increase in all scenarios, driven mostly by intensive energy use in low-income countries. However, per capita energy use in high-income countries remains at a much higher level than in low income countries. Primary energy use in Policy First and Security First increases from about 400 EJ in 2000 to 600–700 EJ in 2030 and around 800–900 EJ in 2050. In Market First scenario primary energy use will be over 1000 EJ in 2050. That would almost double the energy use in Sustainability First scenario. (UN 2008.)



Note: IMAGE modeling results.

Figure 44. *Total Primary Energy Use (UN 2008).*

In terms of the energy mix, fossil fuels continue to dominate energy supply in all four scenarios. Bio fuels will be the most important alternative for oil in Sustainability First scenario. (UN 2008)



Note: IMAGE modeling results.

Figure 45. *Global Primary Energy Use by Fuel (UN 2008).*

Decrease in emissions is highest in Policy First and Sustainability First scenarios (UN 2008).

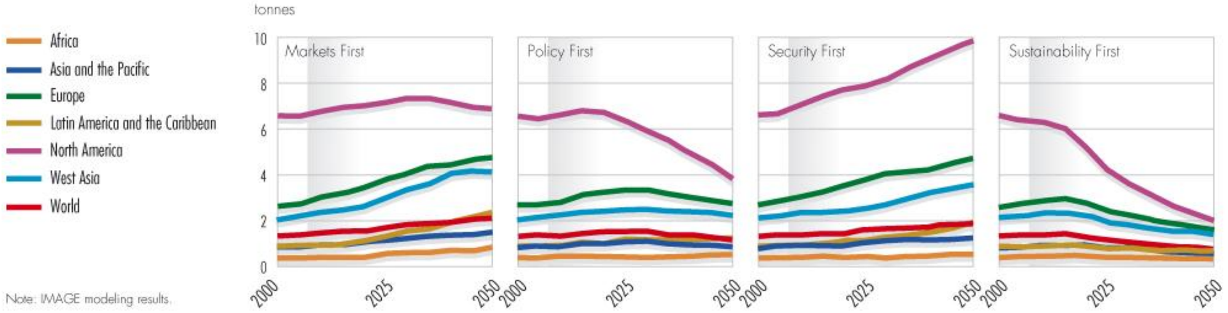


Figure 46. *Per Capita Equivalent Carbon Emissions from Energy and Industry by Region (UN 2008).*

2.1.6. Shell Energy Scenarios to 2050

Shell's scenario group has developed global scenarios since 1970's. Shell's energy scenarios to 2050 highlight the stresses that population growth and economic development are placing on energy supply, energy demand and the environment. According to Shell's scenario group the world is entering to an era of revolutionary transitions where the three hard truths about energy supply and demand can no longer be avoided. (Shell International B.V. 2008.)

Firstly the World is about to face a step-change in energy use. World population is set to increase up to 9 billions by the 2050. At the same time population giants China and India, are entering their most energy-intensive phase of economic growth as they industrialize, build infrastructure, and increase their use of transportation. Demand pressures will stimulate alternative supply and more efficiency in energy use — but these alone may not be enough to offset growing demand tensions completely. Disappointing the aspirations of millions by adopting policies that may slow economic growth is not an answer either — or not one that is politically feasible. (Shell International B.V. 2008.)

Secondly supply will struggle to keep pace. By 2050, growth in the production of easily accessible oil and gas will not match the projected rate of demand growth. While abundant coal exists in many parts of the world, transportation difficulties and environmental degradation ultimately pose limits to its growth. Meanwhile, alternative energy sources such as bio fuels may become a much more significant part of the energy mix — but there is no "silver bullet" that will completely resolve supply-demand tensions. (Shell International B.V. 2008.)

Thirdly environmental stresses are increasing. Even if it were possible for fossil fuels to maintain their current share of the energy mix and respond to increased demand, CO_2 emissions would then be on a pathway that could severely threaten human well-being. Even with the moderation of fossil fuel use and effective CO2 management, the path forward is still highly challenging. Remaining within desirable levels of CO_2 concentration in the atmosphere will become increasingly difficult. (Shell International B.V. 2008.)

To help think about the future of energy, Shell's scenario group have developed two scenarios that describe alternative ways it may develop. The first scenario called Scramble reflects a focus on national energy security. Immediate pressures drive decision-makers, especially the need to secure energy supply in the near future for themselves and their allies. Despite increasing rhetoric, action to address climate change and encourage energy efficiency is pushed into the future. In Scramble scenario primary energy demand raises over 900 EJ per year. Main responses to the increasing energy demand are coal and renewable energy, mainly bio fuels. (Shell International B.V. 2008)

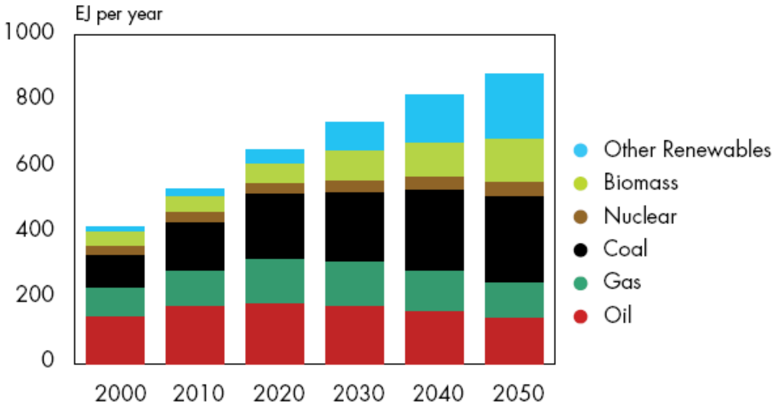


Figure 47. *Scramble: Primary Energy by Source (Shell International B.V. 2008).*

In the second scenario – Blueprints – growing local actions begin to address the challenges of economic development, energy security and environmental pollution. A price is applied to a critical mass of emissions giving a huge stimulus to the development of clean energy technologies, such as carbon dioxide capture and storage, and energy efficiency measures. As a result the carbon dioxide emissions are much lower compared to Scramble scenario. Also the global primary energy demand stays under 800 EJ per year. Primary sources of energy are coal and renewables. (Shell International B.V. 2008)

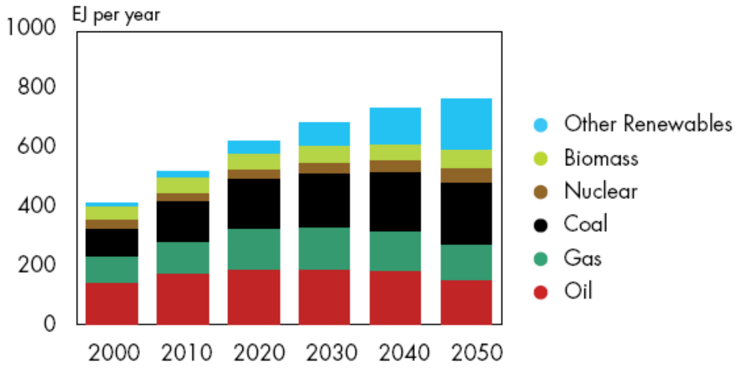


Figure 48. *Blueprints: Primary Energy by Source (Shell International B.V. 2008).*

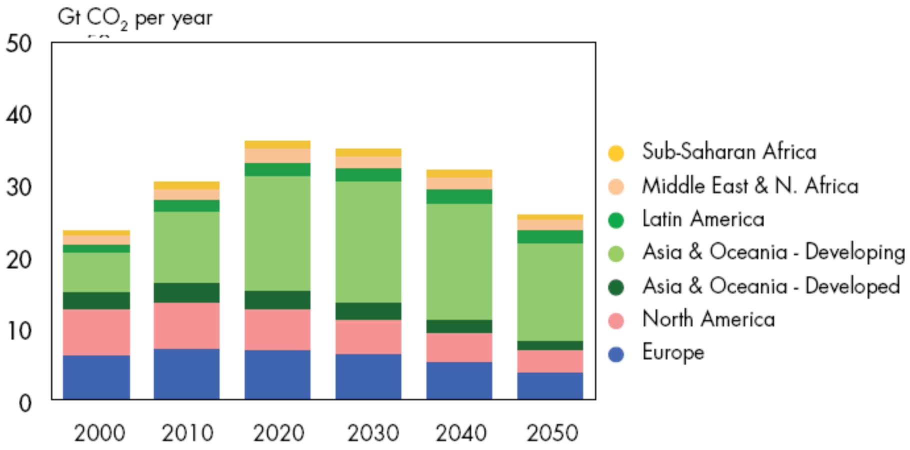


Figure 49. *Blueprints: CO2 Emissions from Energy (Shell International B.V. 2008).*

2.1.7. World Energy Prospects According to Total

Total's report highlights the importance of promoting energy efficient solutions to save natural resources and limit CO_2 emissions. The critical challenge is reconciling two up to now conflicting targets: meeting energy demand and protecting the climate. Therefore development in technical solutions such as CCS to limit related emissions is needed. Also it is necessary to develop alternative and renewable energy options such as nuclear power, biomass, photovoltaic and other renewables to secure the future. (Total 2008)

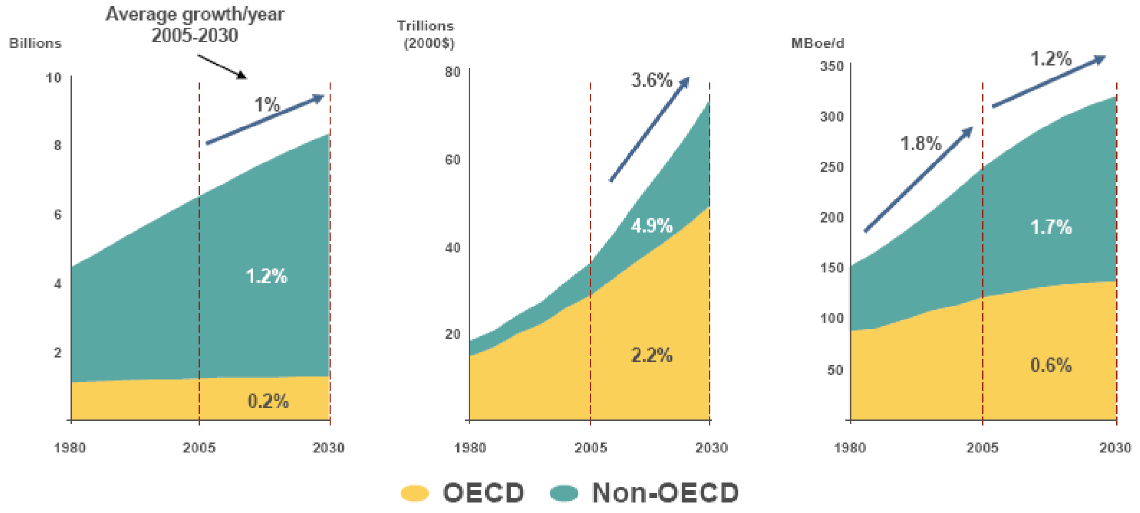


Figure 50. *Projections of Global Population, GDP and Energy Demand Developments (Total 2008).*

According to Total oil and gas remain their positions as leading primary energy sources. In 2030, they are likely to account for more than 50 % of world primary energy consumption (Total 2008).

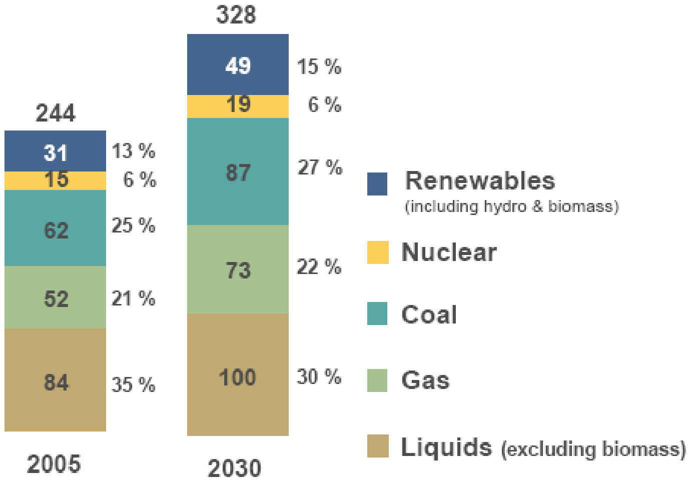


Figure 51. *World Energy Demand (million boe/day) (Total 2008).*

As Total oil and gas remain their positions as leading primary energy sources, the CO_2 emissions are likely to increase (Total 2008).

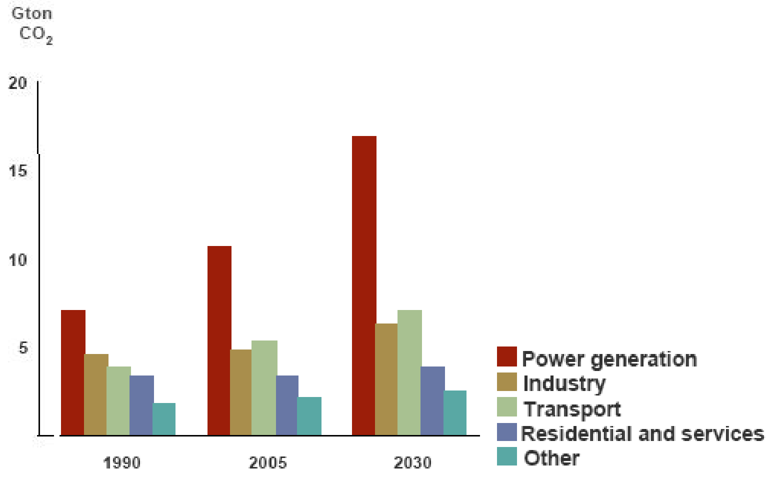


Figure 52. *CO$_2$ Emissions by Sector (Total 2008).*

2.1.8. EREC: Renewable Energy Scenario to 2040

European Renewable Energy Council, EREC, published it energy scenarios to 2040 in 2004. Assumptions made by EREC and its member associations (EPIA, ESHA, ESTIF, EUBIA, EUREC Agency, EWEA, AEBIOM and EGEC) are based on experiences and cumulative knowledge lead to assumptions on expected annual installations growth rates for different technologies and show that by 2040, a share of renewable energy up to 50 % worldwide is possible. (EREC 2004)

Two scenarios have been considered. The First scenario is called advanced international policies scenario (AIP). The assumptions in this scenario are based on ambitious growth rates for renewable energy sources that need additional support measures in order to be reached. It is assumed that regions already active in the promotion of renewables will increase their efforts and that other regions will follow these examples. Higher prices for conventional energy supply are anticipated as well as growing support for electrification of the less and least developed regions by renewables. Implementation of the Kyoto protocol as well as additional measures on the international level for climate protection and for the promotion of renewables is also needed to reach the assumed growth rates. (EREC 2004)

The assumptions for total energy consumption in the scenario are based on a scenario from the IIASA (International Institute for Applied Systems Analysis). It is optimistic about technology and geopolitics and assumes unprecedented progressive international cooperation focused explicitly on environmental protection and international equity. It also includes substantial resource transfers from industrialized to developing countries and spurring growth in the South. (EREC 2004)

	2001	2010	2020	2030	2040
Total Consumption in Mtoe (IIASA)	10038,3	10549	11425	12352	13310
Biomass	1080	1313	1791	2483	3271
Large hydro	222,7	266	309	341	358
Small hydro	9,5	19	49	106	189
Wind	4,7	44	266	542	688
PV	0,2	2	24	221	784
Solar thermal	4,1	15	66	244	480
Solar thermal electricity	0,1	0,4	3	16	68
Geothermal	43,2	86	186	333	493
Marine (tidal/wave/ocean)	0,05	0,1	0,4	3	20
Total RES	1364,5	1745,5	2694,4	4289	6351
RES Contribution	13,6%	16,6%	23,6%	34,7%	47,7%

Figure 53. *The Contribution of Renewable Energy Sources to the World Energy Supply in 2040 - Projections in Mtoe – Advanced International Policy Scenario (EREC 2004).*

The second scenario is called Dynamic current policies scenario (DCP). Dynamic current policies do not mean "business as usual". Assuming that a "business as usual" is seen as impossible for a sustainable future by a lot of decision-makers, the model is based on less international cooperation as the AIP-scenario in the field of RES, but expects ambitious policy measures on national level at least in the industrialised part of the world. (EREC 2004)

Dynamic current policies scenario is a "middle-course" scenario for the total consumption. It incorporates more modest estimates of economic growth and technological development and the demise of trade barriers and expansion of new arrangements facilitating international exchange. (EREC 2004)

	2001	2010	2020	2030	2040
World Primary Energy Consumption (Mtoe)	10038,3	11752	13553	15547	17690
Biomass	1080	1291	1653	2221	2843
Large Hydro	222,7	255	281	296	308
Small Hydro	9,5	16	34	62	91
Wind	4,7	35	167	395	584
PV	0,2	1	15	110	445
Solar Thermal	4,1	11	41	127	274
Solar Thermal Power	0,1	0,4	2	9	29
Geothermal	43,2	73	131	194	261
Marine (tidal/wave/ocean)	0,05	0,1	0,4	2	9
TOTAL RES	1364,5	1682,5	2324,4	3416	4844
RES Contribution	13,6%	14,3%	17,1%	22,0%	27,4%

Figure 54. *The Contribution of Renewable Energy Sources to the World Energy Supply in 2040 – Projections in Mtoe – Dynamic Current Policy Scenario (EREC 2004).*

2.2. Development in China and India

It is common knowledge that China's and India's energy demand affects both the price and fuel accessibility worldwide. It encourages climate change and other environmental problems as well.

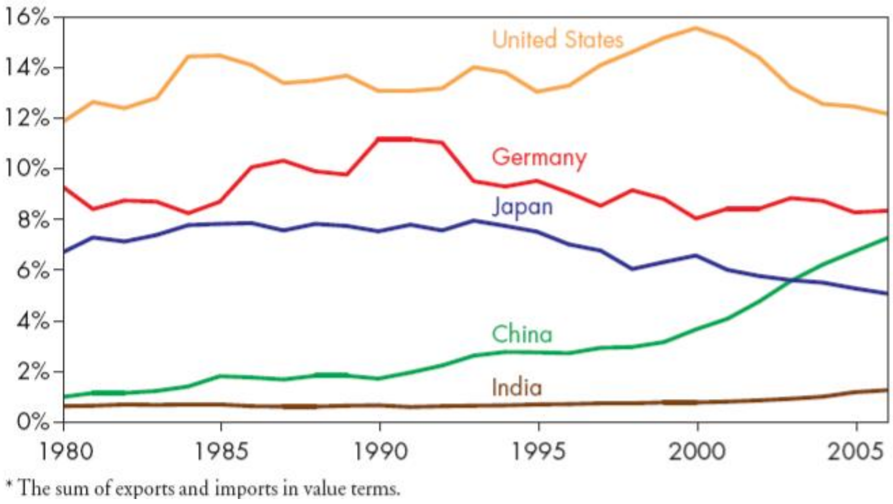


Figure 55. China's and India's Share in World Trade in Goods and Services Compared with Other Countries (IEA 2007).*

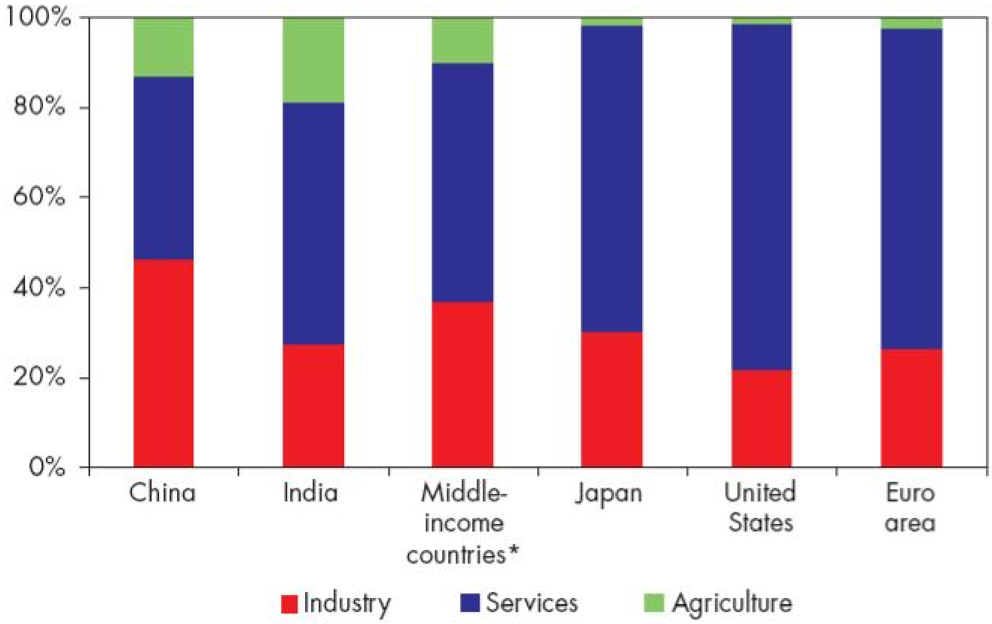


Figure 56. Sectoral Share of GDP, 2004 (IEA 2007).

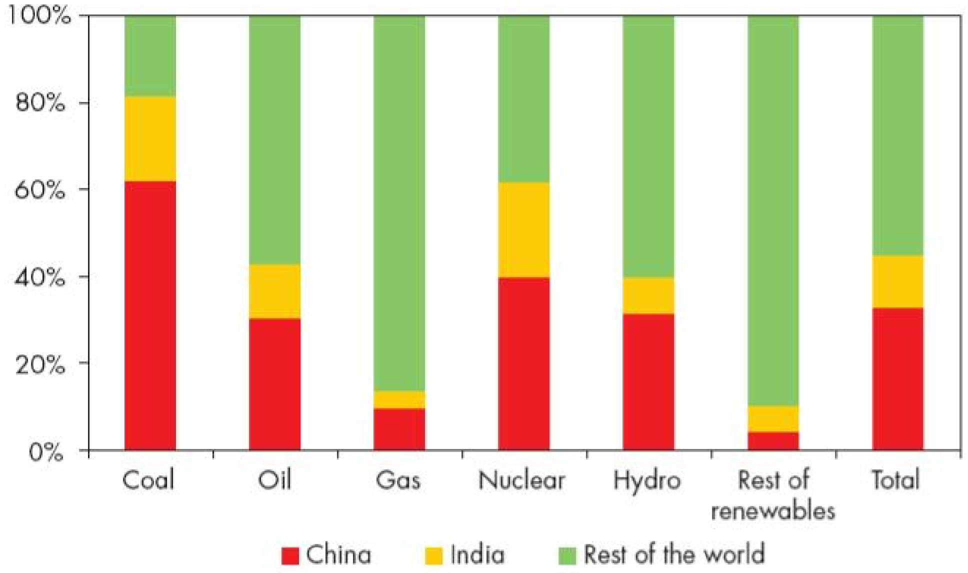


Figure 57. *Shares of China and India in the Increase in World Primary Energy Demand by Fuel in the Reference Scenario, 2005–2030 (IEA 2007).*

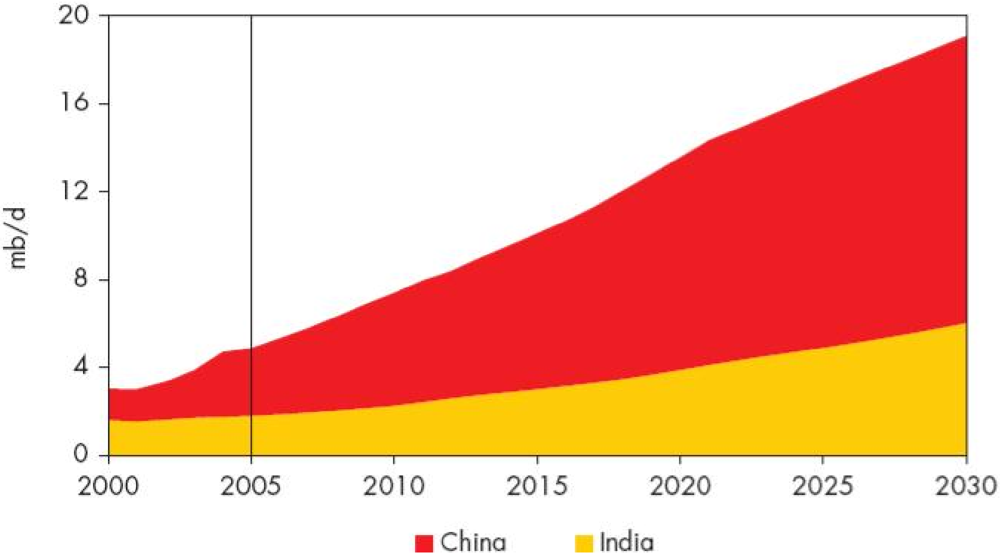


Figure 58. *Net Oil Imports in China and India in the Reference Scenario (IEA 2007).*

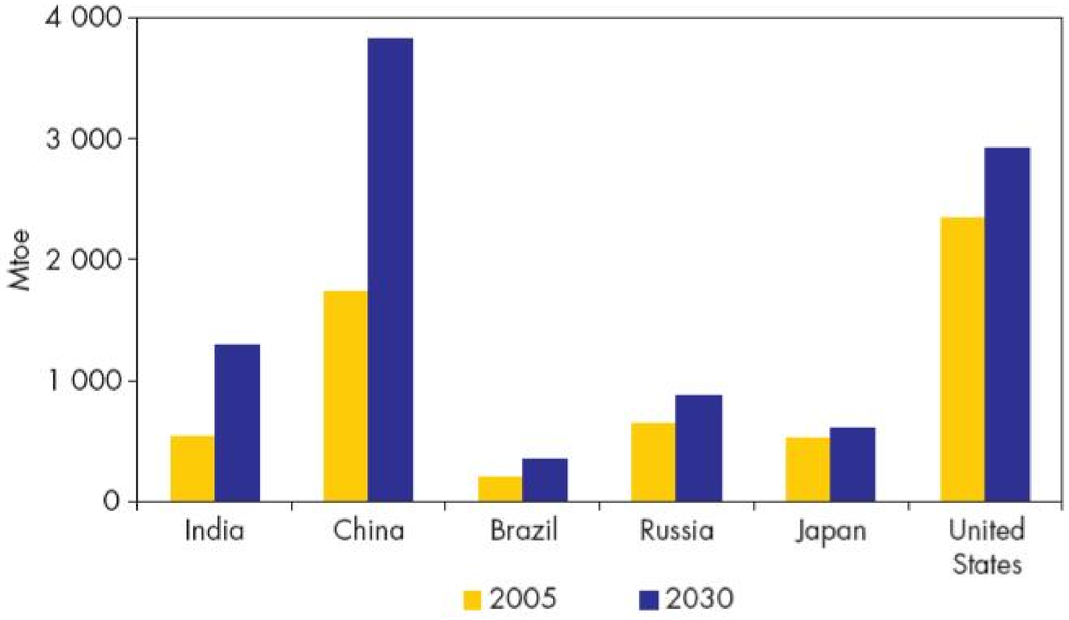


Figure 59. *Primary Energy Demand in Selected Countries in the Reference Scenario (IEA 2007).*

The increase of energy consumption in both of the countries is connected to the rapid growth in their economies. China's economy has grown at an average annual rate of 9.5 per cent and India is not far behind China. Worldwatch Institute believes in the possibility of India taking place as the world's fastest growing economy in the next 15 years. This kind of growth requires much from the energy sources – and not just in India or China. At the moment China is the second largest energy consumer and India the sixth. Both of the countries are pursuing oil from as far as Sudan or Venezuela. Also development in the number of owned cars is rapidly growing in both of them perhaps leading into world's biggest car industry. By 2025 China is expected to burn over 14.2 million bbl oil per day, which would double last years level. Oil import in India is expected to triple to 5 mb/d by 2025. (Makover et al. 2006)

In the BAU scenario of World Energy Outlook 2007 oil maintain its position as world's most important energy source. Energy demand is expected to grow 37 %. Considering the increasing number of cars per capita the projection seems realistic. By 2030 car intensity in China is projected to rise to a car per every sixth Chinese from the today's level of a car per 35 Chinese citizens. In the Reference scenario the quantity of vehicles is projected to be about 270 million, in the High growth scenario near 410 million vehicles, by 2030. (IEA 2007)

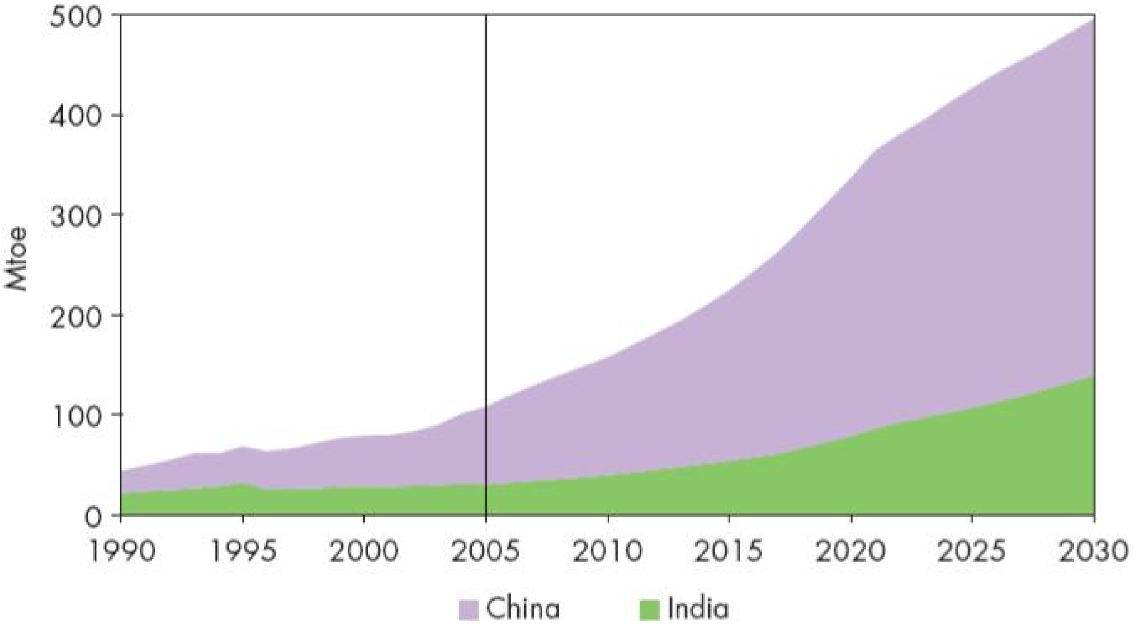


Figure 60. *Road Transport Fuel Consumption in China and India in the Reference Scenario (IEA 2007).*

Coal demand is expected to grow intensively by 2030, mainly due to the increase in electricity production in China and India. Coal share of the energy supply is projected to grow globally from 25 per cent to 28 per cent. (IEA 2007.)

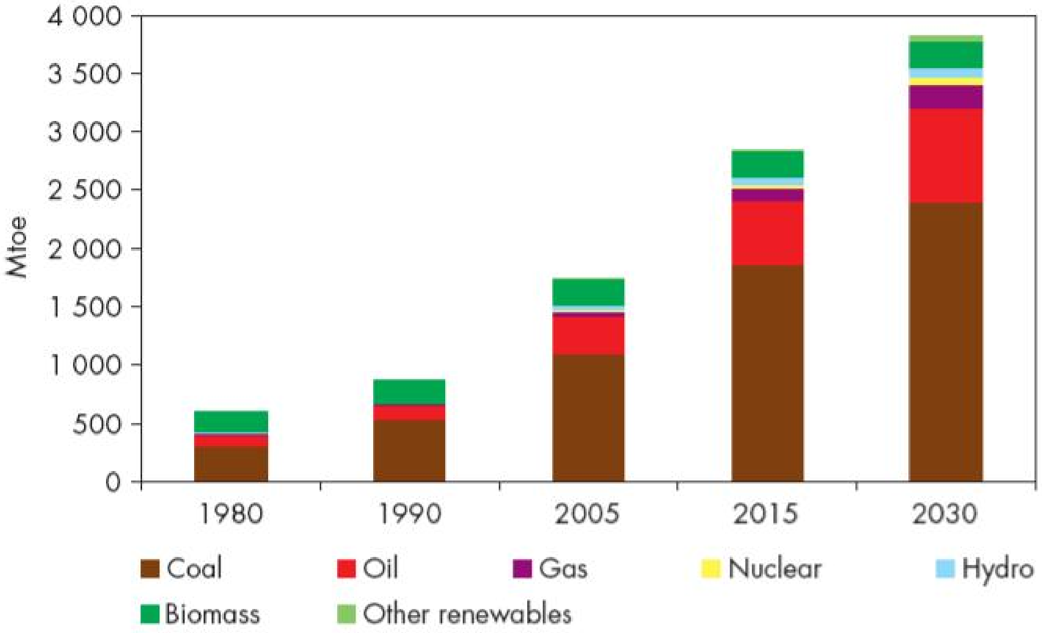


Figure 61. *China's Primary Energy Demand in the Reference Scenario (IEA 2007).*

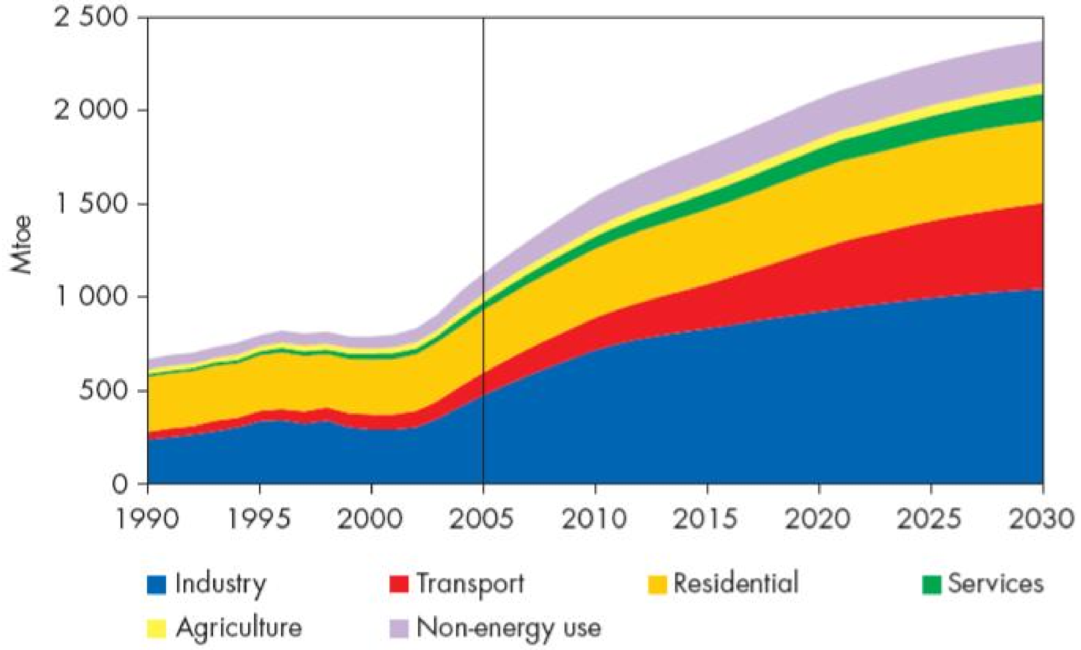
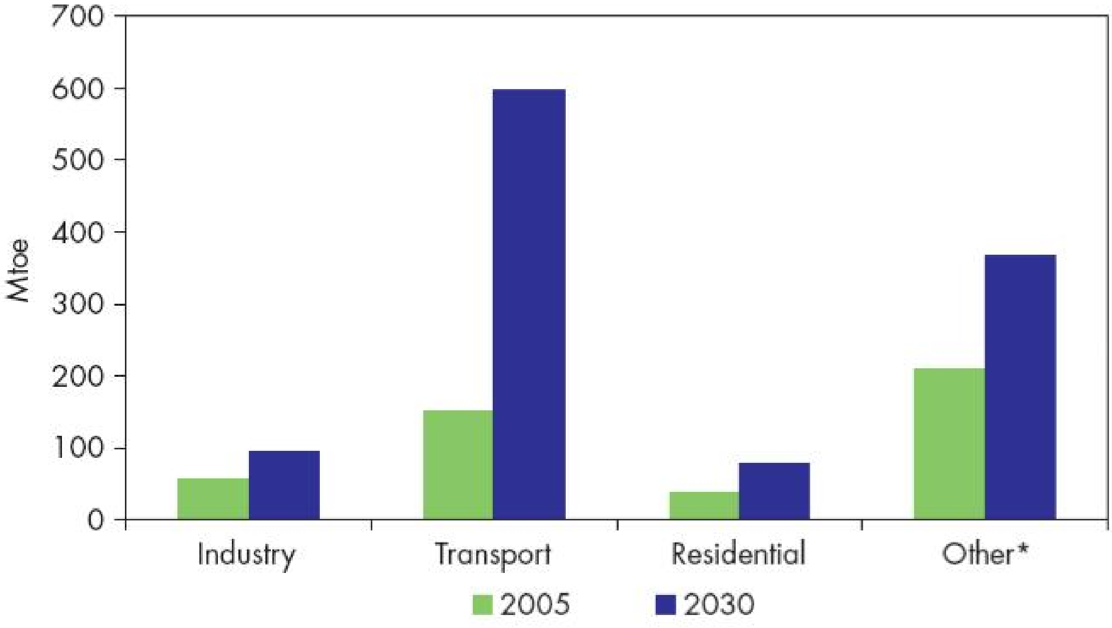


Figure 62. Total Final Consumption by Sector (Mtoe) (IEA 2007).



* Includes power generation, other energy sector, services, agriculture and non-energy use.

Figure 63. Primary Oil Demand in China and India by Sector in the Reference Scenario (IEA 2007).

IEA energy outlook contains BAU model and High Growth scenario for India as well. In the Reference scenario the need for primary energy is expected to reach 1,299 Mtoe by 2030 (537 Mtoe in 2005). Reference scenario is based on the assumption of average annual economic growth rate of 6.3 %, as the High Growth scenario represents an alternative future with 7.8 % annual growth rate. Higher growth rate would lead to increased demand of primary energy (4.2 % annual rate) compared to 3.6 % growth rate in the Reference scenario. Accelerated economic growth would speed up the increase in growth rate of owned cars in India, which would lead to rapid increase in oil demand: 8.3 million b/d by 2030 (in the Reference scenario 1.8 million b/d less). India could become world's third biggest importer of oil soon after 2030. (IEA 2007)

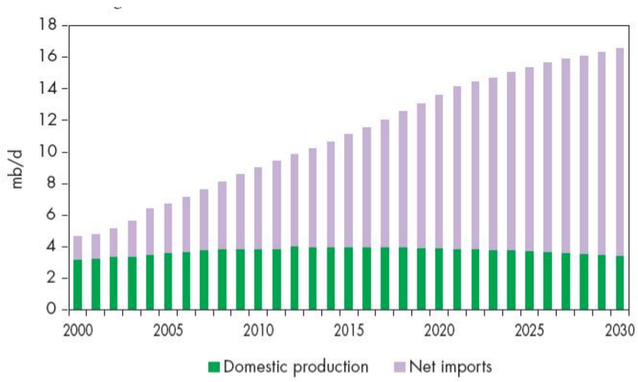


Figure 64. *China's Oil in the Reference Scenario (IEA 2007).*

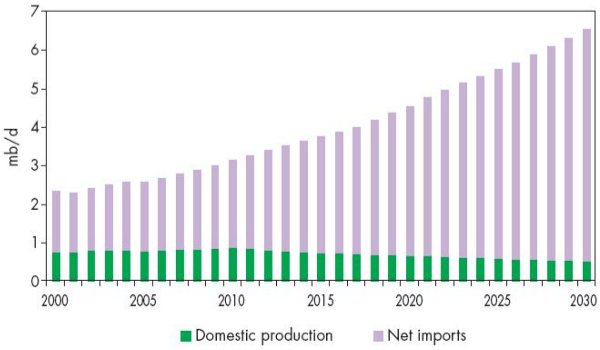


Figure 65. *India's Oil Balance in the Reference Scenario (IEA 2007).*

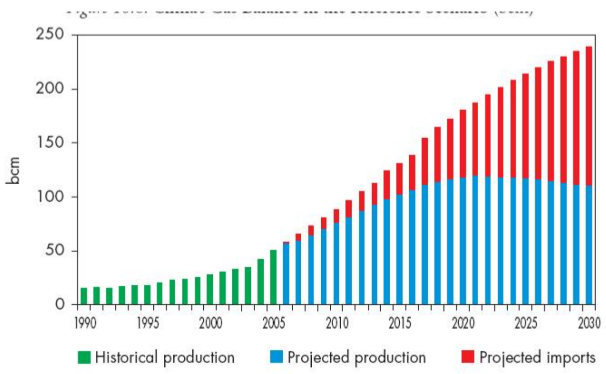


Figure 66. *China's Gas Balance in the Reference Scenario (bcm) (IEA 2007).*

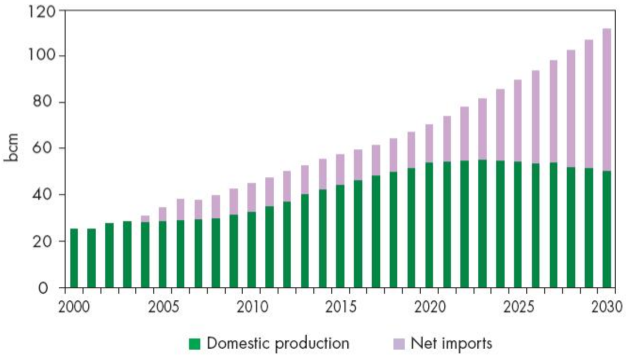


Figure 67. *India's Natural Gas Balance in the Reference Scenario (IEA 2007).*

Faster economic growth would enable electricity for all Indian households by 2030, as Reference scenario projects 96 % of households having access to electricity in the same period. Energy demand is expected to grow 2005–2030 about 180 %, at an annual rate of 4.2 % (3.6 % in the Reference scenario). Economic growth allows quicker transition towards more efficient energy production, which means diminishing use of biomass. India strives for ascending number of nuclear production, which by 2030 would be 21 % higher in the High Growth scenario than in the Reference scenario. Nevertheless the amount of CO_2 emissions is expected to rise to 3.9 Gt by 2030, which is 2.8 Gt more than nowadays. (IEA 2007.)

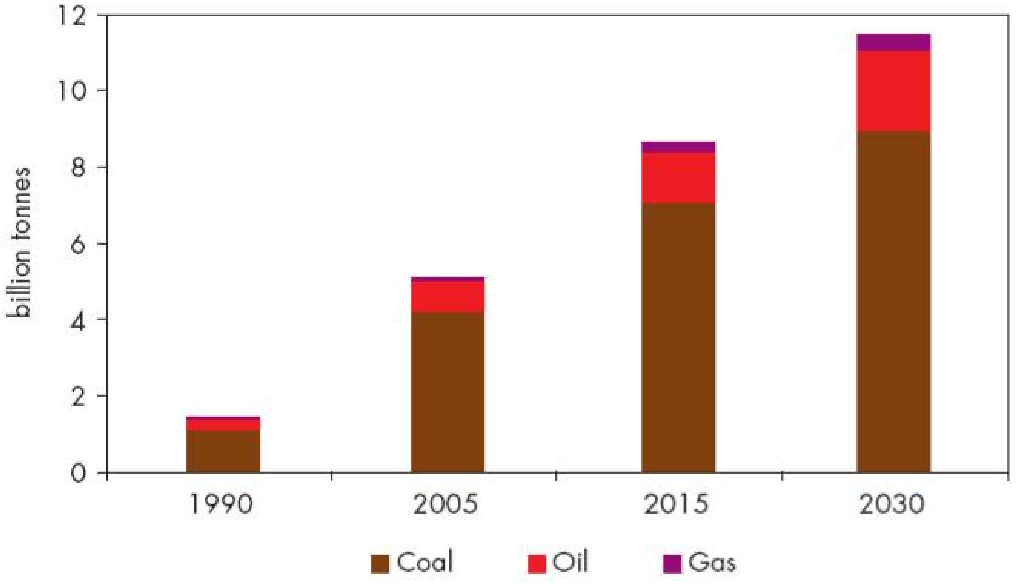


Figure 68. Energy-related CO2 Emissions by Fuel in the Reference Scenario in China (billion tonnes) (IEA 2007).

Both China and India have enormous demand for emission reduction. Both countries are highly dependent on coal. Relatively most efficient measures to decrease emissions concentrate on intensifying the end-use, replacing coal with renewables, natural gas or nuclear power and especially in India modernizing power plants. In China there is significant potential to reduce emissions by decreasing the energy loss in electricity transfer and distribution. (IEA 2007)

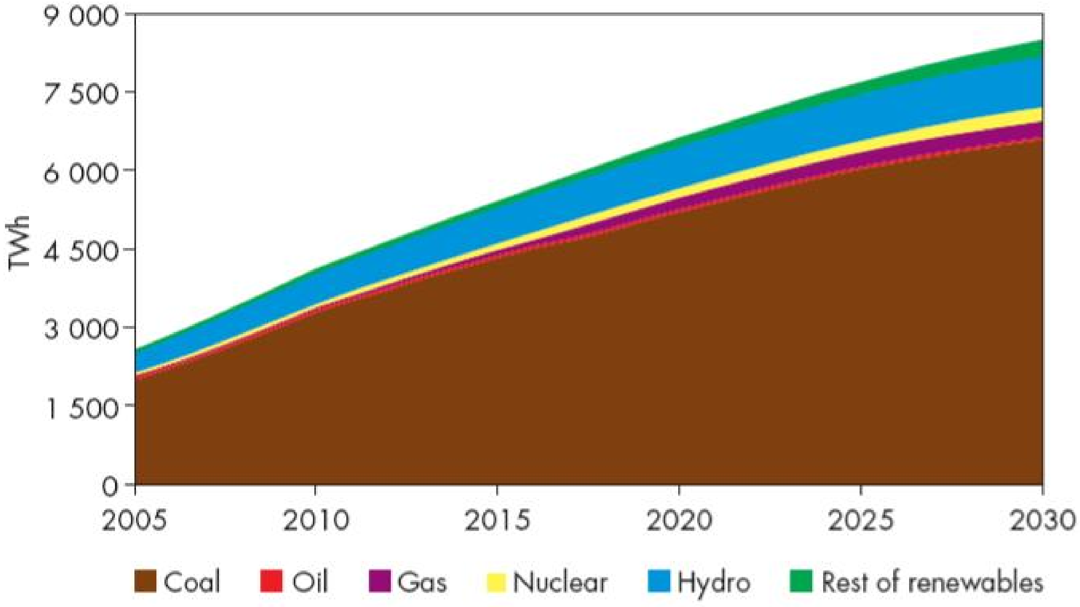


Figure 69. Electricity Generation in China, 2005–2030 (IEA 2007).

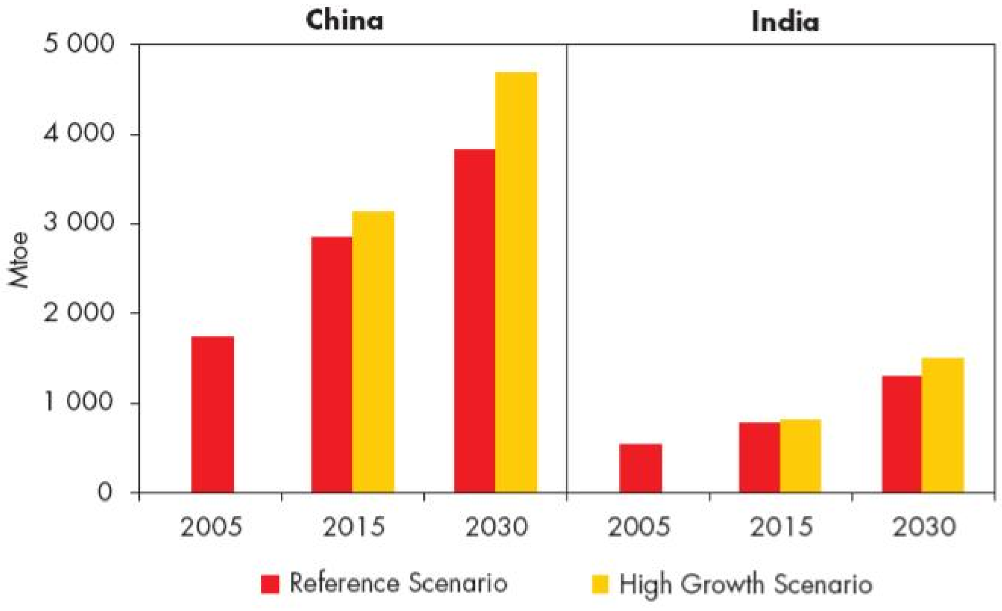


Figure 70. Primary Energy Demand in China and India in the Reference and High Growth Scenarios (IEA 2007).

In the High Growth scenario of IEA the average economic growth rate is projected to be 7.5 per cent per year. In the analyzed period world's energy demand would ascent over 50 % of its current level. India and China are together responsible for 45 % of the increase in demand. In year 2010 China will probably take USA's place as the world's largest energy consumer. (IEA 2007)

These two giants, whose population is 40 % of global population, might speed up the usage of cleaner energy. China is accessing its huge energy flows – bio fuels, solar and wind power. For instance on the Chinese territory and coast the potential of wind power alone is approximately 2,000 GWs, which is one of the biggest in the world. China is the leading country in thermal power usage to water heating, since 60 % of the installed systems are in China. National People's Congress approved a bill favoring renewable energy sources, which bind China to produce 15 % of the state's energy with renewables by 2020. China's official goal is to boost its energy usage by 20 % per every addition in GDP by 2010. (IEA 2007)

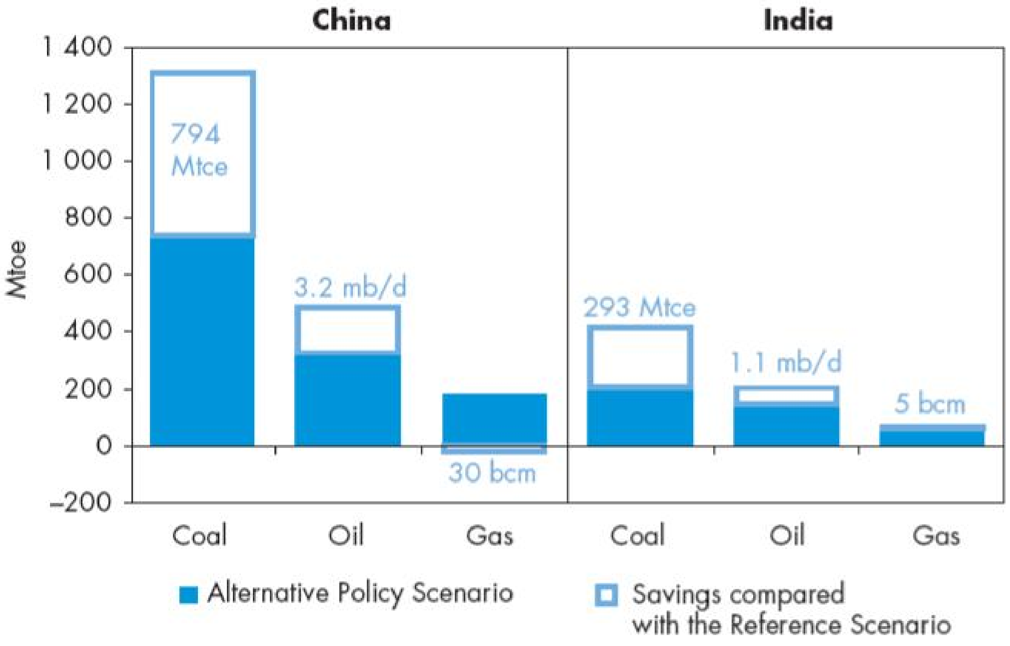


Figure 71. Incremental Primary Fossil Fuel Demand in China and India in the Alternative Policy Scenario, 2005–2030 (IEA 2007).

Chinese government and strong authority concentrated in the provinces make it hard to execute energy programs led by central administration, because of the lack of commitment in provinces. Chinese environmental government is not centralized and coherent, nor is there any remarkable supervisor or coordinator. Part of the Chinese environmental problem is that cheap labor and energy are needed to sustain rapid economic development. Energy price is kept low for alluring investors, and it is a mean to promote low income households. On one hand low prices restrain inflation, but on the other hand they allow the extravagant usage of energy. (IEA 2007)

India has set a goal to produce enough clean energy to be able to electrify all villages by 2010. According to the plan 4,000 MW of renewable energy should be added by 2007 for the goal to be accomplished, so that the share of renewables would rise to 10 per cent. This kind of ambitious goal require huge investments, some estimates claim even 1.5 trillion juans (2006). It is likely that these goals will encourage further innovative actions among Chinese people and business, and will open business opportunities also for their American, European and Asian partners. Both countries have affordable labor, emerging crowd of engineers and know-how. China already is world's largest mobile phone market. Perhaps solar panels, wind mills or hybrid cars are next. (IEA 2007)

2.3. Development in the United States

Energy Information Administrations Annual Energy Outlook 2008 presents diverse scenarios concerning the results of different energy policy paths. It contains a reference scenario which serves as a clear basis against which other alternatives can be compared. The AEO reference case reflects reduced expectations for economic growth: GDP grows at an average annual rate of 2.4 % from 2006–2030. (U.S. Energy Information Administration 2008)

In the AEO reference case the total primary energy consumption grows by 19 percent 2006–2030, from 99.5 quadrillion Btu to 118.0 quadrillion Btu in 2030. Lower estimate compared to previous calculations is influenced by lower economic growth, greater use of more efficient appliances and vehicles, higher energy prices, and slower growth in energy-intensive industries. Residential delivered energy consumption grows in the RS from 10.8 quadrillion Btu in 2006 to 12.9 quadrillion Btu in 2030 (0.7 percent per year). High delivered energy prices and slower growth in commercial square footage lead to slower growth in energy consumption: delivered commercial energy consumption grows from 8.3 quadrillion Btu in 2006 to 11.3 quadrillion Btu in 2030. (U.S. Energy Information Administration 2008.)

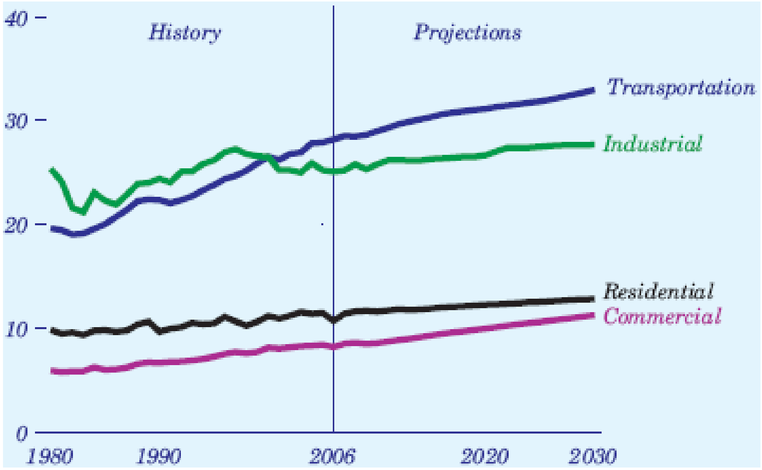


Figure 72. *Delivered Energy Consumption by Sector (quadrillion Btu) in USA. Reference scenario (U.S. Energy Information Administration 2008).*

Since 1997, delivered energy consumption in the USA industrial sector has trended downward, falling from 27 quadrillion Btu to 25 quadrillion Btu in 2006, in spite of rising output. Industrial delivered energy consumption is expected to increase to 27.7 quadrillion Btu in 2030. Growth in the energy-intensive manufacturing industries averages 0.7 percent a year from 2006 to 2030. Delivered energy consumption in the transportation sector grows to 33.0 quadrillion Btu in 2030. (U.S. Energy Information Administration 2008)

Total consumption of liquid fuels, including both fossil liquids and bio fuels, is expected to grow from 20.7 million barrels per day in 2006 to 22.8 million barrels per day in 2030 which is lower estimate than before due to the new LDV CAFÉ standard specified in EISA-2007. Much of the difference appears in the transportation sector. Natural gas consumption increases from 21.7 trillion cubic feet in 2006 to 23.8 trillion cubic feet in 2016, then declines to 22.7 trillion cubic in 2030. Electricity generation accounts for 5.0 trillion cubic feet of natural gas use in 2030. (U.S. Energy Information Administration 2008)

Total coal consumption increases from 22.5 quadrillion Btu in 2006 to 29.9 quadrillion Btu in 2030. Coal consumption is projected to grow at a faster rate toward the end of the period, particularly after 2020, as coal use for new coal-fired generating capacity grows rapidly. Coal consumption in the electric power sector increases from 22.7 quadrillion Btu in 2020 to 27.5 quadrillion Btu in 2030, and coal use at CTL plants increases from 0.6 quadrillion Btu in 2020 to 1.0 quadrillion Btu in 2030. (U.S. Energy Information Administration 2008)

The AEO2008 reference case projects substantially greater use of renewable energy as a result of EISA2007. Total consumption of marketed renewable fuels grows by 3.0 percent per year, from 6.8 quadrillion Btu in 2006 to 13.7 quadrillion Btu in 2030. About 45 percent of the demand for renewables in 2030 is for grid-related electricity generation. (U.S. Energy Information Administration 2008)

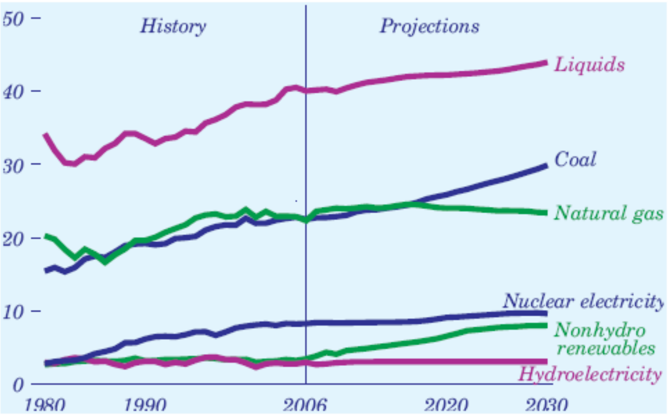


Figure 73. Energy Consumption by Fuel (quadrillion Btu) in USA (U.S. Energy information Administration 2008).

The rapid growth in the use of renewable fuels for transportation reflects the EISA2007 RFS, which sets a requirement for 21 billion gallons of advanced bio fuels and 36 billion gallons of total renewable fuels by 2022 (U.S. Energy Information Administration 2008).

Ethanol use grows from 5.6 billion gallons in 2006 to 23.9 billion gallons in 2030. Ethanol use for gasoline blending grows to 13.4 billion gallons and E85 consumption to 10.5 billion gallons in 2030. The ethanol supply is expected to be produced from both corn and cellulose feed stocks, with corn accounting for 15.0 billion gallons and cellulose 6.9 billion gallons of ethanol production in 2030. Excluding hydroelectricity, renewable energy consumption for electric power generation grows from 0.9 quadrillion Btu in 2006 to 3.2 quadrillion Btu in 2030. (U.S. Energy Information Administration 2008)

Energy intensity, measured as primary use per dollar of GDP, declines by about one-third from 2006 to 2030 in the RS.

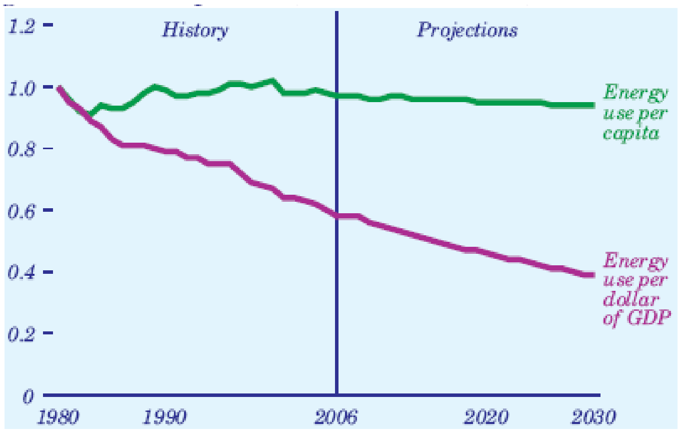


Figure 74. Energy Use per Capita and per Dollar of GDP (index 1980=1) in USA (U.S. Energy Information Administration 2008).

Net imports of energy share are expected to continue meeting a major share of total U.S. energy demand. EISA2007 and the new CAFÉ standards however serve to moderate growth in energy imports. U.S. crude oil production is increases from 5.1 million barrels per day in 2006 to a peak of 6.3 mb/d in 2018, then subsequently declines to 5.6 mb/d in 2030. (U.S. Energy Information Administration 2008)

Total electricity consumption grows from 3,814 TWh in 2006 to 4,972 TWh in 2030, increasing at an average annual rate of 1.1 percent (U.S. Energy Information Administration 2008).

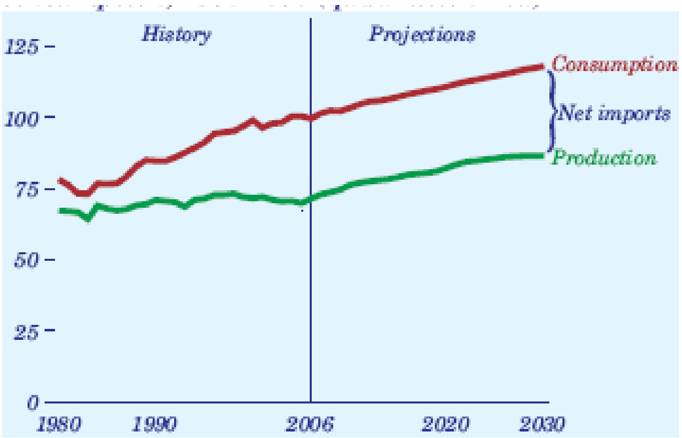


Figure 75. Total Energy Production and Consumption (quadrillion Btu) in USA (U.S. Energy Information Administration 2008).

In the AEO 2008 reference scenario, the coal share of total energy use increases from 23 percent in 2006 to 25 percent in 2030, while the share of natural gas falls from 22 percent to 20 percent, and the liquids share falls from 40 percent to 37 percent. The combined share of carbon-neutral renewable and nuclear energy grows from 15 percent in 2006 to 17 percent in 2030. (U.S. Energy Information Administration 2008)

Taken together, projected growth in the absolute level of primary energy consumption and a shift toward a fuel mix with slightly lower average carbon content cause projected energy-related emissions of CO_2 to grow by 16 percent from 2006 to 2030. Projected energy-related CO_2 emissions grow from 5,890 million metric tons in 2006 to 6,851 million metric tons in 2030. (U.S. Energy Information Administration 2008)

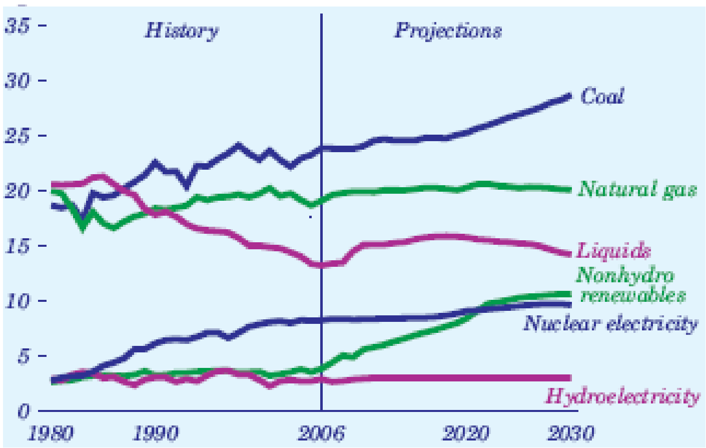


Figure 76. Energy Production by Fuel (quadrillion Btu) in USA (U.S. Energy Information Administration 2008).

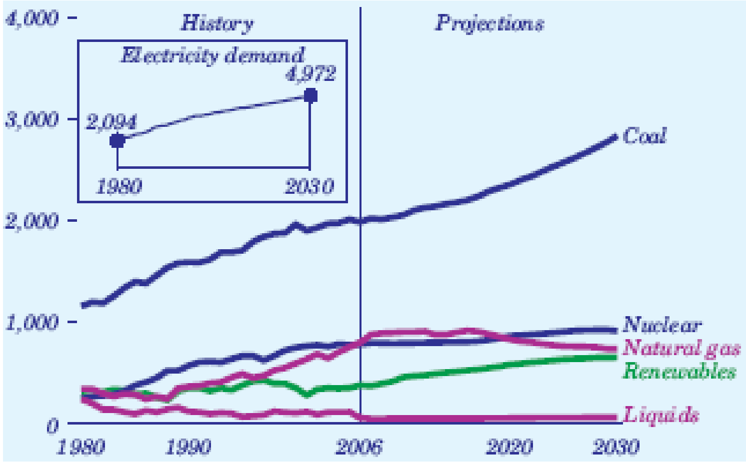


Figure 77. Electricity Generation by Fuel (TWh) in USA (U.S. Energy Information Administration 2008).

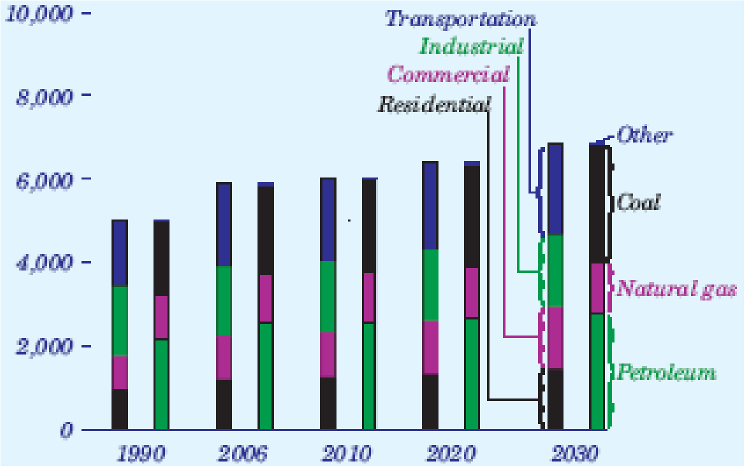


Figure 78. Carbon Dioxide Emissions by Sector and Fuel (million metric tons) in USA (U.S. Energy Information Administration 2008).

AEO 2008 presents three views of economic growth for the projection period. Economic growth depends on growth in labour force and productivity. The high and the low growth cases show the effects of alternative economic assumptions on the energy market projections. In the high growth scenario, GDP growth averages 3.0 percent a year and in the low growth case the percentage is 1.8 per year. Emission projections change with economic growth assumptions. Emissions in 2030 are 9 percent lower in the low growth case and 9 percent higher in the high growth case than in the RS. The relationship is strongest for the industrial sector and to lesser extent in the transportation sector, where economic activity strongly affects energy use and emissions and where fuel choices are limited. In the low growth scenario industrial delivered energy consumption falls to 24.2 quadrillion Btu in 2030, as industrial value of shipments grows only by 0.5 percent per year. In the high growth scenario, industrial value of shipments grows by 2.0 percent per year and energy consumption rises to 31.7 quadrillion Btu in 2030, which is 14 percent higher than in the RS. In 2030, transportation sector energy consumption is about 8 percent higher in the high growth scenario and 8 percent lower in the low growth scenario than in the reference case. The modes with the largest increases are heavy trucks and aircraft. (U.S. Energy Information Administration 2008)

2.4. Development in the European Union

The biggest challenge for the European energy sector in the next decades will be to balance sustainable development, competitiveness and security of supply. The investment needed in this sense is estimated to be huge: about one trillion euros over the next 20 years.

In order to meet the objectives above, the following six priority areas and the related actions have been identified by the Commission of the European Communities (2006):

1. Complete the EU internal gas and electricity markets. This could be done mainly through the development of a European Grid, improved interconnections and coordination between regulators, competition authorities and the Commission.
2. Ensure the EU internal energy market guarantees security of supply and solidarity between Member States. This would be achieved primarily through a European energy supply observatory, which would enhance transparency on security of energy supply issues and energy stocks within the EU.
3. Promote a Community-wide debate on the different energy sources, in order to monitor that the overall EU energy mix pursues the objectives of security of supply, competitiveness and sustainable development.
4. Deal with the challenges of climate change in a manner compatible with its Lisbon objectives. In particular, clear goals should be set to prioritize energy efficiency (with a goal of saving 20 % of the energy that the EU would otherwise use by 2020) and a long-term road-map for renewable energy sources should be implemented.
5. Present a strategic energy technology plan to the European Council and Parliament, so to make best use of Europe's resources
6. Define a common external energy policy, which should include also a pan-European Energy Community Treaty, a new energy partnership with Russia, as well as a new Community mechanism to enable rapid and coordinated reaction to emergency external energy supply situations impacting EU supplies.

In relation to these priorities, scenarios have been developed to forecast the development of energy demand in the next years. One example is the study carried out by National Technical University of Athens for the Directorate-General for Energy and Transport of the European Commission. The main findings of the baseline scenario are reported below (3):

80 % of incremental energy consumption to 2030 will be met by natural gas, which in 2030 will be the second largest fuel, with 32 % of total EU15 primary energy demand. Oil will remain the largest fuel and will meet 35 % of total demand. (Mantzos et al. 2003)

Renewables are forecasted to be the fastest growing energy source, but their share rises from only 6 % in 2000, to 7.4 % in 2010 and 8.6 % in 2030, according to Baseline assumptions. (Mantzos et al. 2003)

Nuclear will increase only marginally (+3 %) in 2010, but its output in 2030 will be some 22 % lower than in 2000, a result due to the nuclear phase-out of some Member States. The consumption of solid fuels will decrease steeply in the medium term, but will regain its 2000 value in 2030, as a replacement to nuclear energy. (Mantzos et al. 2003)

The tertiary sector and transport will be the fastest growing final energy markets, both growing more than overall final energy demand. The rail share of both passenger and freight transport will fall because of large substitution away from rail transport in the countries acceding to EU. The increasing GDP per capita of these areas will also lead to a growing demand for air travel and km travelled per capita in the EU25 (about 50 % increase in the reference period) (Mantzos et al. 2003).

Electricity is forecasted to be the fastest growing fuel in final use (about 1.6 % p.a. by 2030), followed by heat from CHP and district heating plants. Gas also grows above average (1.1 % p.a.), meanwhile oil will increase more slowly: despite growing demand in the transport sector, this result reflects the fuel switching away from oil in other final demand sectors. (Mantzos et al. 2003)

In the Baseline scenario the increase of renewables in final energy demand will be rather slow, by only 0.2 % p.a. (Mantzos et al. 2003)

For electricity generation, over the projection period natural gas becomes the most important source, meanwhile solid fuels, oil and nuclear all lose market shares. Renewables become much more important, almost matching nuclear in 2030, but, under baseline conditions, fail to reach the 22 % target in 2010 the CHP share increases only moderately, despite its key role in the efficient use of fossil fuels. (Mantzos et al. 2003)

Investment requirements in electricity generation are considerable because capacity increases to about 950 GW in 2030. Electricity prices are also forecasted to decrease, thus reflecting efficiency gains derived from technological progress, fuel switching and completion of the internal market. (Capros & Mantzos 2006)

2.5. Development in Russia

In 2005 The Committee for the Future formed a group focused on Russia-issues, which were supposed to collect material about the present state and future development in Russia. The group involved several experts, who expressed their views on the subject. The results of the Russia group were published in year 2007 about the Russia in 2017. (Kuusi et al. 2007)

Russian economic is expected to grow strongly in the near future; possibly some decelerating is seen near 2017. Growth rate is estimated to be 3–6 % in the near future. The exceptionally huge disagreements among estimates reflect the magnitude of uncertainties involving Russian prospects. Russian ruble will strengthen for several years, but it won’t keep the same pace (10 % last few years). Due to growing GDP and strengthening ruble Russian imports increase fast. On the other hand the real strengthening hinders the competitiveness of exports. (Kuusi et al. 2007)

In the beginning of the 21st century Russian oil production grew almost 10 % per year. However, according to the official estimates both oil and gas production will increase only 2 % per year in the near future. If the current trend is to be continued Russian energy production is decreasing already in year 2017. Because of this the surplus of current accounts would be gone in a few years. Then the continuing rising of energy prices in the world markets is likely to compensate the reducing of the exports. (Kuusi et al. 2007)

Besides energy production Russian government has strongly emphasized ICT-related branches as a strategy in the future. The Electronic Russia 2002–2010 program has had 2.6 billion dollars for enabling internet usage and new e-services among citizens and companies. (Kuusi et al. 2007)

Population continues to decrease. It reached its peak at 1992, when it was over 148 million. Now the amount is over 143 million, and according to the Russian Statistics in year 2017 population would be approximately 135 millions. However it must be kept in mind that predictions are sensitive especially to grand population movements. Russia's multicultural tradition ensures that Russia will continue to be the destination for immigrants from the former Soviet Union countries. It is also possible that Russia strives for persuade the approximately 25 million Russians living outside Russia to return. Russia has relatively large age group of those born in the 80s. Still the population achieving the working-age will go halves by 2017. The pressure to adjust in work markets, education and in military is enormous. Because of the weakening relation between working population and people outside work markets current Russian pension system will be inadequate. (Kuusi et al. 2007)

Inequality will strengthen in Russian society. The differences in income and wealth between people and regions remain among the biggest in the world. Development towards urbanization keeps on strong. This will decrease the need to maintain the inherited infrastructure. On the other hand it will set more challenges to the cities ability to take in the new residents. (Kuusi et al. 2007)

Russian experts and the administration are more aware of the problematic scenarios in the future. However, international experience has shown that many of them are hard to change. It is obvious that even with strong will it is hard to get rid of inefficiency, corruption and discretion. Usually it has succeeded only with development towards democracy and civil society. The expansion of the middle class, ICT-development and internationalization could make possible to have openness, equality and democracy at some extent. (Kuusi et al. 2007)

The state of the nature keeps on weakening, though Russia is one of the beneficiaries of the climate change. So Russia holds strong position concerning negotiations about global actions against climate change. Warming climate benefits agriculture and sea traffic can be expanded in the north. The southern parts of the country are likely to suffer and melting permafrost can cause unexpected problems to the energy production and transportation in the northern parts. Even though the average temperature will rise in the north people will continue to centralize into the more dense southern areas. (Kuusi et al. 2007)

The first scenario "Global power player in Energy issues" includes a vision of optimistic development with strengthening principles of law and justice and more diverse economic life. The leading export companies in energy field variegate their business to labor intensive areas. Policy shift is towards less controlled democracy. The scenario can be compared with the situations in Japan and South Korea, which have proceeded to efficient democracy in relatively short time. Of course it must be taken into account that Japan and South Korea were both occupied by USA in the beginning of the process. (Kuusi et al. 2007)

The second scenario “Diverse mosaic – Russia” initiates from the creativity and needs of the new middle class in Russia. The structure of the production continues strongly in the Russian market, especially in the service sector. Large segment of the service sector is focused on consumables distribution and producing consumer services in the home market. The energy export no longer covers the increasing import cost, the balance is provided by the export of services, especially by ICT and international turism. Scenario can not actualize without significant increase in openness towards EU. (Kuusi et al. 2007)

The name “Diverse mosaic – Russia” refers to increasing acceptance of versatility. Traditional Russian traits – resourcefulness and creativity – become national strengths. Even though laws are held binding in big questions and in international relations the authorities’ tolerance towards law bending is high in a local scale. Diverse mosaic -scenario presumes that by year 2017 Russia has evolved to a state which respects and protects individual freedoms. This is accompanied with the prospect of starting the membership negotiations with EU in 2017. Anyhow it is considered too bold to think Russia as a member in 2017. (Kuusi et al. 2007)

Third scenario “The Oligarchy” assumes that strong elite holds the power in Russia with a support of military, police force and energy companies. The elite succeed to maintain considerably high quality of living dependent on export income, even though the basis of the economy remains the same. Living conditions and the standard of living in the middle class are highly dependent on the support to the elite. Major part of the population have low standard of living and are reliant to exchange economy. Civil legal protection and equality do not actualize. National values and security are emphasized. Foreign intervenes are considered as hostile actions and problems are explained to arise from foreign actions. The elite support intolerance towards minorities to distract the dissatisfactions among citizens. The media is run by the elite and activists are silenced. (Kuusi et al. 2007)

First two scenarios are founded on the assumption of Development towards more versatile economic and Russian innovativeness, but the means differ. First scenario takes into account the special traits of Russia and its national traditions. The other scenario resembles the suggestions western communities have presented. Last scenario represents the progress towards more isolated Russia. It hardly can be considered as a positive development. (Kuusi et al. 2007)

Along with the economic growth Russian energy consumption is estimated to keep on growing between 2005 and 2020.

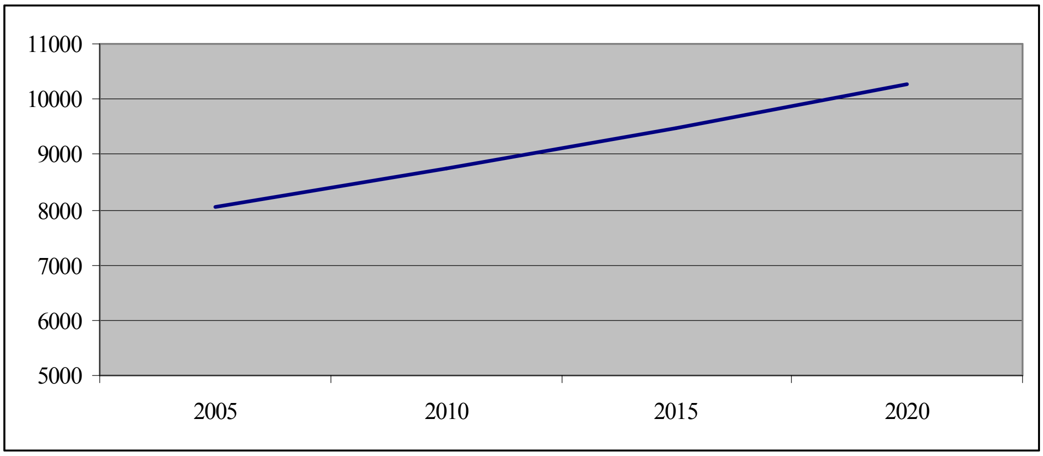


Figure 79. *Consumption of Primary Energy in Russia (TWh) (Ministry of the Russian Federation 2003a).*

Russia's long term goals in energy policy are developing government's transfer payments, advancing energy security, improving energy efficiency and diminishing environmental harms. Russia as a state is dependent on the energy sector and vice versa. On one hand the energy sector is the most important income source, on the other hand it is the biggest receiver of subventions. For the energy sector to maintain its competitiveness the subvention policy must be directed effectively. (Ministry of Energy of the Russian Federation 2003b)

The problems of the energy security in Russia are the weak infrastructure, the pressure on environment by energy production, inefficiencies in the markets, lack of regulations and the dependency on oil and gas. To answer these problems Russia has to modernize its production. The energy consumption structure has to be converted into less oil and gas intensive. This means adding alternative energy production. At the moment Russia's energy intensity is over double compared to rest of the world and triple compared to EU countries. Advancing the energy efficiency is crucial to secure the economic growth. Production need to be directed at less energy consuming industries. Different kinds of energy saving technologies must be deployed. With these actions Russia's energy intensity could decrease even 50 % by 2020. (Ministry of Energy of the Russian Federation 2003a)

Increasing Russia's energy production has also increased environmental harms and threats. Environmental policy has aimed at developing environmental standards to match those of European. Economic guiding and promoting environmental monitoring has been used as means. (Ministry of Energy of the Russian Federation 2003a)

2.6. The Future of International Climate Policy – Burden Sharing Approaches

With the prospect of climate negotiations, experts, stakeholders, and governments have assessed a range of options for advancing the international climate change effort beyond 2012. For instance PEW Center has carried out a broad survey of alternative approaches proposed. The survey encompassed more than 40 proposals either published or publicly presented by 2004. (Claussen & McNeilly, 1998)

Any proposal for advancing the international climate effort comes against the backdrop of the UN Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. The 1992 Framework Convention, ratified by 189 nations, establishes the basic structure of the existing climate change regime. This includes: the ultimate objective of stabilizing greenhouse gas (GHG) concentrations at safe levels; general principles such as precaution, cost-effectiveness, and common but differentiated responsibilities; obligations to report on GHG emissions and national measures to combat climate change; and commitments for assistance and technology transfer to developing countries. The Kyoto Protocol sets forth quantitative commitments by developed countries to reduce their GHG emissions. These commitments take the form of absolute emissions targets, applicable to a basket of six greenhouse gases for a five-year commitment period. The Protocol employs market mechanisms such as emissions trading and the Clean Development Mechanism (CDM), and allows parties to achieve their target in part through sinks activities such as reforestation and forest management. (UNFCCC 1992)

Some of the proposals build on the basic architecture of Kyoto—for example, by extending the CDM or by articulating a pathway towards broader participation. Others depart by varying degrees from the existing architecture—for example, by articulating a different type of commitment (policies and measures rather than quantitative emissions targets); a different negotiating process (national pledges rather than internationally-negotiated commitments); or a different forum (a smaller group of countries rather than a global process). (UNFCCC 1992)

The proposals differ widely in their scope. Some are comprehensive in nature, setting forth a complete picture of a possible future regime. Others address a particular issue in the negotiations—for example, the type of emissions target that should be used or the criteria for differentiating commitments. It is important to recognize that, to the extent, different proposals address different issues, they could be complementary rather than mutually exclusive. (UNFCCC 1992)

One of the most contentious issues of differentiation of (future) commitments is ‘who should contribute when and how much to mitigate global climate change and to the costs resulting from adaptation measures’. The concerns of equity and efficiency are important in the evaluation of the possible burden sharing models, which determine emission commitments for different countries. All in all, it is not an easy task to find a model, which will satisfy all parties. In the next paragraphs some interesting methods and models used to the differentiation of commitments are briefly described. It can be discussed whether these targets should be set for different countries, which are the partners of the Climate Convention, or to the companies, which are the main emitters of the GHGs, or to the final consumers of products and services in other words on 'per capita' basis. (UNFCCC 1992)

The Brazilian Proposal distributes emission reductions to Annex I Parties based on regional contribution to temperature increase due to their historical emissions (since 1890). The burden is shared between industrialised countries on the basis of the cumulative temperature change they have caused, i.e. effective emissions. According to this proposal, countries with a longer history in industrialisation and hence a bigger responsibility would be required to make larger reductions, while those that have industrialised relatively late would have to reduce less. The reduction target for United Kingdom would be 63.3 % whereas for Greece it would only be 7.5 % (UNFCCC, 1997).

The American Pew Center has presented criteria (responsibility, standard of living, opportunity) to group countries into three tiers (high, middle, low) with different levels of action required ('must act now', 'should act now, but differently', could act now'). The tiers are meant to act as indicative groupings for further negotiations. (Claussen & McNeilly, 1998)

In the *Multi-stage approach* a gradual increase in the number of Parties involved and their level of commitment (no commitments; de-carbonisation; stabilisation of emissions; burden sharing) takes place according to participation and differentiation rules (Den Elzen et al, 2002).

One method used in burden sharing proposals is the *triptych approach*, which is a sector and technology-oriented approach that accounts for differences in national circumstances such as population size and growth, standard of living, economic structure and fuel mix in power generation. The Triptych approach is a sector approach distinguishing three categories of emissions, corresponding to three groups of economic sectors: the energy intensive industry, the power producing sector and the domestic sectors. Accounting for varying national circumstances, different criteria are used for each of the three categories to calculate sectoral allowances. (Phylipsen et al, 1998; Groenenberg et al, 2001)

Furthermore, *the multi-sector convergence approach* has many similarities with the region-oriented triptych approach, but has a global coverage. Also, the multi-sector convergence approach contains more sectors than triptych, which makes it more flexible and allows more country-specific circumstances to be taken into account. (Ringius et al, 2000)

A fair amount of attention is also given to different models revolving around the concept of the environmental space and per capita entitlements, including *contraction and convergence*, which is perhaps one of the most comprehensive models devised so far. The contraction and convergence approach tries to use objectively defined criteria for differentiation of commitments and allocates emission allowances on equal per capita base. (IEA 2003)

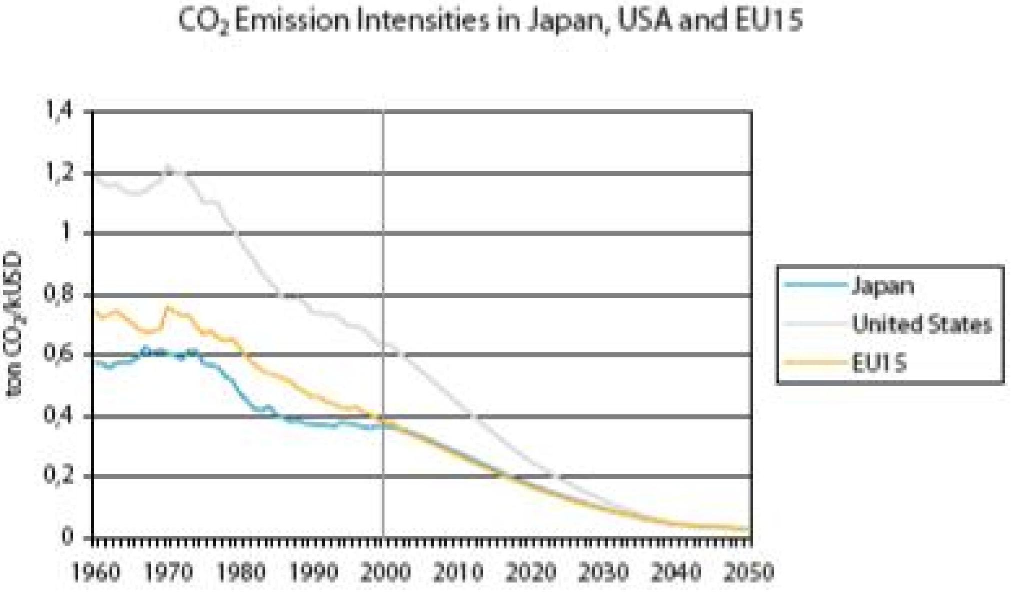


Figure 80. *Change in the CO_2 Intensity of the Economies of Japan, USA and EU15 from 1960 - 2001 and the Required Development up to 2050 in order to Reach the Contraction and Convergence Target of 1.8 tons of CO2 Per Capita (IEA 2003).*

The National Institute of Public Health and the Environment (RIVM) in the Netherlands has developed an interactive analytical computational framework for linking the evaluation of different approaches for the differentiation of future commitments to global climate protection targets. The FAIR (Framework to Asses International Regimes for differentiation of commitments) model can be used to quantitatively explore a wide range of climate policy options for international burden sharing and to evaluate the consequences of different approaches to the differentiation of future commitments. The model includes approaches that have gained policy attention, e.g. the Brazilian proposal, Contraction & Convergence (GCI), Global Compromise (Benito Müller), Triptych approach (UU), Emission Intensity Targets approach. (Netherlands Environmental Assessment Agency 2008)

The FAIR model includes three modes for evaluating international commitment regimes. The first is 'increasing participation' so that the number of parties involved and their level of commitment gradually increase according to participation and differentiation rules (such as per capita income, or per capita emissions). The second is 'convergence', all parties participate in the burden-sharing regime with emission rights converging to equal per capita levels over time and the third is 'triptych': different burden sharing rules are applied for different sectors (convergence of per capita emissions in domestic sector, efficiency and de-carbonization targets for industry and power generation sector). The three modes in FAIR, i.e. increasing participation, convergence and triptych combine both different principles of equity as well as most of the other dimensions of regimes. (Netherlands Environmental Assessment Agency 2008)

3. REQUIREMENTS SET BY THE FINNISH SOCIETY

This section presents energy policy goals in Finland (4.1), scenario elements related to regional structure, transport and the way of living (4.2) plus results from a study dealing with energy attitudes of Finnish companies (4.3). It is important to note that any energy scenarios of Finland are not presented here. This is due to the "tabula rasa" starting point of the scenario process to be carried out in parallel with this background report together with Finnish Energy Industries.

3.1. Energy policy goals

Energy is a very significant issue in the Finnish society. It is an important factor of production for industry, and it has a central role in the life and well-being of human beings. Especially electricity has increased its significance, while a larger part of different services are provided electronically via Internet and mobile technologies. Energy consumption in Finland is one of the highest among industrial countries. This is due to the large share of energy-intensive branches in Finnish industrial structure, need for heating in the cold climate, and sparsely populated country with a fragmented regional structure. Energy use has also several different impacts, which have become more and more important in energy-related decision-making.

Targets and requirements related to energy use have been set up for a long time by the Finnish society. These have been included at political level in policy programmes and starategies dealing with energy, and in climate strategies during the 2000s (National Climate Strategy 2001, Outline of the Energy and Climate Policy for the Near Future - National Strategy to Implement the Kyoto Protocol 2005; and Long-Term Energy and Climate Strategy 2008). These strategy documents cannot cover the whole spectre of different actors' views. Several societal actors have their own strategies, related among other things to energy issues. These strategies cannot be dealt with here in detail, but in the context of requiremets set up by the society it is important to bring out that the society consists of different types of actors with different kinds of energy use. (Ministry of Trade and Industry in Finland 2001; Ministry of Trade and Industry in Finland 2005; Ministry of Trade and Industry in Finland 2008)

Global climate change, and especially carbon dioxide emissions from fossil fuel combustion have in recent years been in the focus of targets related to energy use. Finland as a member of the European Union has to fulfil the commitments based on the UNFCCC Kyoto Protocol. The most significant of them is to limit annual greenhouse gas emissions to their 1990 level during the first commitment period 2008–2012. The Kyoto Protocol identifies six major greenhouse gases; carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). (UNFCCC 2008)

Post-2012 targets to limit greenhouse gas emissions under the UNFCCC negotiations have not been decided yet. However, it can be expected that further targets and related commitments are on the agenda of forthcoming UNFCCC negotiations. European Union has already agreed on a target of 20 % reduction in greenhouse gas emissions from their 1990 level. European Council accepted in January 2008 a "20 20 20 energy package". (EC 2008) It also includes targets related to policy issues such as renewable energy and energy efficiency (see below).

In Finland, a Long Term Energy and Climate Strategy is under preparation. The work is coordinated by the Ministry of Employment and the Economy. When writing this text (September 2008) the strategy is not yet available, so the following text on energy policy goals is mainly based on the previous strategy Outline of the Energy and Climate Policy for the Near Future – National Strategy to Implement the Kyoto Protocol 2005. (Ministry of Trade and Industry in Finland 2005)

The central energy-related policy goals are described in the Outline of the Energy and Climate Policy for the Near Future - National Strategy to Implement the Kyoto Protocol (2005). *Securing energy supply* is the most traditional energy policy goal in Finland and in other countries as well. The target is to preserve a manifold decentralised energy system and secure the availability and sufficiency of fuels, electricity and heat. Security of energy supply in the case of a national crisis such a war is focused on the maintenace of critical energy infrastructures and central national activities. Currently the obligations related to security of supply include fuel reserves taken care by the state and by energy companies and financed by a supply security fee included in energy taxes (CO_2 tax and electricity tax). The national security of energy supply is improved by international agreements and arrangements related to security reserves of fossil fuels which are not presented in detail here. (Ministry of Trade and Industry in Finland 2005)

Developing the energy market is a relatively new energy policy goal. The first legislation aimed to liberalisation of the electricity market was introduced in the early 1990s in Finland, among the first countries in the World. At the EU level, the directive of internal electricity market was given in 1997 and the directive on gas market in 1998. Like in Finland, also in other Nordic counties the electricity and gas markets were liberalised earlier, even foreseeing the timetables defined in the directives. However, the adopted practices in the Norcic countries have been quite different. (Ministry of Trade and Industry in Finland 2005)

After the liberalisation of energy markets new investment decisions have been made by energy companies based on the market situation. This is why the quantitative targets related to energy production and consumption are made for other political reasons than those of traditional energy policy. The most significant of the new reasons is climate policy and related *quantitative targets for greenhouse gas emissions*, which mainly come from fossil fuel combustion in the energy sector. Commitments to the UNFCCC Kyoro Protocol is the main argument behind binding targets for e.g. the use of renewable energy sources in the EU (see below). From the point of view of energy infrastructure, the energy policy goal in the libaralised energy market is to secure the possibilities for easy flexible feed of fules and electricity from different sources into the electricity grid, gas pipelines and othere energy networks, and make the connection to these networks as easy as possible. After the libaralisation of the energy markets and joining the EU, some ideologically conflicting policy goals such as protecting energy self-sufficiency and promotion of domestic energy sources have vanished from the written policy agenda although their significance has practically remained unchanged. (Ministry of Trade and Industry in Finland 2005)

Promoting energy efficiency is a central energy policy goal. It can be divided into end-use efficiency and supply efficiency including the whole energy transforming system from production, transfer/transmission and distibution. Energy end-use efficiency is not a topic of this background report, but the policy instruments of energy efficiency promotion set up at both the EU and national level (such as energy efficiency contracts, energy audits, energy recommendations for public purchases and energy efficviency requirement of electric appliances as well as energy lebels) have been focused mainly on energy end-use. The official EU target is to improve energy efficiency 20 % from the current level until the year 2020 as a part of the “20 20 20 energy package”. (Ministry of Trade and Industry in Finland 2005)

Promoting the yuse of renewable energy sources has rapidly emerged as the most discussed energy policy goal at the EU level. This is due to the fact that the EU has an intent to implement the UNFCCC Kyoro Protocol commitments via quantitative targets for the use of renewable energy. (Ministry of Trade and Industry in Finland 2005)

Directive 2001/77/EC of the European Parliament and of the Council on the promotion of electricity produced from renewable energy sources in the internal market sets a 21 % indicative share of electricity produced from renewable energy sources in total Community electricity consumption by 2010. It defines national indicative targets for each Member State, encourages the use of national support schemes, the elimination of administrative barriers and grid system integration, and lays down the obligation to issue renewable energy producers with guarantees of origin if they request them. With current policies and efforts in place, it can be expected that a share of 19 % by 2010 – rather than the 21% aimed at – will be reached. (COM 2001/77/EC; Ministry of Trade and Industry in Finland 2005)

Directive 2003/30/EC of the European Parliament and of the Council on the promotion of the use of biofuels or other renewable fuels for transport sets a 5.75 % target for the share of biofuels in all petrol and diesel for transport placed on the market by 2010. Member States were required to set indicative targets for 2005, taking a reference value of 2 % into account. This target has not been achieved. Biofuels counted to only 1 % of transport fuels in 2005. The target for 2010 is not likely to be achieved. The Commission expectations are for a share of about 4.2 %. (COM 2003/30/EC; Ministry of Trade and Industry in Finland 2005)

The EU ”20 20 20 energy package” accepted in January 2008 by the European Council includes a directive proposal which aims to establish an overall binding target of a 20 % share of renewable energy sources in energy consumption and a 10 % binding minimum target for biofuels in transport to be achieved by each Member State. This directive proposal also includes binding national targets by 2020 in line with the overall EU target of 20 %. (COM(2008) 30 FINAL)

3.2. Changes in Regional and Community Structures

The regional structure in Finland is a dispersed mixture of central business district in the triangle Helsinki–Turku–Tampere, relatively small cities with and industrial background and a large sparsely populated countryside. A general trend in regional development is growth of the cities, especially the capital region (Helsinki and the surrounding cities and municipalities) in the central business district. The density of population in Finland is very low also in the central areas which increases transport and decreases energy efficiency. Energy consumption of apartments and dwellings increases mainly due to the increase in room area available per person and increasing number of electric appliances. Income level has a clear correlation with the use of private cars. (Lehtilä 2004)

The policy goal relating to the community structure includes decreasing the fragmentation but not increasing the population density. This refers to enhancing the availability of services especially in relation to public and light transport and regional competitiveness. However, public transport services in the countryside and small cities will have a declining trend. The total volume of transport has been estimated to increase 20 % from the 2000 level until the year 2020. (Lehtilä 2004)

Development of the information society; i.e. availability of electronic services and increase of related changes in everyday activities, has been very fast in Finland. One indicator of this is increasing work at home or away from the traditional workplace. This kind of development may decrease the volume of person transport, especially traffic jams. It may also decrease energy consumption of transport and office buildings. In 2000, over 10 % of total workforce was regular or temporary working outside of their workplace in Finland. (Lehtilä 2004)

The role of households and individuals is more significant in energy consumption when energy embedded in commons, (things and services) is taken into account. The number of small households (one or two persons) will increase in the future. The most significant factors affecting change in community structure and way of living include increasing number and decreasing size of households, ageing population, increasing room of apartments/dwellings per person, and increasing purchasing power. (Lehtilä 2004)

Finnish housing stock changes slowly due to the expensive building and housing. Houses are made long-lasting and new production is only 1.3 % of the housing stock. The development of the average housing area is slow: during over 100 years additional space of one room more per house, in average, has been added. In the 1980's an average area was over 69 m^2, a decade later 74 m^2 and in the year 2004 it was 78 m^2. Distribution of the different types of houses in Finland has been stable, most common are blocks of flats with the share of 44 %, one-family houses with the share of 40 % and terraced houses with the share of 14 % of the housing stock. (Lainevuo & Siimes 2001)

The current situation doesn't correspond with the housing wishes of the Finnish people. At the moment about 50 % of the population lives in a block of flats, 30 % in a detached house and 20 % in a semi-detached or a terraced house. However, 57 % of the population would want to live in a detached house, 22 % in a block of flats and 20 % in a semi-detached or terraced house. Living at the countryside is dreamt most commonly by the 30–44 year old people. (Lainevuo & Siimes 2001)

The attraction of the big cities is likely to increase in the future. Especially metropolitan area is the target of the increasing immigration of the foreigners. Finland's internal migration is concentrating increasingly on the big regional centers and the metropolitan area. Population is expected to grow fastest in Pirkanmaa and Uusimaa, about 20 % by the year 2040 and decrease in Kainuu, where the population will diminish 13 % by the year 2040. (Kokkarinen 2007a)

Population movement has a significant influence on the traffic development regionally. Possession and usage of passenger cars is biggest in the framework conventions. The population of the framework conventions is active aged and in addition to work traffic, a lot of business and recreational traffic emerge, for which public transport doesn't suit well. In big cities, there are good opportunities to develop public transport and light traffic routes. The biggest age group in 2040 is expected to be 20–39 year old people, with few people under the age 20, but with plenty old age groups. In the depopulation areas driving with private cars is necessary and public transport requires special arrangements. However, due to the diminishing population, the amount of cars is no longer growing either. Ageing population diminishes the usage of cars, so the amount of traffic doesn't grow that much. In the north, where the size of the families is in average larger, the usage of the passenger car is emphasized due to long distances. (Kokkarinen 2007a)

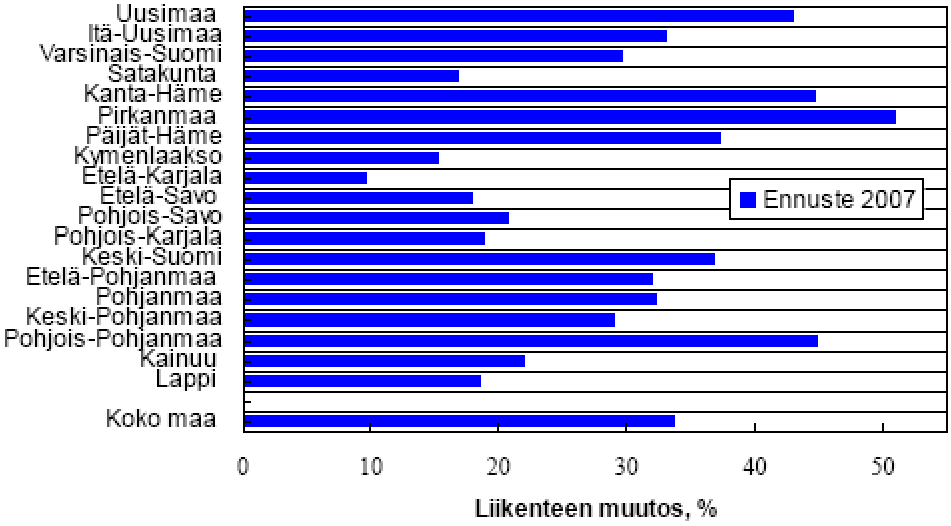


Figure 81. Traffic Growth 2006 - 2040. (Kokarinen 2007b)

The experts have had conflicting views concerning the population age structures influence on traffic development. Most likely in the future aged people demand more from the service level of the society. Motorization of the aged people is expected to grow as well. The idealization of individualism increases also car intensity in spite of the development of environmental values. (Lainevuo & Siimes 2001)

Frequency and length of the recreational trips is expected to grow. Rising of the income is almost directly comparable to the demand for traffic. Development of the electronic business decreases the trips to the stores, but increases the distribution traffic. Net impact is however diminishing of the traffic. Cycling and other light traffic is believed to grow due to increasing health and environmental awareness. (Lainevuo & Siimes 2001)

As the globalization progresses the growth of the air traffic is inevitable. The development of networking increases both passenger and goods traffic. The conveyance of goods will multiply especially in the air and road traffic. Centralization of the population and jobs increases the traffic between the centers. Especially traffic on the major roads, air and rail traffic will probably grow. The development of the remote work doesn't necessarily diminish the net traffic, even though work traffic will decrease. However, remote work possibilities will be beneficial for the evening out the amount of traffic and the traffic jams. Both going to work outside one's own residential area and working across regional borders are believed to continue. Especially if the traffic arrangements develop in the ways that promote private cars, commuting will more and more likely geared out of the region, even if jobs were available near the apartment. (Lainevuo & Siimes 2001)

Change factor	Traffic form							
	Road traffic		Railway traffic		Waterborne traffic		Air traffic	
	Passenger	Goods	Passenger	Goods	Passenger	Goods	Passenger	Goods
1. Economic growth	+2	+2	+1	+1	+1	+1	+2	+2
2. Economic structure changes	+1	+1	0	0	0	0	+1	+2
3. Population changes	+1	+1	0	0	0	0	+1	0
4. Changes in the regional structure	+2 -- 1	0	0	0	0	0	-1	0
5. Community development	+1	+1	0	0	0	0	0	0
6. Technology development	0	0	0	0	0	0	0	0
7. Internationalization	+1	+1	0	+1	+1	+1	+1	+2
8. Traffic policy of the EU	-1	-1	+2	+1	0	0	-1	0(-1)
9. Values								
• Environment	-2[1], +2[2]	-1	+1	0	+1	+1	-1	-1
• Traffic safety	-1	0	+1	0	0	0	0	0
• Individualization	+1	+1	0	0	0	0	+1	+1
10. Development of the logistics		+1		0		0		+2

Figure 82. Summary of the Influence, which the Change Factors Have on Passenger Traffic and Goods Traffic Demand in the Years 2000–2020 (+2=Increases Significantly, +1=Increases, 0=No Real Influence, -1=Diminishes, -2=Diminishes Significantly) (Lainevuo & Siimes 2001).

Community structure may decentralize, if housing density becomes more and more sparse, population increasingly centralizes on the attractive urban areas and the ideal of a detached house remains. More compact community structure is considered less probable as it is desirable. Particularly the growth of the income level is expected to increase the sparseness of the housing density and possession of a car and diminishing the significance of the cost of travelling. (Lainevuo & Siimes 2001)

Housing and building trade is expected to become more and more globalized. As the actual building remains local, the building parts will probably become international export products. Building trade products and services are custom made from preliminary prepared modular parts. Housing planning will be more and more based upon consumers preferences. For the evaluation of the overall quality of the houses branded houses are developed instead of the current mass production houses. Customer service will transform with higher degree into understanding and enabling ways of lives, than traditional housing planning. Instead of regional monopolies and construction zones, culture of building sites regionally, that will allow building competitions for the big areas, consisting of several sites. (Heinonen et al. 2005)

Possibilities and skills for the independent building will decrease. On the other hand, in Finland culture of “building yourself” will continue and detached house builders have a possibility to do so, but on the other hand, a strong trend is the technologization of house industry and independent possibilities will diminish. In addition to current actors, new overall service offerers, operating in the interface of citizen/customer, will aspire to gather housing entities for different residential profiles. In the local level the amount of services will in all likeness to increase. (Heinonen et al. 2005)

4. DEVELOPMENT OF ENERGY RESOURCES / POTENTIALS AND TECHNOLOGIES

According to the Baseline scenario developed by IEA in 2008, total primary energy supply is expected to grow at 1.6 % per year (which means an increase of 104 % un primary energy demand between 2005 and 2050), with coal becoming the predominant fuel in 2050, accounting for 37 % of primary energy use. Oil's share declines from 35 % in 2005 to 27 % in 2050, meanwhile natural gas decreases of only 1 %, reaching 20 % at the end of the review period. In the total demand of the Baseline scenario, the fossil fuels' share increases from 80 % in 2005 to 84 % in 2050: in this case concerns about security would remain, and significant climate change would be the consequence. (IEA 2008)

4.1. Oil

4.1.1. Oil Resources and Reserves

There are several different categories of oil, each having different costs, characteristics and, above all, depletion profiles. Some are easy, cheap and fast to produce, whereas others are the precise opposite. The terms "conventional" and "non-conventional" (or "unconventional") oil are in wide usage, but lack a standard definition, adding greatly to the confusion. In the World Energy Council's (WEC) most recent Survey on Energy Resources (2007), "conventional" oil is identified and defined to exclude the following categories: oil from coal, shale, bitumen and extra-heavy oil. "Reserves" are currently recoverable, both technologically and economically. "Resources" include detected quantities that cannot be profitably recovered with current technology but might be recoverable in the future, and quantities that are geologically possible but yet to be found. (WEC 2007)

According to WEC, the "estimated ultimate recovery" (EUR) of conventional crude oil was about 387,000 million tonnes at the end of 2005. This amount is higher than the amount of 381,000 million tonnes given in the 2005 energy study by the German BRG (Bundesanstalt für Geowissenschaften und Rohstoffe). The regional distribution of "estimated ultimate recovery" of conventional crude oil, comprising cumulative production, reserves and resources, is very uneven. The Middle East has the highest EUR. About 65 % of North America's EUR has been recovered so far. In the CIS countries, this applies to about 37 % and in the Middle East to about 24 % of the EUR. The OPEC countries' EUR is 206,000 million tonnes, accounting over 50 % of the global EUR, of which only about 28 % has been recovered so far. The OECD countries have EUR of only 74,000 million tonnes, of which nearly 62 % has already been recovered. (WEC 2007)

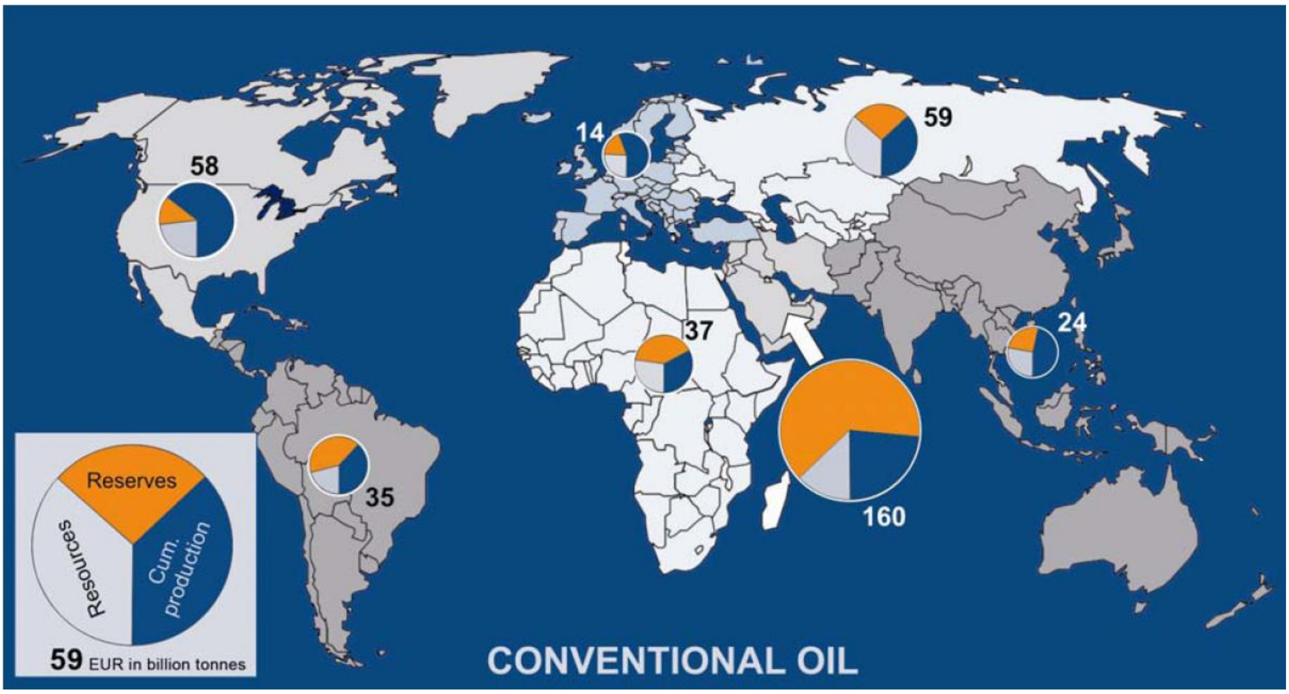


Figure 83. Distribution of the Estimated Ultimate Recovery (EUR) of the Conventional Crude Oil in 2005 (WEC 2007).

About 62 % of the global reserves are located in the Middle East, about 13 % in North and South America and about 10 % in the CIS countries. The OPEC countries have about 76 % of global reserves (of which 61 % is to be found in the Persian Gulf region), the OECD about 7 %, leaving about 18 % for the rest of the world. (WEC 2007)

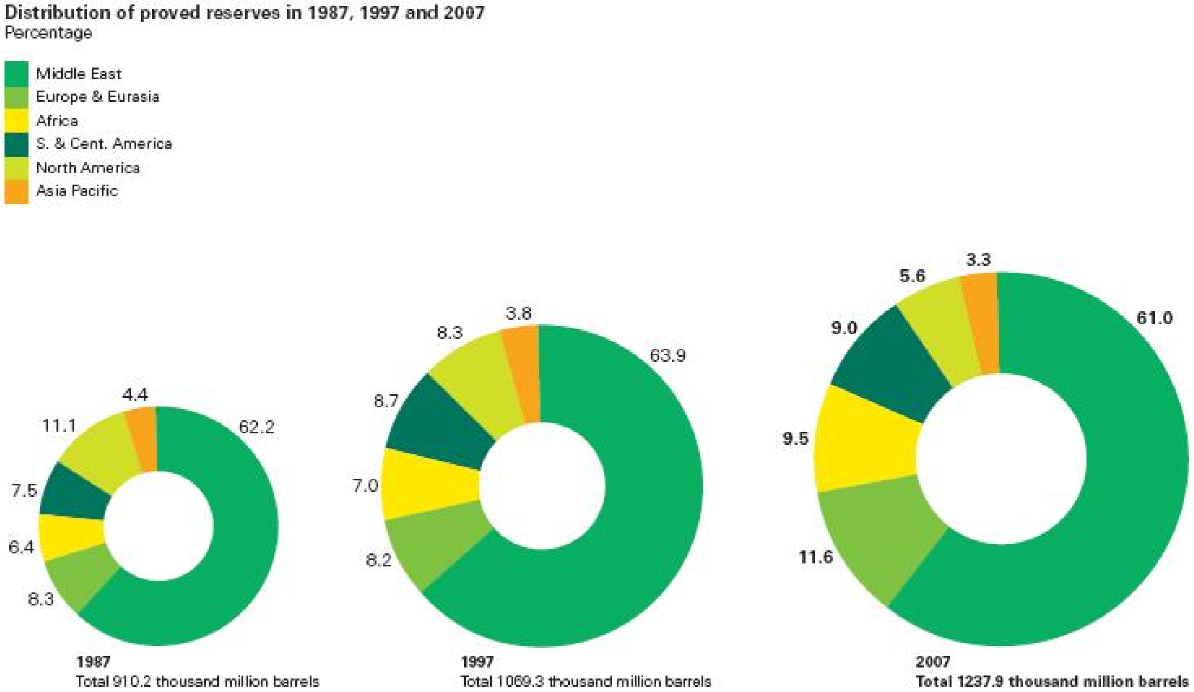


Figure 84. Distribution of Proved Oil Reserves in the World 1987, 1997 and 2007 (BP 2008).

Global crude oil production increased only moderately till 2003. In 2004 and 2005, there was a significant increase up to 3,900 million tonnes – anew absolute production maximum. The regions with the highest production in 2005 were the Middle East, North America and the CIS countries. (IEA 2008)

Cumulative crude oil production until the end of 2005 reached 143,000 million tonnes – half of it was produced within the last 23 years. This means that 47 % of the total reserves of conventional oil discovered so far, has been consumed. Taking into consideration also the expected resources of 82,000 million tonnes, more than 37 % of the EUR has been consumed. The depletion mid-point – when half of the EUR will have been recovered – will be reached within the next 10 to 20 years. Afterwards, the decline of conventional oil production is inevitable. (IEA 2008)

About two-thirds of the crude oil produced in 2005 was transported between different countries and regions, sometimes covering large distances by tanker or pipeline. For crude oil, there is a single global market with nearly uniform prices. However, there was a significant increase in price differentials between oils of different quality due to a general increase in oil prices. (IEA 2008)

4.1.2. Future of Oil

Oil prices have increased sharply in the last years and reached their short-term maximum in July 2008 at US$ 145/bbl for Brent crude. In real terms, this price is the highest recorded in the oil era. In terms of the Euro, this development is slightly more moderate. The reasons for the currently very high oil price are interpreted differently. Some experts regard an imminent shortage of oil reserves (peak oil discussion) as the driving force. Others consider that a combination of different factors is most likely to be the reason for this development. (WEC 2007)

These factors include (WEC 2007):

- increasing demand for oil, after some years of stagnation, caused by prospering economies and strong demand for oil in the USA, China and India;
- supply disruptions caused by strikes in leading supplier countries (Venezuela, Nigeria, Norway) and terrorist attacks in Iraq, as well as natural disasters (e.g. hurricanes in the Gulf of Mexico);
- political instability in the Middle East and the Yukos affair in Russia, as well as a fear of terrorist attacks;
- lack of additional production capacity in most of the producing countries;
- the weak US Dollar;
- speculation in the oil business due to low interest rates on the capital markets.

To summarise, the following developments can be expected for crude oil in the future (WEC 2007):

- From a geological point of view, the remaining potential for conventional oil can provide for a moderate increase in oil consumption over the next 10 to 15 years. After that, an insufficient supply may be expected, owing to decreasing production when the depletion mid-point has been passed. Demand will then have to be met by other fuels. The percentage of oil production by the OPEC countries (especially in the Persian Gulf region) will increase for several decades to come.

- The percentage of non-conventional oil will rise to 5–10 % of total oil production by 2020, as oil prices will stay at relatively high levels. In its International Energy Outlook 2006, the US Energy Information Administration predicted the share of non-conventional oil in world oil consumption as 9.7 % in 2030, including synthetic fuels from natural gas (GTL), coal (CTL) and biomass (BTL), whereas the IEA predicts a share of 8.9 % in 2030 of non-conventional oil in its World Energy Outlook 2005, with synthetic fuels providing 22.5 % of non-conventional oil.
- Predicting oil price fluctuations is very difficult, owing to a variety of factors. Important factors influencing their development are likely to be the behaviour of OPEC countries, the availability of additional production and refining capacities, as well as the development of the global economy. Daily fluctuations in crude oil prices up to a range of several US$ per barrel are likely in both directions, owing to speculation in the oil market business.
- There are numerous uncertainties that could possibly affect the availability of crude oil:
- R/P ratio (resources per production ratio) could possibly be shortened by a downward revision of OPEC reserves. These reserve numbers were sharply boosted in the 1980s, presumably for political reasons in order to keep OPEC production quotas in balance;
- R/P ratio can be lengthened due to uncertainties in reserve assessment. Proved reserve figures do not normally include probable and possible reserves. As a rough indicator of the future availability of geo-energy fuels, the ratio of resources (in the BGR sense of additional reserves) to (proved) reserves can be used. The larger the indicator, the more ‘resources’ can be converted into ‘reserves’.

In terms of global consumption, crude oil remains the most important primary fuel, accounting for 36.4 % of the world’s primary energy consumption (without biomass). Some forecasts of future energy consumption imply that no significant change in the importance of oil will happen in the next few decades. (WEC 2007)

According to the Baseline scenario in IEA publication “Energy Technologies and perspectives 2008”, the demand for oil increases by 86 % from 2005 to 2050, a growth which is unlikely to be met by conventional oil. This means that a considerable increase in non-conventional oil is needed: according to the Baseline scenario heavy oil, tar sands, shale oil and arctic oil account for about 30 % in 2050. For example, open-cast mining is the main production technology for tar sands in Canada (about 80 % of total production), meanwhile underground production of tar sands is less common but with a large potential for expansion. The exploitation of shale-oil is instead limited to some small-scale activities, mainly in Estonia, Brazil and China. As far as R&D is concerned, the investment towards oil technology appears to be on the rise, with about 6.5 billion of USD spent in 2006. (IEA 2008)

Also according to OPEC, the next two decades are expected to see oil set to maintain its major role as a source of energy and oil resource base is expected to be sufficiently abundant to satisfy this demand growth. Moreover, although non-OPEC production is seen as continuing its recent expansion over the medium term, it is generally agreed that OPEC will increasingly be relied upon to supply the incremental barrel. Nevertheless, uncertainties over future economic growth, government policies and the rate of development and diffusion of newer technologies raise questions over the future scale of investment that will be required. These uncertainties, coupled with long lead times, inevitably complicate the task of maintaining market stability. Moreover, medium-term prospects suggest there is a need to ensure that the level of spare capacity is consistent with such stability. (OPEC 2004)

According to the scenario developed by OPEC, the key driver of oil demand will be economic growth, with the major uncertainty being the expansion of productivity in the OECD, and the extent to which this will be influenced by technological advances and the further growth in trade. For developing countries, with largely low capital stock bases and considerable technological catch-up potential, GDP growth rates are expected to be higher. Population expansion will also contribute to economic growth, but there is uncertainty, as to how fast the capital stock and productivity will grow. Both will be positively affected by the liberalization of markets and the increasing importance of trade. The prospects for economic growth in China represent a significant point of uncertainty in the outlook. Over the forecast period, developing countries are assumed to grow at an average of five per cent p.a., with China and South Asia expanding at the fastest rates. Economies in transition have considerable scope for productivity catch-up, while Russia's economy is also benefiting from the impact of high oil prices. Real GDP growth in the former Soviet Union (FSU) of four-to-five per cent p.a. is assumed for the medium term, falling towards three per cent in the longer term. Other growth in Europe is expected to be slightly higher, as, over the forecast period, countries in the region will be trading increasingly with the European Union. (OPEC 2004)

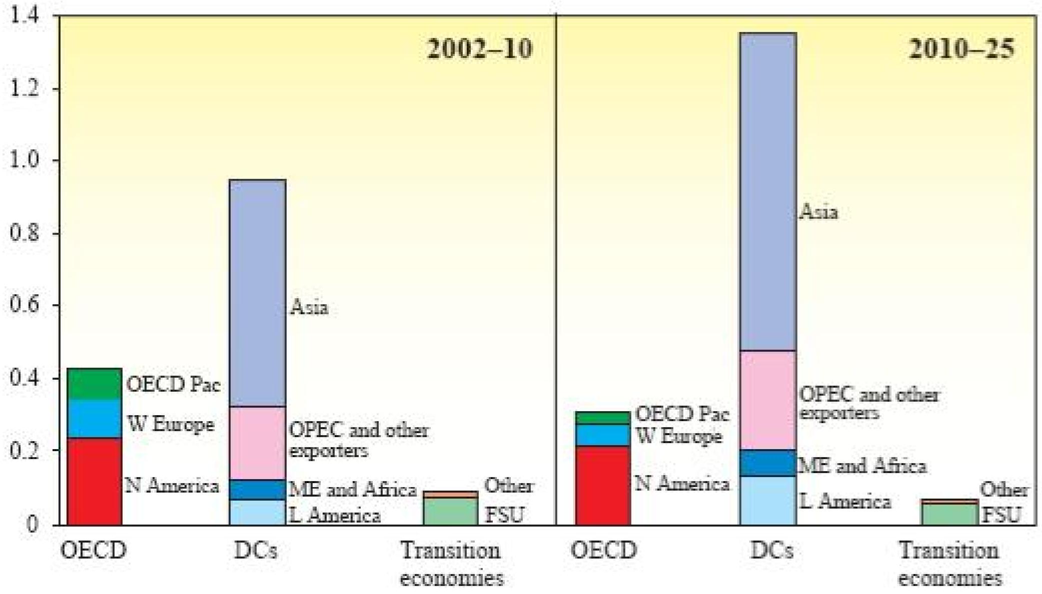


Figure 85. Annual Growth in Oil Demand until 2025 in Mboe/d (OPEC 2004).

The assumptions relative to economic growth rates are coupled with the idea that higher income is followed by a higher share of vehicle ownership, therefore the transport sector, followed by the industry sector, is the most important source of oil demand, as oil is expected to account for the majority of fuel consumption in transportation. (OPEC 2004)

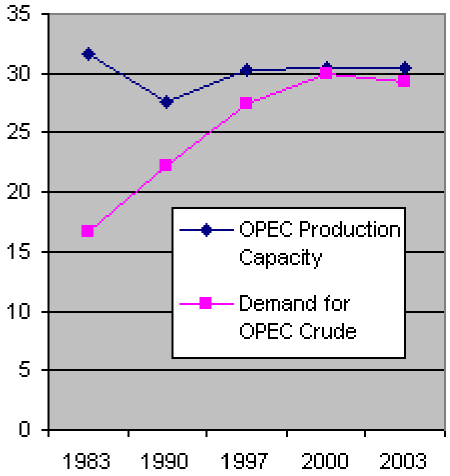


Figure 86. OPEC Production Capacity and Demand for OPEC Crude (Washington Monthly 2005).

Also according to the different scenarios developed by IEA, OPEC production in 2050 will stay at least at the same level of 2005, therefore significant investments especially in the Middle East will be necessary in order to meet demand growth and maintain secure supply of transport fuels, with a key role played by the development of sufficient new oil supply. (IEA 2008)

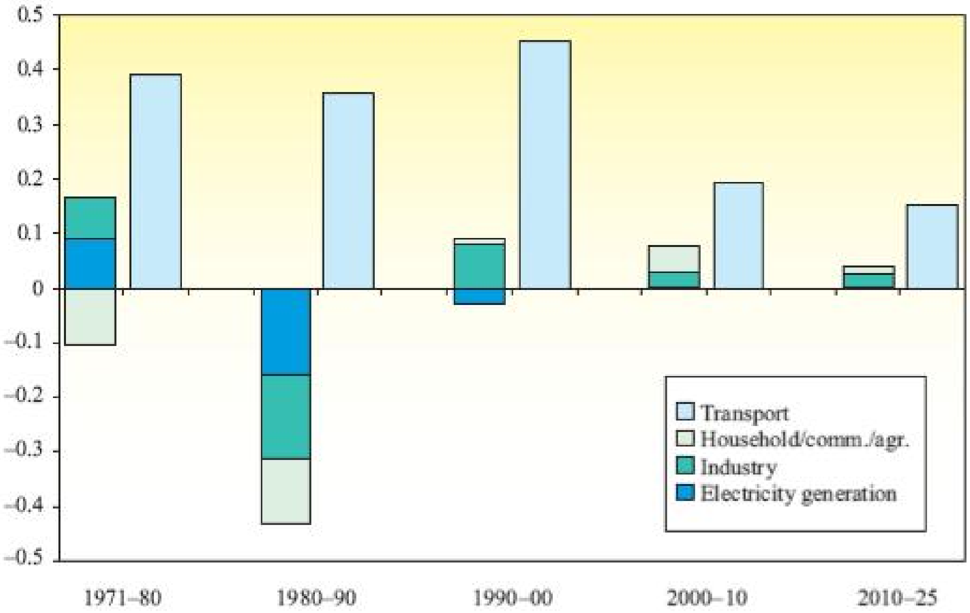


Figure 87. Annual Growth in Oil Demand by Sector in OECD Countries in Mboe/d (OPEC 2004).

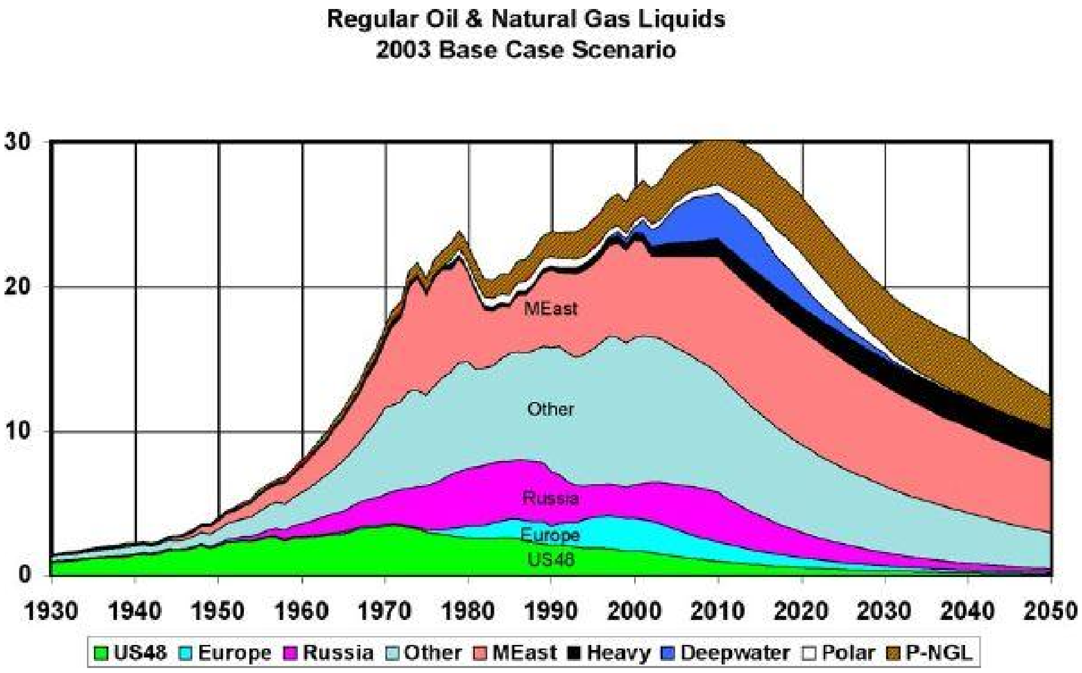


Figure 88. *The Oil Peak According to the Recent Prognosis of the Association for the Study of Peak Oil. Note that the US, Russian and European Oil Supplies Have "Peaked" Already Years Ago. (Exitmundo 2004).*

Peak oil theory has been widely discussed during the last years. The idea of the theory is that the production peak of oil is going to be reached very soon depending on the estimated reserves. Some researches claim that the peak oil has already been passed.

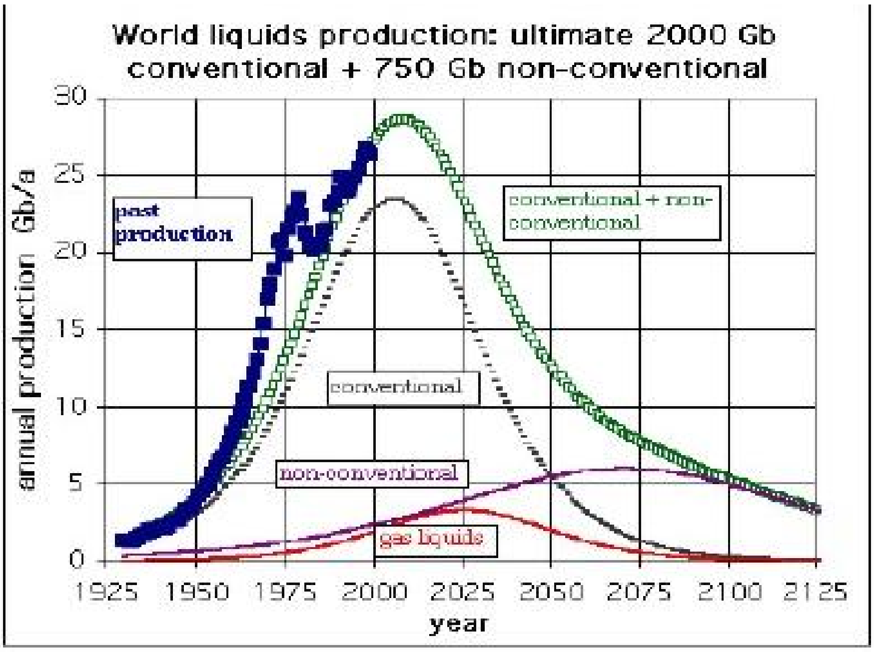


Figure 89. *World Oil Production is Projected to Peak (DOE 2004).*

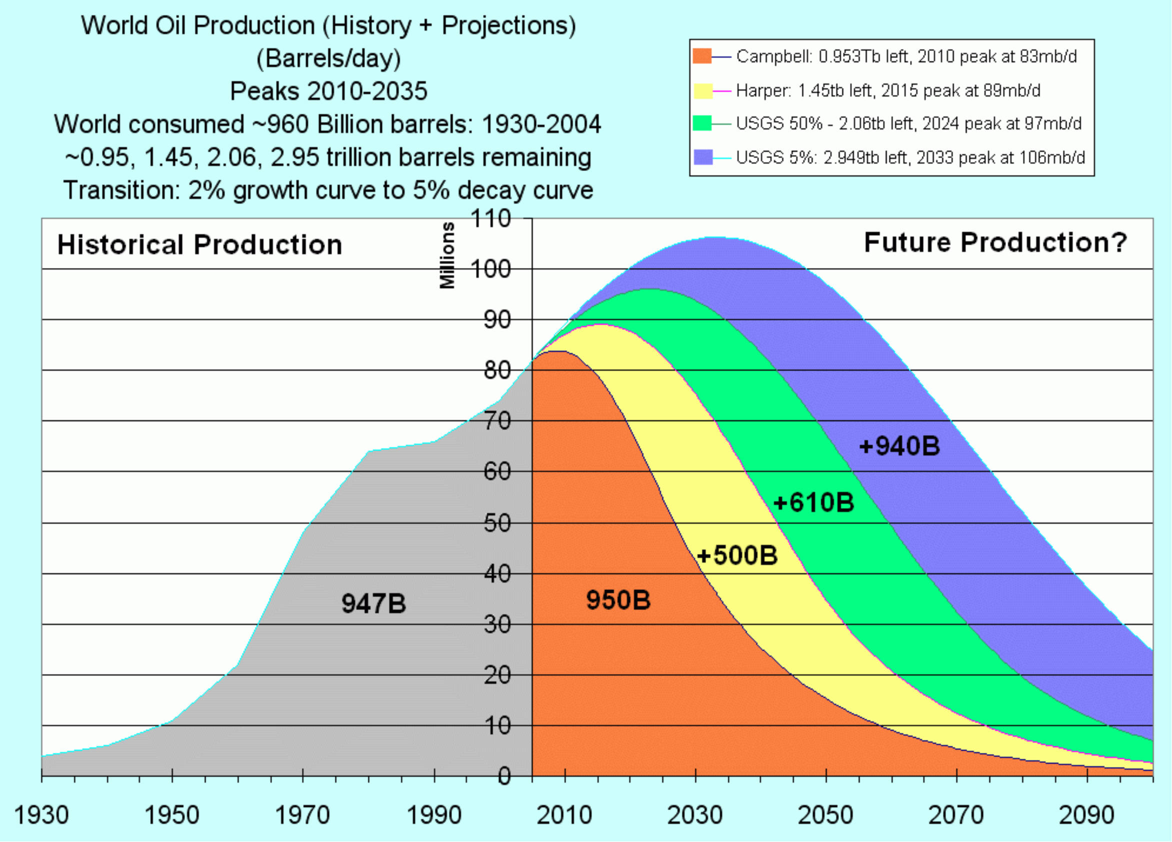


Figure 90. *When the World Oil Peaks (Verosub 2008).*

4.2. Coal

4.2.1. Coal Resources

Worldwide, the use of coal as an energy source remains crucial to the economies of many developed and developing countries, and in particular with the latter, as industrialization and urbanization spread and national energy requirements soar. Thus, coal looks set to retain its position as a secure, reliable source of energy, particularly for the generation of electricity. (IEA 2005)

Coal-fired power generation accounts for 39 % of the world's total electricity production and in some countries, such as the USA, Germany, Poland, Australia, South Africa, China and India, it is very much higher due to its cost competitiveness. While use in some European countries remains static or is in decline, significant increases in coal fired generation capacity are taking place in many of the developing nations, such as China and India, where large capacity increases are planned to make use of abundant coal reserves, which are far more abundant than oil and gas reserves. Coal remains therefore very important for the economies of many countries, but a major challenge is to reduce its environmental impact. (IEA 2005)

Amongst the major energy sources, coal is the most rapidly growing fuel on a global basis. While questions regarding the size and location of reserves of oil and gas abound, coal remains abundant – and broadly distributed around the world. Economically recoverable reserves of coal are available in more than 70 countries worldwide, and in each major world region. After centuries of mineral exploration, the location, size and characteristics of most countries' coal resources are quite well known. Global coal reserves at the end of 2005 were 847.5 billion tonnes. At the current rate of production, global coal reserves are estimated to last for almost another 150 years. These resources consist of bituminous coal (including anthracite), subbituminous coal, and lignite. Finland has no coal resources. (WEC 2007)

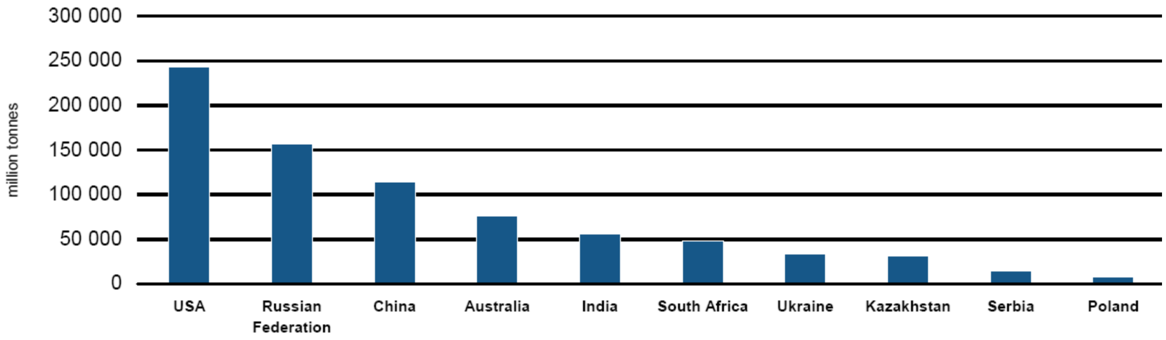


Figure 91. *Distribution of the Total Coal Reserves in the World (WEC 2007).*

"Proved amount in place" is the resource remaining in known deposits that has been carefully measured and assessed as exploitable under present and expected local economic conditions with existing available technology. "Proved recoverable reserves" are the tonnage within the proved amount in place that can be recovered in the future under present and expected local economic conditions with existing available technology. "Estimated additional amount in place" is the indicated and inferred tonnage additional to the proved amount in place that is of foreseeable economic interest. It includes estimates of amounts which could exist in unexplored extensions of known deposits or in undiscovered deposits in known coal-bearing areas, as well as amounts inferred through knowledge of favourable geological conditions. Speculative amounts are not included. "Estimated additional reserves recoverable" is the tonnage within the estimated additional amount in place that geological and engineering information indicates with reasonable certainty might be recovered in the future. (WEC 2007)

Compared with data appearing in the 2004 Survey of Energy Resources, North American reserves are 4,000 million tonnes smaller due to the gradual attrition of US reserves. South America shows a 3,500 million tonnes reduction. In Asia a significant change down 41,000 million tonnes was largely due to improved data for India. European reserves declined by 12,000 million tonnes, over half of which in Poland. (WEC 2007)

Growth in energy consumption is forecasted to continue – at an annual average rate of 1.6 % between 2004 and 2030. Over 70 % of this growth will come from developing countries, where populations and economies are growing considerably faster than in the OECD nations. China alone will account for some 30 % of increased energy consumption. Fossil fuels will continue to provide more than 80 % of the total energy consumption in the future, and – according to the International Energy Agency – coal consumption will see the largest increase in absolute terms, from 2,772 Mtoe in 2004 to 4,441 Mtoe in 2030. The greatest increase in coal consumption will be in the developing countries, with 86 % in Asia, where reserves are large and low-cost. India's coal use is expected to grow by 3.3 % per annum to 2030, more than doubling in absolute terms. OECD coal consumption is likely to grow modestly. (WEC 2007)

4.2.2. Future Trends in Coal

In order to reduce its environmental impact, development and application of Clean Coal Technologies (CCTs), designed to minimize the emissions of various undesirable species from coal-fired power plants, should continue. Further development of CCTs will lead to a number of technology options (Zero or Near-zero Emissions Technologies – ZETs) that emit very low levels of all emissions. (WEC 2007)

Having established that ZETs may have an important role in the coming years, it should be kept in mind that no single system will be capable of meeting all future requirements, hence a portfolio of technologies will be necessary. By not concentrating on a single candidate technology, the associated technological risks can be minimized, and possible routes forward can be tailored to meet the different situations prevailing in different parts of the world. Since the structure of electricity generation sectors and future national power demands are likely to vary significantly between countries and regions, there are likely to be several possible routes forward towards the adoption of ZETs, with some variants being more applicable to the industrialized nations and others focused more on developing countries. Thus, there are many possible routes forward, some based on PCC (Pulverised Coal Combustion) and others on IGCC (Integrated Gasification Combined Cycle), with the latter creating opportunities for combining the technology with fuel cells. In Japan, the EAGLE integrated gasification combined cycle fuel cell (IGFC) project is testing this concept. (WEC 2007)

When comparing PCC and IGCC based systems, the latter presents various advantages, among which (WEC 2007):

- a lower energy penalty than for capture from PCC plant, since the CO_2 content of the pre-combustion, syngas stream is greater and hence more easily captured than from a flue gas
- CO_2 can be captured at a pressure suitable for pipeline transport, thus reducing CO_2 compression costs
- chemical processing of the syngas, coupled with CO_2 capture, yields hydrogen suitable for combustion in gas turbines, direct conversion to electricity in fuel cells or other uses
- low levels of SO_2 emissions can already be achieved and NO_x levels are comparable to those of natural gas fired combined cycles
- solid wastes produced are usually in an inert form, thus their disposal is easier

Moving from existing technologies to ZETs equivalents that incorporate a CO_2 capture stage, will clearly have major cost implications for systems developed from either PCC or IGCC. It has been estimated that for the former, plant capital costs would be 56–82 % greater than current systems, and for the latter, some 27–50 % higher. A large proportion of the increased capital costs are associated with the capture of CO_2 (IEA 2005).

From what was presented above it is clear that only with effective R&D programs in the clean coal technology field, it will be possible for these strategic options to be developed and refined to the point where they can be adopted commercially as part of the solution to global warming and climate change. (WEC 2007)

According to the Baseline scenario developed in 2008 by IEA, the demand for coal is expected to triple between 2005 and 2050, with coal eclipsing oil between 2030 and 2050 and reaching 37 % of total demand in 2050. The three factors driving this growth are the following (IEA 2008):

- high oil prices make coal-to-liquids (CTL) technologies more economical and the production of synfuels from coal also increases
- high gas prices result in more new coal-fired electricity plants being built
- energyintensive industrial production grows rapidly in developing countries (especially China and India), which have large coal reserves and only limited amounts of other resources.

4.3. Natural Gas

4.3.1. Natural Gas Resources

Natural gas is a mixture of hydrocarbon and small quantities of non-hydrocarbons that exists either in the gaseous phase or is in solution in crude oil in natural underground reservoirs, and which is gaseous at atmospheric conditions of pressure and temperature. Natural gas liquids (hydrocarbons exist in the reservoir as constituents of natural gas but are recovered as liquids in separators, field facilities or gas-processing plants. (WEC 2007)

Proved amount in place is the resource remaining in known natural reservoirs that has been carefully measured and assessed as exploitable under present and expected local economic conditions with existing available technology. Proved recoverable reserves are the volume within the proved amount in place that can be recovered in the future under present and expected local economic conditions with existing available technology. Estimated additional amount in place is the volume additional to the proved amount in place that is of foreseeable economic interest. Speculative amounts are not included. Estimated additional reserves recoverable is the volume within the estimated additional amount in place that geological and engineering information indicates with reasonable certainty might be recovered in the future. (WEC 2007)

Gas reserves are geographically concentrated. While about 73 % of gas reserves are concentrated in two areas – the Middle East and the CIS – the geopolitical distribution of gas reserves is rather similar to that of oil. With nearly 90 Tm3, the OPEC countries have about half of total reserves, compared with 75 % for oil. The CIS enjoys a more advantageous situation for gas, with 33 % of reserves against only 10 % of oil reserves. In the OECD countries, the situation is barely different for either energy resource, with less than 10 % of gas reserves and 7 % of oil reserves. By 2020, non-OECD countries could account for about 88 % of world gas trade, including 58 % for OPEC countries. Approximately 44 % of total proven reserves are concentrated in some twenty mega and supergiant fields. Out of these, the world's largest non-associated gas field – North Field/South Pars – straddling Qatari and Iranian waters, accounts for some 49 %. This concentration of gas wealth naturally raises questions of security of supply, of transit, of the potential implementation of an organisation of gas-exporting countries (OGEC) and of assets nationalisation strategies. To address these issues, consuming countries will increasingly respond by diversifying supplies. (WEC 2007)

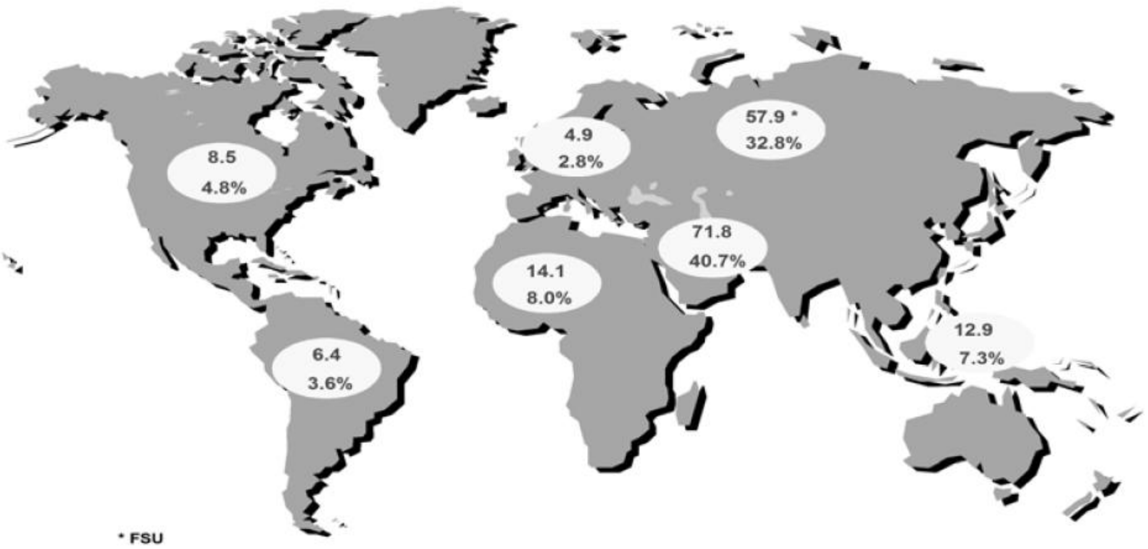


Figure 92. Proved Natural Gas Reserves as at the End of 2005, Tm3 and % of World Total (WEC 2007).

Natural gas is used around the world but the major areas of trade correspond to the OECD regions: North America, Europe and Asia-Pacific. Gas in these markets is used for residential and commercial needs, industrial heat and, increasingly, power production. Natural gas accounts for 21 % of global energy supply, with slightly higher proportions in the relatively mature markets of North America and Europe. Rapid growth since 2000 is expected to moderate in the second half of the decade, but global demand is still expected to increase from 2.8 Tm^3 in 2005 to 3.2 Tm^3 in 2010. The main driver of this growth in OECD countries is power generation, whereas the growth of gas demand in other regions such as the Middle East, China and India is driven by other sectors as well (IEA 2006b).

There are two principal ways of transporting gas from the well-head to the burner tip: through pipelines or in the form of LNG. Both are expensive and require long construction times; therefore, a considerable period is needed to pay back the initial investment. Pipelines are more cost-effective over short distances. Liquefied natural gas is natural gas that has been cooled down to -161°C to make it liquid. This is done in a liquefaction train, a series of process operations from gas to LNG. Often a liquefaction plant starts with one or two trains. Once these trains have proven successful, both technically and commercially, more trains can be added at a lower marginal cost if the resources are sufficient. After liquefaction, the gas is transported in specially-designed ships. At the point of arrival, the gas is returned to its normal gaseous state in a re-gasification terminal. (IEA 2006b)

In power generation, the share of natural gas is greatest in the Middle East, and it is quite high also in the countries of the former Soviet Union (about 43 %), together with Mexico and some Asian countries (IEA 2006a).

4.3.2. Future Trends in Natural Gas

Power generation from natural gas is competitive with today's prices in many areas of the world, but total generation costs are more sensitive to increases in fuel prices in the case of natural gas combined-cycle (NGCC), than in plants using other generation technologies, because fuel costs account for 60–75 % of total generation costs. This means that, comparable increases in different fuel prices for electricity generation would have a greater impact on the economics of NGCC than on other technologies. Developments in the United States and Europe in recent years have confirmed this, since rising prices in natural gas have resulted in a switch to coal-fired generation. The rapid development of natural gas-fired power generation could thus strain gas production and transmission systems and lead to further natural gas price increases. (IEA 2006a)

Within the natural gas market non-OECD countries certainly present the largest potential for growth. Driven by steady population growth and strong economic activity, total energy needs should climb at quite a smart pace, providing natural gas with new opportunities for market development. The fast-growing economies in Asia (including China and India), the Middle East, Africa and even Latin America, promise gas demand growth rates of 3–4 % p.a. by 2020. In some Asian countries, the share of natural gas is boosted to reduce dependence on imported furnace oil, as in Pakistan, moreover in countries like India and Indonesia, fertiliser production (urea, ammonia) will also require growing volumes of natural gas, both as fuel and as raw material. In the Middle East, gas will be increasingly used in seawater desalination plants and in industry in general. In Africa, besides a growing requirement from the power sector, gas network extensions open up broader country-wide developments, such as in Algeria and Egypt. In Latin America, with the exception of Argentina, recent gas market developments indicate that gas still has significant potential for growth. (WEC 2007)

From a sectoral standpoint, the power sector should absorb about 37 % of marketed gas each year by 2020. While industry should maintain its current 25 % share, the residential and tertiary sectors are likely to decline in importance. The abundance of gas reserves already discovered, and the prospects for a large yet-to-find potential, give natural gas a lifetime probably in excess of 130 years, at the current rate of consumption (2.93 Tm^3 in 2006). Additionally, improvements in transportation economics are gradually providing access to a potential of 'stranded' gas, remote from consuming zones, onshore and offshore, currently estimated at 30–35 Tm^3, making it marketable at a competitive price. New frontier areas for exploration are also opening up, in deeper and more complex horizons, technology permitting. (WEC 2007)

4.4. Uranium Resources and Nuclear Technology

4.4.1. Uranium Resources

International organisations in the field of nuclear power collect more or less regularly national estimates of identified and undiscovered uranium resources including expected mining costs. A "Red Book" including the available national estimates have been published since 1965 by International Atomic Energy Agency (IAEA) and Nuclear Energy Agency (NEA/OECD). The content of the Red Book depends on the information submitted ny national authorities. The most recent edition of the Red Book (Uranium 2007 – Resources, Production and Demand) was published in 2008. The following text is mainly based on that edition.

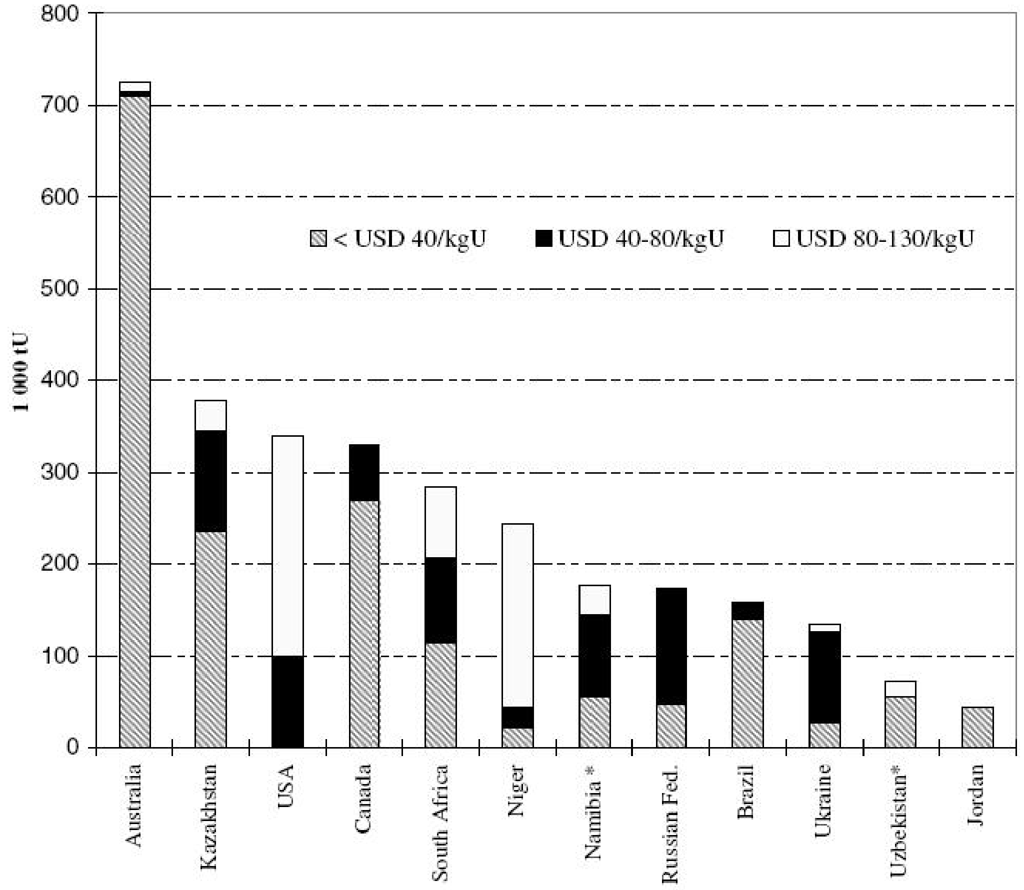
Identified resources (previously Known Conventional Resources) are divided into two classes, Reasonable Assured Resources (RAR) and Inferred Resources. Both classes include three cost categories, <40 USD/kgU, <80 USD/kgU and <130 USD/kgU. (NEA/IAEA 2008)

The following table includes the amounts of Identified Resources (RAR and Inferred Resources) in all cost categories as reported in the Red Book. In comparison to the previous edition (2005) of the Red Book, the resources have slightly decreased in the most attractive category (RAR <40 USD/kgU). On the other hand, Inferred Resources have increased in all cost categories. The distribution of RAR and Inferred Resources in the most important countries are presented in the figures below. (NEA/IAEA 2008.)

Table 3. Identified Uranium Resources (NEA / IAEA 2008).

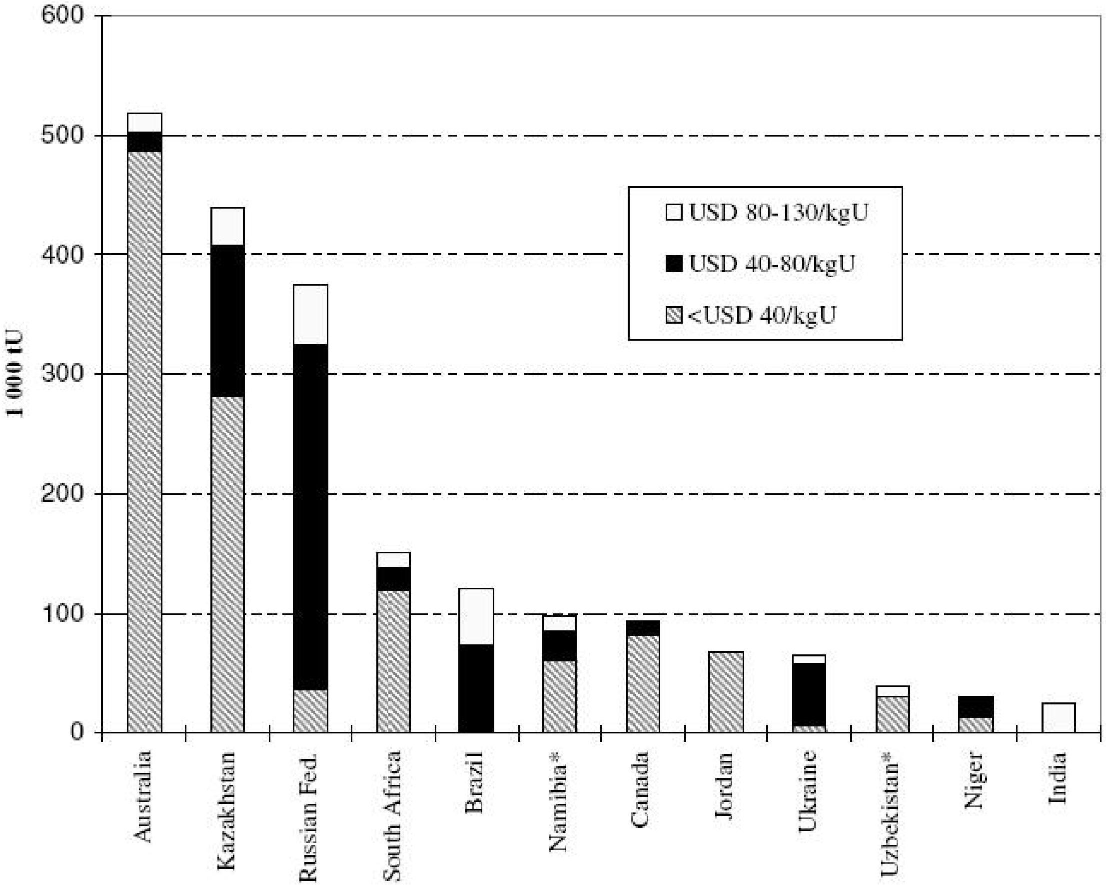
Cost category	Identified Resources 1.1.2007		
	RAR	Inferred resources	Total
<130 USD/kg U	>3,338	>2,130	5,469
<80 USD/kg U	2,598	>1,858	>4,456
<40 USD/kg U*	>1,766	1,204	2,970

*Resources in the cost categories of <USD 40/kgU are likely higher than reported, because several countries have indicated that either detailed estimates are not available, or the data are confidential.



* Secretariat estimate.

Figure 93. Distribution of Reasonable Assured Resources (RAR) in 2007 (NEA/IAEA 2008).



* Secretariat estimate.

Figure 94. Distribution of Inferred Resources in 2007 (NEA/IAEA 2008).

In addition to this, the Red Book includes estimates of Undiscovered Resources. Undiscovered Resources include Prognosticated Resources and Speculative Resources (SR). Prognosticated Resources refers to uranium resources that are expected to occur in well-defined geological trends of known deposits, or mineralised areas with known deposits. SR refers to uranium resources that are thought to exist in geologically favourable, yet unexplored areas. Therefore, Prognosticated Resources are assigned a higher degree of confidence than Speculative Resources. Both classes include the same three cost categories than Identified Resources. (NEA/IAEA 2008)

According to the Red Book, Finnish authorities have reported Identified Resources in the RAR class 1,100 tonnes in the cost category >130 USD/kg U. According to the Centre of Geological Excellence (GTK), Finland does not have any uranium resources which would be economically feasible for nuclear fuel production. However, some mining companies are interested in searching new uranium resources in many countries, possibly also in Finland. This has created some political discussion on e.g. the existing legislation considering mining activities. (NEA/IAEA 2008)

According to Internartional Atomic Energy Agency, thorium is widely distributed with an average concentration of 10 ppm in earth's crust in many phosphates, silicates, carbonates and oxide minerals and is 3 to 4 times more abundant in nature than uranium and has not been exploited commercially so far. Thorium occurs in association with uranium and rare earth elements in diverse rock types: as veins of thorite, thorianite, uranothorite and as monazite in granites, syenites, pegmatites and other acidic intrusions. Monazite is also present in quartz-pebble conglomerates sand stones and in fluviatile and beach placers. Monazite, a mixed thorium rare earth uranium phosphate, is the most popular source of thorium and is available in many countries in beach or river sands along with heavy minerals–ilmenite, rutile, monazite, zircon, sillimenite and garnet. The present production of thorium is almost entirely as a by–product of rare earth element extraction from monazite sand. (IAEA 2005)

Thorium reserves and resources have not been comprehensively estimated so far and different approximations may exist. According to e.g. the German BGR, reserves of more than 2 million tonnes of Th can be considered as a possible base for future fuel supply for nuclear power plants. According to the Department of Atomic Energy in India, the total known world reserves of Th in RAR category are estimated at about 1.16 million tonnes. About 31 % of this is available in the beach and inland placers of India. Other countries having sizeable thorium reserves include Brazil, Canada, China, Norway, Russia, USA, Burma, Indonesia, Malaysia, Thailand, Turkey and Sri Lanka. (IAEA 2005)

Thorium has been considered as a source of nuclear fuel for several different nuclear fission technologies (see below). It cannot be used for nuclear fuel as such. First it needs to be transformed into a fissile form. For utilization of thorium in nuclear power programme, an additional step of first converting fertile ^{232}Th into fissile ^{233}U is needed. ^{233}U is by far the best fissile isotope for thermal neutron spectrum and can be used for breeding in both thermal and fast nuclear reactors. (IAEA 2005)

4.4.2. Nuclear Power in Electricity Production

According to World Energy Council (WEC), in 2007 there were 435 nuclear reactors with a net capacity of 367 GW_e in operation all over the world. 346 of these (net capacity 310 GW_e) are located in OECD countries. In 2005 the share of nuclear power in global electricity production was 16 % and in OECD countries the share was in 2007 as high as 21.6 %. The nuclear share in electricity production has slightly decreased in recent years due to lack of new installations, reactor shutdowns and increased electricity production of other energy sources. However, the average load factor has increased and in 2006 it was 83 % at the global level while the total amount of nuclear-based electricity production was 2,658 TWh. The four nuclear reactors in Finland have traditionally had very high load factors (well over 90 %) because of the large share of base load power in Finnish electricity consumption and the very reliable operation of the nuclear power plants. (WEC 2007)

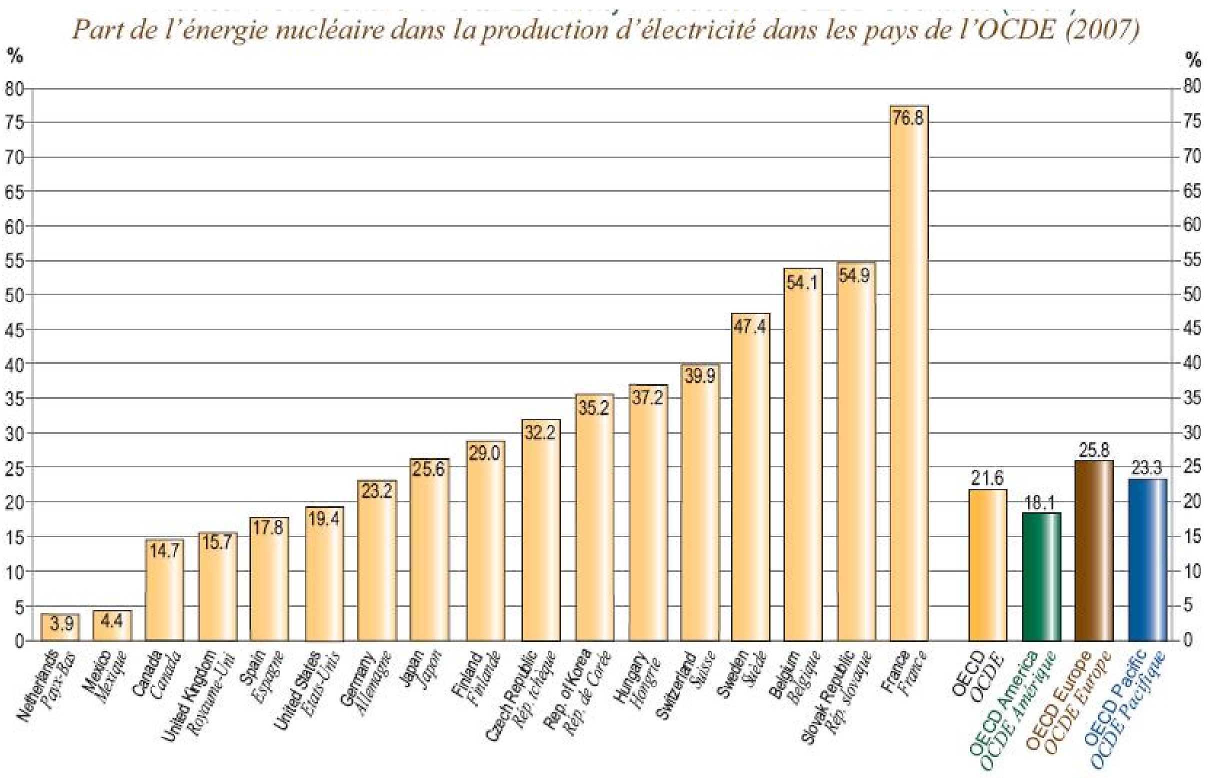


Figure 95. Nuclear Power Share of Total Electricity Production in OECD Countries (WEC 2007).

Progress in international climate negotiations has increased expectations towards more challenging targets for greenhouse gas emission reductions. This has strengthened the role of nuclear power in many countries. It has even been expected that a nuclear renaissance will occur in the next 20 years. World Energy Council has listed examples of emerging policy initiatives dealing with construction of new nuclear power plants: World's most populated and rapidly developing countries China and India are very interested in all options for additional electricity generation, including nuclear power. Russia has presented a plan of doubling the nuclear capacity until the year 2020. South Korea has planned to increase the share of nuclear power from current 40 % up to 60 % in medium term time perspective. Also in the United States different plans for increasing nuclear capacity have been introduced. Furthermore, energy policy in countries such as Belarus, Turkey and Poland has changed to more positive towards nuclear power than earlier. A review provided by European Commission titled "The World Energy Technology Outlook – 2050" provides an estimate of rapid increase in the use of nuclear power in electricity production until the year 2050. Also World Energy Council has presented similar visions supported by e.g. information about surveys dealing with government positions and citizens' attitudes to the use of nuclear power in different countries. (WEC 2007)

4.4.3. Development of Nuclear Technology

Nuclear reactors can be classified by using several different criteria. Major criteria in the literature include the following (GIF 2008):

Classification by use
- research reactors
- production reactors
- power reactors
- propulsion reactors

Classification by moderator material
- graphite moderated reactors
- water moderated reactors
  - light water moderated reactors (LWRs)
  - heavy water moderated reactors

Classification by coolant
- gas cooled reactors
- liquid metal cooled reactors
- water cooled reactors
  - pressure water reactors (PWRs)
  - boiling water reactors (BWRs)

Classification by type of nuclear reaction
- fast reactors
- thermal reactors
- fusion reactors

Classification by role in the fuel cycle
- breeder reactors
- burner reactors

Classification by Generation
- generation I reactors
- generation II reactors
- generation III reactors
- generation III+ reactors
- generation IV reactors

Classification by phase of fuel
- solid fueled reactors
- fluid fueled reactors
- gas fueled reactors.

Here only nuclear reactors used in power plants are dealt with. The majority of nuclear reactors used in power plants are BWRs moderated by light water. Planning process of generation III+ nuclear reactors takes advantage of the accumulated experience from the use of generation I–III reactors. The European Pressurized Reactor (EPR) ordered by Teollisuuden Voima (TVO), currently under construction in Finland by Areva, is classified as a generation III+ reactor. (Gif 2008)

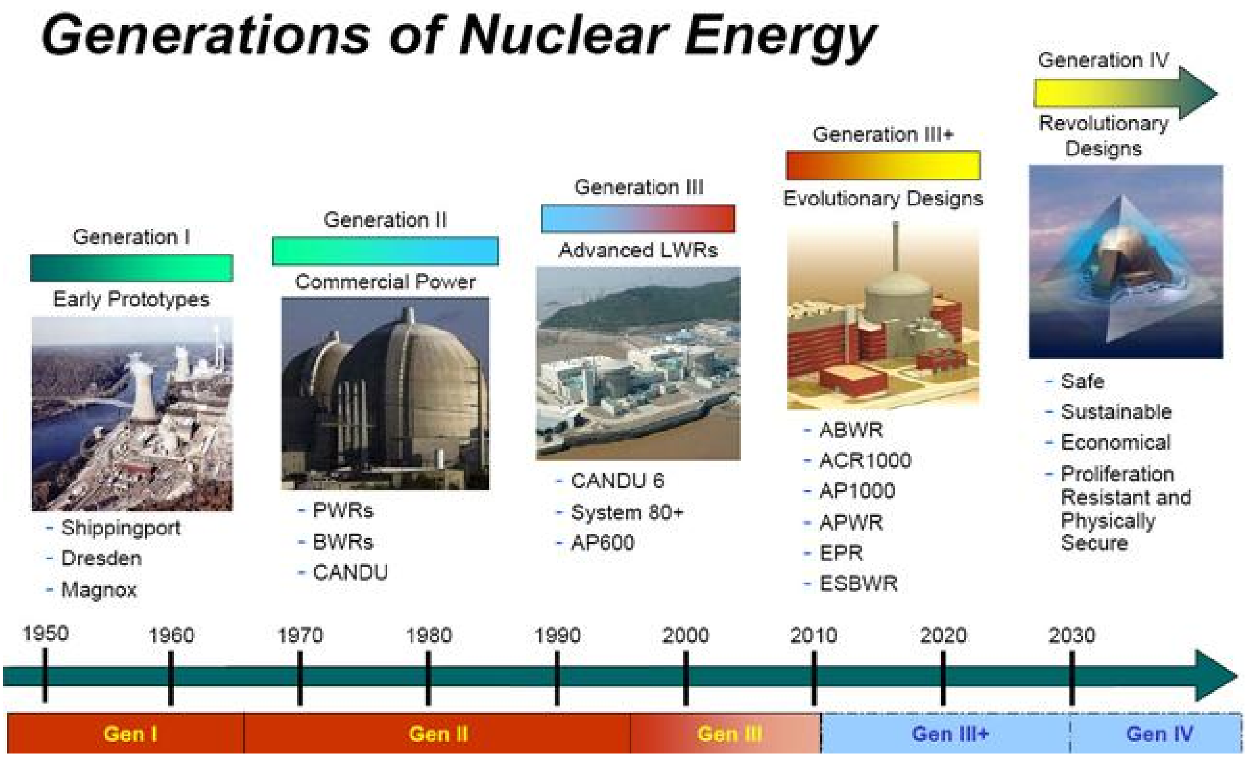


Figure 96. Generations of Nuclear Energy (GIF 2008).

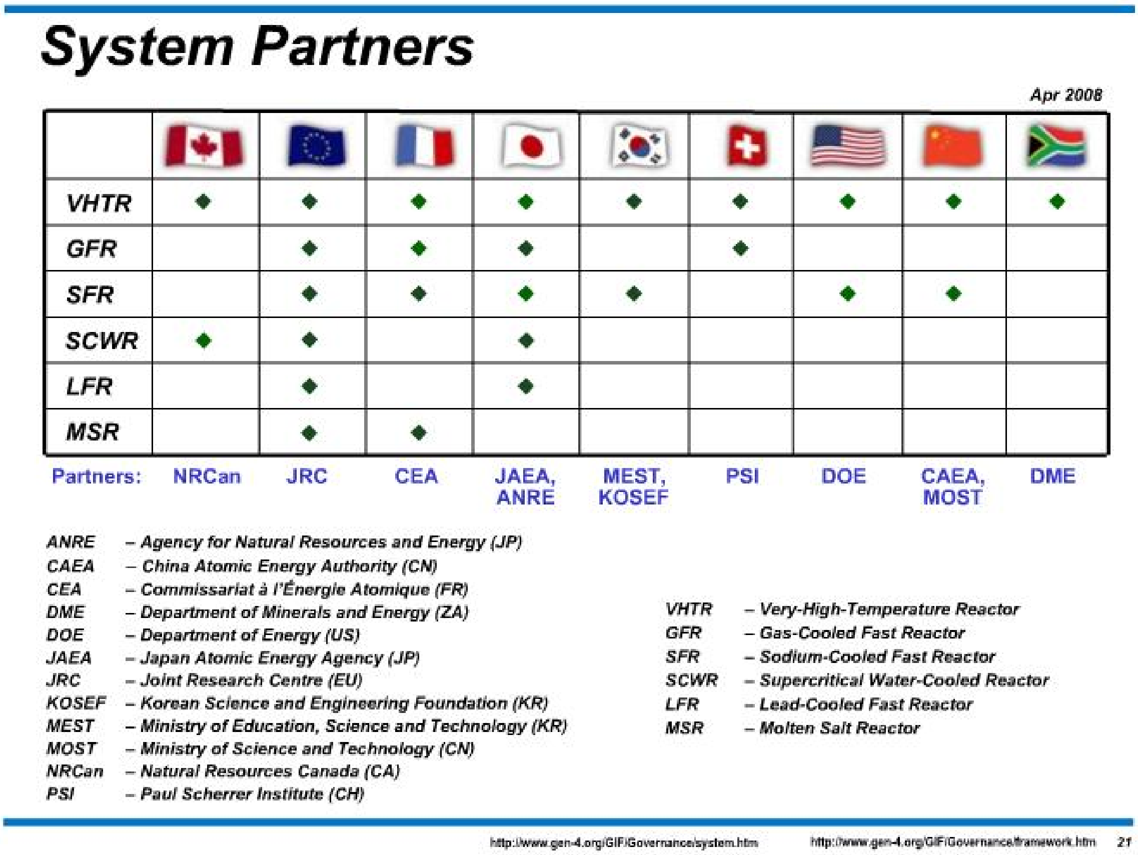
Some countries such as France, Japan, United Kingdom, Russia, United States and India have developed fast breeder reactors (FBR), which are not moderated and produce during operation new nuclear material which can be further used as nuclear fuel. Some FBRs have been in use for electricity production, but often their use has been given up by political decisions. (Gif 2008)

Since then the development of nuclear technology has been more or less focused on so-called generation IV nuclear reactors. In comparison to existing reactors, generation IV reactors will

- be safer
- use less nuclear fuel and be more effective
- produce less radioactive wastes
- be more economical, and
- have smaller investment and operation costs.

If this kind of advantages will be achieved, the reasonable size of nuclear units can be smaller than in current nuclear power plants. This makes generation IV reactors more flexible and thus more suitable to the circumstances in the opened electricity markets. Moreover, the development of nuclear technology towards generation IV reactors may have such an impact on citizen’s attitudes towards nuclear power that the current opposition and change the government position is those countries where increasing the use of nuclear power is not at the energy policy agenda (Gif 2008).

A Generation IV International Forum (GIF) has been established for research and planning of generation IV nuclear reactors. This forum has selected the most promising technologies, and published in 2002 a technology road map for more focused research and planning work. Many reactor types were considered initially; however, the list was downsized to focus on the most promising technologies and those that could most likely meet the goals of the generation IV initiative. Three systems are nominally thermal reactors and three fast reactors. The VHTR is also being researched for potentially providing high quality process heat for hydrogen production. The fast reactors offer the possibility of burning actinides to further reduce waste and of being able to breed more fuel than they consume. These systems offer significant advances in sustainability, safety and reliability, economics, proliferation resistance and physical protection. The first generation IV nuclear reactors are expected to be in commercial use by the year 2030. The development of different generation IV nuclear technologies will naturally be different. (Gif 2008)



System Partners

Apr 2008

VHTR	◆	◆	◆	◆	◆	◆	◆	◆	◆
GFR		◆	◆	◆		◆			
SFR		◆	◆	◆	◆		◆	◆	
SCWR	◆	◆		◆					
LFR		◆		◆					
MSR		◆	◆						
Partners:	NRCan	JRC	CEA	JAEA, ANRE	MEST, KOSEF	PSI	DOE	CAEA, MOST	DME

ANRE – Agency for Natural Resources and Energy (JP)
CAEA – China Atomic Energy Authority (CN)
CEA – Commissariat à l'Énergie Atomique (FR)
DME – Department of Minerals and Energy (ZA)
DOE – Department of Energy (US)
JAEA – Japan Atomic Energy Agency (JP)
JRC – Joint Research Centre (EU)
KOSEF – Korean Science and Engineering Foundation (KR)
MEST – Ministry of Education, Science and Technology (KR)
MOST – Ministry of Science and Technology (CN)
NRCan – Natural Resources Canada (CA)
PSI – Paul Scherrer Institute (CH)

VHTR – Very-High-Temperature Reactor
GFR – Gas-Cooled Fast Reactor
SFR – Sodium-Cooled Fast Reactor
SCWR – Supercritical Water-Cooled Reactor
LFR – Lead-Cooled Fast Reactor
MSR – Molten Salt Reactor

http://www.gen-4.org/GIF/Governance/system.htm http://www.gen-4.org/GIF/Governance/framework.htm 21

Figure 97. System Partners (GIF 2008).

Very-High-Temperature Reactor (VHTR)

The Very High Temperature Reactor concept utilizes a graphite-moderated core with a once-through uranium fuel cycle. This reactor design envisions an outlet temperature of 1,000°C. The reactor core can be either a prismatic-block or a pebble bed reactor design. The high temperatures enable applications such as process heat or hydrogen production via the thermochemical iodine-sulfur process. It would also be passively safe. (Gif 2008)

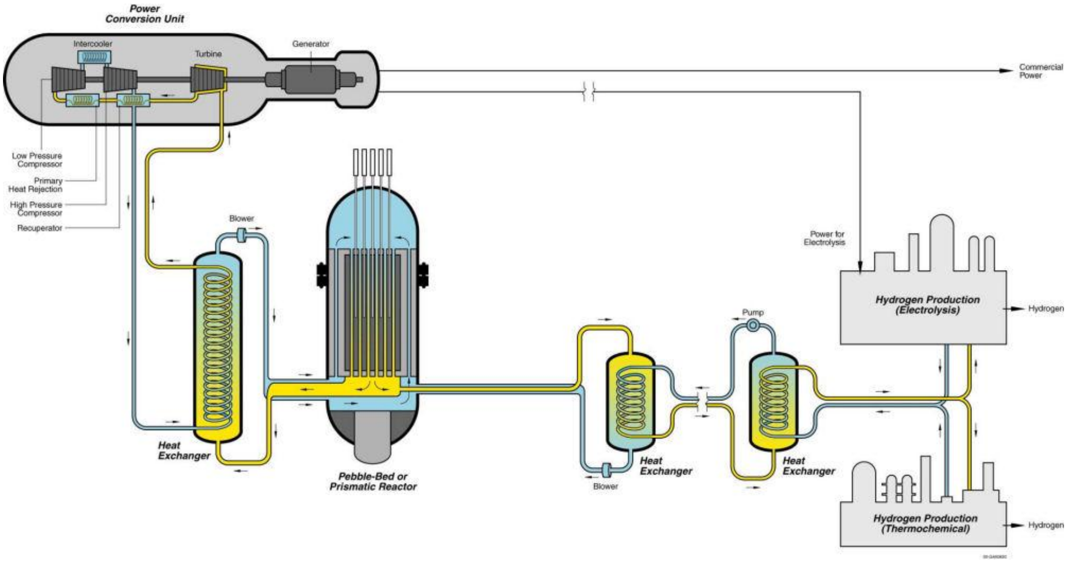


Figure 98. *Very-High-Temperature Reactor (VHTR) (GIF 2008).*

Supercritical-Water-Cooled Reactor (SCWR)

The Supercritical water reactor (SCWR) is a concept that uses supercritical water as the working fluid. SCWRs are basically light water reactors (LWR) operating at higher pressure and temperatures with a direct, once-through cycle. As most commonly envisioned, it would operate on a direct cycle, much like a Boiling Water Reactor (BWR), but since it uses supercritical water (not to be confused with critical mass) as the working fluid, would have only one phase present, like the Pressurized Water Reactor (PWR). It could operate at much higher temperatures than both current PWRs and BWRs. (Gif 2008.)

Supercritical water-cooled reactors (SCWRs) are promising advanced nuclear systems because of their high thermal efficiency (i.e., about 45 % vs. about 33 % efficiency for current LWRs) and considerable plant simplification (Gif 2008).

The main mission of the SCWR is generation of low-cost electricity. It is built upon two proven technologies, LWRs, which are the most commonly deployed power generating reactors in the world, and supercritical fossil fuel fired boilers, a large number of which are also in use around the world. The SCWR concept is being investigated by 32 organizations in 13 countries. (Gif 2008)

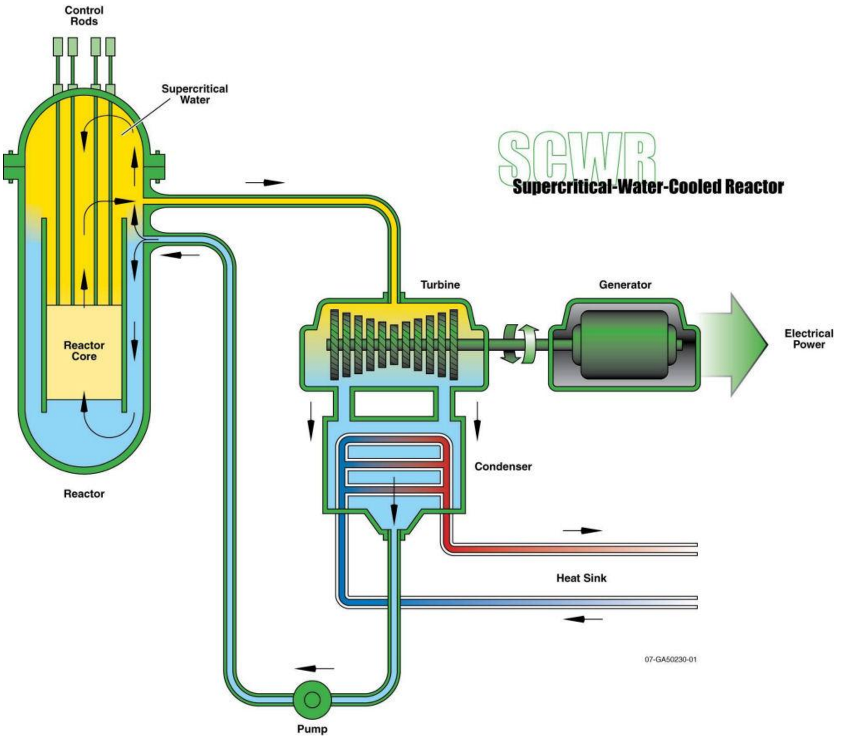


Figure 99. Supercritical-Water-Cooled Reactor (SCWR) (GIF 2008).

Molten Salt Reactor (MSR)

A molten salt reactor is a type of nuclear reactor where the coolant is a molten salt. There have been many designs put forward for this type of reactor and a few prototypes built. The early concepts and many current ones had the nuclear fuel dissolved in the molten fluoride salt as uranium tetrafluoride (UF4), the fluid would reach criticality by flowing into a graphite core which also served as the moderator. Many current concepts rely on fuel that is dispersed in a graphite matrix with the molten salt providing low pressure, high temperature cooling. (GIF 2008)

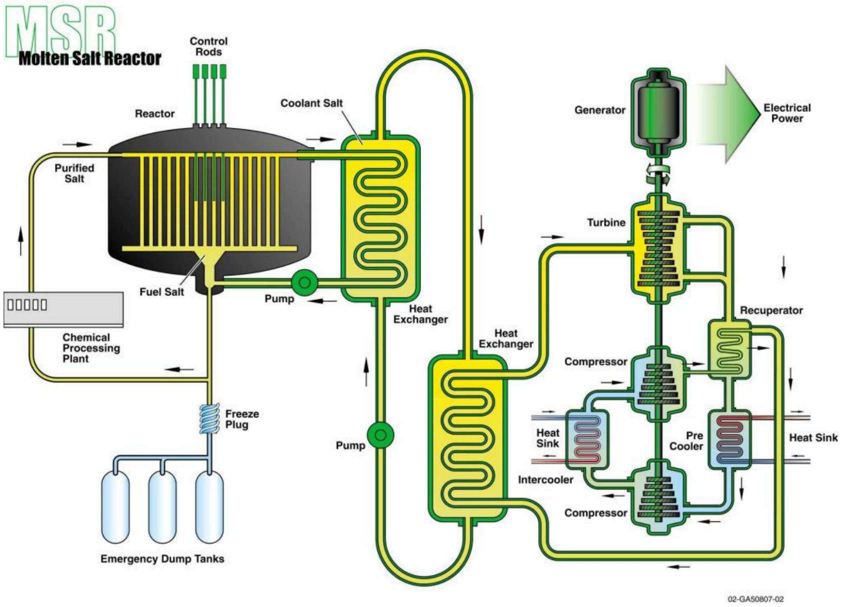


Figure 100. Molten Salt Reactor (MSR) (GIF 2008).

Gas-Cooled Fast Reactor (GFR)

The Gas-Cooled Fast Reactor (GFR) system features a fast-neutron spectrum and closed fuel cycle for efficient conversion of fertile uranium and management of actinides. The reactor is helium-cooled, with an outlet temperature of 850 °C and using a direct Brayton cycle gas turbine for high thermal efficiency. Several fuel forms are being considered for their potential to operate at very high temperatures and to ensure an excellent retention of fission products: composite ceramic fuel, advanced fuel particles, or ceramic clad elements of actinide compounds. Core configurations are being considered based on pin- or plate-based fuel assemblies or prismatic blocks. (GIF 2008)

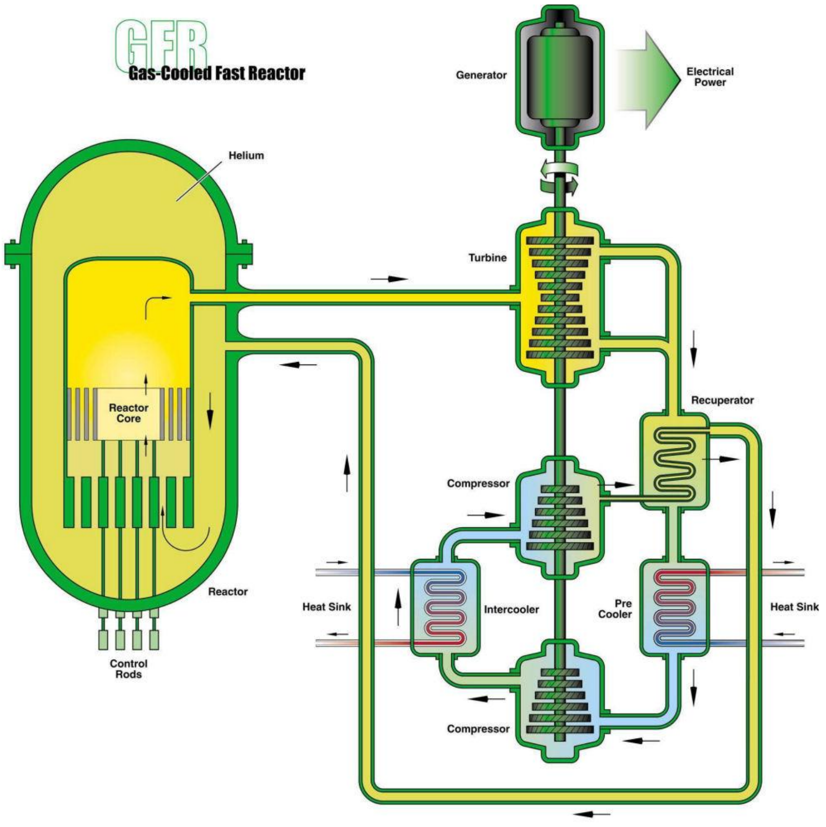


Figure 101. Gas-Cooled Fast Reactor (GFR) (GIF 2008).

Sodium-Cooled Fast Reactor (SFR)

The SFR is a project that builds on two closely related existing projects, the LMFBR and the Integral Fast Reactor (GIF 2008).

The goals are to increase the efficiency of uranium usage by breeding plutonium and eliminating the need for transuranic isotopes ever to leave the site. The reactor design uses an unmoderated core running on fast neutrons, designed to allow any transuranic isotope to be consumed (and in some cases used as fuel). In addition to the benefits of removing the long half-life transuranics from the waste cycle, the SFR fuel expands when the reactor overheats, and the chain reaction automatically slows down. In this manner, it is passively safe. (Gif 2008)

The Integral Fast Reactor or IFR is a design for a nuclear reactor with a specialized nuclear fuel cycle. A prototype of the reactor was built, but the project was cancelled before it could be copied elsewhere. (Gif 2008)

The SFR reactor concept is cooled by liquid sodium and fueled by a metallic alloy of uranium and plutonium. The fuel is contained in steel cladding with liquid sodium filling in the space between the fuel and the cladding. One of the design challenges of an SFR are the risks of handling Sodium. (Gif 2008)

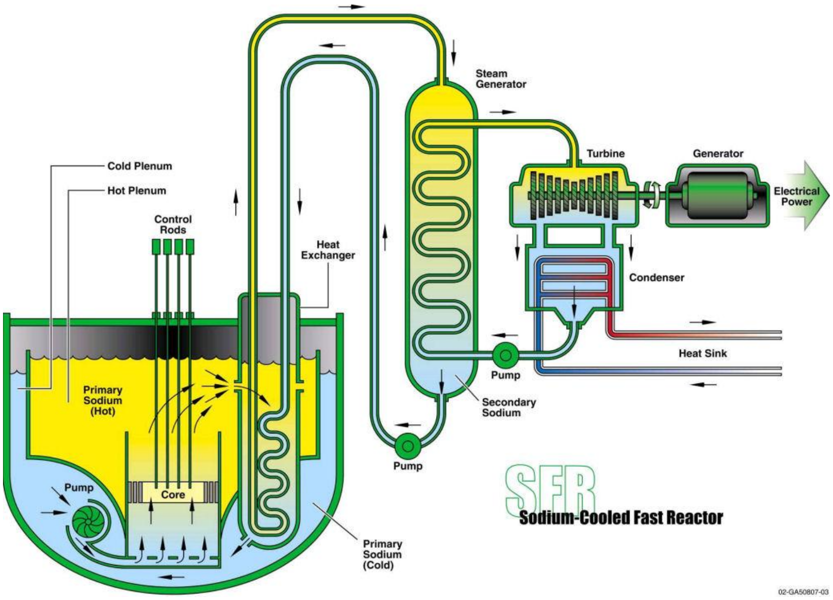


Figure 102. Sodium-Cooled Fast Reactor (SFR) (GIF 2008).

Lead-Cooled Fast Reactor (LFR)

The Lead-cooled Fast Reactor [1] features a fast-neutron-spectrum lead or lead/bismuth eutectic (LBE) liquid-metal-cooled reactor with a closed fuel cycle. Options include a range of plant ratings, including a "battery" of 50 to 150 MW of electricity that features a very long refueling interval, a modular system rated at 300 to 400 MW, and a large monolithic plant option at 1,200 MW. (The term battery refers to the long-life, factory-fabricated core, not to any provision for electrochemical energy conversion.) The fuel is metal or nitride-based containing fertile uranium and transuranics. The LFR is cooled by natural convection with a reactor outlet coolant temperature of 550°C, possibly ranging up to 800°C with advanced materials. The higher temperature enables the production of hydrogen by thermochemical processes. (Gif 2008)

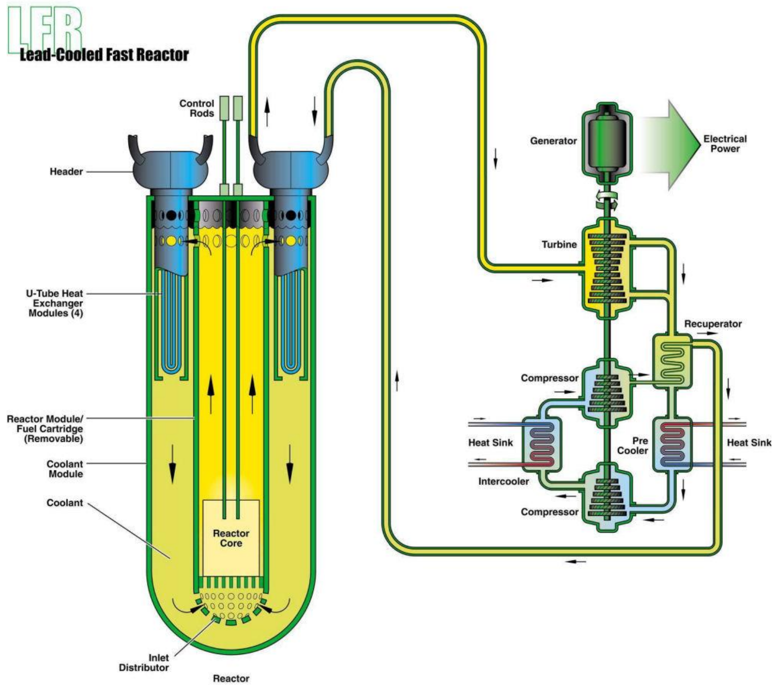


Figure 103. Lead-Cooled Fast Reactor (LFR) (GIF 2008).

A vast majority of nuclear technology development are based on utilization of uranium resources. As noted earlier, thorium can be considered as a source for nuclear fuel but because it cannot be used as such, it must be transformed into fissile material by using additional neutrons. International Atomic Energy Agency lists several experimental and power reactors for thorium utilization. Current activities related to thorium are mostly in India, a country with major thorium reserves and huge increase in estimated energy consumption. Thorium utilization has been earlier under serious consideration in many industrialized countries, but according to IAEA, experimental and power reactors have not been in operation in the recent years. At the moment, the interests towards thorium utilization as a nuclear fuel have been emerging again. Thorium has been mentioned as a potential fuel for LWRs and various generation IV nuclear reactors, especially for gas-cooled fast reactors (GCR) and molten salt reactor (MSR). (Gif 2008)

4.5. Hydro Power

Hydro power is one of the oldest known energy sources. Currently the energy potential of rivers and rapids is not any more used mechanically, instead it is used for electricity production via water turbines. Water turbine is a good example of mature technology, where significant technological developments are not expected. According to British Petroleum (BP), 709 Mtoe hydropower was produced in 2007, which corresponds to over 8,200 TWh electricity. Among the Nordic countries, Norway and Iceland produce almost all electricity by hydro power. The share of hydro is significant in Sweden and Finland as well.

Globally the most significant countries producing hydropower include China, Brazil, Canada, United States, Russia, Norway and Japan. (BP 2008)

World Energy Council has estimated that global hydropower resources would enable a production of 15,000 TWh electricity annually. However, in industrial countries the production capacity of hydripower is close to its maximum value. In other words, almost all available hydropower resources have been taken into use. Suitable resources for additional hydropower production are available in Southern America and Asia. Large-scale hydropower production usually consists of state-owned power plants and traditionally hydropower producxtion haqs been considered as a national issue. (WEC 2007)

The efficiency of hydro power plants is often increased by regulation of the water system; i.e. dams and water reservoirs. Water is stored in reservoirs and feeded in turbins for subsequent changes in electricity needs. However, the amount of annual hydropower production varies quite a lot due to differences in annual precipitation. In addition to large-scale centralised hydropower plants there is also some small-scale and micro hydro power in use, which is characterised my hydropower plants with low efficiency (typically less than 10 MW) for local use and minimal or lacking water regulation. In the EU area, the amount of installed small or micro-scale hydropower in use is about 5,000 MW. (WEC 2007)

In 2007, about 14 TWh electricity was produced by hydropower in Finland. This refers to a 15.5 % share of total electricity supply. The largest amount of built hydropower capacity is located in Norhern Finland, in Oulujoki, Kemijoki and Iijoki which were built after World War II. Continuation of the Northern hydropower building has been discussed a lot during the decades, and the issue is at today’s energy policy agenda. (Vesirakentaja Oy 2008)

Finnish Energy Industries has recently ordered and published an investigation of unused hydropower resources in Finland (Power from water 2007). The investigation covers also those resources located on protected and Natura2000 areas. The investigation covers the need for update of the construction plan, the additional capacity available with construction, annual electricity production of the additional capacity and the controllability of production. (Vesirakentaja Oy 2008)

According to this investigation, the technologically and economically significant but unused hydropower potential in Finland is totally 934 MW which corresponds 2.98 TWh annual electricity production. However, the largest part of this potential is located in sites protected by legislation ot in Natura2000 areas. These include e.g. Vuotos reservoir and power plant (37 MW and 0.33 TWh), Kollaja reservoir and power plant (35 MW and 0.20 TWh), Ounasjoki (349 MW and 1.21 TWh) and middle part of Iijoki (113 MW and 0.44 TWh). The building of these hydropower rites would require changes into existing legislation dealing with hydropower and nature conservation. Outside the protected areas and Natura2000 areas can be found a 330 MW ja 0.58 TWh hydropower potential, which is mainly located in existing hydropower sites where some additional output is available via modernisation of existing hydropower facilities. (Vesirakentaja Oy 2008)

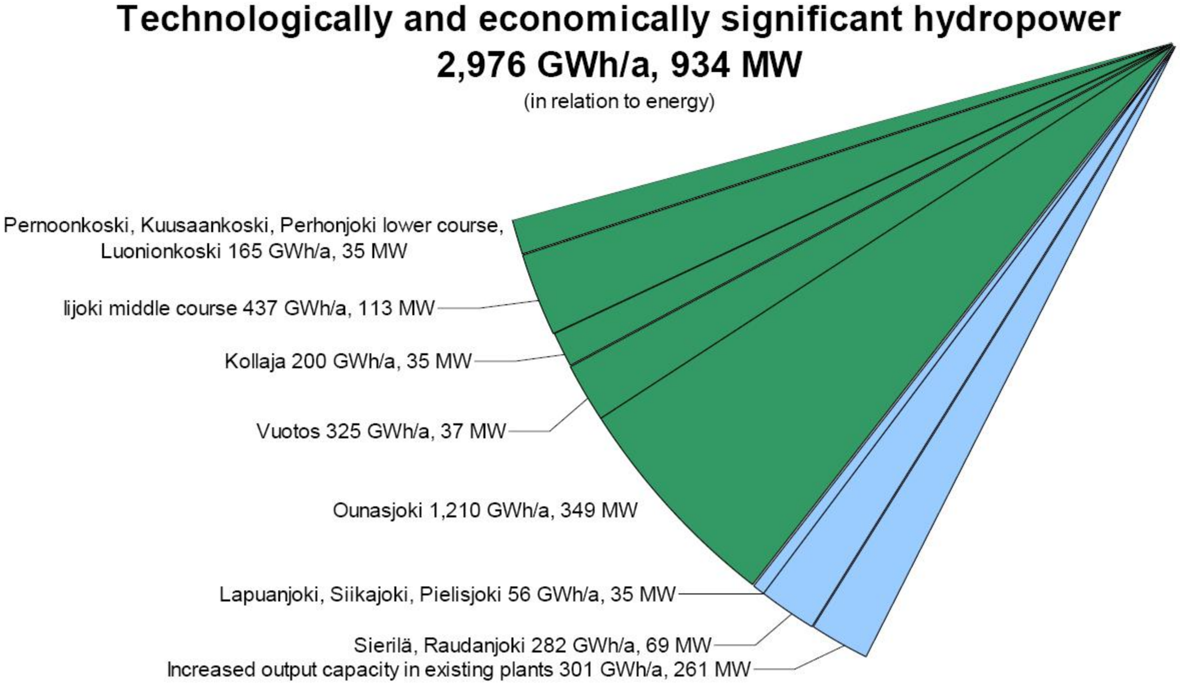


Figure 104. Unbuilt Hydropower Resources in Finland. Green Slices: Protected Areas and Natura2000 Areas (Vesirakentaja Oy 2008).

In addition, there is also a potential of 274 MW and 0.89 TWh suitable fot additional hydropower production but requiring update in old construction plans. This potential is mainly located in the rivers of Pohjanmaa and upper courses of Oulujoki, Iijoki ja Kemijoki. This potential is mainly in protected and Natura2000 areas, only 63 MW and 0.22 TWh is available with curtrent legislation. About a half of this potential could be constructed with investment subsidies for energy plants at their current level. According to the investigation, there is also an additional potential of 368 MW and 2.86 TWh outside of centralised construction possibilities and protected areas, which is called as ”natural hydropower resources”. (Vesirakentaja Oy 2008)

4.6. Solar Energy

4.6.1. Solar Technologies

Nowadays, an extremely large variety of solar technologies are available, and photovoltaics have been gaining an increasing market share for the last 20 years, but global generation of solar electricity is still small compared to the potential of this resource. The current cost of solar technologies and their intermittent nature make them hardly competitive on an energy market still dominated by cheap fossil fuels. From a scientific and technological viewpoint, the great challenge is finding new solutions for solar energy systems to become less capital intensive and more efficient: for this purpose low-cost and/or high-efficiency photovoltaic device concepts are being developed. Solar thermal technologies are reaching a mature stage of development and have the potential of becoming competitive for large energy supply. Intermittency is being addressed with extended research efforts in energy storage devices, such as batteries and other electric storage systems, thermal storage, and the direct production of solar fuels (typically hydrogen). All these are valuable routes for enhancing the competitiveness and performance of solar technologies. (Stanford University 2006)

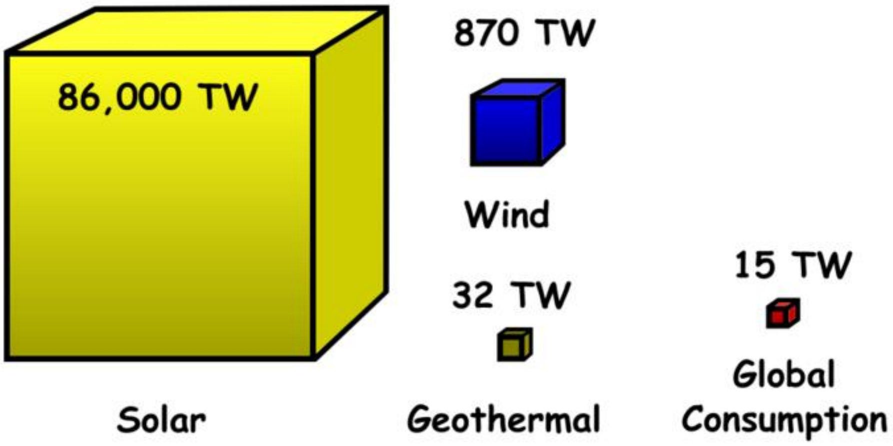


Figure 105. Comparison of Incoming Solar Energy with Other Energy Flows and the Human Global Consumption of Energy (Wikipedia 2008).

According to IEA, the total cumulative installed capacity of PV systems in IEA PVPS (Photovoltaic Power Systems Programme) reached 5.7 GW at the end of 2006, with an increase of 36 % over 2005. This represents around 87 % of the global capacity (6.6 GW), with Germany, Japan, and USA accounting for 70 % of the total capacity (the same countries are the three largest PV manufactures). In the future the trends for PV systems are expected to be positive, with global yearly electricity generation between 1,383 and 2,584 TWh in 2050. (IEA 2008)

Figure 106. Cumulative U.S. PV Installations by Year (US Solar Industry 2006).

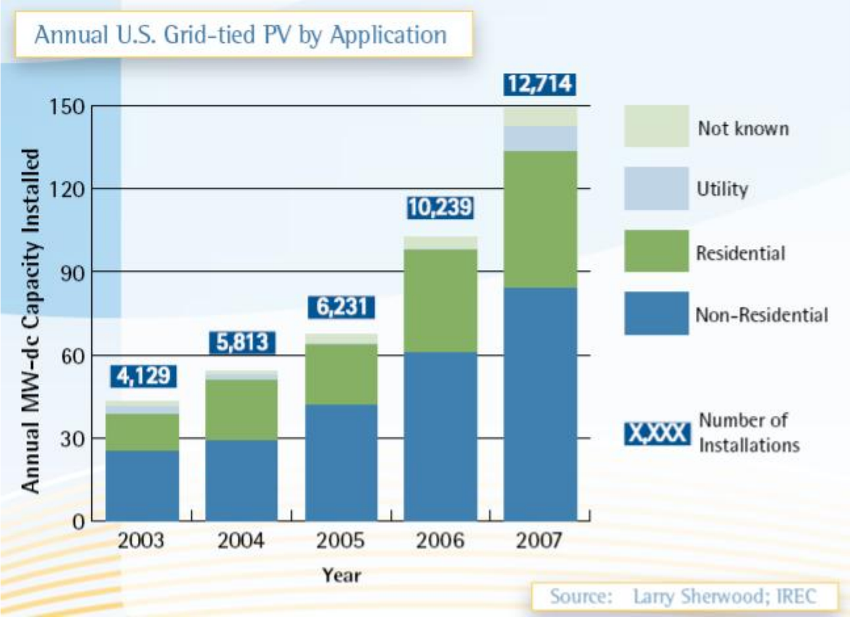


Figure 107. Annual U.S. Grid-tied PV by Application (US Solar Industry 2006).

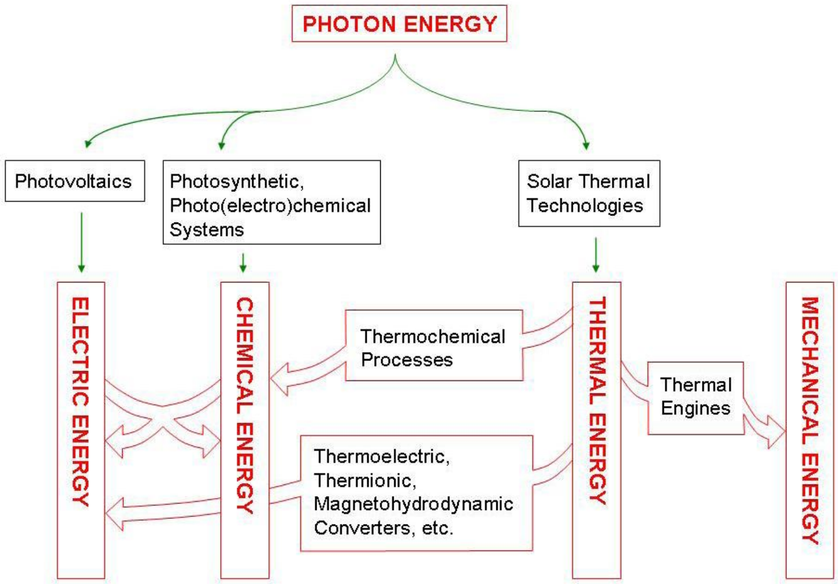


Figure 108. Overview of Available Technologies for Solar Energy Conversion (SEIA 2004).

Photovoltaics directly convert photon energy into electricity: they use inorganic or organic semiconductor materials that absorb photons with energy greater than their bandgap to promote energy carriers into their conduction band. Electron-hole pairs, or excitons for organic semiconductors, are subsequently separated and charges are collected at the electrodes for electricity generation. Thin- film photovoltaics or “3rd generation photovoltaics”, are considered as a promising route to increasing the efficiency and lowering the cost of photovoltaics (Various authors, Standford University 2006). According to IEA forecasts, thin films are expected to increase their market share significantly by 2020, and in particular Si thin-films modules might reach efficiency as high as 18%, thus representing viable solutions for power applications. This new generation of PV is expected to emerge and reach high market shares between 2020 and 2030 (IEA 2008).

Solar thermal technologies convert the energy of direct light into thermal energy using concentrator devices. For electricity generation, the most developed technologies are the parabolic dish, the parabolic trough, and the power tower. Already commercially available, the parabolic dish can be used in single dish applications with output power of the order of 25 kWe, or grouped in dish farms to create large multi-megawatt plants. Parabolic troughs seem most likely to be used for deployment of solar energy in the near-term. Various large plants are currently in operation (California – 354 MW) or in the planning process in the USA and in Europe. Power towers, with low cost and efficient thermal storage, promise dispatchable, high capacity factor power plants in the future. (Standford University 2006.) Investment costs for trough plants are in the range of USD 4 to 9/W, depending on local conditions. Plants under construction are expected to generate electricity at a cost between USD 125–225/MWh. (IEA 2008.)

Photosynthetic, photochemical, thermal, and thermochemical processes can be applied to store solar energy in the form of chemical fuels, particularly hydrogen. Photochemical and photoelectrochemical systems use light-sensitive materials for absorbing photon energy and producing electrons with sufficient energy for splitting water. In thermochemical technologies, concentrated solar flux is used to produce the high-temperatures necessary to drive endothermic reactions such as syngas production from natural gas and water thermal or chemical decomposition. Some biological systems (algae, bacteria, yeasts) produce hydrogen in their metabolic activities. (Standford University 2006)

4.6.2. Market Growth Trends in Solar Energy

Solar thermal is booming worldwide, especially in Europe and USA. In the USA, the total number of shipments of thermal collectors has doubled between 1996 and 2005. The European solar thermal market is also thriving. The market volume in the EU-25 has been very close to 2 GWth newly installed capacity in 2006, compared with 0.6 GWth 10 years before (Levon 2007). The total solar thermal capacity in operation was 5 GWth in 1997, 10 GWth in 2004 and has reached 15 GWth in 2007 (ESTIF 2007). Around 2 million European families already directly benefit from solar thermal energy, as do other frequent users such as hotels, sport centres and office buildings. Apart from policy support, the main drivers of these highly positive trends are growing awareness for solar energy, increasing prices of conventional energies, growing concern over security of supply with imported fuels as well as visible signs of climate change.

The current situation in Austria, where 15 % of detached houses already use solar thermal and in some villages solar collectors can be seen on most roofs, is showing the way for the rest of Europe. The potential for growth in Europe is immense, particularly in market sectors such as multi-family houses, industrial and office buildings. (ESTIF 2007)

European Solar Thermal Industry Federation (ESTIF) presents two 2020 targets, minimal and ambitious, for solar thermal energy development. Technically, ESTIF foresees a market phase-in of new applications, together with considerable advancement in heat storage and solar cooling, to impact the market around 2015-2025. Economically, they anticipate further cost reduction of solar thermal, and the continuing cost increase of fossil fuels. Politically, business as usual is assumed, i.e. fragmented support for the minimal target; strong support EU-wide for the ambitious target. (ESTIF 2007)

In the minimal target (Austria scenario), the minimum goal for the EU in 2020 should be to reach the solar thermal usage of 199 $\mathrm{kW_{th}}$ per 1.000 capita of Austria in 2005, equivalent to a total capacity in operation of 91 $\mathrm{GW_{th}}$ in the EU (ESTIF 2007).

The market growth rate needed to reach this minimal target is 16 % per year, well below the EU average of 2002-2006. However, to reach this target a better political framework is needed throughout the EU, to make sure that the growth is shared in all countries. (ESTIF 2007)

The ambitious target, $1\mathrm{m}^2$ per capita for every European in 2020, can be reached with a suitable support framework. 1 m^2 of collector (0.7 $\mathrm{kW_{th}}$) per capita equals a total capacity 1,190 $\mathrm{GW_{th}}$ in the EU. In the residential sector alone, about two million EU families have already installed this amount of solar capacity. Reaching this target means using solar widely both for cooling and process heat, with majority of this capacity supplying domestic hot water and space heating. The average yearly growth rate of the EU market necessary to reach this target is 31 % – less than the rate achieved in 2006 and only 7 % above the 2002–2006 average. (ESTIF 2007)

A glance at the growing competition for scarce resources on the global energy markets is a persuasive argument for using solar thermal most everywhere possible during the 21st century. Conservatively estimated, this market will have a value in the order of 10,000 billion €, without replacements and maintenance. Europe is in a good position and has the chance to be the main beneficiary of this new global business field. In most renewables, Europe is leading both in technology and in the market volumes. However, in the latter, the Chinese market for solar thermal alone is 7 times bigger than the EU market. However, given the price levels, European manufacturers cannot easily compete in markets like China, India and Turkey. A substantial growth in the domestic EU market is needed for the European to maintain its technological leadership (ESTIF 2007).

World photovoltaic shipments grew by 32 % in 2003, and the industry generated $4.7 billion in revenue. Solar electric systems for homes and businesses dominated the market in the United States, Europe, and Japan as the volume of sales surpassed 740 megawatts (MW), with Europe contributing to around 50 % of the global cumulative capacity.

Increasingly, policies in Europe and Japan (in particular feed-in tariffs and 70,000 or 100,000 roofs programs) are driving technology and market development: support mechanisms are defined in national laws. The introduction, modification or fading out of such support schemes can have profound consequences on PV industries. PV Market forecasts therefore depend on a deep understanding of the political framework. (SEIA 2004)

The next 10 years are critical for worldwide solar power development. This period will determine which nations reap the economic, environmental, security, and reliability values that solar power offers. Actions by government and industry will determine whether solar power is catapulted to a new level, meanwhile investment decisions for research, new manufacturing, and creating new markets will determine where solar power will thrive (SEIA 2004).

SEIA (Solar Energy Industries Association) estimates that, if policies for technology and market development are introduced, the cumulative capacity of installed solar electric systems in the United States will grow substantially from less than 0.4 GW in 2003 to 200 GW by 2030.

The solar PV market has been flourishing over the last years and is forecasted to confirm this trend in the coming years. After an exponential growth in the last 10 years, by the end of 2006 the generating capacity manufactured reached 2500MW, with the main players being Europe, US and Japan (Daviss 2007).

This is the result of the feed-in tariffs introduced first in Germany (which has the 55 % of the world's installed base of PV panels) and, more recently, in Italy and Spain. (Daviss 2007)

EPIA (European Photovoltaic Industry Association) has developed a "policy driven" scenario (in which follow up and/or introduction of support mechanisms, namely feed-in tariffs, in a large number of countries is taken into account) according to which Germany is expected to remain the market leader and even increase its market size considerably over the next years. The biggest growth is foreseen for the Rest Europe in particular in countries such as Spain, Italy, France and Greece. The USA will also be able to use its vast solar potential and will challenge Germany as the Number 1 PV country. PV development in Japan will, to a large extent, depend on the decision of the Japanese government to reintroduce, or not, a support program. Also the Rest of Asia, in particular India and South Korea, will face increasing demand for PV. (EPIA 2008)

Global PV markets have been expanding rapidly over the last decade. EPIA expects a similar market development for the years to come. By 2010 a global annual PV market of 7 GWp can be expected in the privileged Policy Driven Scenario. However, it is evident that such a market growth will require continuous political support in some countries and expanding support in countries which have not been active supporters of PV so far. PV will reach competitiveness with peak power prices in southern Europe by 2015 and in most of Europe by 2020. This so called grid parity is expected to then trigger an extraordinary demand due to PV generated electricity becoming increasingly competitive as a result of a continuous decrease in PV technology prices (thanks to the investment in new designs) and expected price increases of fossil energy sources (EPIA 2008).

The costs of PV systems are still high, despite their decrease with a learning curve of 15-20 % which resulted in a significant decrease in prices from 1990s to 2004. From 2004 prices have increased again, because of both increased demand (especially in Germany and Japan) and shortage of silicon. Currently, crystalline silicon modules are back to 2004 nominal prices and are expected to decrease as new manufacturing plants and silicon-purification facilities come on line. At the moment, PV modules account for about 60 % of total costs, which were around USD 6.25/W at the end of 2006 and are expected to drop to USD 3.75/W to 4.4/W by 2010. The increasing penetration of thin-film modules will help to further reduce the costs (IEA 2008).

4.6.3. Solar energy potential in Finland

Photovoltaics

In Finland there are over 150 km^2 roof or façade surface suitable for photovoltaics. If this surface were covered with solar electric panel, the production would be 14 TWh / year. Due to the power limitations set by the energy system, upper limit of the peak power of photovoltaics can be considered 1 500 MW$_p$ (1.5 TWh / year). Larger amounts require reserve capacity arrangements and in the long run effective energy storage solutions. In table below, there is summarized estimation of the theoretical potential of photovoltaics in Finland. (SOLPROS 2001, 8–9.)

Table 4. Theoretical Potential of Photovoltaics in Finland (SOLPROS 2001).

Summer cottages and holiday camps	10 MWp	10 GWh
Special applications	10 MWp	10 GWh
Public buildings (20 % of the municipalities a'50 kWp)	4 MWp	4 GWh
Roofs of the buildings	14 000 MWp	11 TWh
Facades of the buildings	4 000 MWp	3 TWh
Photovoltaics in the network without additional reserve capacity	1 500 MWp	1.5 TWh

Solar heating

The goal of the national solar power program of measures is 100.000 m^2 solar heating in 2010. In the year 2025 around 1.000.000 m^2 could represent the upper limit of the usage. There are estimations of potential for solar heat in Finland illustrated in the following table below and previous numbers fit well within these estimations. Long-term possibilities are most likely a couple of TWh per year. The upper limit in the long run (year 2050) will be around 10 TWh, which means the last three rows. According to this estimate, the practical potential is naturally lower than these numbers. (SOLPROS 2001, 15)

Table 5. Technical Potential of Solar Heating in Finland (SOLPROS 2001).

Market segment	Collecting area	Energy
Special targets (outdoor swimming pools, sports halls, camping sites, fast food chains etc.)	50 000 m²	20 GWh
Public buildings (20 % of the municipalities a'500 m²)	40 000 m²	20 GWh
Solar heat supplements oil heating (10 % of the renewable oil cauldron)	90 000 m²	30 GWh
Warm service water of the one-family house	1 500 000 m²	0.6 TWh
Replacement of the heavy fuel oil during summertime	280 000 m²	0.1 TWh
Drying of biomass	5 000 000 m²	2 – 3 TWh
Summertime's regional and district heating	5 000 000 m²	2 – 3 TWh
Solar heat's seasonal storage	10 000 000 m²	4 – 5 TWh

4.7. Wind Energy

4.7.1. Background Information

Installed wind energy has been increasing rapidly worldwide over the last 5 years and now accounts for up to 3 % of electricity consumption in Europe, which offsets nearly 50 million tons of CO_2 (European Commission 2007).

According to EIA (Energy Information Administration) wind energy is also becoming increasingly important in the USA: although it has developed rapidly in the United States since 2000, it still did not provide a substantial amount of electricity until 2006, when wind energy produced 27 billion kWh. This represents half the amount provided by biomass, but nearly 83 %more than the amount provided by geothermal. The fact that wind provided 7 % of renewable-based electricity during 2006 (and 28 % of non-hydro renewable generation) is due to the large amount of new wind capacity which has come on line since the turn of the century. In particular, total installed wind capacity increased from 4,417 MW in 2002 to 11,329 MW in 2006, with 2,600 MW of the increase coming during 2006 alone. (EIA 2008)

Utilization of wind energy worldwide is increasing rapidly: 20,073 MW of wind power capacity was installed globally during 2007 to reach a total of 94,122 MW by the end of the year. The global market for wind turbines increased by 31 % in 2007, following growth of 33 % and 41 % in 2006 and 2007 respectively. (EWEA 2008)

The fast growth is particularly visible in Europe, where the European Commission's 1997 White Paper target of 40,000 MW wind power capacity by 2010 in the EU was reached already in 2005. In the EU, installed wind power capacity has increased by an average of 25 % annually over the past eleven years, from 4,753 MW in 1997 to 56,535 MW in 2007. In terms of annual installations, the EU market for wind turbines has grown by 19 % annually, from 1,277 MW in 1997 to 8,554 MW in 2007. (EWEA 2008)

The very rapid growth in Denmark and Germany, up to around 2003/4, has now slowed, but Spain, India, China and the United States are forging ahead and there are plans for further capacity in Canada, the Middle East, the Far East and South America. If the current growth rate continues, there may be about 150 GW of wind by 2010. (WEC 2007)

4.7.2. Wind Energy Industry and Market Trends

In a recent study by a British scientist, the current wind energy technology trends in Europe are investigated. Since captured energy is proportional to the blade area of the wind turbines, wind technology has mostly evolved towards higher and bigger wind turbines over the last decade. Nowadays, the design of wind turbines is undergoing a shift using power electronics to bring additional energy capture and control to the quality of power delivered to the grid. (EC 2007)

Another trend that affects electricity production is repowering, which means the replacement of older, smaller turbines with fewer, larger turbines representing the state of the art in power production. Repowering is expected to increase in years ahead. In 2006, Denmark reduced the total number of turbines, but capacity was increased by 8 MW. Germany removed 79 turbines and added 135 MW of new machines in these areas. In Italy, 46 turbines ranging from 200 kW to 450 kW were replaced by 15 larger machines in the range of 800 kW to 1500 kW. This increased total in-field capacity by 4 MW but had a larger benefit reported in terms of energy production. The Netherlands decommissioned 40 turbines in 2006 Twenty-one of these with total capacity of 4.3 MW were replaced with 13 turbines with a capacity of 26.5 MW, for a net "repowering effect" of 22 MW. (IEA 2006) The timely development of ever-bigger rotor-blades is considered a major bottleneck and a key limiting factor determining the up-scaling pace in the wind industry, and more R&D actions are needed in terms of exploring new ways of transportation, installation and operation and maintenance methods of these big components (WEC 2007), in fact the biggest turbines currently available are 5-6 MW units with a rotor diameter of up to 126meters (IEA 2008). Problems relative to weak grid should also be taken into account: in some cases the local electrical grid may be too weak to handle the electricity output from a large machine (WEC 2007).

Energy payback time is reported to be decreasing considerably, with values around 6–8 months right now, which is similar to conventional energy, but with no ongoing fuel supply costs or waste production. The payback time for CO_2 is between 13 and 20 months, thus showing that the return on investment is rapid in terms of environmental and economic costs. (EC 2007)

At the policy level, the support mechanism which has proven to be the most successful for the promotion of wind energy is fixed feed-in tariffs, and it is also for this reason that Europe is the current leader within this sector, with nearly 75 % of installed wind energy capacity worldwide, and an annual growth rate of the sector which has been close to 30 % over the last 5 years (EC 2007).

New developments are underway in the field of wind energy storage. One example is that proposed by the EU project “Night wind” which aims at using a refrigerated warehouse as a giant battery for wind energy, so to store all electricity produced during night time by windmills all over Europe, and to release this energy again during the peak electricity demand hours in daytime (Night Wind). Other options are electricity storage in redox flow batteries (a class of devices which employ an electrolyte where energy is stored and a cell stack where energy conversion occurs), pumping pressurized air in geological formations and releasing it at night or when the wind does not blow, or mechanical energy storage, precisely in the form of flywheels like those offered by Beacon POWER (BEACON Power).

Other new R&D developments connected to wind power technology include super conducting generators (thanks to which 50-60 % reduction in weight and size are expected), smart rotors (which would aid load reductions), but also new concepts like “flying windmills” (a novel design in which turbines are tethered to the ground and tap jet stream wind currents) or floating structures for off-shore turbines. Research for hybrid systems is also underway, as in the case of Poseidon’s Organ, in which a floating off-shore wave power plant also serves as foundation for wind turbines. (IEA 2008)

As mentioned previously, the cost of wind power has declined steadily over the last decades, therefore wind prices are expected to fall during the next two-three years. According to the IEA forecasts, this will lead to a decrease in prices for the installation of wind technologies, which, in 2020, will make electricity produced from onshore wind competitive with that produced from fossil fuels, as it already is at good wind sites. (IEA 2008)

Price projections estimate that in 2015 costs will be about US cents 5.3/kWh at a high wind site and about 6.3/kWh in a medium wind site (IEA 2008).

The same forecasts show that the deployment of onshore wind technologies will continue to be dominated by Western Europe until 2020, when investments in China and USA are expected to pick up. By 2025 onshore wind installations will attain a capacity of 200 GW and after that will remain relatively constant, meanwhile in China onshore wind power will reach 250 GW by 2040. As far as offshore wind is concerned, the commercialization will be reached between 2035 and 2040, when it will get to about 250 GW. Because of the higher capital costs requirements (turbines are on average about 20 % more expensive than onshore and tower and foundations can cost more than 2.5 times the price of an onshore project of the same size), the deployment of this technology will be limited to Western Europe, OECD Pacific and OECD North America. (IEA 2008)

Off-shore wind however, presents various advantages, such as alleviating concerns about despoiling the landscape and reduction of intermittency issues, since the wind regime is more stable. On the other hand a solution to intermittency and grid stability may lie in the development of more sophisticated grid management systems, demand-side management systems and electricity storage systems as those described above. (IEA 2008)

Six leading wind turbine manufacturers accounted for about 90 % of the global market in 2006: turbine manufacturing continues to expand in Europe and new plants are opening in China, USA and India. The growth in this sense is very large: four of the leading companies in this sector, including India's Suzlon, have opened plants in the USA in 2006, meanwhile the Chinese Goldwind has reached the top ten in terms of market share worldwide. (IEA 2008)

According to GWEC (Global Wind Energy Council), 2007 was the best year so far for the global wind industry, with close to 20000 MW installed. This development was lead by the US, China and Spain, and it brought the world-wide installed capacity to 94,123 MW. This is an increase of 31 % compared with the 2006 market, and represents an overall increase in global installed capacity of about 27 %. "The growth rates we are experiencing in wind energy continue to exceed our most optimistic expectations," said GWEC Secretary General Steve Sawyer. "Globally, wind energy has become a mainstream energy source and an important player in the world's energy markets, and it now contributes to the energy mix in more than 70 countries across the globe. (GWEC 2008)

The top five countries in terms of installed capacity are Germany (22.3 GW), the US (16.8 GW), Spain (15.1 GW), India (7.8 GW) and China (5.9 GW). In terms of economic value, the global wind market in 2007 was worth about 25 bn EUR or 37bn US$ in new generating equipment. (GWEC 2008)

China in particular has seen a doubling in its annual market, with 3,304 MW of wind energy capacity added during 2007, representing market growth of 145 % over 2006, and now ranks fifth in total installed wind energy capacity with 5,906 MW at the end of 2007. However, experts estimate that this is just the beginning, and that the real growth in China is yet to come. Based on current growth rates, the Chinese Renewable Energy Industry Association (CREIA) forecasts a capacity of around 50,000 MW by 2015. The manufacturing industry of wind energy in China is booming, in fact, while in the past imported wind turbines dominated the Chinese market, this is changing rapidly as the growing wind power market and the clear policy direction have encouraged domestic production. At the end of 2007, they were 40 Chinese manufacturers involved in wind energy, accounting for about 56 % of the equipment installed during the year, up from 41 % in 2006. "This percentage is expected to increase substantially in the future. Total domestic manufacturing capacity is now about 5,000 MW, and is expected to reach 10-12 GW by 2010" predicts GWEC President Prof. Arthouros Zervos. Established major Chinese manufacturers are Goldwind, Sinovel Windtec, Windey and Dongfeng Electrical. While in 2006, only about 400 MW of new capacity was manufactured by Chinese manufacturers, in 2007, the top two Chinese companies (Gold Wind and Sinovel) alone accounted for 1,460 MW of the new installed capacity, representing about 42 % of the annual market. This compares to only 37 % provided by the top three foreign manufacturers (Gamesa, Vestas and GE). (GWEC 2008)

As far as the European market is concerned, the big surprise was Spain with 3,522 MW of new capacity installed in 2007, the highest amount of any European country ever, earning it second place globally after the US. Total installed wind energy capacity now stands at over 15 GW in Spain, but there was also sustained growth in France with 888 MW of added capacity to reach 2,454 MW and Italy, with 603 MW added for a total of 2,726 MW. The new Member States performed well and increased installed capacity by 60%, with Poland, the most successful, reaching a total of 276 MW. The Czech Republic installed 63 MW, its best year ever, and Bulgaria 34 MW. Nevertheless, a handful of markets pulled in the opposite direction, including Germany, whose annual market shrank by 25 % compared to 2006. Portugal and the UK also slumped. As a result, the overall annual market growth in Europe in 2007 was of only 11 %. (GWEC 2008)

Another remarkable trend is that, while Europe remains the leading market for wind energy, new installations represented just 43 % of the global total, down from nearly 75 % in 2004. For the first time in decades, more than 50 % of the annual wind market was outside Europe, and this trend is likely to continue into the future. While Europe, North America and Asia continue to see the most important additions to their wind energy capacity, the Middle East/North Africa region increased its wind power installations by 42 %, reaching 538 MW at the end of 2007. New capacity was added in Egypt, Morocco and Iran. Growth in the Pacific region was led by New Zealand with 151 MW in new capacity, which nearly doubled the country's total installations, reaching 322 MW. While Australia had an exceptionally weak year with only 7 MW of new installations, the change in government at the end of 2007 spurs hopes for a brighter future for wind energy. Within hours of being sworn in to office, the new Labour Prime Minister Kevin Rudd signed the ratification of the Kyoto Protocol, and the new government is now making good on its promise of a target of 20% power production by renewables by 2020. (GWEC 2008)

Still according to GWEC, the global wind market is predicted to grow by over 155 % from its current size to reach 240 GW of total installed capacity by the year 2012. This would represent an addition of 146 GW in 5 years, equaling an investment of over 180 bn EUR (277 bn US$, both in 2007 value). The electricity produced by wind energy will reach over 500 TWh in 2012 (up from 200 TWh in 2007), accounting for around 3% of global electricity production (up from just over 1 % in 2007). The main areas of growth during this period will be North America and Asia, and more specifically the US and People's Republic of China. This forecast exceeds previous estimates by GWEC, and the total installed capacity for 2010 has been corrected upwards to reach 171.9 GW (from 149.5 GW). The average growth rates during this five year period in terms of total installed capacity are expected to be 20.7 %, compared with 23.4 % during 2003–2007. In 2012, Europe will continue to host the largest wind energy capacity, with the total reaching 102 GW, followed by Asia with 66 GW and North America with 61.3 GW. The additions in installed capacity every year are predicted to grow from 19.9 GW in 2007 to 36.1 MW in 2012, with an average growth rate of 12.7 %. Considering that annual markets have been increasing by an average of 24.7 % over the last 5 years, growth could be much stronger also in the future, were it not for continuing supply chain difficulties which considerably limit the growth of annual markets for the next two years. This problem should be overcome by 2010, and along with the development of the offshore market, growth rates are expected to recover in the next decade. (GWEC 2008)

Asia is predicted to overtake Europe as the biggest annual market, with as much as 12.5 GW of new wind generating capacity installed during the year 2012, up from 5.2 GW in 2007. This growth will be mainly led by China, which has since 2004 doubled its total capacity every year, thereby consistently exceeding even the most optimistic predictions. By 2010, China is expected to be the biggest national annual market globally. This development is underpinned by a rapidly growing number of domestic manufacturers operating in the Chinese market, delivering home made turbines to large scale wind energy projects. Already in 2007, 40 domestic suppliers supplied 56 % of the new installations in the domestic market, up from 41 % in 2006. While China will emerge as the continental leader in Asia, sustained growth is also foreseen in India, while other markets such as Japan, South Korea and Taiwan will also contribute to the development of wind energy on the continent. The European market will by 2012 have fallen to third place in terms of annual installations (10.3 GW), behind North America (10.5 GW). Overall, this means that over 71 % of new installations will occur outside of Europe in 2012, up from 28 % in 2004 and 57 % in 2007. While in terms of total installed capacity, Europe will continue to be the biggest regional market its share will have fallen to 42.4 %. The large scale development of offshore wind energy is further delayed and will only start to have a significant impact on European market growth towards the end of the time period under consideration. However, it is expected that offshore development will lend new momentum to growth in Europe during the next decade. In Europe, Germany and Spain will remain the leading markets, but their relative weight will decrease as a larger number of national markets emerge on the scene. While the spectacular growth of the Spanish market in 2007 with over 3.5 GW of new installations will not be sustained, a stable pace of 2–2.5 GW per year on average can be expected, enabling Spain to reach the government's 2010 target of 20 GW. The size of the German annual market will continue to decrease, but it will remain the second strongest European market for the 2008–2012 period and the biggest in terms of total installed capacity. By 2010, offshore developments will give new impetus to the German market, resulting in stronger growth. Other important markets in Europe will be France and the United Kingdom, each increasing by an average of 1 GW per year. The North American market will grow even stronger than previously thought, led by significant growth in the US, as well as sustained development of the Canadian market. In total, North America will see an addition of 42.6 GW in the next five years, reaching 61.3 GW of total capacity in 2012. This represents an average of 8.5 GW of new capacity added every year, the bulk of which will be in the US. These figures assume that the US Production Tax Credit (PTC) will continue to be renewed in time for the current strong growth to continue. Moreover, high level engagement of an increasing number of US states, 26 of which have already introduced Renewable Portfolio Standards, will also assure sustained growth. A change in US administration may further underpin this development. Latin America is expected to contribute to the global total in a more substantial way in the future, mainly driven by Brazil, Mexico and Chile. By 2012, the total installed capacity in Latin America and the Caribbean will increase 8-fold to reach 4.5 GW, with an annual market of 1.4 GW. However, despite its tremendous potential, Latin America is likely to remain a small market until the end of the period under consideration, progressing towards more significant development in the next decade. The Pacific region will see around 2.3 GW of new installations in 2008-2012, bringing the total up to 3.5 GW. While in Australia, wind energy development slowed down considerably in 2006 and 2007, the outlook for the future is more optimistic, mainly thanks to the change in federal government at the end of 2007, the ratification of the Kyoto Protocol and the pledge to implement a new target for 20 % of electricity to come from renewables by 2020. New Zealand, however, got new impetus with 151 MW of new installations, and many more projects are at various stages of development. Africa and the Middle East will remain the region with the smallest wind energy development, with a total installed capacity of 3 GW by 2012, up from 500 MW in 2007. However, it is expected that market growth will pick up in the coming five years, with annual additions reaching around 800 MW by 2012. This development will be driven by Egypt and Morocco, with some development also predicted in other North African and Middle Eastern countries. (GWEC 2008)

Figure 109. *Global Cumulative Wind Power Capacity 1990–2007 (in MW) (GWEC 2008).*

Figure 110. *Top Annual Markets in the World (MW) (GWEC 2008).*

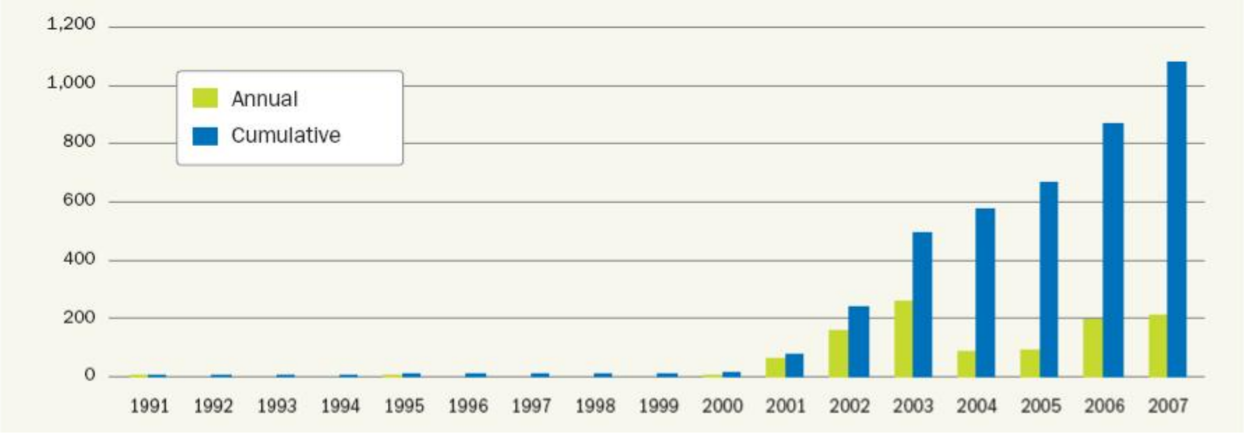


Figure 111. *Offshore Wind in the EU (MW) (GWEC 2008).*

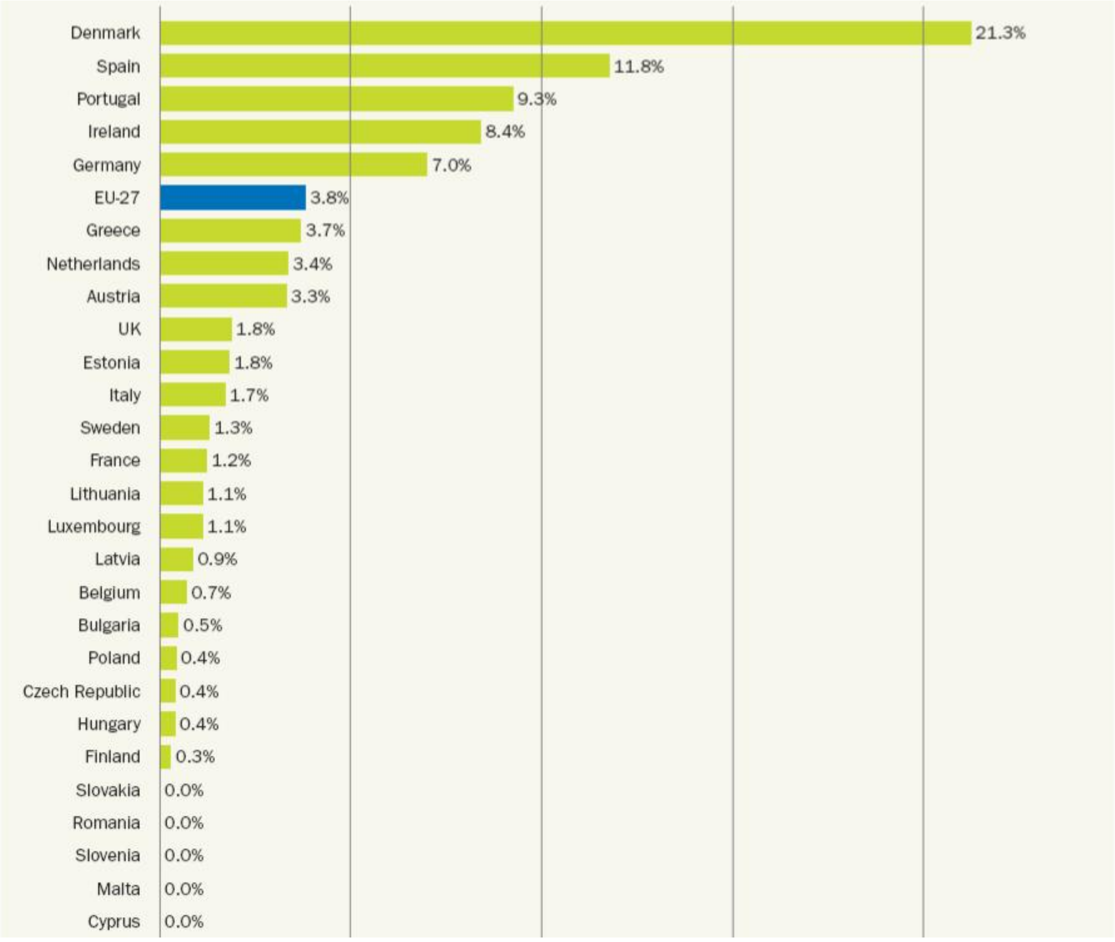


Figure 112. *Wind Power's Share of Electricity Demand (EWEA 2008).*

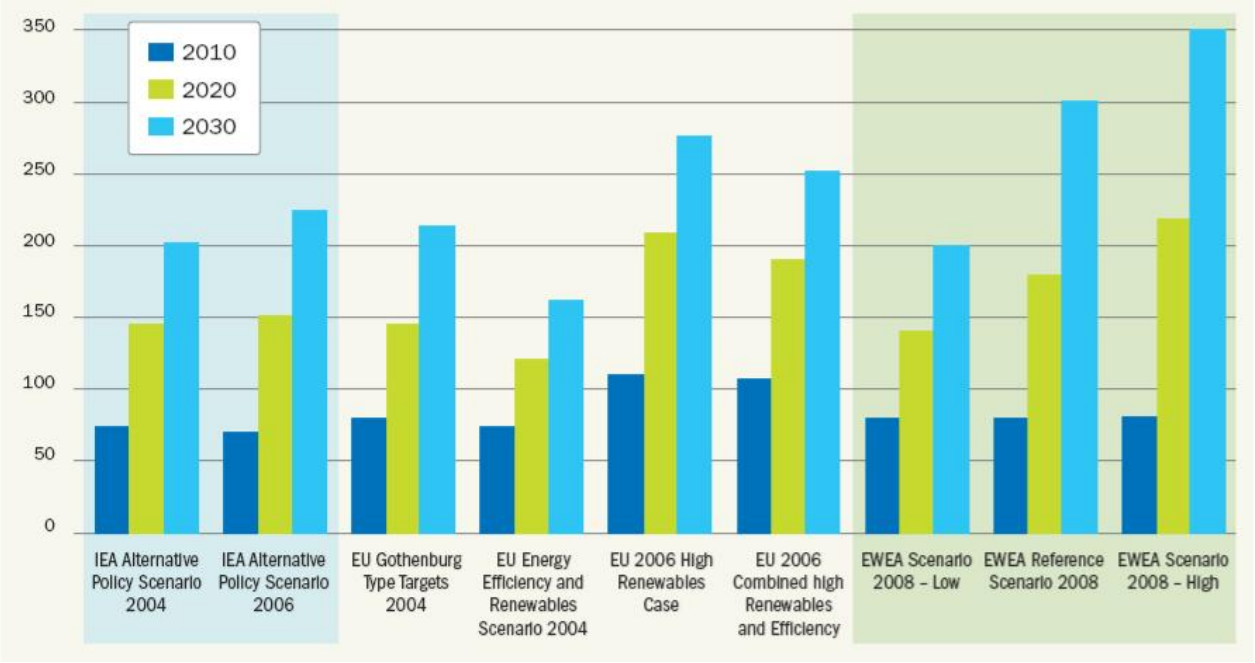


Figure 113. *Advanced Scenarios for 2010, 2020 and 2030 (EWEA 2008).*

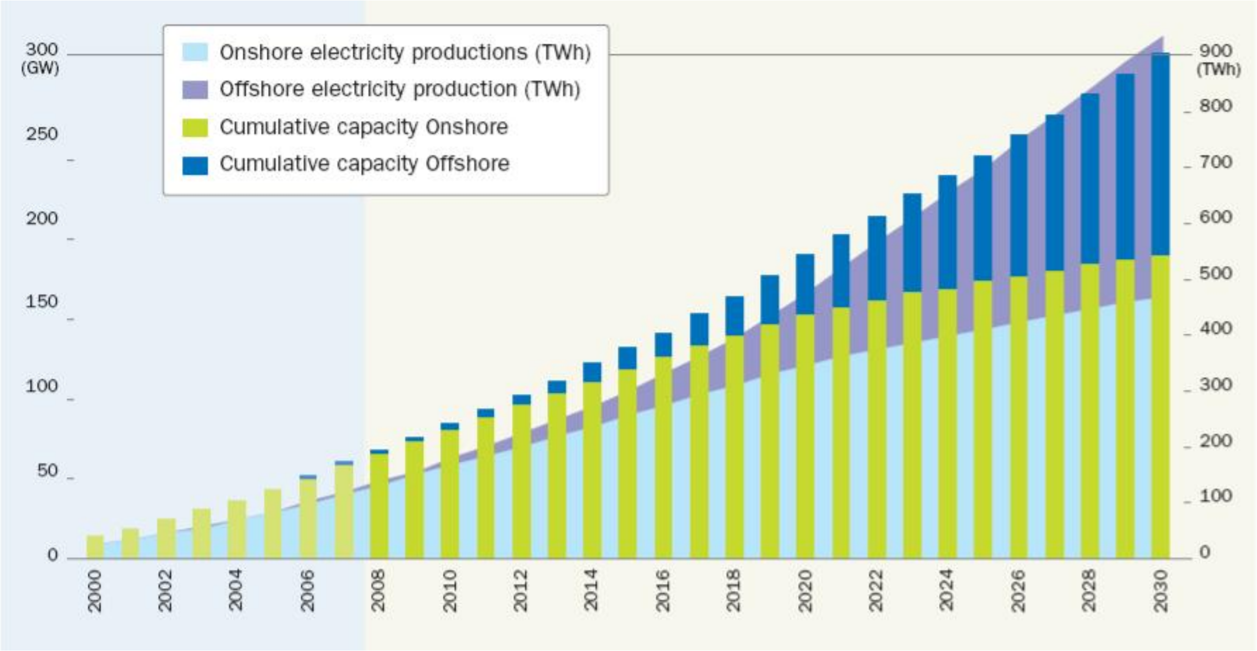


Figure 114. *Electricity from Wind up to 2030 (EWEA 2008).*

	1995	2000	2007	2010	2020	2030
Wind energy share (reference)	0.2%	0.9%	3.7%	5.0%	11.6%	20.8%
Wind energy (RE & eff. case)		0.9%	3.7%	5.2%	14.3%	28.2%
Wind power production (TWh)		23	119	176	477	935
Reference Electricity demand (TWh)*		2,577	3,243	3,554	4,107	4,503
RE & Eff. case Electricity demand (TWh)*		2,577	3,243	3,383	3,345	3,322

Figure 115. *Wind Power's Share of EU Electricity Demand (EWEA 2008).*

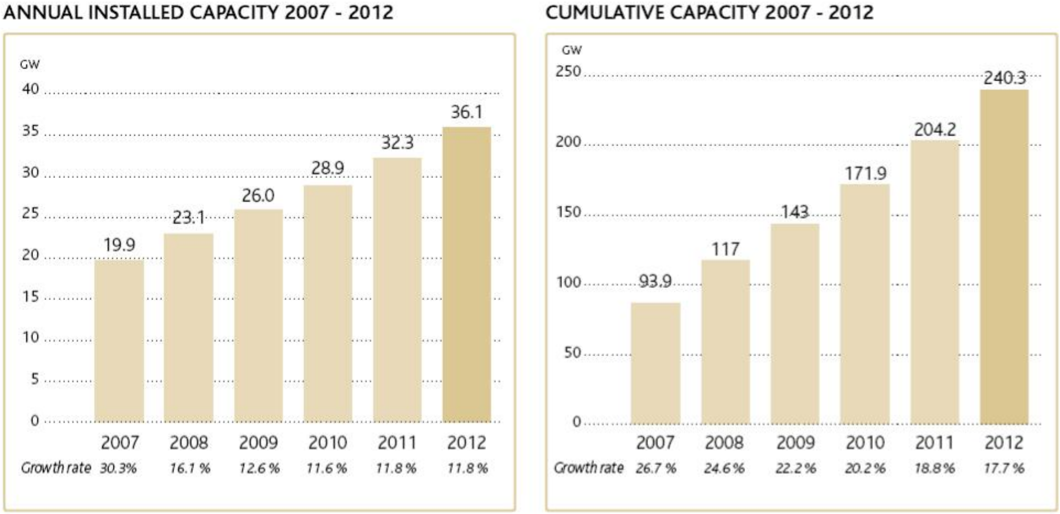


Figure 116. *Forecasts of Cumulative and Installed Capacity of Wind Energy in the Period 2007–2012 (GWEC 2008).*

4.7.3. Wind Energy potential in Finland

Wind Energy potential in Finland according to WWF Finland (2007) and theoretical provincial disquisitions are 9 000–10 000 MW (30 TWh). Out of this figure off-shore potential is 5 000–8 000 MW. Lauri Luopajärvi (2008) estimates the economically viable potential to produce wind power in Finland by the year 2020 to be 2 000 MW (6.1 TWh). (Korpinen et al. 2007, 4; Luopajärvi 2008)

According to the ecological criteria of WWF, the added wind power areas to the landscape plans should be checked, about two thirds of the potential suggested to the sea areas or in the other words about 2 220 wind farms, measures up to the ecological criteria set by WWF. In the fell areas more careful nature study should be done. In regard to the inland wind potential, no official or complete records are made.

Finding out the potential would require updating of the wind atlas. Current wind atlas was done by Meteorological Institute in 1991 and a new one is under way and will be finished by the end of the year 2009. (Korpinen et al. 2007, 4; Laatikainen & Jussila 14.5.2008)

4.8. Bioenergy and Peat

The term bio energy denotes the use of vegetable matter as a source of energy; it covers a variety of fuels, with applications in all the major sectors of consumption – power generation, transportation, industry, households, etc.

4.8.1. Wood Fuels

There are two very different populations using wood fuels. One, typically an OECD member country, uses highly-efficient combustion technology under tight regulations on emissions. The other (estimated at three billion people) uses small-scale appliances, which are both inefficient and highly polluting.

Wood Fuel is usually classified into three main commodities: fuel wood, charcoal and black liquor. Black liquor is the spent pulping chemicals and the lignin component of wood after chemical pulping, it is fired in a chemical recovery boiler and process steam and electricity are also produced. Fuel wood and charcoal are the traditional wood forest products, and even today almost half of all of the forest harvest is for energy, with the remainder for industrial use (lumber, veneer and paper). Charcoal is produced by the thermal conversion of wood (and other biomass). This transformation has losses in the form of combustible gas and condensable materials (wood tar), which are not always recovered for either material applications or energy purposes. The energy efficiency of charcoal production ranges from 25 % in Africa (using mainly artisanal methods) to 48 % in Brazil which uses industrial kilns with extensive energy and materials recovery. (WEC 2007)

4.8.2. Biomass Conversion

The largest secondary transformation of biomass after charcoal production is in the electricity sector. For many years biomass processing industries such as sugar, wood products and chemical pulping (black liquor) have installed combined heat and power (CHP, also known in the USA as cogeneration) plants. Many of these have been relatively low-steam-temperature installations, with only sufficient electricity to meet the plant processing needs (WEC 2007). One example of this technology is the Alholmens Kraft CHP plant in Pietarsaari, the largest biomass-fuelled power plant in the world, producing 100 MW process steam for the adjacent paper mill, 240 MW for utility generating electricity, and 60 MW heat output for district heating. (IEA 2008)

Co-firing is another option for electricity generation: it involves combining biomass material with coal in existing coal-fired boilers. Coal-fired boilers can handle a pre-mixed combination of coal and biomass in which the biomass is combined with the coal in the feed lot and fed through an existing coal feed system. Alternatively, boilers can be retrofitted with a separate feed system for the biomass such that the biomass and coal actually mix inside the boiler. (EIA 2002)

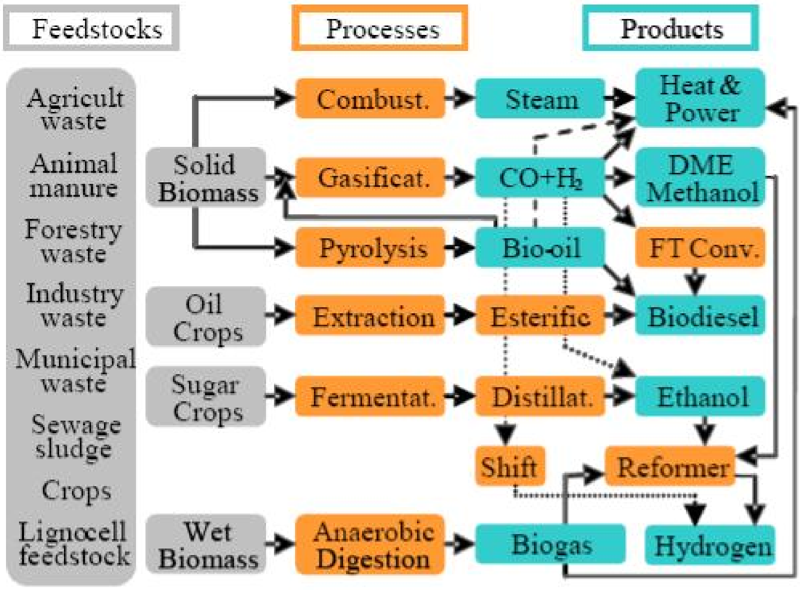


Figure 117. Biomass Conversion Paths (IEA 2007).

4.8.3. Biofuels

Ethanol

2006 was the year in which biofuels for transportation came into very public prominence, as rising world crude oil prices stimulated the US President in his January state-of-the-union address to advocate increased support for ethanol, both in its current production from maize and the future option of producing it from the extensive lignocellulosic resources contained in agricultural straws and wood. (WEC 2007)

As a consequence of the high prices of traded crude oil in the last few years, many countries advanced their bio fuel goals and, in the case of Brazil and the USA, large production gains occurred. The proportion of the world's gasoline pool provided by the 2006 estimate of ethanol output is about 2.5% (1.1 EJ of ethanol and 37.5 EJ of gasoline). (WEC 2007)

The expansion of biofuels is not without controversy, as the production of ethanol from corn is only marginally energy-positive at about 1.4:1, while that from sugarcane in Brazil has a ratio of about 8 units of renewable liquid fuel to one of fossil energy input. And whereas Brazil has foregone most agricultural subsidy to its sugar industry, the agricultural sectors of both the USA and the EU countries are engaged in vast subsidies on agricultural commodities in general, and on ethanol or other biofuels specifically. (WEC 2007)

Biodiesel

The other significant biofuel is biodiesel, which is currently produced from vegetable oils, animal fats and grease by esterification. The vegetable oils with carbon chain lengths of between 16 and 22 carbon atoms are generally in the form of triacyl glycerides (TAG) which on transesterification with methanol produce glycerol as a by-product and FAME (fatty acid methyl ester) as the precursor to biodiesel. The second-generation biodiesel is often called 'renewable diesel' and is produced by treating vegetable oil with hydrogen over catalysts in oil refineries, to either blend or be co-processed with 'fossil diesel. The resultant product can be used in the range of B5–B50. In addition to vegetable oils, animal fats such as tallow and waste grease can also be converted to FAME; they are the lowest-cost resources available, mainly in urban areas. (WEC 2007)

The commercial resource base for vegetable oils comprises about 20 different species with soybean oil, palm/palm kernel oil, sunflower, rapeseed (Colza), and coconut oils being the largest sources. World consumption for all purposes is increasing at about 4 % per year, however the largest growth rates are in palm oil which together with soy oil comprise 50 % of the annual vegetable oil production. Despite the current minority position of biodiesel relative to ethanol, the adoption of mandates in several countries will fuel a large growth in the near future. Brazil, for example, has a nationwide mandate for B2 in 2008 resulting in an estimated 1.1 hm3 demand for biodiesel (935 kt). The EU mandates for 5.75 % biofuels in the transportation sector by 2010 are driving the rapid growth of biodiesel in the major EU economies and, like ethanol, production has leapt in the last few years (WEC 2007). The agricultural commodity base of the current biofuels has ramifications for the sustainability of the food and animal-feed supply system, and many countries are looking to other biomass resources and second-generation biofuels for sustained growth. (WEC 2007)

AEBIOM (European Biomass Association) suggests that the concept of sustainability should not only be applied to biofuels but also to the production of all energy crops as well as all conversion routes, be it for biofuels, biogas, heat or electricity purposes. The food and feed production should also be sustainable. Therefore an integrated approach which can take into account the following criteria is necessary (AEBIOM 2007):

- administrative and economic consequences should be acceptable and should not decrease the competitiveness of biofuels
- redundancy with the existing European agricultural cross-compliance scheme should be avoided
- certification system should be set while taking into account the existing certification schemes which are applied for various biomass sources (FSC for forest, RSPO for palm oil, RTSS for soybean, etc), so to be set only for those missing parts that are not covered by existing reliable certification scheme

Third and Fourth Generation Biofuels

Third generation biofuels and products are made from energy and biomass crops that have been designed in such a way that their very structure or properties conform to the requirements of a particular bioconversion process. They may be produced from waste rather than primary crops, thus not putting pressure on world food supplies. Commonly they are produced from algae, which present high yields and can grow in places away from forests and protected areas. (IEA 2008)

Because third-generation biofuels are still under development and production experience is still lacking, IEA forecasts that these fuels will give little contribute before 2050 (IEA 2008).

Fourth generation biofuels are based on engineering or breeding of energy crops that absorb unusually high levels of CO_2 (for example eucalyptus trees), and when combined with CCS, may result in a two-fold reduction in carbon emissions, defined as more carbon removed from the atmosphere than released. Fourth generation biofuels may be produced also through fast pyrolysis, a process which utilizes the burning or smouldering of biomass at 400–600 °C in the absence of air. Its by-product, called *biochar* may act as an efficient substrate for microbial populations which fix nitrogen, phosphorus and other nutrients as well as carbon and water in the soil. Recent studies suggest that biochar-improved soil could sequester up to 150 tonnes more carbon than unimproved soil and, according to some estimates, amending only 10% of the biologically active agricultural land on the planet today with biochar could help to attain a carbon negative status in a relatively short time (Pretorius 2007)

Biogas

Biomass conversion into biogas can be either from fast thermo-chemical processes (e.g. pyrolysis) which can produce biogas and other fuels, with only 2 %–4 % of ash, or from slow anaerobic fermentation, which converts only a fraction (50 %–60 %) of feedstock but produces soil conditioners as a byproduct. In the case of pyrolysis the process is carried out at high temperatures (300–700°C) and material decomposition products are solid (charcoal), liquid (oil) or gaseous. Slow pyrolysis produces solid products, meanwhile modern fast (flash) pyrolysis at moderate temperature provides up to 80% bio-oil. In order for biogas to be produced, high temperatures are required. (IEA 2007b)

This biogas can be used in combustion engines (10 kW to 10 MW) with efficiency of some 30%-35%; in gas turbines at higher efficiencies or in highly-efficient combined cycles. Biomass integrated gasification gas turbines (BIG/GT) are not yet in commercial use, but their economics is expected to improve. The first integrated gasification combined cycle (IGCC) running on 100% biomass (straw) has been successfully operated in Sweden. Technical issues appear to have been overcome. IGCC plants are already economically competitive in CHP mode using black-liquor from the pulp and paper industry as a feedstock. Other developments have brought Stirling engines and organic Rankine cycles (ORC) closer to the market whereas integrated gasification fuel cell plants (IGFC) still need significantly more R&D. (IEA 2007b)

Current Status and Future Trends

According to IEA, in the power sector, about 21 % of the biomass is used for co-firing, mostly together with coal. In industry, 200 Mtoe of liquids produced from biomass, mainly methanol, are projected to be used for the production of petrochemicals and 45Mtoe for bio-lubricants. A further 150 Mtoe of biomass derived liquids is projected to be used in the building sector, largely as substitutes for traditional biomass or liquefied petroleum gas (LPG), which are currently used for cooking. In needs to be noted that the conversion of biomass to liquids creates a significant conversion loss. The remaining biomass (about 980 Mtoe) is forecasted to be used to provide direct heat in the industry and building sectors. (IEA 2008)

A wide range of conversion technologies are under continuous development to produce bioenergy carriers for both small and large scale applications.

Advancing technologies include biomass integrated gasification combined cycle (BIGCC) systems, pyrolysis and second generation biofuels. Many are close to commercial maturity but are awaiting further technical breakthroughs to increase the process effciency, followed by large scale demonstrations to help reduce the risks and further bring down the costs. Second generation biofuels for example may one day use biochemical technologies to convert the cellulose to sugars that in turn can be converted to bioethanol, biodiesel, di-methyl ester, hydrogen and chemical intermediates in large scale bio-refineries. In addition biochemical and thermo-chemical synthesis processes could be integrated in a single bio-refinery such that the biomass carbohydrate fraction is coverted to ethanol and the lignin-rich residue gasified and used to produce heat, electricity and/or fuels, thus greatly increasing the overall system efficiency to 70–80%. Both concepts however remain some way off reaching the commercial scale, despite decades of research investment. (IEA 2007a)

Biomass integrated-gasification, combined-cycle (BIGCC) technologies have the potential to contribute CO_2 savings by 2050 of between 0,22Gt/year and 1.46 Gt/year, assuming successful development of this technology. If BIGCC plants are linked with CCS, and the biomass used is replaced by growing future crops or replanting forest, such an approach would actively reduce atmospheric concentrations of CO_2. (IEA 2008)

Around 400 GW of modern biomass heat-production equipment, consuming around 300 Mt/year of biomass, currently produces around 4.5 EJ/year (or 105 Mtoe/year) of direct heat, assuming a conversion factor of 75 %. By 2005, over 40 GW of biomass-fired power generation capacity had been installed worldwide, generating 230 TWh/year of electricity. If a capacity factor of 60 % and a conversion factor of 25 % are assumed, this would consume approximately 240 Mt/year of biomass. In the case of liquid biofuels, around 120 Mt of biomass were consumed in 2005, to produce 19 Mtoe of biofuels, with an average conversion efficiency of 50 %. (IEA 2008)

Costs of biomass derived energy are expected to decrease over time, due to both technology learning and economies of scale in larger commercial plants. Current bio-electricity generation costs of around USD 62 to 185 per MWh could reduce by 2050 to between USD 49 to 123 per MWh. Transport biofuels could reduce from the current USD 10 to 31 per GJ to between USD 7 and 12 per GJ. Heat production is expected to remain at around today's cost of USD 4 to 19 per GJ during the forecast period. (IEA 2008)

According to IEA's forecasts, in 2050 more than 100 EJ/year of biomass would be supplied from agricultural residues and wastes (with costs ranging from USD 2 to 3 per GJ, making them the most cost-competitive source), an additional 125 EJ/year of material could come from high-yielding perennial crops (at costs of USD 3 to 5 per GJ) and a further 75 EJ/year could come from growing energy crops on 60 Mha of marginal lands, thus giving a total resource of 300 EJ/year. (IEA 2008)

The main barriers to widespread use of biomass for power generation are cost, low conversion efficiency and feedstock availability. Most important are the lack of internalisation of external costs in power generation and effective policies to improve energy security and reduce CO_2 emissions. In the long term, bio-power potential will depend on technology advances and on competition for feedstock use, and with food and fibre production for arable land use. Competition may not be an issue until 2020 if industrial-scale production and international standards facilitate biomass international trade. While long-distance transportation reduces economic and environmental attractiveness of biomass, conversion into "bio-oil" (e.g. by pyrolysis) could facilitate international trade. Risks associated with widespread use of biomass relate to intensive farming, fertilizers and chemicals use and biodiversity conservation. Certifications that biomass feedstock is produced in a sustainable way are needed to improve acceptance of public forest and lands management. Nutrients should be returned to forests and land through ash from biomass combustion to alleviate nutrients loss and need for fertilisers. While over-exploitation of biomass resources in developing countries should be avoided, biomass can be important for using marginal land and bringing socio-economic benefits in these regions. (IEA 2007b)

4.8.4. Peat resources of Finland

Photo: Jari Väätäinen, GT. (Geological Survey of Finland 2008).

In the Finnish energy economy, peat is used to replace imported fuels. Two-thirds of the energy consumed in Finland has been generated with imported fuels. At present, peat is used in around one hundred larger applications. The biggest ones are located in the inland cities co-generating electricity and heat mainly with peat. Peat energy cover 6 % of total energy in Finland. (Lahtinen et al. 2005)

In Finland, peat is mainly used in energy generation or in horticulture. Energy peat accounts for 90% of the total peat production and horticultural peat for around 6–7%. Some peat is used in municipal sludge and bio waste composting plants and as bio filters; as litter material in animal husbandry; as oil-absorbent; in textiles; and in balneology. (Lahtinen et al. 2005)

Peat lands, which are technically suitable for the peat industry in Finland, cover a total area of 1.2 million ha and contain 29.6 billion m ^{3} of peat *in situ*. Calculations of economical and environmental facts that will limit the use of mires have not been taken into account. Slightly humifed peat suitable for horticultural and environmental use totals 5.9 billion m ^{3} *in situ* and energy peat totals 23.7 billion m ^{3} *in situ* with an energy content of 12 800 TWh. The effective energy density of the areas appropriate for energy production is 0.54 MWh/ m ^{3} *in situ*. (Lahtinen et al. 2005)

Sphagnum peat account for 54 % and *Carex* peat for 45 % of recoverable peat reserves. The remainder, 1 %, is composed of *Bryales* peat, the bulk of which are encountered in the North-Finland area. The highest values of humification degree are located in Finnish Lake area, in Central Finland. The average ash content is 3.4 % of dry mass, sulphur content 0.20 % of dry mass and dry bulk density 87 kg/m3 *in situ*. (Lahtinen et al. 2005)

The mean depth of the geological peat land is 1.41 m. In the area exceeding 1.5 m in depth the peat layer is 2.50 m thick on an average. Thirty-seven per cent of the mires, covering a total area of 1.9 million ha, are over 1.5 m deep. Total Finnish national peat reserves are account for 69.3 billion m ^{3} *in situ*. Dry solids total 6.3 billion t. The carbon storage of Finnish mires is 3.2 billion t. (Lahtinen et al. 2005)

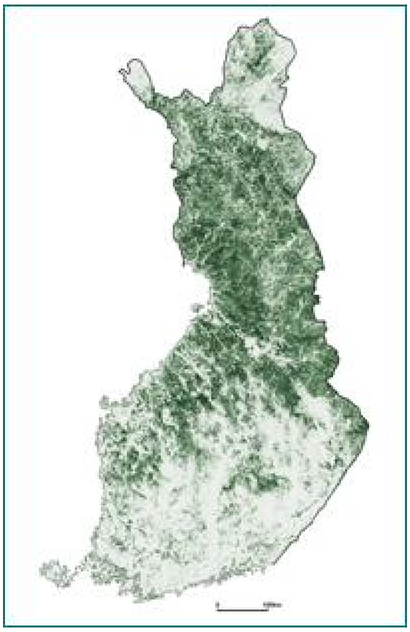


Figure 118. Distribution of Peat Land in Finland (Green). 28 % of Finnish Territory is Peat Land. (Geological Survey of Finland 2008).

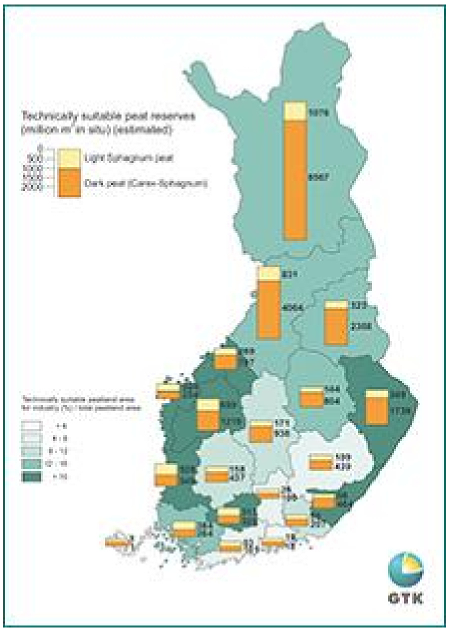


Figure 119. Technically Suitable Peat Resources in Finland. Energy Peat 23.7 Billion Cubic Meters and Environment and Horticulture Peat 5.9 Billion Cubic Meters (Geological Survey of Finland 2008).

The use of peat has established its position in the Finnish energy system. Peat has traditionally been well available and thus its security of supply has been considered good. It has also been regarded as a high-quality indigenous fuel. In recent years many investments have been made in power plants using indigenous fuels and in co-use of peat and wood. In fact, the use of the peat and wood fuels is very closely inter-linked and their use supports one another. (Lahtinen et al. 2005)

Regionally speaking, peat consumption is highest in North Ostrobothnia and inland. The negative effects of peat use are considered to be the high carbon dioxide factor of peat combustion and in some cases the possible effects of production on the local environment. (Lahtinen et al. 2005)

Emissions trading, which was started at the beginning of 2005, weakens the competitiveness of peat in relation to other fuels. When the value of an emission allowance rises enough, also the use of coal may become cheaper than that of peat in installations in which peat has earlier been the main fuel. (Lahtinen et al. 2005)

If the current role of peat is to be maintained, the sufficiency of the peat production sectors necessary for peat production should be secured, which should also be taken into account in regional land use planning. The security of supply of peat should be ensured, e.g. by developing stockpiling, regardless of the weather conditions and variations in demand. The preservation of the competitiveness of the operating environment in the long term is a prerequisite for the continuity of production. (Lahtinen et al. 2005)

Peat should remain competitive particularly in relation to the imported fossil fuels in order to allow the investment potential of the installations using indigenous fuels. Policy outlines for the role of the energy use of peat, which lay the basis for sustained operational planning, will be required for the Climate and Energy Strategy. (Lahtinen et al. 2005)

Annually 20–30 milj. M^3 of peat is used – from which 18–28 TWh is energy peat (Silpola 2007). Finland's energy peat reserves content is 12800 TWh (Virtanen et al. 2003). In 2006 the amount of peat from Finland's total energy consumption was about 6 % (Figure 120) (Tilastokeskus 2007a). Less than 1 % from Finland's peat land area is in peat harvesting from which 90 % is in energy peat harvesting (Energiateollisuus 2007). In year 2006 industrial peat harvesting area was 74 9000 ha including active and temporarily set-aside peat extraction fields (VAHTI 2008).

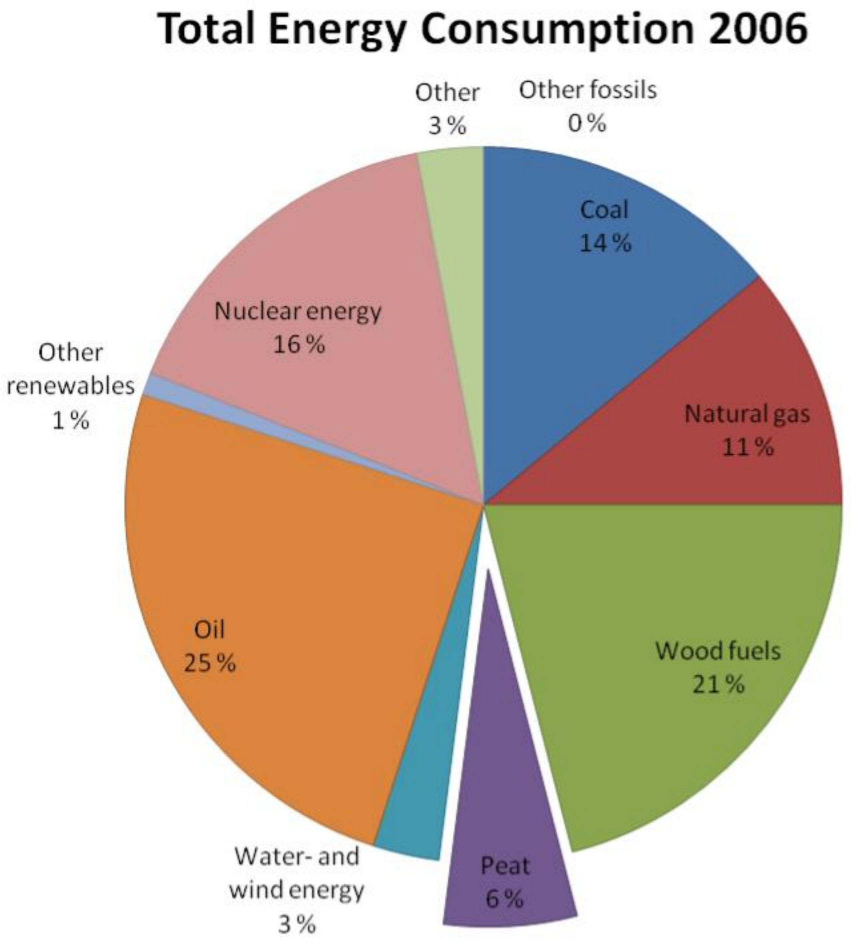


Figure 120. Total Energy Consumption in Finland in 2006 (Tilastokeskus 2007).

The inorganic carbon or carbon dioxide (CO2) of the atmosphere starts to form into organic carbon in peat lands first by photosynthesis from the plants and in litter production and ends slowly through the peat land's oxic surface layer into the anoxic layers (Laine *et al.* 2000).

About 90% of bound carbon in photosynthesis decomposes aerobically in the surface layer of peat lands. When the organic substance has reached the anoxic state, and when only more difficult decomposable carbon compounds are left, the decomposition gets remarkably slower. This part of organic matter is formed as peat. (Laine *et al.* 2000). The formation speed varies in Finnish peat lands between 0.2–4.0 mm a-1, average being about 0.5 mm a-1 (Korhola & Tolonen 1998). By mass this is about 40 g m-2 and as carbon about 20 g m-2 in a year (Laine *et al.* 2000). According to Minkkinen (1999), peat lands in Finland bind carbon with a total of 4.2 Tg annually. Finnish peat lands are hundreds or thousands years old. Most of them have reached their present extent already ca. 3000 B.P. (Korhola and Tolonen 1998)

About one-third of the total pool of soil carbon in the world is stored in northern peat lands (Gorham 1991). The total amount of carbon of all boreal and subarctic mires is between 270 and 370 Pg (Turunen *et al.* 2002). Peat lands are important terrestrial carbon stores and they show large temporal and spatial variation in the atmospheric exchange of CO2 and CH4 (Alm *et al.* 1999). Anthropogenic activities have enhanced the emissions of greenhouse gases such as carbon dioxide (CO2) and nitrous oxide (N2O) from organic soils (Maljanen *et al.* 2007). Drainage and cultivation of peat lands initiates decomposition of the stored organic material because of new oxygen entering into the soil and therefore CO_2 and N2O emissions increase while CH_4 emissions decrease (Kasimir-Klemedtsson 1997).

Pristine peat lands act as carbon sinks in the long run (Leijting 1999). Carbon cycling in pristine boreal peat lands has been extensively studied and gas fluxes have been found to vary widely. Both ombrotrophic (nutrient poor) and minerotrophic (nutrient rich) mires can be either net sources or net sinks of CO_2 at the annual level. The great variation in the annual CO_2 balance is a consequence of inter-annual and spatial variation in the hydrology and thermal conditions (Saarnio *et al.* 2007).

The natural carbon cycle of mire ecosystems is not responsible for the current anthropogenic global warming and therefore the annual CH_4 and CO_2 effluxes are not reported in the national greenhouse gas inventories (Saarnio *et al.* 2007).

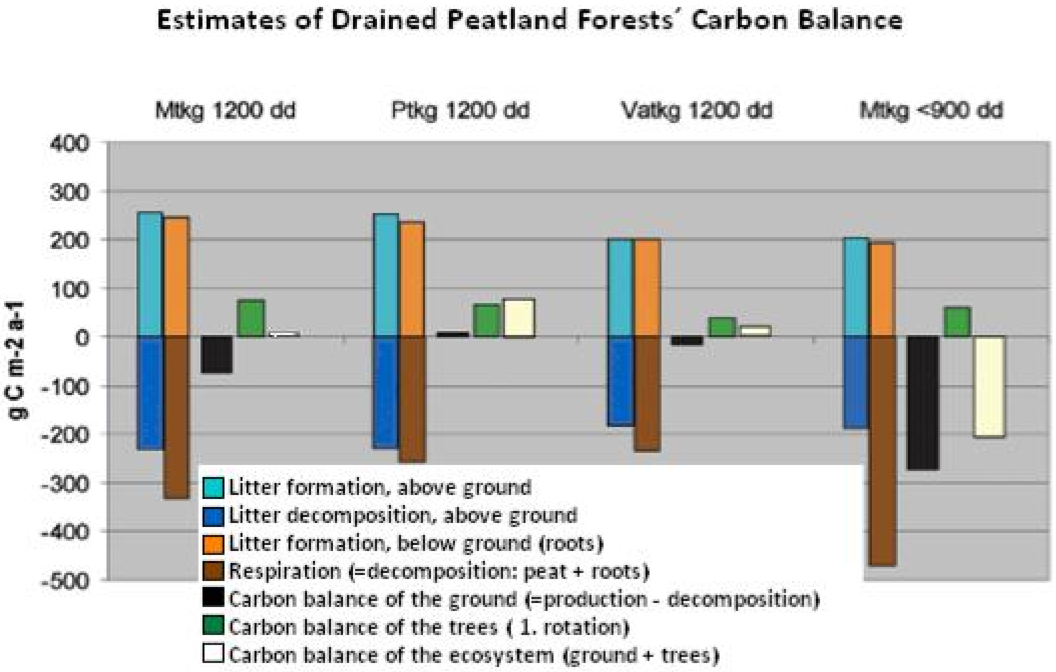


Figure 121. *An Example of Carbon Fluxes from Different Peat Land Types Drained for Forestry. Vatkg-Mtkg in South Finland (1 200 dd) and Mtkg in North Finland (>900 dd). (MMM 2007)*

In the previous figure Vatkg is Dwarf-shrub type, Mtkg is *Vaccinium myrtillus* type, Ptkg is *Vaccinium vitis-idaea* type. Negative values indicate the loss of carbon emission, positive the input of carbon emission.

4.9. Bioenergy Potentials in Finland

In the following, there are some calculations about Finland's bio energy potentials. Noteworthy is that the calculations are made using differing criteria. For instance, maximum potential refers to the total amount of certain bio energy available in Finland restrictions aside. Other calculations limit the potential due to technical, economical or ecological reasons. Economic potential refers to the bio energy potential that is economically viable to produce. Technical potential refers to the potential that is technically possible to produce. Environmental reasons can also limit in certain areas the maximum potential of a certain bio energy form.

4.9.1. Biomass potential of the Finnish forests

Forest biomass is renewable, but nevertheless a limited resource and its use must be built on a sustainable basis. Estimations of availability begin from the theoretical maximum potential. This consists of two major sources. First, it includes all residual biomass left in the forest in conjunction with timber harvesting. Secondly, it includes the small-tree biomass, which is removed, or should be removed for reasons to do with silviculture in precommercial thinnings of young stands. The former is dependent on the markets of forest products, whereas the latter is free of market fluctuations. Only a part of the maximum biomass potential can be recovered. Following technological, socio-economic and environmental factors affect the availability: (Hakkila 2004, 26–28)

- Price development of alternative fuels, taxes and subsidies
- Development of procurement technology and logistics
- Motivation of forest machine and truck contractors to participate
- Development of the quality requirements of forest chips. For example, will the foliage be taken or left?
- The acceptance of private forest owners, which is affected by the price paid for biomass
- The energy and climate policies at the national and EU levels. The trade of CO_2 emissions will be of utmost importance.

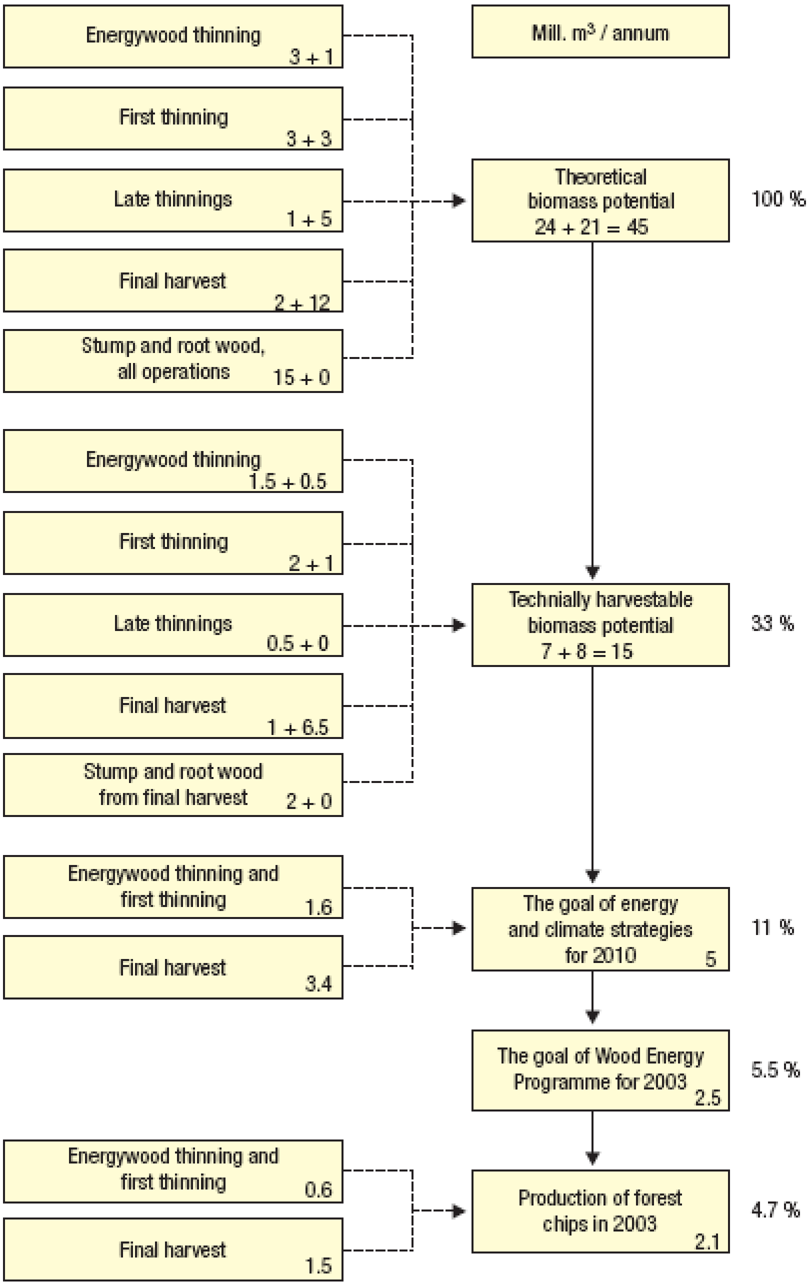


Figure 122. The Biomass Potential of the Finnish Forests. The First Part of the Series of the Numbers Refers to Stemwood and the Second Part to Crown Mass (mill. cubic meters/annum) (Hakkila 2004).

In the previous Figure, the technological and environmental factors have been taken into account, but no price assumptions have been applied. The technically harvestable potential is estimated separately for five different types of logging operations (Hakkila 2004, 26–28):

- Energywood thinnings are tending operations in young stands in which the owner has earlier neglected good forest management. Because of the small size of the trees, the primary product is fuel. The age of the stands is typically 15–25 years and a majority is dominated by pine, but the removals may be composed of hardwoods. The cost of harvest is high, and subsidies are necessary to make the recovery possible.

- First thinnings refer traditionally to the first commercial logging operation of a stand, normally at the age of 25–40 years. Pulpwood is the primary product, but as 20–30 % of the stemwood drain does not meet the minimum dimensions of pulpwood, first thinnings may also yield substantial quantities of fuel wood. Later thinnings leave only small amounts of stemwood at the site. Residues contain mainly crown mass, the separate recovery of which would cause logging damage to standing trees and unnecessary nutrient loss at a critical development phase of the stand. Production of forest chips is not recommended at this stage.
- Logging residues from final harvest are composed largely of crown mass which is abundantly available, especially in spruce stands. Logging residue chips are therefore produced mainly from the crown mass of spruce. Conditions of recovery are favorable. No subsidies are available.
- Stump and root wood from final harvest can be salvaged from clear-cut areas of mature spruce stands. Typically, logging residues have already been collected from the same site.

A summary of the amount and structure of the technically harvestable biomass reserve is demonstrated in following figure 123. More than a half of the harvestable reserve is crown mass including foliage. If the objectives set for forest chips are to be met, crown mass must be accepted as a source of fuel regardless of its inferior quality and accelerated nutrient loss. The technology of harvesting needs to be developed to keep needle removal at an acceptable level. (Hakkila 2004, 26–28.)

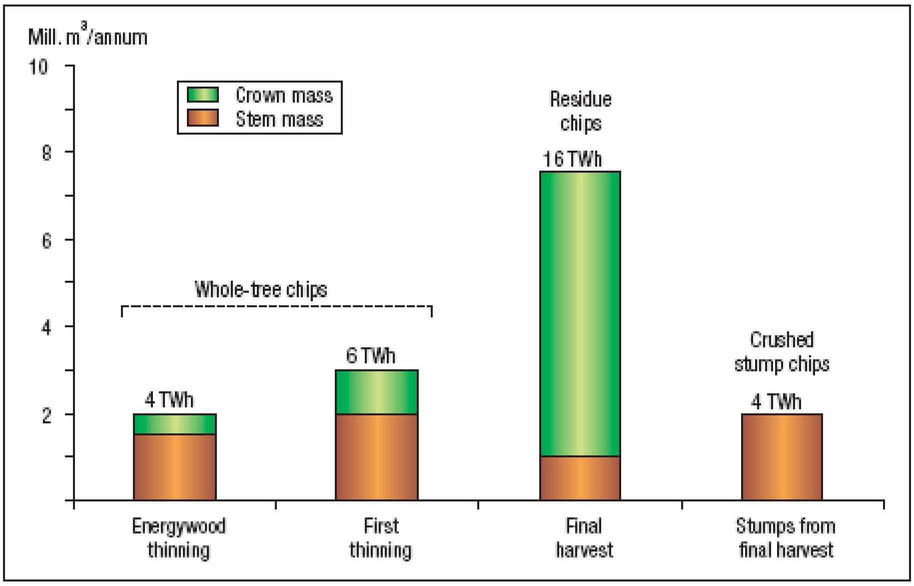


Figure 123. Technically Harvestable Biomass Potential of the Finnish Forests (Hakkila 2004).

4.9.2. Field biomass potential in Finland

Finland's cultivated area is 2.3 million hectares (2006). Grain is cultivated in 1.17 million hectares and forage grass plants in 0.64 million hectares. Abundant 0.1 million hectares of harvest has been taken abroad unrefined. The area of oil plants is 100 000 hectares. During the time Finland has been the member of EU, the amount of fallow has been 10- 11 % of the cultivated area. In Finland, 1.7–1.8 million hectares of field is needed for the production of food and forage. About 0.5–0.7 million hectares could be used for energy without any danger to the food production in Finland. If in this area of 500 000 hectares, for instance reed canary grass would be cultivated and assumption of the level of the harvest would be 20 Mwh / hectare, this corresponds the potential of 10 Twh. (Asplund 2008, 25.)

4.9.3. Biogas Potential in Finland

Vehicle use potential of biogas from waste

Ari Lampinen (2003) has estimated the yearly production potential of biogas for vehicle use in Finland. The yearly potential of biogas (methane) is in Finland 14 TWh. It would be enough fuel for 700.000 passenger cars, if they drove city-orientated driving (consumption 10 1/100 km) on average 20.000 km/year or nearly 50.000 buses, if they drove on average 100.000 km/year. (Lampinen 2003)

With current technology, quickly decomposing organic material is easiest to utilize, while wood-based waste and plastic waste processing is more difficult. For that reason, wood-based waste and plastic waste as well as industrial solid waste (apart from food industry) have been left out of this examination of potentials. In addition, these wastes have other recycling possibilities. Methane from the dumping places is included, for it must be collected in any case. (Lampinen 2003)

Table 6. The Yearly Production of Biogas (Methane) from Waste in Finland (Lampinen 2003).

Source of methane	**Mass of the composing organic waste (t)**	**Produce of methane (m^3/t)**	**Energy (TWh)**	**Fuel for cars (pieces)**	**Fuel for buses (pieces)**
Methane from the dumping places			1.5	75 000	5 000
Community biowaste (kitchen waste)	360 000 (fresh weight)	100	0.36	18 000	1 200
Community wastewater	160 000 (suspended matter)	200	0.32	16 000	1 100
Manure	21 500 000 (fresh weight)	20	4.3	220 000	15 000
Agricultural plantwaste	4 000 000 (fresh weight)	170	6.8	340 000	23 000
Food industry's waste	960 000 (fresh weight)	50	0.48	24 000	1 600
Industrial wastewater	22 300 (suspended matter)	200	0.04	2 000	130
IN TOTAL			**14**	**700 000**	**47 000**

Biogas potential of energy crops and crop residues

Annimari Lehtomäki (2006) has studied the methane potentials of different energy crops and crop residues. In her study Jerusalem artichoke, reed canary crass and timothy-clover grass gave the highest methane potential per hectare, corresponding to gross energy potential of 28–53 MWh ha^{-1}. Thus, up to 3000–5000 m^3 of methane can potentially be obtained from one hectare of energy crops cultivated for biogas production, corresponding to approximately 40 000–60 000 km in passenger car transport per hectare. Consequently, one to three passenger cars (average distance driven approximately 20 000–30 000 km per year) could potentially be fuelled by one hectare of energy crops. For example, if the area corresponding to the set aside agricultural land in Finland (195 929 ha in 2004, Statistics Finland 2005) was used for production of energy crop as substrates for biogas production, the methane production could potentially cover the yearly consumption of 8–25 % of the passenger cars in Finland (2 246 726 passenger cars in 2004, Statistics Finland 2005). These previous figures represent the theoretical potential of methane production from energy crops, and the energy consumed during the production of the biomass and operation of the anaerobic digestion process has not been taken into account when calculating the gross energy potentials. (Lehtomäki 2006, 66–68.)

4.10. Ocean Energy

Since the late 1990s a number of small companies have tried to develop a range of different wave energy technologies as a non-polluting source of energy, which has resulted in a number of full-size devices being deployed in the sea. In some countries, these initiatives have been accompanied by government-funded activities, as well as developments in international organisations such as the European Commission and the International Energy Agency. (IEA 2008)

Wave energy can be considered as a concentrated form of solar energy, where winds generated by the differential heating of the earth pass over open bodies of water, transferring some of their energy to form waves. The amount of energy transferred and hence the size of the resulting waves, depends on the wind speed, the length of time for which the wind blows and the distance over which it blows (the 'fetch'). In this way, the original solar power levels of typically ~ 100 W/m^2 can be transformed into waves with power levels of over 1,000 kW per metre of wave crest length. (IEA 2008)

Waves lying within or close to the areas where they are generated (storm waves) produce a complex, irregular sea. These waves will continue to travel in the direction of their formation even after the wind dies down. In deep water, waves lose energy only slowly, so they can travel out of the storm areas with minimal loss of energy as regular, smooth waves or 'swell' and this can persist at great distances from the point of origin. Therefore, coasts with exposure to the prevailing wind direction and long fetches tend to have the most energetic wave climates, such as the western coasts of the Americas, Europe, Southern Africa and Australia/New Zealand. (IEA 2008)

The global wave power resource in deep water (i.e. 100 m or more) is estimated to be in the range of 1-10 T. As the waves move to shallower waters they lose energy, but detailed variation of sea-bed topography can lead to the focusing of wave energy in concentrated regions near the shoreline, called 'hot spots'. The economically exploitable resource is about 140 - 750 TWh/yr for current designs of devices when fully mature. (IEA 2008)

Many wave energy devices are at the R&D stage, with only a small range of devices having been tested at large scale or deployed in the oceans. This slow rate of progress is due to the fact that wave energy devices face a number of design challenges, among which the variability in wave power intensity and wave direction. (IEA 2008)

4.10.1. Current Technologies

Four of the main types of device deployed at large scale over the past few years are the following:

Oscillating Water Column: it comprises a partially submerged structure forming an air chamber, with an underwater aperture. This chamber encloses a volume of air, which is compressed as the incident wave makes the free surface of the water rise inside the chamber. The compressed air can escape through an aperture above the water column which leads to a turbine and generator. As the water inside falls, the air pressure is reduced and air is drawn back through the turbine. Both conventional (i.e. unidirectional) and self-rectifying air turbines have been proposed. Even with this commonality of operating principles, the examples of oscillating water column actually deployed vary considerably from the bottom-standing, shoreline-based concrete device developed by Wavegen (2007) in Scotland, to the tethered, near shore steel device deployed by Energetech (2007) in Australia (WEC 2007).

Figure 124. Shoreline-based Concrete Device in Scotland (WEC 2007).

Figure 125. Near Shore Device in Australia (WEC 2007).

The Pelamis: this is a floating device comprised of a series of cylindrical hollow steel segments that are connected to each other by hinged joints. The device is approximately 120 m long, 3.5 m in diameter and is loosely moored in water depths of ~ 50 m so that it points into the waves. As waves run down the length of the device, the segments move with respect to each other and actuate hydraulic cylinders incorporated in the joints to pump oil to drive a hydraulic motor/generator via an energy-smoothing system. The device has been deployed in Scotland and a small scheme of three devices is currently being deployed in Portugal (WEC 2007).

Figure 126. The Pelamis (WEC 2007.)

The Wave Dragon. This device uses a pair of large curved reflectors to gather waves into the central receiving part, where they flow up a ramp and over the top into a raised reservoir, from which the water is allowed to return to the sea via a number of low-head turbines. A quarter-scale prototype (58 m wide x 33 m long) rated at 20 kW has been deployed in a Danish inlet and a full-size device (estimated to have a generation capacity of ~ 4 MW) is being constructed for a site in Wales (WEC 2007).

Figure 127. The Wave Dragon (WEC 2007).

The Archimedes Wave Swing: This consists of a buoyant cylindrical, air-filled chamber (the 'Floater') that can move vertically with respect to the cylindrical 'Basement', which is fixed to the sea bed. As a wave passes over the top of the device, it alternatively pressurises and depressurises the air within the Floater, changing its buoyancy, which causes the Floater to move up and down with respect to the Basement. This relative motion is used to produce energy, using a linear electrical generator. A 2 MW Pilot scheme has been deployed and tested in Portugal (WEC 2007).

Figure 128. Archimede Wave Swing (WEC 2007).

Despite the fact that wave energy is a relatively immature technology, and that the technologies are being developed by small companies, with a total investment of US$ 5–10 million in each company, wave energy presents two important advantages over other renewables (WEC 2007):

- outside the tropics, storms are usually more intense and frequent during winter, which results in wave power levels being higher in that season. Therefore wave energy provides good seasonal load-following for those regions where peak electricity demand is produced by winter heating and lighting requirements (e.g., northern Europe, western Canada and north-west USA).
- wave energy is predictable for one to two days ahead, because satellites can measure waves out in the ocean that will later impact on devices around the coast. This predictability will allow for less spinning reserve than is often required to support more intermittent renewable energy sources.

However, wave energy has to face various difficulties as in many countries there is a high cost associated with obtaining permits and carrying out environmental impact assessments. Moreover, once deployed in free energy markets, wave energy has to compete with established renewable energy technologies that have benefited from billions of dollars of cumulative investment. (WEC 2007)

As stated by the IEA, one of the major problems that wave energy has to face is that the pilot projects need to be relatively large-scale in order to stand offshore conditions, thus implying high costs and risks. These factors have inhibited the early development of wave energy technologies, as only in recent years adequate government funding has been made available to support sizeable pilot projects. (IEA 2008)

The sampling of projects being developed worldwide which is reported in the list below, is instructive for the kinds of technologies that are being developed and used and any problems they may be encountering (EIA 2008).

- A 27 MW wave energy project in Portland, Victoria, Australia.
- Wave Hub Project in North Cornwall, United Kingdom.
- A 22.5 MW wave park in Agucadoura, Portugal, Power Technology.Com,
- “Pelamis, World’s First Commercial Wave Energy Project, Agucadoura, Portugal.”
- Limpet wave project on the Island of Islay, Scotland

A possible roadmap of the development of different aspects of wave energy is shown below.

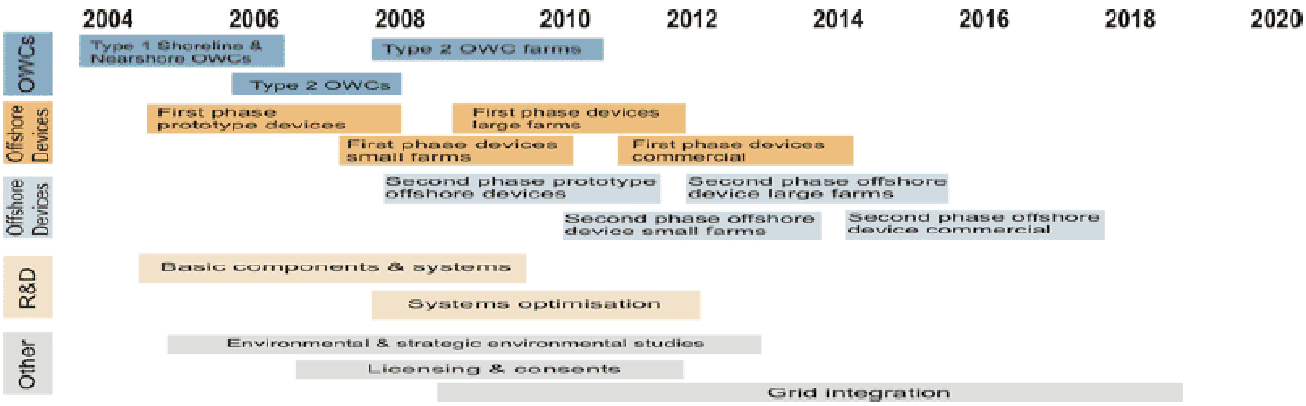


Figure 129. Roadmap for Wave Energy (WEC 2007).

4.10.2. Situation in European Countries and Future Development

According to IEA, currently R&D is focusing on moorings, structure and hull design methods, power take-off systems, as well as wave behavior and hydrodynamics of wave adsorption. Research efforts on turbines and rotors will need to focus on cost-efficiency, reliability and ease of maintenance, particularly in developing components that can resist hostile marine environments. Control systems for turbine speed and rotor pitch will also play a major role in maximizing power output. (IEA 2008)

United Kingdom is the leading country in wave and marine currents energy, and it has developed some specific policy instruments, such as capital grants, feed-in tariffs and tradable certificates. (IEA 2007)

In Ireland, the Government launched, in March 2007, the White Book “Delivering a Sustainable Energy Future for Ireland”, which set a target deployment of 500 M W of ocean energy power by 2020. This document followed the strategy document for ocean energy launched in 2006 by the Irish Government. (IEA 2007)

In Portugal, the government launched an attractive feed-in tariff of up to 26 c€/kWh for the demonstration phase (which decreases for the pre-commercial and commercial phases), and a pilot zone with simplified licensing procedures designed to support both the initial phase of the demonstration and the pre-commercial and commercial phases of wave energy utilization. (IEA 2007)

In Spain, there is no national strategy for ocean energy, however one Spanish region – the Basque Country – has a target 5 MW of installed wave power by 2010 and for that purpose, an investment of 15 M € has been allocated (IEA 2007).

In France, a first governmental initiative took place in ocean energy: a new law setting a feed-in price of 15 c€/kWh for electricity produced using wave energy was launched in March 2007 (IEA 2007).

In Denmark, since the end of the Danish Wave Energy development program in the year 2002, there has been no dedicated development policy on ocean energy. However, interest in developing wave energy technology among developers is growing in Denmark, with much work carried out on a private basis. (IEA 2007)

In Sweden, activities in wave energy have achieved considerable developments in 2007 with funding from the Swedish Energy Agency, a governmental entity (IEA 2007).

In Norway the world's first prototype on osmotic power is under construction and further research activities and developments on wave energy and tidal energy are taking place with support from the Norwegian government and through EC funding (IEA 2007).

4.11. Hydrogen and Fuel Cells

4.11.1. Technology

Fuel cells are devices that employ a reaction between hydrogen and oxygen to produce electricity and heat, the reverse of water electrolysis. Fuel cells are categorized by the type of electrolyte they employ, such as polymer electrolyte (PEFC), phosphoric acid (PAFC), molten carbonate (MCFC) and solid oxide (SOFC) fuel cells. (JETRO 2006)

Practical uses for PEFCs are anticipated in many sectors, including commercial/industrial and household distributed power, as well as mobile energy for cars (most Japanese carmakers are developing fuel-cell vehicles) and portable devices. PEFCs are small yet deliver high output, and start/stop easily due to low operating temperatures. (JETRO 2006)

Installations are proceeding with PAFC systems developed for commercial and industrial cogeneration, and fueled with natural gas, LNG, LPG, naphtha and methanol. Advantages of these PAFC systems include very low environmental impact and low noise, but significant demerits include high purchase and operation cost. (JETRO 2006)

MCFCs are electrolyte fuel cells that use carbonate ions to produce a simple electric charge. Operating at comparatively high temperatures of 600°–700°C, MCFCs produce high-grade exhaust heat, and can be used for air conditioning, hot water, heating, and large-scale power generation. They can be used together with micro gas turbines for highly efficient combined power generation, and can run on various types of fuel. (JETRO 2006)

Although MCFCs are not noteworthy for overall efficiency, they can offer outstanding power-generation efficiency, which is highly valued by customers placing priority on electricity over heat. MCFCs are also superior in terms of running costs. Accordingly, demand is expected to rise among food-related and sewage-treatment plants that generate digester gas. (JETRO 2006)

A diverse range of applications is expected for SOFCs, from micro systems to medium- and largescale systems. In particular, high expectations are placed on distributed power sources, stationary power sources, and cogeneration systems (simultaneous supply of power and heat or hot water), especially in Europe and North America. High temperature SOFCs are now in the confirmation test stage, but problems related to long-term generating performance, cost reduction, and reliability must be solved in order to achieve practical application. (Kawamoto 2008)

4.11.2. Applications and Market Trends in Fuel Cells

These years are of uppermost importance for the fuel cell industry commercial breakthrough. Small portable applications, for example, will see their commercial launch in 2009, with mobile phones and toys/gadgets, followed by notebooks, mp3 players, military communication equipment and chargers. Large portable products powered by fuel cells will see the fastest short-term growth in the military sector, with items such as battery chargers and portable generators for different uses. (Makover et al. 2006)

The niche transport sector has experienced the fastest growth in the fuel cell industry since 2005 and is forecasted to continue to grow strong for a number of years, with tens of thousands of military, light and heavy duty vehicles being sold in 2012. New fuel cell powered scooters, forklifts, golf-wagons, wheelchairs and motorbikes will also be introduced in the market. Moreover, due to environmental concerns, trains and aircrafts are new potential application areas. (Makover et al. 2006)

The automotive sector will also experience a commercial breakthrough: All major car manufacturers develop FCVs and FCV hybrid concepts, as they look at FCVs as a new business opportunity. The mass market penetration estimated at 2020–2025, depending on investments in infrastructure development, but at least Daimler, Honda, GM and Hyundai plan to bring cars for customer promotion before 2010. Early sales price estimated at $US 50,000 / car. (Makover et al. 2006)

The small stationary sector is expected to see a steady growth for several years, with the fastest growth in Europe and moderate growth in the US, meanwhile Japan will continue to dominate the market. Of all the units installed it needs to be noted that PEMFC systems account for > 90 %, but SOFC systems (presently < 10 %) are likely to increase their market share since 2008–2009. The main marketable products will be small emergency units, but a significant growth in CHP residential units expected in Europe. Moreover, off-grid and remote applications will also be possible thanks to wind and solar power. (JETRO 2006) This is the case of Denmark, where wind power is already reaching such a high penetration in the Danish electricity system, that a solution to spill-over problems must be found. Surplus wind power can therefore be used to produce hydrogen, either directly for vehicle storage tanks in the garages of each building, or to a store associated with the building. A storage size of 1/2 m3 metal-hydride store per average one-family dwelling is sufficient to store any arising surplus and take care of every deficit. (Makover et al. 2006)

Due to incentives, especially in Europe, the main marketable products in the large stationary sector will be biogas (biomass, waste) based systems. Coal gas based systems give significant long-term opportunities (thanks to US energy politics). In both cases the customers will be most likely either hotels/holiday centers (for image creation reasons), or data centers, hospitals and other premium power (for energy security issues). (Jumppanen 2008)

The established technologies for hydrogen production are natural gas reforming, coal gasification and water electrolysis, but these processes would need to be significantly more efficient and cost-effective in order to produce high volumes of hydrogen for energy use. For this reason, most of the current R&D is looking at making natural gas reforming, coal gasification in IGCC plants and electrolysis highly efficient. (IEA 2008)

In most cases the available technologies are applied to small-scale decentralized production units, since these do not require any expensive infrastructure for hydrogen transportation and distribution. However, decentralized technologies are relatively inefficient and expensive: at the moment this option costs more than USD 50/GJ, meanwhile centralized production options promise, in the long run, hydrogen at USD 10/GJ to USD 15/GJ. Long-term costs for high-temperature water splitting could range from USD 10/GJ (using nuclear) to USD 20/GJ (using solar heat), while higher costs are projected for other technologies. (IEA 2008)

Apart from the cost issues, according to IEA projections the main problem will be the shift to an entirely new system of vehicles and fuels, which are unlikely to happen unless strong policy interventions are applied. (IEA 2008)

4.12. Energy Storage

4.12.1. Why Energy Storage?

Energy storages have been internationally seen as a key component for the further implementation of distributed energy. Most of the problems in power quality, distribution reliability and peak power management can be solved with energy storages. Energy storages give new possibilities for demand side management and for customer level energy cost control. Cost effective, smart energy storages give new potential for building energy management especially when they are used in combined heat and power (CHP) production systems such as fuel cells and microturbines. Energy storages give possibilities to manage uncontrollable power production in renewable energy production systems such as photovoltage and wind power systems. Uninterruptible power delivery can be essential in single family houses for example when they are used as a home office with computer systems or they have critical medical equipment that could be more common in near future. (EC 2008)

- Energy storage is needed to store electricity, heat and cold, which is produced at times of low demand and low generation cost and from intermittent energy sources such as wind and solar power. It is released at times of high demand and high generation cost or when there is no more generation capacity available. (EC 2008)
- Reliable and affordable energy storage is a prerequisite for using renewable energy in remote locations, for integration into the energy system and the development in a future decentralised energy supply system. Energy storage therefore has a pivotal role to play in the effort to combine a future, sustainable energy supply with the standard of technical services and products that we are accustomed to and need. (EC 2008)
- Energy storage is the most promising technology currently available to reduce fuel consumption in the transport sector. (EC 2008)

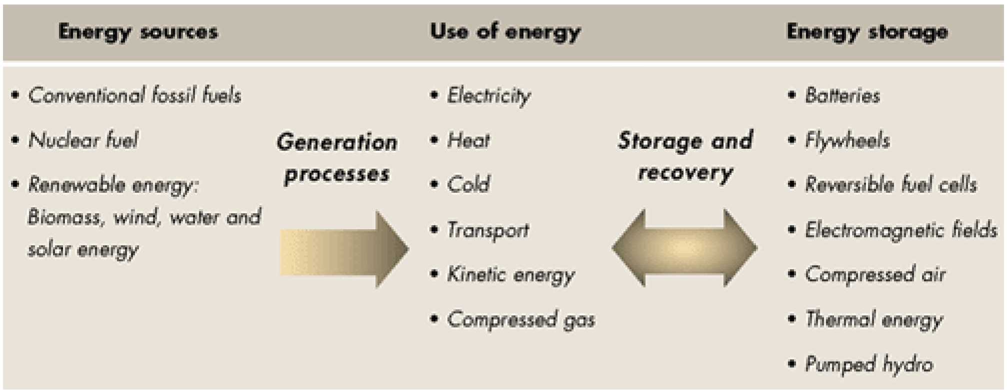


Figure 130. Diagram of Energy Sources, Use of Energy and Energy Storage (EC 2008).

4.12.2. Current Uses of Energy Storage Technologies

- The decision to use an energy storage system depends both on the requirements of the application and the cost of competing solutions. In renewable energy systems, for instance, the use of fossil fuel based back-up generation and grid connection are competing solutions. (EC 2008)
- Power stations, compressors, heating systems, etc. all have different performance characteristics as regards their response time to changing demand, their lead times for starting up or shutting down, and their most efficient points of operation. (EC 2008)
- Energy storage systems can usually be replaced by conventional energy generation. However, this can lead to an inefficient use of fossil fuels and a demand for investment in additional energy generators with high power output and fast response time. (EC 2008)
- The time required for energy generation from renewable sources, be they electricity or heat, cannot always be matched to the time of demand.

- Energy storage systems are therefore an integral part of any renewable energy sources (RES) system. (EC 2008)
- Even when fuel-powered generation is used to cover periods of low RES generation, energy storage is required for economic reasons, as it is cheaper than the frequent use of a motor-driven generator. (EC 2008)
- Also, the stability of the electricity system and quality of the voltage supplied will be considerably higher when an energy storage system is used. The technical and economic optimum concerning the size of an electricity storage system needs to be defined in each case individually. (EC 2008)
- Conventional, commercially available lead-acid batteries have a very high-energy efficiency and all other technologies have to compete with this.
- Batteries are the most expensive item in RES systems when the system's total lifetime costs are considered; and there are big variations in battery lifetime in different installations. (EC 2008)
- Excess electricity can always be stored cheaply in the form of heat and for a long time. However, the value of heat energy is much lower than the value of electricity. (EC 2008)
- In solar thermal systems for heating and cooling it is also necessary to store energy because heat generation depends on solar radiation for energy production. Overview of the technology. (EC 2008)

4.12.3. Energy Storage Technologies

- Batteries
- Flywheels
- Reversible fuel cells
- Electromagnetic
- Compressed air
- Super-capacitor
- Pumped hydro storage

Different energy storage technologies coexist because their characteristics make them attractive to different applications. From a user point of view there are both technical and commercial criteria for selecting the most suitable technology. (EC 2008)

Batteries and Advanced Batteries

Rechargeable batteries or accumulators are the oldest form of electricity storage and widely used. Batteries store electric energy in a chemical form. Their performance is linked in a complex manner to the materials used, the manufacturing processes and the operating conditions. Consequently, progress in battery technology is slow and the transfer of laboratory results into commercial applications is sometimes risky. Lithium ion and nickel-metal-hydride (NiMH) batteries are the only new battery technologies which have achieved significant market penetration in the last decade. Batteries can respond to changes in power demand within microseconds. Only super-capacitors equal such a response time. Batteries usually have very low standby losses and can have high energy efficiency, depending on the application and the details of the operation. Most batteries contain toxic materials, hence the ecological impact from uncontrolled disposal of batteries must always be considered. (EC 2008)

Super-Capacitors

Super-capacitors store electrical energy in the electric field between two electrodes. Ultra-capacitor, super-capacitor and electric double layer capacitor (EDLC) are also called electro-chemical capacitors working with chemical reactions or not like true capacitors. The fundamental design and electrical properties are those of conventional capacitors used throughout the electrical and electronics industry. EDLC uses electric double layer capacitance on both positive and negative electrodes. (EC 2008)

Reversible Fuel Cell Systems and Redox Flow Batteries

Fuel cells convert hydrogen from a storage tank and oxygen from the air to water and generate a current from the electrochemical process. The electrochemical reaction itself is reversible. The fuel cells' energy capacity is determined by the size of the storage tanks for the active materials, and the power by the area of the electrodes and design of the reactor. Standby losses are low because the active materials are kept physically separate. Redox flow batteries are systems using materials other than hydrogen and oxygen. Their energy efficiency is higher than those of reversible fuel cells, but still below the energy efficiency of most batteries. (EC 2008)

SMES (Super-Conducting Magnetic Energy Storage Systems)

SMES store energy in the magnetic field of a coil made from special alloys. By cooling the conducting wires to - 269°C the resistance of the material to electrical current disappears, allowing it to conduct very high currents without electrical losses. When looking at the complete system, however, it is clear that there is considerable energy requirement for refrigeration. Also, the current has to flow through non-super-conducting components and solid-state switches, which cause resistive losses. Despite this, the overall efficiency in commercial applications is very high. (EC 2008)

Flywheels

The energy is stored as kinetic energy in a rotating mass. The amount of energy stored increases with the square of the rotational speed, which is limited by the tensile strength of the material used. (EC 2008.)

Thermal Storage (Heat and Cold)

Conventional heat and cold storage systems simply store excess energy in a large tank using the working medium at the temperature required for later use. Virtually every cooling and heating system has such storage tanks. (EC 2008)

Compressed Gas Storage

Compressed air tanks are widely used in industry to provide a constant source of compressed air with uniform pressure in the range of 8-10 bar. There is renewed interest in compressed air storage for covering the demand of peak electricity or for small wind/hybrid applications, where the energy-to-power ratio of batteries is unsuitable, either because the energy content is very high but the power requirement low, or the energy through-put is very high compared to the energy content. (EC 2008)

Pumped Hydro Storage

Pumped hydro storage is a conventional energy storage technology utilised by the electrical industry. Water in a basin at the top of a mountain is used to drive a generator in a reservoir at a lower level. When surplus energy is available, the water is pumped back up again. The power output and the cost efficiency of pumped hydro storage depends on the difference in height. (EC 2008)

4.12.4. The Future Potential and Challenges of Energy Storage Technology

The main applications of Energy Storage systems are stand-alone systems with the highest potential in third world countries as well as isolated and interconnected grids for stability and management purposes in industrial countries. (EC 2008)

The perception of renewable energy systems and decentralised energy resources depends on the demonstration of their ability to supply with high-quality and with economic profitability. Energy storage systems have to compete against the present over-capacity of power stations and power generators with short start-up times, such as gas turbines and gas or diesel motors with the appropriate emission controls. (EC 2008)

Energy storage systems enable energy services belonging load management, to peak shaving, power quality and uninterruptible power supply (EC 2008).

Reliable and affordable electricity storage is a prerequisite for optimising the integration of renewable energy systems. Energy storage therefore has a pivotal role to play in the effort to combine a future, sustainable energy supply with the standard of technical services and products. (EC 2008)

For both stationary and transport applications, energy storage is of growing importance as it enables the smoothing of transient and/or intermittent loads, and down-sizing of base-load capacity with substantial potential for energy and cost savings (EC 2008).

Energy storage is a key element in achieving the EU policy goals for sustainability, air quality and cost-effective, competitive goods and services (EC 2008).

4.12.5. Carbon Nanotubes

The range of applications employing carbon nanotubes for energy storage and conversion include fuel cells, batteries, supercapacitors, solar cells, and thermionic power devices. In fuel cells, carbon nanotubes are likely to be utilized for hydrogen storage and in developing new composite materials for proton exchange membranes. They also represent a promising material for lithium storage in lithium-ion batteries and may even find a use in novel carbon-carbon battery types. Other potential applications are supercapacitors, where nanotubes could be used as electrodes in electrochemical double layer capacitors. Nanotube-based composite materials are expected to have a high impact in solar cells industry, while an exotic class of devices is about to exploit thermionic emission of carbon nanotubes for producing electric energy from residual heat.

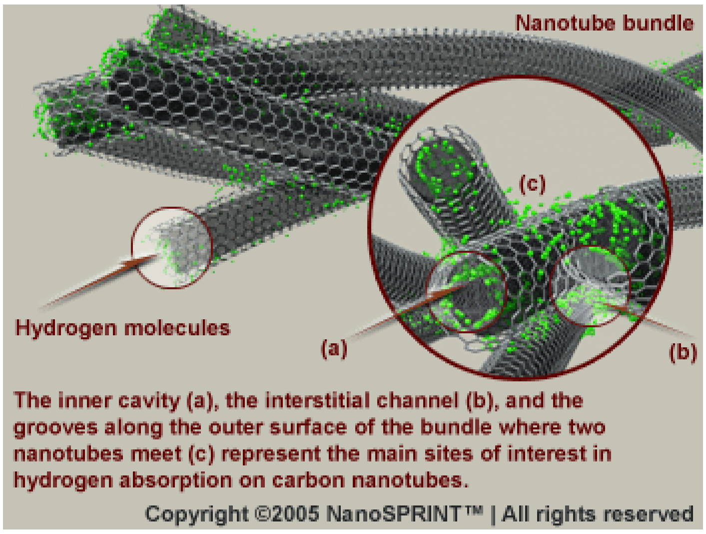


Figure 131.

Therefore, the use of nanotubes in energy storage and conversion applications has the potential to affect several major industries. In the automotive industry, nanotube research could permit hydrogen energy to substitute conventional solutions sooner than expected, replacing internal combustion engines with fuel cells. Since hydrogen can be converted into electricity with only water as emission and with very high operating efficiency, another probable use could be in stationary low scale power plants or energy storage facilities, probably as a complement to solar or wind-based power plants. Solar cells could also benefit from the development of nanotube composites, which allow building of increasingly cheaper, lighter and more efficient photovoltaic cells. In the consumer electronics market, methanol-based micro fuel cells, which are currently developed as energy sources for portable devices, could complement lithium-ion, lithium sulfur, and carbon-carbon batteries employing nanotubes. Carbon nanotubes could also penetrate the aerospace industry, thanks to thermionic power devices, which are able to extract the energy from the residual heat in jet exhaust flow.

Nanotubes are most likely to have an impact in the energy storage and conversion field of applications. Whether their potential for hydrogen storage will be confirmed or not, nanotube-reinforced composites and nanotube-based catalyst supports will likely improve electrodes and proton exchange membranes in fuel cells. Electrodes for lithium batteries are also a sure target and a huge market in the same time. The third major field of research is represented by the solar cell industry, where nanotubes are expected to boost the performances and to significantly lower the costs. Unlike more exotic applications (such as carbon-carbon batteries or thermionic power devices), nanotube-based fuel cells, photovoltaic cells and batteries are expected to hit the market within a decade, as prices will surely drop.

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Nanotubes Power Paper-Thin Battery

By Katherine Noyes
TechNewsWorld
08/14/07 2:48 PM PT

Developed by a team of researchers at Rensselaer Polytechnic Institute (RPI), the nanoengineered battery is 90 percent cellulose, made up of the same plant cells used in nearly every type of paper. Infused in that paper, though, are aligned carbon nanotubes, which act as electrodes and allow the battery to conduct electricity.

The result is a lightweight, ultra thin, completely flexible storage device that can be rolled, twisted, folded or cut into any number of shapes with no loss of mechanical integrity or efficiency. The paper batteries can also be stacked, like a ream of printer paper, to boost the total power output.

Details are outlined in the paper, "Flexible Energy Storage Devices Based on Nanocomposite Paper," published in the *Proceedings of the National Academy of Sciences*. The project was supported by the New York State Office of Science, Technology, and Academic Research (NYSTAR), as well as the National Science Foundation (NSF) through the Nanoscale Science and Engineering Center at RPI.

Taken together, the devices can provide the long, steady power output of a conventional battery as well as a supercapacitor's quick burst of high energy needed for starting things like engines.

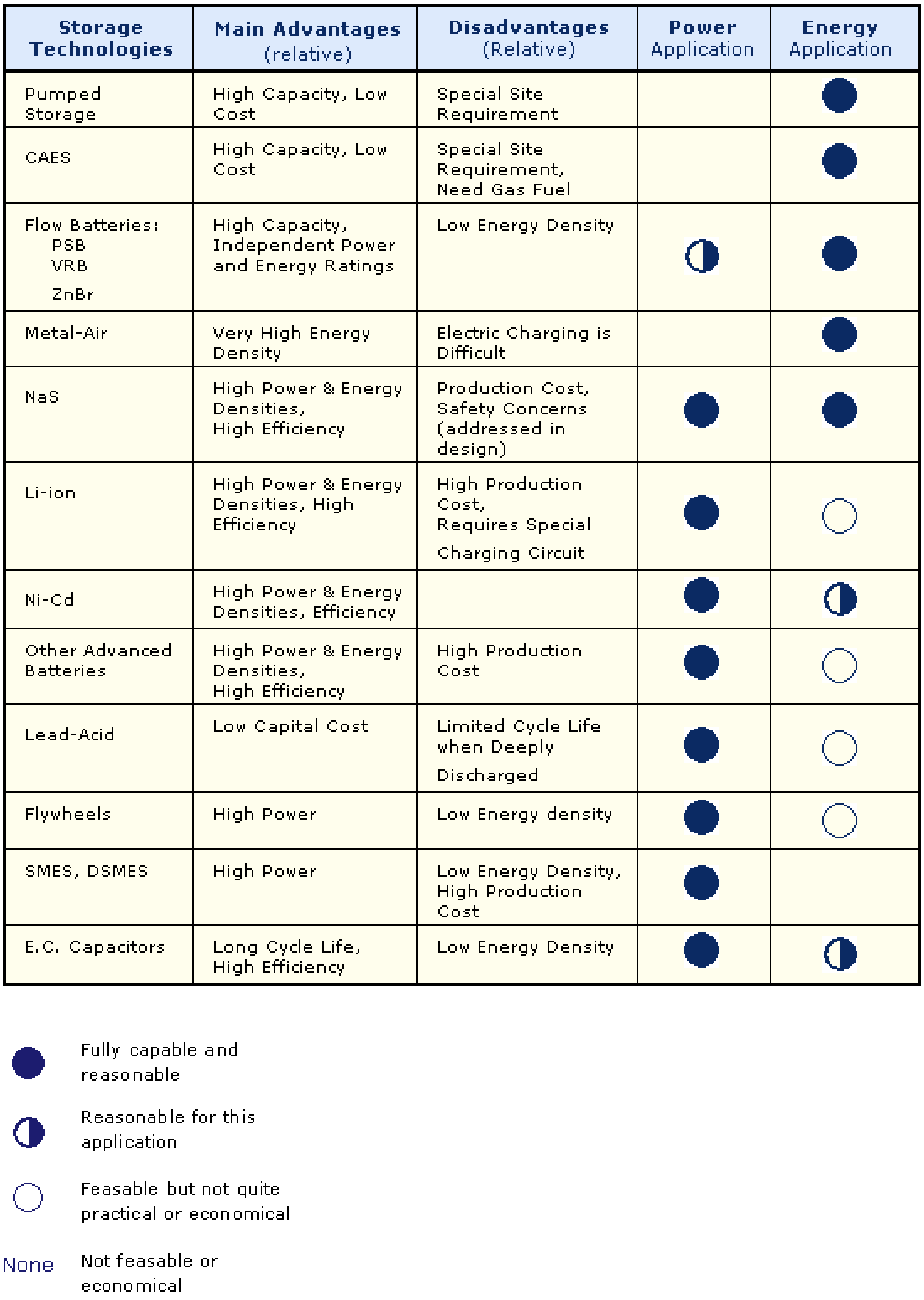
The researchers used ionic liquid, essentially a liquid salt, as the battery's electrolyte, but they also printed paper batteries without adding any electrolytes and demonstrated that naturally occurring electrolytes in human sweat, blood and urine can be used to activate them.

The devices are completely integrated, and can be printed like paper.

Potential applications span the spectrum, including not just lightweight handheld devices but also automobiles, aircraft and boats. Because the paper could be molded into different shapes, such as a car door, it could spur a new generation of automotive innovations, for example.

Thanks to paper's essential biocompatibility, the devices also have potential as power supplies for devices implanted in the body.

4.12.6. Comparison of Different Energy Storage Technologies



Storage Technologies	**Main Advantages** (relative)	**Disadvantages** (Relative)	**Power** Application	**Energy** Application
Pumped Storage	High Capacity, Low Cost	Special Site Requirement		●
CAES	High Capacity, Low Cost	Special Site Requirement, Need Gas Fuel		●
Flow Batteries: PSB VRB ZnBr	High Capacity, Independent Power and Energy Ratings	Low Energy Density	◐	●
Metal-Air	Very High Energy Density	Electric Charging is Difficult		●
NaS	High Power & Energy Densities, High Efficiency	Production Cost, Safety Concerns (addressed in design)	●	●
Li-ion	High Power & Energy Densities, High Efficiency	High Production Cost, Requires Special Charging Circuit	●	○
Ni-Cd	High Power & Energy Densities, Efficiency		●	◐
Other Advanced Batteries	High Power & Energy Densities, High Efficiency	High Production Cost	●	○
Lead-Acid	Low Capital Cost	Limited Cycle Life when Deeply Discharged	●	○
Flywheels	High Power	Low Energy density	●	○
SMES, DSMES	High Power	Low Energy Density, High Production Cost	●	
E.C. Capacitors	Long Cycle Life, High Efficiency	Low Energy Density	●	◐

●	Fully capable and reasonable
◐	Reasonable for this application
○	Feasable but not quite practical or economical
None	Not feasable or economical

Figure 132. Energy Storage Technologies (ESA 2003).

Ratings

Large -scale stationary applications of electric energy storage can be divided in three major functional categories (ESA 2003):

- Power Quality. Stored energy, in these applications, is only applied for seconds or less, as needed, to assure continuity of quality power.
- Bridging Power. Stored energy, in these applications, is used for seconds to minutes to assure continuity of service when switching from one source of energy generation to another.
- Energy Management. Storage media, in these applications, is used to decouple the timing of generation and consumption of electric energy. A typical application is load leveling, which involves the charging of storage when energy cost is low and utilization as needed. This would also enable consumers to be grid-independent for many hours.

Although some storage technologies can function in all application ranges, most options would not be economical to be applied in all three functional categories.

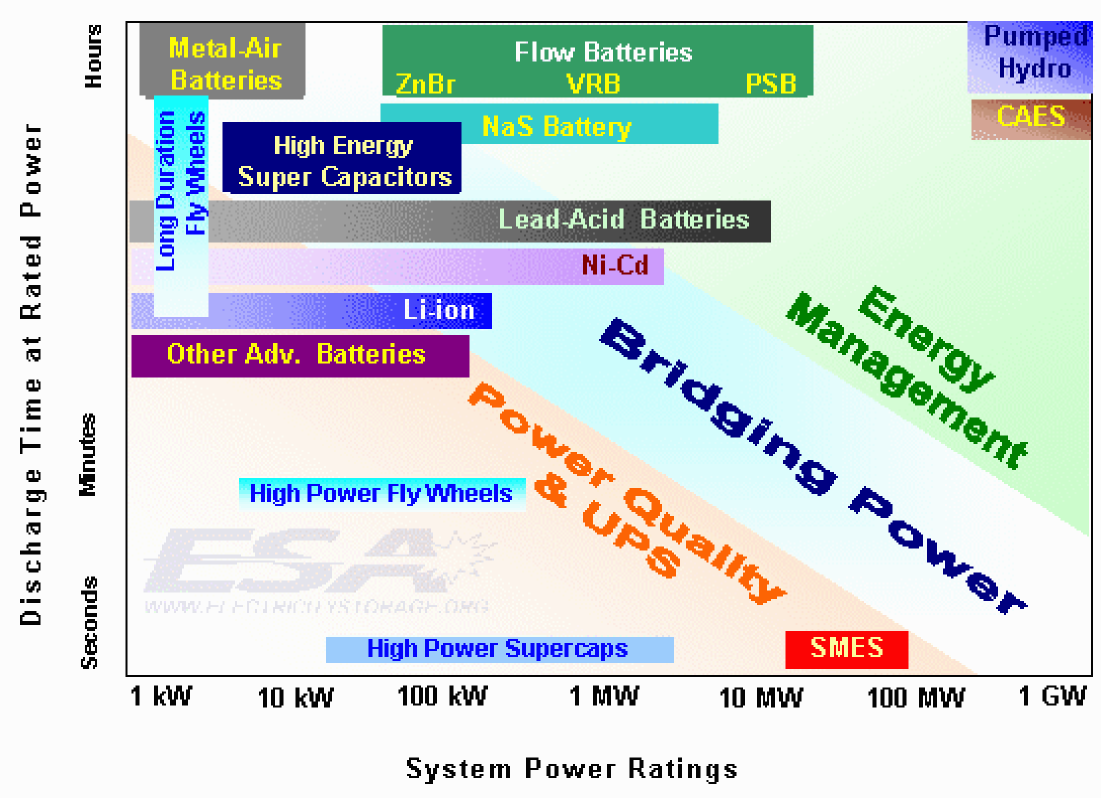


Figure 133. Electricity Storage (ESA 2003).

Efficiency

Efficiency and cycle life are two important parameters to consider along with other parameters before selecting a storage technology. Both of these parameters affect the overall storage cost. Low efficiency increases the effective energy cost as only a fraction of the stored energy could be utilized. Low cycle life also increases the total cost as the storage device needs to be replaced more often. The present values of these expenses need to be considered along with the capital cost and operating expenses to obtain a better picture of the total ownership cost for a storage technology. (ESA 2003)

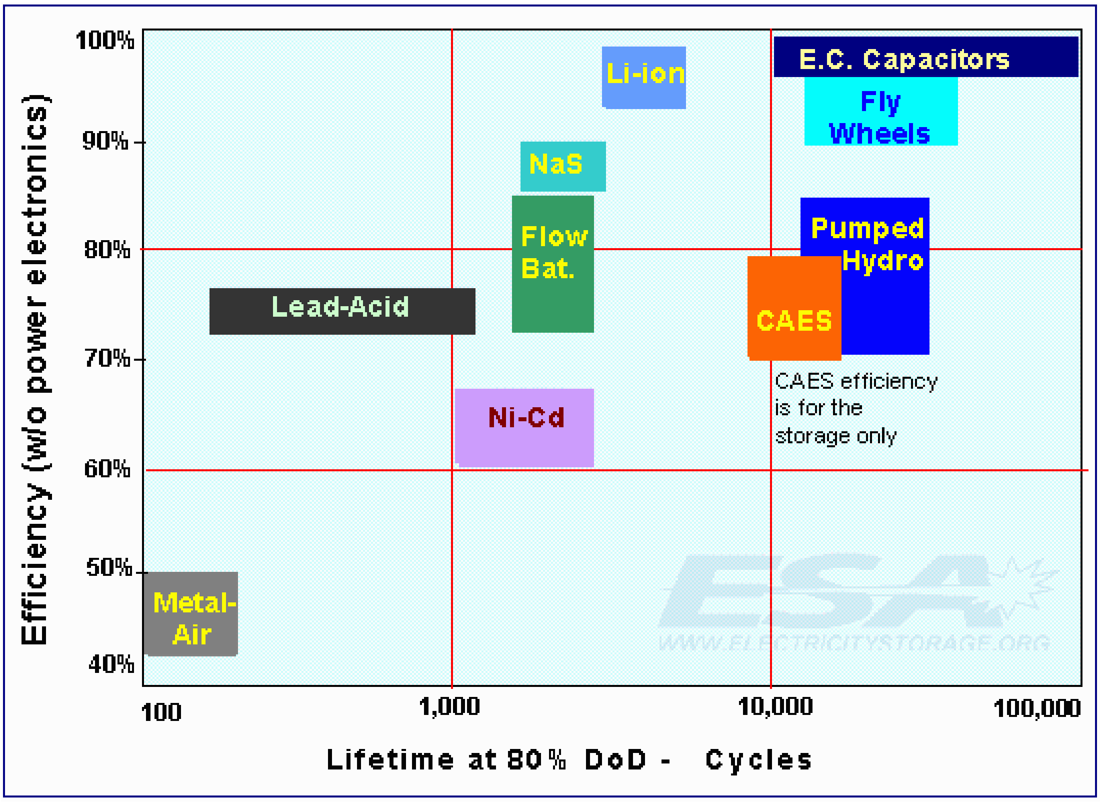


Figure 134. Technology Comparisons: Life Efficiency (ESA 2003.)

Size and Weight

Size and weight of storage devices are important factors for certain applications. Metal-air batteries have the highest energy density in this chart. However, the electrically rechargeable types, such as zinc-air batteries, have a relatively small cycle life and are still in the development stage. (ESA 2003)

The energy density ranges reflect the differences among manufacturers, product models and the impact of packaging (ESA 2003).

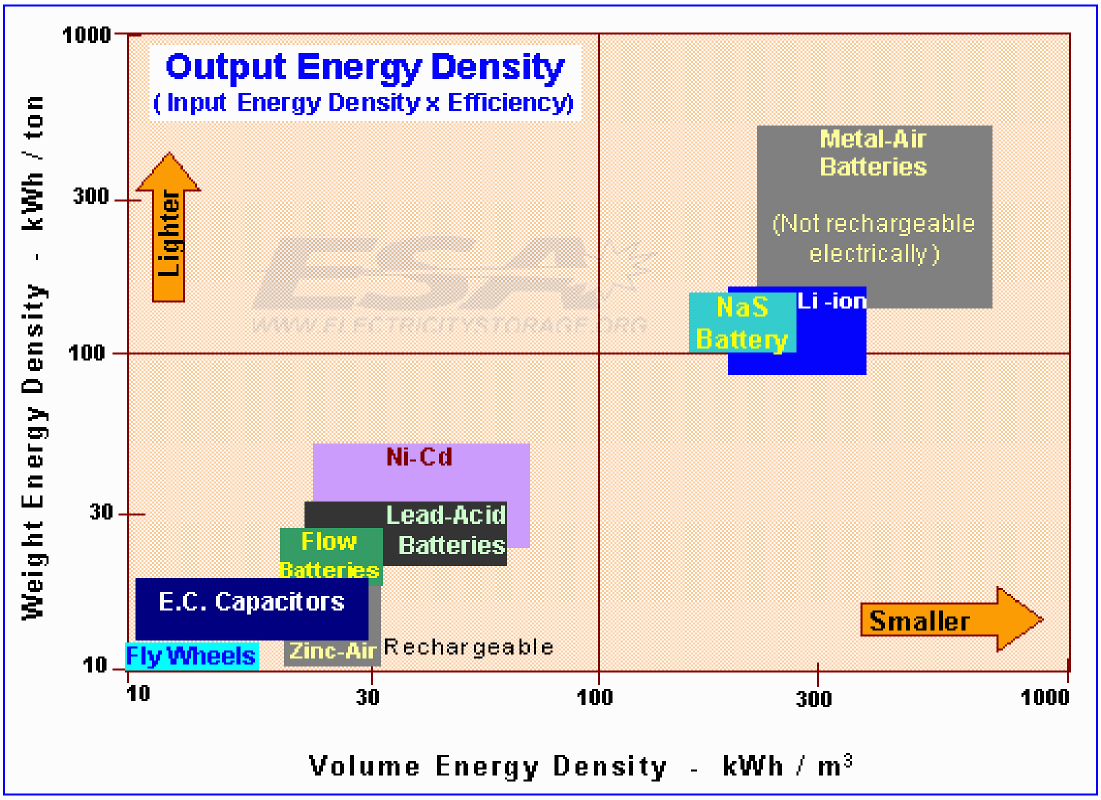


Figure 135. Technology Comparisons: Size and Weight (ESA 2003).

Per Cycle Cost

Per-cycle cost can be the best way to evaluate the cost of storing energy in a frequent charge/discharge application, such as load levelling (ESA 2003).

This chart shows the capital component of this cost, taking into account the impact of cycle life and efficiency. For a more complete per-cycle cost, one needs to also consider O&M, disposal, replacement and other ownership expenses, which may not be known for the emerging technologies. (ESA 2003)

It should be noted that per-cycle cost is not an appropriate criterion for peak shaving or energy arbitrage where the application is less frequent or the energy cost differential is large and volatile. (ESA 2003)

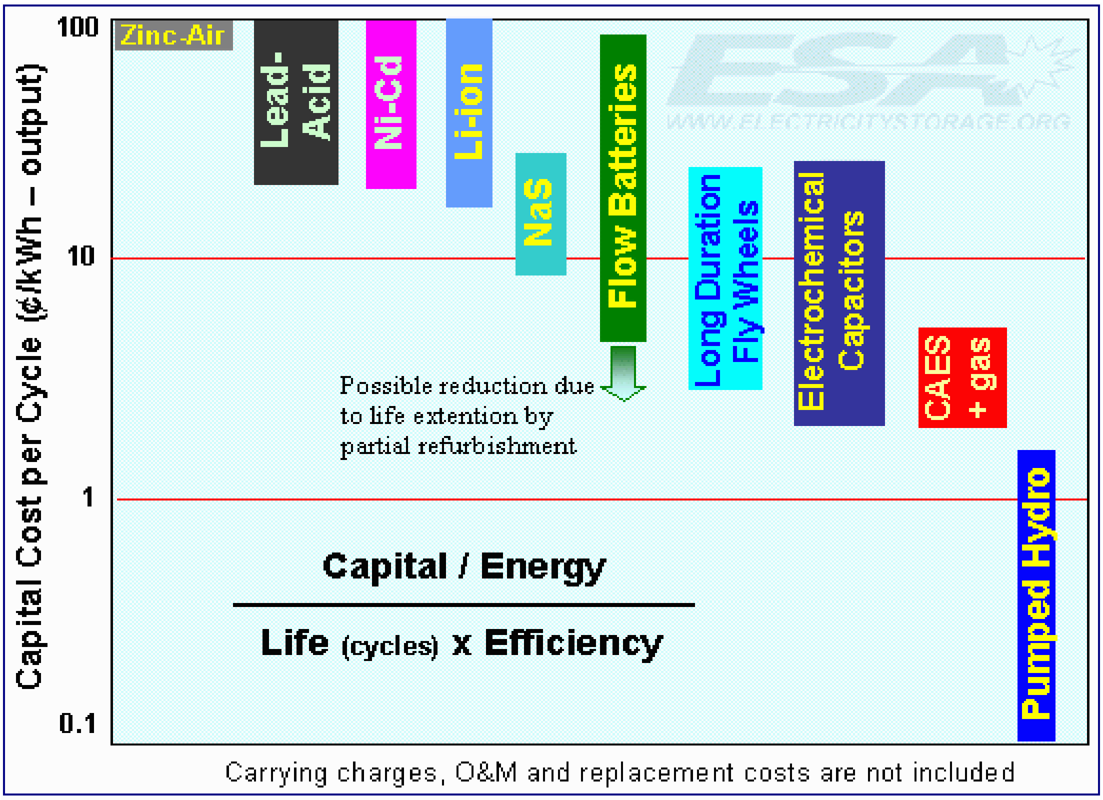


Figure 136. Technology Comparisons: Per Cycle Cost (ESA 2003).

Capital Costs

While capital cost is an important economic parameter, it should be realized that the total ownership cost (including the impact of equipment life and O&M costs) is a much more meaningful index for a complete economic analysis. For example, while the capital cost of lead-acid batteries is relatively low, they may not necessarily be the least expensive option for energy management (load leveling) due to their relatively short life for this type of application. (ESA 2003)

The battery costs in this chart have been adjusted to exclude the cost of power conversion electronics. The cost per unit energy has also been divided by the storage efficiency to obtain the cost per output (useful) energy. (ESA 2003)

Installation cost also varies with the type and size of the storage. The information in the chart and table here should only be used as a guide not as detailed data. (ESA 2003)

Notes:

1. The costs of storage technologies are changing as they evolve. The cost ranges in this chart include approximate values in 2002 and the expected mature values in a few years.

2. The Metal-Air batteries may appear to be the best choice based on their high energy density and low cost, but the rechargeable types have a very limited life cycle and are still under development.

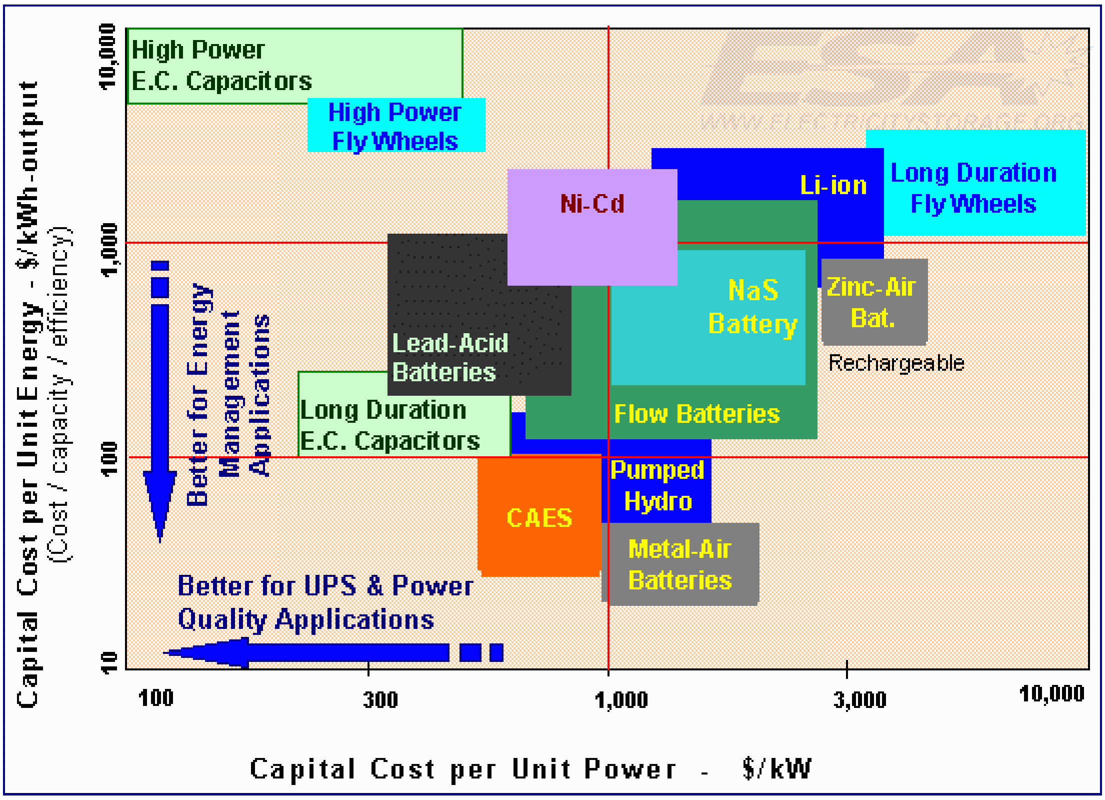


Figure 137. Technology Comparisons: Capital Cost (ESA 2003).

4.13. Carbon (CO_2) Capture and Storage (CCS)

4.13.1. Technologies

CO_2 capture and storage (CCS) is separation of CO_2 from anthropogenic sources, transport to a storage location, and isolation from the atmosphere. CCS would be an option in the portfolio of actions for stabilization of greenhouse gas concentrations while allowing for the continued use of fossil fuels. (Rubin et al. 2005)

Capture of CO_2 can be applied to large point sources, and storage could take place in geological formations or the ocean, in mineral carbonates, or by using the CO_2 in industrial processes (Rubin et al. 2005).

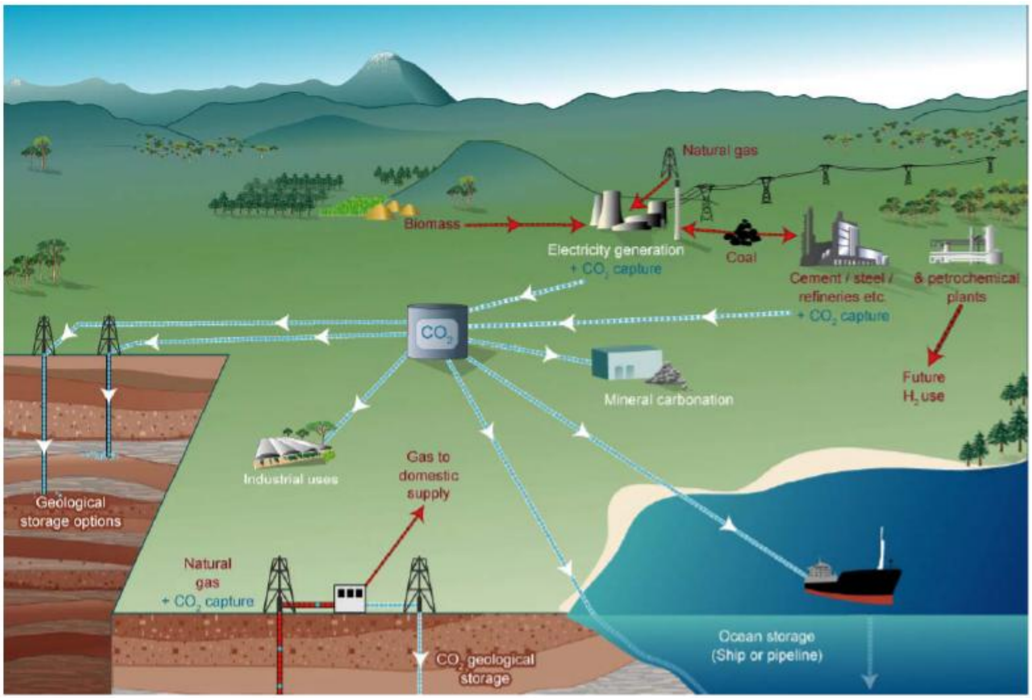


Figure 138. *Schematic Diagram of Possible CCS Systems. It Shows the Sources for which CCS Might Be Relevant, Transport of Carbon Dioxide and Storage Options (Rubin et al. 2005).*

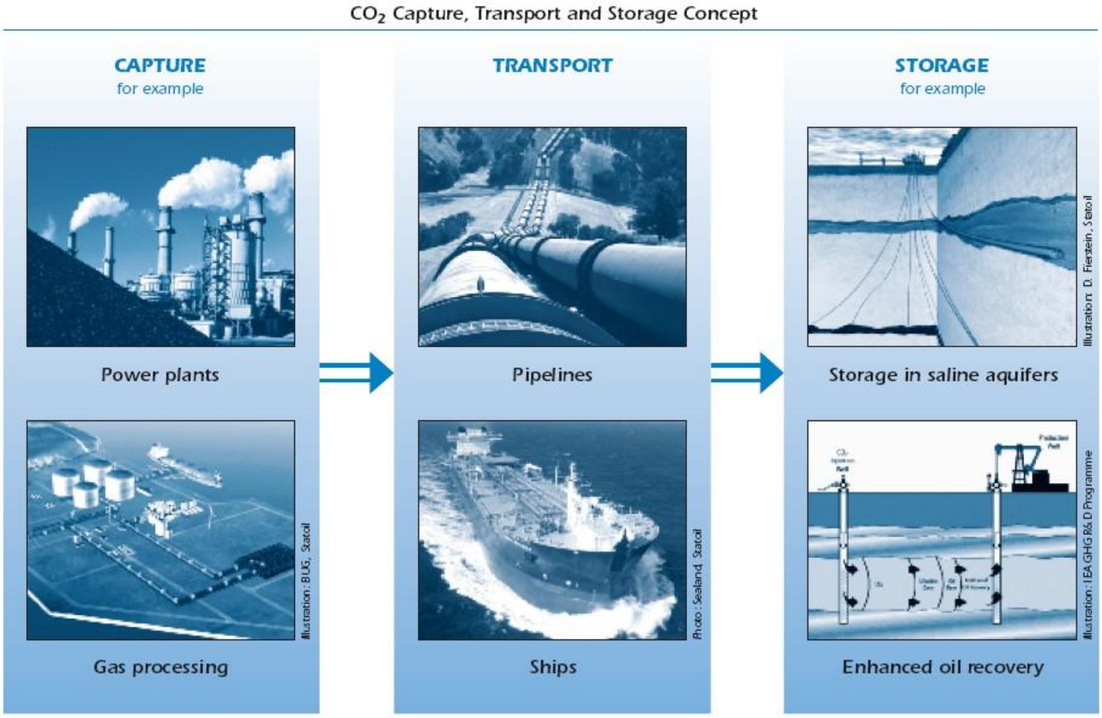


Figure 1249. *CCS Systems (IEA 2004.)*

4.13.2. Current Status of CCS Technology

Components of CCS are in various stages of development. Complete CCS systems can be put together from existing technologies that are mature or economically feasible under specific conditions. (CO_2CRC 2008)

Pipelines are preferred for transporting large amounts of CO_2 for distances up to around 1,000 km. For smaller amounts or larger distances overseas, use of ships to transport CO_2 is economically more attractive. (CO_2CRC 2008)

Storage of CO_2 in deep geological formations (oil and gas fields, saline formations, unminable coal beds) uses many of the same technologies that have been developed by the oil and gas industry and has been proven to be economically feasible under specific conditions for oil and gas fields and saline formations. (CO_2CRC 2008)

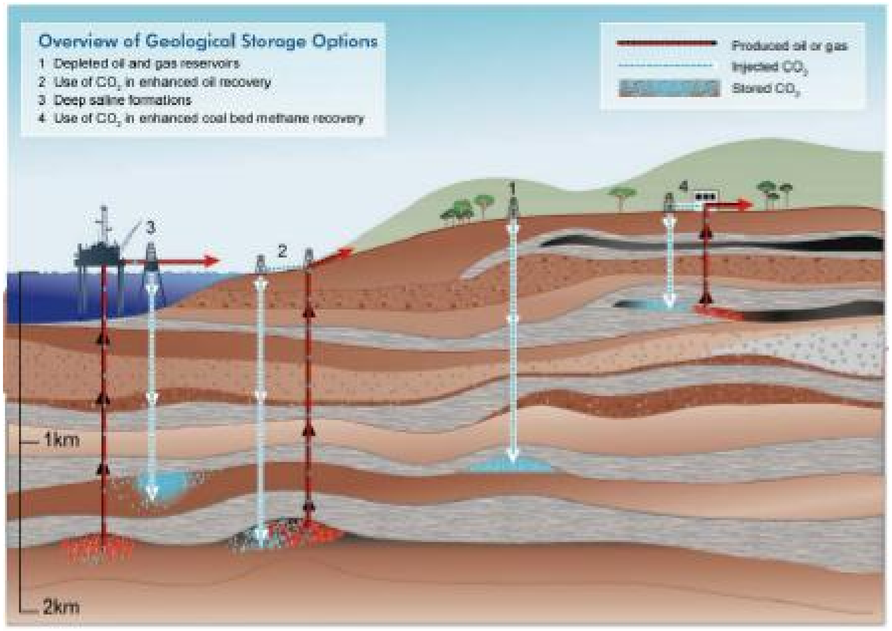


Figure 140. Overview of Geological Storage Options (CO_2CRC 2008).

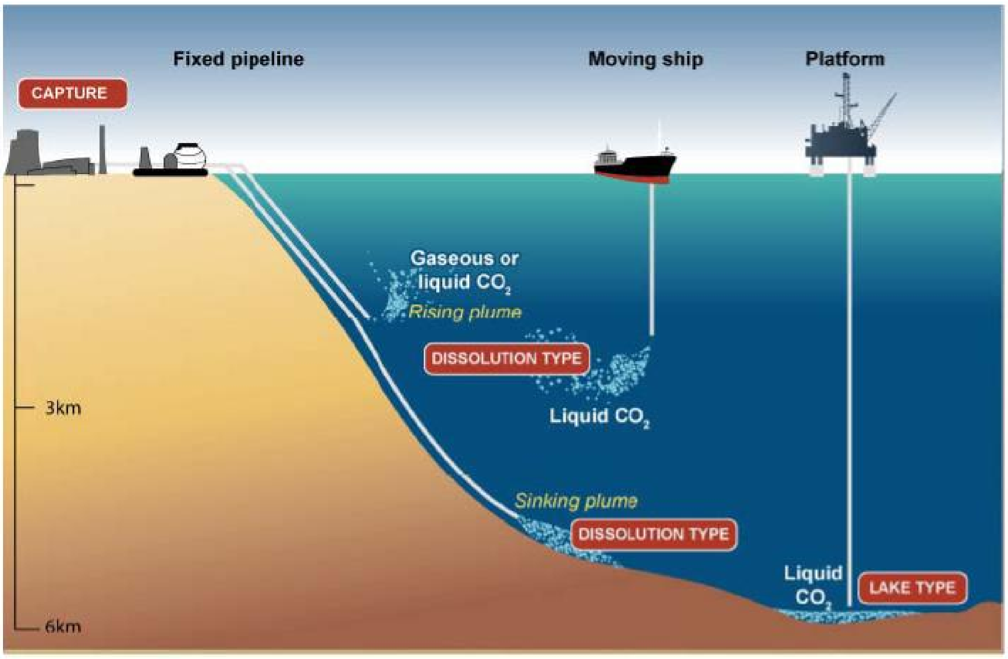


Figure 141. Overview of Ocean Storage Options (Global Warming 2008).

Ocean storage could be done in two ways: by injecting CO_2 into the water column (typically below 1,000 meters) via a fixed pipeline or a moving ship, or by depositing it via a fixed pipeline or an offshore platform on the sea floor at depths below 3,000 m, where CO_2 is denser than water and is expected to form a "lake" that would delay dissolution of CO_2 into the surrounding environment (see Figure 141). Ocean storage is still in the research phase and especially Japan has been active while the USA has practically withdrawn form the area. (Global Warming 2008)

The estimated geological reservoir capacities are 900 Gt CO2 in disused oil and gas fields, 40 Gt CO_2 in unmineable coal beds and 400–10,000 Gt CO2 in deep saline reservoirs. To put these capacities in perspective, in 2002 global CO_2 emissions from fuel combustion amounted to about 24 Gt CO_2 and are projected to reach 38 Gt – CO_2 per year in 2030. (Global Warming 2008)

4.13.3. Environmental and Economic Benefits

Carbon dioxide emissions are the main source of climate change and the reduction of the emissions is crucial for environmental sustainability. CO_2 capture and storage offers one way of reducing the emissions. Nevertheless, one should keep in mind that the CCS is an end-of-pipe solution, and should therefore be considered only once a maximum efficiency improvement has been achieved on the power production process. (Stone et al 2009)

The net reduction of emissions to the atmosphere through CCS is influenced by the fraction of CO_2 captured, the loss in overall efficiency of power plants or industrial processes due to the additional energy required for capture, transport and storage, and the fraction of CO_2 retained in storage over the long term. (Stone et al 2009)

CCS has value to mitigation as it may reduce overall mitigation costs and increase flexibility in achieving greenhouse gas emission reductions. The application of CCS would depend on technical maturity, costs, overall potential, regulatory aspects, environmental issues and public perception. (Stone et al 2009)

With respect to storage in depleted oil reservoirs, one option consists in injecting CO_2 into almost depleted oil fields so as to enhance oil production. This process, called the Enhanced Oil Recovery process (EOR), currently uses about 45 Mt CO_2/year and is most commonly used in the USA. Transposing this process for Enhanced Gas Recovery (EGR) is not currently used, although such projects have been proposed in Canada and the Netherlands. CO_2 can also be injected into suitable coal seams, producing methane that is pushed out by the incoming CO_2. There have been few Enhanced Coal Bed Methane (ECBM) trials in the world to date. The benefits from the enhanced fossil fuel production is calculated to amount €0–29/t CO_2; compared to capture costs of €16–42/t CO_2. This offers the opportunity to offset part or even all of the capture costs. (Stone et al 2009)

CCS technology does not offer considerable employment effects since the planned projects are mainly large scale offering only limited employment possibilities in the process operation and some in the equipment manufacturing (Stone et al 2009).

CCS technology can form an important process option in the shift towards hydrogen economy. If hydrogen is produced from natural gas or coal the CCS technology can form part of the process chain. (Stone et al 2009)

4.13.4. Market Trends for CO_2 Capture Technologies

From a market perspective, chemical absorption-based processes, which are readily available, will be the first to fulfil the needs of the CO_2 capture technology market. Once membrane technology is fully developed, it will progressively replace absorption technology. (EC 2005)

Although capturing is technically feasible today, the cost of this process is a major issue. Capture costs are currently estimated at €50–60/t, whilst the target costs are €30-40/t for Japan, €20-30/t for Europe and $10/t for the USA. (EC 2005)

The CO_2-EOR potential in the North Sea is significant. On the Norwegian Continental Shelf alone, the potential incremental oil from CO_2-EOR projects has been estimated to be in the region of 1.5–2.0 milliard barrels, thereby inferring a requirement for 500–650 Mt CO_2 in the Norwegian sector until 2025. Similar figures are anticipated for the UK offshore oil sector. (EC 2005)

4.13.5. Barriers to Use and Local Health, Safety and Environmental Risks

Continuous leakage of small quantities of CO_2 over a long time frame could offset the benefits of CCS for mitigating climate change and, depending on the storage option and the selection process, leaks could become a disperse emission source, which would be difficult to control. (IPCC 2005)

The local risks associated with CO_2 transport could be similar to or lower than those posed by comparable operations. For existing CO_2 pipelines, mostly in areas of low population density, accident numbers reported per kilometre pipeline are very low and are comparable to those for hydrocarbon pipelines, and the impacts would probably not be more severe than those with natural gas accidents. If a sudden and brief large release of CO_2 occurred, the local impacts on health could be significant; a concentration of CO_2 greater than 7–10% in air would cause immediate dangers to human life and health. (IPCC 2005)

Risks posed by geological storage would depend on the criteria and available subsurface information used for site selection, the design of the monitoring program to detect problems, the regulatory system, and the appropriate use of remediation methods to stop or control CO_2 releases if they arise. (IPCC 2005)

There are two different types of leakage scenarios: 1) Abrupt leakage, through injection well failure or leakage up an abandoned well, and 2) more gradual leakage, through undetected faults, fractures, or wells. Impacts of elevated CO_2 concentrations in the shallow subsurface could include lethal effects on plants and subsoil animals, and contamination of groundwater. High fluxes in conjunction with stable atmospheric conditions could lead to local high CO_2 concentrations in the air that could harm animals or people. (IPCC 2005)

The chronic effects of direct CO_2 injection into the ocean on ecosystems over large ocean areas and long time scales are unclear. In contrast, adding CO_2 to the ocean or forming pools of liquid CO_2 on the ocean floor at industrial scales will alter the local chemical environment to an extent that has been shown in laboratory studies to cause mortality of ocean organisms. (IPCC 2005)

At normal conditions, the atmospheric concentration of CO_2 is 0.037 %, a non-toxic amount. Most people with normal cardiovascular, pulmonary-respiratory, and neurological functions can tolerate exposure of up to 0.5 to 1.5 % CO_2 for one to several hours without harm. (IPCC 2005)

Higher concentrations or exposures of longer duration are hazardous – either by reducing the concentration of oxygen in the air to below the 16 % level required to sustain human life, or by entering the body, especially the bloodstream, and/or altering the amount of air taken in during breathing. Protective standards have been developed for workers who may be exposed to CO_2. These standards could form a basis for protection of the population at large against exposure to CO_2. (IPCC 2005)

4.13.6. CCS Use in Different Countries

Large point sources of CO_2 are concentrated in major industrial areas, mostly in industrialized countries, but also in developing countries. CO_2 sources are often close (< 300 km) to areas that potentially hold reservoirs for geological storage. Only a small proportion of large emission sources might be close to ocean storage locations. (IPCC 2005)

The timing of the entry of CCS technologies into a particular region is influenced by local conditions such as the relative price of coal and natural gas in a region. The policy regime, and in particular the extent of emissions trading can influence where CCS technologies are deployed. (IPCC 2005)

Currently, three large-scale CCS systems are in place: in Norway, Canada, and Algeria. There are altogether four commercial capture projects in Asia, five in North America, one in Europe and one in Latin America. R&D capture projects are mainly in North America (23) and Europe (14). Geological and ocean storage demo and R&D projects are also mainly in North America (40) and Europe (22) and some in developing countries (9). (IPCC 2005)

Due to its large and increasing fossil-fuel-based power production systems, China represents a great potential market for CCS technologies (IPCC 2005).

5. DEVELOPMENT OF THE ENERGY MARKETS

The energy policies of European Union are among the strongest factors determining the future of energy markets in Finland. The most central objectives of European energy policy are sustainable development, competitiveness and energy security. On the other hand, the Finnish energy sector is in good position to influence these policies as the Nordic power market and cross-border trade continue to be progressive in comparison to most other regions of the Union (see e.g. Nordel 2007).

The primary objective of common European energy markets is increasing competitiveness. The integrated European energy markets and their regulation play a critical role in European competitive strategy. Competitive and efficient European electricity and gas markets are aimed at affecting the energy prices for the benefit of European societies, industry and citizens. Energy pricing is seen as a key factor for the wellbeing of European citizens, while electricity and gas markets are critical inputs for the industry. Increasing competition in the energy sector is considered to increase efficiency and service supply in the energy sector, to support technology development and price competition. (COM 2007-528; COM 2007-529)

Competitive and efficient electricity and gas markets can also play a role in combating climate change. Only in a functioning market, it is possible to create a functioning emission trade system and industry based on renewable energy sources. These are needed to comply with the target of European Council, requiring that 20 % of primary energy consumption must be covered with renewable energy by year 2020. Also well functioning retail markets plays a significant role in climate change mitigation by increasing consumers awareness of household energy consumption and energy costs, as all measures aiming at CO_2 emission reductions and increasing energy efficiency presume measures taken by private households. (COM 2007-528; COM 2007-529)

In addition, competitive EU wide electricity and gas markets are seen indispensable for securing European energy supply, because only Europe-wide and competitive markets create accurate investment signals and provide equal network access for all potential investors. Cross-border interconnections were originally developed for mutual support between countries and regions in emergency situations, but they are increasingly being used for trading between states. In addition, competitive markets are seen to create real and effective incentives for both network operators and producers to realize the extensive investments required in EU during the following decades. Modern societies are in a critical manner dependent on security of energy supply. Countries that do not possess sufficient supply of fossil fuels are facing increasing insecurity in availability of primary energy. In addition, the aging of European power transmission and distribution networks in threatening security, reliability and quality of supply. (COM 2007-528; COM 2007-529)

The transmission and distribution systems are commonly run by natural monopolies, either national or regional bodies, under energy authorities' supervision, while the generation sector is increasingly competitive. The basic elements of market restructuring involve unbundling of the potentially competitive services from the core of natural monopolies, (introducing competition in the services provided over the networks, and introducing the regulation of natural monopolies in order to ensure reasonable tariffs and non-discriminatory network access. (see e.g. Energiamarkkinavirasto 2008)

The requirements of developing European electricity markets include separation of supply and production activities from network operations, harmonization of powers of national regulatory authorities and strengthening their independence. Further requirements include creating a system for coordinating national regulators' cooperation, establishing a mechanism for transmission system operators for coordinating network operation and increasing efficiency in cross-border power trade and transparency of energy markets. (COM 2007-530; COM 2007-531)

The process of liberalizing the electricity and gas market started about 10 years ago. During this time, many of Europe's citizens have benefited from more choice and more competition, with improved service and security. The Nordic countries have been European forerunners in power sector liberalization and development of a genuinely competitive international market area for electricity. However, the process of developing real competitive markets is far from complete, because the ultimate objective in development of internal electricity and gas markets is the creation of real European end user markets. All retails markets within the Union have been opened to competition since July 1 2007, however in practice many consumers are tied to their traditional supplier, as the required legislative framework has not been developed. In practice, a large proportion of the EU's citizens and businesses lack a genuine choice of supplier. Market fragmentation along national borders, a high degree of vertical integration and high market concentration are at the root of the lack of a truly internal market so far. (ERGEG 2007)

5.1. Role of third countries in EU internal energy markets

The new directives require factual unbundling of transmission network operators and distribution and generation activities on both national level and union wide. In particular, this requirement dictates that a distribution or generation company operating in any Member State may not own nor operate transmission network in any Member State. This requirement applies similarly to enterprises both from and outside the Union. In addition, legislative measures guarantee that in case enterprises from third countries seek to acquire or control a significant share of a network within EU, they are required to present unambiguous verification that they are following the same unbundling principles as enterprises in the Union. Similarly, transmission network or TSO should not be under control of third counties nor individual coming from third counties, with the exception of a specific agreement between EU and respective third country. (COM 2007-530; COM 2007-531)

5.2. Development of Market Regulation

Considering the significance of availability of electricity to the functioning of the whole society, gives the requirement of public service to the reliability of power system. It is controversial, whether completely liberalized market system could satisfy this requirement tolerably (See Brennan 2005). Substituting competition for regulation has been more successful in economic sectors such as aviation and banking, yet after the dramatic turns of financial crisis in autumn 2008, more regulation is called for at least in the latter. In some other industries, such as telecommunication and electricity, competition and markets liberalization has been more difficult from the start, because these industries have segments with characteristics of natural monopolies.

Power generation and trade have been liberalized in many countries, while long distance transmission and local electricity distribution continue to be regulated monopolistic operations. It seems therefore appropriate to target regulation where it supports market development in those parts of the systems where requirements for competition are innate. It may be also worth asking whether the competition is actually worthwhile, if the restructuring and regulatory structures necessary to ensure competition themselves are costly. (Brennan 2005.) In addition, the relation between competition and regulation should strive for the goal of serving European citizens and national economies as efficiently and equitably as possible. Developing the European energy markets aims at strengthening of the regulatory framework to support market functioning. Measures related to this are involved in strengthening the powers of national regulatory authorities and creating an independent organization for natural regulators cooperation.

5.3. Cooperation of Regulatory Authorities in the Energy Sector

Even though the internal market for energy has developed significantly, there are regulatory issues to be solved, particularly on cross-border issues. Commission-initiated self-regulatory forums like the Florence (electricity) forum and the Madrid (gas) forum have been working to bring the respective stakeholders together in order to strengthen cooperation. In addition, an independent advisory group, called the "European Regulators Group for Electricity and Gas" (ERGEG) was established by the Commission in 2003 from representatives of the national regulatory authorities. (ERGEG 2007)

ERGEG activities have advanced the completion of the internal market in gas and electricity by issuing non-binding guidelines and addressing recommendations and opinions to the Commission. Nonetheless, the initiation of self-regulatory forums and setting up of ERGEG has not resulted in the real progress towards the development of common standards and approaches that are needed to create functioning cross-border and regional markets, and ultimately, a European energy market. The present decision making process within ERGEG usually requires the agreement of 27 regulators and more than 30 transmission system operators to reach agreement, which has not lead to real decisions on the difficult issues. (ERGEG 2007)

At moment, the grid codes under which electricity companies must operate, differ greatly between Member States and often even within a single Member State. The grid codes need to undergo a process of convergence and then harmonization if the objective is to truly create integrated energy markets in the EU. In order to realize an independent organizational body with appropriate powers to support cooperation and development of energy markets, the creation of a more powerful network of national energy regulators is therefore under consideration. (ERGEG 2007)

5.4. Functions of the proposed Agency for the Cooperation of Energy

The proposed regulatory authorities' cooperation agency would have the following functions at European level: In order to improve the handling of cross-border situations, the agency would provide a framework for national regulators to cooperate. The agency would establish procedures for cooperation between national regulators, in particular concerning the exchange of information and the sharing of competence where more than one Member State is involved. (COM 2007-530; COM 2007-531)

The second duty would be regulatory oversight of the cooperation between transmission system operators. The agency would assume responsibility for monitoring and reviewing the activities of the European Network of Transmission System Operators for Electricity and of the European Network of Transmission System Operators for Gas, including in particular their investment plans, and in the preparation of technical and market codes. (COM 2007-530; COM 2007-531)

With regard to the technical and market codes, the agency would be authorized to ask transmission system operators to revise their drafts or to deal with specific issues in more detail. In addition, the agency would be able to recommend that the Commission make these codes legally binding, in case voluntary implementation should prove to be insufficient or not suited to certain issues. In addition, the agency would be able to take specific decisions on individual technical issues and have a general advisory role concerning market regulation issues with regard to the Commission. Moreover, the agency could issue non-binding guidelines to disseminate good practices among the national regulators. (COM 2007-530; COM 2007-531)

5.5. Long-term supply contracts

Bilateral contracts help energy intensive industries obtain more predictable energy prices. However, such contracts contain the threat to open competition by closing the downstream market of the supply chain and thus hindering customers from changing their supplier. In order to reduce insecurity on the market, the Commission intends to provide guidelines on whether such bilateral long-term contracts are in compliance with EC competition law. (COM 2007-528; COM 2007-529)

6. ENERGY TRANSMISSION AND DISTRIBUTION

The functioning of electricity transmission and distribution are inseparable from the functioning of electricity markets. Modern societies are increasingly dependent on undisrupted electricity supply. The most significant societal factor influencing the development of power transmission and distribution is the change of community structures and consumption structure. Transmission and distribution infrastructure is also challenged by the changing power generation structure, which is driven by, among other matters, the rise of distributed generation technologies and renewable energy sources. (Vajjhala et al. 2008)

Future uncertainties in electrical networks are numerous: availability and production of primary energy; liberalized trade, inducing changes in power transmission flows, intermittent power supply from distributed generation units, regulatory frameworks and investment incentives for new innovations. Redesigning electrical networks in a way that responds to these challenges calls in for substantial investment. (Kumpulainen et al. 2006)

The importance of new network solutions is emphasized in improving security of supply. As the society develops, location of new electrical power utilities/generation plants/(appliances) becomes more challenging than earlier. This calls for introduction of new innovative solutions and measures. In addition, environmental and landscape impacts of network operations receives closer attention for the whole lifecycle of the equipment. (Kumpulainen et al. 2006)

At the same time, consumption preferences of electricity users are changing. Regardless of energy efficiency measures, electricity consumption in homes and service sector is likely to increase. Electricity will be used to substitute for other energy uses, in particular those harmful to the climate. Heat pumps and electric cars will affect how distribution network is used. Importance of energy efficiency will rise to a significant level and the role of renewable energy sources will be given emphasis to. Interest towards small-scale power production will increase, as will the number of heat pumps on heating homes. Due to the new ways of consuming, storing and producing electricity, estimating energy demand will become more complicated, which in turn increases uncertainty in network business. Subsidies directed e.g. to renewable energy, such as feed-in tariff, may cause pressure to raise the network tariffs. (Kumpulainen et al. 2006)

The architecture of European power networks has over the decades developed to serve an infrastructure, where large generation facilities are located far from points of electricity consumption. Because electricity generation currently is for the most part based on fossil fuel facilities, the infrastructure for transporting both fuel and power has been developed accordingly. However, as European energy supply is now anticipated to shift towards low carbon sources, the infrastructure will also evolve. Renewable energy has only recently emerged as a policy and technology priority, and electrical networks are central to meeting goals for new development. (Kumpulainen et al. 2006)

Transmission and distribution networks are indispensable part of renewable energy infrastructure. The significance of access to network for renewable energy is widely understood. However, it is helpful to bear in mind that dedicated renewable energy quotas and other steering measures are policy instruments, and the planning of such instruments is typically not based on assessment of availability of transmission and distribution capacity or assessment of technological or economic renewable energy potential. Therefore, renewable energy generation and power delivery are not usually connected in policy planning as they implicitly are in project planning. (Kumpulainen et al. 2006)

For renewable energy facilities, such as wind farms, where operating costs are typically low and capital costs, including transmission, are often a significant component of total project costs. In addition, as renewable energy resources are often located in remote locations, greater reliance on renewable electricity generation is bound to result in a geographic shift in the location of generation capacity. On the other hand, adequate existing transmission access may act as a driver of early large-scale, grid-connected renewable energy development. As the electric power sector shifts toward greater use of renewable resources, transmission policies and renewable policies should be evaluated together. (Kumpulainen et al. 2006)

6.1. Restructuring and Unbundling of Transmission from Trade and Generation

Existing legislation requires both legal and functional unbundling of transmission and distribution from trading and generation operations. On European Union level, legal and functional unbundling only concerns transmission system operators and large distribution system operators serving more than 100 000 customers. EU member states have followed this requirement by applying various organization structures. Many of member states have established completely separate enterprise for network operations, while some others have established a legal person that is part of the integrated enterprise.

Three kinds of problems may arise, if network operator is a legal entity within an integrated company. Firstly, the transmission system operator may treat its affiliated companies better than it would treat competing third parties. Integrated companies may use network assets to make entry more difficult for competitors. Legal unbundling does not solve the conflict of interest within integrated companies, whereby the supply and production interests aim to maximize their sales and market share while the network operator is obliged to offer non-discriminatory access to competitors. Secondly, non-discriminatory access to information cannot be guaranteed under the current unbundling rules, as there is no effective means of preventing transmission system operators releasing market sensitive information to the generation or supply branch of the integrated company. (COM 2007-528)

Third problem is that integrated companies have distorted investment incentives. Vertically integrated network operators have no incentive for developing the network in the overall interests of the market. Quite the opposite, they have an inherent interest to under-invest in new networks when this could benefit their competitors and bring in new competition. Instead, the investment decisions made by vertically integrated companies tend to be biased to the needs of own sales companies. This undermines the EU's competitiveness and its security of supply and prejudices the achievement of its climate change and environmental objectives. (COM 2007-528)

6.2. Cooperation of transmission network operators in Europe and Nordic Countries

Market harmonization presumes effective cooperation between transmission system operators, in addition to an unambiguous and secure regulatory framework, including coordination of regulatory actions. This presumes that rules and procedures governing access to network to be unified, and information and data exchange between TSOs to function effectively and investment in cross border transmission capacity to be closely coordinated. Gas and electrical transmission system operators are already engaged in voluntary cooperation within currently existing structures such as ETSO (European Transmission System Operators), GTE (Gas Transmission Europe), UCTE (Union for the Coordination of Transmission of Electricity) and EASEE-Gas (European Association for the Streamlining of Energy Exchange). (COM 2007-528)

Voluntary cooperation is limited by lack of legal validity, enabling countries according to their deliberation to withdraw from common technical standards and developing power and gas network connections and coordinating network operations. Three kinds of gaps exist regarding development of market and technical rules: the present rules do not cover all sectors that need to be harmonized; national rules are not compatible, and rules are either not legally binding or their execution cannot be monitored. Difficulties in coordinating development of electric and gas network connection and operation are displayed in trading limitations and delivery interruptions. It has been therefore proposed that transmission operators intensify their cooperation in several central areas. (COM 2007-528)

The Nordic infrastructure of electricity transmission and distribution is relatively progressive, providing a solid ground for further development. The main areas are network operation control, condition monitoring, demand side management, measurement technologies and related data exchange. Nordel is the cooperation organization of Nordic transmission system operators, aimed at advancing seamless cooperation in the Nordic electricity market area as a part of North-East European electricity markets, as well as maintaining high level of security and reliability in the Nordic power system. (Nordel 2007)

In the Nordic countries, electricity production systems differ greatly from one country to another, partly due to historical reasons and partly owning to the fact that the national systems are subject to different legislation and to supervision by different official bodies. The purpose of the Nordic Grid Code is to accomplish coherent and coordinated Nordic operation and planning practices between the national transmission system operators, to establish the favourable conditions for development of a functioning and effectively integrated Nordic power market. The Nordic Grid Code governs technical cooperation between the transmission system operators in the interconnected Nordel countries: Norway, Sweden, Finland and Denmark. The Code concerns the transmission system operators (TSO's) functioning in the operation and planning of the electric power system, in addition the market participants' access to the grid. The Nordic Grid Code lays the foundation for technical rules governing the cooperation of the Nordic transmission systems operators and is a step towards the harmonization of present national rules. A central objective is to develop a common understanding of satisfactory operational reliability and quality of delivery in the Nordic power system. A new element in the Code since 2007 is set of regulations on connecting wind turbines in the transmission system. (Nordel 2007)

6.3. Challenges in developing power transmission and distribution

Electricity distribution business has undergone significant changes over the past decades, and the restructuring of the industry is still in progress. While EU legislation requires unbundling of distribution system operators serving more than 100 000 customers, in Finland, where unbundling has advanced further, legal unbundling of network operations are required when energy transmitted in a distribution network exceeds 200 kWh/a. According to Finnish legislation, all electrical networks below 100 kV voltage level are defined as distribution networks. The prevalent distribution voltage levels are 0.4 kV and 20 kV. (Energiamarkkinavirasto 2008)

Information societies of today are highly dependent on reliable electric power systems, and the functioning of the distribution networks largely determines the availability of electricity within a society. In addition, the voltage quality at customer supply terminals is determined by the characteristics of distribution networks. (Kumpulainen et al. 2006)

Strong driving forces in distribution business appear to be regulation, the changes in owners' profit objectives, organizational developments, and technological innovations. Regulation has significant impact on the overall development of the industry because companies tend to adapt to their operating environment, aiming to optimize their performance under a given regulatory regime. (Hänninen et al. 2006)

As energy industry has become increasingly competitive, both private and municipal owners of distribution companies are now considering the commercial interests in electricity distribution alongside their public service obligations. Therefore, ensuring that electricity distribution business remains an attractive investment object is essential for maintaining reliable electric power systems. (Hänninen et al. 2006)

While electricity distribution companies nowadays experience competition, being a regulated industry makes electricity distribution business differ from most conventional commercial businesses. The major difference is that in the regulated industry a single driving force, regulation, plays an essential in determining the operational framework of the regulated sector. Electricity distribution is an industry with long asset lifetimes, typically of 30–50 years. As today's decisions have such far-reaching impacts, regulation has an exceptionally influential position regarding the future of electricity distribution. (Hänninen et al. 2006)

Regulation models, on the other hand, are typically in place approximately 3–5 years on average. Further, regulation even has power to shape other driving forces of the sector, e.g. by either promoting or prohibiting organizational and technological developments. Therefore, understanding the long-term consequences of any regulatory actions is crucially important. As regulation strongly directs the development of the distribution sector, clear definition of the long-term strategic goals of regulation and sound understanding of their practical implications are called for. (Hänninen et al. 2006)

Finally, the aging distribution networks all over the western world will soon require extensive refurbishment programs. In the near future, the question how to rebuild the networks will be of high relevance. Underlying factors of the need to renovate distribution networks in the sparsely habited areas of Finland involve aging of the network and increased expectations for supply reliability, in addition to political steering aimed at expanding distributed and renewable electricity generation. At the moment, medium voltage networks are the most vulnerable part of distribution system, their faults causing most of the duration of interruption experienced by customers. Over 90 % of the interruptions experienced by the customers are caused by faults in distribution networks. Moreover, about 90% of the 140 000 km medium voltage distribution network in Finland consists of open wire lines, that are subject to disturbances caused by weather, such as storms and thundering. Climate change is believed to increase occurrence of storms and failure frequency of overhead lines. (Hänninen et al. 2006)

Therefore, a key question is how to promote innovations in the electricity distribution sector in the long-term. The need for refurbishing the existing electricity distribution networks provides a chance to adopt new technologies in the sector. At present, as EU policies strongly promote new and renewable technologies, and the new Finnish national climate and energy strategy foresees reducing energy consumption and strong increase in the use of renewable energy, this is particularly important. (Hänninen et al. 2006)

6.3.1. Future grids

The future vision adopted by the European Commission is that distribution grids will become active and will have to accommodate bi-directional power flows. The European electricity systems have moved to operate under the framework of a market model, in which generators are dispatched according to market forces and the transmission grid control centers undertake an overall supervisory role, including responsibilities on active power balancing and ancillary services such as voltage stability. The primary role of distribution networks in delivering energy to end-users, on the other hand, has changed little. Distribution networks tend to be radial with mostly unidirectional power flows. (Kumpulainen et al. 2006)

Future models for the electricity grids have to meet the changes in technology, in the values in society, in the environment and in commerce. Thus, security, safety, environment, power quality and cost of supply are all being examined in new ways and energy efficiency in the system is taken ever more seriously for a variety of reasons. (Kumpulainen et al. 2006)

European and national measures set binding obligations for low carbon power production, new and old renewable energy technologies and efficient utilization of heat. Energy policies of the European Union strongly encourage the development of distributed electricity generation and strive to realize and progressive network infrastructure. The starting point for these aims is that application of new network technologies are considered critical for transforming the European electrical transmission and distribution networks and successfully managing the forthcoming power sector challenges. Among other measures, this includes network technologies that increase power transmission and reduce losses, hence improving efficiency of generation and supply, and utilization of power electronics that improve supply quality. (Energiamarkkinavirasto 2008)

6.3.2. Distributed generation

Distributed generation is generally understood as electricity production that is located in proximity of point of demand and connected to distribution network. Distributed generation effectively changes the operation of distribution network, even if microgrids are not in question. Instead of the present, unidirectional power flow, the flow in the network would be bidirectional and depend on momentary output of local generation units. Distributed generation units can be classified by size into micro generation (2-200 kVA), generation connected to distribution network (0.2–2.0 MVA) and generation connected to regional transmission network (2–20 MVA). Although technologies or fuels are not defined, distribution generation technologies are often identified with utilization of renewable energy sources. (Willis & Scott 2000)

In Finland, relatively small amount of distributed generation capacity has been connected to distribution networks until now. Development of micro and small-scale power generation strongly depends on political decision-making, in addition to development of technologies and energy prices. At present, EU policies strongly encourage distributed generation. Political decisions on European Union level stipulate increasing renewable energy use, which supports distributed energy. In addition, emission trade improves the competitiveness of renewable energy. Challenges from investor perspective lie in maturity of technologies and economic profitability. In electrical power system, increasing distributed generation changes increases complexity of the system. This will set new requirements e.g. for voltage control and protection solutions. (Kumpulainen et al. 2006)

Requirements for distributed electricity generation

The change of the electricity supply structure towards progressively more DG, RES and active grids requires that a number of wider factors be addressed:

- Improvements of security standards in the context of critical infrastructures;
- Integration of both central and distributed generation;
- Integration of innovative technologies into existing grids;
- Harmonization of equipment standards to allow “plug-and-play”;
- Increased funding for large research incentives, including public and private sharing;
- The impact of neighboring electricity systems on the European network;

For electric utilities, distributed generation may appear to reduce energy transmitted through the network and thus income. Therefore, tariff structures need to be revised (more power-based) in order to ensure sufficient resources can be allocated to network maintenance and development. In the long term, however, distributed energy resources can be help improve system reliability and power quality. If the aim is to draw benefits from improved quality and reliability in low voltage networks through increased amount of distributed generation and energy storage, development of microgrids is needed. (Kumpulainen et al. 2006)

Microgrids are low voltage networks that incorporate DG sources with local energy storage devices and controllable loads, such as water heaters and air conditioning. Within the main grid, a microgrid can be regarded as a controlled entity, which can be operated as a single aggregated load or generator, and, given attractive remuneration, as a small source of power or as ancillary service unit supporting the network. (Kumpulainen et al. 2006)

Typical total installed capacity of a microgrid ranges from a few hundred kilowatts up to a couple of megawatts. Larger units are typically connected to transmission grid. Although microgrids mostly operate connected to the distribution network, they are capable of islanding. In case of a fault in the upstream network, a microgrid can automatically be transferred to islanded mode, and be resynchronized after restoration of the upstream network voltage. This feature can help increase reliability of supply in case of large faults. (Kumpulainen et al. 2006)

Technologies enabling Smartgrids

- Active distribution networks, revealing characteristics of today’s transmission grids
- New network technologies that facilitate increased power transfers and losses reduction (e.g. GIL, superconductivity, high operating temperatures, FACTS technologies, etc.)
- Wide deployment of communications to enable grid automation, on-line services, active operation, demand response and DSM
- Power electronic technologies for quality of supply
- Stationary energy storage devices.

Superconducting hydrogen-electricity grid - The grid of the future?

On August 14, 2003, electricity failed in New York City, plunging 48 million people throughout the northeastern U.S. and Ontario into a night of darkness. Even more extensive blackout affected 56 million people in Italy and Switzerland a month later, calling attention to pervasive problems with modern interconnected electrical networks. The increasing pressure on existing high-voltage transmission grids and recent large power outages in the U.S. and Europe has brought idea of a superconducting grid into the spotlight again.

Super Cable is a superconducting conduit cooled by hydrogen that can simultaneously deliver electrical power and hydrogen fuel. The cable contains a pair of DC superconducting wires at +/- 50 kV carrying 50 kA, a current far higher than in a conventional wire. Such a cable could carry approximately 5 GW over several hundred kilometers at nearly zero resistance. Since the cable carries hydrogen as its cryogenic coolant, it has the double advantage of transporting energy in chemical as well as in electrical form.

Boosting renewables and hybrid vehicles

Such a hydrogen-filled “SuperGrid” would serve also as a vast energy storage. It would enable the transport of large amounts of electrical power from remote renewable or nuclear energy power stations. Power stations could also operate an electrolysis plant to produce hydrogen. The intermittent output of renewable energy power stations could be compensated by a shift in the electricity/hydrogen blend produced. Super Grid could also dramatically reduce fuel costs for a future transport sector based on electric- and hydrogen-powered hybrid vehicles.

Safety, reliability and investment cost are barriers

A prototype of Super Cable still has to be built. Existing nuclear, hydrogen and superconducting technologies, supplemented by selected renewable energy, provide all the technical ingredients required to create a SuperGrid. A major technological challenge is ensuring the environmental safety and the reliability of the grid when a Super Grid cable fails. Moreover, the explosive potential of hydrogen requires an absolute hermetic seal of the line. Another barrier to overcome is that the investment costs will probably exceed the amount and timescale that is attractive to private investment. Mustering the social and national resolve to create it may be a challenge. However the benefits would be considerable.

7. SUMMARY

Overall, it can be stated that the future of energy consumption and production can develop towards various directions. Different energy scenarios offer certain aspects of future development, but are always tied to their own presumptions, predefined research targets and the material available and thus are not always entirely comparable. They do however give ideas of the future of energy consumption and production likely to be, if no measures are taken to alter it, and then, alternative futures.

In this report, global energy scenarios have been covered, with the overview of the most well known and recently published scenarios. Major economies in the world, whose development will most likely have a huge impact on other countries and especially Finland, have been introduced and include China, India, Russia, the United States of America and also an intergovernmental organization, the European Union. Finnish development in regards to energy policy goals and strategies presents the path, toward which the current policy makers are leading the Finnish energy consumption and production. Also changes in Finnish regional structure, transport and the way of living are considered as factors, which in their part influence the state of the future, as far as energy matters are concerned.

Estimations of the energy resources and their potentials are an indication of the options available to the energy production sector. Different energy technologies with the focus on their impact on climate and the directions that the technology developments are expected to take in the future, offer seeds for thinking about the future of the energy production. Fossil fuels: oil, coal and natural gas, nuclear power and renewable energies, such as solar energy, wind energy, ocean energy and bio energy have been introduced as technologies available as well as carbon capture and storage technologies, energy storage in general and hydrogen and fuel cells technologies with the known applications for the technologies.

In addition, the development of energy markets has been viewed, with the possibility of liberalizing further the electricity and gas markets in Europe. The development of market regulation and the cooperation amongst the regulatory authorities in the energy sector and then the functions, which such regulatory authorities would have on European level, if energy markets were to consist of the whole EU, have been presented in this report.

Related to the functioning of energy markets are also the energy transmission and distribution. Challenges and uncertainties in electrical power generation are numerous and therefore it is beneficial to ponder the possible future energy production patterns to improve the network infrastructure accordingly. Legal and functional unbundling in transmission from trade and generation as well as cooperation of transmission network operators in Europe and especially Nordic countries have been viewed in this report as well as the challenges that lie ahead in regards to energy transmission and distribution as well as future models for the electricity grids.

All and all, in this report, different perspectives on possible future developments have been introduced, with the purpose of giving ideas of the ways that the future might look like. The information given in this report can be helpful in the scenario making process, similar to the one in progress instigated by Finnish Energy Industries (Energiateollisuus ry) and implemented by Turku School of Economics, Finland Futures Research Centre. Report will then offer certain options and possibilities for the future and it can be used at the different stages of the future process by the participants involved in it.

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