Energy resources and their utilization in a 40-year perspective up to 2050

A synthesis of the work done by the Energy Committee at the Royal Swedish Academy of Sciences

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Executive summary

Global trends in energy supply and consumption are unsustainable. The major energy carriers, the fossil fuels, besides being depleted, cause severe damage to environment and health. But the energy demand by a growing world population has to be satisfied. By 2050 major changes of the global energy system have to be implemented, and especially the use of fossil sources of energy must be reduced to a minimum. The greatest potential for increased supply of non-fossil energy up to 2050 are in the first place to be found in the already established power sources, hydro, nuclear, wind and bioenergy. Among other renewable energy sources it seems very likely that solar energy will also be a major provider of electricity by 2050 when also more should be known about the potential of water waves, now at the demo stage. Other energy alternatives still on the research level include artificial photosynthesis, 4th generation nuclear fission reactors, fusion energy, hydrogen as an energy carrier. In addition, totally unexpected discoveries and solutions may emerge out of research and science. In parallel to a changeover to non-fossil energy, a more efficient use of energy must be achieved. For this, increased use of electricity and more efficient heating and cooling systems are key elements.

Bearing in mind that the major portion of a growing global population needs to improve their well-being, it is hard to see how the energy can be reduced before 2050. However, the fossil energy must decrease. According to the Energy Committee's studies, non-fossil energy could increase from current 30 000 to 80 000 TWh. The fossil energy is derived, using forecasts for oil and gas reserves, and the amount of coal production is taken to be consistent with the two degree goal. The result is an increase of energy supply from 140 000 to 170 000 TWh where 90 000 TWh (54%) is fossil energy to be compared with the 2007 figure of 110 000 TWh (80%). In these projections, electricity increases from 20 000 to 45 000 TWh because it is produced by all the renewable. Electricity has a high exergy value and can be used much more efficiently than a corresponding amount of thermal energy. Below are summarized the main results of the Energy Committee's studies.

Energy from biomass. Bioenergy will increase in importance, but it competes for raw materials with the food-, paper-, and wood - industries. The two major constraints on biomass use are related to maintaining biodiversity and providing food for a growing world population. Biodiversity is threatened by extensive monocultures and by deforestation. Primary biomass from forests should be used for other purposes than burning it and primary agricultural production should be used to feed people before making biofuels. The major biomass option should be residues from forestry and agriculture together with organic wastes. These biomass options have a potential for providing as much bioenergy as is currently traded, implying a doubling from current 15 000 TWh per year up to about 35 000 TWh.

Energy from moving water. Hydropower is presently the most important source of renewable power generation. Conventional hydropower production amounts to just under 3 000 TWh worldwide. The world's total technically feasible hydropower potential has been estimated to be about 16 500 TWh/year, while the economically feasible part of that potential is estimated to be around 9 500 TWh/year. Up to 6 500 TWh of additional renewable power would thus, in theory, be available for further hydropower development. However, in reality, there are many social-ecological, safety, legal and policy constraints and concerns that need to be accounted for. Most of the hydropower development potential is found in developing countries, whereas for example the EU already has exploited most of the readily accessible resources.

Solar energy. Direct sunlight is potentially the most powerful renewable energy source. The technologies are developing rapidly. The main constraints are high costs and its intermittency. With integrated heat storage and hybrid technology Concentrating Solar Power (CSP) has the potential to provide significant amounts of base load power, but will be feasible only in areas with much direct sunlight, i.e. in or close to desert areas. Spectacular efficiency increases of Concentrating PhotoVoltaics (PV) devices will increase the importance of PV systems. Photovoltaic and heating panels – providing power to private houses, shopping centres etc. will grow rapidly, especially if economic support systems are introduced.

Nuclear energy. According to the World Nuclear Organization, there are at present 438 reactors in operation in 30 countries. These provide 3 000 TWh,15 % of world electricity and 30 % within the EU. Totally 52 reactors are under construction, 143 are being planned and 344 are being proposed in 43 countries. Together these reactors have a potential of producing 7 000 TWh electricity. A new generation – Gen III – of reactors is under introduction. It relies on the experience gained from existing reactors, and brings in new improvements particularly on safety systems. Also the back end of the fuel cycle will be improved to meet concerns on waste management and proliferation risks. The next generation of nuclear - energy systems, the so-called Gen IV, are expected to have advantages that include sustainability, reduced capital costs, enhanced safety, minimal generation of waste, and further reduction of the risk of weapons - materials proliferation. In addition to electricity production, Gen IV reactors should also be able to produce hydrogen, heat and desalination of seawater.

Wind power Wind power is rapidly increasing. The energy provided in 2008 was 260 TWh corresponding to 0.2 % of global energy consumption and 1.3 % of global electricity supply. The Global Wind Energy Council (GWEC) Outlook 2008 lists three scenarios - reference, moderate, advanced - for 2020 and 2050. According to the moderate scenario, wind power will provide 1 740 TWh by 2020 and 4 818 TWh by 2050. Predictions of the future penetration of wind power into the electricity market are critically dependent on a number of policy measures and will be especially influenced by climate driven energy policies. Very large investments will also be necessary as is shown by the IEA's Blue Map Scenario which includes 5 000 TWh wind electricity by 2050 at a cost of USD 700 billion. Initially the balancing of the intermittency of wind power will be done by fossil fuels. In a fossil – free future. other ways of balancing must be found. For example large scale pumped - storage systems, demand management and large continental and intercontinental power networks may develop into cost effective options. Later, a combination of concentrating solar power with heat storage and wind power may further increase the capacity of wind power.

Fossil fuels It is very likely that the world in the near future will face an era of limited resources of easily accessible conventional oil. By 2050 the oil supply will definitely be smaller than at present, while alternative hydrocarbon resources in form of so-called unconventional oil are expensive to produce, and exploitation involves significant environmental problems. Coal reserves worldwide are estimated to last over 200 years, but coal power leads to the biggest CO_2 emissions per unit produced energy among hydrocarbons. The consumption of natural gas, which gives rise to less carbon dioxide than coal or oil, is expected to grow and gas reserves are estimated to last for some decades. By the mid-century, coal is expected to be the major fossil energy provider with 40 000 TWh whereas gas and oil together will provide 50 000 TWh.

Energy resources and their utilization in a 40-year perspective, up to 2050.

1. Introduction

To avoid acute economical, social and environmental problems worldwide, we need a global energy approach, with the widest possible international cooperation. Considerably increased resources for R & D on alternative non-fossil energy sources, as well as on efficient and sustainable use of energy, particularly electricity, are necessary. In order to develop a sustainable energy system beyond the fossil fuel era, we need a full system analysis of the energy sector based on realistic time scales.

Sustainability and environmental considerations are essential for any future energy system. Readily available, inexpensive and environment-friendly energy provides the foundation for economic growth and prosperity and it is of particular importance that the developing world is included when restructuring the whole global energy situation. Life cycle assessments and sustainability analyses will help in coping with many alternatives.

As pointed out in the recent World Energy Outlook 2008 by the International Energy Agency (IEA) current global trends in energy supply and consumption undoubtedly are unsustainable, and very drastic measures are required to limit the use of fossil sources of energy. According to the Outlook, energy efficiency, renewables, biofuels, nuclear energy, carbon capture and storage (CCS) are key elements for combating the effects of fossil fuel burning.

The two decades considered in the outlook seem short for major changes in supply and use of energy. Implementing new energy-efficient schemes in transportation and buildings will take time. Likewise, replacement of fossil fuels by electricity, which is the main output from the alternative energy sources, implies large infrastructure changes. To avoid a squeeze situation, it seems therefore more appropriate to set 2050 as a target time, when major changes have to be implemented.

Predictions and scenarios of future climate, environment and human health vary within wide limits. Despite the uncertainty as to what is going to happen, we can no longer postpone our actions. Countermeasures must be prepared now since the consequences will become worse and enormous as time goes by - shift in climatic zones, melting glaciers and sea ice, sea level rise, acidification, lost biodiversity, more weather extremes and health problems etc.

The IEA 2008 Blue Map Scenario [1] assumes large investments in non-CO_2 emitting energy sources for the period 2010-2050 resulting in an annual global production of 19 000 TWh of renewable energy by 2050. The scenario includes new generation capacity comprising 2 200 fossil plants with carbon sequestration, 1 300 nuclear plants, solar panels on 8 600 km^2 land and 700 000 large wind turbines producing 5 000 TWh annually by 2050. A global revolution is needed in the ways that energy is supplied and used according to the Agency.

In spite of all efforts to supply alternative energy, fossil fuels will most likely provide at least half of the global energy by 2050 which in absolute terms imply as much as at present. CO_2 will therefore continue to accumulate in the atmosphere unless drastic measures are taken in order to sequestrate it. Techniques already exist for removing the produced CO_2 either at their sources (CCS) or by extracting it directly (“vacuum cleaning”) from the atmosphere.

The greatest potential for an increased supply of non-fossil energy up to 2050 are in the first place to be found in already established sources like hydropower, nuclear energy, wind energy and bioenergy which have a potential for a doubling of their current supplies up to 2050. There are however drawbacks that need to be taken into account, such as the waste and proliferation risks with nuclear energy, the intermittency of wind power and the many factors that constrain bioenergy production, for example environmental and biodiversity reasons, competition with food and other biomaterials.

In parallel to a gradual changeover to non-fossil alternative sources, a more efficient use of energy must be achieved. Increased use of electricity and more efficient heating in the industry and housing sectors are key elements.

An emerging renewable source with great potential is solar energy, in particular concentrating solar power (CSP) systems; a hot liquid is produced and stored so that vapour can be extracted in order to actuate turbines for generating electricity round the clock. Hence, the intermittency connected with most renewable sources can be handled. By 2050 solar energy very likely will be a major option for electricity production.

By 2050 more should be known about the potential of water waves, an alternative renewable energy option that is now at the demo stage. Other alternatives still on the research level include artificial photosynthesis, hydrogen as an energy carrier, 4th generation nuclear fission and fusion energy. In addition, totally unexpected discoveries and solutions may emerge out of research and science.

1.1 Energy technology perspectives 2008 - Scenarios and Strategies to 2050, Book published by the International Energy Agency, 2008.
http://www.iea.org/W/bookshop/add.aspx?id=330

2. Resources. The sun provides power for most renewable sources; moving air, moving water, biomass and direct solar radiation. A small portion of the water movement is generated by the gravitational forces between the moon, earth and sun. The solar constant, 1.35 kW/m^2, defines all solar radiation intercepted by the earth outside the atmosphere. Only about half of the incident power reaches the surface of the earth where it maintains biological processes, creates movements and heat. The solar power reaching the earth is about 6 000 times the current anthropogenic power generation of 14 TW.

There is also a lot of stored energy available. The interior of the earth stores enormous amounts of geothermal energy. The heat in the uppermost 10 km of the Earth's crust is 50 000 times greater than the energy content of all oil and natural gas resources according to the Earth Policy Institute [2]. The crust also contains fossil fuels of solar origin as well as lithium, thorium and uranium that can fuel nuclear reactors. The sea contains a lot of uranium and deuterium, resources useful for nuclear fission and fusion reactors. These sea resources correspond to 1 billion respectively 150 billion years of powering the world with energy, longer than the sun shines. There is no lack of energy resources!

2.1 Lester R. Brown et al, Time for Plan B – Cutting Carbon Emissions by 80% by 2020, Earth Policy Institute, 2008.
http://www.earth-policy.org/datacenter/pdf/80by2020notes.pdf

3. Life Cycle Analyses. Land use change, material shortage, environment pollution, accumulation of greenhouse gases, accumulation of nuclear waste are examples of unwanted consequences of energy generation. To take the various constraints into account, Life Cycle Analyses (LCA) are usually adopted. These analyses include costs for a given generated energy unit from the cradle to the grave. Private costs are directly connected to the energy generation processes and external costs are estimates of the health and environmental effects.

One of the larger independent investigations made on costs of generating electricity in Europe is the EU project CASES (Cost Assessment of Sustainable Energy Systems), which started in 2006 and ended in 2008. 26 partners in 20 countries participated [3.1]. The project gives the cost of the complete life cycle for producing energy in different ways.

- Private costs have been calculated with the *Average Levelized Generating Costs* (ALLGC) methodology. The generation costs (in EuroCents/kWh) are calculated on the basis of net power supplied to the station busbar, where electricity is fed to the grid. This cost estimation methodology discounts the time series of expenditures to their present values in 2005, which is the specified base year, by applying a discount rate of 5%. The levelized lifetime cost per kWh of electricity generated is the ratio of total lifetime expenses versus total expected output in KWh. The total lifetime expenses include the value of the capital, fuel expenses and operation and maintenance expenses, inclusive the rate of return equal to the assumed discount rate of 5%.

The external costs include the costs of CO_2 abatement effects but do not include serious nuclear accidents and the risk of nuclear weapons proliferation. However, even if there is a high level of public concern about the possibility of such an accident, the experts assign very low probability of the kind of failure that would produce a severe accident for the type of reactors used in Western Europe. The methodology adopted to estimate the emissions of pollutants for energy generation subdivides the process of electricity generation into four sub-processes representing the life cycle stages: power plant construction, fuel supply, power plant operation, power plant dismantling. Figure 1 shows the calculated costs for a selection of electricity generation technologies.

Another interesting result of LCA analyses is on the resource requirements for different energy sources which have been studied at the Institute of Energy Economics (IER) at Stuttgart University [3.2, 3.3]. Of course the results depend to some extent on the choice of parameters but they give interesting information which helps to assess the sustainability of each source.

3.1 CASES (Cost Assessment for Sustainable Energy Systems), Development of a set of full cost estimates of the use of different energy sources and its comparative assessment in EU countries. Last update September 2008.
http://www.feem-project.net/cases/

3.2 Alfred Voss, Material needed for different electricity sources, Report IER 2005/07, Stuttgart and presentation to the Symposium Energy2050, Stockholm October, 2010.
http://energy2050.se/uploads/files/voss.pdf

3.3 Torsten Marheineke, Lebenszyklusanalyse fossiler, nuklearer und regenerativer Stromerzeugungstechniken, Dissertation 2002, Universität Stuttgart.
http://elib.unistuttgart.de/opus/volltexte/2002/1144/pdf/Dissertation_Marheineke_Torsten.pdf

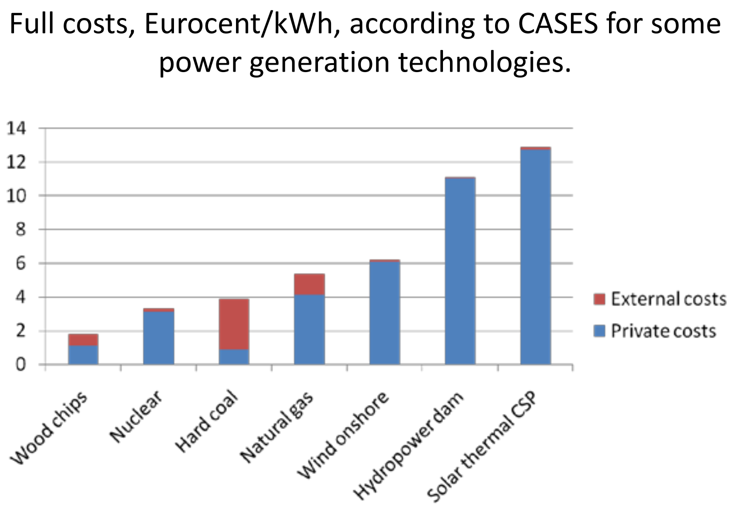

Figure 1. Full costs of selected electricity generation technologies assuming a 5% interest rate. The costs are levelized lifetime costs per kWh of electricity generated. The assumed lifetimes are 35 years for biomass CHP, 35 years for gas and hard coal CHP with extraction condensing turbine, 30 years for solar thermal, 20 years for wind and 120 years for hydropower.

	Iron [kg / GWh_{el}]	**Copper** [kg / GWh_{el}]	**Bauxite** [kg / GWh_{el}]
Hard Coal	**1700**	**8**	**30**
Lignite	**2134**	**8**	**19**
Gas CC	**1239**	**1**	**2**
Nuclear (PWR)	**457**	**6**	**27**
PV Polycryst 5 kW	**4969**	**281**	**2189**
Wind 1.5 MW (5.5 m/s)	**3066**	**52**	**35**
Wind 1.5 MW (4.5 m/s)	**4471**	**75**	**51**
Hydro 3.1 MW	**2057**	**5**	**7**

Sorce: Alfred Voss, Presented at Symposium Energy2050 October 19-20, 2009, Stockholm and Report IER Stuttgart 2005/07

Figure 2. Material needed for different energy sources calculated from data of German utilities in operation 2001 and extrapolated to 2010; Table 6.1 in reference 3.2. The approximate input data are for Installed power/Degree of utilization/Facility lifetime:
Hard Coal-750MW/47%/35years, Lignite-750MW/50%/35years, Gas-780/58%/35years, Nuclear-1470 MW/40years, Solar photovoltaics polycrystalline-5kW/10%/25years, Wind 4.5 Wind 4.5 m/s-1MW/20years, Wind 5.5 m/s-1.5MW/20years, Hydro-3.1MW/90%/60years.

Wind speeds are for 10 m above the ground level.

4. Climate. The increasing atmospheric CO_2 content is beyond any doubts caused by human activity. [4.1]. Exactly how much of the current global warming that should be ascribed to the accumulation of CO_2 and how much that depends on other factors is not easy to quantify. The warming during the last decades has been manifested through high global temperatures, increased sea level rise and increasing melting of glaciers and sea ice whereas the situation concerning inland ice is unclear. The period during which direct global measurements have been made is too short for clear conclusions. Continued satellite based measurements of the global radiation balance during the next decades are expected to improve future climate forecasts and the role of the carbon dioxide. If the most extreme IPCC2007 scenario, 5 --6 degree temperature increase, would occur, consequences would be enormous. The uncertainties are however considerable, especially what concerns the influence of clouds and aerosols and the associated change of solar influx at the earth's surface. Despite the uncertainties of the causes for the climate change, a reduction of the use of fossil fuels must be an essential objective of future energy policy, seeing that the other environmental and health effects of fossil fuels are also full of risks. In figure 3, the CO2 emissions per produced kWh for different energy sources are shown.

4.1 The Scientific Basis for Climate Change, Statement by the Royal Swedish Academy of Sciences, 22 September 2009.

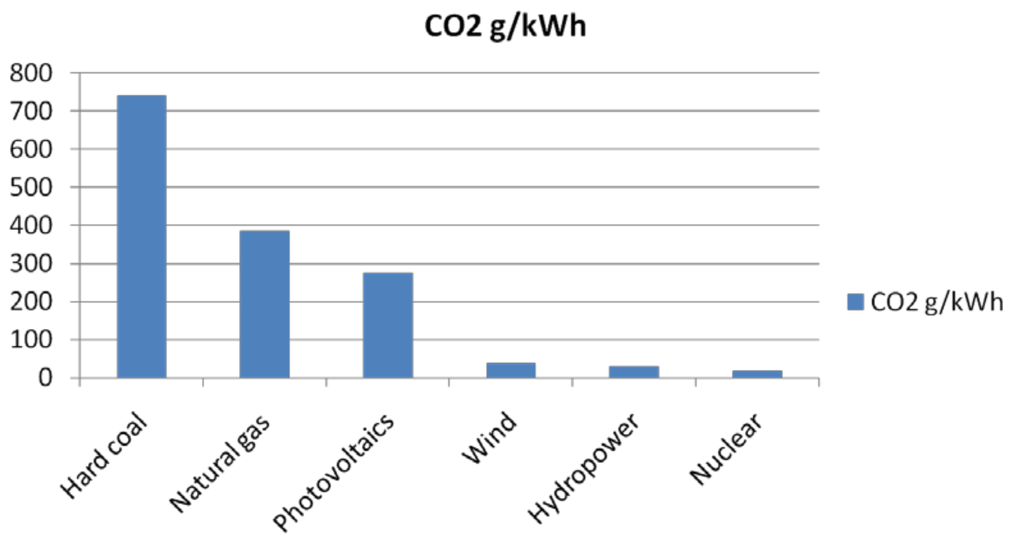

Figure 3. The CO2 emissions calculated in reference 3.3 for common power sources given as gram CO_2 emitted per produced kWh. Input data as for figure 2 except for wind which is calculated for 1 MW and 5.5 m/s.

5. Efficient use of energy. Three forms of energy are being of interest for human needs: light, movement and heat. In the old incandescent light bulbs, only about 1 % of the supplied energy was in the form of light, the rest being heat. Modern energy-saving gas discharge tubes are more efficient and the light produced is about 10 % of the supplied energy. The new generation of light sources based on diodes utilize more than u 50 % of the electrical energy for light production. Generation of movement, for example in a combustion engine of a car, is only 25 % efficient, the rest of the fuel chemical energy being heat. Electrical energy is converted to movement with nearly 100 % efficiency. A heat pump needs 2 - 3 times less electrical energy for production of heat as compared with the heat energy of a fuel. These examples show the superiority of electricity as an energy carrier. Electricity propagates mechanical motion for example from moving water to an electric motor with small losses! Wherever combustion is required, it should be done in large plants which allow for high - temperature operation and efficient removal of undesired waste products. With increasing temperatures, higher efficiencies for conversion of the chemical energy in the fuel to electricity can be reached. The energy of the fuel can be further utilized by combining heat and electricity generation.

Concerning future energy efficiency improvements it is hard to make a general global forecast since the energy situation varies very much from country to country. Developed countries have a completely different situation from developing countries and people in Southern and Northern countries have different needs. There are many different suggestions on how to reduce the energy consumption by large factors [2.1, 5.1]. In theory the developed nations can certainly reduce their energy usage considerably. However, in practice, efficiency measures will take time. Sweden's 4.5 million housings cannot be changed overnight to the standards of passive houses which are well isolated and require a minimum of heat energy. Within the transport sector, changes should be easier to implement more rapidly. since several generations of vehicles will be introduced before 2050.

A study of how much the energy consumption can be reduced in Sweden up to 2050 has recently been completed [5.2]. The study shows that reductions by 33 % for the transport sector and 19 % for the housing and service sector are realistic goals. For the industry sector it was noted that over the last 40 years, the energy consumption has been roughly constant, while the industry productivity increased by more than a factor two. This has been possible thanks to successive improvements of the energy efficiency. If the productivity continues to grow it will probably be difficult to reduce the industry's energy consumption, but if it remains at today's level as much as 20% less energy would be needed by 2050. All in all the total Swedish energy consumption by 2050 may be reduced by between 16 and 23% compared with the present situation. The study shows that there is a lot of inertia in making radical changes in the consumption of energy. Changes will take time!

5.1 Ernst Ulrich von Weizäcker, Amory B Lovins, L Hunter Lovins, Factor Four: Doubling Wealth, Halving Resource Use, First published in Earthscan Publications Limited, UK 1998 and a report to the Club of Rome.

5.2 Energiutskottet, Uttalande av Kungl. Vetenskapsakademiens Energiutskott om effektivisering av energianvändningen i Sverige fram till 2050, Stockholm 3 maj 2010.

6. Energy from biomass. The Energy Committee's studies are summarized in [6.1]. Bioenergy will increase in importance, but it competes for raw materials with the food, paper, and wood industries. The two major constraints on biomass use are related to maintaining biodiversity and providing food for a growing world population. Biodiversity is threatened by extensive monocultures and by deforestation.

At present deforestation, especially of rain forests, leads to a reduced natural carbon capture and storage corresponding to the anthropogenic CO_2 emissions of the whole USA. There are many different causes for the deforestation: increased use of wood for heating, excessive production of biomaterials and removal of forests to get land for for cultivation of soy bean and palm oil. Presently the planet has about 40 million km^2 forest land, 30 million km^2 pasture land and 15 million km^2 crop land. The main priority before any major increase of forests for bio-energy purposes must be to stop deforestation. It is well known that the rain forests in Brazil and in Indonesia are particularly threatened. According to UN FAO statistics, the rate of deforestation between 2000 and 2005 were 0.6% out of a total of 4.7 million km^2 for Brazil and 2% out of a total of 0.89 million km^2 for Indonesia. The average deforestation for the world for the same period was 0.18%. But there are also reforestation of land for example in China, Russia and Sweden. In Sweden reforestation in the order of 10 -20% of the annual growth has been registered continually since the second world war except for a few years in the mid seventies. Figure 6.1 made by Per-Olof Nilsson [6.2] shows how the annual growth of the Swedish forest was utilized during 2004. As can be seen there is room for using logging residues, particularly tops and branches, for additional energy generation and still maintaining the supply to industry and reforestation.

About a billion people are chronically undernourished and these people, as well as an additional 2-3 billion people expected by 2050, need food. Recent estimates of current agricultural production show that it should be sufficient but not much more for the present world population provided the food distribution system is fair. [6.3, 6.4]. Before any massive production of biofuels, all primary agricultural production should therefore be used to feed people. Moreover, decreasing supplies of cheap energy from fossil fuels and limited supplies of water for irrigation. which are prerequisites of today's highly intensive agriculture, may result in lower yields. This will be compensated to a certain extent by modern plant breeding, including genetic modification.

The net energy content of potential global food supply for 2005 was estimated to be in the range 7200-9300 TWh, to be compared with the food requirements, 7100 TWh for the current global population [6.4]. Clearly, very little, or nothing, remains for biofuel from agricultural primary crops. It should be noticed that the industrialization of the agricultural sector led to a significant increase of productivity to reach the present situation, but in recent years the productivity has leveled off. The expansion potential for global agriculture is limited by availability of land, water and energy. Estimates point to that only some 10 per cent increase of agricultural land could be expected [6.5]. A future decrease in supply of fossil energy and ongoing land degradation may also be a risk for the agriculture. Nevertheless, the recent Swedish study [6.4] has arrived at the conclusion that biofuels produced from residues and bioorganic waste theoretically could replace one fourth of the global consumption of fossil fuels for transport.

The uncertainties involved in prediction of future bioenergy production are considerable. The International Energy Agency (IEA) has assessed the potential for generating energy fromBiomass [6.6]. The estimates range between one tenth and three times the world's total energy supply, which is currently 140 000 TWh per year. In a world aiming for a large scale deployment of bioenergy, the potential is assumed to be between 55 000 and 110 000 TWh by using current agricultural land and pasture land, about 17 million km^2. In their most pessimistic scenario forest residues, agriculture residues, dung organic wastes have a potential of about 15 000 TWh which would about double the present bioenergy share of the global primary energy.

Considering the boundary conditions, maintaining biodiversity and securing a sufficient future food supply, the major future bioenergy options are mainly residues from forestry and agriculture together with organic wastes. The numbers given by IEA [6.6] and by Kersti Johansson et al [6.4], suggest that an additional 20 – 25 000 TWh could be achievable under these conditions. An increase of traded bioenergy from some 15 000 TWh up to about 35 000 TWh implies more than a doubling of the present situation and seems to be within reach. The figures will of course vary very much between countries and regions. In a country like Sweden, biomass is already extensively used for energy purposes and a 50 % increase in bioenergy supply may be more realistic than a doubling. What to do with this biomass remains an open question. Several options are being investigated on how to convert cellulosic residues to next generation of biofuels. The most inefficient way of using the biomass is by direct burning. It should be used as much as possible for cogeneration of heat, electricity and second generation biofuels. The use of large plants allow for efficient energy conversion and removal of waste in exhaust gases and ashes. The use of wood in individual households should be avoided for these reasons.

6.1 Karl Fredga et al, Bioenergy – Opportunities and constraints, Energy Committee Report, June 2008.
http://www.kva.se/Documents/Vetenskap_samhallet/Energi/Utskottet/rapport_energi_bio_eng_2008.pdf

6.2 Per Olov Nilsson, Biomass flows in Swedish forestry 2004. Report 23/2006, Swedish Forest Agency.
]

6.3 Sven Kullander, Energy from biomass, Special Topics on Energy Supply and Climate Change: A Physics Perspective, The European Physics Journal, Volume 176, September 2009, page 115.

6.4 Kersti Johansson et al, Agriculture as provider of both food and fuel, Ambio Nr 2 2010.

6.5 Michael Krause, Hermann Lotze-Campen, Alexander Popp, Spatially-explicit scenarios on global cropland expansion and available forest land in an integrating modeling framework, International Association of Agricultural Economists Conference, Beijing, China, August 16-22, 2009,
http://ageconsearch.umn.edu/bitstream/51751/2/Krause_%20et_al_iaae_090630_final.pdf

6.6 Potential Contribution of Bioenergy to the World's Future Energy Demand. International Energy Agency, IEA Bioenergy: ExCo: 2007: 02.
http://www.idahoforests.org/img/pdf/PotentialContribution.pdf

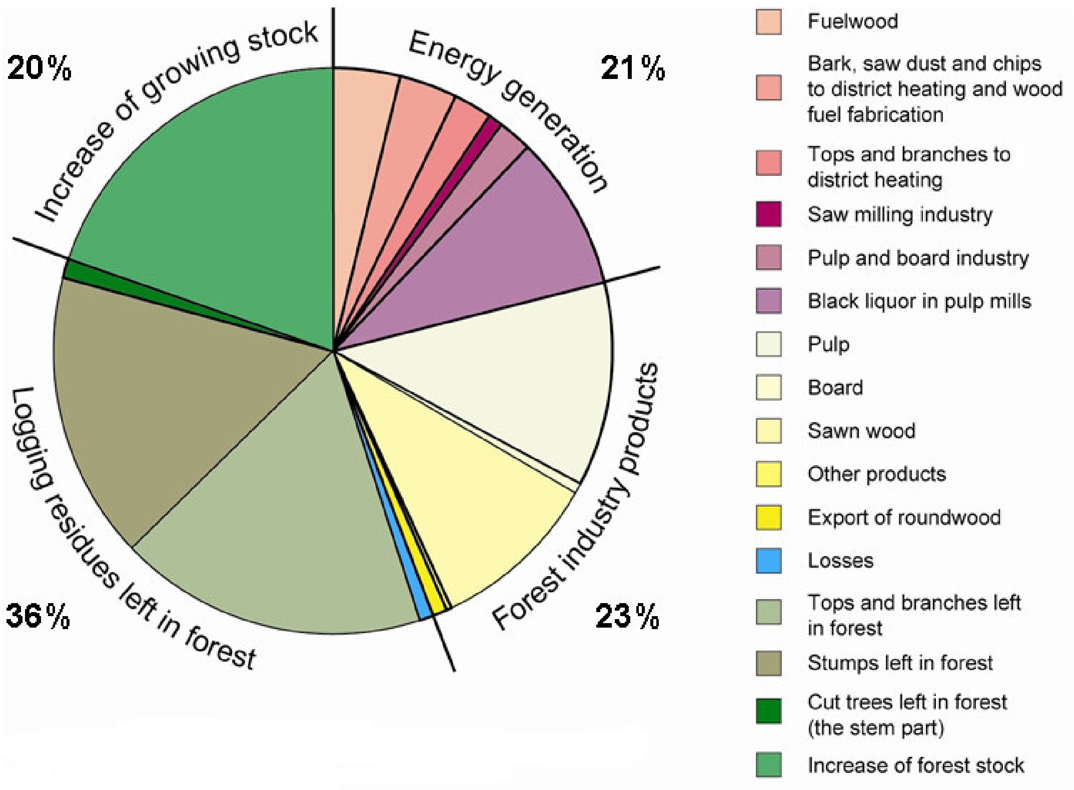

Figure 6.1. Growth, felling and harvest of forest biomass in Sweden subdivided according to end product in 2004. The growth was 75.9 megatons of dry matter with an energy content of 380 TWh. The energy generation was 21% corresponding to 80 TWh. (After P O Nilsson).

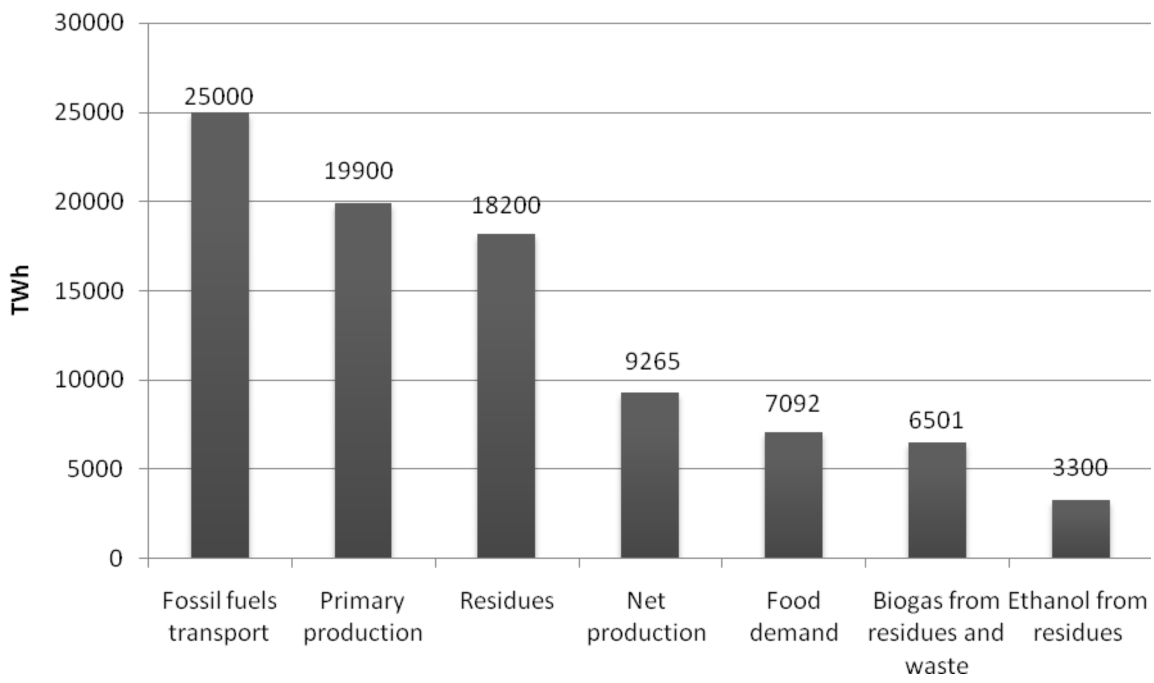

Figure 6.2. Global agricultural production of primary crops and residues and scenarios for biogas and ethanol production compared to present consumption of fossil motor fuels and global food demand. (Kersti Johansson et al).

7. Energy from moving water. Hydropower is a key energy resource. It presently constitutes the most important source of renewable electrical generation. The storage capacity of hydropower offers the operational flexibility needed for quickly responding to fluctuating electricity demands. This improves electricity grid stability and reliability as well as supports the deployment of intermittent renewable energy, such as wind and solar power.

In the most recent world energy assessments with data for 2005, conventional hydropower production was 2 830 TWh and represented 87 % of all renewable power worldwide. The world's total technically feasible hydropower potential has been estimated to be about 16 500 TWh/year, while the economically feasible part of that potential is estimated to be around 9 500 TWh/year [6.1]. Up to 6 700 TWh of additional renewable hydropower would thus, in theory, be possible to exploit according to these estimates. However, in reality there are many social-ecological, safety, legal and policy constraints and concerns that need to be accounted for when assessing the actual possibilities and desirability of further hydropower development. These constraints and concerns remain yet to be rationally weighted into realistic cost - benefit and feasibility assessments, which include also relevant valuation and accounting of the ecosystem services and social-ecological externalities that are affected by and associated with hydropower and its possible alternatives for renewable energy production. The situation is complex and strong political governance is needed to initiate and support the research, development and application efforts that are required for identifying and pursuing a sustainable and rational role and magnitude of hydropower as part of the general policies, strategies and practices for increased production of renewable energy in the future.

Most of the hydropower development potential is found in developing countries, whereas Sweden and the EU already have exploited most of the readily accessible resources. However, also existing dams require modernization and improvements, for safety reasons and for adaptation to expected future climate change. For both new hydropower projects in developing countries and modernization projects in countries with already well developed hydropower capabilities, it is essential to support research and development efforts for enabling increasing hydropower generation and efficiency, while water ecosystem functions and conditions are maintained or improved.

Besides traditional hydropower, less mature technologies for energy production from moving water have large theoretical potential for renewable energy production. From the five different types of existing ocean - energy generation systems: tidal, wave, marine currents, temperature gradients and salinity gradients, only tidal energy has so far reached a mature status of providing electricity commercially in different parts of the world. In 2001, tidal electricity represented only 0.02% of the global renewable electricity production of about 3 000 TWh. This production, 0,6 TWh, is expected to be increased relatively soon by new developments in progress. The estimated global annual theoretical potential is 300 TWh.

Wave energy has a high theoretical potential varying from 8 000 to 80 000 TWh/year. At present, however, only 140-750 TWh is economically exploitable annually with commonly available technological designs. This capacity could rise to 2 000 TWh if potential technological improvements are realized. Even if significant electricity production cannot be expected from non - traditional hydropower in the next few decades, strongly increased research and development efforts are recommended for investigating feasibility and enabling a sustainable use of this renewable energy potential.

7.1 RSAS Energy Committee, Statements on energy from moving water, October 9, 2008.
http://www.kva.se/Documents/Vetenskap_samhallet/Energi/Utskottet/uttalande_energi_vatten_eng_2008.pdf

Figure 7.1 The Three Gorges Dam in China is the world's largest dam, 185 meters high, with an installed power of 18 GW and with 100 TWh electricity production per year. It was built between 1993 and 2006. In order to exploit the full technical-economical potential of hydropower by 2050 new hydropower corresponding to between one and two Three Gorges Dams would have to be built every year!

8. Solar energy. Direct sunlight is potentially the most powerful renewable energy source. In less than an hour, the earth receives the same amount of energy from the sun as is used globally during a year. An area in Sahara of 175x175 km^2 fitted with solar modules (25% efficiency) would be sufficient to generate the present global electricity supply of 20 000 TWh/year. The low energy density of sunlight makes it necessary to optimize the efficiencies of collection and the conversion to electricity.

Utilization of sunlight can be made with a wide diversity of techniques, varying greatly with the physical principles of energy conversion [8.1]. Photovoltaic (PV) techniques are based on the photo-physical properties of materials to create electricity directly from the photons of sunlight. PV cells, usually quite small, are combined to window- size panels, that typically generate between 60 and 200 W in full sunlight, depending on technology and size. Panels can be assembled to systems that vary in size between simply one and several thousand units. Generation of electricity is instantaneous and silent. The dominating technology has so far been cells based on silicon photovoltaics (Si-PV) which make use of similar manufacturing technologies as the electronic industry does. The resource base is enormous since silicon is one of the most common elements in the Earth's crust, but production of Si wafers is today energy and time demanding and has so far been relatively expensive. An alternative to Si cells are so-called thin film (TF) cells. These are made out of much thinner layers than Si-PV and can be produced using less energy and in a shorter time. There are also other interesting PV technologies such as dye-sensitized solar cells (DSSC) and carbon-based conducting polymer PV. These are only in a stage of early research and it is unclear if and when they may enter the market of large scale power production.

PV technologies have shown an impressive exponential growth, approximately 40 % annually during the last decade. Globally, the cumulative installed solar power increased from 6.8 GW in 2006 to 9.2 GW (10 TWh/y) in 2007 of which 52 % is installed in Europe. The trend of rapid increase in global - market volume is expected to continue, but is limited by the annual production capacity which currently amounts to 4 GW. PV installations worldwide are estimated to reach 1 000 GW (1 400 TWh/y) by 2030, with thin film systems increasing their market share from the current roughly 10 % of the total PV market.

The concentrating solar power (CSP) technique is based on the principle of concentrating the sunlight (25-3000 times) before it is absorbed on the collector. The concentrated light can produce heat at high temperatures and drive a thermal cycle (thermal CSP), just as in fossil or nuclear plants, or be aimed at small and efficient photovoltaic cells (Concentrating PV).

The thermal CSP is developed along some different techniques: dishes, towers and troughs. Dishes are units with reflecting mirrors concentrating light on to a small volume of a heat transfer medium, for example an expanding gas, which provides heat to drive a small engine. Tower plants consist of a great number of heliostats (mirrors that follow the sun) reflecting light towards a receiver on top of a large tower. Troughs, or the similar linear Fresnel-mirrors, concentrate the light on receiver pipes. In the tower and trough receivers, air, steam, liquid mineral oil or molten salts is heated. Air and steam can be used directly as working medium in a power cycle, while the heat transfer medium only provides heat for a power cycle. Dish and concentrating PV systems are modular with sizes of about 20-75 kW while towers and trough/linear Fresnel plants generate electricity from a few up to hundred MW. These plants with large central generation have economical benefit from their large sizes and can employ daily energy storage, by keeping a heated medium in large isolated tanks. As thermal storage is more efficient and considerably cheaper than electric storage, this enables a rare opportunity of renewable base-load power.

CSP thermal technologies have developed slowly since the early 1990s but now seem to have entered a strong developmental stage. Today, thermal CSP contributes only just above 400 MW to the global power supply, but new large plants providing altogether 9000 MW are either under construction or at a planning stage. Dish Stirling systems constitute an extreme growth market in relative figures, with only a few demonstration units yet in operation but tens of thousands contracted, adding up to hundreds of MW.

So far, a breakthrough has been limited by the high costs involved and the intermittent nature of solar radiation. The latter factor makes it necessary to ensure that back - up energy sources are available. While global energy prices are rising, the costs for solar energy tend to be decreasing. The cost of Concentrating Solar Power (CSP) technologies is anticipated to become comparable to that of conventional power sources within the next two decades. With integrated heat storage and hybrid technology, CSP has the potential to provide significant amounts of base load power, but will be feasible only in areas with a high input of direct sunlight, i.e. basically in or close to desert areas. Huge infrastructure investments will then be required, including high capacity electricity connections from solar - rich areas to regions with high consumption. In some countries, CSP plants can become a dominant domestic-power supplier, and a provider of electricity for export. The latter would also require long range, high capacity, continental power grids. Recent advances in increasing substantially the efficiency of concentrating PV technology are also very interesting for this development. An efficiency world record of 41.1 % has been reached recently for a sunlight concentration of 454 times onto a three-junction solar cell [8.2].

These PV systems can also be of interest for local small - scale solar energy systems. Such small - scale systems, both photovoltaics and heating panels, will become increasingly important for example in private and public buildings. In these smaller - scale systems, batteries can be used to store the energy.

In its study of solar energy one conclusion out of the Energy Committee's work was that solar technologies are developing rapidly and that before the end of the 21st century, probably within the next 50 years, solar energy can become a major global energy provider [8.3].

8.1 Erik Pihl, Concentrating Solar Power, Report RSAS, April 2009.
http://www.kva.se/Documents/Vetenskap_samhallet/Energi/Utskottet/rapport_energi_sol_eng_2009.pdf
8.2 W.Guter et al, Current-matched triple-junction solar cell reaching 41.1% conversion efficiency under concentrated sunlight, Applied Physics Letters vol.94, pp.223504/1-3, 2009.
8.3 RSAS Energy Committee, Statements on Solar Energy, November, 2008.
http://www.kva.se/Documents/Vetenskap_samhallet/Energi/Utskottet/uttalande_energi_sol_eng_2008.pdf

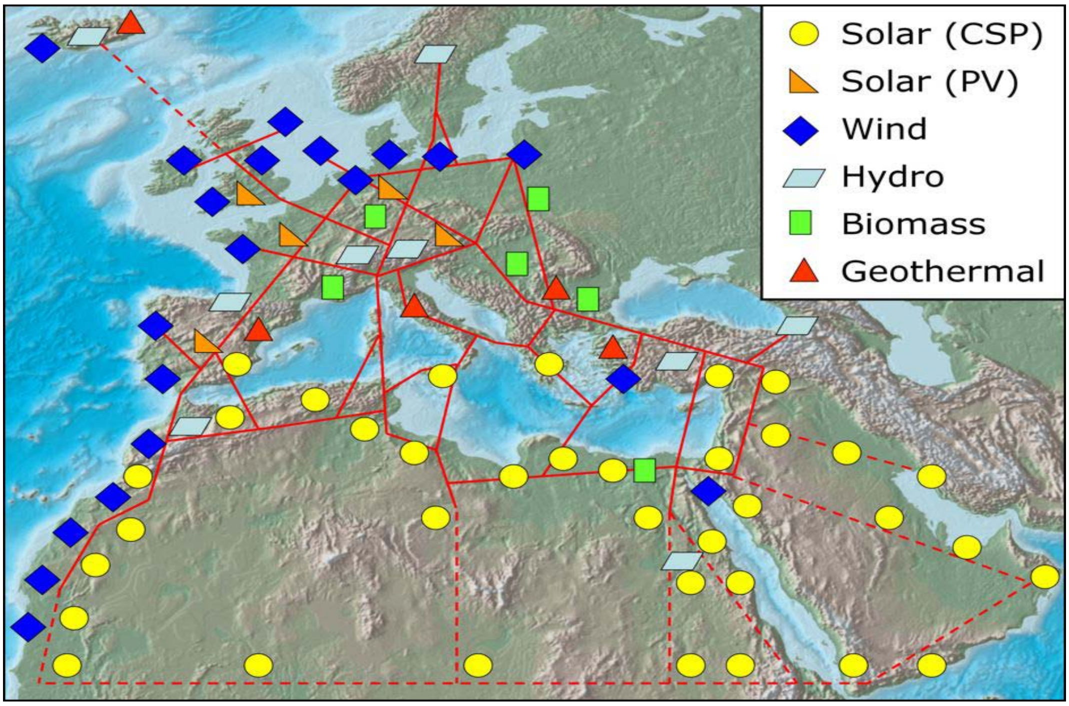

Figure 8.1. The Desertec project aims at providing 15% of the European electricity demand by HVDC interconnections from solar power installations by 2050. (www.desertec.org)

9. Nuclear energy. According to the World Nuclear Organization, there are at present 438 reactors in operation in 30 countries. These provide 15 % of electricity worldwide and 30 % within the EU. Totally 52 reactors are under construction, 143 are being planned and 344 are being proposed in 43 countries.

Facing the challenge of a strong increase of the worldwide demand for nuclear energy, there is now a large industrial offer of Gen III reactors (Gen abbreviates Generation) on the market. This new generation of reactors relies on the experience gained from existing light water reactors (Gen II) and brings in new improvements particularly on safety systems, which will have more automatic controls and be less dependent on the operators. Also the back end of the fuel cycle will be improved to meet concerns on waste management and proliferation risks. One of the first of these Gen III reactors, the European Pressurized Reactor, is being built in Olkiluoto Finland by the French company AREVA. Also Japanese and US nuclear industry have elaborated new designs for emerging markets. Various passive safety features are considered for example by Toshiba Westinghouse and General Electric.

The US has initiated an international forum of governments, industry and research communities in developing the next generation of nuclear energy systems to follow the Gen III systems, the so - called Gen IV. Four of these new reactors are of the breeder type which use the uranium fuel 100 timed more efficiently than the current and the planned Gen III reactors. The goal is to develop systems that would be available for worldwide deployment in 15-25 years from now. These future power plants are expected to have advantages that include sustainability, reduced capital costs, enhanced safety, minimal generation of waste, and further reduction of the risk of weapons materials proliferation. In addition to electricity production, they should also be able to produce hydrogen, heat and desalination of seawater.

According to the views of the Energy Committee [9.1] it is essential that the plans for the development of nuclear energy worldwide get our full attention. The funds for nuclear R&D have already been increased in several countries, in particular those that take part in the Generation IV International Forum. To contribute to the ambitious goals set up for the proposed Gen IV reactors in a reasonably short time, significantly increased resources for research are needed. The answers will guide us in deciding the role of nuclear - fission energy in the future global energy mix. The Gen IV initiative is an open international and collaborative effort with no military intention, which makes it quite different from the development of previous generations of nuclear systems. It will be important also for othercountries with nuclear energy, to increase their public funding in order to be able to collaborate internationally and have access to the new technologies emerging from nuclear R&D.

9.1 RSAS Energy Committee, Statements on Energy from Nuclear Fission, 29 June 2006
http://www.kva.se/Documents/Vetenskap_samhallet/Energi/Utskottet/uttalande_energi_karnkraft_eng_2006.pdf

10. Geothermal energy. Geothermal energy is derived from heat within the earth. The energy resources range from the extremely hot magma in the earth´s mantle, to hot rock kilometers below the surface of the earth´s crust, to shallow ground in addition to groundwater. Hydrothermal reservoirs constitute the most significant type of geothermal energy production today, utilizing the heat in the crust in which high temperature pressurized groundwater has accumulated and serves as a medium for removing thermal energy from the earth's crust by means of heat pumps.

Energy from geothermal resources has two distinct applications: electricity production and direct heat use. Worldwide, geothermal electricity production amounts to 60 TWh (2006) according to the World Energy Council, but it is concentrated in only about 25 countries. Electricity production from geothermal energy may be increased in the future but at present it is mainly restricted to countries and regions with active tectonic plate boundaries and active volcanoes. Further technological developments may increase the potential in those regions and even extend the potential to other regions of the world, but the economic viability of such developments remains to be proved.

In contrast, the economic potential of geothermal energy for direct heat applications has increased in the last two decades due to the development of ground - source heat pumps. The total amount of energy produced from geothermal resources for direct heat uses was 78 TWh in the end of 2005 (World Energy Council, 2007). This production is widespread geographically over 70 countries in the world.

In general, the currently exploited geothermal resources for both electricity and heat supply are only a small fraction of their estimated theoretical potential. Globally the technical potential is estimated to be hundred times that of hydropower (World Energy Assessment, 2001). This theoretical estimate is also practically untested and considerable research and development efforts and resources are needed for mapping out the geothermal resources, as well as for improving and practically testing the economic viability and large - scale feasibility of the technologies for surveying and harnessing it.

11. Fusion energy. Fusion is a truly sustainable energy source. The "fuel", heavy water and lithium, is widely distributed on the earth and sufficient to last for billions of years. But fusion energy will, according to present knowledge, not be available yet for many decades. More concerted scientific research and technology development on an international scale is required for fusion to become a cost - effective energy source in this century.

Research on fusion energy is, after the approval of the international ITER project (International Thermonuclear Experimental Reactor) project, focusing on magnetic confinement of the tokamak design. A tokamak is a type of device that confines a plasma to a donut shape by magnetic fields The tokamak was invented in the 1950s by the Soviet physicists Igor Tamm and Andrei Sakharov.

ITER is a large-scale scientific experiment intended to prove the viability of fusion as an energy source, and to collect the data necessary for the design and subsequent operation of the first electricity-producing fusion power plant. In ITER, studies will be done of a burning fusion plasma at reactor - like conditions of discharge pulses with a duration of minutes at a fusion power of 500 MW.

The incredibly complex ITER tokamak will be nearly 30 meters tall and weigh 23 000 tonnes. It is being built in Cadarache in Southern France in a collaboration financed by China, the European Union, India, Japan, South Korea, Russia and the United States, representing over half of the world's population.
The profound experience gained up till now on tokamak research makes it possible to predict fairly well the performance of the ITER experiment, and a road map with clearly given milestones has been set up. Following ITER, the next step will be a DEMO reactor, designed and built on the basis of experiences gained from the ITER experiment. The fusion physicists

plan that a decision on a DEMO reactor can be made already in 2020, only after a few years of experiments at ITER. This planning appears optimistic. After a satisfactory operation of a DEMO reactor, a first power-producing reactor can be designed and built. Such a power-producing reactor is expected to be ready for use around 2050. These estimates are however uncertain and made on the assumption that no major difficulties will be encountered.

The Energy Committee finds that fusion energy has a potential of becoming a long - term environmental friendly and material efficient energy option [11.1]. In view of its importance it is necessary that, besides the huge investments spent on the large international facilities, basic and applied research connected with fusion is supported at universities and national laboratories in order to exploit all the emerging new knowledge. Even if the track currently leads to tokamak reactors, it should not be excluded that other solutions, non-tokamak magnetic confinement, inertial fusion or tabletop fusion, may emerge in the quite long period during which magnetic-confinement fusion is being developed.

11.1 RSAS Energy Committee, Statements on Energy from Nuclear Fusion, 29 August, 2007.
http://www.kva.se/Documents/Vetenskap_samhallet/Energi/Utskottet/uttalande_energi_fusion_eng_2007.pdf

12. Wind power. Wind power is increasing rapidly, in particular in North America, Europe and Asia. At present USA and Germany are the main suppliers of electricity from wind power. Globally the installed wind power increased during 2008 by 29% to 120 GW. The energy provided was 260 TWh corresponding to 0.2 % of global energy consumption and 1.3 % of global electricity supply. The effective yearly on-time was 2200 hours of full power which means that the capacity factor was 25%. The Global Wind Energy Council (GWEC) assumes that this rapid increase will continue over the next 5 years and that 332 GW (371 TWh) will be installed by 2013. In its Outlook 2008 the GWEC gives three scenarios for the wind electricity production 2050, the moderate scenario being 4 818 TWh.

The view of the Energy Committee is that wind power will grow in importance in future electricity supply [12.1]. In the next few decades it will to some degree replace fossil power but it will, at the same time also depend on fossil-based power for the balancing of its intermittency. In the long term, 2050 and beyond, when wind power is expected to have a substantial share of the electricity market, CO_2 emission - free electricity plants that are well suited for balancing the wind intermittency will be required.

Predictions of the future penetration of wind power into the electricity market are critically dependent on a number of policy measures and will be especially influenced by climate driven energy policies. Very large investments will also be necessary as is shown by the IEA’s Blue Map Scenario which includes 5 000 TWh wind electricity by 2050 at a cost of USD 700 billion. This implies an average eight per cent increase per year over the next 40 years. This is considered to be a very high growth rate for a global energy system, i.e. an energy system so large that it affects the entire world.

Future large continental and intercontinental power grids may enable higher penetrations of wind since contributions of wind power from a larger area will tend to reduce its intermittency. The choice of windy onshore and/or offshore locations will improve the capacity factors for wind power. Also large - scale storage systems such as thermal storage, being considered for Concentrating Solar Power, Pumped Hydro Storage, Compressed Air Energy Storage, Flywheel, small-scale battery systems, specially designed nuclear reactors and demand management could develop into economically viable solutions for improving the penetration of wind and other intermittent power systems. An early review of storage options is found in reference 12.2. Besides the technical aspects of wind power, further studies on the social, environmental and economical implications are needed.

12.1 RSAS Energy Committee, Statement on wind power, 18 January 2010.
http://www.kva.se/Documents/Vetenskap_samhallet/Energi/Utskottet/uttalande_energi_vind_eng_2010.pdf
12.2 Septumus van der Linden, The Commercial World of Energy Storage: A Review of Operating Facilities, Energy Storage Council, 2003.
http://www.energystoragecouncil.org/Septimus%20van%20der%20Linden%20ESC%20presentation.pdf

13. Oil. It is very likely that the world in the near future will face an era of huge challenges in view of the limited resources of easily accessible conventional oil. An increasing demand for oil from emerging economies, like China and India, is likely to further accentuate the need for new solutions.

The current rate of consumption of oil is 84 million barrels per day (1 barrel=159 liters) or 30 billion barrels per year. The 2008 figures are slightly higher than the 2007 figures according to the BP statistical review. The oil production may therefore already have reached a peak or a plateau according to predictions by leading representatives of the Association for the Study of Peak Oil and Gas [13.1]. Most major oil fields are well matured so a shortage of supply of conventional oil can be expected within one or two decades. Many geologists maintain that there is still much conventional oil to be discovered, but these new reservoirs will mainly be found in places (e.g. the Arctic) where the production cost will be much higher. Including these, the reserves of conventional oil are estimated to be 1 200 billion barrels. By 2050 the supply of conventional oil will definitely be much smaller than at present.

Only the Middle East and possibly the former Soviet Union countries have a potential to increase their production rate to compensate for reducing rates from other countries.

The very large alternative hydrocarbon resources (so-called unconventional oil), in addition to the conventional oil, available and predicted for future discovery, include gas (1000 billion barrels of oil equivalent), heavy oil and tar sands (800 billion barrels) and oil shales (2 700 billion barrels); liquefied coal provides an additional reserve and methane hydrates existing in vast quantities may prove to be economic. With the exception of gas, all this unconventional oil is expensive to produce and exploitation involves significant environmental problems.

The Energy Committee is of the opinion that oil shortage is not mainly an energy problem but a severe liquid fuels problem [13.2]. Immediate measures have therefore to be taken to reduce the vehicle dependence on liquid fossil fuels. The transportation system including public transportation will have to be changed substantially. Until these measures have been implemented, demand of oil for the needs of a globally increasing transport sector will continue to rise. The development of future transportation systems and increasing the capacity of oil production will require very large-scale projects taking time, perhaps ten to twenty years to implement. These need to be started immediately to mitigate the problems otherwise likely to occur in the coming decades.

13.1 Kjell Aleklett and Colin Campbell, The peak and decline of world oil and gas production, Minerals and Energy - Raw Materials Report, Volume 18, Number 1, 2003 , pp. 5-20(16).
13.2 RSAS Energy Committee, Statements on oil, 14 October 2005.
http://www.kva.se/Documents/Vetenskap_samhallet/Energi/Utskottet/uttalande_energi_olja_eng_2005.pdf

14. Coal. Coal currently supplies 39% of the world's electricity. The availability of low-cost supplies of coal in both developed and developing countries has been vital to achieving high rates of electrification. In China for example, 700 million people have been connected to the electricity system over the past 15 years. The world yearly consumes over 4050 megatonnes of coal.

The World Energy Council 2009 estimate of proven coal reserves worldwide are 826 billion tonnes. This means that there is enough coal to last over 200 years. Coal is located worldwide – it can be found on every continent in over 70 countries, with the biggest reserves in the USA, Russia, China and India.

Coal is used by a variety of sectors – including power generation, iron and steel production, cement manufacturing and as a liquid fuel. The majority of coal is either utilized in power generation – steam coal or lignite – or iron and steel production – coking coal.

Coal production has grown fastest in Asia, while Europe has actually seen a decline in production. The top five producers are China, USA, India, Australia and South Africa. Much of global coal production is used in the country in which it was produced, only around 18% of hard - coal production is destined for the international coal market.

According to the World Coal Institute, global coal production is expected to reach 7 billion tonnes in 2030 – with China accounting for around half the increase over this period. However, since coal production leads to the biggest CO_2 emissions per unit energy, among the hydrocarbon fuels, it is essential to implement sequestration schemes and start a massive investment in alternative energy sources in order to limit future emissions of greenhouse gases and other dangerous substances. In this context should be mentioned the work by the Uppsala and Newcastle hydrocarbon groups showing that the global coal production is likely to peak between 2026 and 2034 [14.1, 14.2].

14.1. S.H. Mohr, G.M. Evans, Forecasting coal production until 2100, Fuel 88 (2009) 2059.
14.2. Mikael Höök, The future of coal,
http://www.tsl.uu.se/uhdsg/Personal/Mikael/Coal_2009-02-25.pdf

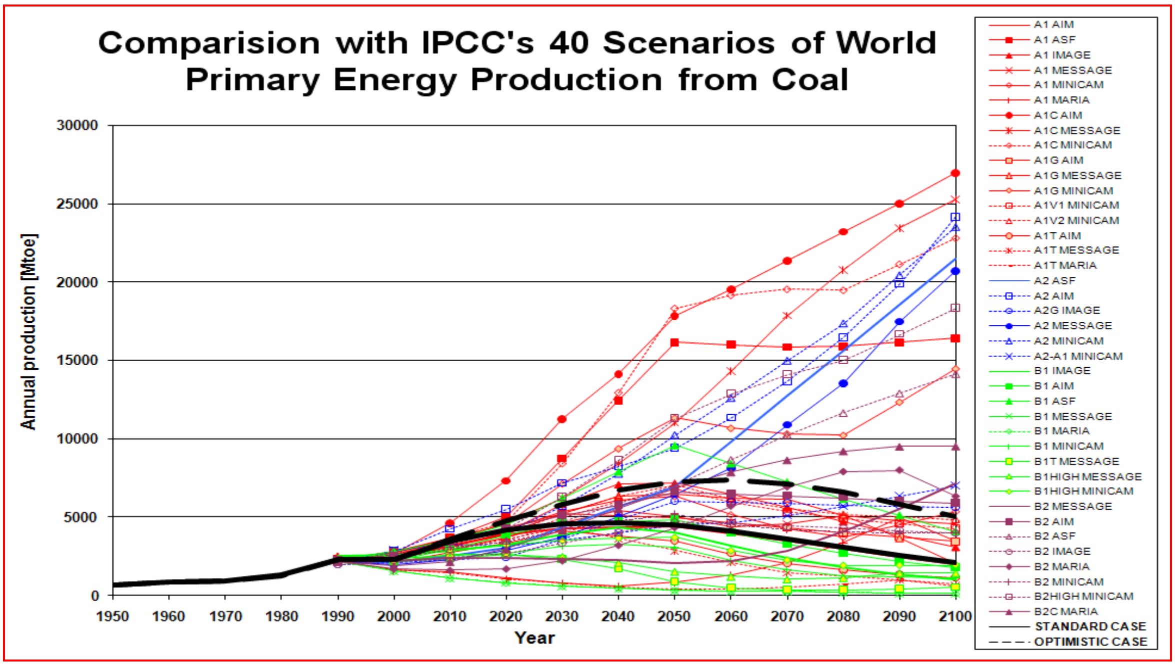

Figure 14.1. The future energy production from coal has been estimated, taking into account all logistics boundary conditions [14.2]. The curve in bold lines represents the estimate with the currently given reserves. The dashed curve shows rhe result for a doubling of the reserves. In neither case will the annual production reach 20 000 Mtoe which are the figures calculated for a scenario which may lead to a temperature increase of 6 °C according to IPCC scenarios.

15. Gas. Worldwide, total natural gas consumption was 3 000 billion m^3 in 2008 and is expected to grow by 50 % up to 2030. According to the BP Statistical Review, the world proved reserves at end of 2008 were 185 trillion m^3 corresponding to a ratio of 63 years for the reserve to annual production ratio. It should be noted that three countries, Russia, Qatar and Iran have 55 % of the proved reserves. Natural gas produces less carbon dioxide when it is burned than coal or petroleum, so governments may encourage use of gas to displace other fossil fuels. Natural gas is expected to remain a key energy source for industrial sector uses and electricity generation for many years. The industrial sector currently consumes more natural gas than any other end - use sector and by 2030, forty percent of world natural gas consumption is estimated to be used for industrial purposes. In particular, new petrochemical plants are expected to rely increasingly on natural gas as a feedstock - particularly in the Middle East, where major oil producers, working to maximize revenues from oil exports, turn to natural gas for domestic uses [15.1]. In the electric power sector, natural gas is an attractive choice for new generating plants because of its relative fuel efficiency and low carbon dioxide intensity. Electricity generation accounts for 32 percent of the world's total natural gas consumption and this is expected to increase slightly during the coming decades.

15.1. Bengt Söderbergh, Production from Giant Gas Fields in Norway and Russia and Subsequent Implications for European Energy Security, Doctoral thesis, Uppsala University, 29 January 2010.
http://www.fysast.uu.se/ges/en/publications/production-from-giant-gas-fields-in-norway-and-russia-and-subsequent-implications-for-e

16. The energy situation 2050

The strategy for estimating the energy situation around 2050 is to maximize the contributions from non-fossil energy and then to add contributions from fossil energy sources which will stabilize the CO_2 concentration at 450 ppm. The bioenergy is assumed to double compared to the present situation and provide 35 000 TWh including 5 000 TWh electricity per year. It is assumed that co-generation technologies will be utilized as much as possible. Hydropower is assumed to be extended to its full economical-technical potential of 9 000 TWh and wind power to 5 000 TWh annual production according to the moderate scenario by the Global Wind Energy Council. Solar energy is assumed to enter a stage of mass production within the next decade and then to be economically competitive. Contributions from photovoltaics and concentrating solar power summed together are estimated to provide 3 000 TWh electricity. Concerning nuclear energy it is assumed to provide 7 000 TWh electricity per year. This figure can be estimated from the number of existing reactors and the number of reactors presently being built, planned and proposed assuming the additional reactors have an average power of 1 GW. These numbers add up to 29 TWh non-fossil electricity to which should be added electricity from fossil gas, 4 000 TWh, and coal, 12 000 TWh. Altogether by 2050, 45 000 TWh of electricity supply is a possible but very ambitious goal.

The total primary supply of non - fossil energy 2050 is estimated to be 80 000 TWh which come essentially from bioenergy (35 000 TWh),nuclear (21 000 TWh), hydro (9 000 TWh), wind (5 000 TWh) and solar (9 000 TWh). It should be noted that no heat is associated with the electricity production from hydro and wind power. Concerning the fossil energy, it is assumed that oil will have halved by 2050 compared to today, that the gas supply will be back at today's level following a few decades of boom [16.1] and that the amount of coal will be determined by the CO_2 emission constraint as formulated by the IPCC; the net emissions need to be limited to 2 200 billion tonnes over the next hundred years (22 billion tonnes per year on average) in order to stabilize the carbon dioxide concentration at 450 ppm, which gives a 50 percent likelihood that the two degree goal will be achieved [16.2]. The IPCC figures also include deforestation contributing currently by 24 percent of the unbalance of carbon dioxide exchange; 9 billion tonnes per year comes from deforestation and 28 billion tonnes from fossil fuel burning. An important first priority must be that deforestation can be halted by 2050.

The goal for the Energy Committee's considerations is that the CO_2 emissions from fossil energy use should be down to 22 billion tonnes by 2050. It is found that the emissions from the burning of oil and gas, 50 000 TWh, and coal, 30 000 TWh, produce 20 billion tonnes CO_2 just under the limit that will stabilize the CO_2 concentration at 450 ppm. Additional energy from coal - fired power stations can be supplied if they can be built, incorporating the separation and storage of carbon dioxide, a technology that is now viewed with considerably more optimism than just some years ago. It is estimated that this will reduce the efficiency of the power stations by around 10 per cent and raise the cost of electricity production by 10 to 20 percent. In the Energy Committee's scenario it is assumed that by 2050, coal-fired plants built with this technology will provide 10 000 TWh. The resulting energy supply from coal, gas and oil sums up to 90 000 TWh in 2050. This is 20% lower than the 110 000 TWh produced in 2008. However the fossil share of the energy supply has gone down from 80% in 2008 to 54% in 2050.

The scenario presented here is in line with the International Energy Agency's blue scenario [16.3] in which the goal is to reduce the CO_2 emissions by 50% up to 2050. The blue scenario is an extension of the Accelerated Technology scenario which builds on technologies that already exist or under development. The cost for this scenario which aims at coming back to the 2005 CO_2 emissions by 2050, is estimated to 17 trillion dollars. In the blue scenario a further 45 trillion dollars need to be invested particularly in the transport sector. The enormous task in front of the world community can be exemplified by figures on the average year – by - year deployment in the power sector between 2010 and 2050; 55 fossil - power plants with CCS, 32 nuclear plants, 17 500 large wind turbines and 215 million square meters of solar panels. In the transportation sector 1 billion zero-emission vehicles would be employed by 2050.

16.1 Global Energy Systems group in Uppsala, Private communication.
16.2 Sven Kullander, Easier to meet the two degree goal in an electric society, Aricle in Climate challenge – the safety's off , Formas Fokuserar 15, p. 333, 2009.
16.3 International Energy Agency, Energy Technology Perspectives, Scenarios & Strategies to 2050 (In support of the G8 plan of action), OECD IEA 2008.

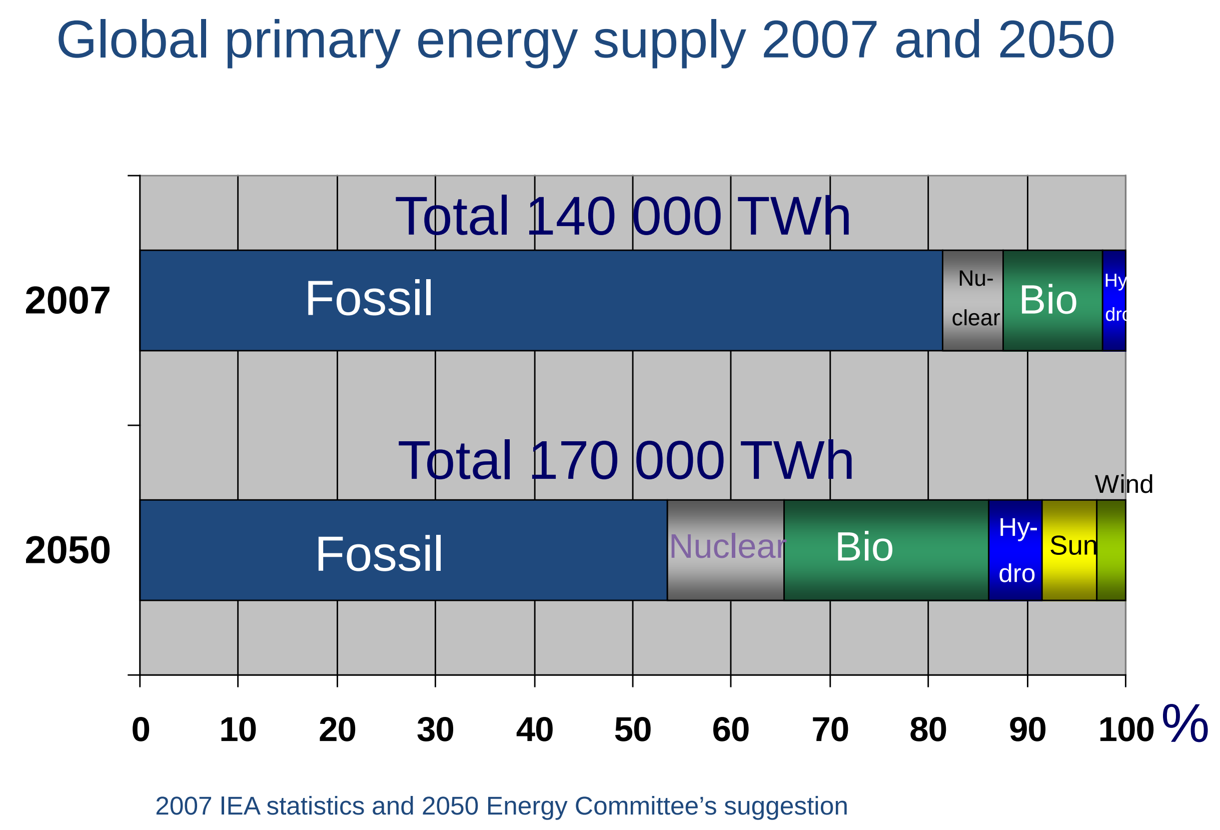

Figure 16.1. Global primary energy supply 2007 and 2050.

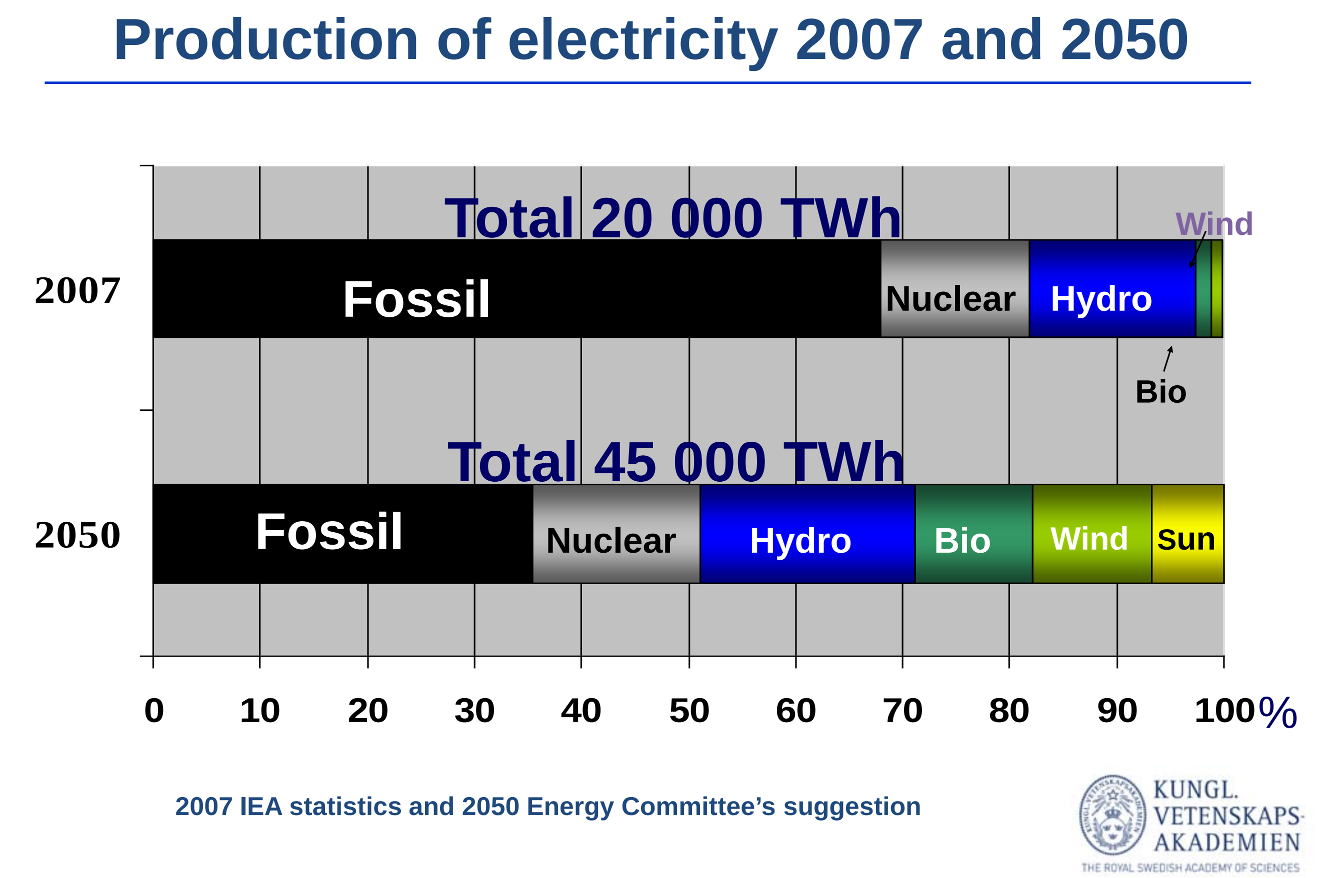

Figure 16.2. Production of electricity 2007 and 2050