The World Needs a New Energy Paradigm

Dick Hedberg, Sven Kullander, Harry Frank

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Abstract During 19–20 October 2009, the Royal Swedish Academy of Sciences arranged the international symposium *Energy 2050* in Stockholm. The symposium was held in association with the Swedish EU presidency in autumn 2009. Internationally renowned scientists assessed the energy issue in a broad perspective, with particular emphasis on the possibilities of a fossil-free future. The symposium focused on key topics emanating from the in-depth energy studies carried through by the Academy's Energy Committee since 2005. The world community is facing a challenge of historic proportions to define a new energy paradigm based on fossil-energy substitutes. This article gives an overview of the current global energy situation (2007) and of the technologies which have the major potential for supplying energy up to year 2050 without jeopardizing the CO₂ emission targets.

Keywords Energy · Fossilfree energy · Paradigm · Renewable energy · Geothermal energy

THE ENERGY COMMITTEE

The Royal Swedish Academy of Sciences' overarching goal is to promote the sciences and strengthen their influence on society. Among a series of instruments to fulfil this objective are thematic committees focusing on important social issues treated from a scientific point of view. The Energy Committee, consisting of representatives from each of the Academy's 10 classes/disciplines and other qualified members, was set up in 2005 and has since then carried through some 10 in-depth projects regarding energy sources and energy systems.

During 19–20 October 2009, the Royal Swedish Academy of Sciences, through its Energy Committee, arranged

the international symposium *Energy 2050*. The symposium was held in association with the Swedish EU presidency in autumn 2009 and focused on key issues emanating from the Energy Committee's work during 2005–2009, especially the possibilities to reduce the contribution of fossil fuels to the global energy system. Internationally renowned scientists—among them two Nobel Laureates—assessed the energy theme in a broad perspective, with particular focus on how rapidly a change to “fossil-free” society can be accomplished. His Majesty the King Carl XVI Gustaf of Sweden and the EU Energy Commissioner Andris Piebalgs attended parts of the symposium. The programme (see pages 7–9) comprised six sessions, each reported on in this issue.

In addition, the symposium provided a special message for the COP15 UN Climate Change Conference, December 2009 in Copenhagen entitled ‘Global climate change is essentially a global energy change’ (see page 10).

An overview of the main future energy sources and the Energy Committee's conclusions from the seminal work are given below.

BACKGROUND

Energy production and consumption have a major impact on society and nature. Especially the use of fossil fuels is a clearly unsustainable activity with potentially catastrophic consequences. At present, fossil fuels account for more than 80 % of the energy produced globally. The annual rate of oil consumption is 30 billion barrels (1 barrel = 159 l). Most major oil fields are well matured, and the remaining conventional oil to be discovered is mainly to be found in places where production costs will increase substantially. The global reserves of conventional oil are estimated to be some 1,200 billion barrels whereas the so-called

unconventional oil sources predicted for future discovery—oil shale, heavy oil and tar sands—amount to 4,500 billion barrels of oil equivalents. Liquefied gas and coal provide additional reserves and methane hydrates, which exist in vast quantities, may prove to be economically feasible. With the exception of gas, all this unconventional oil is expensive to produce and exploitation involves significant environmental problems. By 2050, the supply of conventional oil will definitely be much less than at present.

World consumption of coal is more than 4050 Mt annually, and there are almost 1,000 billion tons of proven coal reserves worldwide, which can last for a couple of 100 years. Since, of the hydrocarbon fuels, coal is the largest source of CO₂-emissions per unit energy produced, it is essential to implement sequestration schemes and launch massive investments in alternative energy sources as soon as possible. Worldwide, annual natural gas consumption is 3,000 billion m³, which is expected to grow by 50% up to 2030. The proven reserves amount to 185 trillion m³ corresponding to 60 years use. Natural gas produces less carbon dioxide when burned than do coal and petroleum, and so replacement of other fossil fuels by natural gas should be encouraged. Natural gas is expected to remain a key energy source for industrial use and electricity generation beyond the mid-twenty-first-century.

The increasing atmospheric CO₂ content is beyond any doubt caused by human activity, however, when it comes to global warming it is not easy to quantify exactly how much of this warming should be ascribed to the accumulation of CO₂, and how much to other factors. According to the assessment of Royal Swedish Academy of Sciences' Energy Committee, at least half of the observed temperature rise is of anthropogenic origin. Global warming over the last decades has been manifested in high global temperatures, increased sea level rise, and the melting of glaciers and sea ice. However, the period during which direct global measurements have been made is too short for any clear conclusions to be drawn. Continued satellite-based measurements of the global radiation balance over the coming decades are expected to improve future climate forecasts and our knowledge about the role of the CO₂. If, the most extreme IPCC 2007 scenario, i.e. 5–6 degrees temperature increase, should occur, then the consequences will be enormous. The uncertainties are, however, considerable, especially in regard to the influence of clouds and aerosols, and the associated change in solar influx at the earth's surface. Despite the uncertainties in regard to the causes of climate change, a reduction in the use of fossil fuels must remain the major goal for future energy policy, not the least in view of the risks involved for the environment and human health.

Currently, the global primary energy supply amounts to approximately 140,000 TWh (Tera Watt hours) a year. In

order to explore possibilities to reduce the contribution of fossil fuels to the global energy system—the greatest challenge of our time—is the common denominator in the work carried out by the Energy Committee. The Committee has selected 2050 as a realistic target for the implementation of major changes in the global energy system.

Today, the major potential for changes in energy supply up to the year 2050 are to be found in the already established technologies such as hydropower, nuclear-, wind- and bioenergy. Yet, in all of these technologies, there are drawbacks that need to be taken into account: i.e. environmental protection and jurisdiction in connection with hydropower, waste and proliferation risks with nuclear energy, the intermittency of wind power, and the many factors that constrain bioenergy production, such as environmental and biodiversity issues, competition with food and other biomaterials, etc. In parallel to a shift to a non-fossil energy supply, a radically more efficient use of energy needs to be achieved. Increased use of electricity, not the least in the transport sector, and more effective heating and cooling of buildings are key elements in this process. In addition, efficiency in the use of energy in industrial processes is essential.

Promoting energy efficiency, for example, by way of a fairly large changeover towards increased use of electricity as an energy carrier, should make it possible to reduce global energy consumption. According to the estimates of the Academy's Energy Committee, it appears to be realistic to count on a global primary energy supply of 170,000 TWh in the year 2050, i.e. markedly less than the supply estimated in the scenarios presented by established organizations, e.g. the IEA. The Energy Committee's scenario includes a substantial decrease in the use of fossil fuels, a doubling of nuclear energy, more than a threefold increase of renewables, but first and foremost, an increase in the production of electricity from 20,000 TWh in 2007 to 45,000 TWh in 2050. The potential of upcoming energy options such as artificial photosynthesis, fusion energy, fourth generation nuclear fission, water wave power, etc. should become clearer by 2050, by which time totally unexpected discoveries and solutions may also emerge from technological and scientific research. One of the emerging renewable sources with enormous potential is solar energy, especially concentrating solar power (CSP) systems producing hot liquids for operation of electricity-generating steam turbines.

HYDROPOWER

Among renewable energy sources, hydropower is by far the dominating source, representing 87% of all the renewable power worldwide. The storage capacity of hydropower makes it unique among renewables in that it can supply

operational flexibility for quick response to changes in electricity demand, due to day and night variations or intermittent dropping-off by wind- and solar-energy sources. At present, some 3,000 TWh hydropower are produced annually, while the economic potential has been estimated to be around 9,500 TWh; the technically feasible hydropower potential is much higher. Most of the hydropower development potential is to be found in developing countries, whereas, for example, Europe already has exploited most of the readily accessible resources. Nevertheless, the existing dams and turbines in Europe require modernization and improvements, not the least for adaptation to expected future climate change.

There are social–ecological, safety, legal and policy constraints and concerns that need to be taken into account when assessing the possibilities for hydropower expansion. These have to be carefully considered in any cost–benefit and feasibility analyses. Ecosystem services and social–ecological externalities that may be affected by the expansion of hydropower must also be included in these analyses.

In addition to dam-based or traditional hydropower, there are alternative ways to take advantage of energy from moving water. For example, wave energy is estimated to have a very high theoretical potential between 8,000 and 80,000 TWh annually. Currently, only 140–750 TWh is economically exploitable with the available technology, but 2,000 TWh could be realistic due to further technological improvements.

BIOENERGY

For bioenergy, a basic recommendation is that primary biomass should be used for other purposes than for burning. Instead, the main bioenergy potential is to be found in residues from forestry and agriculture together with organic wastes. These biomass options can probably provide as much bioenergy as is currently traded globally, implying a doubling by up to some 30,000 TWh annually. However, in countries like Sweden where biomass is extensively used for energy purposes, a 50% increase may be more realistic than a doubling. Modern plant breeding methods, including genetic modification, will most likely make substantial contributions to higher agricultural and forestry yields. On the whole, it can be assumed that bioenergy will increase in importance. This increase will likely take place in spite of the fact that bioenergy, in view of the raw material needed, will compete with the global need for food, paper wood products, etc.

The major constraints relating to biomass use for energy purposes are the need to ensure stable food production for a growing world population and to maintain the basis for global biodiversity. Today, about one billion people are

chronically undernourished at the same time as the world population is expected to grow by 2–3 billion individuals during the next few decades. The energy content of all primary agricultural production during a year is 19,000 TWh, equivalent to 17% of all the annually consumed fossil energy. Seen from this perspective, it is obvious that primary agricultural production should be used to feed people before any massive production of biofuels is considered. Biodiversity is threatened by extensive monocultures and deforestation. Already, deforestation has been causing enormous losses in the natural carbon capture and storage capacity that rainforests provide.

Biomass should primarily be used as much as possible for the combined generation of heat and electricity and for second-generation biofuels produced from cellulose residues. Large plants are desirable since combustion as well as the removal of toxic substances in exhaust gases and ashes will be more efficient in larger operations.

NUCLEAR ENERGY

At present, nearly 440 of the so-called Generation II fission nuclear reactors are in operation in 30 countries, providing 16% of electricity worldwide. Nuclear energy appears to be undergoing a renaissance worldwide. Fifty-five new reactors are being built around the world, 137 are planned, and 295 are proposed for the future. Facing the challenge of a strong increase in the worldwide demand for nuclear energy, there is currently a rather large industrial offer of Generation III reactors on the market. This new generation of technology relies on the experience gained from existing light water Generation II reactors, but brings new developments and improvements, particularly on the safety systems, with more automated controls and less dependence on the operators. In addition, the back end of the fuel cycle will be improved to meet concerns relating to waste management and proliferation risks.

An international forum of governments, industry and research communities has been initiated for the development of the next generation of nuclear energy systems, the so-called Generation IV, to be deployed in a period of 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 a further reduction in the risk of weapons materials proliferation. The fact that radioactive waste from Generation II- and III-reactors can be reprocessed to provide fuel for the Generation IV-reactors, with drastically shortened half-life of waste, brings the problem of terminal storage into a new perspective. In addition to electricity, the Generation IV reactors should also be able to produce hydrogen, heat and desalination of sea water.

Provided that nuclear energy gains public acceptance, it is estimated that around 7,500 TWh electricity could be made available by 2050.

In contrast to the fission technology discussed above, fusion energy will not be available for many decades, but it has the potential to become a long-term environmentally friendly and material-efficient energy option. Fusion is a truly sustainable energy source since the fuels (deuterium and tritium), including the lithium needed for breeding of tritium, are available and abundant on earth, and “melt-down” incidents are impossible; the reactor will not contain long-lived radioactivity.

GEOTHERMAL ENERGY

Geothermal energy is derived from heat within the earth. The heat ranges from extremely hot magma in the earth's mantle, to hot rock kilometers below the surface of the earth's crust, and to warm groundwater at shallow ground levels. Today, the groundwater reservoirs constitute the most significant type of geothermal energy supply; the groundwater serves as a medium for the removal of thermal energy from the crust by means of heat pumps. Energy from geothermal resources has two distinct applications: electricity production and direct heat use. Electricity production from geothermal energy, today, is in the order of 60 TWh per year around the world, and may increase in the future. However, this energy source is mainly concentrated to regions with active tectonic plate boundaries and volcanoes. On the other hand, the economic potential of geothermal energy from direct heat applications has increased in the last two decades due to the development of ground-source heat pumps, which now amounts to nearly 100 TWh. In general, the currently exploited geothermal resources for both electricity and heat are only a small fraction of their estimated theoretical potential. Globally, the technical potential is estimated to be orders of magnitude larger than that of, for example, hydropower, but this is still practically untested. Considerable research and development efforts, including resources, are needed for mapping out geothermal resources, as well as for improving and testing the economic viability and large-scale feasibility of the technologies for surveying and harnessing this energy source.

WIND POWER

Wind power usage is increasing rapidly, in particular in North America, Europe and Asia. At present, the USA and Germany are the main suppliers of electricity from wind power. Globally, the installed wind power increased during

2008 by nearly 30% to 120 GW (Giga Watt). The energy provided was 260 TWh corresponding to 0.2% of the global energy consumption and 1.3% of global electricity supply. A problem with wind power is its intermittency, which means that a wind power plant produces and delivers energy corresponding to its maximum capacity only occasionally, i.e. when wind conditions are optimal. The produced energy is quantified by the installed power multiplied by the hours in the year (8,760) and a capacity factor, expressed as the ratio of the actual energy produced to the hypothetical maximum possible, i.e. running full time at rated power. Statistics of wind energy around the world show that the capacity factor on average is 23%, corresponding to 2,000 maximum-capacity hours in a year.

If wind power is part of a larger energy system, then the intermittency leads to a need for quick power replacement in the system when wind capacity fails. Today, back-up electricity generation comes mostly from fossil fuels. In countries with a large supply of hydropower, like Sweden, the hydropower plants may well be used as back-up for the intermittent wind power, in addition to supplying base electricity to the system. This need to balance wind power affects the hydropower supply of base electricity in a negative way, which is also the case for fossil fuel plants.

Strong wind power expansion may result in spill wind electricity, i.e. to situations when the wind power plants produce more energy than can be consumed in a given region, and a channel needs to be found for the surplus. This is the case in Denmark with some 20% wind energy penetration in the electricity system, and only half of that accommodated within Denmark over the last 5 years, with the rest sold at loss to neighbouring countries. Extended continental and inter-continental power grids can reduce the intermittency problem, as well as, for example, pumped or battery storage solutions. Life cycle analyses show that the full cost for electricity generated by wind power, excluding costs for expanding the power line network and the back-up power, is comparable to the costs for electricity generated from coal power plants, but twice as high as for electricity generated by nuclear power and biofuelled Combined Heat and Power. However, wind power compares favourably with other renewable alternatives.

Wind power will increase in importance as a future electricity supplier. In the next few decades, it is expected to replace fossil power to some degree, but it will at the same time also depend on fossil-based power to balance the intermittency involved. In the long-term, 2050 and beyond, when wind power is expected to have a substantial share of the electricity market, CO₂ 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. The Energy Committee's scenario for electricity production in the year 2050 includes 5,000 TWh wind electricity. With a total production of 45,000 TWh, of which half is renewable electricity, this implies that wind electricity has a share of some 10% of the 2050 global electricity production and 22% of the global renewable electricity production.

SOLAR POWER

Solar energy is one of the most important and viable alternatives for the provision of future sustainable energy. The resource base is virtually unlimited and technologies are developing rapidly, implying that solar technologies within half a century can dominate the powering of human societies. Utilization of sunlight is possible using a wide variety of technologies, which can deliver energy in different forms, such as electricity, high or low quality heat, or synthesized fuels such as hydrogen and hydrocarbons. The main technologies are Photovoltaics (PVs), Concentrating Solar Power (CSP), and Solar Heating and Solar Fuel Synthesis.

The PV systems use the photo-physical properties of materials to create electricity directly from the photons of sunlight. Small PV cells are combined in panels, which in turn can be assembled into systems that vary in size from a very simple one unit or several thousand units. Cells based on silicon photovoltaics have till now been the dominant product on the market, but production of silicon wafers is both time and energy demanding as well as expensive. A viable alternative is the so-called thin film (TF) cells. These are much thinner than SiPV films and can be produced using less energy and in a shorter time. However, other possible emerging PV technologies are still in a stage of early research and may be of interest in the future.

The CSP technique is based on the principle of using highly (up to 3000 times) concentrated sunlight. The light which is concentrated with reflecting mirrors can produce heat at high temperatures and drive a thermal cycle (thermal CSP) or be aimed at photovoltaic cells (Concentrating PV). Large plants can generate electricity up to 100 MW and employ daily energy storage, by keeping a heated medium in large isolated tanks. According to the joint European–Middle East–North African DESERTEC project, it should be possible to provide the region with a majority of its electricity demands by means of CSP-generated electricity from Sahara and a transmission grid by 2050.

Solar heating makes use of a collector, a surface with high absorption of light, from which the heat is transferred to a liquid or air system, to be used for heating indoor air or tap-water. Hot liquid can be stored for periods of hours in small tanks or in large-scale seasonal storage in bedrock or

large tanks. Photovoltaic/thermal (PV/T) hybrids are under development, basically made up by PV cells cooled by liquid or some other medium, from which both electricity and heat can be extracted.

Solar energy can also be converted into chemical energy. One option is to split water into hydrogen and oxygen in a high-temperature catalysed reaction using CSP-devices; another is electrolysis of water using solar-produced electricity.

While global energy prices are rising, the costs of solar energy tend to decrease. The cost of CSP technologies is anticipated to become comparable to that of conventional power sources within the next two decades. With integrated heat storage, CSP has the potential to provide significant amounts of base load power, but will be feasible only in areas with high input of direct sunlight, i.e. in or close to desert areas. In addition, local small-scale solar energy systems, PV and heating panels, will become increasingly important, for example, in private and public buildings.

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Sven Kullander is a Professor emeritus of high energy physics of Uppsala University. He is the Chairman of the Energy Committee at the Royal Swedish Academy of Sciences and the Vice President of the European Academies Science Advisory Council. In recent years, he has worked on energy issues in particular bioenergy.

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Harry Frank has held various positions between 1969 and 2008 as follows: 1969–1980: Researcher and Project leader at ASEA in thyristor-technology for all applications (AC–DC trains). 1980–1994: Division Manager at the company Reactive Power Compensation (FACTS). 1994–2002: Director of Research at ABB Sweden, directly involved in the development of transmission and distribution systems (AC–DC), (HVDC) and FACTS) and renewable energy sources (wind, solar, wave, water and biomass). 2002–2008: Business Development at ABB mainly in energy-related subjects. Currently, he is serving as the Professor at Mälardalens University in innovation technology for energy. He is also the Member of the Royal Swedish Academy of Sciences; the Royal Swedish Academy of Engineering Sciences, Cigré; and IEEE.

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Programme

Monday 19 October

8:00 Registration

8.45 Participants are requested to take their seats

9:00 Welcome address and introduction

Gunnar Öquist, Permanent secretary of the Royal Swedish Academy of Sciences (RSAS)

Sven Kullander, Chairman RSAS Energy Committee

9:20 Session 1. Climate change and mitigation

Chairs: Kerstin Niblaeus, RSAS and Rickard Lundin, RSAS

9:30 Beyond fossil fuels: environmentally carbon neutral and regenerative chemical recycling of carbon dioxide to methanol (dimethyl ether, DME) for energy storage, transportation or household fuels and source materials for synthetic hydrocarbon products

George A. Olah, 1994 Nobel Laureate Chemistry, University of Southern California, USA

10:00 Managing the build-up of carbon dioxide from fossil fuel consumption

Klaus Lackner, Professor, Columbia University, New York, USA

10:30 Geoengineering the Climate: the findings of the Royal Society study

Peter Cox, Professor of Climate System Dynamics, University of Exeter, UK

10:50 The status of climate change research

Lennart Bengtsson, Professor, Max Planck Institute, Hamburg, Germany

11:20 Discussion

11:50 Lunch

13:00 Session 2. Renewable energy

Chairs: Harry Frank, RSAS and Georgia Destouni, RSAS

13:10 Innovation: the key to a successful development of renewable energies

Carlo Rubbia, 1984 Nobel Laureate Physics, CERN, Geneva, Switzerland

13:40 Concentrating solar power: a roadmap from research to market

Robert Pitz-Paal, Professor, Germany Aerospace Center, Köln

14:10 Energy from wind

Hermann-Josef Wagner, Professor, Ruhr-Universität Bochum, Germany

14:40 Wave power and second generation biofuels

Tomas Kåberger, Director General, Swedish Energy Agency

15:00 Discussion**15:30 Coffee break****16:00 Session 3. Outlook on energy efficiency**

Chairs: Bengt Kasemo, RSAS and Sir Brian Heap, Vice President, European Academies Science Advisory Council

Panel discussion

Ola Alterå, State secretary, Ministry of Enterprise, Energy and Communications

Ernst Ulrich von Weizsäcker, Professor and Co-Chair, International Panel for Sustainable Resource Management

Bernard Bulkin, Dr and Chairman of the Board, Chemrec AB

Tomas Kåberger, Director General, Swedish Energy Agency

17:30 End of day 1**17:45 Drinks in Gallery Aula Magna****Tuesday 20 October****9:00 Session 4. Nuclear energy**

Chairs: Karl Grandin, RSAS and Peter Jagers, RSAS

9:10 The future of nuclear energy

Mujid Kazimi, Director, Center for advanced nuclear energy systems, Boston, USA

9:40 Subcritical thorium reactors

Carlo Rubbia, 1984 Nobel Laureate Physics, CERN, Geneva, Switzerland

10:10 Fusion energy – ready for use by 2050?

Friedrich Wagner, Professor, Max-Planck Institute for Plasma Physics, Greifswald, Germany

10:40 Discussion**11:10 Session 5. Fuels for transportation**

Chairs: Bengt Nordén, RSAS and Bertil Fredholm, RSAS

11:20 Low carbon vehicles

Julia King, Professor and Vice-Chancellor, Aston University, UK

11:50 Lunch**13:00 Batteries for transportation now and in the future**

Jean-Marie Tarascon, Professor, Université de Picardie Jules Verne, Amiens

13:30 Fossil motor fuels around 2050

Kjell Aleklett, Professor, Uppsala University, Sweden

14:00 Discussion**14:30 Coffee break****15:00 Session 6. Life cycle analyses and resource assessments**

Chairs: Karl-Göran Mäler, RSAS and Karl Fredga, RSAS

15:10 A systems ecology view on bioenergy/biofuels

Sergio Ulgiati, Parthenope University of Napoli, Department of Sciences for the Environment, Napoli, Italy

15:40 Life cycle analyses for different energy sources

Alfred Voss, Head of Institute for Energy Economics, Stuttgart, Germany

16:10 Discussion**16:40 Closing remarks**

Chair: Gunnar Öquist, Permanent secretary, RSAS

16:45 EU energy strategies

Andris Piebalgs, EU Energy Commissioner, Brussels, Belgium

17:00 Message for the UN Copenhagen Climate change conference

Sven Kullander, Chairman RSAS Energy Committee

17:15 End of Energy 2050 symposium

Endorsed by the Energy 2050 conference in Stockholm 19–20 October 2009

Global climate change is essentially a global energy change

The World community is facing a challenge of historic proportions to work towards a new energy paradigm. A deliberate and controlled reduction of the CO₂ emissions must be an essential objective of the future global energy policy for several reasons having in mind that fossil reserves of oil and gas are being depleted at an accelerating rate. Not only the climate effects of fossil fuel burning but also other environmental and health effects are full of risks. We ask the policy makers assembled in Copenhagen to take note of the following points:

1. **Time is of the essence for radical urgent changes to the global energy system.** The world has been increasingly powered by fossil fuels over the last 150 years and now this trend will have to be reversed in a much shorter time period. Huge changes that will affect and concern society and individuals will have to take place in a well thought-out manner. The political decisions made over the next few years will profoundly affect future generations.
2. **Life cycle analyses and ecological economics are essential prerequisites for future policy thinking.** Human energy activities must be developed so that land, water and air are not drastically affected. All future energy options should rely on sustainable fuel and construction materials which are in principle recyclable or durable. The future challenges cannot be met by providing more energy and resources and then wasting them due to an inefficient use. Efforts for increased efficiency would make more credible all the other efforts for a transition to emission-free energy production taking into account all the externalities, including environmental and social impacts. So far the global economy has not been willing to cost the depletion of natural resources or the detrimental effects on the environment of production, distribution and consumption of energy. These factors must be included since economic criteria guide policy makers and business people.
3. **Agriculture production should be used primarily for food while avoiding global deforestation and maintaining biodiversity.** Even with such restraints a lot of bio-energy can be extracted from residues and organic waste. The 9–10 billion people expected in 2050 will need food with an energy content of about 10 000 TWh per year (2 500 kcal/person/day). Several times more energy, today of fossil origin, has to be provided for food production and distribution.
4. **Electricity will have to become the major energy carrier in the future** since most of the non-fossil energy sources provide electrical energy. Electricity converts to mechanical motion with nearly 100 % efficiency, compared to perhaps 25 % for combustion. Therefore significant savings can be achieved, for example, by replacement of combustion engines with electric motors.
5. **Investment in energy research and development is crucial** if we are to achieve the emergence of a sustainable energy system beyond the fossil-energy era. Activities in the energy sector should be coordinated worldwide in order to avoid a future crisis, and technically advanced countries have a particular responsibility. It is important to make a full system analysis of the energy sector and to have realistic estimates of time scales, costs, environmental effects and the adaptability of various energy systems. A more direct exchange of information between policy makers and scientists is of vital importance and will help to speed up matters.

On behalf of the Energy Committee

Sven Kullander

Chairman

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