ENERGY-BASED LIFE SUPPORT SYSTEM DEVELOPMENT INFORMATION AND KNOWLEDGE

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Summary

Available resources of oil and natural gas will sustain current energy consumption for half a century, whereas uranium and coal will sustain present energy consumption for one to two centuries. Apart from resource depletion, the use of fossil fuels and uranium is coupled with adverse environmental effects.

Transition to sustainable energy supply is not merely a technical issue involving energy conservation and shift to renewable energy sources. Changes in the organization of the energy supply industry as well changes in, e.g., economic settings and legislation are required to sustain a transition to sustainable energy supply.

1. Introduction

Energy is a prerequisite for sustaining human habitats, ranging in use from maintaining appropriate temperature levels in dwellings via cooking and providing light, to providing power for transportation.

Energy systems for maintaining human habitats can be passive as well as active. Passive systems make use of solar radiation for heating dwellings, natural convection for cooling dwellings and food, and sunlight for illumination etc. Other systems make use of the active combustion of fuels, the active circulation of energy carrying fluids or means of conversion between different forms of energy in, e.g., boilers, solar heat collectors, engines, wind turbines, etc. Generally, there has historically been a shift from passive systems to active systems. At the same time, energy systems to sustain human habitats have required increasing amounts of fuel—amounts at unsustainable levels due to resource depletion and various environmental aspects. Depletion and environmental effects apply to fossil fuels as well as to, e.g., firewood, where usage has surpassed natural production.

There is an important distinction between renewable energy sources which are inexhaustible and expendable sources of energy such as fossil fuels and fissile material for nuclear power. Expendable energy sources are per se limited, and thus in the long term unsustainable. A sustainable energy supply must, therefore, be based on renewable energy sources. The only issue is the length of the transition period.

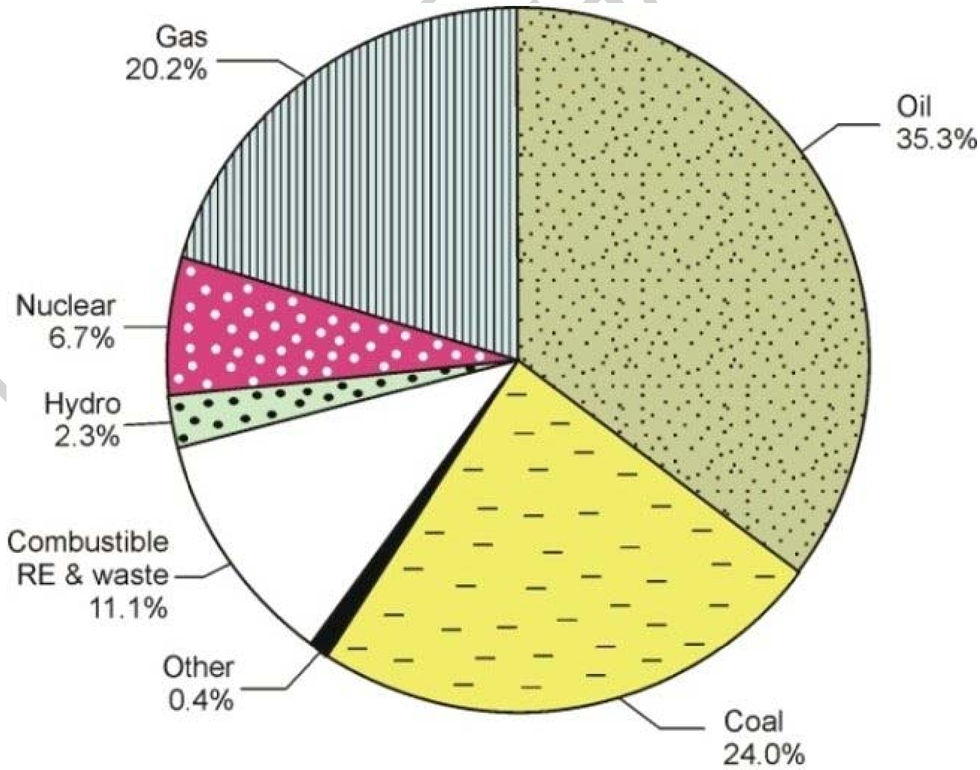

Figure 1. World energy supply shares in 1996

As indicated in Figure 1, gas, oil, coal and fissile materials account for approximately 86% of world energy consumption. The share is even larger as a certain share of the combustible waste is produced during the use of energy sources such as oil as a feedstock, e.g., for plastics production. Current (beginning of the twenty-first century) energy consumption is, therefore, not sustainable in the long term because of resource depletion. Estimated global reserves will sustain current demand for oil and gas for half a century and demand for coal for two centuries, but for less time than this with growing demand. Adverse environmental effects from energy use form other threats to present-day levels of energy consumption. Active response to the anthropogenically enhanced greenhouse effect caused by excessive energy consumption will include capping fossil fuel combustion, i.e., remedial measures. Most other environmental effects related to energy consumption may be averted by means of various so-called “end-of-pipe measures.”

The level of energy consumption in different parts of the world is determined by various factors, including the economic level of development, climate, and locally available energy sources. Dwellings in inhospitably cold areas require room heating. In both warm and economically developed areas, there are typically important energy needs for cooling. Abundance of energy sources also affect energy consumption. Areas with an abundance of energy sources often have competitive advantages with regard to energy-intensive industries, which are consequently often located in such areas. Energy prices in such areas will typically not give incentives to conserve energy or even to use it efficiently.

Transition to sustainable energy use will require a range of technical changes. From exploiting nonrenewable energy sources, renewable sources must be tapped and solutions must be tailor-made to local conditions. The efficiency of energy conversion and transmission must be improved and various energy processes must be integrated so that, for example, excess heat (cooling water) from electricity generation is utilized purposely. Excess heat from electricity production typically accounts for from half to two thirds of the calorific value of the fuel used. End-use energy consumption must be minimized through improving the efficiency of appliances, through improving the thermal efficiency of dwellings, through altering behavioral patterns and optimizing the localization of industries, and through the localization of dwellings relative to work, recreational activities, and shopping. Not only technical changes are required in a transition to sustainable energy use; technological changes of the energy system are also required. Technology embraces techniques, knowledge, organization and product (Figure 2).

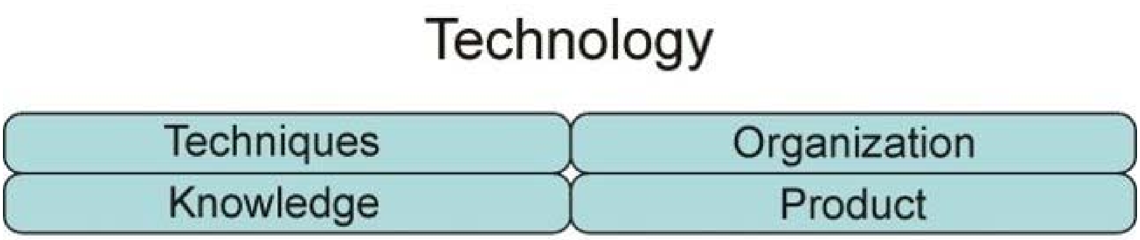

Figure 2. The four components of technology

Techniques are the technical infrastructural means, knowledge is the intellectual base required for the operation and maintenance of the techniques, organization is the human resource structure required to operate and maintain the technique, and product is the outcome—in this case the fulfillment of various energy needs such as transportation, mechanical power and illumination. The transition towards sustainable energy use will accordingly require research and development, not only in techniques, but also in technologies, as the actual transition will require both technological changes and changes in techniques.

Technical research may be defined as research in specific technical solutions to specific problems, whereas technological research in this context is often rather rather paving the way for techniques by exploring the technical, economic, sociological, organizational, and legal barriers (etc.), and the possibilities for utilizing various techniques, as well as for establishing the various prerequisites for the techniques. Analyses of power balances in energy systems with substantial amounts of electrical power from fluctuating production techniques (e.g., wind, wave and solar) being fed into the grid do not have immediate effects on the actual design of production plants, but may have long-term effects on the development of the energy system by identifying possibilities.

Likewise, a distinction may be made between the development of techniques and the development of technologies. In the development of techniques, a close product-oriented angle is applied with certain techniques being the final outcome. In the development of technologies, development embraces various different stages through to the technique being viable under commercial conditions and functioning with a proper organizational setting.

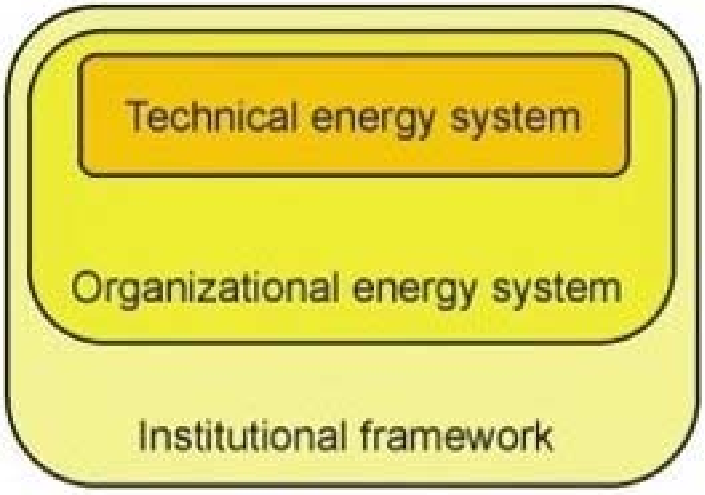

Figure 3. The technical energy system, the organizational energy system and the institutional framework. (The technical energy system contains the physical objects of the infrastructure. The organizational energy system describes how the various physical objects of the technical energy system are grouped by owner. The institutional frameworks are publicly determined factors including (a) various economic conditions such as subsidies, energy taxes and minimum prices for electricity generated on wind

turbines; (b) legislation including efficiency standards, requirements of the organizational structure; and (c) covenants and policy goals)

To sustain a transition to sustainable energy use, a number of organizational changes are required. Existing organizations established to operate the presently used energy systems must be restructured to accommodate the requirements of new energy systems. New organizational structures must be dynamic to assist the continuous innovation, development, and optimization of the energy system, and organizations and economic settings must be structured to secure the efficient use of energy (see Figure 3).

Legislation must be adjusted to assist the transition to sustainable energy use. Integrating environmental externalities into energy supply costs, and thereby evening up cost differences, will favor renewable energy sources. Establishing efficiency standards for appliances and vehicles, for instance, will stimulate innovation.

There are important distribution and development issues in regard to energy use in industrialized vs. developing nations, e.g., fair distribution of resources, and economic development without reenacting the energy and environmental history of the industrialized countries. This will involve the transfer of capability building knowledge rather than technology to increase local awareness and to increase local ability to choose or design appropriate energy paths tailor-made for local conditions.

2. Energy from a Technical Perspective

In parallel with continuous rising demands for various energy services in dwellings, production, transport, etc., the need for energy has risen historically. The Earth has a number of potentially exploitable energy sources, most of which stem directly or indirectly from solar radiation, but even with the numerous sources, fossil fuels are of paramount importance in modern energy supply. Energy reserves that were built up over eons however, are being depleted in what geologically constitutes a brief time span.

2.1 Energy Sources

Solar radiation is the primary energy source in the world. Solar radiation may be utilized directly via solar collectors or solar cells. Solar cells generate electricity directly in a photovoltaic process, whereas solar collectors heat a fluid that can be used for heating purposes or for electricity generation through turbines.

The indirect uses of solar radiation are more diverse. Solar warming of soil and water may be exploited directly, or via the use of, for example, heat pumps in the form of indirect solar collector. Through photosynthesis, plants sequester carbon from the atmosphere in addition to binding hydrogen and other elements from water and soil. The energy contents in plants may be released on demand through combustion.

Fossil fuels—oil, coal, natural gas—are reservoirs of fossilized photosynthetically generated plant material or the fossilized remains of organisms which bred on the plant material.

Atmospheric movements, and hence wind power, are attributable to atmospheric pressure variations caused by temperature variations triggered by solar warming.

Wave power is wind power harnessed by the upper levels of the water in oceans and lakes.

Hydropower is the tapping of the solar radiation-run global water cycle, in which water is evaporated from water reservoirs and falls as precipitation at higher ground levels having thus gained potential energy.
Nuclear power can be used in three main processes. Fission is what is usually referred to as nuclear power, i.e., the splitting of uranium, plutonium or thorium atomic nuclei, thereby releasing thermal energy. Geothermal energy from volcanic activity is attributable to natural nuclear fission in the earth. Fusion—the merging of light atoms, e.g., hydrogen and helium, is not yet harnessed. Fusion only takes place uncontrollably in stars and in hydrogen bombs, but as the world has ample supplies of hydrogen in water, this is an area of research.

The last main category of energy sources is the gravitational force between the earth and the moon. This force causes tidal differences which may be exploited for energy purposes (see Table 1).

Solar—direct	**Solar—indirect**	**Nuclear**	**Gravitational force**
Solar radiation	Photosynthesis Geothermal energy Wind power Wave power Hydropower	Fission Fusion Geothermal energy	Tidal power

Table 1. Energy sources

2.2 Fluctuating Sources of Energy vs. Reserves of Energy

An important distinction in regard to energy systems operation is between sources of energy that compose a reserve of energy that may be utilized on demand, and sources of energy that fluctuate uncontrollably. Fissile materials, fossil fuels, crops harvested for energy use, and geothermal energy, may be utilized on demand. Hydropower and tidal power may also be utilized on demand in a controlled manner subject to generally foreseeable limitations and diurnal and yearly variation. In most energy plants trapping solar radiation for heating purposes, heat storage is used to even out energy supply differences resulting from diurnal up to yearly variations. Electricity generation from solar radiation in either photovoltaic processes (solar cells) or thermodynamic processes (steam turbines), and electricity production from wave and wind power is meteorologically determined and may not be used on demand. Energy systems exploiting fluctuating energy sources thus require backup from controllable energy sources, or energy storage, or means of adapting energy consumption to the immediately available energy sources.

2.3 Replenishment Rates of Sources of Energy

The various sources of energy may also be distinguished by their replenishment rates into two rather broad categories—expendable sources of energy, and renewable sources of energies. Expendable sources of energy include fissile materials and fossil fuels. Fossil fuels have replenishment rates that are irrelevant in energy supply terms. Nuclear geothermal energy may be categorized as both an expendable and renewable source of energy. Depending on the rate of drainage of underground heat reservoirs and on the nature of these reservoirs, they may or may not be practically exhaustible. A similar relationship applies to solar geothermal energy.

Renewable energy sources have comparably high replenishment rates relative to other time spans in human lives. Some sources of renewable energy have a permanent nature (not counting diurnal and yearly variation). Among these are hydropower, solar radiation, and wind and wave power. These may be tapped continuously as the source has a permanent energy flow. Other renewable sources of energy, such as energy crops, have lengthy time spans ranging from a seasonal level for cereals, to a few years (for willow, for example) or decades (for various other types of trees).

Various bio-fuels, most notably firewood, are only renewable to the extent that use does not exceed the net production of a given area. In many areas, use of wood (for example) exceeds production, thus causing deforestation and erosion. It should also be noted that there is another issue, yet to be resolved. The growing of crops in common industrialized farming requires the use of fertilizers, pesticides and various machinery. If bio-fuels are cultivated in such a manner, a number of indirect energy uses will follow. The production of fertilizers as well as of pesticides requires fuel, and machinery for tilling the soil will equally require an energy input. When crops are grown for food, it is not very relevant to weigh the energy input (fossil fuels) against the energy output (digestible joules), as there is no substitutability between the input and the output. However, there is substitutability in regard to crops grown for energy purposes, and it is, therefore, very relevant to weigh energy outputs against energy inputs. The overall viability of using bio-fuels depends on the ratio of fuel output to fuel input.

2.4 Climatic Availability of Energy Sources

Climate influences both the availability of energy sources and the demand for energy. Renewable energy sources in particular are determined by climate. Solar radiation decreases with latitude although even in Northern Europe, solar collectors supply many houses with hot water for consumption during the summer. Closer to the equator, the output for a given area of solar collectors is larger, and the season is longer, so solar collectors may be used all year round to supply hot water. Production based on solar cells also varies with latitude.

Wind power naturally varies with wind speed. In a transition to renewable energy based energy supply, it is important to address not only the average wind speeds of a given area, but also the yearly distribution. The potential for hydroelectricity varies with precipitation, and geography must support hydroelectricity—i.e., render difference in level as well as the possibility of containment of a reservoir. The growing of bio-fuels is also affected by various climatic factors—sunshine, temperature levels, and precipitation, and by soil conditions.

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Biographical Sketches

Poul Alberg Østergaard has been an assistant professor at the Department of Development and Planning, Faculty of Engineering and Science, Aalborg University, Denmark, since 1998. His field of research includes technical energy systems analyses as well as analyses of the organizational and economic changes needed to further changes in the energy system towards sustainable energy use. He is presently (2001–2003) the head of a research project aimed at analyzing the technical problems incurred when going from energy systems with power production centralized in a few large power stations to energy systems with geographically distributed power production based on, e.g., wind turbines, small-scale cogeneration plants, and solar cells. He teaches in the M.Sc. program in Environmental Management and the M.Sc.Eng. program in Environmental and Energy Planning at Aalborg University. He has an M.Sc.Eng. and a Ph.D. in energy planning,

Prof. Frede Hvelplunds background is Economy and Social Anthropology, and he works at the Department of Planning and Development at Aalborg University, Denmark. His research deals with the links between technical development and socioeconomic-political conditions determining this development. The research is especially carried out within the field of Energy Planning. He has, since 1976, developed this area especially related to the transformation from fossil fuel- and uranium-based technologies to solutions based upon the increased use of energy conservation and renewable energy. In connection with this he has participated in the development of several energy plans in which this transformation is brought into focus. It is a main line in this work, that there is a broad spectrum of new technical solutions, and that their implementation requires the development of new institutions at the administrative as well as the political level. Most of his publications are written in Danish, with the purpose of both developing scientific knowledge, and supplying a scientific background for the transformation to energy conservation and renewable energy based energy systems in Denmark. The publications (many articles and books) thus have played a role for the democratic process leading to the ongoing transformation within the Danish energy system. Regarding international activities, he is the coauthor of an alternative energy plan for the former DDR, and an alternative energy plan for a part of Thailand. He also has worked with energy research and energy planning in Africa, South America and Eastern Europe. Furthermore, he has published an array of articles in international journals such as *Energy Policy*, *Scandinavian Housing and Planning Research*, *Energy the International Journal*, etc.