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SUSTAINABLE ENERGY

Many simultaneous actions are needed in order to achieve a globally sustainable socio-technical system. The first two lines of attack listed below have been addressed in the chapters on Energy S&D and Efficiency respectively; this chapter focuses on renewable alternatives to fossil fuel and nuclear power as sources of energy.

Strategies (mainly social) to reduce aggregate consumption

1. Adopt a less energy-intensive style of living in the high consumption countries through a combination of frugality and conservation (there is no evidence that this would affect the NICs such as China).
2. Reduce armaments[1], space ventures and megaprojects.
3. Target all development assistance to population control, including research into the cultural causes of high birth rates (which are not necessarily correlated with either affluence or poverty). Clearly technology has many roles to play particularly in the development of culturally acceptable technologies of population control, but there is no consensus on the correct technical solutions, let alone the political ones.

Efficiencies

1. Increase efficiency of end-use applications. This area offers the greatest scope but we are dealing with socio-technical systems and the human factor is central.
2. Increase efficiency of power generation through research and development of new technologies and removal of institutional barriers.

Alternatives

There are many alternative sources of energy to replace fossil fuels and nuclear power. Their present disadvantage is in cost, their advantage is that they are potentially sustainable and generally non-polluting. A survey of the principal alternative energy sources is the topic of this lecture.

Figure 192 shows that the sources of alternate energy come from the interior of the Earth, the Moon, and the Sun. The sun is by far the most important source.

EARTH

The earth is radioactive at depth and it also re-radiates heat absorbed from the sun. The net outflow or flux at the surface of the earth averages 50 mW/m2. Heat energy recovered from the earth is called geothermal.

There are four types of geothermal heat recovery system.

High temperature gradient	Normal temperature gradient
Geysers	Shallow geothermal (~100 m)
Hot dry rock	Deep geothermal (1- 4 km)

High geothermal gradient

Hydrothermal sources

Springs and boreholes to tap naturally hot waters in regions of unusually high gradient Possibilities for this exist in BC similar to the active and successful operations in the Imperial Valley CA, USA (1 GW), Philippines and New Zealand. Some come naturally to the surface as geysers. The steam is used to drive conventional electric turbines.

Hot Dry Rock

Boreholes drilled into regions of Hot Dry Rock through which fluids could be circulated to remove the heat. Certain locations in the UK indicated promise for this technology: the problem was to open suitable fractures in the rock. Experiments to date have not been encouraging.

Normal geothermal gradient

Deep geothermal

Schemes using medium temperature water in regions of normal gradient (30 to 50°C/km). Abandoned wells drilled for oil but finding brine may have an abundant supply of hot water at 2000 to 3000 m. A proposal has been made for the Town of Edson, Alberta, to use geothermal water at either 1500 m with a temperature of 45 °C or 3500 m at 95 °C with heat transfer being effected by a heat pump driven by natural gas. No new technology is required but experience in the cost of construction has to be obtained. In the UK, proposals for using geothermal water as feed stock for power stations show savings of 5% in the amount of fossil fuel used. In Springhill N.S., the mines abandoned after the 1958 disaster have a temperature of 20°C. This energy is extracted by heat pumps and used by local industry.[2]

Although a survey indicates that about 5 GW of low temperature deep geothermal energy is being used in the world[3], this does not look a promising major source. The problem is primarily economic but many areas of the technology need more research[4].

Shallow geothermal

The use of heat pumps to extract very low grade heat from shallow groundwater beneath a building or from rivers. For example Carleton University extracts heat from the groundwater beneath the campus; the Festival Hall in London extracts heat from the Thames. A heat pump is simply a reverse-flow refrigerator[5] and, like a fridge, it uses chlorofluorocarbons as refrigerant gases. These are now environmentally unacceptable and replacement fluids or new technologies need to be found.

MOON

Mills or turbines placed in the path of strong tidal flows turn the gravitational energy of the moon into kinetic energy that can be used to grind wheat or to generate electricity. This is an ancient technology. There is an old tide mill still operative in England that was built in 1610[6]. The World's largest tidal operating system at La Rance in France generates 240 MW, five times Calgary Power's Ghost River Plant. Canada's Bay of Fundy seems an ideal location for a tidal power station and has been under investigation for many decades. A pilot project across the Annapolis River was installed in 1984.[7] Problems so far identified include massive fish kills in the turbines and disruption of the sedimentary regime.

As an alternative to estuarine locations, tide-mills could be anchored to the sea floor and supported by a buoy. So far, calculations show that the price is not competitive.[8]

Fig. 192 RENEWABLE ENERGY RESOURCES

- **EARTH** — Geothermal
  - High gradient
  - Normal gradient
- **MOON** — Tidal
- **SUN** — Solar
  - Direct
    - Heat
      - Passive
      - Active
        - Tracking
        - Stationary
          - Ocean
          - Land
    - Light
      - Photochemical (BIOMASS)
      - Photovoltaic
        - Terrestrial
        - Extraterrestrial
  - Indirect
    - Hydro
    - Wind
    - Wave
    - Current

SUN

Solar radiation can provide available energy either directly or indirectly through differential heating of the atmosphere and evaporation of surface water..

Direct sources of solar energy

Direct solar energy is divided into long and short waves or, in other words, heat and light.

Heat

Solar Heat can be collected **passively** for domestic use: this is a matter of intelligent architecture (design) or the installation of convection flat-plate collectors - a favourite low cost project in subtropical countries; particularly common in Australia and Israel. The Rocky Mountain Institute, directed by Hunter and Amory Lovins, has, for years, provided a demonstration of the effectiveness of passive solar heat systems. More recently, Autonomous and Sustainable Housing Inc. of Calgary has built a passively heated home/office in Calgary which is able to operate comfortably in Alberta's severe winters without any supply of natural gas.

Active heat collection involves the input of energy (work) to (i) circulating pumps for heat exchangers in conjunction with a variety of stationary devices, (ii) tracking parabolic reflectors -(dishes and troughs) or (iii) multiple heliostats which focus the sun's rays on a central heat collector. The tracking systems need considerable astronomical sophistication and computer assisted hardware. The largest solar installation in the world at the time of writing covered 518 ha in the Mojave Desert and supplied two generating stations, each with a nominal capacity of 80 MW.[9]

A recent invention focuses the sun's rays with a funnel shaped device onto a set of ceramic pins enclosed in gas under high pressure (one megapascal). Temperatures of 1200-1350°C are attained in the gas which is used to drive gas turbines. Israeli scientists are "cautiously optimistic" that this equipment could generate electricity a process competitive with fossil fuels.[10]

The difference in temperature between warm tropical sea water at the surface (40 °C) and at depth can be exploited by means of a heat pump. This is called Ocean Thermal Energy Conversion (OTEC). Only models have been constructed. The economics would be promising if it were not for the fact that the most suitable areas for installation are usually oil and gas rich. An invention operating on the same principle would use the difference in temperature between ground level and a condensing station 5 km up in the atmosphere. The tower would be supported by helium balloons.

Light

Photochemical reactions

Light can also be used by natural or artificial **photosynthesis** using the active ingredient of chlorophyll. Photosynthesis, besides feeding us and all other animal life, can provide renewable energy in the form of biomass. Stored biomass comprises the fossil fuel endowment of the earth. Lynn Margulis recently reiterated the fact that we are "using 40 percent of net photosynthetic production for humans and you've got to be out of your mind if you think we can use 80 percent."[11]

In the scenario for future energy supply developed by The Energy Foundation [12] (Table below), **biomass plays a major role amongst the renewables** especially for direct fuel use (as methanol, ethanol, hydrogen and biogas)**,** followed by "intermittent renewables" (wind and direct solar power), hydroelectric power and electrolytic hydrogen generated by wind turbines and photovoltaic cells. Their scenario for 2050 falls between the Brundtland A and B scenarios at about 20 TW of thermal energy equivalent, for a population of about ten billion[13]. This target is based on the work of the Intergovernmental Panel on Climatic Change and to achieve it would also require enormous improvements in energy efficiency. All parties are agreed that drastic changes to government policy would be required in order to meet these targets.

Energy Source	Thermal Energy/TW (Direct Fuel)	Electrical Energy/TW
Coal	1.47	0.25
Oil	1.99	0.00
Gas	1.73	0.91
Nuclear	0.00	0.21
Hydro	0.00	0.54
Biomass	3.45	0.46
Intermittent (H2)	0.52	1.29
TOTAL	9.16	3.66 (generated by 11 TW)

Energy Foundation prognosis for CE 2050 recalculated to SI.

The scenario calls for some 400 million ha of biomass plantations. This represents 3% of Earth's ice-free land area, only 11% of which is considered arable. Energy inputs, in the form of fertilizer, harvesting and hauling, will be required; but outputs will typically be enhanced 10 to 15 times (EROI = 10 to 15). If the harvested energy were to be discounted according to economic practice it would not be viable because of the elapsed time between investment and return.

The expectations of this scenario have been challenged by Reid Bryson formerly of the Center for Climatic Research, University of Wisconsin, who forecasts an absolute sunshine limit to the world's population at about 9.2 billion people.[14]

Current use of biomass in Canada is focused on the conversion of food grains to alcohol. This is technology is promoted in order to increase agricultural subsidies; it makes no economic sense. Ethanol plants commenced in Ontario during 1995 will benefit from an 8.5 c/L federal tax exemption and a 14.7 c/L provincial tax exemption. Moreover, the agricultural industry is subsidized to the tune of over $2 billion per year.

On a pure fuel-energy basis I have calculated that each litre of diesel oil used in cultivation will yield an energy equivalent of 34 L in ethanol (see box).

36 L of diesel fuel were used in Ontario during 1991 to grow each tonne of grain.
Each tonne of grain is estimated to contain 40 bushels.
5 million bushels of corn will be processed in the Cornwall plant of the Seaway Valley Farmers Energy Corporation to produce 50 ML of ethanol, i.e., 10 L/bushel.
Therefore each tonne of grain should yield 50 X 40 = 2000 L of ethanol
Each litre of diesel should result in the production of 2000/36 = 55 L of ethanol.
The energy content of diesel oil is (estd.) 37 MJ/L; that of ethanol is 23 MJ/L.
On an energy basis the yield must therefore be reduced to 55/37X23= 34 (gross).[15]

Unfortunately, I have no estimates of the extraction subsidy (the energy required to transform the grain into ethanol); and there are other energy costs involved in growing the grain (fertilizer, manpower, depreciation on the embodied energy of farm equipment etc.).

Another possible way of using biomass in a cold climate is by **coppicing** fast-growing species of poplar or alder. Following the "energy crisis" - 1975-1985 - the

National Research Council developed alternative energy technologies based on this resource.[16]

Rapid Thermal Processing,[17] a Canadian patented system, is treating 30 t/d of sawdust. It is estimated that a plant treating 100 t/d would produce enough bio-oil to generate about 8 MW of electricity. This is just one of the many new technologies, including landfill gas use, and the combustion of municipal solid waste, that will be using biomass when economic circumstances warrant.

Biomass is neutral with respect to the carbon dioxide cycle. The carbon released in combustion is taken up by the new crop.

Photovoltaic reactions

Light can be used by photovoltaic cells that turn light directly into electric current. Many remote sites, satellites and space stations have photovoltaic panels for electricity supply. A continuous supply of photovoltaic energy could be generated by large collectors in space, then beamed to earth in the form of microwaves. Photovoltaic sources of energy will have an increasingly important role to play.

The commonest photovoltaic devices are made out of specially prepared silicon wafers. Pure silicon is not sufficiently conductive and has to be "doped" with another element such boron to improve its conductivity before being sliced into wafers. Then the front surface of each wafer is doped with a second impurity such as phosphorous which results in the establishment of a permanent electric field. Facing the sun, the cell receives a stream of light particles (photons) some of which make electrons jump loose from their atoms of silicon. The electrons are directed to the front of the cell by the electric field. There they are collected in a wire and flow as electricity to light a lamp or charge a battery or drive a motor. The circuit must be completed by a wire to the back of the cell to return electrons to the system.

Although the raw material of silicon is common sand, the preparation of the doped wafers is an extremely high-technology activity requiring sophisticated equipment and elaborate "clean rooms". The cost is therefore high, although mass production is bringing it close to the range of competing systems. There is ample scope for research into ways to increase its cost effectiveness e.g. by focusing the sun's rays from a wider area by means of special lenses, and by experimenting with different doping agents.

An interesting feature of photovoltaic cells is that they operate most efficiently in cold conditions. This has special significance for Canada. The efficiency with which they convert solar energy varies from over 30% under laboratory conditions to 10% for the experimental cheap thin-film photovoltaic roof shingles. A good commercial cell will have an efficiency of about 17%.[18]

Indirect sources of solar energy

The sun's radiation evaporates water which is carried to higher elevations, thus gaining gravitational potential, and is deposited there as rain and snow. This is the source of hydroelectric energy. The sun's radiation also heats the earth and oceans and differentially heats the atmosphere in contact with them. This generates wind which gives rise to ocean currents and to waves besides powering turbines of various designs.

Hydroelectric Power

Hydro is already an important contributor to the world's energy supply with about 0.5 TW of installed capacity. It is a very efficient technology which converts 80-90% of the mechanical energy of the water into electricity. It is believed that world's long term economic potential might be three or four times that figure -- say around 2 TW.[19] Although the world's largest hydraulic turbines are still those installed at the Grand Coulee dam, rated at 815 MW each, the largest multiple-turbine installations are in Brazil. The station at Itaipu, on the Paraná River has recently achieved its design capacity of 13.22 GW[20]. An attractive and growing application is in small-scale hydro installations using new technology. These may be considered "alternate technologies" because many are developed by aid agencies and not-for-profit organizations. A small hydroelectric demonstration project at the Waterton Dam in south west Alberta was connected to the electric grid in 1992. This is a 2.4 MW plant built at a cost of 3.65 M$ (1.52 $/W)

Hydro is not going to solve the supply problem. There are many adverse factors to hydro power: siltation, danger of rupture of dams, water-born disease in tropical countries, loss of agricultural land, loss of fish stocks since few tropical species can use fish ladders[21], displacement of population (See chapter on The Green Revolution). Nor is hydro a truly sustainable energy source since the reservoirs have a limited life and the technology to replace a dam holding up a silt-filled reservoir can hardly be imagined.

Wind turbines

Conventional wind power is one of the oldest ways of harnessing the sun. The landscape of mediaeval England looked like picture postcards of the Netherlands or the island of Mykynos to-day. This field has attracted a tremendous amount of research.

The main technical problems with wind power are related to its intermittent nature: the periods when there is no wind and the periods when it is too strong. A cheap reliable DC/AC converter is needed for feeding into the grid. The load factor (the proportion of time the mills are actually generating current) of the California wind farms is reported to be only 9.1% The main problem is storage. It is obvious that a national electricity grid cannot be dependent upon an intermittent and unpredictable source of supply. Independent producers have to obtain an "allocation" of the amount of power the grid is willing to accept. Large scale installation of wind turbines is limited by this factor. The most promising long term solution is to use wind power to make electrolytic hydrogen from water[22]. This, in its turn, will be dependent on the development of suitable technology to convert the hydrogen back into electrical power through fuel cells or other devices. In temperate or warmer climates surplus energy can be used to recharge hydroelectric reservoirs with storage water. Small-scale storage of energy has been achieved by compressing air in cylinders and using it to drive a reversible motor/dynamo.[23]

The Alberta Office of Renewable Energy Technology initiated a series of demonstration projects in 1989. The technical problems of wind generation in cold climates are very different from those in California. Every one of the state-funded wind generators in Montana "succumbed to nature's extremes that froze gear-boxes and bent props" in December 1989[24]. Funding has now been terminated by the Alberta Government but a number of installations are still operating in the Pincher Creek area (August 1996). Fifty-seven KENETECH Model 33M-VS horizontal axis turbines, each with rotor diameter of 32 m, are installed on Cowley Ridge. The machines are variable speed and pitch, controlled from a central computer in Pincher Creek and have a total power allocation of 19 MW. Not far away, there is an experimental installation of ten vertical axis ('egg-beater') turbines with a total power of 1.5 MW. The Dutch Valley Produce Wind Farm, owned by a Hutterite colony, consists of three Danish design 65 kW wind turbines. All these installations feed to the grid which buys the power at 14.6 $/GJ (5.27 c/kW.h). The price of natural gas is 3.30 $/GJ and the cost of electrical power from the new coal-fired plant near Edmonton will be 16.66 $/GJ. The City of Calgary charges customers about 14.44 $/GJ.

Installed cost for commercial machines run between 1 and 2 $/W.

Vertical axis wind turbines need far less structural strength than the commoner horizontal axis machine. They are independent of wind direction but usually need some auxiliary equipment for start-up. The National Research Council has researched these and built prototypes. Hydro-Quebec and the NRC built a 96-m tall vertical axis turbine at Cap Chat designed to yield 4 MW. The cost was 35.2 M$ i.e. 8.8 $/W. The program was scratched as part of the Mulroney government's policy to reduce investment in alternative energy. It was taken over by the builder, Lavalin Engineers Inc. which has operated the installation as part of the Quebec electricity grid for the last few years.

At least 1 GW of wind energy has already been installed in California. The ultimate global capacity of wind power exceeds tidal, hydro and geothermal combined. However, if wind extraction were to be pursued with "enormous diligence" the level of energy capture might be such as to significantly perturb the natural energy processes and change the climate[25]. Nevertheless, from *a purely meteorological viewpoint*, an extraction rate of two terawatts could be contemplated. for the USA and 130 TW for the entire world. In practice, however, nothing like this could be achieved. The area required by wind farms is by no means negligible. It has been estimated that a farm producing 1.2 GW (the amount to be output by the new nuclear reactor at Sizewell, U.K.) would cover 290 to 370 km^2 (about three townships). This figures out at an area of 0.3 m^2/W

Wind farms generating 35 TW (the high Brundtland scenario) would therefore require about one billion hectares of land surface. This is about two thirds the area of arable land on the globe (1.4 billion ha).

A reasonable estimate of the ultimate contribution of wind to the world's energy needs would be in the range of 1 to 3 TW.

Environmentally, wind farms are unwelcome on aesthetic grounds and produce substantial levels of noise pollution. However, in contrast to solar installations, they can share the site with pastoral activities.

Wave Power

Both land based and freely floating devices have been invented to harness the mechanical energy of waves. Britain and Norway have ideal wave climates. The three principal types involve: straight mechanical energy from flexible rafts; turbines driven by the water; turbines driven by air trapped in an oscillating column. Schemes generating 2 GW at a cost of 6 G$ were proposed for the Hebrides during the oil price escalation. But there are many technical problems including engineering to withstand severe storms. Norway had a major loss of their wave machine in 1988. The British Osprey wave power machine was destroyed off the north Scottish coast in the summer of 1995. A Japanese model, The Mighty Whale, is planned for completion in 1997. It is hoped to convert 16 to 20% of wave energy into electricity at 30 Yen/kW.h (about 3 times cost of conventional energy).[26]

The actual cost data are now uncertain as it was found that the British Ministry of Energy had fraudulently recorded less than the observed efficiency during a sea test.

Ocean currents

Ocean currents driven by wind are more persistent than the wind itself. It has been proposed to mount low velocity turbines in the path of these currents. A vertical axis machine with blades 100 m long might generate 10 MW in a 2 m/s current. The Gulf Stream passes the Miami Coast at 2.5 m/s. Lisseman[27] says taking 10 GW out of this system would have no noticeable effect on the current regime. He reckons he could do it for an installation cost of 1 $/W.

Conclusions

Research into alternative energy systems faces the problem of scale. Until large-scale production is achieved, installed cost per watt will remain higher than the cost of conventional fossil fuel sources. Nevertheless, in remote sites or specially favoured localities (very windy or sunny places, for example) power can already be delivered at a lower cost than through conventional means.

The overarching problem for so many alternative systems is their intermittent nature, which requires the development of efficient large-scale storage technology. Research into this aspect of the problem is in its infancy. As mentioned above, a hydrogen-based system seems to hold the greatest promise, but DaimlerBenz, who seem to be most advanced in hydrogen technology for automobiles, have decided to produce the gas on board the vehicle by reformation of methanol. The DaimlerBenz prototype vehicle uses a Ballard fuel cell (Ballard is a British Columbia company). Methanol can be produced from biomass but it is economically attractive to produce it from natural gas, a fossil fuel, in which case the carbon dioxide emission problem is not eliminated, although it is reduced by 50%[28]. Moreover, water vapour, a radiatively active gas, is produced in large quantities and might result in microclimate modification.[29]

For a long time into the future, the capital installations necessary for the production of alternative energy equipment will be the product of conventional manufacture and will thus embody congealed fossil fuel energy. In other words, the first stages in developing alternative sources involve the diversion of fossil-based energy rather than its substitution. This should suggest to governments - the only institutions capable of long-term planning - that the move to sustainable energy must take place **before** the exhaustion of fossil fuel supplies.

Review Questions

1. What areas of Canada do you think would be suitable for various types of geothermal energy?

2. What is a promising way of storing large amounts of wind-generated energy in situations where it cannot be taken by the grid?

3. Describe three ways in which biomass might be used as a source of renewable energy. What is the effect of biomass use on the amount of carbon dioxide in the atmosphere?

4. How can the direct heat of the sun be harnessed?

5. What are the environmental drawbacks of wind power?

6. What do you understand by "allocation" in the context of independent power production?

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[1]Regarding the diversion of energy into armaments, Seymour Melman has calculated that over his period of study the US Department of Defense spent $7,620 billion while the value of plant and services in the rest of the economy was $7,292.

[2]"Springhill mines heat town's economy" Report on Business, 2 Jan 1991, B4.
In New Brunswick, a study (Chandra, 1985) indicated that there were economic opportunities for heating large office complexes providing a gradient of 30 °C/km could be found. Alberta has many regions with a gradient of 50 °C/km.

[3] Elkington p.130

[4] Hunt, Table 1-3-1

[5]See Figs. 193, 209 and attachment for details of operation.

[6]Elkington, p.281

[7]Report on Business, 8 Aug 1989, B3.

[8]New Scientist 2 Apr. 1993 p.10

[9]Guiness Book of Records, 1996.

[10]Watzman, Haim (1996) Solar power turns on the heat. *New Scientist*, 11 May 1996, p.21.

[11]Margulis is Distinguished University Professor of Biology at the University of Massachusetts at Amherst. Utne Reader , March-April 1996, p.73.

[12]Johansson et al. 1993, p2.

[13]Johansson et al. provide electrical energy forecasts in TW.h/a and fuel energy forecasts in EJ/a. Both have been converted to power forecasts in TW. To obtain the total primary power use of 20 TW, I have assumed that three units of thermal power are needed to generate one unit of electrical power. I believe this makes the total comparable to the Brundtland Commission forecasts.

[14]Personal communication.

[15]Sources (i) Shell Pecten 14 Mar 1995; (2) Clarence Swanton & David Clements of the Dept. of Crop Science, Guelph (reported by Globe and Mail Middle Kingdom 26 Dec 1995, A5).

[16]Alternative Energy Technology in Canada: NRC's Energy R&D Program 1975-1985. Ottawa: National Research Council 1986.

[17]RD Bulletin, Government Services, Canada. No.245, Sept.1993.

[18]Elizabeth Manning "Heat on a hot, thin roof" *New Scientist* 13 July 1996.

[19]Johansson et al. p77.

[20]Guiness Book of Records, 1996.

[21]"Dam in Thailand threatens a way of life". Globe and Mail 4 Mar.1996.

[22]The electricity can also be used on the spot to make ozone, a non-polluting substitute for chlorine in all bleaching and disinfectant applications.
[23]University of Bristol exhibit at the Intermediate Technology Centre, Machynlleth, Wales.
[24]Mike Lamb "Caution urged by windmill expert". Calgary Herald, 29 Dec. 1989, B6.
[25]Gustavson, 1979
[26]"The mighty whale that rules the waves". New Scientist, 25 Nov. 1995, p.42.
[27]Reference not immediately available.
[28]DaimlerBenz, *Environmental Report 1996*, p11.
[29]I have no quantitative data on this phenomenon at the present time.