mechanical and electrical) will be needed. They will need a support staff of 200 scientists and technicians to handle the quality control, environmental and other duties that will be necessary. Obviously our educational facilities will have to be examined now if the needed professional staffs are to be produced in Canada to service the coal mining industry during its growth years.

If additional coal is required for synthesizing, then obviously additional professional men and women must be trained.

Whether coal supplies should be reserved to provide chemicals, synthetic fibres, foodstuffs, etc. in the future, is a question that should be weighed against the volume of Canadian coal reserves. We have on hand 10.2 billion tons measured, 50.7 billion tons indicated and 59.3 billion tons inferred for a total of 120.2 billion tons, enough to last us hundreds of years by the standards of the year 2000. The synthetic products of coal will require energy to produce so there is a very good chance that our coal reserves can both produce the products and provide the energy needed to do so.

The technological capabilities that have to be developed in Canada for our energy future by the early 21st century are

(i) The capability to use geothermal energy;
(ii) The capability to gasify Canadian coals;
(iii) The capability to develop the Athabaska reserves below 150 feet;
(iv) The capability to generate hydrogen on a large scale;
(v) The capability to use solar energy for space heating;
(vi) The capability to produce synthetic fuels based on man-made carbon-hydrogen bonds.

A. E. PALLISTER,
Vice-Chairman,
Science Council
of Canada,
speaking to the
10th Commonwealth
Mining and Metallurgical
Congress, Ottawa,
Sept. 3, 1973.

SOLAR ENERGY and WORLD PROBLEMS

Extensive solar energy utilization is likely to be a long-term affair. This summary deals with the non-electric and the electric power generation areas of solar energy utilization. A plea is made for a generous amount of energy being available for each person in the world, a goal requiring reduced world population.

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MOST OF the summary version of this talk deals with the present situation and future possibilities of solar energy utilization.

Conventional sources of energy, such as hydrocarbons, have finite useful lifetimes and cannot meet world needs indefinitely. With the continued growth of world population and industrialization, new, essentially inexhaustible, energy sources need to be developed and phased into production as conventional sources approach exhaustion. In the long run, yet probably within the next 40 or 50 years, solar and fusion energy seem most promising. Solar energy has the virtues that it is free, essentially inexhaustible, and non-polluting. Some of its disadvantages are that it is a cyclic rather than continuous source; its magnitude varies with position and weather; and, most important, it arrives with a low power density.

In spite of its disadvantages, to what degree could solar energy supply earth's needs? Currently, the world uses appreciably less than 1Q($Q=10^{18}$Btu) per year; by the year 2000 between 1 and 2 Q usage is likely. The total solar energy intercepted by the earth in a year is of the order of 5000 Q. Although only 47% reaches the surface of the earth, there is clearly enough available if it can be economically collected and converted to useful form. The low power density at the surface, about 160 watt/m^2, averaged over day and night and the entire surface, is the main impediment to surface solar energy harvesting. Although there seem to be no fundamental difficulties in principle, there remain formidable engineering problems before solar energy can supply an appreciable fraction of the world's needs. It has been estimated, however, that solar energy will be extensively used for residential space and water heating in the USA by 1993; for total energy systems in commercial plants by 2000; and for large-scale power generation by 2016. By the year 2020, it is expected that solar energy could potentially satisfy as much as 26% of the total USA energy demand.

Utilization

Solar energy utilization is conventionally divided into non-electric and electric power generation areas. Two main

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SOLAR

non-electric categories are heating and cooling of buildings and bioconversions for fuels. The general area of biological photosynthesis, where overall energy conversion efficiency lies in the range of 0.3 to 3%, was not directly considered in the talk. A promising solar-energy-related biological line of research is that of inducing nitrogen-fixing bacteria to associate with important cereal crops. Such association could greatly reduce the nitrogen-containing fertilizer requirement for such crops. The energy for nitrogen fixation would ultimately be solar here, and it would allow considerable overall energy savings. Researchers at Cornell University have estimated that almost one-third of the energy expended for corn production in the USA is associated with the nitrogen fertilizer used. Further, George Sweeney of A. D. Little, Inc., has concluded that the energy consumed by commercial ammonia synthesis in 1972 was equivalent to 300 million barrels of oil. Success in this line of research could thus be very meaningful for Canada with its extensive wheat production.

The figure shows a diagram of a simple solar energy collector-heater. A well designed solar energy heater can have as high as 40% overall energy conversion efficiency; and it has been estimated that present solar collection technology could allow the savings of 70% of residential energy expenditures in the Southwestern USA. When higher temperatures are required, as for steam power generators, parabolic rather than flat solar collectors must be used to focus the sun's rays on the heat transfer fluid. At present, however, the cost of producing electricity by this route is perhaps as much as four times higher than that for fossil fuels or nuclear fission power plants.

In addition to direct solar thermal energy conversion for electric power generation, such power can be produced by photovoltaic conversion, ocean thermal energy conversion, hydropower, and wind conversion. This summary does not deal with the last two possibilities, which have either a small total energy production potential or appear uneconomic for large scale power production.

Photovoltaic converters, or solar cells, using such materials as CdS or Si in a pn-junction configuration, currently are costly and have low efficiencies. Maximum practical efficiency probably lies between 15 and 20%. Thus, covering the entire roof of a typical house with solar cells would not yield enough power to satisfy all the energy needs of the house. Solar cells currently cost about $30 per peak watt and about $150 per 24-hour average watt, about 100 times too high to allow them to be cost competitive. The National Science Foundation projects the peak watt cost at as low as $5 by 1977 and has set a goal of 50¢ by 1979. Promising possibilities are the mass production of continuous single-crystal silicon ribbon and the production of low-cost (and low efficiency) polycrystalline material. Peter Glaser of A. D. Little has suggested a far out application of solar cells. His idea is to dispose large-area collectors in earth orbit at about 22,000 miles, and to transmit the collected energy to earth via microwaves. This approach does not seem economic or perhaps even safe at the present time.

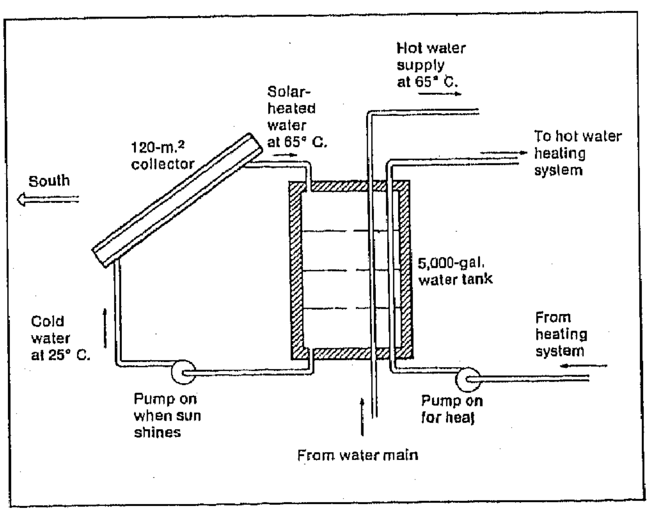


Figure 1 — The simplest solar energy systems are those designed for domestic space and hot water heating. In such systems an inclined southerly-facing flat collector is typically coupled with a heat storage system from which heat can be drawn when required. This diagram shows a combination system which provides domestic hot water at 65°C and hot water, as well, for space heating. From "Solar Energy: Its Time is Near", Technology Review 76, No. 2, page 34, December 1973.

Ocean based solar energy conversion is planned to take advantage of the ~ 20°C difference in temperature between the warm surface layer of the ocean in e.g. the Caribbean Gulf Stream and the cold water at 600-800 meters depth. A heat engine using a very low boiling-point working fluid, such as ammonia, is envisioned. Because of the low Carnot efficiency, very large volumes of water would have to be processed, and it has been proposed that the boiler and condenser be operated underwater, where water pressure on the outside could balance internal pressures, allowing much cheaper construction. Although 70% of the solar energy absorbed by the earth passes through the 360 million square kilometers of ocean surface, making it the largest solar energy collector, ocean thermal energy conversion is unlikely to develop fast enough to yield significant power in the near future. Nevertheless, it holds appreciable promise in the long run.

Symptom of a Limited World

The energy shortage is both a symptom and a warning. There was once no shortage of energy; there is a shortage now because people in economically developed countries continue to use more and more of a limited supply of energy. In fact, the USA and Canada lead the rest of the world in per capita energy consumption.

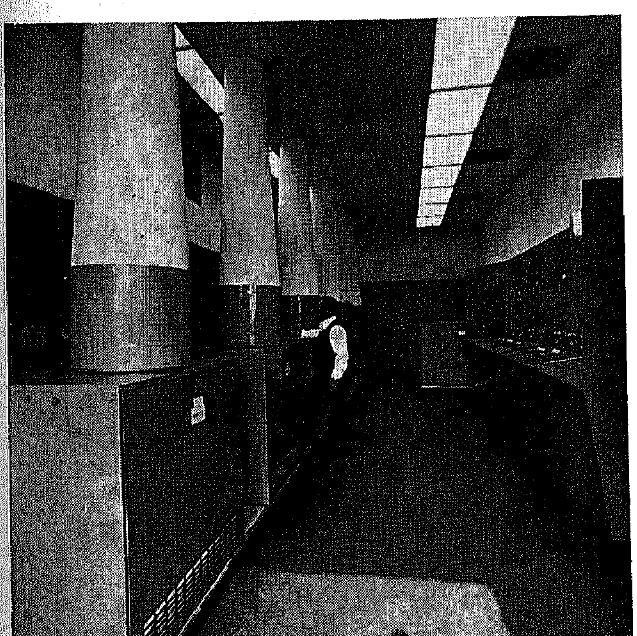
There is no question that high energy use is a concomitant of what most people who have experienced it consider the "good life." It can free more people for artistic and intellectual endeavors, common marks of a high level of civilization. In the old days, only a few people were free in this sense; the rest were slaves of one kind or another, there to provide the needed background energy. Today the world has the potential for universal freedom of this kind if the constraints of society and energy availability allow it. To achieve it, I believe we need to design and realize a world which maximizes the product π_w of human quality times human quantity, a very different goal than "the greatest good for the greatest number."

Those of us in the developed world look more and more insular and uncaring as we continue to increase our total energy consumption at rates of 5 percent per year or more while elsewhere more and more humans go hungry and even starve. But even if cheap fusion energy were available and maximum solar energy were utilized so that the present world population could have the current USA per capita energy consumption (leading to a total energy release of about 1.2Q/yr), the world would soon develop serious problems of shortages of non-renewable natural resources and unacceptable local hot spots. Even today, the energy release in Manhattan, NY is over six times the average of the sun's energy absorbed there. Further increases in population and/or per capita energy use could lead eventually to sufficient warming of the whole biosphere to cause serious effects on global weather. Unlimited energy availability is not the answer because spaceship earth is intrinsically finite. Quantity must thus be limited but quality need not be.

In the energy shortage we begin to feel one of the first major symptoms of the problem of a limited world. Unless population growth is soon limited by man's own reason, famine and war will do it for us. I believe that all humans deserve to have available a high level of energy, not just those of us in favored countries. Our present selfish maintenance of a shaky metastable equilibrium between haves and have-nots is foredoomed to eventual failure. I further believe that much energy can be available for all if we are realistic about what is possible in a finite earth.

To my mind, it is clear that π_w is far from maximized with the present world population level. Population should be controlled and reduced across the world, us and them, so that a generous amount of energy would be available for each person. Note that 10^9 people each using on the average 20kwh (twice the current US level) leads to about 0.6Q/yr, not an entirely impractical long-term value. A stable population level based on shared renewable energy and material natural resources is possible and infinitely desirable. We are far from such a level today.

Today we deal with a symptom, energy needs and shortages, not with the basic cause of our problems, too many people to share the wealth of the world at a civilized level. While it is well to consider the magnitude of the energy problem and how it may be ameliorated, wouldn't it be sensible to make mildly optimistic estimates for the year 2000 of total energy availability from all sources now operative and under development and use these results as one of the inputs for a study of what a viable equilibrium population which maximizes π_w should indeed be? The hour is late; the need is great; let's get on with the job of establishing π on earth for all.



Fuel cell experimental installation by Hydro-Québec in Québec.

NON-CONVENTIONAL SYSTEMS

The energy conversion areas which could be developed usefully in Canada, in the next few years are wind, energy, fuel cells and thermoelectric power generation. We can contribute useful research toward the hydrogen economy.

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THE WORLD'S energy sources can be divided into two groups, *Energy Capital* and *Energy Income*. *Energy Capital* results from storing solar energy in the form of chemical energy by the action of living organisms several million years ago. The fuels containing this chemical energy — coal, gas, oil — are known as fossil fuels. Extravagant use of these fuels can lead to their exhaustion. Nuclear energy is strictly energy capital too but, in the case of fusion energy, the potential supply is virtually unlimited. *Energy Income* refers to renewable energy and is exemplified by winds, hydraulic energy, geothermal energy, biomass energy and, above all, direct solar energy.

Whether or not one accepts the idea that growth should continue at the rate implicit in the forecasts of energy needs given in the other four papers, it certainly would be desirable to improve the efficiency with which energy of either group is utilized. In many instances energy passes through the form of electricity and the situation regarding the conversion of energy income into electricity is the theme of this presentation.

Several of the devices and schemes proposed for energy conversion involve a *heat engine*. In heat engines, thermal energy is converted into mechanical energy, which can then be turned into electricity. Unfortunately there is a theoretical upper limit to the efficiency of this operation, known as the *Carnot Efficiency*. Conventional power stations can operate at an efficiency of about 40%. We will now consider other systems.

Magnetohydrodynamic Power Generation

An MHD generator converts the kinetic energy of a flowing conductor into electricity by applying a magnetic field perpendicular to the flow. The electrical energy appears in the third perpendicular direction. The effect was demonstrated by Faraday as long ago as 1836, with the Thames as the conductor. MHD generators, however, use an ionized gas (plasma) as the conductor. This avoids the solid moving parts of electromechanical converters. The possibility of flowing liquid metals is under consideration.

The conductivity of the gas is increased by the addition of cesium which is very expensive. Although only 0.01% of the gas is ionized the kinetic energy of the neutral molecules is utilized through collisions with the magnetically affected ions. Good insulating refractory walls are a problem at the present operating temperature of 2000°C so that non-thermal ionization from a nuclear reactor is hence appealing. Up to now air-cooled electromagnets have been