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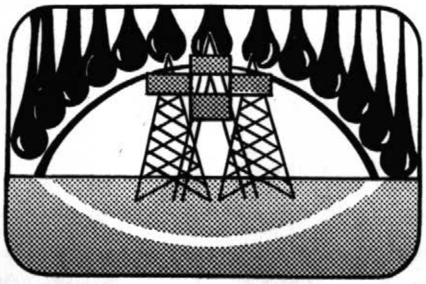

Energy – Challenge of Man's Future (Part 2)

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"In any weather, at any hour of the day or night, I have been anxious to improve the nick of time, and notch it on my stick too; to stand on the meeting of two eternities, the past and future, which is precisely the present moment; to toe that line."
Henry David Thoreau; Walden, 1854

Nuclear Energy – "A dream that is coming to birth"

We stand at the meeting of two eternities, the petroleum past and the nuclear future. The increasing and unsustainable demand for petroleum and natural gas energy has resulted in present shortages and astronomical prices, but no such limits are in sight for nuclear energy, in Canada or the rest of the world. "Do we really need this new source of energy?" Glenn Seaborg said when he was chairman of the Atomic Energy Commission. "Not only do we need nuclear power, but this source of energy has, historically speaking, been discovered just in the nick of time." (McPhee, 1973).

The demand for uranium oxide will increase steadily and exponentially at a nearly five year doubling rate (Runnalls, 1972; Nininger, 1973) a rate of change unprecedented in the history of mankind (Fig. 1). By 1985, annual western world requirements will exceed 100,000 tons of U_3O_8. The cumulative total production by then will be 1,000,000 tons, about equal to the presently measured $10 a lb. world reserve (1,208,000 tons) which can be mined from deposits in the United States, Canada, South and Southwest Africa, Australia, France, Gabon and Niger (Griffith, 1967; Williams, 1969). This uranium will feed more than three times the 300 nuclear fission reactors with a capacity of 263,000 MWE installed, committed or planned throughout 26 countries by June, 1973 (Mooradian, 1974) (Fig. 2). 50,000 MWE would provide electricity for the whole of Canada. Pickering's 2,000 megawatt CANDU plant had a capital cost of $750 million, including loading (Woodhead, 1973). 50,000 MWE would cost $20 billion, the sum that could be generated as economic rent from the sale of Alberta's conventional crude reserves, leaving Canada in complete control of her energy resources at the end of the fossil fuel era in the 1990s.

Canada's measured reserves of uranium and thorium are sufficient for our needs in any conceivable eventuality for the rest of this century and our resource base is large though unmeasured (Folinsbee and Leech, 1974). Uranium and thorium are not scarce elements in the earth's crust, but the largest single measured reserve of uranium lies in the

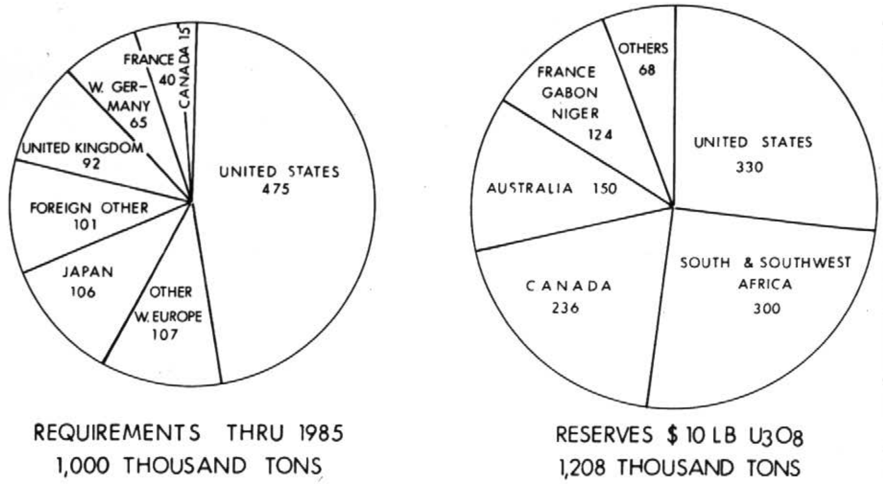

Figure 1
World uranium requirements and proven reserves available at $10 per lb. of U_3O_8 *are in approximate balance through 1985.*

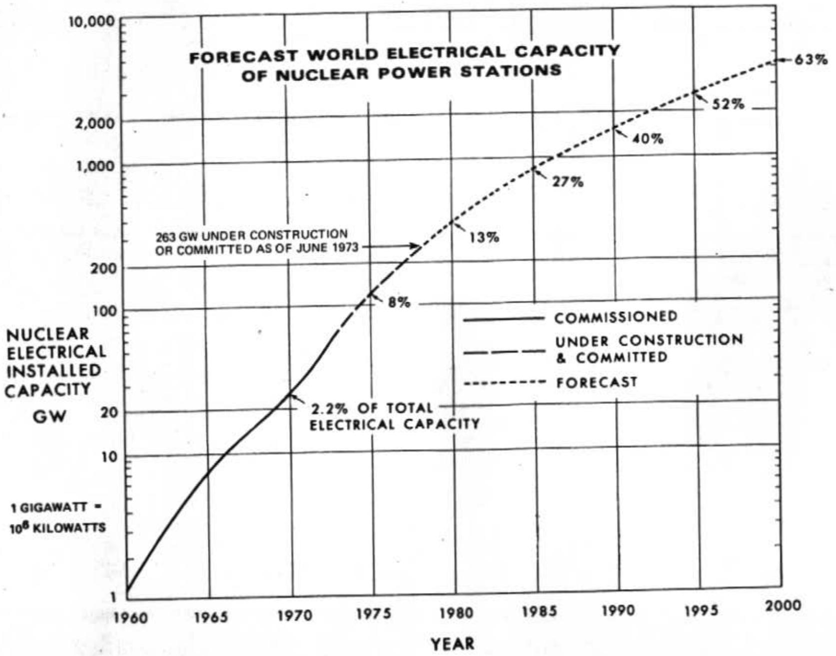

Figure 2
Forecast of world electrical capacity of nuclear power stations (excluding China) suggests nuclear power will dominate by the end of this century (Mooradian, 1974).

Precambrian pebble conglomerates of Elliott Lake, Ontario, where two companies, Denison Mines and Rio Algom control much of the world's low cost uranium. These are backed up by the Agnew Lake thorium – uranium placers where there are three pounds of thorium for every pound of uranium, waiting to be mined and burnt as U^{233} in future CANDU reactors. Much of the Blind River ore has been committed to far-sighted foreign buyers in Japan, West Germany, the United Kingdom and Spain. More small but rich deposits are concentrated in the uranium-studded shield of northern Saskatchewan at Beaverlodge (Eldorado Nuclear), Carswell Dome (Mokta) and Rabbit Lake (Gulf). A Rabbit (the fast breeder) may again keep Saskatchewan, stripped of her petroleum resources, from shivering in the cold of a prairie winter.

On the other (warm) side of the world, in South Africa 20 per cent of the world's uranium reserves lie in placer channels together with the gold washed off an ancient Precambrian terrain (Robertson, 1970). Further reserves, adding another third to the world's reserve pie, are being outlined in the Western U.S., some by Canadian companies (Rio Algom, Kerr Addison, Noranda, Denison) for a traditionally protected market free of export restrictions. The newest uranium discoveries, adding a further 150,000 tons to the total reserves, have been made in Australia (Peko Wallsend, Western Mining, Asarco) and South America will undoubtedly be next on the list. Argentina has recently announced the finding of more than enough uranium to fuel its newly purchased CANDU reactor.

These are all reserves at a $10 per pound U_3O_8 price, but moderate increases in price lead to immense increases in available uranium. At higher prices, a variety of sources become economic, from niobium-bearing carbonatites to granite pegmatites and migmatites, uraniferous shales and phosphorites. Deposits like Rossing of South West Africa (Rio Tinto Zinc) – perhaps 3,000,000 tons of U_3O_8 in pegmatites grading 1.4 lbs./ton – become mineable, and the Charlebois Lake uraniferous pegmatites of Saskatchewan become interesting (Mawdsley, 1952). Even with present day Pickering technology, the price of uranium could rise to $100 per pound U_3O_8 before the fuelling cost would match that of a coal-fired station in Ontario using low-sulphur coal (Mooradian, 1974), a price at which even sea-water uranium extraction is feasible and available to every nation of the world.

It is easier to appreciate the vast quantities of energy obtainable from these deposits if we put their energy content in terms of barrels of oil. The rich concentration of uranium at Rabbit Lake will be drawn from a rabbit hole 1400 feet long, 400 feet deep and 400 feet long, at a rate of 15,000 lb. U_3O_8 per day. Fuelling a conventional reactor will produce energy equivalent to 300,000 bbl oil, in a CANDU reactor, 1,000,000 bbl oil or in a breeder reactor, 90,000,000 bbl oil. In one year, Rabbit Lake can supply as much energy fuel, used in a breeder reactor, as 30 Athabasca tar sand plants over a 30 year lifetime. Similar calculations (Dyne, 1974) for the 200,000 tons of uranium oxide in the Blind River deposits show that it contains the energy equivalent, burnt in a CANDU reactor, of 22 billion barrels of oil, three times our known 7.7 billion barrels of conventional petroleum reserves and comparable to the 26.5 billion barrels of mineable tar sand oil (Govier, 1974). In addition, recycling plutonium waste from CANDU's spent fuel would provide another 20 billion barrels of oil energy equivalent, and use of the breeder reactor would allow recovery of energy equivalent to 2000 billion barrels of oil, the world's total oil resources (Hubbert, 1971).

These possibilities are not all in the realm of hopeful mythology, since raw materials are plentiful and current technology is at an advanced commercial stage of development. Further evolutionary development of our Canadian CANDU reactor, such as adoption for use of thorium as fuel, "requiring only modest expansion of our national effort," can expand our existing resources for hundreds of years "without closing any of the options for the fast breeder reactor". Ideally, "in the most sensible of all sensible worlds", the cycle for thermal reactors would be based on U^{233} transmuted from thorium, while

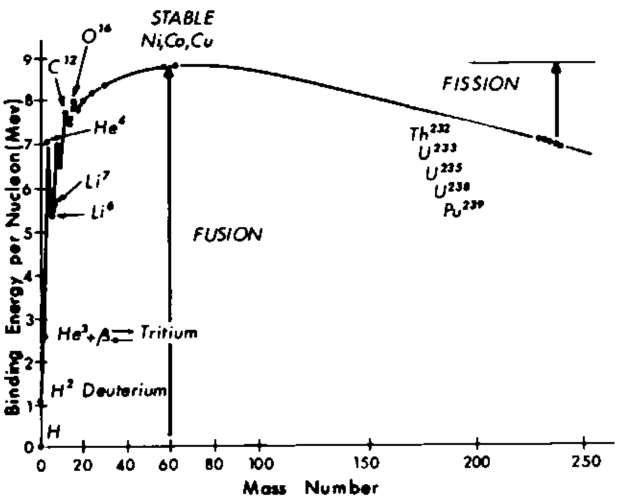

Figure 3
The curve of binding energy mankind has bent to various Promethean purposes (McPhee, 1973).

fast breeder reactors would be fuelled by plutonium from U^{238} (Mooradian, 1974). Light-water reactors and gas-cooled reactors are undergoing technological evolution elsewhere in the world, and one in particular, Gulf's high temperature gas-cooled reactor, uses thorium for one of its fuels. This reactor, in the pilot plant stage of development at Fort St. Vrain, near Denver, Colorado, operates at 900°C with 45 per cent efficiency and low thermal pollution. It has been licensed by Gulf to the German and French atomic energy industries.

There have been no known deaths or injuries to the general public due to the nuclear aspects of civil nuclear power programmes, thanks to the safety by foresight imposed upon nuclear technology (Hurst, 1974). Risks of radiation doses are no worse than apparently acceptable risks of many conventional occupations and far less than the risk of death to a trawler fisherman, aircraft crew, or construction worker (Butler, 1974).

Nuclear produced electricity is difficult to store, but off-peak loads can be used on a large scale to produce hydrogen for synthetic fuels, an alternative made more attractive every day by the high and rising price of petroleum and natural gas. The synthetic process, involving hydrogenation of tar, coal, atmospheric carbon dioxide or the carbon in limestone may provide substitute fuels ranging from hydrogen through synthetic methane to liquid hydrocarbons at a cost comparable to that from $8 a barrel petroleum and $1.25 MCF natural gas (Lewis, 1974). In the U.S., trying harder than Canada, the source material for synthetic fuel production is likely to be coal (Lessing, 1973; Abelson, 1973; Winsche *et al.*, 1973) and research is developing methods of converting gritty disagreeable coal into a clean easy to handle fuel, methanol (Reed and Lerner, 1973) or a high methane pipeline gas or lower quality power generation gas. Exotic newer methods of obtaining gas from solvent-refined coal are in the works, but there is only one coal-to-oil process working, producing a barrel or two of oil per ton of coal. To meet only 10 per cent of U.S. requirements in the early eighties, thirty plants costing nine billion dollars would need to be built, and synthetic oil facilities would cost about the same. These massive requirements of effort and money remind us of our tar sands schemes, but in the energy hungry U.S. situation, the same nine billion dollars in 1980 would supply only three per cent of gas import requirements.

Over the long term, unless there is a convulsive, and in our opinion unlikely, change in life style, the U.S. will require such massive amounts of energy that only a technological revolution and conversion to nuclear produced hydrogen or an efficient solar economy will solve the problem.

Current fusion technology, based on the curve of binding energy (Fig. 3) and magnetic confinement, laser or implosion phenomena to induce deuterium-deuterium or deuterium-tritium fusion will take at least as long to develop as fission technology. Fusion will not begin to reach commercial practicality until the year 2000 A.D. at the earliest (Mooradian, 1974). Within this decade, however, a crash programme by the U.S. to phase out petroleum and natural gas as major energy sources and substitute methanol from coal or liquid hydrogen produced by nuclear electricity is technologically feasible. It certainly can be achieved before the year 2000 (Jones, 1971; Gregory, 1973). Hydrogen, yielding three times more energy per pound than gasoline and compatible with internal combustion and gas turbine engines, is more readily storeable than electricity and may be transportable through our present pipeline transmission systems (it tends to make steel brittle). Fuel cell technology, a spin-off from the Apollo space program, allows direct, efficient, noise and pollution-free reconversion of hydrogen or methane to electricity (Conway and Vijh, 1974).

While we are waiting for these technological solutions and the energy mobile to become operable (Rose, 1974), each of us may have to conserve energy by wearing more sweaters and turning the lights 'way down low or driving around packed with six other people in a Volkswagon microbus, that most efficient way to get there (Wilson, 1974). We will substitute electricity for petroleum products to power trains, cars or pipeline pumps, and take advantage of geothermal energy in British Columbia (Garland, 1974) or dam the flowing tides in the Bay of Fundy as a make work project and probably the most uneconomical power in the world. Alberta's coal might be moved to the rest of Canada instead of Japan, as coal on an electrified unit train or in a slurry pipeline, or be converted to hydrogen, methane or electricity at the mine site. The tar sands and heavy oil deposits will supply petrochemicals and a limited amount of gasoline, and an arctic gas pipeline will carry fuel south and bring comfort to the north.

Taylor and Hempstone (1973) hold that though it would be difficult it would not be impossible to grow enough plants for combustion in vast greenhouses in the deserts. In our more northerly latitudes we will need to use synthetic fuel derived from nuclear energy to run tractors over the wheat farms of Saskatchewan. In the corn belt of the U.S. 80 gallons of gas are used to cultivate, fertilize and harvest one acre of corn (Pimentel *et al.*, 1973). If all the corn grown in the U.S. were converted to alcohol it would provide only a giant hangover and 1/1000 of the energy presently consumed as petroleum (Barbat, 1973). Our high standard of living depends heavily on an abundant supply of energy to supplement the sun's (fusion) energy and support our western agricultural methods and the "green revolution".

Our nick of time has arrived. As the ancient alchemists searched for the philosopher's stone to turn all else to gold, so we must search for ways to bend the curve of binding energy to our use (Fig. 3). Only one gram of a stone of earth, uranium, transmuted to plutonium, changed to fire in that bright flash that destroyed Nagasaki in 1945. E(20,000 tons of TNT equivalent) = m(1 gram of plutonium) x c(speed of light)^2. We now have the power to forge the heavy end of the curve of binding energy to peaceful uses. Hydrogen and the other light elements at the other end of the curve have proven more untractable, but ultimately the whole of the curve will bend to the will of man and limitless Promethean fire will be unbound from earth and water.

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