The Coming Global Oil Crisis

Alternative Energy Sources

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Oil fuels the modern world. No other substance can equal the enormous impact which the use of oil has had on so many people, so rapidly, in so many ways, and in so many places around the world.

Oil in its various refined derivative forms, such as gasoline, kerosene, and diesel fuel, has a unique combination of many desirable and useful characteristics. These include a current availability in abundance, a currently high net energy recovery, a high energy density, ease of transportation and storage, relative safety, and great versatility in end use. Oil is also useful as more than an energy source. It is the basis for the manufacture of petrochemical products including plastics, medicines, paints, and myriad other useful materials. Finally, the asphalt "bottoms" from refineries have converted millions of miles of muddy trails around the world into paved highways on which transport vehicles fueled by oil run.

Alternative energy sources must be compared with oil in all these various attributes when their substitution for oil is considered. None appears to completely equal oil.

But oil, like other fossil fuels, is a finite resource. True, there will always be oil in the Earth, but eventually the cost to recover what remains will be beyond the value of the oil. Also, a time will be reached when the amount of energy needed to recover the oil is equals or exceeds the energy in the recovered oil, at which point oil production becomes no more than a break-even, or a net energy loss situation.

Oil being the most important of our fuels today, the term "alternative energy" is commonly taken to mean all other energy sources and is used here in that context. Realizing that oil is finite in practical terms, there is increasing attention given to what alternative energy sources are available to replace oil. The imperative to pursue alternative energy sources is clearly established by two simple facts. The world now uses more than 26 billion barrels of oil a year, but new discoveries (not existing field additions) in recent years have been averaging less than seven billion barrels yearly. The peak of world oil discoveries was in the mid-1960's. Inevitably, the time of the peak of world oil production must follow, with most current estimates ranging from the year 2003 (Campbell, 1997) to 2020 (Edwards, 1997). Significantly, all estimates of production peak dates are within the lifetimes of most people living today.

The amount of energy an individual can directly or indirectly command largely determines that individual's material standard of living. This, of course, also applies to nations as a whole. To provide adequate energy for future generations introduces the concept of sustainability. What significant energy sources can be drawn on indefinitely?

"Sustainable" is a popular and pleasant word, but when it is used it needs to be clearly defined and placed within certain parameters. The term "sustainable growth" is popular with Chambers of Commerce as well as with corporations, but if this means increase in use of any resource, including land for more people, more water for more people, and more and more food, or more "things", then the term "sustainable growth" is an oxymoron (Bartlett, 1994). Growth in terms of numbers of anything cannot be sustained indefinitely. Sustainable growth in terms of better medical care, improved sanitation, and other related qualities of life, and of intellectual endeavors, among other things, is possible, and should be a continual goal.

Any consideration of "sustainable" must also be framed in the concept of a fixed size of population. People use resources. And all energy resources, even solar energy, are limited (Hardin, 1993). The problem of population size is politically sensitive and therefore largely avoided in discussions. But the energy problem cannot be sustainably solved if the demand target is a continually growing population. It is important to keep this overriding fact in mind. Eventually it will have to be faced. In defining a sustainable society, it is also necessary to determine what a reasonable standard of living is to be achieved. This does not lend itself to an easy definition as various cultures have differing views.

In considering what significant (in terms of quantity and quality) sustainable alternative energy sources may exist, the factors of population and living standards must be addressed. These matters are beyond this discussion, which simply presents the basic facts of alternative energy sources. How these sources, with their advantages and limitations may be applied to society at large is here left for economists, sociologists, and politicians.

Energy interchangeablity. There is much casual popular thought that energy sources are easily interchangeable. "When we run out of oil we will go to alternative fuels." "We can run our cars on solar energy." Such statements are legion. But the transition to alternative fuels will not be simple nor as convenient as is the use of oil today, and it will involve much time and financial investment. Energy carriers in terms of varied end uses and ease of handling and storage, are not easily interchangeable.

We here briefly examine alternative energy sources as to their advantages, limitations, and their prospects for replacing oil in the ways and great volumes in which we use oil today. Alternative energies closest to conventional oil (from wells) are first considered, and then our energy horizons are expanded.

Energy sources can be divided into renewable and nonrenewable.

Alternative Energy Sources

Nonrenewable	Renewable
Oil sands, heavy oil	Wood/other biomass
Natural gas	Hydro-electric power[2]
Coal	Solar energy
Shale oil	Wind energy
Gas hydrates	Wave energy
Nuclear fission	Tidal power
Geothermal[1]	Fusion
	Ocean thermal energy conversion
1. Renewable for space heating	2. Not renewable with reservoirs

Nonrenewable Energy Sources

Oil sands/heavy oil. This oil exists in huge quantities (trillions of barrels) particularly in Alberta, Canada and Venezuela. It is true oil but in deposits which take special methods to recover the oil. Oil sands must either be mined, or recovered by the SAGD (SAG-D) process (steam assisted gravity drainage) in which steam is injected in the upper of two parallel pipes and the oil is collected in the lower pipe. The oil must have lighter hydrocarbons added to it to allow it to flow and be processed into conventional petroleum products. Heavy oil deposits can be injected with hot water or steam. Because of the energy expended in these processes, the net energy recovery is considerably less than oil from conventional drilled wells.

At present about 500,000 barrels a day are recovered from the Athabasca oil sands of Alberta. To increase this 10-fold to 5 million barrels a day would be a very large task, with severe environmental limitations. This must be put in the perspective of the 76 million barrels of oil the world now consumes daily. Other similar oil deposits have the same problems of scale and net energy recovery. In total, oil sands and heavy oil can replace conventional oil only to a small degree. Canada's domestic needs for oil, with its growing population and increasing industrialization, will likely soon absorb all the additional oil which can be produced from oil sands and heavy oil with no surplus to export.

Natural gas. Natural gas is methane (CH4) which commonly has minor quantities of noncombustible gases such as carbon dioxide and nitrogen associated with it. Natural gas is termed "associated gas" when it occurs with oil, or "nonassociated gas" when it is not found with oil. Natural gas is derived from organic material and can be formed at essentially normal atmospheric temperature (such is the origin of "swamp gas" and the gas associated with garbage dumps, now in places used for fuel to generate electric power).

Oil also is derived from organic materials, but to derive oil from organic material, the material must pass through an "oil window". This is a temperature-time relationship ranging from 700C to about 1500C (158-3020F). Below about 16,000 feet (4880 meters), the Earth is so hot that oil cannot exist and only gas is found below that depth.

In terms of energy, one cubic foot of gas at one atmosphere has 1000 Btus. Fifty-six hundred cubic feet (157 cubic meters) of gas has the same energy equivalent as one barrel of oil. Natural gas is the cleanest burning of the fossil fuels, and for that reason is the fuel of choice over coal for electricity production as boiler fuel and in gas turbines. Natural gas can be used as a substitute for gasoline or diesel fuel in internal combustion engines, and is so used in a few places.

Natural gas is commonly moved by pipeline. It can be shipped in cryogenic tankers but this is expensive and does not lend itself economically to large scale transport, whereas oil is shipped economically worldwide. Natural gas can be converted to a liquid (GTL--gas to liquid), and such conversion plants are being built in areas not served by pipelines (e.g., the North Dome Field of Qatar). The end product is a high grade substitute for gasoline. However, the volumes of GTL which can be produced are modest and somewhat more expensive than gasoline.

Natural gas is more widely distributed than oil. But estimates are that in total its energy in reserves is equal to or slightly less than that in world oil reserves. Natural gas (and in GTL) is an alternative energy to petroleum, but natural gas is also a finite fossil fuel.

Coal. Coal is a very large energy source, but it must be mined, it is not nearly so easy to handle and transport as is oil, and it has much less energy density. For use in producing electricity in power plants (burned under boilers), coal can replace oil. But converting it to a liquid fuel which might be used in motor vehicles is expensive, and doing this on a scale which could significantly replace oil in vehicle use would require impossibly large mining projects. Coal can replace oil in some uses. Although considerable progress has been made, coal production and burning still have environmental problems which are of major concern. Adding to the greenhouse effect is one. The energy in coal reserves worldwide is greater than oil, but it, too, is a finite fossil fuel.

Shale oil. Production of oil from oil shale has been attempted at various times for nearly 100 years. So far, no venture has proved successful on a significantly large scale (Youngquist, 1998b). One problem is that there is no oil in oil shale. It is a material called kerogen. The shale has to be mined, transported, heated to about 4500C (8500F), and have hydrogen added to the product to make it flow. The shale pops like popcorn when heated so the resulting volume of shale after the kerogen is taken out is larger than when it was first mined. The waste disposal problem is large. Net energy recovery is low at best. It also takes several barrels of water to produce one barrel of oil. The largest shale oil deposits in the world are in the Colorado Plateau, a markedly water poor region. So far shale oil is, as the saying goes: "The fuel of the future and always will be." Fleay (1995) states: "Shale oil is like a mirage that retreats as it is approached." Shale oil will not replace oil.

Gas hydrates. These are very large deposits of methane which are in a solid substance composed of water molecules forming a rigid lattice of cages. These are discussed separately in this treatise.

Nuclear fission. There are two isotopes of uranium, uranium-235 and uranium-238. Only uranium-235 is fissionable, and it is only .7 percent of all uranium. The 99.3 percent which is uranium-238 is not fissionable, but uranium-235 can be used to produce a new element from uranium-238, plutonium-239, which is fissionable. Although uranium in both forms is a finite resource, converting uranium-238 to plutonium-239 (a process called "breeding") could possibly extend our use of uranium for power by perhaps 100 times (Meyers, 1983). However, plutonium is an exceedingly toxic substance, and also the basis for a deadly bomb. Because of this there is much opposition to the breeder reactor, and to uranium for power in general due to safety and environmental considerations. However, coal and uranium are the only two alternative sources of energy which can be developed in large amounts, and provide a dependable base load in the reasonably near future. Nuclear power development has been stopped in the United States. Elsewhere, some countries are abandoning nuclear power (e.g., Sweden, Germany), whereas others are pursuing it (e.g., Japan, Russia). Ultimately, however, nuclear power in any form is nonrenewable because uranium reserves are limited.

The end product of nuclear fission is electricity. How to use electricity to efficiently replace oil (gasoline, diesel, kerosene) in the more than 700 million vehicles worldwide has not yet been satisfactorily solved. There are severe limitations of the storage batteries involved. For example, a gallon of gasoline weighing about 8 pounds has the same energy as one ton of conventional lead-acid storage batteries. Fifteen gallons of gasoline in a car's tank are the energy equal of 15 tons of storage batteries. Even if much improved storage batteries were devised, they cannot compete with gasoline or diesel fuel in energy density. Also, storage batteries become almost useless in very cold weather, storage capacity is limited, and batteries need to be replaced after a few years use at large cost. There is no battery pack which can effectively move heavy farm machinery over miles of farm fields, and no electric battery system seems even remotely able to propel a Boeing 747 14 hours nonstop at 600 miles an hour from New York to Cape Town (now the longest scheduled plane flight). Also, the considerable additional weight to any vehicle using batteries is a severe handicap in itself. In transport machines, electricity is not a good replacement for oil (Jensen and Sorensen, 1984). This is a limitation in the use of alternative sources have where electricity is the end product.

Where oil is used for electric power production, nuclear fission can replace oil as a fuel. However, in the U.S. now only about 2 percent of electric power is generated from oil. Elsewhere, such as island economies, oil is now the chief source for electric power generation and nuclear fission has the prospect of significantly replacing that oil.

Geothermal energy. This is heat from the Earth. In a few places in the world there is steam or very hot water close enough to the surface so that the resource can be reached economically with a drill. The steam, or hot water flashed to steam, can turn a turbine, turning a generator producing electricity. At best, because of the scarcity of such sites, geothermal energy can be only a minor contributor to world energy supplies, and the product is electricity, which is subject to limited end uses. It should be noted that all electric power geothermal generating site reservoirs are now declining, because the geothermal requirements to produce electric power draw down the reservoirs faster than their recharge ability. Some projects are now reinjecting water from the condensed steam back into the reservoir to see if this problem can be mitigated, but results so far are inconclusive. However, when lower temperature reservoirs are used for space heating, with a more modest demand on the reservoir using down-well heat exchangers or ground to air heat pumps using the natural heat flow of the Earth, geothermal energy appears to be a renewable energy source.

Renewable Energy Sources

Wood and other biomass. Wood has long been used as a fuel, now to the extent that large areas worldwide are being deforested resulting in massive erosion in such places as the foothills of the Himalayas, and the mountains of Haiti. Wood can be converted to a liquid fuel but the net energy recovery is low, and there is not enough wood available to be able to convert it to a liquid fuel in any significant quantities.

Other biomass fuel sources have been tried. Crops such as corn are converted to alcohol. In the case of corn to ethanol, it is an energy negative. It takes more energy to produce ethanol than is obtained from it (Pimentel, 1998). Also, using grain such as corn for fuel, precludes it from being used as food for humans or livestock. It is also hard on the land. In U.S. corn production, soil erodes some 20-times faster than soil is formed. Ethanol has less energy per volume than does gasoline, so when used as a 10 percent mix with gasoline (called gasohol), more gasohol has to be purchased to make up the difference. Also, ethanol is not so environmentally friendly as advocates would like to believe. Pimentel (1998) states:

> Ethanol produces less carbon monoxide than gasoline, but it produces just as much nitrous oxides as gasoline. In addition, ethanol adds aldehydes and alcohol to the atmosphere, all of which are carcinogenic. When all air pollutants associated with the entire ethanol system are measured, ethanol production is found to contribute to major air pollution problems.

With a lower energy density than gasoline, and adding the energy cost of the fertilizer (made chiefly from natural gas), and the energy costs (gasoline and/or diesel) to plow, plant, cultivate, and transport the corn for ethanol production, ethanol in total does not save fossil fuel energy nor does it's use reduce atmospheric pollution.

A comprehensive study of converting biomass to liquid fuels by Giampietro and others (1997) concludes:

> Large scale biofuel production is not an alternative to the current use of oil, and is not even an advisable option to cover a significant fraction of it.

Hydro-electric power. Originally thought of as a clean, non-polluting, environmentally friendly source of energy, experience is proving otherwise. Valuable lowlands, which are usually the best farmland, are flooded. Wildlife is displaced. Where anadromous fish runs are involved as in the Columbia River system with its 30 dams, the effect on fish has been disastrous. Only to a small extent is hydro-electric power truly renewable. This is when the "run of the river" without dams is used, as, for example with a Pelton wheel. If reservoirs are involved, in order to provide a dependable base load as is the case of most hydro-electric facilities, hydro-electric power in the longer term is not a truly renewable energy source. All reservoirs eventually fill with sediment. Some reservoirs have already filled, and many others are filling faster than expected. A dam site can be used only once.

We are enjoying the best part of the life of huge dams. In a few hundred years Glen Canyon Dam and Hoover Dam will be concrete waterfalls. And, again, the end product is electricity, not a replacement for the important use of oil derivatives (gasoline, etc.) in transportation equipment.

Solar energy. This is a favorite possible source of future energy for many people, comforted by the thought that it is unlimited. But, quite the contrary is true. The Sun will exist for a long time, but at any given place on the Earth's surface the amount of sunlight received is limited--only so much is received. And at night, or with overcast skies, or in high latitudes where winter days are short and for months there may be no daylight at all, or available in small and low intensity quantities. Direct conversion of sunlight to electricity by solar cells is a promising technology, and already locally useful, but the amount of electricity which can be generated by that method is not great compared with demand. Because it is a low grade energy, with a low conversion efficiency (about 15%) capturing solar energy in quantity requires huge installations--many square miles. About 8 percent of the cells must be replaced each year. But the big problem is how to store significant amounts of electricity when the Sun is not available to produce it (Trainer, 1995), for example, at night. The problem remains unsolved. Because of this, solar energy cannot be used as a dependable base load. And, the immediate end product is electricity, a very limited replacement for oil. Also, adding in all the energy costs of the production and maintenance of PV (photovoltaic) installations, the net energy recovery is low (Trainer, 1995).

Wind energy. This energy source is similar to solar in that it is not dependable. It is noisy, and the visual effects are not usually regarded as pleasing. The best inland wind farm sites tend to be where air funnels through passes in the hills which are also commonly flyways for birds. The bird kills have caused the Audubon Society to file suit in some areas to prevent wind energy installations. Locally and even regionally via a grid (e.g. Denmark) wind can be a significant electric power source. But wind is likely to be only a modest help in the total world energy supply, and the end product is electricity, no significant replacement for oil. As with solar energy, the storage problem of large amounts of wind generated electricity is largely unsolved. Wind cannot provide a base load as winds are unreliable.

Wave energy. All sorts of installations have been tried to obtain energy from this source, but with very modest results. Piston arrangements moved up and down by waves which in turn move turbines connected to electric generators have been tried in The Netherlands, but the project was abandoned. Waves are not dependable, and the end product is electricity, and producing it in significant quantities from waves seems a remote prospect.

Tidal power. It takes a high tide and special configuration of the coastline, a narrow estuary which can be dammed, to be a tidal power site of value. Only about nine viable sites have been identified in the world. Two are now in use (Russia and France) and generate some electricity. Damming estuaries would have considerable environmental impact. The Bay of Fundy in eastern Canada has long been considered for a tidal power site, but developing it would have a negative effect on the fisheries and other sea-related economic enterprises. It would also disturb the habits of millions of birds which use the Bay of Fundy area as part of their migration routes. Tidal power is not a significant power source. The end product is electricity.

Fusion. Fusion involves the fusion of either of two hydrogen isotopes, deuterium or tritium. Deuterium exists in great quantities in ordinary water, and from that perspective fusion is theoretically an almost infinitely renewable energy resource. This is the holy grail of ultimate energy. Fusion is the energy which powers the Sun, and that is the problem. The temperature of the Sun ranges from about 10,0000C on its surface to an estimated 15 to 18 million degrees in the interior where fusion takes place. Containing such a temperature on Earth in a sustainable way and harnessing the heat to somehow produce power has so far escaped the very best scientific talent. However, even if commercial fusion were accomplished, the end product again is electricity, not a direct convenient replacement for oil.

Ocean thermal energy conversion (OTEC). Within about 25 degrees each side of the equator the surface of the ocean is warm, and the depths are cold to the extent that there is a modest temperature differential. This can be a source of energy, using a low boiling point fluid such as ammonia which at normal atmospheric temperature of 700F (210C) is a gas, colder water can be pumped from the deep ocean to condense the ammonia, and then let it warm up and expand to gas. The resulting gas pressure can power a turbine to turn a generator. But the plant would have to be huge and anchored in the deep open ocean or on a ship, all subject to storms and corrosion, and the amount of water which has to be moved is enormous as the efficiency is very low. How to store and transport the resulting electricity would also be a large problem. OTEC does not appear to have much potential as a significant energy source, and the end product is electricity.

NOT Primary Energy Sources

Hydrogen and fuel cells. References are sometimes made as to using these for energy sources. Neither is a primary energy source. Hydrogen must be obtained by using some other energy source. Usually it is obtained by the electrolysis of water, or by breaking down natural gas (methane CH_4). Hydrogen is highly explosive, and to be contained and carried in significantly usable amounts it has to be compressed or cooled to a liquid at minus 2530C. Hydrogen is not easy to handle, and it is not a convenient replacement for pouring 10 gallons of gasoline into an automobile fuel tank.

Fuel cells are being developed for use in transportation (automobiles, trucks, buses, etc.) but fuel cells have to be fueled with hydrogen. Fuel cells are not a source of energy in themselves, but are a possible ultimate substitute for the internal combustion engine. However, putting the infrastructure in place to effectively and economically produce and store hydrogen on the widespread basis as oil and its derivatives are today, is an enormous, costly, and long term task. The ultimate result can hardly be as versatile and convenient as is the use of oil products today around the world.

Living off our Capital and the Limits of Technology

We now live in very fortunate times. In the combination of the versatility of end uses, energy density, ease of handling and storage, and being now able to produce it relatively inexpensively and in great volume, there is no energy source comparable to oil. But living in a chiefly petroleum fueled economy and in a fossil fuel economy in general, we are living off our capital, which is unsustainable.

In a very perceptive volume for the time it was written, British physicist C. G. Darwin (1952) recounts the several "revolutions" which have taken place in the progress of human history, such as the most recent one, the Industrial Revolution. He states there is one more revolution coming:

> The fifth revolution will come when we have spent the stores of coal and oil that have been accumulating in the earth during hundreds of millions of years...it is obvious that there will be a very great difference in ways of life...a man has to alter his way of life considerably, when, after living for years on his capital, he suddenly finds he has to earn any money he wants to spend...The change may justly be called a revolution, but it differs from all the preceding ones in that there is no likelihood of its leading to increase in population, but even perhaps to the reverse.

There is a popular belief that somehow technology can indefinitely rescue the human race from whatever predicament it may get itself into--solve all problems. Pimentel and Giampietro (1994) have warned:

> Technology cannot substitute for essential natural resources such as food, forests, land, water, energy, and biodiversity...we must be realistic as to what technology can and cannot do to help humans feed themselves and to provide other essential resources.

Bartlett (1994) has observed:

> There will always be popular and persuasive technological optimists who believe that population increases are good, and who believe that the human mind has unlimited capacity to find technological solutions to all problems of crowding, environmental destruction, and resource shortages. These technological optimists are usually not biological or physical scientists. Politicians and business people tend to be eager disciples of the technological optimists.

This is not to say that technology cannot continue to produce many good things in the future. But we must not confuse technology which uses resources with creating the resources. The world is finite; there are limits. Nature has given us a great inheritance formed in the Earth by myriad geological processes over millions of years consisting of a huge variety of resources, including, importantly now, fossil fuels. This is a nonrenewable bank account against which we have been writing larger and larger checks as the needs of an increasingly industrialized growing world population have been supplied.

But eventually this account will be exhausted, and we will have to bestir ourselves to get out and live on current income, the first need of which apparently will be to replace oil. How many people can a renewable energy resource income support? And what will be the resources we will use to do this?

Cohen (1995) has discussed this, as is the title of his book, "How Many People Can the Earth support?" But, perhaps the question should be phrased "how many people should the Earth support?"

The optimum size of this population can hardly be estimated now with any great degree of accuracy, but some suggestions have been made. Pimentel and Pimentel (1996) believe that a world population of two billion might be sustained in some reasonable degree of affluence. Other estimates have been made and it is significant that most of them determine a figure which is substantially smaller than is the size of today's population.

Trainer (1995), in a comprehensive study of renewable energy sources, has made a well-supported clear statement:

> Figures commonly quoted on costs of generating energy from renewable sources can give the impression that it will be possible to switch to renewables as the foundation for the continuation of industrial societies with high material living standards. Although renewable energy must be the sole source in a sustainable society, major difficulties become evident when conversion, storage and supply for high latitudes are considered. It is concluded that renewable energy sources will not be able to sustain present rich world levels of energy use and that a sustainable world order must be based on acceptance of much lower per capita levels of energy use, much lower living standards and a zero growth economy.

Conclusions

Transition to an entirely renewable sustainable energy resource economy with resulting changes in lifestyles is inevitable. Will it be done with intelligence and foresight or will it be done by harsh natural forces? This is one of the main challenges which lie before us.

It seems likely that a sustainable energy mix will be broader that it is today where oil and natural gas make up more than 50% of our supplies. And energy in total will likely be more costly than our energy bill today. The transition to this wider diversity of energy sources will proceed slowly and probably be somewhat provincial depending on what regional resources are available.

Energy is the key which unlocks all other resources, and it will continue to be the key to human physical prosperity. It is significant that both the per capita use of oil, and the per capita use of energy in total both peaked in 1979 and have been falling ever since (Duncan, 2000). We may already be seeing the beginning of the fifth revolution to which Darwin referred.

The British scientist and statesman, Sir Crispin Tickell (1994) has clearly summed up our situation:

We have done remarkably little to reduce our dependence on a fuel [oil] which is a limited resource and for which there is no comprehensive substitute in prospect.

The challenge of conversion to alternative energy sources with the concurrent problems of population size and stabilization, and adjustment of economies and lifestyles is clearly at hand. A realistic appraisal of the future encourages people to properly prepare for the coming events. Delay in dealing with the issues will surely result in unpleasant surprises. Let us get on with the task of moving orderly into the post-petroleum paradigm.

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