Biomass Energy - Food or Fuel - A Global Perspective[1,2]

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Abstract

The world has become addicted to liquid petroleum fuels. It has been advocated that the US should move toward energy security by reducing foreign sources of oil and expanding the role of biomass as a domestic renewable energy source. This path presumably would result in fewer carbon dioxide emissions and less environmental consequences than traditional sources, while promoting sustainable economic development. Some crops, such as corn (Zea mays) and soybean (Glycine max), have been suggested to replace imported oil as feedstocks for ethanol and biodiesel. Some other crops, e.g. switchgrass (Panicum virgatum), tree species, and organic byproducts or wastes, are under consideration as feedstocks. Major efforts to investigate the production and conversion of these renewable energy sources have been funded for several years, involving many scientists and engineers in numerous states and countries. Much research remains to be done before cellulosic ethanol will be ready technologically and economically as a suitable fuel substitute and most of the solutions that have surfaced will compete directly with resources needed for food or feed. The essay presents some of the unstated or suppressed assumptions underlying current programs and the seductively simplistic, sometimes misleading policies advocated, condenses pertinent scientific knowledge, suggests the urgent need to decrease demand for liquid transportation fuels, indicates that other renewable energy sources with great potential have not been exploited, articulates the need to modify current assumptions and investigate other options, asserts that substituting fuel security for food security is immoral, and challenges readers to become knowledgeable in these matters.

Introduction

Biomass for energy – "Everything is related to everything else."

Indeed, that is the case. Using biomass for energy brings up aspects of geology and chemistry, thermodynamics, photosynthetic efficiency, transportation systems, land use policy, world population, ethics, politics, sociology, economics. I intend to show that there are many ramifications and consequences flowing from misguided but politically correct perceptions. These have led policymakers to render decisions and promulgate mandates that are unwise and will not lead to rational energy policies for this country, nor for the world. These political decisions were made without the full consideration of the unintended consequences that might ensue, and with disregard of applicable scientific principles that nullify some of the assumptions made.

There is no space to present many detailed data or conclusions, even to follow some topics down the paths they suggest. I shall raise topics. I shall articulate some of the implicit assumptions made, which then made conclusions inescapable even though not based on reality. It is my intent to challenge the readers to learn more about the themes that I shall identify. Accordingly, I propose to omit specific references, as would be expected in a scholarly paper. This posture will permit me to integrate opinions and statements from multiple sources. Instead, I have included in the List of References and Information Sources not only those from which I have abstracted information, but also others that I read and that I felt would be useful to the readers who wish to extend their horizons.

It is my sincere hope that readers will make up their own informed minds about the issues involved in the elaboration of a sensible energy policy, and then will take the kinds of actions that are appropriate in our country to change the attitudes of their compatriots, captains of industry, lawmakers and deciders. The subjects to be considered are complicated and intertwined, a great subject for a semester- or year-long seminar of an interdisciplinary nature. Untangling them brings the risk that simplification does not do justice to the intricacies of the problems.

The Transportation Energy Problem

What is the problem that the US campaign for the use of biomass as energy feedstock intends to resolve? The objective stated by our national leaders is that imports of petroleum from members of the Organization of Petroleum Exporting Countries (OPEC) and other nations for mobile fuel transportation has reached too high a level and is a security issue. Indeed, US oil imports, which in the 1970s at the time of the OPEC embargo were 30-35% of total consumption, have exceeded 60% of an increased consumption

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in recent years, and this percentage continues to increase. In fact, the US consumes over 3,180 million L/day, four times more than any other advanced country (Fig. 1).

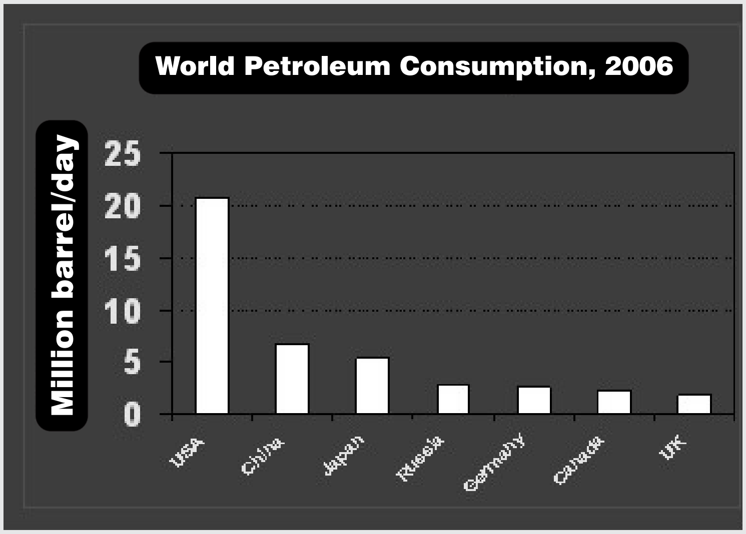

Figure 1. Daily consumption of petroleum by selected countries, 2006 (US Energy Information Administration, 2006)

In part, this high consumption rate derives from the low Corporate Average Fuel Economy (CAFE) standards enacted in 1975. Even these low standards were opposed strenuously by the automobile industry and other special interests. These standards required only an average vehicle fleet consumption of 9.45 L/100 km (25 miles per gallon) but exempted vans, sport utility vehicles (SUVs) and light trucks. The standards were supposed to be increased 10 years later. Instead, it took 32 additional years, until December 2007, for mandating the adoption of 13.2 L/100 km CAFE by 2020 and expanding the covered vehicle population. The high fuel consumption rates resulting from these low standards have led to the massive oil imports by the US and created a security issue, putting the country at the mercy of foreign governments, some of which may change their currently friendly stance at a moment's notice.

Faced with this serious situation, the US government has decided that oil for mobile liquid fuel must be supplanted by ethanol derived from biomass, up to 136 billion L/year in 2022. Should the US attempt to meet this goal, it will become apparent before that year arrives that there does not exist sufficient biomass in the country to produce such quantities of ethanol. Even if that is not recognized, it will not be possible to implement such a five-fold increase over current levels, since the ethanol industry, currently in its infancy, already has created many disruptions in US and world agriculture, food supplies and economic realities. A greater production would become untenable.

The Ethanol Mandate

Fareed Zakaria recently wrote in Newsweek that many Americans, citizens of the strongest nation in the world, view themselves as besieged. Thus, the decision to use the simplistically seductive solution of ethanol as a liquid mobile fuel was justified in the minds of many as the appropriate response to the implied potential blackmail from oil-producing countries. These reactions are embodied in the Energy Policy Act of 2005, various Executive Presidential Orders, and most recently in the Energy Independence and Security Act of 2007 enacted last December. These decisions were propelled in large part by the ethanol advocacy of employees of the Environmental Sciences Division of the Oak Ridge National Laboratory (ORNL) and of the Economic Research Service (ERS) of the US Department of Agriculture (USDA), and by statements by several politicians and government bureaucrats. These ethanol advocates ignored the report of the Alternative Fuels Task Force of the American Institute of Chemical Engineers in 1997 and various publications by the ecologist Pimentel from Cornell University and the chemical engineer Patzek from the University of California since 2005 and even earlier.

Nonetheless, numerous grant applications for biomass/biofuel research in the last decade refer to the USDA ERS Billion-ton Report and contain statements such as "The US Department of Energy (USDE) and the USDA are both strongly committed to expanding the role of biomass as an energy source ... they support biomass fuels as a way to reduce the need for oil and gas imports; support the growth of agriculture ...; to foster major new ... biorefineries. Annual biomass supply of more than 1.2 billion Mg can be accomplished with relatively modest changes in land use and agricultural and forestry practices. We must invest significantly in alternative fuels." Actually, about 60% of all cellulosic biomass each year in the US would be required to obtain the 1.2 billion Mg. The mandates promulgated by Congress and the President resulted in an avalanche of proposals seeking funding for biofuel for ethanol, reminding us again of the old adage cited by Edward Hodnett in the 1870s that "if you do not ask the right questions, you do not get the right answers"!

Some of the questions that should be asked, and for which scientifically valid answers should be provided, might include: which alternative fuels are energy efficient, and what are the computations that prove this, considering the complete cycle of production; are the byproducts fully utilized, and what is the extent to which they are a drain on the system; which land use, and agricultural and ecological systems are to be altered, and what will be the probable quantitative short- and long-term consequences of each change, and what might be the unintended consequences; what will be the effects on soil erosion, on wildlife habitats, on greenhouse gas emissions; what will be the additional needs for federal and state subsidies; who are the individuals, companies or industries that will benefit, and to what extent; are the assessments not only local ones, but regional, country-wide, and global?

Policy makers should demand that the answers to such questions be provided before policies are changed or mandates established. However it is often more convenient, when considering agriculture, industry, or special groups and interests such as the Global Climate Coalition, the Information Council on the Environment, and their constituent companies, to espouse carrots (subsidies) rather than to talk about scientific facts or sensible logic.

Subsidies and economic advantages have permeated discussions about ethanol from biomass, sometimes even mistaking folk culture for science. Ethanol from maize (= corn) has been in the vanguard, even though the entire US corn crop of today could supply only 10-12% of the fuel "demand"; even though the demand for ethanol was bound to increase, as it did from 2006 to now, the prices of many commodities and supplies in addition to those directly involved; even though it would cause major land use dislocations, and increase nutrient runoff into the Mississippi River and the resulting dead zone at its mouth; even though it would decrease erosion control, reversing the trends adopted at considerable cost since the 1940s; and it would diminish wildlife habitats and encourage the plowing up of areas deservedly placed in the Conservation Reserve Program (CRP).

The Real Fuel Problem

The sweeping advocacy of ethanol from corn has led some to ask whether biomass use for fuel is a chimera and whether we wish to exchange food security for fuel security. Even though this new energy source is as old as the first campfire, does it not rather make sense to consider its use as a short-term, stopgap palliative that may give us, and the rest of humanity, the time to consider objectively and scientifically the whole energy problem, and to carry on research into viable long-term alternatives, in order to convince humankind of the need to implement the best alternatives rather than the ones, cheapest in the short run, that will enrich the few? I shall endeavor in the remainder of this presentation to present several of the solutions that have been propounded and to suggest some of the reasons why they are illogical, and to propose possible conclusions for meeting rational demands for energy from an expanding world population desiring a better quality of life.

Ethanol from Corn and Other Crops

Let us first consider the production of ethanol from maize. When grown on soils capable of high production in areas of favorable climate under best management practices, corn yields in recent decades can be very high, reaching area-wide averages of up to 11 Mg/ha (~160 bu/acre),occasionally more, in portions of a state. What are the energy inputs that make this possible? In varying quantities and degrees of essentiality, they include nitrogen fertilizer, phosphorus and potassium fertilizers, agricultural limestone, improved hybrid seed, several kinds of large field machines, herbicides, insecticides, transportation equipment, roads from field to storage to refineries to consumers, electricity, gasoline and diesel fuels, lubricants, storage buildings, processing machinery (and buildings to house it), industrial acid, enzymes and microorganisms. Note that these inputs essentially are all derived to some extent from fossil energy, either directly or indirectly. Therefore, to reduce our dependence on imported liquid fossil fuels, we propose to use corn, a product of mostly fossil energy, to generate ethanol to feed our internal combustion engines! Does that make any sense?

Ethanol Production from Corn

How is ethanol obtained from corn and other grains? In dry milling, which accounts for over 80% of US ethanol production, the entire grain is ground into flour, water and enzymes are added, the “mash” is processed at high temperature, cooled, and then fermented with yeast for 40 to 50 hours. After fermentation, the ethanol is separated from the remaining “stillage”, concentrated to 95% ethanol, and then dehydrated to 200-proof. The liquid in the stillage is removed from the solid material, dried, and then added back to the solids to form dry distillers' grains with solubles (DDGS) which can be used for livestock feed.

In wet milling, the grain is soaked in water to which sulfuric acid has been added. After steeping, the slurry is ground and the germ is separated for its oil. The protein in the remaining solids is dried to become corn gluten, used as poultry feed. The starch can then be fermented into ethanol as described earlier.

In addition to the energy inputs listed earlier that are required to produce the crop, many additional inputs are needed to process the crop into ethanol. In varying quantities, these include the energy required to mine and process the ores and fossil minerals needed for manufacturing and housing the hydrolytic and fermentation equipment, the energy needed for obtaining the acid, water, enzymes and microorganisms essential to the process, as well as the more obvious requirements for transportation, equipment operation, drying, handling, storing and transportation of the ethanol and the byproducts or other residues. The whole process is further complicated by the fact that the ethanol has to be transported by trucks or on railroads operated with fossil fuels, since no existing pipelines can be used for ethanol, which would corrode the present national system. Thus, expanded ethanol production will have to be accompanied by the development of new infrastructure for its distribution across the country.

Rationale for Producing Ethanol as a Fuel

The advocates of using corn and other feedstocks for ethanol base their position on need, feasibility, and cost effectiveness. The fact that there is an urgent need to reduce US consumption of imported petroleum, however, does not necessarily mean that this need should be filled by ethanol. Although production of ethanol from corn grain is feasible, a proposition that was amply demonstrated during Prohibition and is still practiced somewhat by moonshiners in Appalachia, it does not follow that the process is effective or cheap. The proponents of ethanol production from plant parts have claimed that the procedure is either energy neutral or generates more usable energy than contained in the crops originally, and that it is cost effective. Cost effectiveness does not necessarily equate to energy effectiveness. Proponents' publications illustrate some of the reasons for erroneous conclusions. They have omitted from their calculations the energy required to manufacture some of the essential machinery and additional buildings and operations required for biofuel production. They have also subtracted from the total energy input the energy required to produce unavoidable byproducts in addition to the energy used to produce the starch in the corn kernel. Few investigators have researched or highlighted this lapse. Correctly-calculated energy effectiveness and scientific accuracy should be included and documented in future proponent publications.

Were we to use science first, before asserting cost effectiveness and issuing political mandates, we would observe and measure, develop assumptions to be tested, conduct comparative experiments, draw inferences from the data; we would arrange for control groups and employ valid statistical procedures; we would evaluate all the data before reaching conclusions, and not allow their publication without cautions before their independent verification; and we most definitely would not decide on policy until after all these steps were completed and the defensible conclusions reached from a relatively large body of evidence. We would remember that correlation is not causation. We would not allow science to be trumped by other considerations.

Ultimately, we would not forget the fundamental phenomena of physics and chemistry known as the Laws of Thermodynamics, recognized ever since the days of Sadi Carnot (1824) and James Joule (1858). As applied to energy, these laws state that it cannot be created or destroyed, and that if no energy enters or leaves a system, the potential energy will always be less than that in the initial state. Consequently, for the energetic success of converting crops to ethanol, it will be necessary either for Congress to repeal, or for the President to veto, the Laws of Thermodynamics. Thus, ethanol production for use as fuel cannot be justified on the basis of science, but instead must rely on directives, on short-term financial gains by the few, or on international considerations of Machiavellian proportions.

Who Benefits from Corn Biofuel?

We have been told that ethanol fuel would benefit the US. Publications on the thermodynamics of the transformation show that it will require more energy to produce ethanol than will be generated by the process; readers are referred to these publications for the calculations involved. When ethanol is burned, carbon dioxide is emitted, thus increasing greenhouse gases and contributing to climate warming. A few farmers have benefited from higher corn market prices and the \$0.51/gal subsidies provided to encourage ethanol production. On the other hand, the cost of many of the supplies they need for their operations and to sustain their families have increased substantially. The primary beneficiaries of corn ethanol production are the large commercial producers listed in Table 1. It is estimated that there are now or under construction over 140 ethanol refineries in the country, with most of them concentrated in the Corn Belt, and it has been projected that more are still planned. However, some already find themselves in financial difficulties, and it is doubtful that all the contemplated biorefineries will be built unless bolstered by government subsidies.

Another major group of beneficiaries includes feed producers and feedlot operators (Table 2). Not coincidentally, many of the top ethanol producers are also top feed purveyors. Historically, the major feedlot operators also have been the major grain merchants, since they discovered several decades ago that their profits were considerably larger when they marketed cereals as meat rather than as grain. In pursuit of this goal, they perpetrated a major propaganda coup against American consumers, convincing them that high-choice or prime meat with white fat was much superior to choice or low-choice meat with little yellow fat. Beef cattle (Bos spp.) that have been fed with grain for the 3-4 months preceding slaughter have white fat, thick subcutaneous fat layers and much marbling; these characteristics diminish cooking time and may enhance flavor.

On the other hand, cattle are ruminant animals which do not need any grains to sustain themselves and grow, because the numerous microorganisms in their rumens break down the cellulose, hemicelluloses and other components of fibrous feed for use in their metabolism. When the microorganisms die, their components benefit the host ruminant animal. Thus, ruminant animals, such as cattle, sheep (*Ovina aries*), goats (*Capra* spp.), and camels (*Camelus* spp.), provide a means of harvesting the solar energy used in photosynthesis by inedible plants for their benefit as well as for their human shepherds, supplying food, shelter, fuel, fertilizer, and edible protein. In most of the world outside of North America, ruminant animals do not have access to grains, which are reserved for human consumption and to some extent for poultry and swine. Yes, their meat has yellow fat and little marbling; the

Table 1. Major 2007 US ethanol producers (Adapted from Renewable Fuels Association, 2007).

	Million L per year
A. D. M. (started in 1979)	4,044
POET (new, major builder of plants)	3,961
VeraSun Energy	1,285
US BioEnergy	1,134
Aventine Renewable Energy	782
Anderson Albion Ethanol	624
Global Ethanol Midwest Grain	574
Cargill	454
Golden Grain Energy	415
GRAND TOTAL for all refineries	24,358

Table 2. Major 2007 US feed companies (Adapted from Renewable Fuels Association, 2007).

	million Mg/year
Land O' Lakes - Purina	11.6
Cargill	8.6
A. D. M.	2.9
Heiskell & Co.	2.5
Westway Feed Products	2.0
Kent Feed Products	1.8
Southern States Coop	1.5
Ridley Inc.	1.4
Quality Liquid Fuels	0.7
Pennfield Corp.	0.6

fat color has no effect on the taste, and the scant marbling is easily offset by proper cooking.

The advocates of corn biofuel production point out that the dry distillers' grains (DDG) byproduct can be used for feeding cattle. That is true, but let us consider the implications as they involve ethanol production. In the first instance, as mentioned above, ruminant animals do not need grain. Secondly, feeding cattle corn grain or DDG increases the number of pathogenic Escherichia coli bacteria in the gastrointestinal tracts of the animals and possibly in the beef produced. Finally, if cattle are fed DDG, dried down to 10% water, either energy will be consumed to dry those grains originating from the milling processes, since the DDG will have to be stored and/or shipped to the feedlots, or feedlots of sufficient size to utilize the daily production of wet grain will have to be adjacent to the biorefineries.

Animal nutritionists have determined that the ration of cattle should not contain more than 40% DDG, because a larger presence results in digestive upsets in the consuming animals due to the high content of protein and fat in the DDG. Most feedlots can turn over their feeding spaces 2.5 times per year, and each head is usually fed for 120 days. In 2006, the US ethanol production of about 25 billion L would have resulted in the availability of about 36 million Mg of DDG. Consequently, since the 15 million head of cattle on feed could have consumed only about 16 million Mg of DDG, another 20 million Mg would have remained available for the entire dairy, swine, and poultry populations in the country. Perhaps that much DDG could have been consumed by these animals, but it is unlikely. What will be the fate of the 100+ million Mg of DDG accompanying in 2022 the production of 136 billion L of ethanol from corn, with a five- to six-fold increase in the DDG produced? The Energy Independence and Security Act of 2007 does not consider this issue.

Ethanol and Cellulosic Ethanol Production from Other Biomass Sources

There are numerous bioresources other than corn that have been proposed as feedstocks for mobile fuel energy. A few are advanced to produce biodiesel, but most of them would be used to manufacture ethanol. The production of ethanol from the lignocellulosic materials generally would be similar to that described earlier for corn, with the additional costly requirements for biomass harvest, transport and handling, followed by chopping and other pretreatments, most of which have not yet been researched beyond the laboratory bench. An additional disadvantage is that no potential feed byproduct is generated, though sometimes the portions that cannot be broken down are used for fuel in the processing plant.

Nevertheless, some crops have major advantages as biofuel under specific circumstances. The most outstanding example of a useful ethanol source is sugarcane (Saccharum officinarum), the stems of which contain over 20% sugars in the juice. Ethanol has been a major source of subsidized mobile fuel in Brazil where petroleum resources had not been located until recently. After a painful conversion period, most of the Brazilian motor vehicular fleet was adapted to burning ethanol. The recent discovery of off-shore petroleum may allow a partial return to the more efficient petroleum-based motor fuels, at the same time as it has increased oil consumption by over 40% since 2000 and probably will create additional economic dislocations for that country. After the sugar is extracted from sugarcane using water and heat, the remaining bagasse can be used to fuel the biorefinery, or it can be used as a source of cellulosic ethanol. Sugarcane is more efficient than US corn as a biofuel:

there can be three crops/year in the tropical climate and the stand survives 4 to 5 years, growing again and again from rattoons. On the other hand, continuous sugarcane cropping depletes the organic matter and native soil fertility that have been relied on so far, creates environmental impacts as serious as those that accompany corn ethanol production, and eventually this cropping will require supplemental inorganic fertilization to maintain high production levels.

Perennial and annual high-producing C4 grasses have been proposed as sources of bioethanol. Such crops include switchgrass, johnsongrass (*Sorghum halepense*) and sweet sorghum (*S. bicolor*). Both switchgrass and johnsongrass are perennials, can form dense stands of tall vegetation, and can produce in excess of 10 dry Mg/ha; unlike corn and sugarcane, no valuable byproducts can be obtained from these grasses when transformed into ethanol. In some states, johnsongrass is classified as a noxious weed because of its aggressive nature in fields of corn and other crops. Switchgrass, a native of the North American prairie, grows in most of the US where rainfall is adequate for its needs. It performs well if harvested not more than once or twice a year, but tends to decrease in stand density if cut frequently or grazed too low. The seedlings are slow to develop and require 1 to 2 years to form a dense stand. Although it has been touted as not requiring fertilizer, the need for at least 50 kg of nitrogen/ha/year and phosphorus will become evident after a few years during which its extensive and vigorous root system will have extracted the native fertility underlying its sward.

Prior to processing at the refinery, the harvested cellulosic plant parts usually will need to be chopped into small pieces. This process, which requires substantial amounts of energy, is required to decrease the volume of material to be transported and to facilitate the chemical treatments after grinding. It was determined a few years ago that chips made from pine trees could not be transported economically to a processing plant further than 40 km. Thus, to haul switchgrass pieces, which are less dense than wood chips, refineries would have to be less than 80 road km apart.

Several other crops have been suggested as sources of sugar or cellulosic ethanol. Some of them are currently under evaluation for this purpose, mostly in North America or Western and Central Europe. These potential feedstocks include sugarbeet (*Beta vulgaris*), alfalfa (*Medicago* spp.), various species of Brassicas, forestry litter and crowns, coppice growths, and plantations of fast-growing tree species in short rotations [beech (*Fagus* spp.), birch (*Betula* spp.), poplar (*Populus* spp.), willow (*Salix* spp.), mimosa (*Mimosa* spp.), maple (*Acer* spp.), and pine (*Pinus* spp.)]. Many of these trees seem to meet the needs and ecological restrictions of higher-latitude areas, with their cooler and shorter summers than found in the US, and grow on less productive soils in relatively flat areas.

Some other crops have been identified recently as having potential for producing large amounts of biomass, such as the giant grass *Miscanthus giganteus* for the southern US and the rapidly growing Jatropha curcas in the tropics; their potential will need considerable additional investigation before it can be realized. Once more productive genomes than exist currently are isolated or created from species already adapted to the tropics, it then may not be feasible even for improved crops grown under temperate climates to compete successfully for the biofuel market. An innovative project in the US Southwest has suspended plastic bags containing water and algae (various groupings within the supergroup *Primoplantae*) from racks in the hot desert sunlight. Under these conditions, the algae are reported to grow extremely rapidly, capturing much photosynthetic energy which can be harvested frequently. Whether these procedures will turn out to produce as much energy as is claimed, and whether they become feasible and economical on a large scale, remain to be determined.

Lastly, a few crops have been advanced as sources of biodiesel. Soybeans, until recently grown for its proteins and oils, can be an excellent source of biodiesel in warmer temperate and subtropical climates. Similarly, biodiesel can be produced from rapeseed (sometimes called canola, *Brassica napus*) in the cooler climates of Canada and Western Europe. Palm oils (*Elaeis oleifera* and *E. guineensis*) are being used for the same purpose in tropical and equatorial climates, as encountered in Brazil, Indonesia and Malaysia. Unfortunately, the lure of rapid profits from palm oils has induced the wholesale devastation of rainforests and exposed their organic soils to the oxidation and destruction that take place when these soils are exposed to direct sunlight and rainfall.

Some proponents have advocated the use of crop residues for the production of cellulosic ethanol, such as corn stover, wheat (*Triticum aestivum*) straw, and rice (*Oryza sativa*) hulls. Such activities should be investigated thoroughly before implementation on a large scale. Up to now, many citations in the literature indicate that preventing the return of at least two-thirds to three-fourths of these residues to the soil results in lowered soil fertility and organic matter, eventually engendering lower productivity and soil erosion. Recycling of yard and municipal wastes represents a path to utilization of materials high in organic matter and potential energy, especially since environmentally-safe waste disposal is presently a drain on municipal finances. There is a need for research to determine the better and more economical ways to handle these materials and extract their potential energy safely.

A large obstacle facing attempts to generate ethanol or diesel from all these potential sources is our ignorance of the specific chemical structure of the compounds that need to be taken apart. Although the nature of hemicelluloses and cellulose is generally well understood, we do not have strains of microorganisms that can produce efficiently large amounts of the enzymes needed for fermentation of cellulosic mash into ethanol. Understanding the nature of the substrate is essential to the development of advanced strains of microorganisms. Promising results have been obtained in Wisconsin with *Trichoderma rici*. Though advances in molecular engineering are likely to generate eventually more desirable genomes of such organisms, many research resources and much time will have to be expended before practical, environmentally-acceptable and economic solutions are obtained. A much more considerable obstacle is lignin, constituting up to 20% of many herbaceous plants, and even more in trees. The exact nature of the structure of lignin is not known. Although there obviously exist microorganisms and fungi that can digest the lignin component of trees rotting on the forest floor, much work needs to be done to isolate, study and learn enough about them to master their use. How many years will be required before this is accomplished is anyone's guess, particularly in a national climate where legislatures are loath to invest many public resources in biological research.

Energy for the World

Essentially all the energy on the earth has come from the sun in ages past, or is received now from the only star in our solar system. Some of the energy sources, such as geothermal heat or radioactive minerals, evolved with the origin of the planet. Others were created during geologic ages lasting about 700 million years, when green plants growing profusely in warmer climates than occur now at the same latitudes (because of the movement of tectonic plates), were fossilized after their remnants were subjected to heat and pressure. Other sources of energy derive from the effects of gravity, lunar rotation or incoming solar energy, generating tides, ocean currents and waves, rivers and winds. Less than 2% of the solar energy which impinges on the outer reaches of the planet reaches the surface of the earth and only a much smaller portion is captured by green plants during photosynthesis. Humanity is entirely dependent upon this Lilliputian portion for its food on the only planet it has, but advocates of biomass/biofuel propose that we could use up to 40 million ha to feed internal combustion engines, emphasizing the detachment that many Americans feel from agriculture, even though they still insist on three squares a day.

We are now living during an episode (Figure 2) in the maturation of the earth when photosynthetic energy elaborated during millions of years and preserved in the bowels of the earth is being used to maintain and improve upon a quality of life already very high for many, but not all, inhabitants. Major world energy consumption started with coal and the Industrial Revolution of the 19th century, was greatly amplified after Henry Ford started creating automobiles for mass consumption in 1903, and has been satiated by the unceasing extraction of oil from the earth initiated by John Rockefeller with Standard Oil Company in 1870, originally intended for kerosene lamps. Most knowledgeable experts assert that about half of these geologically-preserved energy sources already have been consumed, most of them by combustion, while generating greenhouse gases. It is possible that some additional sources may be found in the future, or that usable products can be extracted from extensive shale or oil sand deposits. Portions of the known coal and natural gas, and about a third of the petroleum, are feedstocks for the chemical engineering industries that manufacture compounds that otherwise would not exist. The US is considered the Saudi Arabia of coal; does that permit us to evaporate our mines into the atmosphere, as questioned by Svante Arrhenius? It would therefore behoove humanity not to squander these irreplaceable resources, and to enter rapidly into urgent programs of research and development to find and implement substitutes for mere oxidation.

Energy Demand

So far in this essay, the emphasis has been on means of supplying mobile fuel energy for the "demand". What is this demand? Is it the need, increasing yearly all over the world, although in some countries more than in others, presumed to be that quantity that would be consumed were there no constraints of any kind? Is it an untouchable, sacred entity? Needs are met when the supply of a product equals the demand for it. If the demand should exceed the supply, there are two possible solutions to satisfy the need for equilibrium: either increase the supply, or decrease the demand.

Are we asking the wrong questions? Is the shortage in the US, in the developed world, in the developing world, a shortage of gasoline and diesel fuel? Let us recall that, in the US, each day, we burn 75 million L of

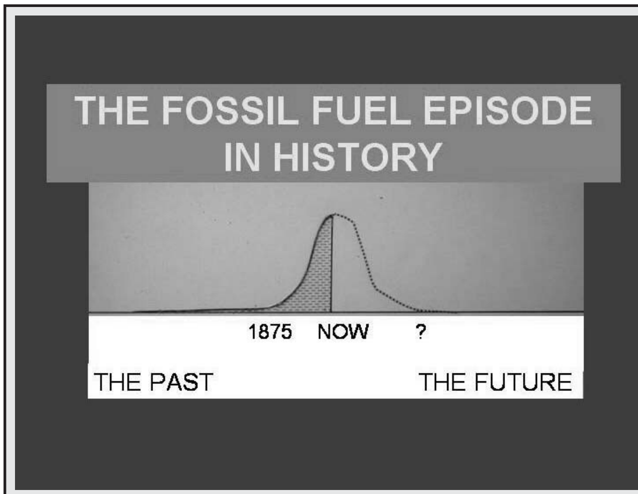

Figure 2. The fossil fuel episode in history.

gasoline. Let us recollect that each day, all over the world, the fossil fuels that humans burn required about 3,000 years of accumulation during the Carboniferous and other ages. Should not the questions be, if there is an insufficiency of transportation energy for the demand, whether sources other than liquid fuel could be used, or whether the demand is so sacred that it cannot be decreased?

Different countries have set their needs differently (Table 3) and meet them at different levels. Developing countries currently have low needs, but these are increasing, especially in a rapidly changing country such as the People's Republic of China (PRC). Developed countries vary also: although the US has fewer people than Western Europe, its consumption of energy, both on a per person basis and country-wide, is considerably larger. It is questionable whether the extravagant energy consumption in the US can be maintained in the future. Some compromises between unrestrained consumption and uses in equilibrium with essential needs may have to be developed. For instance, automobile engine power (165 W = 220 hp) and capacity (3.4 L) in the US are considerably greater than corresponding values for cars in Western Europe (~90 W and 1.8 L, or less, respectively). These countries also have many cars that use engines burning diesel fuel, and over half of all new autos burn diesel. Diesel fuel has an overall efficiency 20% greater than gasoline, when considering the heavier weight of diesel engines and the distance traveled per liter of fuel for cars of the same weight.

We should question whether oil or renewable biofuels are the only usable sources of transportation energy that we could employ. Many other sources could be used if some research and development were expended to develop integrated approaches and if the proper incentives were put in place. A few of these, to be discussed later, would include mobile energy sources, such as photovoltaic cell car roofs, similar to those used for panels of the international orbiting space station. In most instances, however, energy could be generated more efficiently and economically, in a more environmentally respectful manner, at central points to supply continent-wide electrical grids rather than in each individual vehicle.

In 2005, 88% of the electricity generated in the US originated from fossil fuels (Table 4). When falling water or natural gas is used, there are minimal environmental pollution considerations, but emissions from coal burning, such as carbon and sulfur dioxides, nitrous oxide, mercury and fine particulates, create a major disadvantage which generating utility companies have been slow to admit and control. Once the methods and locations to be used for the disposal of wastes from nuclear fission power plants are decided, and breeder reactors are allowed to function securely, this source of energy generation should expand greatly. After all, countries such as France, Germany and Finland, each smaller than any of the conterminous US states, generate over three-fourths of their power needs from nuclear fission power plants. Their success is due in no small part to their use of the same design for all their plants. France does not feel the need to re-invent the blueprints for each new plant like the US does. Eventually, it is to be hoped that nuclear fusion plants will replace the fission ones, but this goal has eluded its pursuers ever since the 1950s. The replacement of power plants burning coal, petroleum or natural gas by nuclear plants has been unnecessarily slow in the US, due to the high initial capital cost to be met by private investment, to the essential need for redundant safety mechanisms when using highly radioactive materials such as plutonium, and to the stubborn inability of some high-minded citizens to understand the scientific processes involved and to comprehend their safety when carefully controlled by public regulations.

Table 3. Energy consumption in several countries or areas in 2003 (Adapted from World Energy Council, 2004).

Place	MW/person	million persons	TW use/year
United States	1.14	290	3.3
Western Europe	0.50	484	2.4
China (PRC)	0.12	1,287	1.5
Africa	0.05	856	0.4
India	0.04	1,050	0.5

In spite of all these real but solvable objections, it is clear that the production of usable energy from fossil fuels must diminish greatly in the near future, both because of decreasing sources and due to the imperative need to control emissions of carbon dioxide into the atmosphere (Figure 3). Carbon dioxide concentration in the atmosphere has been increasing steadily since measurements in the atmosphere and in air bubbles contained in polar ice fields have been feasible (210 ppmv 650,000 years ago, ~300 in 1880, ~355 in 1990, and over 380 ppmv now). Carbon dioxide is the major greenhouse gas; hence, it is at the root of the climate warming and the many potential consequences of rising sea levels and climatic shifts that have been predicted.

The Energy Crisis

Government officials and other persons have insisted that the US has been in an energy crisis ever since 11 September 2001, because the country imports increasingly large quantities of petroleum from Persian Gulf countries, Nigeria and Venezuela, and of natural gas from Russia, Algeria, and other countries. Is this crisis an emergency? If it were, it would have been expected that at least a few of the practices invoked during the emergency of World War II might have been summoned: strict rationing of fuel, widespread recycling of all products that require energy for their manufacture, and an active educational program to engender a pervasive and patriotic sense of obligation by citizens to their country.

Instead, we have to conclude that there is no emergency: 75% of all commuters are allowed to be alone in their car; 20% of all petroleum is consumed by long-haul trucks that could be passengers on railroads; reasonable speed limits that give some consideration to geographical differences but that would decrease fuel consumption and provide more safety are neither set nor enforced; the interstate highway system, proposed for national security, has become an intra-urban stratagem to facilitate unrestrained despoiling of land resources, enrich developers, and spread shopping malls and exurbs; light trucks driven by urban cowboys mostly to satisfy their egos are exempt from CAFE standards; tens of millions of liters of gasoline are consumed each weekend during several months each year to ferry athletes in jet planes and to propel road vehicles for hundreds of thousands of fans to football and basketball games, to NASCAR races, etc .... ; and no one questions the use of engines of 150 W or more in SUVs to transport home millions of 60-kg shoppers and their 10 kg of groceries. From these examples, and many more that could be mentioned, it is not possible to conclude that there is an energy emergency in the US.

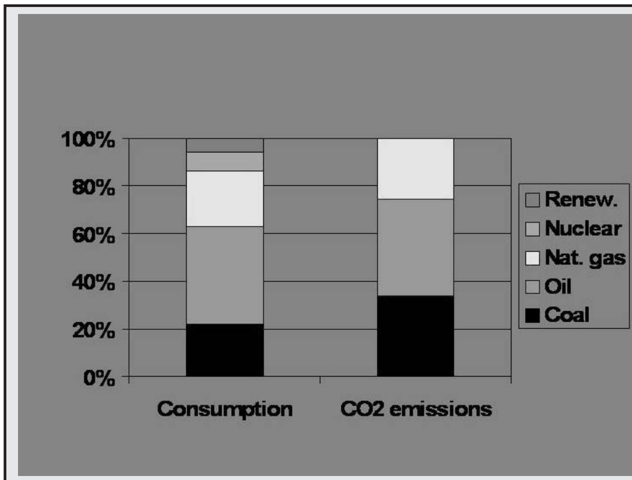

Figure 3. Energy consumption and related carbon dioxide emissions in 2004 in the US (World Energy Council, 2007).

The Association of American Railroads states that the freight pulled by one locomotive is equivalent to that requiring 280-500 trucks, depending upon the density of the cargo. The gains in railroad fuel efficiency, which have doubled from about 30 Mg/km/L of fuel in 1980, when there were three million trucks on US highways, to 60 in 2003 when over nine million trucks populated the roads, could increase still further. There is no comparison possible in efficiency between railroads and trucks: a long-haul truck tugs about 1.5 Mg/km/L of burned fuel. It would seem that a serious effort at fuel efficiency would eliminate most long-haul trucks from the subsidized highways, resulting in a longer life expectancy for the roads. Intermodal systems, which now carry only 10 to 15% of the freight, should be expanded considerably, if necessary, with the subsidies now provided for roads and trucks. Rails could then haul freight profitably and truck hauling would be limited to local deliveries. Obviously, the distances considered to be local deliveries would be adjusted for population density: 'local' distances in the western US would be longer than those allowed in the eastern states. Other rail lines than those used for freight could be developed to provide the kind of rapid public transportation pioneered by Japan and France on shorter distances than encountered in the US. No country has been able to develop an efficient public transit system without government support; therefore this option also would require substantial government support in the US, adjusted for geographical differences.

World Food Production

The world population today is estimated to be about 6,600,000,000 people. It is anticipated that it will increase to over 10 billion within two or three decades, regardless or in spite of whatever programs of birth control or family planning are conducted in populous areas like the PRC or Brazil, ignored in others like Indonesia or the Middle East, or condemned by various religions. The Food and Agriculture Organization of the United Nations (UN) estimates that 800 million people today do not get enough protein or calories on a daily basis, but the UN World Health Organization conjectures that over half the humans in the world suffer from malnutrition.

Economic advances or pessimistic world views appear to be the major agents that restrict family size at this time. The earth has about 12 million ha of land out of its 60 total million ha, but only about one million ha are arable. The land resources used to grow the food that each human being requires daily are not expected to become any larger; climate warming may even reduce these areas if sea levels rise. It should be noted also that the populations of various countries on the several continents are not proportional to the quantity of arable land available, magnifying the current and future problems. Although few of the grasslands that have not been plowed are capable of producing food for direct human consumption, they cover more land (about 2.5 million ha) than that which is arable, but they are extremely variable in their distribution and accessibility among continents. One of the few means of converting the solar energy striking these areas is through the intermediary of grazing animals, since they can utilize cellulose for their metabolism.

Rational Land Use

Ever since *Homo sapiens* shifted from hunter-gatherer societies to the agrarian societies that made civilization possible, human beings have known that there are many different kinds of soils, and that some are productive and others are not. Unfortunately, now that so many persons in the developed world are removed by one or more generations from tilling the land, most are not aware of this truism. A very small portion of the world is capable of being used for growing the food (Figure 4) we must eat daily, 365 days/year, for as long as each of us lives. Most of the world is too dry or too wet, too hot or too cold, too steep or too rocky or too salty to be suitable for growing crops. This reality underlies the need for husbanding the little land there is and to reserve it for the best use it can have, not only for today but for future generations. The mere fact that an area is labeled as marginal is meaningless, as when proponents claim that switchgrass can be grown on marginal land, implying it will not displace an important crop or use. The word "marginal" must be immediately followed by the intended crop or activity. For example, a soil which could be said to be marginal for corn production might be very well suited to the growing of a small grain like wheat; and one not suited to an annual crop might be proper for a perennial valuable hay crop like alfalfa, requiring establishment once every five to ten or more years, depending on the management followed; and an area that to the untrained person's perception might seem marginal, because no cultivated crops could be grown there, may be perfectly well suited to a perennial pasture grass such as tall fescue (Lolium arundinaceum) or to a native grass prairie.

Hugh Bennett, creator and first leader of the USDA Soil Conservation Service (SCS), embraced in the 1930s the concept of land capability classes (Figure 5). This concept has been expanded recently by the Natural Resources and Conservation Service (NRCS), incorporated into various bills passed by Congress, and is supposed to guide land use in the US. It is to be hoped that, in the future, land in the lower-numbered land capability classes, which are best suited to growing crops for human food or industry feedstocks, or forage for the sustenance of livestock, will be reserved for those purposes rather than for destructive uncontrolled development or for growing plants from which ethanol is obtained for burning in internal combustion engines.

Harnessing Solar Energy Directly

Photovoltaic cells could be mounted on trellises so as to shade unproductive lands; these areas would be able to capture, with present (second-generation) positive-negative technology, 150 to 200 times as much solar energy as productive green plants can accomplish with photosynthesis from the same exposed area. Still, at this time, only 12% efficiency in capturing solar energy is available, generating 1.2 watt/0.01m2. Some photovoltaic farms actually exist in Portugal and Germany. Other potential major uses for photovoltaic cells, hesitatingly embraced recently, can be to generate the electric energy for heating and cooling homes, business and manufacturing plants, such as at the headquarters building of Google. Future advances in efficiency to 40% or more may be achieved with the third- and fourth-generation technologies currently being researched and should greatly decrease the drain on electrical grids for manufacturing, heating and air-conditioning. These new systems will emerge as decreases in cost accompanying mass manufacture and architectural mandates are realized, and better equipment for storing usable energy during daylight for use at night and on cloudy days is developed.

Setting Priorities

To a considerable extent, the ways in which we propose to harness and use solar energy depend upon what each one of us feels is important for our children, grandchildren and future generations world-wide. In the US, a glimpse at public expenditures for research and development is available by looking at the budget of the USDE and illuminates what is thought to be important. The large expenditures for coal and oil programs relative to all others clearly show the overwhelming weight given these resources and the influence of the special interests involved. The budgeted amounts for all other potential programs plainly indicate the lack of concern by both the USDE and Congress in exploring and emphasizing ecologically sustainable and environmentally neutral energy sources. These sources include photovoltaic cells, wind turbines, geothermal wells, submerged propellers

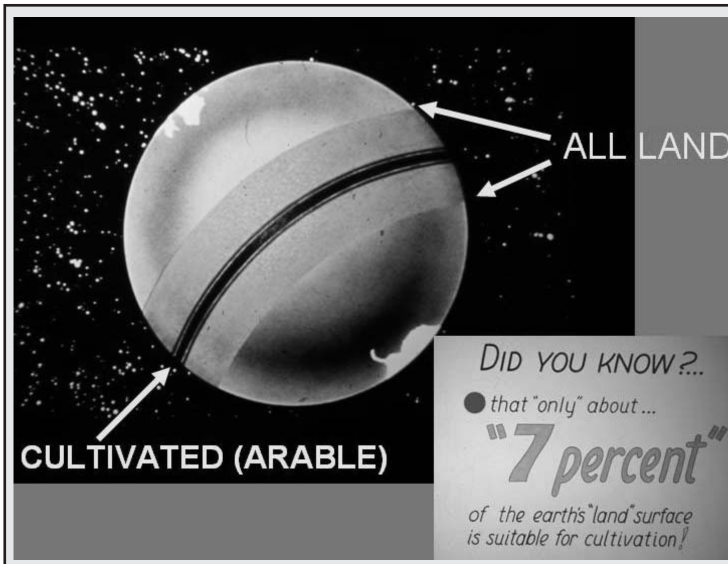

Figure 4. Re-arranging world geography to allow the viewer to conceptualize better the small amount of cultivated land available in the world for food production.

driven by tides or buoys moved vertically by ocean waves, even electric vehicles which would decrease substantially the demand for imported petroleum. However, when expenditures for nuclear power and other research, excluding all weapons systems, are included, all other energy research allocations disappear into relative insignificance.

It was much more difficult for me to determine the parceling of research resources in the USDA. A thorough search of documents available on the internet and in the library did not divulge and identify the portion of agricultural research and development funds meted out to biomass/biofuel/energy compared to all other research and extension activities. The Current Research Information System (CRIS) computer system revealed that there were 194 biofuels and bioenergy projects in October 2007, to which 24% of the total research budget were allotted;most of the remaining funds were reserved for health and diseases, food and food safety, and a few other topics. It was not possible to determine the funds budgeted for the National Research

Initiative (NRI) and their allocation to various project categories. However, since FY 2003, federal investment in agricultural research and development has fallen about 24%, a decline that will have detrimental effects on the nation's economy. The proposed FY09 budget continues to underfund agricultural research programs. This is even more serious that might appear at first since so many of the resources have been coopted for energy programs instead of invested for food and environmental challenges.

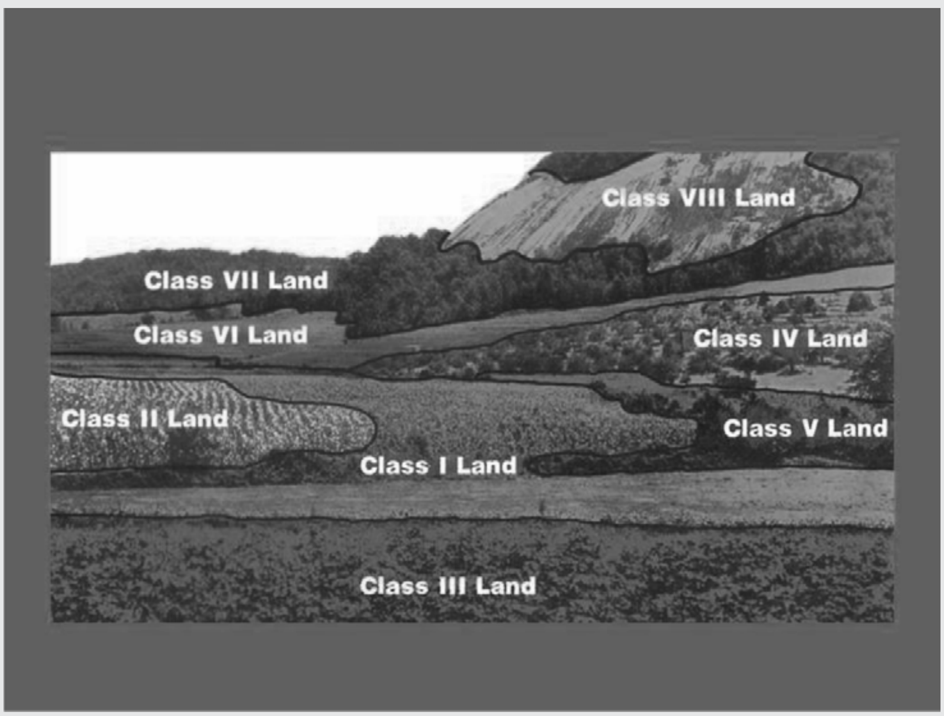

Figure 5. Land capability classes in the US, as determined by the USDA Soil Conservation Service.

Many of my colleagues share my view that the recent downgrading of the research and extension funding of the Hatch and Stennis Acts, responsible for 135 years of the unparalleled, magnificent performance of American agriculture, is leading to the collapse of the unique land-grant system. In its place, a competitive system restricted to the limited choices of an elite group of reviewers and bureaucrats favors biomass/biofuel and molecular genetics, while displacing attention from the more urgent but traditional problems facing the agriculture of today. Admittedly, some of the forces responsible for this shift have their origin in the overwhelming portion of the agricultural budget in the 2007 bill devoted to food stamps ($190 billion) and subsidies ($42 billion), and the attempt by bureaucratic accountants to eliminate important and necessary programs that have less political support.

In spite of all these impediments, it is difficult to understand why inertia and powerful lobbies are allowed to sway the public and the legislatures to the extent that research, development and deployment of many innovative ways to generate and use energy are neglected. Some examples follow. Electric, hybrid and plug-in vehicles are slowly entering the market, but require more capital investment by companies and purchasers than vehicles with traditional internal combustion engines. There is little research on batteries that can hold a large charge for more than a few hours of use, on economical cells that utilize hydrogen from either electrolysis of water or thermal fracturing to generate electricity and exhaust water, and there is not much research on how to expand super-cooled technology from short distances to make a national electrical grid system more rapidly feasible. The use of ground heat exchange structures, wall and roof insulation, and photocells for new buildings might be not only encouraged, but mandated for new construction by forward-looking regulatory zoning bodies.

Perhaps the efforts of the Clinton Climate Initiative to encourage a new equilibrium in the market for energy conservation will be successful, regardless of the politics in Washington, DC. Due to the air pollution they created when burning coal, locomotives have been electrified in New York City since 1902; many railroad lines in high population areas are electrified, but the nation-wide networks still operate on fossil fuel rather than electricity from the grid, a switch that was carried out in several European countries a long time ago. Hundreds of square miles in the windy portions of the country could generate electricity from wind power, but the US trails Germany in using this power source. Of the 26 sites that have been identified so far in the world as suitable for the generation of electricity from tidal power, and which could generate 400 TWh/year (400 million million W hr/year), four have been constructed - none is in the US; yes, they do require a very large initial capital investment, but once built, the energy generated is practically free. They also may interfere with fish movement, but new systems consisting of submerged propellers which do not interfere with animal movement are under investigation.

Some Final Remarks

It is not possible in a presentation such as this to cover all appropriate aspects, to dissect all details, to not omit some items that others would deem essential. As stated earlier, my intent was to pique the curiosity of the readers to the extent that they would expend the energy - yes, that word again - to learn more about the topics of biomass/biofuel/food and related themes. I hope I have been successful.

Obviously, my ire has been raised by what I consider willful mis-statements by leaders and agencies of our government. I agree with the late Senator Barry Goldwater who reportedly said that "simple honesty is not too much to demand from people in government". Unfortunately, as the columnist/economist Thomas Sowell recently wrote "in politics, there are few skills more richly rewarded than the ability to misstate issues to make them sound attractive". Teaching the public and policy makers about energy problems, transport fuels, food production and land allocation, is neither easy nor rapid. However, as Kung-Fu (Confucius) wrote over 2,500 years ago "if the government is wrong and nobody dares to say so - that is the one thing that could ruin a country". There will no doubt flow some good from the basic research being funded in molecular engineering, pathways of transformation, biochemical changes, enzyme production by engineered microorganisms, and all other aspects of lignocellulosic ethanol production, but are these advances worth neglecting the applied research that has made American agriculture the most efficient and productive in the world?

If we recognize that ethanol production from biomass is only a short-term makeshift approach for providing mobile fuel until such time as plug-in vehicles equipped with better batteries become available and affordable to the mass market in parallel with public transit, most non-emergency or perishable freight is hauled by rail, then the question remains: Can we decrease the "demand" without affecting too drastically our quality of life? Can we recollect that it will take 1.5 L of ethanol from over 13.5 kg of corn grain to be the equivalent of 1 L of gasoline, and that two times or more as much cellulosic biomass than corn grain is required to result in a liter of ethanol? Can we conceive of the fact that the 2007 US ethanol production was equivalent to only three days of Saudi Arabian petroleum extraction? If ethanol production requires more than a half-dollar subsidy for its production, is it worth all the dislocations its production causes in the food and feed markets? Is ethanol production clean and green, when its use generates carbon dioxide? How long do we wish to suffer from public transit amnesia or tolerate the abolition of electric tramways by competitors until we can find antidotes for ignorance, indifference and special interests?

Table 4. Sources of electricity in the US in 2005 (Adapted from National Renewable Energy Laboratory, 2007).

Source	% of total
Coal	49.7
Natural gas	18.7
Nuclear	19.3
Hydroelectric	6.5
Petroleum	3.0
Other	2.8

Conclusions

The stopgap production of ethanol from sugars to provide mobile fuel is expensive and causes dislocation in other agricultural commodities. Cellulosic and lignocellulosic ethanol production is theoretically possible but many aspects require research which may not be completed until other paths to energy independence are implemented.

Energy independence will require a painful revolution in many aspects of human societies worldwide; it will necessitate a change from indifference to consciousness of the inter-connectedness of physical, biological and human processes; it will demand an outlook reversal to a critical mass of urgent opinion so that proposed cures will not be worse than the affliction. There is no doubt that, to ensure humanity's survival, there will have to be either some reduction in the quality of life to which people have grown accustomed in developed countries, and some education to help people modify the implications of quality living.

A conservative land use policy including both urban and rural elements will need to be implemented in all countries, whether developed, developing, or undeveloped, to preserve and, where possible, to recover food-producing resources and to conserve rather than burn or waste irreplaceable minerals and fossils.

There will need to be institutions in developed countries with programs similar to the one which landed a man on the moon in 10 years. These programs of research and development will engage in renewable energy capture and the rapid implementation of scientifically tenable solutions. Means other than growing biomass and oxidizing the resulting biofuel, thereby releasing additional greenhouse gases into the atmosphere, will have to be investigated further, made more accessible, economical and widespread, to enhance rational and environmentally conscious capture of solar energy. These pathways will include substitution of private vehicles by public transit and of trucks by railroads, and the enhancement and wider utilization of mobile and grid energy systems with photovoltaic and hydrogen fuel cells, electric batteries and geothermal heat, wind, wave and tidal power, nuclear fission and fusion, and other systems yet undreamed of that future research will expose.

Lastly, it will require recognition that the use of land which is capable of producing food to feed "infernal" combustion engines, especially in a country where most people claim to be religious, is unethical and immoral.

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