Why We Need The Solar−Hydrogen Economy Now

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Why We Need The Solar−Hydrogen Economy Now
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World Permanent Oil Crises

In Chinese, the word "crisis" or "wei−chi" translates into "danger + opportunity". We are certainly living in "revolutionary" times which provides lots of opportunities. Today's energy systems did not arise just through the hidden hand of market forces; although, markets played an important role. Technology advances also played a major role. There are three concerns that compel us to rethink U.S. energy strategy−−our environment, our economy and our security.1, 5c

Our addiction to fossil fuels (coal and oil) is literally killing us.
Fuel combustion from automobiles and power plants is the primary source of large numbers of the health and crop−damaging and global warming air pollutants. Oil alone is responsible for smog, nitrogen oxides, sulfur oxides, and harmful volatile organic compounds (VOCs). This urban air pollution is indirectly responsible for killing an estimated 310,000 Europeans and 50,000 Americans each year.2a−d To this, we must add the regional and global destruction of forests, crops and fish by acid rain. For example, over 50% of the Black Forest in Germany is denuded and the soil pH is so acidic from the acid rain and VOCs that it will not support new saplings.3a In addition, green−house gases and their global warming consequence are causing harsh droughts, devastating floods and decline in crop yield..

Health effects of air pollution range from minor irritation of eyes and upper respiratory system to chronic respiratory disease, heart disease and, lung cancer. For example, air pollution has been shown to aggravate the frequency and severity of asthma attacks. Both short−term and long−term exposures have also been linked with premature mortality and reduced life span.3b

In San Jose, Costa Rica, the problem of smog is dramatic since the entire central valley is adversely affected. A survey has shown that 60% of the tourists have no desire to return due to high levels of air pollution. The "San Jose flu" is the nickname given for a sore throat due to air pollution. There is a major international effort being initiated to assist Costa Rica in making a rapid transition to the Solar−Hydrogen Economy.

Carbon emissions from power plants are projected to increase by 45% between 2000−2025 due to proposed construction of new coal−fired plants. However, a renewable electricity standard of 20% would reduce the growth in power plant carbon emissions by 59% by 2020. For the automobile, if we add hybrid vehicles to the U.S. fleet with an average fuel economy of 55 mpg by 2020, each vehicle would eliminate 60 tons of global warming emissions.4

The global warming due to carbon emissions has a more sinister effect on the earth's surface. Prof. Oechel (San Diego State University) has stated, "as the frozen Arctic melts and exposes more of the Arctic Ocean, there is less white surface to reflect the sun's heat back into space. Thus, the more darker open water there is to absorb the heat, the floating ice melts even faster. More than a third of the summer sea ice has disappeared in the past 30 years". In addition, he states, "as the global warming thaws and dries out more and more of the vast tundra, old decayed vegetation releases carbon dioxide which warms the atmosphere even more". It is a never ending increasing annual cycle until the tundra supply is exhausted.5a

The urgency of global pollution and health effects requires that in 10−20 years, we had better have moved to a level of 50−70% replacement of fossil fuel by solar energy to avert human and ecological disaster.5b,c The question remains: "Can we phase out fossil fuels before 2025?"

Population and Energy Growth

In 2004, the U.S. consumed 99.7 quad BTU (quadrillion BTU, or 1015 BTU) of all energy, for a population of 270 million people or 0.37 quad per million people.6 Residential energy consumption for 2004 was 11.4 quad BTU (gas and electric).6 The U.S. has 8% of the world's population, yet consumes over 25% of the world's energy supply to maintain its lifestyle. Our accustomed lifestyle will automatically be reduced as the price of energy goes up. This is already happening in regional "pockets" within the U.S.

There has been more than a doubling of the world's population since 1950, but the global economy has increased 6−fold from $6 trillion to $37 trillion.7a The population growth has been responsible for roughly half of the growth in global demand for goods and services since 1950. The other half has been rising affluence of the major nations. Even a small percentage increase in population adds up to an enormous additional burden on the Earth's natural systems and resources. In effect, the global economy, as now structured, is outgrowing the Earth's ecosystem.

We see the signs of this stress on the ecosystem due to our large fossil energy consumption. We have collapsing fisheries, rising temperatures, more destructive storms, eroding soils, shrinking forests, disappearing species and falling water tables. One can go on down the list. These are all manifestations of increasing stress from a global economy that is outgrowing its support system.

Energy Options

In 2005, the world produced 425 quad BTU (1015 BTU) from petroleum (primary level), coal, natural gas, nuclear fission, and renewable sources (hydroelectric, biomass, geothermal, solar, and wind). This breaks down as follows5b:

Petroleum 36.8%

Coal 25.2%

Natural gas 26%

Nuclear 7.5%

Renewable 3.6% (made up of hydroelectric 2.4%, biomass 0.17%, solar 0.60%, wind 0.03%, geothermal 0.43%)

Although biomass is a "renewable" it is also a carbon−based fuel that can be burned directly or converted into other carbon−based fuels such as ethanol to generate carbon dioxide, a greenhouse gas. One might argue that since the carbon dioxide came from a biomass that it would return to grow plants making it a zero balance on carbon dioxide. However, the atmospheric half−life of carbon dioxide is greater than two years yielding an impact on the total reservoir of atmospheric carbon dioxide. This leaves nuclear and the remaining renewables (hydroelectric, solar, wind, geothermal and tidal) as our only non−carbon energy options.7b

1. Nuclear Power

As recently as the 1970s, there was almost universal agreement on the notion that nuclear power was the energy source of the future. This high technology power generator was seen as the inevitable replacement for fossil fuels. Thousands of nuclear reactors, with generating capacities as high as 4,000 gigawatts (109 watts) were projected worldwide by the year 2000 according to the International Atomic Energy Agency.9

The 1980s witnessed a virtual worldwide collapse of orders for new nuclear power plants. The previous 10 years (1970−80) had been marked by frequent technical mishaps, serious accidents, huge cost escalations, and a rapid decline in public acceptance of nuclear power. Since 1987, many European countries have abandoned the use of nuclear energy.10a,b Austria (1978), Sweden (1980) and Italy (1987) voted to oppose or phase out nuclear while Ireland prevented a nuclear program there. Poland stopped the construction of a nuclear plant. Belgium, Germany, Netherlands, Spain, and Sweden decided not to build new plants and intend to phase out nuclear power. Germany has agreed to shut down all nuclear power plants by 2020.10b Switzerland has had a moratorium on construction of nuclear power plants for 10 years. Electricity planners were beginning to favor faster and cheaper efficiency improvements over commitments to massive centralized nuclear power stations.10a

Today, nuclear power has fallen far short of expectations. Just 343 gigawatts of nuclear power are actually in use, which is less than 1/10th of the amount expected. Currently, nuclear power provides about 7% of the world's electrical demand. Over the past 25 years in the U.S., no nuclear power plants have been built while a growing number of aging reactors are retired. These massive centralized units are now dinosaurs that are costing the public to phase them out.10b

The reasons for the collapse of nuclear power systems include: safety problems, inability to dispose of nuclear waste, and the potential uncontrolled proliferation of fissile materials in the hands of terrorists. In the late '80s and early '90s, The Three−Mile Island, Chernobyl and the Monju breeder (Sea of Japan) nuclear incidents led the death knell of the nuclear industry.10a As serious as these problems are, there is a secondary and more fundamental failure of nuclear energy to establish itself as an economically competitive means of generating electricity. By taking into account the cost of uranium mining, processing, isotope enrichment, and conversion to nuclear power rods, there is only a net 3% margin over cost at the current electric rate.10c However, with Government subsidies, it was a little more profitable for the nuclear power companies. Thus, nuclear fission power is no longer an option.

Controlled nuclear fusion, i.e. hydrogen fusion, is also not an option. In 1950, Dr. Edward Teller theorized the existence of nuclear fusion. However, even with heavy Government research subsidy in the intervening 50 years, there has not been any demonstrated sustainable controlled nuclear fusion power source. Nuclear fusion is now waiting on advances in superconducting magnets and new alloys for high temperature containment. Both of these are large technical obstacles. In addition, there is only a 100 years' supply of the lithium−tritium fuel. These problems are not expected to be overcome in the foreseeable future. Government funding for nuclear fusion has declined over the past 5 years and is expected to decline in the future.11 Even with massive Government funding, nuclear fusion would not expected to be commercialized until after 2060 if at all. Thus, nuclear fusion will NOT be available when the remaining fossil fuel supply is exhausted. We now have to actively develop other energy options while we still have sufficient fossil fuel to make the transition.

2. Renewables

Renewable energy has become big business. In 2004, global investment in renewable energy set a new record of $30 billion.12a A major transition to renewable energy is already in motion in Europe and Japan with the U.S. lagging far behind. At the current rate of growth of the Solar−Hydrogen Economy, in 15 years we will see 30% of the world's energy as renewable energy for electric power production, heating, cooking and transportation.

The key to a reliable, diversified solar energy system based on renewable resources will be the use of hydrogen as a major energy carrier and storage medium. In the short term, deriving hydrogen from natural gas for the initial generation of fuel cells would allow the easy transition to the Solar−Hydrogen economy.

Currently, the U.S. is safely using 9 billion of cubic feet per day of hydrogen for all sorts of petrochemical and food processes and rocket propulsion.13

Solar−Hydrogen Economy

The 20th century was the age of the Petroleum Economy while the 21st century is certainly the age of the Solar−Hydrogen Economy.12b The global Solar−Hydrogen Economy that is now emerging follows a different economic logic; one that is closer to the decrees of the information age. Under this economic paradigm, new machines and methods are once again being invented, while companies are restructured. A growing number of mainstream energy companies including British Petroleum (solar energy), Shell Oil (hydrogen, wind power, photovoltaic, bioenergy), and General Electric (fuel cells, micro−turbines) are investing in the solar based technologies.

1. Wind Power to Hydrogen

Wind power has also emerged as a serious option for generating electricity and, hence hydrogen. Electric cost for wind power, in some parts of the world, is now coming in under the cost of coal, which has been traditionally the cheapest source of electricity generation. In 1993, wind power was selling for 7.5 cents/kWh. In 2005, because wind turbine generated electricity has already reached technological maturity, it is now selling for 4−6 cents/kWh with projections to 3.5 cents/kWh.14a Currently, In California, about 1.5% of State's total electricity is produced by wind power.14b Europe could easily get 30% of its electricity from wind power alone.

The latest wind turbine models which are made by companies based in Canada, Germany, India, Spain and the U.S., have variable−pitch fiberglass blades that are as long as 120 feet, electronic variable speed drives, and microprocessor controls. In 2005, North America saw record growth in wind turbine sales. In the US alone sales broke $3 billion in 2005 from $2 billion in 1998 and is projected to be $7.5 billion in 2010.14b

In many of the U.S. States, the wind blows at all hours of the day and night. This intermittent wind power electric generation is ideal for hydrogen production. In January, 2006, it was announced that one of the first US−based hydrogen fueling stations to use electricity from wind power to produce hydrogen from water is under way in North Dakota. Basin Electric Power Cooperative awarded a contract to Hydrogenics Company for construction in Minot, N. Dakota of a wind to hydrogen system.15 This wind pathway to hydrogen will bring down its cost.

2. Solar Photovoltaic Energy to Hydrogen

The solar energy alone falling on the earth's surface each day is equal to 6,000 times the total commercial energy use. The limiting factor is that the sun does not shine at night. The electricity must be stored in some fashion, whether from wind generation or photovoltaic generation. Conversion to hydrogen generated by the electrolysis of water is the best energy storage media. Hydrogen is nearly the environmentalist's dream. When it burns, it emits no carbon dioxide, carbon monoxide, no volatile organic compounds, no fine particles and no sulfur dioxides. The main by−product of hydrogen combustion is water vapor, while fuel cell exhaust is also water vapor

The U.S. development of solar photovoltaic (PV) power started in the mid 1950s, and was accelerated in the 1960s by the U.S. space program. As a commercial industry in 1972, it cost $500/watt. By 1980, the installed cost was around $100/watt and by 2005 the installed price was between $6−8/watt while self−installed was $2/watt.16a,b

It took the PV industry 27 years to reach its first gigawatt (109 watts) of global PV capacity. Then, 4 years later, it reached 2 gigawatts. From 1994 to 1997, shipments of solar cells doubled.9,16 During the period 1997−2000, PV cell production has tripled which is a 44.3% per year compound growth.16 Residential applications make up about 25% of the total sales. In 2006, the new Federal tax credits for consumers that include PV cells will help to accelerate this rate of growth in the Solar−Hydrogen Economy.17

Today's most efficient commercially available PV cells (Sanyo) operate at around 17% efficiency. However, two separate research advances in 1999 promise to increase that to 30%. This efficiency has already been achieved with reflected solar power to PV cells.18

Solar PV cells generated electricity can be converted into hydrogen using a water electrolyzer. Newer advances indicate that water electrolyzers now are nearly double the efficiency of converting solar energy into hydrogen.19a

It takes about 52 kWh to generate and compress about 1 kg of hydrogen at an electric cost of $3.12 using wind power base rate of $0.06/kWh and an electrolyzer.19b However, overhead costs might bring this to $4.60 With the newer high pressure electrolyzers, the cost would be less. For a fuel cell car, this should get around 30 miles. Gasoline in Sweden with the carbon tax and also Germany is now over $5.50/gal while in Amsterdam it is near $7/gal.19c

3 Solar−Stirling Energy to Hydrogen

Solar−Stirling engine technology for generating electricity from a heat source has been around since 1816 when the Scottish Reverend Robert Stirling at age 25 developed the first prototype.20 A Stirling engine is a mechanical device which operates on a closed air regenerative thermodynamic cycle. This was 40 years ahead of Mr. M. Carnot and his famous thermodynamic Carnot cycle on which all heat engines operate today.20,21a

In 1937, the first Stirling engine was devised to power a small electric generator for radio sets. In 1938, the first hot−air Stirling engine was built, producing 16 watts. During 1946−48, the U.S. Navy had a contract with North American Phillips for the development of a Stirling powered electric generator.21a In 1979, the Stirling Thermal Motors (STM) company was founded and developed the current state of the art kinematic Stirling engine capable of 25 kW at 40% efficiency.21a Thus, the Solar−Stirling engine at 40% efficiency is a better strategy than PV cells (17% efficient) for generating electricity. Currently, there are over 25 Stirling engine companies worldwide.21b

4. Fuel Cells

The technology that will transform and drive the solar−hydrogen energy system is the fuel cell. Fuel cells use an electrochemical process that combines hydrogen and oxygen producing water and electricity. Avoiding the inefficiency of combustion, current fuel cells are theoretically twice as efficient as conventional heat engines (83% vs. 32−40%), have no moving parts, require little maintenance, and emit only water vapor. However, current low temperature fuel cell practical efficiency for autos is 30−35% and is being improved. In 2006, FuelCell Energy, Inc. achieved a new performance of 56% combined efficiency in a fuel cell/turbine system for a stationary system utilizing fuel cell's waste heat.22a The fuel cell is not limited by the Carnot heat engine cycle.22b,c

Fuel cells can be used in factories, offices and homes to generate electricity. In 2005, there are over 60 fuel cell companies that manufacture components or total systems. Up through 2005, Plug Power company has installed over 191 stationary fuel cell systems in factories and offices in 17 countries. However, fuel cells are more expensive up−front but require much less maintenance costs over time than VRLA batteries. VRLA batteries must be maintained and serviced fairly frequently and are considered hazardous material at the end of their life cycle which must be included in their original cost.22d

Emerging Solar−Hydrogen Energy Infrastructure

The massive centralized energy plants in the past made economic sense when they were built large, such as 1,000 megawatts. Downsizing and decentralization is becoming the major feature of the Solar−Hydrogen Economy. The new economy will place an affordable, reliable, and accessible power supply near where it is needed. This would retrace the computer industry's path from the mainframe to desktop computers in the past 20 years, and resurrect Thomas Edison's vision of decentralized, small−scale power generation.23

In 1997−2000, a consortium of U.S. DOE, South Coast Air Quality Management District and 11 companies have demonstrated the hydrogen generation and fueling technology for hydrogen powered vehicles at the Xerox facility in Los Angeles, for the City of West Hollywood, and Government vehicles in Sacramento. This project is the largest "stand alone" solar photovoltaic system for hydrogen production in the U.S. as an advent for the California Solar−Hydrogen infrastructure. This project paves the way to nation−wide use of solar hydrogen powered vehicles and is the first in a series of hydrogen fueling stations stretching across Los Angeles.24a In late 2005, California now has 16 hydrogen fueling stations with another 15 in the planning stage.24b In January 2006, Quantum Fuel Systems Technologies delivered five Toyota Prius hybrid vehicles that were converted to hydrogen fuel to the City of Santa Ana, California under contract from South Coast Air Quality Management District (AQMD). These H2 Prius vehicles are the first of AQMD's "Clean Air Pilot Program". This program, financed by AQMD and five southern California cities, will eventually develop and demonstrate 30 hydrogen hybrid vehicles for these five cities.25a,b Crash tests with autos having hydrogen tanks show that the hydrogen disperses straight up and there is no "danger time" as with petroleum fuel spills on the ground that can ignite or explode.25b

In recent decades, Iceland has utilized its geothermal and hydropower sources for much of its electricity. However, it was dependent on importing oil for the fishing fleet and other needs. In September 2000, Iceland announced that the whole nation is converting over to hydrogen power. Iceland's President Olaf Grimsson stated, "we are making Iceland a kind of trial base to see what we can develop for our entire (global) society". It has strong Icelandic legislature and European companies' support including Daimler−Chrysler (Germany), Shell Oil (Netherlands), and Norsk Hydro (Norway).26a In 2003, Daimler−Chrysler put three fuel cell powered urban buses into 5−day a week operation in Reykjavik. In November 2005, the buses were inspected and their performance exceeded all expectations. In 2006, the buses will be placed into 7−day a week testing program to check the reliability of their fuel cells.26b At Iceland's Keflavik Airport, a Plug Power Co. GenCore stationary fuel cell is currently undergoing a reliability test as a back−up power supply. The hydrogen comes from the nearby city of Reykjavik via tank transport.26c Iceland expects to be a net hydrogen exporter.26a

In Japan, under the WE−NET program, a wide range of development activities are being conducted on every aspect of hydrogen energy infrastructure. In 1997, the design of a 200,000 cubic meter liquid hydrogen tanker ship with prismatic tanks and spherical tanks was completed. A ship length of 290−320 meters, 48−65 meters width, twin hull design with a speed of 25 knots was evaluated.27

Bavaria is going heavily into the Solar−Hydrogen Economy. In 1996, the Bavarian Hydrogen Initiative, prepared by an industrial consortium and the German Aerospace Establishment, proposed to establish containerized liquid hydrogen (LH2) supply from the Canadian Quebec hydro−electric project. A "LH2 Bus Demonstration Project" was tested in Munich during 1996−1998. This was successfully demonstrated.5c

The Euro−Quebec Hydro−Hydrogen Pilot Project (1992−1998) has demonstrated, in extensive testing, the vessels necessary for storage of liquid hydrogen, acid fuel cells for electric generation, a hydrogen bus project in Montreal and a hydrogen powered passenger ship in Italy. This project later included the Bavarian hydrogen bus project.13,22

In August, 2000 Ford Motor Company issued a purchase order to Stuart Energy Systems to evaluate its Personal Fuel Appliances over the next two years The appliance converts water and electricity into pressurized hydrogen for fuel cell vehicles. Stuart Energy Systems has been collaborating with Ford Motor since 1995 on projects relating to the hydrogen fuel infrastructure. The Stuart Appliance approach was identified by Ford as being an effective solution to the hydrogen fuel infrastructure.5c

It is less expensive to move hydrogen up to 1,000 miles by pipeline than an equivalent amount of electricity. Liquid hydrogen is the safest and most economical choice for moving energy across oceans.25c Hydrogen is the safest of all fuels. It is 14 times lighter than air; therefore, it rapidly disperses into the atmosphere in the event of accidental release.25c

Pathways for Change to Solar−Hydrogen Economy

So the challenge is: how do we restructure the Petroleum Economy into the Solar−Hydrogen Economy so that we can stabilize the eco−system relationship and allow economic progress to continue?7

Technologies and hydrogen infrastructure, such as discussed above as well as others are already in place, can pave the way for an energy transition during the next 10−15 years that is as profound as the last major energy transition which occurred over a century ago. Although the details of the Solar−Hydrogen economy are not mapped out, the broad outlines are clear. They suggest that the new energy economy will be highly efficient and decentralized. Over time, hydrogen will become the main fuel for the 21st century, derived first from natural gas but later produced from water using solar energy. The use of natural gas as a "bridge" to hydrogen will allow a relatively seamless sequence to a renewable energy based system.13

The implications of a shift to the Solar−Hydrogen Economy are profound. The world would be freed from dependence on oil, finally ending the geopolitical nightmare that has preoccupied national security planners for the last 50 years.13

Energy transitions do not occur in a vacuum. Past shifts have been propelled by technological change and a range of social, economic and environmental forces. Understanding these forces is essential for mapping out the path that humanity may follow in the next 20 years. The next step in the new economy is implementing mass production. The costs of the new modular energy devices are expected to fall dramatically as their markets expand.

Systematic change can begin slowly, but gain momentum quickly. The pace and direction of an energy transition are determined not just by technological developments, but also by how industries, governments and societies respond to them.

The question arises: How can we deliver energy to a fuel cell auto without the total hydrogen delivery infrastructure in place before 2025? A solution would be by installing small "stand alone" solar−hydrogen generation and storage units having a single pump outlet at each commercial gasoline station. They can be turned on or off as the need arises. Re−plumbing this unit into multiple pump outlets can occur as demand increases. How realistic is this goal? It could be done by a consortium of all major oil companies agreeing on implementing the solar−hydrogen generation units at all their gasoline stations and a milestone table for phasing out all gasoline service. Thus, all produced hydrogen would be the same quality with no "brand" differences, e.g. Shell, Exxon, etc. The competition would be simply based on cost and service. All of this is dependent on the major auto makers moving forward with the fuel cell auto.

Economic and commercial considerations are at least as important as technical. In the interim, many customers will be paying a premium for environmentally clean products. Politically driven technology choices may occur. Targets should be set and then industry should be allowed to get on with developing the technologies and infrastructure. That is the way to make rapid progress and to introduce hydrogen technologies through a broad market focus, guided, but not controlled, by benign Government regulations.28

There are seven factors that can speed the change to the Solar−Hydrogen Economy:

(1) That renewable energy and energy efficient technologies are available at a price which is competitive, e.g., wind power is already competitive.

(2) That sufficient financing is available to build the solar energy manufacturing plants and provide the 25 year solar mortgages which will allow ordinary householders to retrofit their homes and invest in solar shingles.

(3) That businesses are ready to play an expansive entrepreneurial role by developing and spreading the new technologies.

(4) That supportive policies are in place at the municipal, state, and federal levels of government; and that the equivalent subsidies be removed from fossil fuel production which is currently subsidized to the extent of $20 billion/year in the U.S. For example, the Federal Government has already passed tax incentives for installation of home PV systems in 2006.

(5) That public education campaigns promote and explain the need for the transition.

(6) That non−profit societies, coalitions and partnerships work at the local level to promote, educate, and lobby for the new energy economy as the solution to global pollution and warming.

(7) That global treaties, technology transfer agreements and investments are put in place to speed the energy changeover, equivalent to the Manhattan Project. We have done it before and can do it again.

If these conditions are put in place, the new energy changeover can be driven by a tightly−woven partnership in which these seven factors: technology, capital, entrepreneurship, policy, education, citizen activism and global co−operation. Each plays an essential role.

The bottom line on this is that from an industry point of view this restructuring of the global economy to make it environmentally sustainable and to enable current economic progress to continue is the greatest investment opportunity in history. Even the past growth of the computer market will pale in comparison. There has never been anything like it.7

Conclusions

From the analysis of the foregoing technical and economic survey, it is obvious why we need a Solar−Hydrogen Economy now due to the following factors:

1) The use of fossil fuel creates global warming and air pollution

2) Air pollution creates degradation of forests, agricultural and human health and mortality

3) Global warming is melting the Arctic ice cap.

4) Nuclear fission and nuclear fusion are not viable energy options due to nuclear waste problems, security from terrorists, and future shortage of nuclear fuel.

5) Due to the rapidly increasing imported oil costs, it is necessary for the U.S. energy market to convert from fossil sources to Solar−hydrogen sources to maintain a viable economy.

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