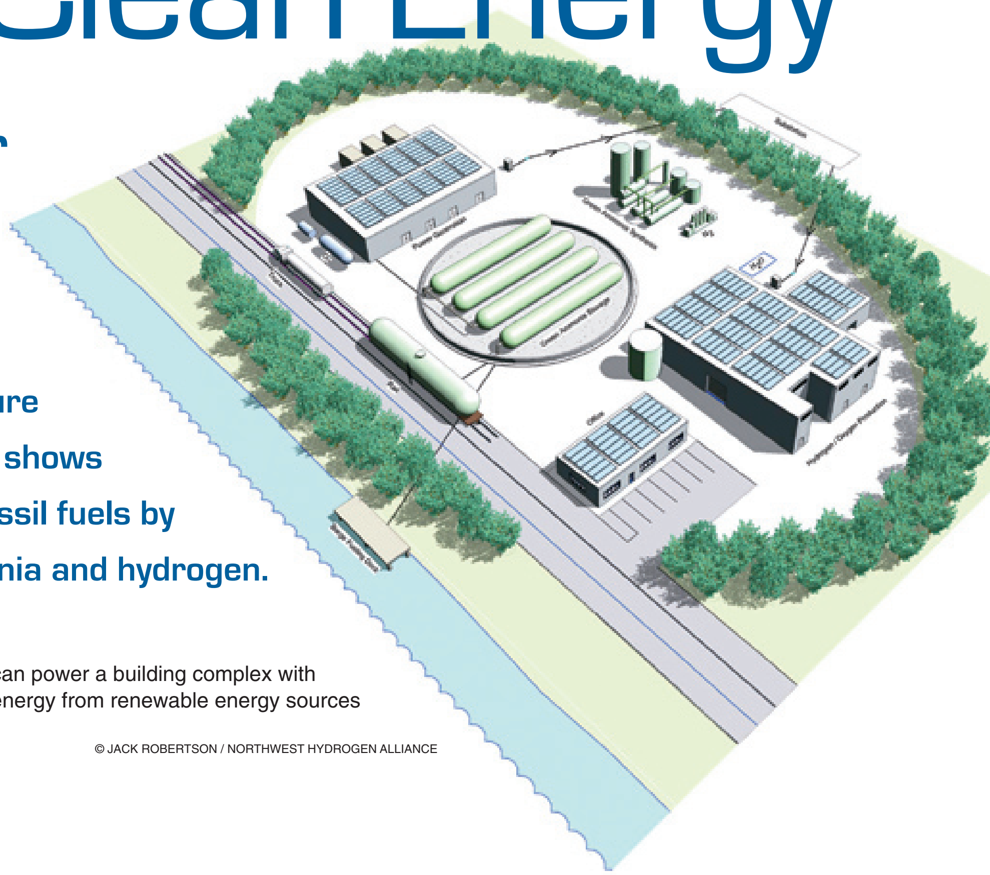
A Convenient Truth About Clean Energy

By Carl E. Schoder

The Earth is awash in energy; we just need new infrastructure to tap it. A chemical engineer shows how we could break free of fossil fuels by deploying the power of ammonia and hydrogen.



The prototype Hydrogen Hub electricity system can power a building complex with anhydrous ammonia fuel. The system captures energy from renewable energy sources and stores it in anhydrous ammonia.

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Gas stations will make way for vehicle refueling stations that generate energy on-site via solar and wind power. This scene on the Dahme River outside Berlin, Germany, shows one such present-day refueling station. The boats draw power from the solar energy reserves.

The convenient truth is that the world does not have an energy shortage; it simply lacks an energy infrastructure capable of using the abundant source of solar energy that we receive from the sun every day. The current worldwide demand of about 363 terawatt-hours per day could be met by covering just 0.5% of the world's land area with silicon solar panels. Doing so, and building out other necessary infrastructure requirements, could meet our energy needs and eliminate dependency on nonrenewable petroleum.

As we examine our energy future, we should keep in mind three fundamental requirements:

1. Abundance. Because of the value that energy gives us in improving the quality of life, the long-term abundance of an energy source and of the materials required to produce it is very important.

2. Cleanness and greenness. Clean, green energy is important because we only have one Planet Earth. When we pollute and damage it, we are destroying our home.

3. Widely distributed availability. Moving energy from point to point is an energy-consuming and wasteful practice, so ease of transport and accessibility are important considerations in building the energy future.

Energy Supply

We typically refer to fossil fuels as sources of energy. In reality, fossil fuels are stored forms of potential energy created from solar energy ages ago, so the real source was the sun. These fossil fuels are nonrenewable sources of energy; formed over eons, they are now being spent in a matter of decades.

Gasoline, diesel, biodiesel, ethanol, methanol, hydrogen, and electricity are not true sources of energy because they need to be converted from other sources into these more convenient forms. Whenever one type of energy is converted into another type of energy, some of the source energy is lost as waste heat or friction (entropy). This entropy waste is one of many reasons why the conservation of all natural materials—including petroleum—is for the betterment of society.

Solar energy, however, is different; it is constantly being generated and radiated into the universe. Any solar energy that we do not use becomes wasted light and heat energy, dispersed into the empty void of space as a sort of dark, weak energy that is unavailable for our use.

A basic source of energy is fusion energy, which is in fact the primary source of all energy in the universe. Our sun is a fusion energy source, as are all of the billions of suns in the universe. Our sun has been producing reliable fusion energy for several billion years and is estimated to have a remaining life of more than 4.5 billion years. All we need is an infrastructure to collect and utilize the already ample solar energy it sends our planet's surface daily—more than 2 million terawatt-hours.

How much solar energy do we receive from the sun? Let us look briefly at the sources.

Amount of Solar Energy Available

There are four major types of energy sources that we get from the sun: heat, wind power, photosynthesis (biomass cultivation), and photovoltaic power. Heat is what warms the earth and makes it livable as a planet. Wind power is available, useful, and relatively inexpensive, but it is too limited to fulfill worldwide demands. Biomass is also an available option, but as a product of photosynthesis, it is less efficient than photovoltaic generation of electricity. Also, the competition for resources among agriculture, forestry, and energy must be carefully and cautiously evaluated before considering the use of biomass for energy on a large scale.

Now let us look at how much photovoltaic solar energy is available from the sun. Starting with National Oceanic and Atmospheric Administration Solar Constant data measured at the stratosphere, we can estimate the average amount of sun continuously reaching the Earth's surface at 174 watts per square meter, which obviously varies by latitude, season, cloud cover, and other variables. In the region from the southern tip of Greenland in the north to the outer rim of the Antarctic Circle in the south, where most of the energy demand is and where most of the solar energy generators would be constructed, the amount of continuous solar exposure is greater than average, so the 174 watts per square meter is a valid and conservative value for estimating solar generation potential.

Energy Storage

The key to fundamental requirement #3, availability of energy, is storage. We shall now examine ammonia as a viable carbon-free energy storage option.

Ammonia (NH_3) is a compound of one part nitrogen and three parts hydrogen. We are specifically interested in anhydrous ammonia (without water) as opposed to aqua ammonia, and with dissociated ammonia (the nitrogen and hydrogen components are split, with the resulting dissociated ammonia gas comprising 75% hydrogen by volume).

Since dissociated ammonia is a gas, it is not a convenient storage medium. However, the combination of a tank of anhydrous ammonia connected to an on-demand ammonia dissociator is a surprisingly efficient energy storage and supply system. The "ammonia/dissociator" combination compares favorably with fossil fuels in volumetric energy density.

In addition to its reasonable energy densities, ammonia and hydrogen are carbon-free energy sources. To be completely carbon-free, the source of hydrogen for the manufacture of the ammonia must be by water electrolysis. The electricity to electrolyze the water would be most efficiently provided from solar energy sources, such as photovoltaic or solar thermal collectors. An advantage of the anhydrous ammonia/dissociated ammonia energy storage system is that, by comparison, current battery technology is 15 to 60 times bulkier by volume.

The Carbon-Free Energy World Of the Future

I envision a combination of on-site and remote energy-generating facilities of appropriate sizes to be designed for the residential, commercial, industrial, and transportation energy sectors, with the emphasis on on-site facilities. A typical on-site, carbon-free energy system would consist of:

- A solar array (PV or thermal).
- An electricity converter system capable of supplying both DC and AC electricity.
- A water electrolysis system.
- A unit for extracting nitrogen from air.
- A Haber-type ammonia generator making anhydrous ammonia from hydrogen and nitrogen.
- An anhydrous ammonia storage tank.
- An on-demand ammonia dissociator.
- Various pumps and compressors.

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The Aswan Dam in Egypt (pictured above) and other hydroelectric dams would be great sites for future solar-energy plants, according to Schoder. The solar plants could store their extra electricity in the dams' reservoirs and harness it during nighttime hours.

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Work crews gather on a Florida beach in the wake of the June 2010 Gulf Coast oil spill. Schoder points out that even though fossil-fuel electricity may now cost less per kilowatt than many renewable alternatives, it carries many hidden costs, such as unexpected environmental disasters.

U.S. Energy Consumption, Current and Potential

(Average annual consumption, in Terawatt-hours)

	Fossil-Fuel		Renewable Energy		Total Consumption	
Energy Sector	**2004-2007**	**2050**	**2004-2007**	**2050**	**2004-2007**	**2050**
Residential	1,814	36	146	1,924	6,247	2,046
Commercial	1,122	22	35	1,135	5,242	1,239
Industry	5,804	116	571	6,259	9,714	6,439
Transportation	8,218	164	127	8,059	8,370	8,224
U.S. Total	16,959	339	879	17,376	29,473	17,948

In a scenario assuming that 98% of energy is supplied by renewables, the United States could see 98% reductions of electricity retail sales and electrical system energy losses, and an overall savings of 39% in total average energy consumption by 2050.

Source for 2004-2007 figures: *U.S. Energy Information Agency Annual Energy Review*, 2008. Author's projections for 2050.

A wind turbine would be a desirable addition in areas of strong wind power. All of these system components are currently manufactured, but research and development would be required to provide a better variety of sizes and capacities for the various energy sectors.

Let us design an energy system using the United States as an example, though the principles will be applicable to the whole world. We will look at the areas of housing, commerce, manufacturing, and transportation. The numbers are rounded calculations based upon U.S. Energy Information Agency (EIA) data for 2004 through 2007. Estimates can be made into the future using population extrapolations.

The U.S. Energy Consumption table shows average annual consumption for the four energy sectors and a what-if scenario involving the essential removal of all fossil fuels for energy generation. The numbers for 2050 show a future transition from fossil-fuel energy generating plants to mostly renewable-energy generating facilities, including the use of anhydrous ammonia with on-demand dissociators for space heating at night and when solar energy is limited. This would be supplemented as needed with some remote renewable energy generating facilities in areas of high wind or solar insolation.

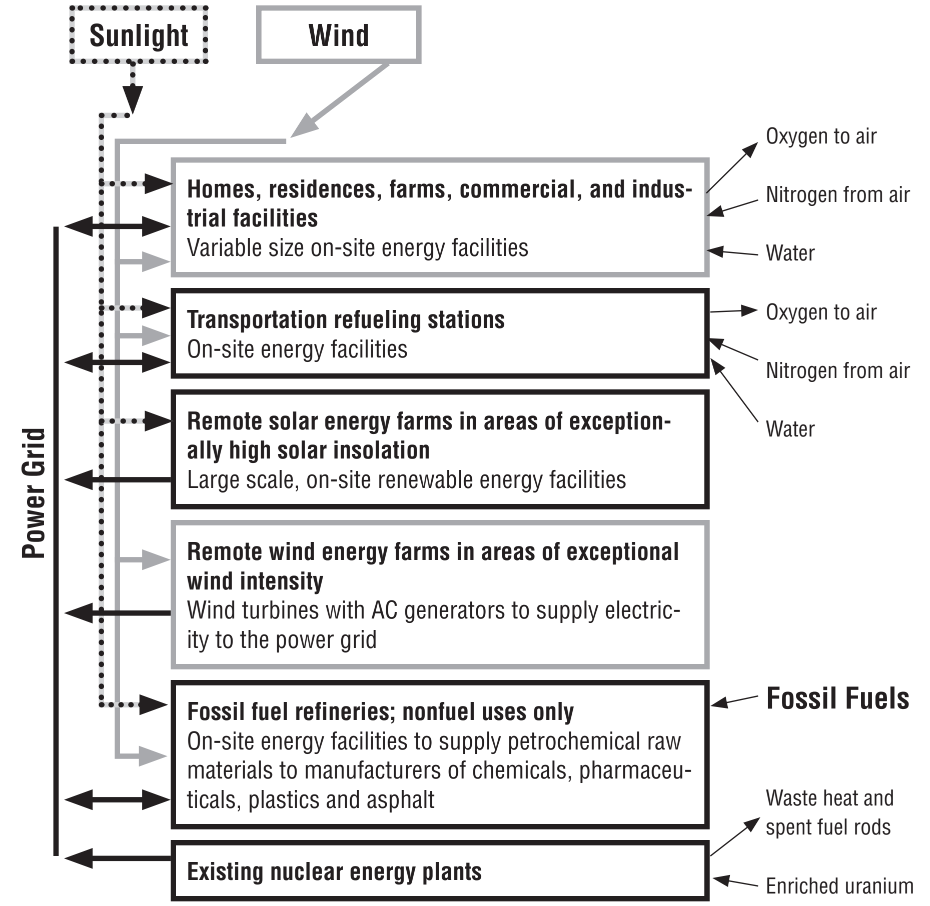
This change would have tremendous benefits in energy conservation, CO_2 emission reductions, safety, and improved security. The numbers show a 39% decrease in U.S. energy consumption from more than 29,400 terawatt-hours per year to less than 18,000 terawatt-hours per year. There would also be a reduction in CO_2 emissions of about 98% from current energy generation using mostly fossil fuels. In all, it would be a huge step to a brighter, cleaner, and safer world of the future.

It will be imperative to maintain an adequately up-to-date electricity grid. The grid will have a significantly diminished load, but it will still have to provide flexibility, load leveling, and backup for inevitable equipment and system failures, as well as the variability of local climate changes that affect solar energy generation. In addition, there will be some demand for large, remotely located solar-energy generating plants in areas with above-average solar insolation, such as the southwestern United States, to add energy to the grid as backup power.

Consumption by Energy Sector

• **Residential consumption.** U.S. households consume about 6,247 terawatt-hours of energy per year (not including energy used for transportation). But that total would transition to about 2,046 terawatt-hours per year in the homes of the future using on-site generation. The future household would have an on-site energy system to provide on-demand

A Diagram of the Carbon-Free Energy System of the Future



electricity and dissociated ammonia (75% hydrogen) for a 24-hour-per-day energy supply. The house would have electric heat and/or a furnace, which would be fueled with dissociated ammonia. It would also have a dispensing station to provide electricity and ammonia to the family's fuel-cell cars fueled by dissociated ammonia. A farmhouse would have a larger anhydrous ammonia synthesizer and storage tank for fertilizing crops.

• **Commercial buildings and facilities.** Commercial buildings and facilities would reduce consumption to about one-fifth of current rates. Future commercial buildings would have systems similar to residential, but with a broader range of capacities. The facility would have electric heat and/or a furnace, which would be fueled with dissociated ammonia and a dispensing station to dispense electricity or ammonia to the business's fuel-cell cars fueled by dissociated ammonia.

• **Industry and manufacturing facilities.** The U.S. industrial sector could shift to running on only two-thirds of its present level of electricity consumption by 2050. Industrial facilities would also have on-site energy generating facilities similar to those described above but with an even greater variation of sizes and components. Existing industrial plants with limited open land may need to supplement their on-site generation with grid-supplied electricity from solar facilities in the southwestern United States (another reason to maintain the electric grid).

• **Transportation.** Present-day "gas stations" would be replaced by transportation refueling stations that charge batteries and dispense anhydrous ammonia. Almost all transportation fuel would be generated on-site using photovoltaic and wind/solar energy facilities. This would practically eliminate the transport of fuel by trucks on the highway system, which would reduce transportation consumption by about 146 terawatt-hours per year and significantly reduce the danger of collisions and spills on the highway system.

An example of the transportation vehicle of the future is the Apollo Energy Systems electric car designs, such as the Silver Volt II, which has a patented propulsion system supplied by an anhydrous ammonia fuel tank. Research and development is needed to design similar propulsion systems for trucks, buses, trains, and airplanes.

Lowering the Costs of Energy

Solar energy has been wrongly conceived to be very expensive compared with fossil fuels. This is probably due to the idiosyncrasies of internalizing and externalizing various costs of energy. As the recent Deepwater Horizon's oil platform explosion and resulting leak has shown, such costs have not been planned for and will now have to be added to the future cost of the supply of fossil fuels. The area of the costs of fossil fuels is indeed a messy, murky, smelly oligarchic sea.

With the gradual buildup of a photovoltaic infrastructure, electricity and dissociated ammonia (75% hydrogen) will become the primary energy source for stationary needs and for transportation and other mobile needs. However, petroleum and other fossil-fuel resources will continue to be valuable and necessary commodities, since fossil resources have other uses than the production of energy. One-eighth of U.S. oil is not burned as fuel, but is instead used to make other materials, such as asphalt for roads and buildings, as well as fertilizers, plastics, pharmaceuticals, and other chemical products.

There will be no serious abandonment or obsolescence of petroleum facilities. Older facilities will gradually be phased out and not replaced. New high-efficiency refineries can be built to supply feedstock for the nonenergy products of fossil resources. High-efficiency vehicles, machinery and systems, as well as conservation, will be needed to move toward energy sustainability.

Over several decades, the world will go from a primarily carbon-based energy system to a primarily "solar-ammonia-hydrogen" energy system. Carbon-dioxide emissions will be greatly reduced, and global warming may cease to be a problem. The environment will be cleaner, safer, and more secure. Underwater oil wells will no longer be needed. Oil spills will be a thing of the past. In addition, the new solar technologies will be a source of significant new jobs.

Creating the desired solar-ammonia-hydrogen infrastructure will require the strong cooperative support of governments throughout the world. Governments must rethink their energy policies by reducing or eliminating the hundreds of billions of dollars in annual subsidies for fossil fuels and incorporating all costs—including extraction damages; CO_2 buildup; resource depletion; air, soil, and water pollution; acid rain; and biodiversity losses—into the price of fossil fuels. Security costs should also be included in the price of fossil-fuel energy and nuclear energy.

The model for this approach exists today in many European nations whose governments are already using taxes and incentives to fund new renewable energy infrastructures. As Jeff Immelt, the CEO of General Electric, has said, "Europe today is the major force for environmental innovation. European governments have encouraged their companies to invest in and produce clean power technologies."

One way of covering the infrastructure building costs would be a worldwide "carbon tax" or "resource extraction tax" on all carbon-containing fuels, like petroleum, natural gas, and coal. It would essentially be a fee charged for resource depletion. Implementing this tax would motivate consumers to burn up less gasoline and force businesses to innovate in green technologies. This is a classic case where an old quote of former Senator Jack Kemp is applicable: "Tax that which you want to discourage and subsidize that which you want to encourage."

A tax of 5% might be a fair starting point. The proceeds would be used to build plants that manufacture photovoltaic-grade silicon and silicon photovoltaic panels. Soon after start-up, these plants would be converted to run on photovoltaic electricity generated by panel arrays manufactured on-site.

Where possible, these plants should be located near sites of abundant sand and water. Sites near hydroelectric dams are ideal because the plants could harness the dams for potential energy storage by using excess photovoltaic electricity to pump water uphill into the reservoirs as a source of potential energy for nighttime use. Four ideal locations would be near Hoover Dam outside of Las Vegas, Nevada; near Grand Coulee Dam in Washington state; near the Aswan Dam in Egypt; and near the Three Gorges Dam in China.

Around 90% of the photovoltaic panels produced by the plants would be sold for residential and commercial rooftop photovoltaic electricity generating units. Low-interest loans must be made available to buyers, initially, to subsidize the capital costs until manufacturing supply and panel efficiency are optimized. The remaining 10% of the photovoltaic panels produced by the plants would be installed at the site to supply electricity to the local electrical grid for grid-supplied electricity. This approach would continue until the world's current electricity demands are met from renewable energy sources.

The carbon tax funds would also be used to build photovoltaic solar panels to supply electricity to "filling stations" for recharging electric vehicles and making hydrogen by electrolysis and anhydrous ammonia to supply fuel-cell vehicles. The arrays of panels would be built over the highway roadbeds so as not to use additional land area. I believe that it would even be possible to build airplanes that would fly using dissociated ammonia or liquid hydrogen as a fuel.

The world will then have converted to a primarily solar-ammonia-hydrogen energy world, free of its dependence on fossil fuels. Any remaining coal, petroleum, or natural gas reserves left at this time would be put into restricted feedstock reserves for pharmaceuticals, plastics, and petrochemicals. The result would be a sustainable, carbon-free world energy supply for centuries to come.

Rethinking the "Good Life"

Our sun will not last forever. However, if we convert to a carbon-free energy system, we should be able to extend our comfortable life on Earth for several billions of years. How we do this is up to us. We can continue to eat our free lunch of fossil fuels until their depletion, or we can start now to convert to a carbon-free energy system in a well thought-out manner over the next 40 or 50 years.

We, the global community, have to make a choice between cheap, dirty, harmful fossil fuels or slightly more expensive clean energy, which is available but for which we lack the appropriate infrastructure. The cost of a world with vastly less climate change, terrorism, and environmental damage is to readjust our priorities and pay more for energy and less for war and for damage from climate, environment, and weather problems.

A significant contribution to our current world energy situation is the consumption creed that has been pushed upon us by the marketing geniuses of the global corporations. The public has been enticed by those corporations to buy more and save less.

I believe that, if we continue this consumption cult, we will be bringing on serious problems, such as climate change and religious wars, and much unnecessary suffering. On the other hand, if we insist on a resource depletion fee or carbon tax instead of begging for cheap oil, these problems can be avoided. A long-range solution in the form of carbon-free energy is feasible and doable if we plan now, spend for the future instead of the present, and conserve more while spending less. ❑

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