The Energy-Climate Crisis is Your Business

Part VIII: Let the Sun Shine–Limitless Energy, Cheaper Than You Think[1]

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"Let the sun shine in" – The Age of Aquarius – Fifth Dimension, 1969

Each year, humanity uses 15 trillion watts of energy to power its progress. That's equivalent to the output of about 15,000 large power plants. Every hour of every day, the sun radiates more energy than all humanity uses in an entire year. If only 10 % of the impinging solar energy were converted to electricity, a square of land, just 100 miles on a side could contain enough photovoltaic cells to supply the entire U.S. with its electricity needs – and it would be pollution- and carbon-free. Yet today the total global solar capacity is only about 7 gigawatts – equivalent to about 7 nuclear plants – while coal supplies more than 1000 gigawatts of electricity, worldwide. Why is that?

To understand the challenges associated with solar energy and how they are being addressed, it is convenient to divide solar energy into two categories, photovoltaic systems, where electricity is generated directly by sun rays impinging on a semiconductor material such as silicon, and thermal systems, wherein the sun's rays are used to create high-temperature steam that drives a turbine to generate electricity.

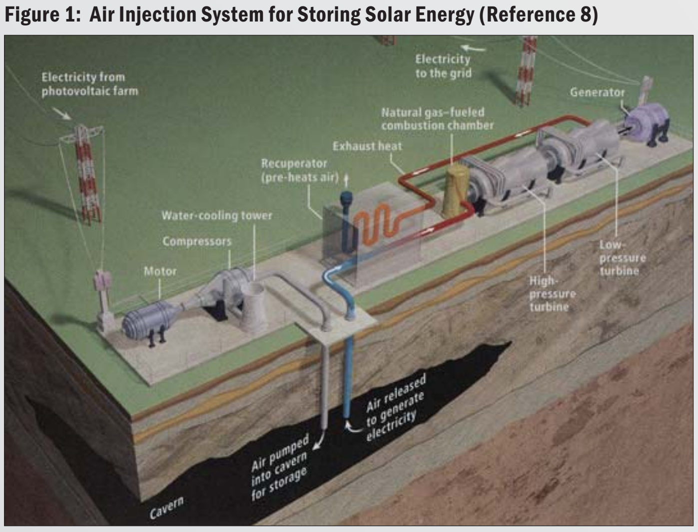
Photovoltaic Systems

There are three challenges with photovoltaic systems. **First**, there is a large complex existing power infrastructure that companies are reluctant to replace because of their large invested capital. **Second**, sunshine does not reach the entire surface of the earth 24 hours a day 365 days a year, and therefore a cost-effective means of storing solar energy is necessary if it is to play a major role in continuous power generation. Some means of capturing and saving intermittent solar energy is imperative, so that energy is available on demand when the sun is not shining, e.g. in the evening. **Third**, although prices have fallen dramatically, traditional silicon photovoltaic cells previously have not been cheap enough to compete with conventional energy sources, such as coal, oil, and gas.

The **first issue** of sunk capital is as much a political one as it is economic. However, with the rapidly decreasing cost for the manufacture of silicon and other types of photovoltaic cells, and with any kind of tax or trading price on carbon emissions, this issue should disappear, strictly on economic grounds.

The **second issue** of energy storage is the same challenge facing wind power and was addressed in Part VII of this series[2]. Several technologies have been developed to address this issue. They include pressurizing air and storing it underground, with subsequent release through power generating turbines, when demand requires energy; pumping water uphill and discharging it through turbine generators during high demand periods; super-capacitors for electrical storage and discharge when extra power is required; high-power flywheels that store energy mechanically for conversion back to electricity; high-capacity lithium batteries; flow batteries that use molten salt as the electrical source; and hydrogen production via water electrolysis and conversion of the hydrogen to electricity when needed via a fuel cell. Perhaps the most promising technology is air storage as shown in **Figure 1**.

Figure 1: Air Injection System for Storing Solar Energy (Reference 8)

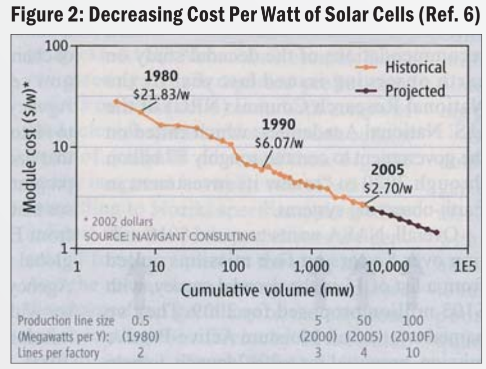


By far the biggest challenge has been the **third issue**, i.e. the cost to manufacture high-efficiency photovoltaic cells. There are three approaches being developed to lower the cost of photovoltaic cell manufacture. The first is increasing the efficiency of crystalline silicon cells, while lowering the manufacturing cost by investing in large scale production lines. The second is via recently-developed technologies that can produce silicon or other cells cheaply in large quantities. The third approach is by concentrating the highest level of efficiency on to the smallest possible silicon cells and then interfacing these cells with optical lenses that concentrate the sunlight, multiplying its intensity 500–1000 times.

Solar energy is priced on a per peak-watt basis, i.e. the maximum wattage output of a cell during peak periods of sunshine. In 2007, the peak-watt price was $4. Most industry analysts have generally projected that with the combined advantage of an energy storage system and a price per peak-watt of $1, solar-generated electricity can compete with fossil fuel generated electricity, globally.

Most next generation photovoltaic systems are moving away from single crystal silicon, which must be so pure that there is not more than one impurity atom per trillion atoms of silicon. An exception to this is Innovalight, in Santa Clara, California[3]. Using nanotechnology – engineering materials on the atomic scale – Innovalight has reduced the amount of silicon required per watt of electricity from 15 grams for a conventional cell to 0.04 grams – a factor of nearly 400 times. This system also allows for high throughput manufacturing which cuts the cost by another 10 times compared to conventional photovoltaic cells. Another advantage of Innovalight's technology is that by controlling the size of the silicon particles that are cast as a film, it is possible to tune into the entire wavelength spectrum of sunlight. This means increased efficiency and higher energy output. By the end of 2009, the company aims to produce enough flexible solar material to generate 100 megawatts of electricity at the amazingly low cost of 30 cents per watt. While the theoretical efficiency limit for crystalline silicon is 33%, it appears that the Innovalight technology could achieve 44%, and as high as 68 % with an optical concentrator.

Figure 2: Decreasing Cost Per Watt of Solar Cells (Ref. 6)



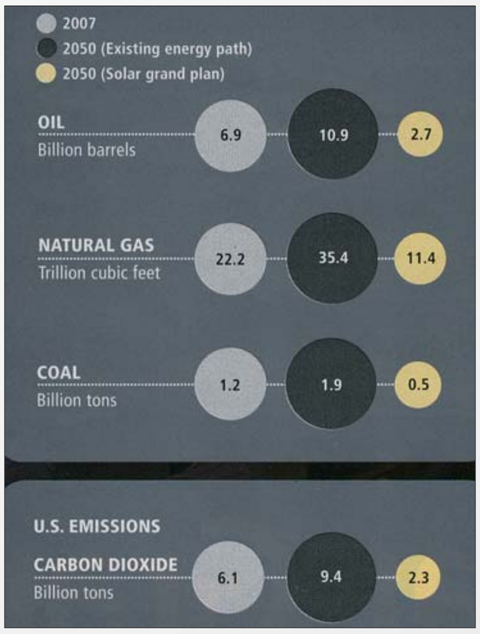
First Solar is another innovator in photovoltaic systems[4]. The company has plants in Ohio, Germany and Malaysia and can produce in 2½ hours, glass photovoltaic modules that are 2 feet wide and 4 feet long, having an efficiency of 9 %. These modules sold in 2007 for $2 per watt, but improvements are driving the selling price to less than $1 per watt. The company has long-term contracts with European and Canadian companies to supply modules that can generate more than 795 megawatts, i.e. nearly eight times the total shipped in 2006 from every solar factory in the U.S.

A third approach is being taken by Energy Innovations[5]. This company is concentrating the energy of the sun. Our sun radiates energy very diffusely, 1000 watts per square meter of the earth's surface, whereas a simple hair dryer radiates 1,000 watts per square inch. Thus the sun is 16 times more diffuse than a common hair dryer. To power a typical large city such as San Francisco requires about 1 gigawatt of electricity. Using conventional photovoltaic cells would re-quire 4 square miles of silicon. Energy Innovations' concentrator technology reduces this requirement by a factor of 800. As shown in **Figure 2**, all of this effort has led to a marked decrease in the cost for producing photovoltaic solar cells[6].

Solar Thermal Systems

Solar thermal systems, often called concentrated solar power (CSP), uses huge arrays of mirrors to focus sunlight on a boiler to produce high-temperature steam to run a conventional turbine generator and produce electricity. There are

Figure 4: U.S. Grand Solar Plan – Fuel Consumption and GG Generation (Reference 9)



several types of CSP systems; Parabolic Mirrors that heat tubes containing a heat-transfer fluid; Power Towers wherein a tower containing a heat-transfer fluid is surrounded by hundreds of mirrors that individually track the sun; Dish-Stirling systems, which look like a field of giant sunflowers, each dish being a circular array of mirrors focusing the suns rays on a Stirling heat engine, invented 200 years ago by Scotsman, Robert Stirling; and a Linear Fresnel system, wherein the solar concentrator is a series of independently tracking mirrors that together approximate the shape of a huge trough mirror[7].

Figure 5: U.S. Grand Solar Plan – Technologies and Requirements (Reference 9)

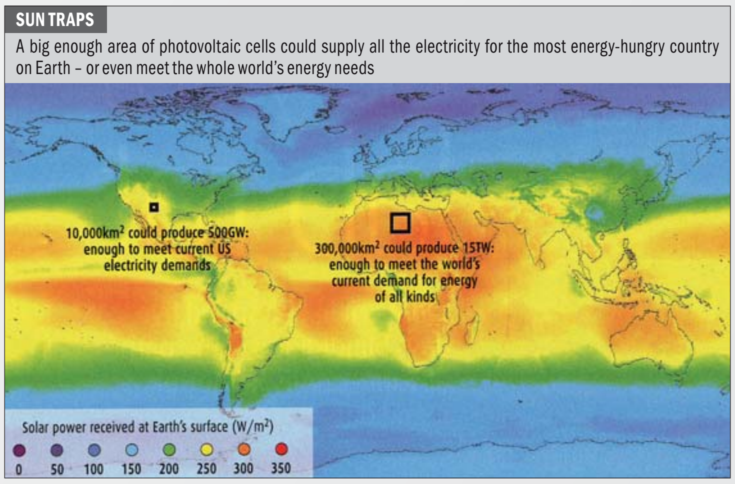


Figure 3: U.S. Grand Solar Plan – Technologies and Requirements (Reference 9)

TECHNOLOGY	CRITICAL FACTOR	2007	2050	ADVANCES NEEDED
PHOTOVOLTAICS	Land area	10 sq milies	30,000 sq miles	Policies to develop large public land areas
	Thin-film module efficiency	10 %	14 %	More transparent materials to improve light transmission; more densely doped layers to increase voltage; larger modules to reduce inactive area
	Installed cost	$4/W	$1.20/W	Improvements in module efficiency; gains from volume production
	Electricity price	16¢/kWh	5c/kWh	Follows from lower installed cost
	Total capacity	0.5 GW	2,940 GW	National energy plan built around solar power
COMPRESSED-AIR ENERGY STORAGE (with photovoltaic electricity)	Volume	0	535 billion cu ft	Coordination of site development with natural gas industry
	Installed cost	$5.80/W	$3.90/W	Economies of scale; decreasing photovoltaic electricity prices
	Electricity price	20¢/kWh	9¢/kWh	Follows from lower installed cost
	Total capacity	0.1 GW	558 GW	National energy plan
CONCENTRATED SOLAR POWER	Land area	10 sq miles	16,000 sq miles	Policies to develop large public land areas
	Lolar-to-electric efficiency	13 %	17 %	Fluids that transfer heat more effectively
	Installed cost	$5.30/W	$3,70/W	Single-tank thermal storage systems; economies of scale
	Electricity price	18¢/kWh	9¢/kWh	Follows from lower installed cost
	Total capacity	0,5 GW	558 GW	National energy plan
DCTRANSMISSION	Length	500 miles	100,000–500,000 miles	New high-voltage DC grid from Southwest to rest of country

The advantage of CSP systems is that it is easier to store heat than electricity, and in being able to do so for just 16 hours, it has been estimated that more than 90 % of current U.S. power demand could be met at prices competitive with fossil fuel systems.

Major utility companies are investing heavily in this area. Pacific Gas and Electric Company signed a 25-year arrangement with Solel Solar Systems of Israel to buy power from a 553 megawatt solar thermal plant Solel is building in California's Mojave Desert. The plant will supply 400,000 homes when completed in 2011[8].

Solar Grand Plan

To see how advanced and competitive solar technologies have become, consider the results of a detailed analysis and plan recently proposed for the U.S.[9]. By 2050, this approach cuts foreign oil dependence to zero; it significantly eases global tensions and lowers military costs; it provides a massive trade deficit reduction; it slashes greenhouse gas emissions to 62 % below 2005 levels; and it increases domestic jobs significantly – all based on essentially available technology.

A summary of this plan and its goals are shown in **Figures 3 and 4**, respectively. The consequence of this plan is that by 2050, there is a massive switch from coal, oil, natural gas and nuclear power plants to solar power, wherein 69 % of the U.S.'s electricity and 35 % of its total energy are supplied by clean carbon-free solar energy. This strategy would eliminate 300 large coal-fired power plants and 300 large natural gas plants and all of the fuel they consume. This requires that 46,000 square miles of government-owned land in the Southwest be converted to solar energy generation. About 30,000 square miles would be used for photovoltaic arrays, and 16,000 square miles for thermal solar systems. As shown in Figure 1, excess day-time energy would be stored as compressed air in underground caverns to be tapped during night-time hours. Compressed-air energy sources have been operating reliably in Huntforf, Germany, since 1978, and in McIntosh, Alabama, since 1991.

This plan also requires that a high-voltage, direct-current power transmission line be built from the Southwest to major distribution areas such as Los Angeles, Chicago and Atlanta. DC lines are cheaper to build than AC lines and also suffer much less energy losses during transmission of the electricity.

This plan requires $420 billion of subsidy by the U.S. government, but the payback is much great than this number. From now until 2020, the government would provide guaranteed 30-year loans, and agree to purchase power and provide price-support subsidies. However, this energy plan would eliminate $300 billion per year of foreign oil with crude oil priced at just $60. This plan would be self-sufficient after 2050 and would not require further subsidies. By 2100, with a modest addition of wind energy, geothermal, and biomass fuels, 100 % of all U.S. electricity and 90 % of its total energy use would be supplied by the sun and other carbon-free sources. Energy-related carbon emissions could be reduced to 92 % below 2005 levels.

The $420 billion could be generated by a modest 0.5 cents per kilowatt-hour (kWh) tax. Since electricity in the U.S. today sells for 6–10 cents per kWh, adding 0.5 cents seems reasonable.

This plan is targeted at the U.S., but as shown in **Figure 5**, essentially all of the world's energy requirements could be supplied by the sun. It interesting that the most desirable locations for situating solar plants are in the developing world[10].

I am not suggesting that the world move immediately to a total solar world, but it is clear that solar energy could play a leading role in our global energy future. The technologies are available. All that is necessary is the will.

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[1] Parts I and II of this series outline the Global Energy Security and Climate Change issues, respectively; Part III provides a summary of a workable solution; Part IV presents an analysis of nuclear power; Parts V and VI describes the role of vehicular transportation with a focus on hybrid, electric and fuel-cell cars; and Part VII details the potential of wind power. See www.LeadersMagazine.Cz, volumes 2, 3, 4, 5, 2008 and 1, 2 2009.
[2] Ibid, Volume 5, 2008.
[3] Fred Krupp and Miriam Horn, "Earth: The Sequel," W. W. Norton & Company, New York, 2008, p. 21.
[4] Ibid, p. 31.
[5] Ibid, p. 32.
[6] Robert F. Service, "Can Upstarts Top Silicon?" Science, February 8, 2008, p. 718.
[7] Susan Moran and J. Thomas McKinnon, "Hot Times for Solar Energy," World Watch Magazine, March/April 2008, p. 29.
[8] Peter Fairley, "Storing Solar Power Efficiently," Technology Review, September 27, 2007.
[9] Ken Zweibel, James Mason, and Vasilis Fthenakis, "Solar Grand Plan," Scientific American, January 2008, pp. 48–57.
[10] Bennett Daviss, "Our Solar Future," NewScientist, December 8, 2007, p. 37.

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