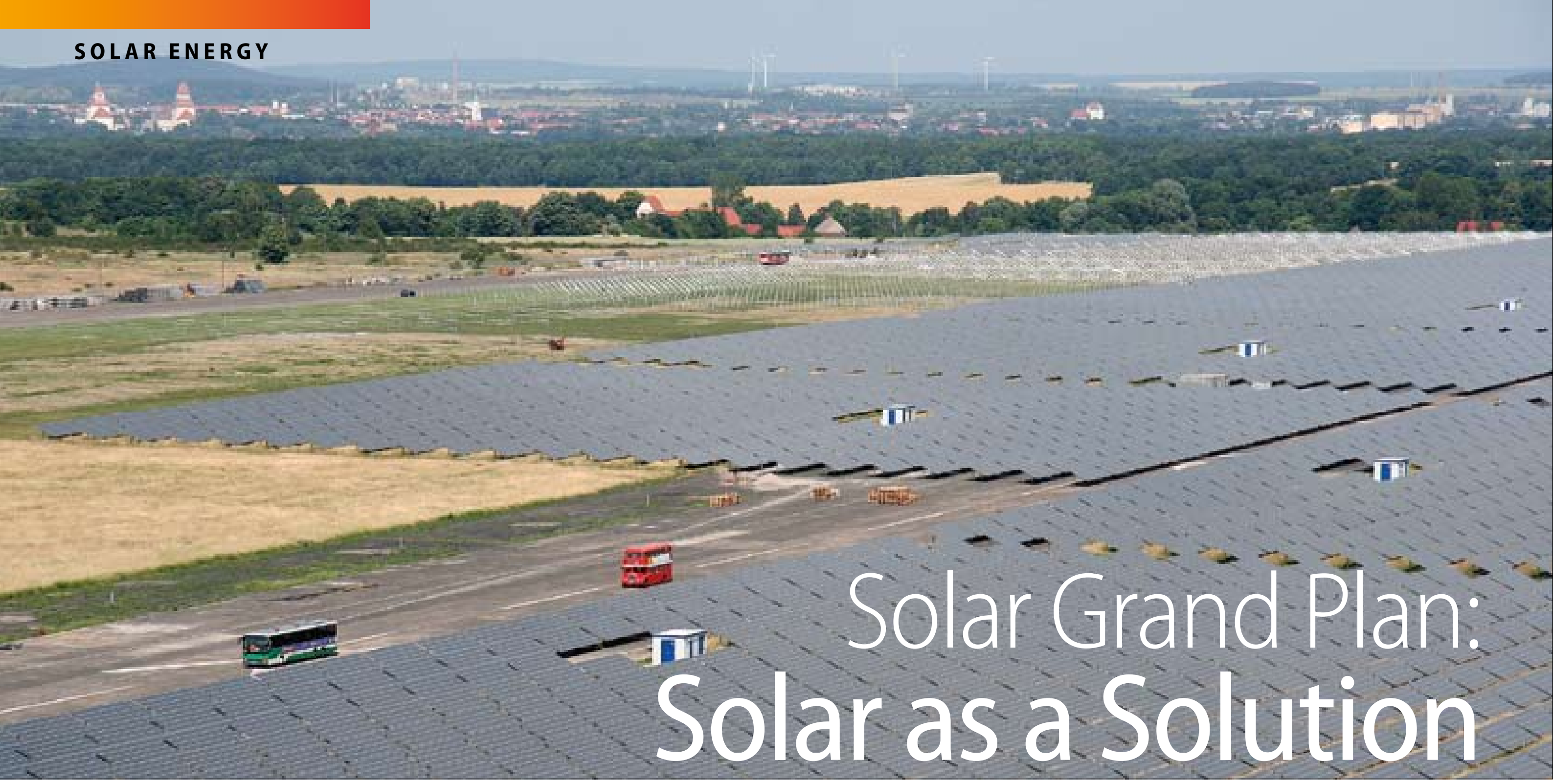

Solar Grand Plan: Solar as a Solution

Fig.1: Juwi Group is installing 40 MW of First Solar modules in Waldpolenz, Germany. At the time of the announcement, it was both the largest planned and lowest priced PV system in the world. The price was € 3.25/W which was then equal to $ 4.2/W. This dollar-priced system installed in the US Southwest would produce electricity at about 16 ¢/kWh without any incentives.

Photo: Juwi Group

The US Solar Grand Plan (as published in Scientific American, January 2008, and translated into nineteen languages), represented a proof of concept that society could look to sunlight for the solution to climate change and energy cost. Exclusively for *S&WE* the authors of this plan, James Mason, Vasilis Fthenakis and Ken Zweibel, give an comprehensive update of their ideas.

A secondary purpose was to alert people to the relative size of the different resources available in a carbon- and nuclear-constrained world. Solar has two orders of magnitude resource availability advantage over wind, and more over biomass, geothermal, and waves. Finally, the article emphasised the value of converting sunlight where it is most intense rather than just on our own roofs. In no case are these findings exclusionary – it is still good to put solar on our roofs, still good to deploy as much wind as possible, and still good to find special niches for other renewables. It is just that solar has to be the biggest part of any realistic solution.

The Pieces of the Solar Plan Puzzle

There are a number of clearly identifiable pieces of the Solar Plan that together provide a solution to energy and environmental problems for the 21st century. They are:

- economical conversion of sunlight to electricity,
- some aggregate method of dealing with sunlight's variability to allow dependable, economical power
- the economical transmission of power from high sunlight regions,
- the weaning of transportation from oil to electricity.

There is very good news about all this, perhaps better than we deserve for how little we have invested to-date. Solar thermal electricity has been reborn from its decadal sleep and is being implemented in sunny places worldwide. Photovoltaics has been nurtured by German incentives and is approaching economic acceptability. The zooming price of oil has rekindled serious efforts to make electric and fuel cell cars, and the gasoline-electric hybrid has shown that electrifying transportation is a viable hope. High-voltage DC transmission lines have been demonstrated, as have large electric storage facilities using compressed air. Driven by rising carbon dioxide and oil prices, these are big changes in the handful of years since the start of the century. We can be appreciative and thankful.

So how far away are we from implementing the Solar Plan?

The stunning truth is we are there right now. With defensible financial offsets for externalities, solar electric technologies – PV and CSP – are economical right now. We can get $4/W PV systems like those being made by First Solar, 16 ¢/kWh PV (Figure 1) and CSP right now in the US Southwestern deserts (Figure 2) or the Sahara or Gobi. With a 30 % subsidy attributable to externalities, this meets the price (12 ¢/kWh) California utilities are willing to pay for any daytime electricity – and the rest of California's electricity options have fuel price escalations hidden under the hood. (Of course, some places in the US pay less than California. But some pay more, and with under 20 % loss for 3000 miles of high-voltage DC transmission, all can access the solar in the US Southwest at reasonable prices.)

In sunny locations, solar electric is economical if we include about 30 % more for externalities (climate change, air pollution and fuel price escalations, not to mention war). Society may be amazed and ask, "How did we get here so quickly?", but the better question would be, "What can we do to take advantage of this opportunity?"

Wait a moment. Isn't solar intermittent and non-dispatchable? Doesn't this mean we have to wait?

We do not have to wait because initially we can build solar as fast as possible without getting to the point of needing much electric storage. Solar meets our needs well because most demand is during the day, when solar is "on". The ups and downs of daytime solar can be minimized by collecting electricity from different regions along the long-distance transmission line (Figure 3 and Perez et al. 2006), which minimizes the short and midterm effects of clouds. Slower output variations can be covered by dispatching existing fossil fuel power plants. Further smoothing can result from adding wind to the same HV DC line. Until we reach double digit solar use, we can build as rapidly as possible without adding storage. Meanwhile, we can further develop and demonstrate our storage and smoothing strategies for when we really need them.

We can build solar in the world's deserts and high plateaus while we build transmission lines and begin to incorporate small amounts of compressed air energy storage for PV and thermal storage for CSP. We can examine other methods for smoothing and shifting output like flow batteries, high-temperature batteries, smart-grid options linked to distributed storage (even those using batteries in electric vehicles), or linkages with other, compensating renewables, especially wind.

Fig. 2: BrightSource/LUZ II Solar Energy Development Center located at the Rotem Industrial Park in the Negev in Israel. Brightsource has a contract to install half-gigawatt (expandable to nearly 1 GW) for Southern California Edison. *Photo: BrightSource*

Fig. 3: Siemens has built several GW of high-voltage DC transmission lines worldwide. This is a 235-MVA-HVDC power transformer for the Australia-Tasmania undersea cable. An even larger line is being built in China (1400 km with a power transmission capacity of 5 GW). *Photo: Siemens*

Should We Do the Solar Plan or Something Else?

As we experience the shift to renewables, we are seeing a maturing of perception about how we can effectively move forward. Until now, renewables have been an indistinguishable lump – all promising, but all uncertain in their impact. Awareness has been compounded of hope, ignorance, skepticism, and entrenched biases. We must accelerate the shift to accurate, reasoned insights if we are to reach a point where we can move forward effectively.

As we implement the first set of renewables solutions, there is a process of elimination underway. People are learning the true strengths and limits of various options.

Wind has taken off, but people are now more aware of its dependence to the third power on wind speed. Half the wind speed implies eight times the cost. But even though wind cannot meet all our energy needs, it is an excellent complement to solar, as it produces more at night and in winter. For the burgeoning field of charging electric hybrids, wind can play an immense and crucial near-term role (since most early charging is likely to be at night). Wind should be implemented as much as possible.

Meanwhile, people have turned to biofuels as an alternative to oil. Ethanol in the US cannot come close to meeting our demand for fuel due to its low sunlight-to-fuel conversion efficiency, and water use will be a continual challenge. No biofuel can overcome these issues (land area and water), even cellulosic, so we are thinking of biofuels only as satisfying the fuel needs that can not be replaced by electricity.

Indeed, we see a surge of interest in electric vehicles, starting with hybrids. Numerous companies are announcing plug-in hybrids as early as 2010. An electric transportation sector would change the energy equation in favor of the consumer – even today's solar can produce at costs that would be equivalent to about $2/gallon gasoline (depending on distribution costs), less than half of what the US consumer is now paying (due to the efficiency of electricity in electric motors, which is about two and half times that of burning a fuel in an internal combustion engine).

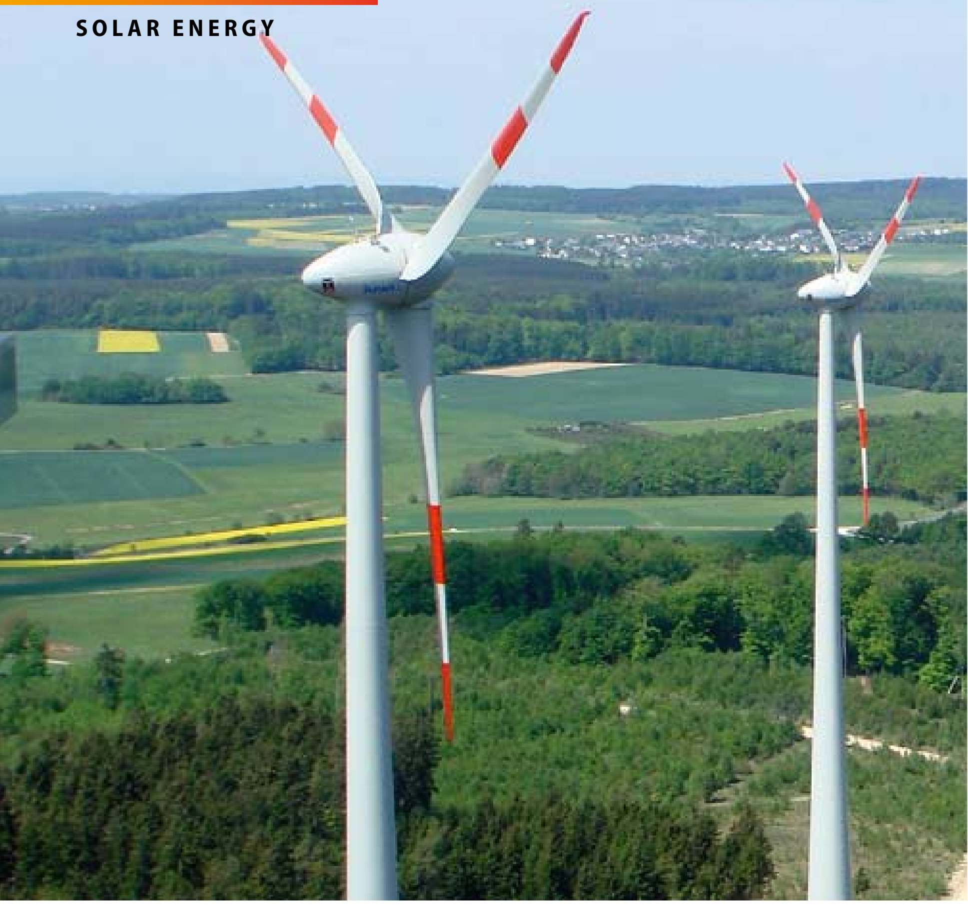

Fig. 4: Wind will be of immense importance during the transition to plug in hybrid vehicles, since most charging will be done at night when there is no solar and plenty of wind (Morbach wind farm, Germany).
Photo: Juwi Group

As hybrids are adopted, the driving question will quickly become: Where are we going to get the electricity without making global warming worse? The answer is wind and solar. They can provide almost all the new electricity. Within the US, an accelerated plan to shift to electric hybrids could eliminate all foreign oil by 2020, if the US vehicle fleet could be turned over in that period. The use of electric transportation with solar and wind is a practical solution to oil dependence and is beginning to spread among forward-thinking policy people worldwide.

The fact is, something like the Solar Plan is already underway. People are recognizing the value of sunlight for multi-gigawatt production and commissioning large solar plants in excellent solar locations in Spain and the US Southwest. Others are looking at North Africa. As these plants are built, the opportunity they present will become more publicly clear. So let's ask ourselves some tough questions about the Solar Plan:

1. Have we missed something: Is the Grand Plan fatally flawed?
2. Will it create more problems than it solves?
3. Is there a better plan?
4. Should we wait?

Is the Solar Plan fatally flawed?

Is there some obnoxious failing like inability to payback energy, hidden sources of carbon dioxide in the life cycle, or terrible problems with land area? But these issues have been rigorously examined repeatedly by the Solar Plan authors and other professionals and found to be inconsequential. Solar systems pay back their energy input in something like 1-2 years (Fthenakis et al. 2008), yet they last over 30 years (and perhaps 60-100 years). Currently experienced annual degradation of solar PV is about 0.5 % per year. Given the tiny operating costs associated with, e.g., large nontracking systems, no one will plow under a field of solar after 30 years because it is down only 15 % in output. After the loan is paid off, the energy is almost free.

Since energy is paid back quickly, so is carbon dioxide. Land area is actually an advantage of solar, as (including, e.g., strip mines) coal needs about the same land area as solar (Kim and Fthenakis 2008), but not all in one place. Perez (2007) calls attention to the fact that for only 7 % of US electricity, hydroelectric dams created about 100,000 km² of artificial lakes, destroying the underlying ecology. We calculate (assuming 10 % system efficiency, 2400 kWh/m²yr desert sunlight, a packing factor of 2.5 times as much land as module area) that to meet 100 % of all current US electricity would require about 42,000 km² in the US Southwest – less than half as much land as hydro, for 12 times as much electricity! And the land is not underwater! Case closed! Yet consider how many uninformed critics have raised land use as a putatively deadly negative about solar energy. (The reason land area is more challenging for biomass is that sunlight-to-biomass efficiency is 20 times less than solar efficiency, multiplying land demand by 20. And the reason it is true for wind is that there aren't enough high wind regimes.)

We know that there are still challenges:

- Compressed air may be adequate economically, but are there enough practical sites at reasonable costs (including the cost of validating them)?
- Is there enough tellurium for cadmium telluride to provide terawatts? Or will other PV technologies be needed, and if so, will they succeed to the same degree?
- Will the electrification of transportation really proceed apace and without technical pitfalls?
- Have we planned for enough storage; i.e., are all seasonal shortfalls fully taken into account when worst-case sunlight and highest demand scenarios converge? But can this be ameliorated anyway, by reasonable geographic distribution of solar or back-up alternatives like wind?
- What about scale-up issues: rapidity of production volume increases; size of resource needs; transmission and integration with the existing grid; cost overruns and shortages; artificially high prices?

These are not flaws. If anything, they are traditional warnings, alerts, and engineering challenges associated with any massive project (and of course, this would be the largest project the world has ever seen). Once we recognize that all this technology already exists and is within a reasonable societal externality cost of being cost-competitive, we can simply move ahead. We have much to manage in the way of challenges, but they are the normal business of an abnormally large economic opportunity.

Will the Solar Plan create worse, collateral problems?

Actually, the Solar Plan is designed to reduce problems like carbon dioxide. But will it bring unknown, new

ones? This deserves some thought, and during implementation, some ongoing attention. We welcome such scrutiny.

Implementing the Plan will certainly facilitate the ongoing expansion of our consumer society. We will make more, use more, do more, and invite more growth. But within the 21st century, solar will allow us (to first order) to do it sustainably by solving our carbon-fuel related crises: pollution, supply, and political tension. Is it a permanent solution? No. Sustainability is "in the era of the beholder," and our descendants will have to seek their own approaches to the double bind of desired growth within a finite environment. The solar solution solves our most egregious current sustainability crises; but surely we will find many others, some catalyzed by the continued consumption solar allows.

Is there a better plan?

How about carbon sequestration and nuclear? Carbon sequestration would need orders of magnitude more underground volume than compressed air, and we have already recognized that developing geological formations for compressed air is a challenge. Do we want to do it for carbon dioxide, a dangerous gas? Mineral carbon sequestration may be a hope but its feasibility is not proven. Nuclear? Well, we live in an imperfect world, and nuclear is a dangerous tool. If we have equivalent nonnuclear choices, our choice may be to do those instead.

Is there a better solar plan than big, centralized solar and long-distance transmission? How about roofs, parking lots, and other underused areas in distributed locations? When we consider this, we are fighting two factors: Large systems are always cheaper than small ones

Fig. 5: Distributed solar: SunEdison 1 MW PV installation in progress on a Walgreens in Woodland, CA, USA

Photo: SunEdison

and desert locations have better sun. But we are also ignoring that distributed solar (Figure 5) adds local jobs, energy security, dependability, and reduces the overall need for storage by providing geographical diversity – even to the point of providing to time zones that are in the dark. (Europe, Africa, and Asia have an advantage over the western hemisphere in this because with ten thousand mile long transmission, a good deal of night time demand could be met from the other side of the eastern hemisphere, if political uncertainties can be overcome.) If we make solar the norm in these distributed locations, maybe we can lower the cost of small systems nearly to the cost of large ones. And any storage technology has to be measured against the value of the locally available solar energy it replaces. Given this, the best plan is to move forward with solar in the best locations, but add solar and wind along the long-distance lines, implementing storage only as it becomes necessary.

The Solar Grand Plan as published in Scientific American, January 2008

The Solar Grand Plan was a proof of concept that sunlight could economically and practically supply all of the United States' energy needs during the 21st century. It attacks the assumptions that solar is not able to meet major energy demands; that solar is too expensive; that solar cannot meet night time and winter demand; that solar cannot meet transportation demand; and that we have to wait some indeterminate amount of time for a breakthrough to do all this.

A critical foundation of the plan is that sunlight is several orders of magnitude larger than any other non-nuclear, non-CO_2 resource. The world must shift to electric transportation to avoid further demand for fossil fuels, and no biofuel can fill this need. There are essentially only four Grand Plans – solar, nuclear, coal electricity and fuel, and nonconventional oil. Our article established the fortitude of the Solar Plan so that it can be fairly assessed in relation to the others.

The Solar Plan takes advantage of our best sunlight in the Southwest. We suggest making most of our electricity there and transmitting it by low-loss, high-voltage DC lines nationwide. The distribution will add up to 20 % more to the cost of the feedstock electricity (which is now about 16 ¢/kWh). If instead we made it throughout the country, solar electricity would cost between 20 % and 70 % more because of the less intense sunlight. Storage using compressed air is given as an example of an economical choice.

Our plan links up well with similar plans for Europe, Africa and the Mideast (TREC), and an Asian plan for China and Japan. We are promulgating an "idea whose time has come." There is no question that there is a world solar plan capable of meeting the globe's energy demand in the 21st century while ending the threat of carbon dioxide emissions.

The Plan published in this article has taken some small but important steps beyond our initial vision, e.g., in including more wind and distributed PV, and somewhat less storage in our early needs.

Should we wait?

The current state of carbon dioxide build-up and the onslaught of higher energy prices suggest that we are past waiting.

So what should we do?

The Japanese and Germans really set the tone for the growth of solar with deployment subsidies, while the US played a part in innovative thin films. Spectacular growth in the PV market allowed both economies of scale and the transition to new technologies. More recently, deployment programs in Southern Europe have helped catalyze CSP. The US lacked federal deployment programs, but states stepped in with Renewable Portfolio Standards, some with solar carve outs. In all these cases, people's vision helped catalyze change. It was not just the contributions of scientists or companies but the positive politics of solar that led to implementation.

Suggested immediate actions:

1. In the best regional solar locations worldwide, subsidize solar installations to the extent needed to meet all accessible demand.
2. Start building efficient, high-voltage DC transmission lines from these locations to major demand centres. Mandate rights of way based on societal value rather than local preferences.
3. Include high wind regime locations and significant distributed solar from different time zones along the HV DC to provide balanced daytime output and wind power for night time vehicle charging.
4. Locate and start building compressed air energy storage to demonstrate viability and value.
5. Assess regional electric distribution grids to upgrade them for dependability while including intermittent solar electricity. Add distributed storage and complementary renewables as needed.
6. Address cost reduction in smaller, distributed systems by standardizing solar as part of every new available site, starting with large flat roofs, parking lots, rights of way, and similar underused areas.
7. Introduce "solar grids" (solar, transmission, storage, distribution) throughout less-developed countries. (Form a study group to optimize this process.)
8. Provide government-backed, low interest loans for expansion of solar manufacturing companies and related aspects of the value chain, especially the use of key, mined natural resources. Require the separation and storage of critical by-products like tellurium and indium for growing future needs.
9. Assess and revise all tax strategies with regard to these opportunities: In many cases, merely removing layers of taxation can make new energy technologies

competitive without explicit subsidies (e.g., eliminating property tax, dividend tax, and corporate income tax throughout the renewables supply chains).

10. Provide R&D tax credits and fund sufficient public sector applied R&D to catalyze further advances.

11. Maintain market-level oversight to prevent demand-driven price gouging – reduce public sector incentives annually in a predictable, non-disruptive fashion.

12. Set up a worldwide Solar Advisory Board to assist in planning and oversight.

Afterthoughts

It is interesting to contemplate this as a worldwide collaboration rather than a traditional competition among nations, like the "space race." Similar plans have been contemplated in Asia and Europe (e.g., TREC, *http://www.desertec.org/*). We face a truly global issue. Our approach should not only be forward-looking in terms of carbon dioxide and oil dependency, it can be a way for parts of the world to simply leapfrog the fossil fuel infrastructure. We have not even considered one of the best approaches to smoothing the intermittencies of solar – vast global grids (Dorn et al. 2007, slide 43). The sun is shining constantly, 24 hours a day, and HV DC lines are especially designed for underwater transmission linking continents. Solving energy price issues and global warming collaboratively would provide us with a template for meeting future global challenges.

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