A Study of Very Large Solar Desert Systems with the Requirements and Benefits to those Nations Having High Solar Irradiation Potenial

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Table of Contents

I) Introduction 3
II) Current situation of world energy and environment.. 3
a) Outlook for World Supply / Demand by Region.. 4
b) The NASA earth at night map 5
c) Africa's population in the dark 7
III) World PV Potential using Desert Utilization 8
a) World primary energy supply 9
b) PV system feasibility in world deserts (Table 1) 10
c) Very large scale PV (VLS PV) 12
IV) Realizing Large Scale PV in the desert -- Genesis Project 12
a) Life Cycle framework of the case study... 14
b) Requirements to construct a 100 MW VLS PV system...................................... 15
c) Potential of VLS - PV: Summary of the advantages 16
V) Cost trends 16
a) Solar PV System and Module Manufacturing Cost Breakdown.......................... 17
b) Production costs 18
VI) Economic benefits of the PV Roadmap 19
a) U.S. Solar Power Shipment, Installations and Employment 19
b) Total Investment and Jobs Map 20
VII) Silicon Feedstock Shortage... 21
a) Chinese manufacturing cost advantages... 22
b) Alternatives to Silicon Crystalline Cells 23
c) Self-Assembling' Solar Cells 25
VIII. Concentrating Solar Power (CSP) **27**
a) SES Dish Stirling System Technology... 28
b) Trends sterling engine 30
IX. Transmission the key requirement 31
a) Characteristics of transmission 31
X. Three VLS solar proposals: resource and markets 32
a) Gobi desert for China 32
b) Concentrating Solar Power for the Mediterranean Region 33
d)Mojave desert for the US 35
XI. Summary and Conclusion…………………………………………………...….35

I) Introduction

This paper provides the background research, including planning and implementation of large scale solar energy systems. Ten years ago, Sanyo Electric proposed the Silk Road Genesis Project to develop large solar arrays in the Gobi Desert and linking to Japan and China using high voltage transmission lines. Advancements in solar technology, cost reductions and concerns about climate change are now making large scale solar viable. PV system providers will be keen to develop this enormous market potential in all desert regions.

II) Current situation of the environment

The current global situation of environmental pollution, climate change and energy demand urgently requires dramatic political, economic and technical decisions -- in order to avoid a potential collapse of environmental and social systems. Around the world, electricity remains the vital component of national and international development. The implementation of renewable energy resources can provide solutions to these challenges by stimulating the early implementation of economically viable sustainable energy technologies.

Many technological innovations have taken place in the past few years. This development is especially geared towards increasing efficiencies, lowering the costs and reducing emissions. The International Energy Agency forecasts that world energy demand will grow steadily over the next five years despite high prices, thus straining the supply chain. The IEA expects energy demand will grow at 1.6 percent per year, to nearly 335 million barrels of oil equivalent per day (MBOE/D). The fastest-growing segment of demand will be fuel for electricity generation, followed by transportation and chemical production. Among fossil fuels, coal and natural gas usage will grow at about 1.8 percent each, followed by oil at about 1.4 percent.

Pollution from energy generation accounts over 50% of all pollution today.

Electric power production is the largest contributor to global warming, acid rain, glacier melt and disease migration. The California EPA[1] estimates that fossil fuel-based power generation has an environmental health cost of 10.5 cents per kilowatt hour.

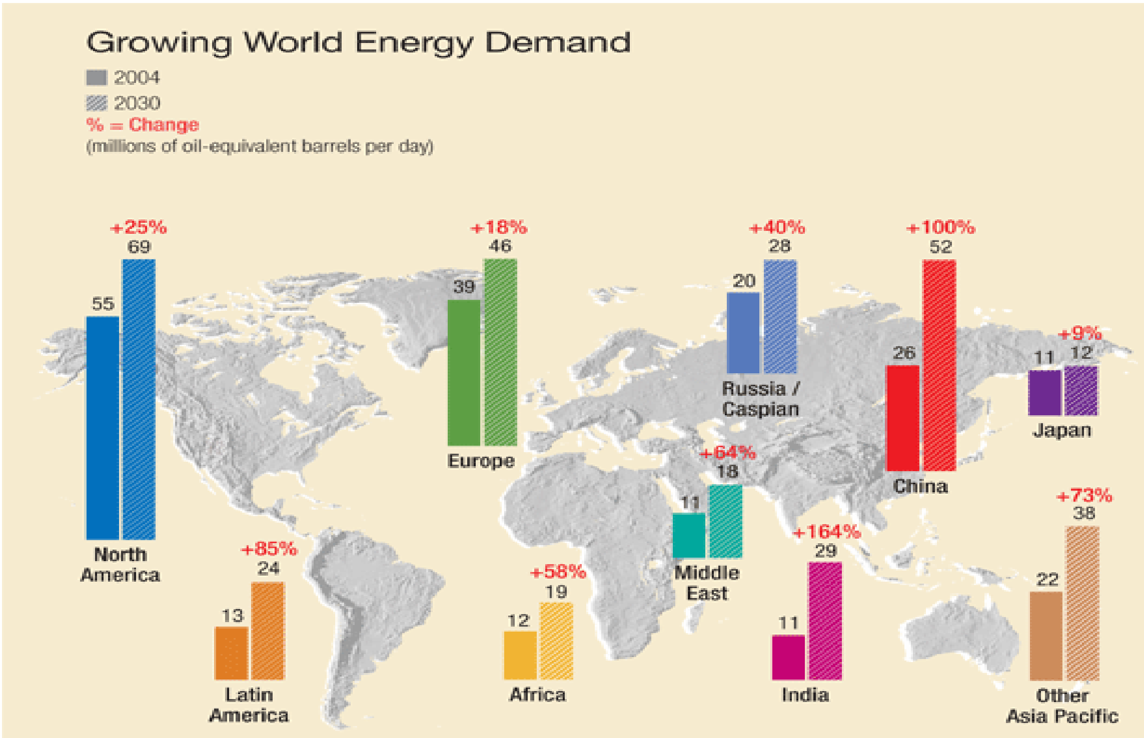
Increased production and use of fossil fuels, especially coal, has severe local and regional impacts. Locally, air pollution already takes a significant toll on human health. Acid rain precipitation and other forms of air pollution degrade downwind habitats-- especially lakes, streams, and forests -- plus damaging crops and buildings. One recent study warns that, in the absence of sulfur abatement measures, acid depositions in parts of China and South Asia could eventually exceed the critical load for major agricultural crops by a factor of 10 [[2]]. Without the use of the best available technology and practices, coal mining leads to land degradation and water pollution, as does the disposal of hazardous coal ash. On a global level, increased burning of fossil fuels will mean an accompanying rise in greenhouse gas emissions, along with the potential adverse impacts of global warming and other climate changes.

Nuclear fuel, too, has obvious environmental costs associated with its production and disposal, although nuclear power produces virtually none of the air pollution and carbon dioxide discharges of fossil fuels.

According to the US Department of Energy, America needs 20,000 megawatts (MW) of new power generation every year for the next twenty years in order to meet projected demand, and an additional 2,000,000 MW outside the U.S. over the same period.

The energy demand is growing on the different continents unequally. The demand for energy in the world has experienced a sudden increase in the developing regions, particularly in Asia, and predictions are that in 2030, demand will increase by 66% compared to 2000. The Asian region (excluding Japan) will account for almost 40% of that growth.

a) **Outlook for World Supply / Demand by Region** **(Figure 1.)**



The World energy outlook for 2030 by Region

To meet this voracious demand without polluting our environment is not possible without renewable energy.

Among the six primary renewable resources (solar, wind, hydro, geothermal, biomass, ocean), solar energy offers extraordinary potential for three main reasons. First, solar offers totally harmless operation for the immediate environment: no noise, movement, smoke, dust, waste, nor any kind of physical risk. Second, the potential for solar energy generation is virtually unlimited, and will never run out. Lastly, the cost of solar power is expected to compete with conventional sources within the next few years due to technical improvements and mass production.

"Thinking about the long lead times for the development of energy technology, it is urgently necessary to seek new energy seeds applicable for the next generation".

Kosuke Kurokawa, Tokyo University of Technology

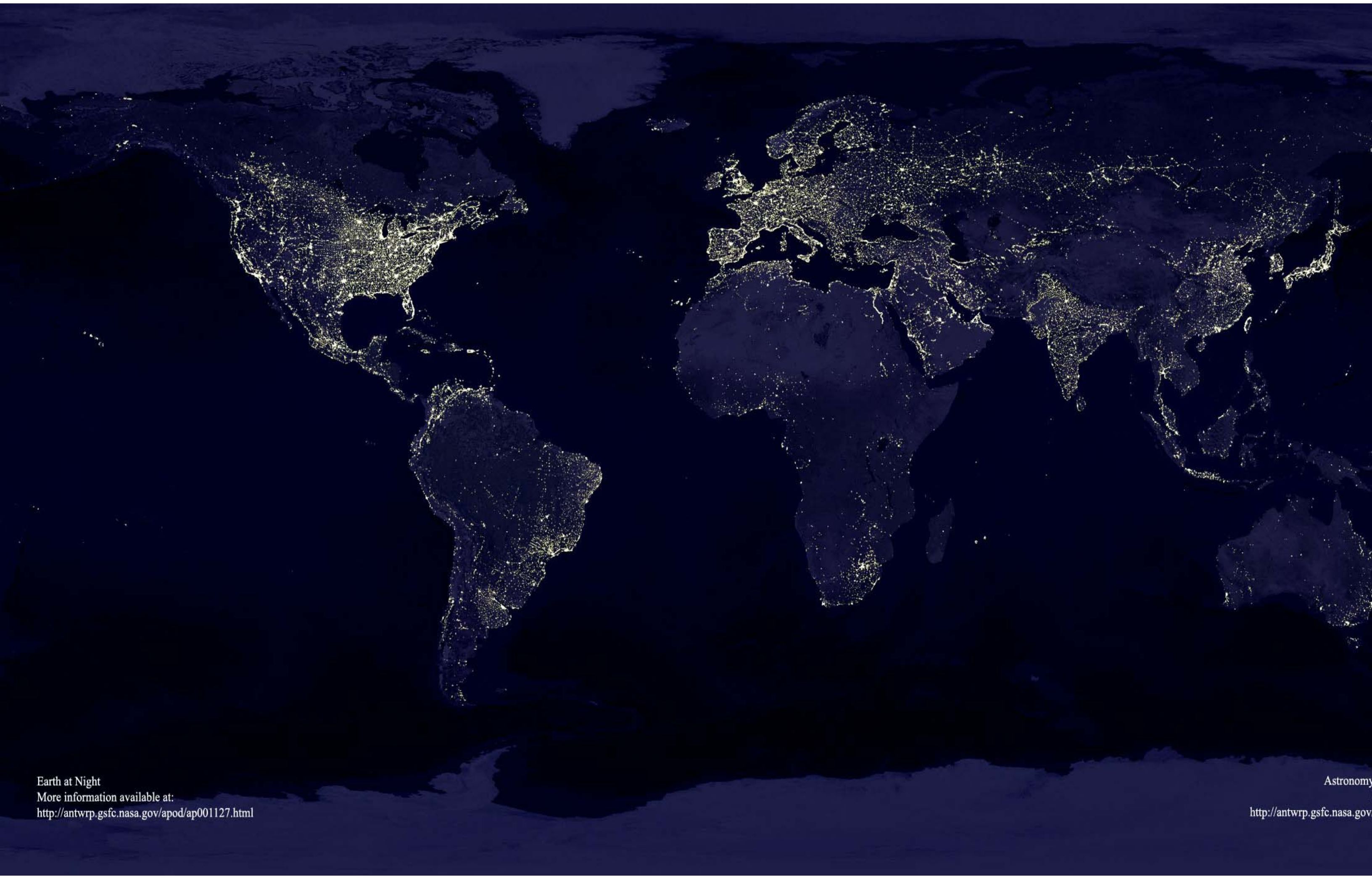
Note:

1 California Environmental Protection Agency (http://www.calepa.ca.gov/)

2. World Energy Council (WEC) and International Institute for Advanced Systems Analysis (IIASA), *Global Energy Perspectives to 2050 and Beyond* (WEC, London, and IIASA, Luxemburg, Austria, 1995), pp. 82-86. Exhaustive Information available at World Resource Institute www.wri.org

b) <u>The NASA earth at night map</u> (Figure 2.)

The map below depicts electricity use world-wide on any given evening, highlighting areas of prosperity. Yet 1.6 billion people, 25 % of humanity, remain in the dark. Those people without access to electricity survive without refrigeration, lighting, or clean water. Nearly all the lights in this map are supplied via high voltage transmission lines, and 100 nations already exchange power across borders. To meet the UN Development Goals, a combination of grid-connected and stand alone renewable electricity development will elevate a community out of basic poverty in a an environmentally sustainable manner. While most nations use polluting fossil and nuclear fuels, abundant renewables like hydro, geothermal, biomass, wind and solar exist on every continent. Linking the renewable electricity resources in Africa and South Asia will provide the foundation for ending hunger and poverty. As you can see in Africa, millions of people have no electrical services, and denude their local environment by using firewood and cow dung for their daily energy needs.



1.6 billion people, 25 % of humanity, remain in the dark

Some facts worth mentioning regarding the lights on the Earth at Night map:

1. The lights in Canada are 58% hydropower while in the United States 91% of electricity comes from fossil and nuclear power.
2. Brazil gets 83% of its energy from hydropower
3. 509 million people in Sub Saharan Africa live in the dark, they have no access to electricity. (compare the map below)
4. In Iceland 100% of the energy comes from hydro and geothermal with excess to create hydrogen for fuel cells.
5. 99% of Norway's power is of hydro while 96% in the UK is fossil or nuclear power
6. There are a lot of sunlight in South Asia, but 713 million people out of 1.4 billion people in South Asia (South Asia: Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka) still have no electrical services.
7. 98% of Chinese people have electricity access, however 82% is produced form fossil and nuclear fuels.
8. Australia is blessed with solar, geothermal and tidal resources, but is still using 92% fossil fuels. In contrast to his neighboring country New Zealand, which gets 68% of their electricity from hydro and geothermal.

"The best way to convince anyone about new technologies and practices is to show them what their friends and neighbors are doing - and many countries on the African continent have been carrying out important, cutting-edge solar programs for decades".

Scott Sklar, President of The Stella Group
co-author of "A Consumer Guide to Solar Energy

See the whole Scott Sklar interview:

http://www.renewableenergyaccess.com/rea/news/section?id=15

Source:

NASA Digital Archive

C. Mayhew &. Simmon (NASA/GSFC), NOAA/ NGDC, DMSP

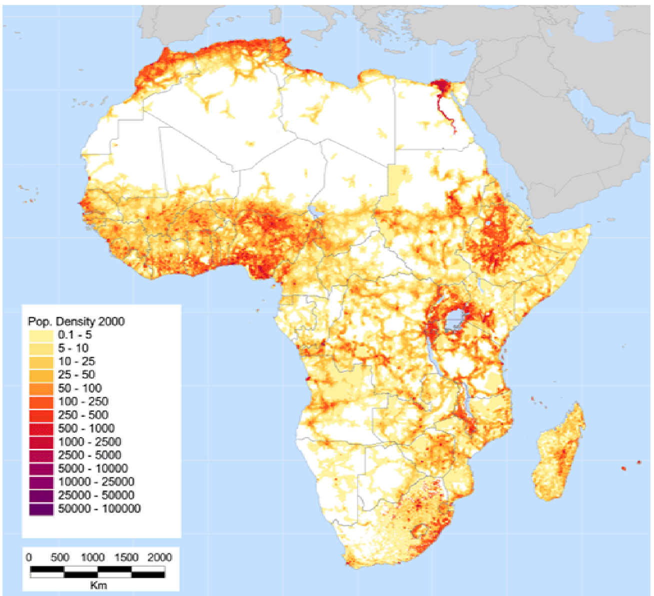
Global Energy Network Institute / NASA earth at night map

http://www.geni.org/globalenergy/multimedia/earth-at-night016.gif

CIA World Factbook http://www.cia.gov/cia/publications/factbook/
IEA Energy Statistics http://www.iea.org/Textbase/stats/
World Energy Council http://www.worldenergy.org

c) **<u>Africa's population mostly in the dark</u>** **(Figure 3.)**

This Map indicates the inhabitants in Africa per sq. km. Compared with the nighttime map, it's clear that 509 million people (approximately half of all Africans**)** in Sub-Saharan Africa have no access to electricity. For very good reason, Africa is called "the dark continent".



509 million people in Sub-Saharan Africa have no access to electricity

"For the first time in history it is now possible to take care of everybody at a higher standard of living than any have ever known. Only ten years ago the 'more with less' technology reached the point where this could be done. All humanity now has the option of becoming enduringly successful."

Buckminster Fuller , 1980.
Visionary engineer from his book "Critical Path"

The Sahara Desert alone can capture enough solar energy to supply all the world's electricity needs and more. The potential is there, reported the United Nations Environmental Program

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<u>Source:</u>

National Center for Geographic Information and Analyses.
http://www.ncgia.ucsb.edu/pubs/gdp/pop.html

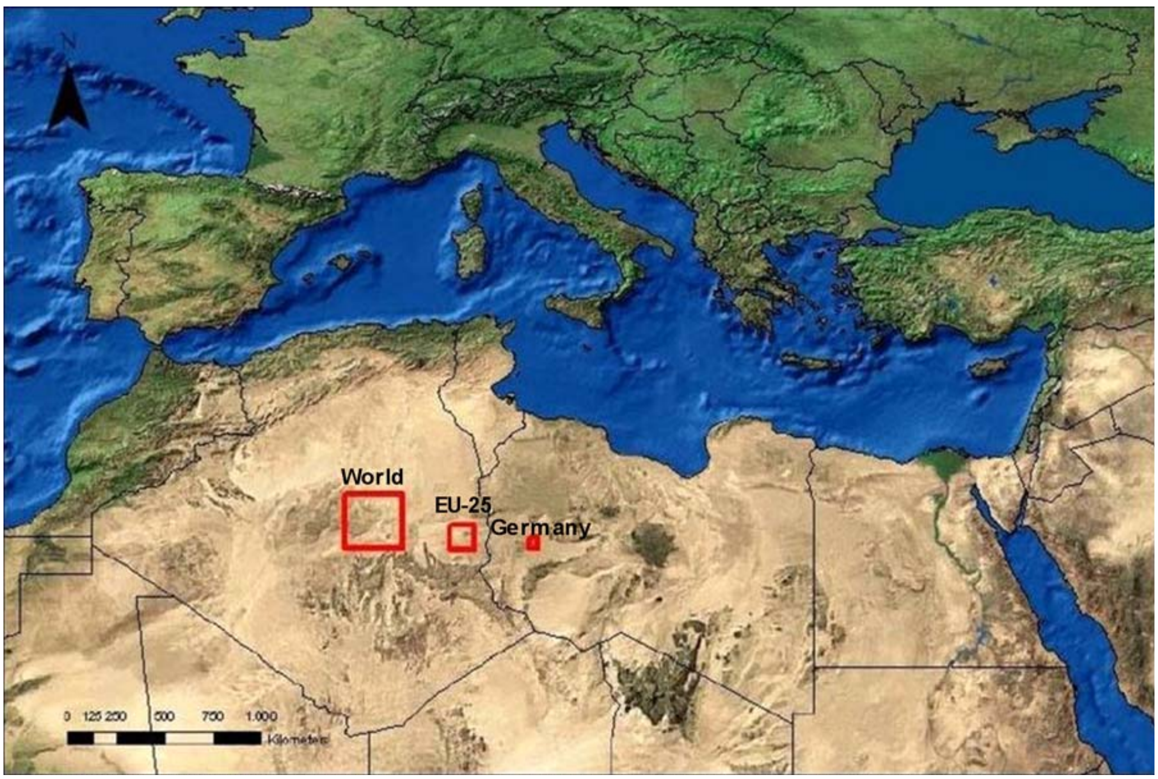
http://www.geni.org/globalenergy/library/buckminster_fuller/index.shtml

III) World photovoltaic (PV) Potential by Desert Utilization

The theoretical potential of solar energy is enormous -- far beyond what the world could ever require. With today's PV efficiencies, solar energy from desert regions would be more than enough to meet all the electricity demand in both industrialized and developing countries.

One third of the planet's landmass is covered by desert, which receives intensive solar radiation every day. Several experts studies have estimated that using just 4% of the total desert area for solar systems is sufficient to supply all the electrical energy requirements of the world.
From the map below, one can see that strategy would require small desert areas in the Mojave, Sahara, Gobi, India, Angola, Chilean and Australian deserts.

Figure 4. shows the theoretical footprint needed for solar power plants to generate sufficient electric power in order to meet the energy demand of the World, Europe (EU-25) and Germany respectively.



Using the solar radiation of just 4% of the world's desert is sufficient to meet all world electrical energy requirements today.

Source:

(Data by the German Center of Aerospace (DLR), 2005)
Out of a study from the DLR, P. 12 and 26
Further information:
http://www.dlr.de/en/desktopdefault.aspx

http://www.trecers.net/concept.html

a) **World Electricty Consumption**

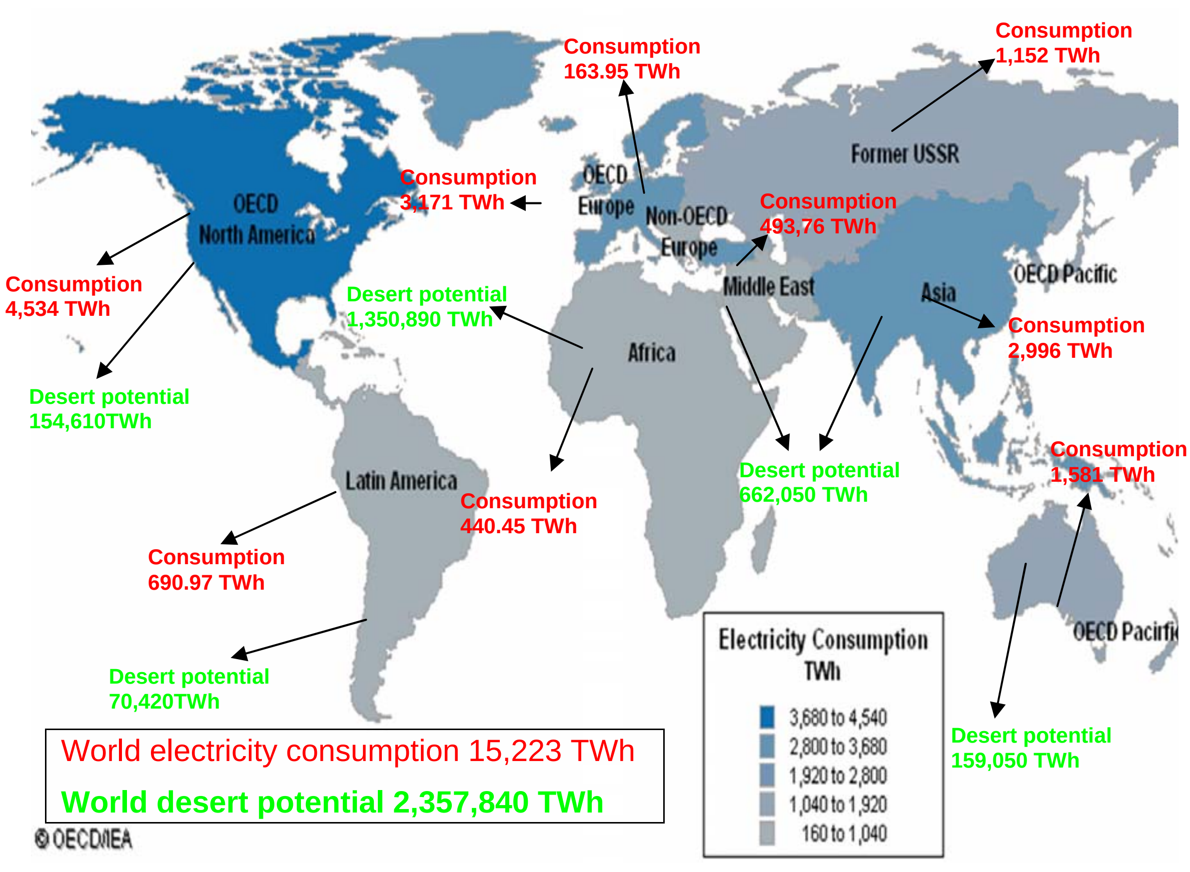
China and India, where economic growth rates are remarkable and major percentages of their energy needs are fulfilled by carbon-rich coal, have large desert areas. Therefore, their solar energy potentials are quite high. Large scale photovoltaic systems would also contribute to the regions economy and would solve the energy supply problem as well as suppress carbon dioxide emission.

In the Gobi desert alone, the total 2357.84 x 10^3 TWh (8486.67 x 10^{21}Jule) which equals almost 20 times the total world primary energy supply 10,723 MTOE (IEA, 2003) (3479.51x10^{20} Jule)

The possibility of PV technology development into the global network depends upon its resource potential first. To show it, energy to be generated by bulk systems over major deserts in the world is estimated. The desert is unused land and irradiation is much higher than other areas.

PV Solar Energy production from desert region becomes almost 20 times as much as the world primary energy supply.

(Figure 5.)



According to Solar Development (2003), by utilizing only 1% of the earths desert with solar thermal electric generators, it would allow us to produce clean solar electric energy that can provide more electricity than is currently being produced on the entire planet by fossil fuels.

Further Information

http://www.iea.org/Textbase/subjectqueries/maps/world/ele.htm

b) <u>PV system feasibility in world deserts</u> (Table 1)

Desert Name (a1)	Area $10^4 km^2$ (a2)	Annual Ave. Irradiation (b)	Annual Reference Yield h (c)	Possible PV Array Capacity [TW](d)	Annual Electricity Generation 10^3 [TWh] (d), (e
North America					
Great Basin	49	20.32	2,060.22	41.65	60.07
Chihuahuan	45	19.68	1,995.33	38.25	53.43
Sonoran	31	17.21	1,744.90	26.35	32.18
Mojave	7	21.16	2,145.39	5.95	8.94
Subtotal	132			112.2	154.61
South America					
Patagonian	67	12.81	1,298.79	56.95	51.78
Atacama	14	22.08	2,238.67	11.9	18.65
Subtotal	81			68.85	70.42
Australia					
Great Victoria	65	21.57	2,186.96	55.25	84.58
Great Sandy	40	23.11	2,343.10	34	55.77
Simpson	15	21.57	2,186.96	12.75	19.52
Subtotal	120			102	159.86
Asia					
Arabia	233	22.24	2,254.89	198.05	312.61
Gobi	130	16.53	1,675.96	110.5	129.64
Karakum	35	16.34	1,656.69	29.75	34.50
Kyzylkum	30	16.34	1,656.69	25.5	29.57
Takla Makan	27	16.19	1,641.49	22.95	26.37
Kavir	26	18.33	1,858.46	22.1	28.75
Syrian	26	18.1	1,835.14	22.1	28.39
Thar	20	21.44	2,173.78	17	25.87
Lut	5	21.09	2,138.29	4.25	6.36
Subtotal	532			452.2	622.05
Africa					
Sahara	860	24.99	2,533.71	731	1,296.50
Kalahari	26	22.54	2,285.31	22.1	35.35
Namib	14	22.54	2,285.31	11.9	19.04
Subtotal	900			765	1,350.89
Grand Total	**1765**			**1500.25**	**2,357.84**

<u>[Note]</u>
(a) Tokyo Astronomical Observatory: Rika-Nenpyo, 1993, p.673
(b) World Irradiation Data Book, FY 1991 Nedo Contract Report*
Nasa Report: http://eosweb.larc.nasa.gov/cgi-bin/sse/sizer.cgi?email=na
MJ = Mega Jule, 1 kWh = 3,6·106 Jule,
3.6 MJm-2h-1=1kWm-2
(c) = (b)x 365d/3.6 MJm-2h-1,
(d)= 0.17x1kWm-2x(a)x0.5
Efficiency 17%**
50% space factor
(e)=(d)x0.7x(c)
performance ratio 70% system***

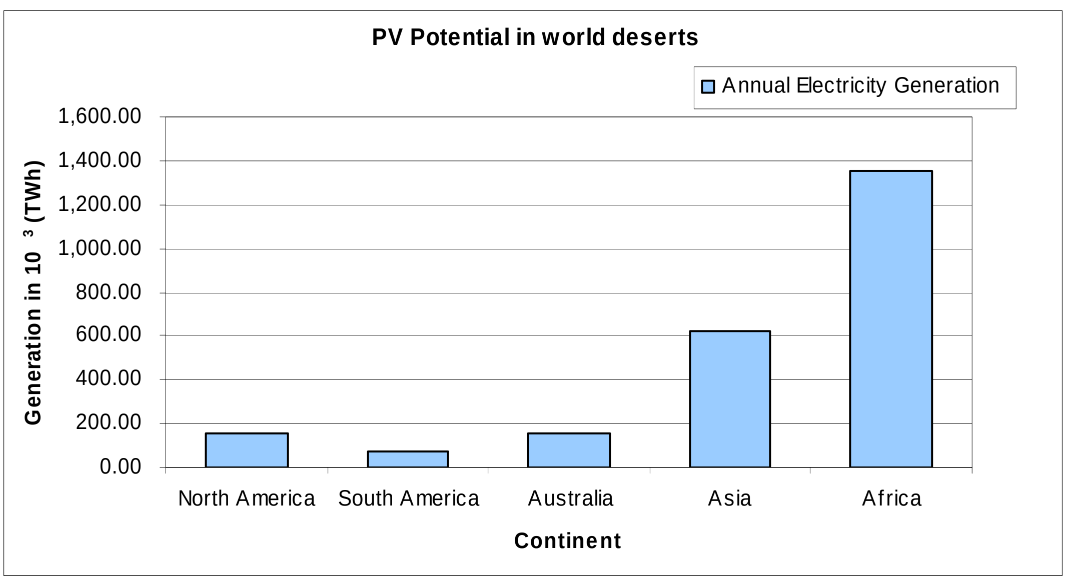
***Irradiation** data is important to start a discussion about the potential of VLS-PV systems. The Japan Weather Association (JWA) collected irradiation and air temperature data from every meteorological organization in the world. Data items are monthly means of global irradiation, monthly means of ambient air temperature, and monthly means of snow depth. The data were collected from 150 countries, from 1600 sites throughout the world available. Monthly global irradiation was estimated form monthly sunshine duration where there were no irradiation data.

****Calculated for solar cell made of single-crystal silicon with 17% Efficiency**

Efficiency is how much of the energy provided by the sun is transformed into electricity.
In PV solar cells, made of silicon, positive and negative charge carriers flow freely when light strikes the surface of the cell (photoelectric effect), producing direct current (DC) which can then be used to power motors or charge batteries. If solar power is to be used by consumers with 110 volt alternating current (AC), or if it shall be directly fed into the grid and 'sold' (grid coupling), then an inverter is needed.

Efficiency of a solar cell made of single-crystal silicon: about 24 % (laboratory) and 14 to **17 %** (production)
Efficiency of a solar cell made of polycrystalline silicon: about 18 % (laboratory) and 13 to 17 % (production)
Efficiency of a solar cell made of amorphous silicon: about 13 % (laboratory) and 5 to 7 % (production)
Efficiency of a solar cell made from CIS thin film technology: about 13 % (laboratory) and 8 to 10 % (production)
30.4% sunlight-to-grid conversion efficiency is the current world's record for commercial solar generation equipment

*****Performance Ratio:**
Within the realm of Photovoltaic, the term "performance ratio" refers to the relationship between actual yield and target yield. The performance ratio of a photovoltaic system is the quotient of alternating current (AC) yield and the nominal yield of the generator's direct current (DC). It indicates which portion of the generated current can actually be used. A photovoltaic system with a high Efficiency can achieve a performance ratio over 70 %. The performance ratio is also often called the Quality Factor (Q). A Solar Module based on crystalline cells can even reach a quality factor of 0.85 to 0.95 (performance ratio = 85 - 95 %).



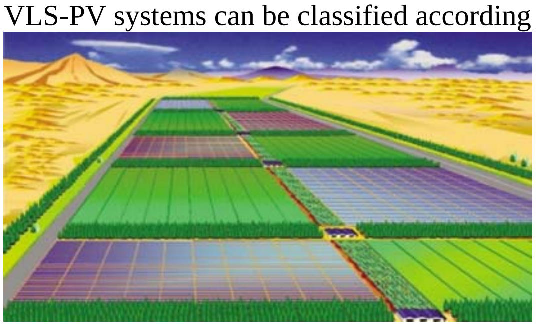
This Chart indicates the PV Potential per continent. As you can see Africa has by far the highest potential with a generation of 1300.00 in 10^3 (TWH) (Figure 6.)

World Changing writes about the potential for solar energy within Africa "...solar has the potential to be a life-saver, providing clean energy in the remotest of locations. With no moving parts, solar panels are harder to make but simpler and cheaper to maintain than traditional diesel-powered generators, needing only batteries to store the power accumulated over the course of a sunny day...Photovoltaics are perhaps the ultimate in leapfrog energy systems. Solar can be used anywhere the sun shines, without the ongoing expense of trucking in and consuming fuel. While the maintenance of the systems isn't difficult, it provides opportunities for local business development..."

c) Very Large Scale Photovoltaic (VLS PV)

The size of a VLS-PV system may range from a few megawatts (MW) to many gigawatts (GW), consisting one plant, or an aggregation of many units that are distributed in the same district and operate in harmony with each other.

The amount of electricity generated by VLS-PV systems can be considered significant for people in the district, the nation or for the entire region -- possible interconnecting several nations. VLS-PV systems can be classified according to the following concepts, based on their location.



land based (arid to semi arid, deserts)
water-based (near lakes or international waters) to assist in water pumping
local options which enable distribution to remote villages in developing countries -- or even large populations centers in developed nations

VLS-PV system in a desert area (Figure 7.)

IV) Realizing Large Scale PV in the desert / Genesis Project

The utility scale systems which have been installed to date are interconnected to the power network, and support electricity demand growth during peak usage times. Masaru Yamano, Vice Chairman of Sanyo Electric Co., made public a grand plan for building a network of solar power stations dotting the deserts of western China, at around 40 degrees north latitude. The Silk Road Genesis plan is projected to supply electricity to parts of China, neighboring countries and also contribute to enhanced development of the deserts: promoting greening, agricultural and industrial development. This plan has been drafted by researchers from Sanyo Electric, Toshiba Corp, Takenaka Corp. and others. The blueprint calls for construction of solar power plants, each with a capacity of 100 megawatts, at 139 locations. Ultimately forming a chain, running east to west - a few plants to be built at a time - between 2001 and 2020. Linked by high-voltage transmission wires, they would form a network capable of supplying about 100 million kilowatts in 2020. As one station would cost some ¥10 billion (= $ 84 million) to build, total investment would run to about ¥23 trillion (= $ 200 billion) by 2020.

A Project GENESIS image of a VLS-PV system in a desert area.
(Figure 8.)

The planners predict revenues from electricity generated would make it possible to pay back the investment and earn roughly ¥140 billion (= $1.2 billion) in profits in 2020. In addition, since solar power is a pollution-free energy source, the Silk Road Genesis plan is expected to reduce consumption of fossil fuels in China and decrease acid rain in Japan.

Silk road

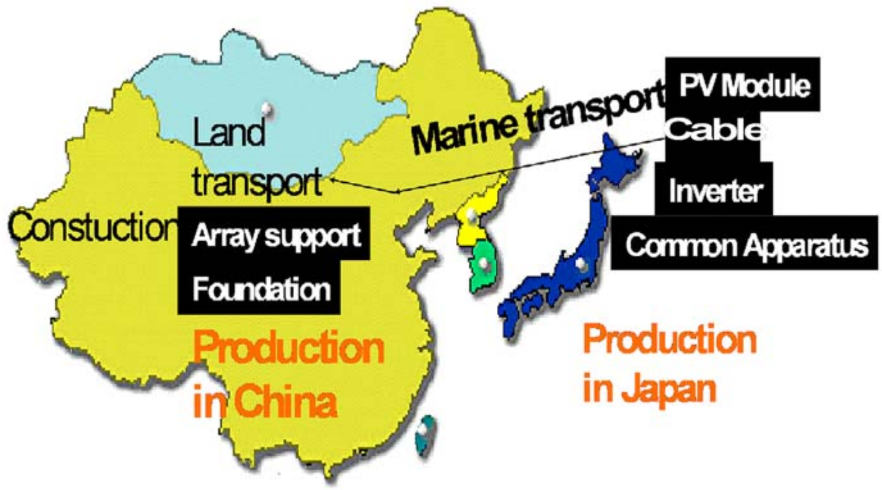
Silk Road: the location for the Genesis Project in Gobi desert (Figure 9.)

Case studies on the Gobi Desert from a Life Cycle Analysis

The introduction of VLS-PV systems in desert areas seems attractive from an economic point at this time, even using existing PV system technology. We must pay attention not only to the economic aspect but also to the entire energy and environmental aspects, since PV systems consume a lot of energy at their production stage and therefore emit carbon dioxide (CO_2) as a result. Therefore, the feasibility of VLS-PV systems was evaluated in depth from a complete life-cycle analysis.

The Gobi Desert was chosen as the installation site of VLS-PV systems in this study. This desert, which lies in both China and Mongolia, is around 1.3 x 10^6 km^2 in size and is located between 40 N and 45 N. Installation of the VLS-PV systems in the Gobi Desert has some advantages. It is a stone desert rather than sand, and an existing utility grid is relatively close to this desert. In this study, it was assumed that the 100MW VLS-PV system would be installed in the Gobi Desert in Chinese territory.

This Map indicates the Live Cycle framework for the VLS-PV Solar Field proposal in Gobi Desert. **(Figure 10.)**



Live Cycle framework for proposal in Gobi Desert indicate that large installations are quickly attainable to meet existing energy needs

a) Life Cycle framework of the case study

It was supposed that array support structures, transmission towers and foundations for the array support structures would be produced in China and that other systems components would be manufactured in Japan. All the components are transported to some installation site near Hoh-hot in the Gobi Desert by marine and land transport.

Land transport is also taken into consideration. Land cost is not considered since deserts have nominal other uses, but land preparation was taken into account.
In this study, a south facing fixed flat array structure was employed and the array tilt angle was given as a variable parameter (10°, 20°, 30°, 40°,). Both PV module price and inverter price were also considered variable parameters. System performance ratio was assumed to be 78% by including operation temperature, cell temperature factor, load matching factor, efficiency deviation factor and inverter mismatch factor (=0.90). It should be noted that the efficiency deviation factor involves long term performance degradation (0.5 % /year) as well as short term surface degradation by soil (=0.95)

The number of PV modules in a string was taken to be 21. Then the rated output form one sting is 2.5 kW. Accordingly, a 250 kW PV array requires 100 PV module string. Two of these 250 kW PV arrays located north and south in parallel form the 500 kW system with a 500 kW inverter and a 6.6 kV / 500 V transformer.

Japanese experience in civil engineering and the local labor situation in China, local labor requirement was also estimated for system construction such as PV module installation, array support installation, production and installation of common apparatus.

.

b) Requirements to construct a 100 MW VLS PV system

Table 2 shows a summary of requirements to construct a 100 MW VLS PV system to be built by nine people working in shifts 24 hours a day. (Table 2.)

Summary of total requirements for a 100 MW VLS-PV system in the Gobi Desert

Item	Unit	10°	20°	30°	40°
Material requirement					
PV module[1]	piece	840000	840000	840000	840000
PV module size	m^2	0.43	0.43	0.43	0.43
Cable	m^3	35235	37450	37406	41037
Foundation	m^3	46487	46487	69391	98801
Common apparatus					
Inverter (with transformer)	set	202	202	202	202
6.6 kv capacitor	set	202	202	202	202
6.6 kv GIS[2]	set	4	4	4	4
110 kv/6.6kv transformer	set	5	5	5	5
110kv GIS[2]	set	4	4	4	4
2.4 MVA Capacitor	set	1	1	1	1
Common power board	set	1	1	1	1
Transportation					
Heavy oil consumption	ton	145	145	147	148
Transmission					
Cable	km	134	134	134	134
Pylon(steel)	ton	742	742	742	742
Foundation	ton	1715	1715	1715	1715
Construction					
Labour requirement	man-year	2711	2752	2831	2911

[1] The number of PV modules in a string was taken to be 21. (output form one sting is 2.5 kW)
[2] geographic information system

Study Source:
Energy from the desert, Editor Kosuke Kurokawa, Published by James & James Ltd
Photovoltiac Power Systems Executive Committee of the International Energy Agency.
Labor cost for the operation was estimated based on the assumption of a 100 MW VLS-PV system that was being built 24 hours a day by nine persons working in shifts.
The annual labor cost for electrical engineering was assumed for these operators. Maintenance cost was also calculated based on actual results of a PVUSA project, that is the cost of repair parts was 0.084%/year of the total construction cost and labor for maintenance was one person per year.

c) <u>Potential of VLS - PV: Summary of the advantages</u>

The advantages of VLS-PV systems are summarized as follows.

1. It is relatively easy to find suitable land around deserts for large energy production by PV systems.
2. Deserts and semi-arid lands are normally in isolated areas -- causing fewer NIMBY (not in my backyard) issues.
3. The estimated potentials of such areas could supply all world energy needs now and into the future as demand grows in the 21st century
4. When large-capacity PV installations are constructed, a step by step development is possible through utilizing the modularity of PV systems. According to regional energy needs, plant capacity can be increased gradually. This offers a simpler energy path for developing areas.
5. Even large installations could be developed quickly to meet existing energy needs.
6. Remarkable contributions to the global environment can be expected through reduced CO_2 emissions.
7. When a VLS-PV system is introduced to a region, other positive economic impacts may occur: such as technology transfer to regional PV industries, new employment and economic growth.

These advantages make it very attractive option and worthy of discussion regarding global energy requirements of the 21st Century.

"if I where you, I would stop trying to make Saudi Arabia the oil capital of the world and make Saudi Arabia the energy capital of the world. You should take your cash right now and go out and buy half the solar capacity in the whole world and you should start at the equator. All the way around the equator and go north and south until you put solar power everywhere the weather will tolerate it. You will save the planet, and get richer."

Bill Clinton, speech in Saudi Arabia in January 2006 to 400 business people from the Persian Gulf.

V) Cost trends

Although PV is currently at a disadvantage because of its high cost, PV has the best long term potential because it has the most desirable set of attributes. The potential for a PV system can vary widely depending on a variety of factors -- including system size, location, customer type, grid connection and technical specifications. For example, for building-integrated systems (BIPV), the cost of the system will vary significantly depending on whether the system is part of a retrofit or is integrated into a new building structure. Another factor that has been shown to have a significant effect on prices is the presence of a market stimulation measure, which can have dramatic effects on demand for equipment in the target sector. The installation of PV systems for grid connected applications is increasing yearly, however the grid-connected market must still depend upon government incentive programs. The installed cost of grid connected systems varies widely in price depending on national support programs and labor costs in country.

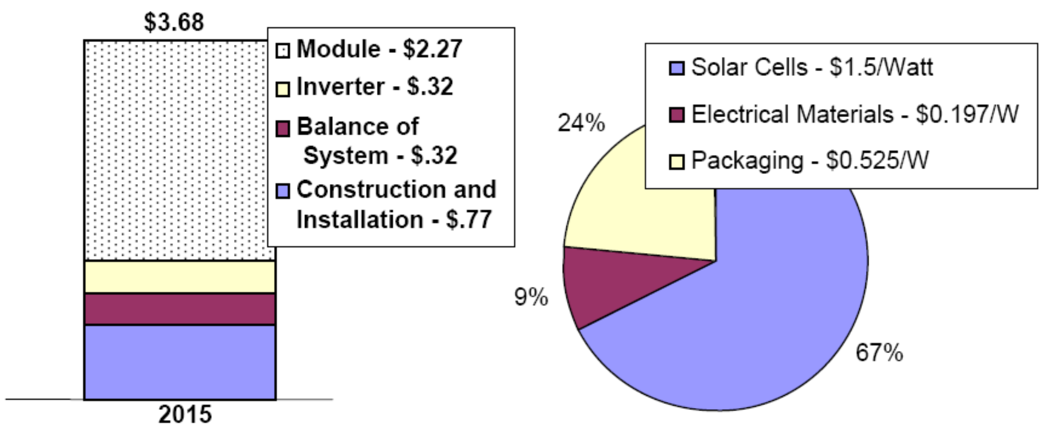
(Figure 11.) shows the component costs of PV system and module prices in the main manufacturing countries. Recently, these costs show a slight increase in some markets due to high demand. Long term, there appears to be a continued downward cost curve.

One way to accelerate that trend is to step up the economies of scale for the typical PV plant. Today, the largest plant has a capacity approaching 100 MW/year. It would take such a plant 10 years to produce enough equipment to match the power-generating capacity of one large sized coal fired power plant.

Another path towards radically lower cost is technology step change. The technology in use today is based on crystalline silicon. This is an inherently material intensive technology. It requires batch production methods in clean rooms and is now relatively mature. The great hope for the future lies with thin film technologies (and even a carbon based product), which are much less material intensive and sustainable for continuous production processes. They offer the potential to shift to lower cost production methods and higher output

The NREL (National Renewable Energy Laboratory) cost breakdown shows the fraction of the total module cost that goes into different module components. Both the PV Roadmap and the NREL cost assumptions are based on grid-connected systems.

a) Solar PV System and Module Manufacturing Cost Breakdown



The NREL cost breakdown (Figure 11.)

As a result of this cost breakdown, we have cost information for 5 keys elements plus construction and installation.
The "Module Solar Cells" consists of the actual solar cells, "Module Electrical Materials" comprises the electrical connections within the module, and "Module Packaging" includes the top surface, encapsulant, rear layer and frame. The "Inverter" group consists of the inverter. The "Balance of System" has the most components -- consisting of the batteries (where applicable), blocking diode, charge controller, circuit breakers and fuses, meter, switch gear, and wiring.

If there is a decision to bring electricity to the rural areas, then PV is already less expensive than any other source. If you use special applications like for ventilation, then solar modules from renewable is cheaper than combustion machines. If people in the developing countries would start to utilize Renewable Energy applications, which do not cost more than conventional . . . then there is good development. But only if they would start with this. And they should. This is only the introduction to a long process. If this introduction has stable bases, stable legal frameworks, then the speed will become faster and faster. The slower steps are always the first steps.

Hermann Scheer,

Member of the Bundestag, Member of the German House of Parliament, President of EUROSOLAR, General Chairman of the World Council for Renewable Energy

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From an interview with Herman Scheer:

http://www.folkecenter.dk/en/articles/HScheer_aburja.htm

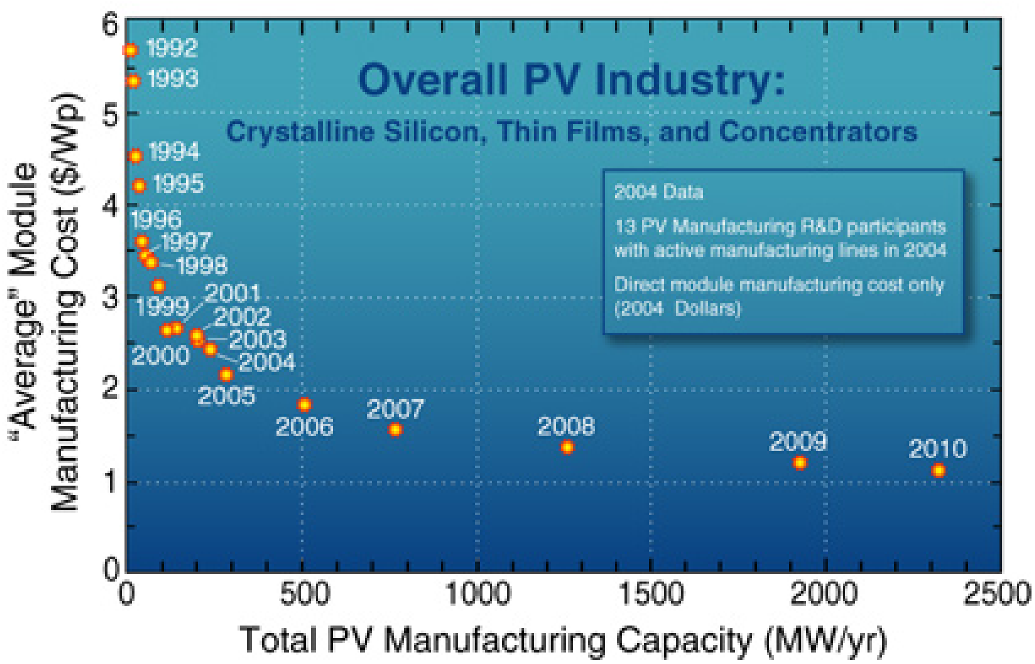
b) <u>Production costs</u>

Production costs are decreasing steadily, and there could be even greater cost reductions with the second-generation production line now under construction. First Solar is pursuing a development path that could result in production costs of less than $1 per Watt in high volumes. But this is only the first step.

Manufacturing the modules represents approximately half the cost of PV power. Other cost elements include the cost of mounting hardware and electrical components such as inverters, and labor for installation.

All those elements add up to a typical "installed cost" of around $6 or more per watt today, of which roughly $2.50 is the cost of purchasing PV modules. Lowering PV production costs to $1 per watt or less would be a significant achievement and help to improve PV electricity's cost-competitiveness, said NREL's Ken Zweibel. (Project Leader Thin Film PV).

The lowest cost is obtained by optimizing the watts obtained per square foot, the product cost per square foot, the lifetime, and the installation costs. This means that the manufacturing cost and the cost of raw materials become very important.



PV Industry Cost/Capacity (DOE/US Industry Partnership)

The graph shows continued progress toward decreasing costs of manufacturing and increasing production capacity. (Figure 12.)

<u>Further Information:</u>

National Renewable Energy Laboratory
http://www.nrel.gov/features/02-04_solar_costs.html

VI) Economic benefits “PV Roadmap”

The “PV Roadmap” is an industry led effort to assess the best mix of research and market development supports to accelerate PV development. They predict that with a reasonable set of incentives the solar photovoltaic market in the U.S. could grow more than 30% per year over the next 20 years, from 340MW of installed capacity to 9600 MW. An increase in PV installations of this magnitude will produce substantial economic benefits for the states and regions that build these installations. Because PV technologies use more labor per MW installed than other renewable technologies, the direct job benefits to the regions that install systems are significant. Nevertheless, the economic benefits extend well beyond the immediate installation and even beyond the regions where the installations occur. A program of the size documented in the PV Roadmap will create a substantial, new demand for the components and sub-components that go into a PV installation. In order to fully document the extent of the economic benefits offered by the PV Roadmap plan the total economic stimulus must be mapped. Manufacturing accounts for the largest portion of the cost of photovoltaics, and that manufacturing could occur in places other than the installation location, bringing economic benefits to other places in the country.

a) <u>U.S. Solar Power Shipment, Installations and Employment</u> (Table 3.)

		2004	2010	2015	2020	2030	2050
Annual U.S. Shipments (MW peak)	Baseline	120	240	480	950	2,400	5,500
	Roadmap	120	510	2,300	7,200	19,000	31,000
Cumulative U.S. Installations (MW peak)	Baseline	340	1,500	3,800	8,200	28,000	100,000
	Roadmap	340	2,100	9,600	36,000	200,000	670,000
Employment [c]	Baseline	20,000	23,000	28,000	37,000	59,000	95,000
	Roadmap	20,000	29,000	62,000	130,000	260,000	350,000

Job growth in the U.S. -- solar PV could grow more than 30% per year over the next 20 years, from 340MW of installed capacity to 9600 MW

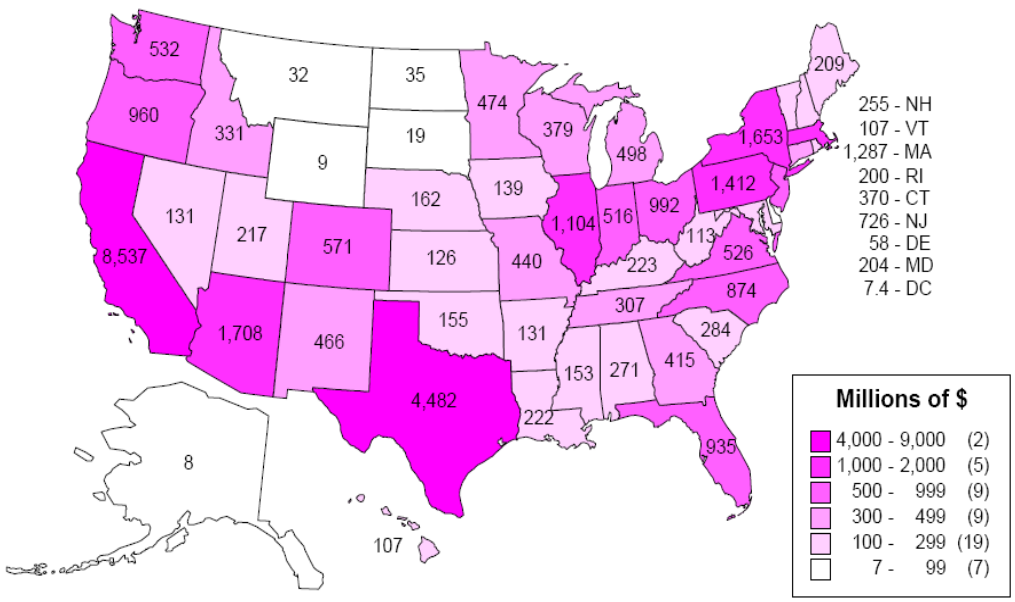
The size of the potential PV market is used as an input to the REPP Job Locator model (Renewable Energy Policy Project) in order to determine the number and geographic distribution of the jobs created as a result of the Roadmap being pursued.

Here are the summary goals of that effort:
• Total installed capacity will increase from 340 MW now to 9,600 MW by 2015.
• This represents a $34 billion investment - $27 billion manufacturing and $7 billion for construction and installation.
• Direct employment will increase from 20,000 now to 62,000 by 2015.
For comparison, if the PV Roadmap is not implemented and business-as-usual continues, baseline predictions show only 3,800 MW installed by 2015 and only 28,000 jobs

b) <u>Total Investment and Jobs Map</u>

The analysis of the 9,260 MW development proceeds in three steps. The first step is to determine how the total cost of the new PV development will flow into demand for the various system components. Next, identify the total demand among the regions of the country. Then allocate the manufacturing investment according to the number of firms in each region with the technical potential to manufacture PV components, and the installation costs according to the potential demand for PV installations. Third, distribute the job allocation according to the same location information for manufacturing and installation. This results in a geographic "map" of investment and job location. This job allocation will often be determined by state incentive and/or subsidy programs.

The US Investment and Job Map indicates the benefits of 9260 MW Solar Energy. Direct employment will increase from 20,000 now to 62,000 by 2015. (Figure 13.)



By investigating the location of potential PV component manufacturers and the location of demand for PV installations, this report shows how economic benefits from pursuing the PV Roadmap would flow into the states. While California and Texas take a large portion of the investment, the rest is well distributed throughout the country. All but 6 states would receive more than $100 million in investment. The PV Roadmap calculates that the number of jobs in PV will increase from 20,000 now to 62,000 by 2015. A recent REPP study showed that for PV, 80% of these jobs are in manufacturing, and the other 20% in construction and installation. The total employment resulting from the PV Roadmap is spread among states based on the allocating investment. These results indicate that investment in PV could provide economic benefit across the country. The 20 states that would receive the most investment from PV account for 75% of the manufacturing jobs lost in the last 3½ years. The table below shows the top 20 states ranked by received investment, along with job loss demographics.

It is also interesting to examine which states receive the most job creation relative to the number of jobs lost since the dot.com bust.

State Ranking by Total Investment and Job Creation

State	Manufacturing Jobs	Manufacturing $Millions	Const. & Install. Jobs	Const. & Install. $Millions	Totals Jobs	Totals $ Millions	Manufact. Jobs Lost, Jan. 2001 - August 2004
California	6,858	5,500	3,578	3,037	**10,437**	**8,538**	343,600
Texas	5,205	4,175	361	307	**5,567**	**4,481**	177,600
Arizona	1,987	1,594	134	114	**2,122**	**1,708**	39,300
New York	1,607	1,289	428	364	**2,035**	**1,652**	148,500
Pennsylvania	1,610	1,291	143	121	**1,752**	**1,412**	161,200
Massachusetts	1,275	1,023	311	264	**1,586**	**1,286**	84,800
Illinois	1,217	976	151	128	**1,368**	**1,104**	145,600
Ohio	996	799	227	193	**1,223**	**991**	173,000
Oregon	1,134	910	59	50	**1,193**	**960**	25,800
Florida	783	628	361	307	**1,144**	**935**	64,100
North Carolina	876	703	202	171	**1,078**	**874**	162,900
New Jersey	781	626	118	100	**899**	**726**	71,200
Colorado	624	500	84	71	**708**	**572**	36,100
Washington	609	489	50	43	**660**	**531**	66,700
Virginia	549	440	101	86	**649**	**526**	62,400
Indiana	589	473	50	43	**640**	**515**	70,900
Michigan	470	377	143	121	**613**	**498**	142,600
Minnesota	520	417	67	57	**587**	**474**	56,800
New Mexico	493	395	84	71	**577**	**467**	7,000
Missouri	469	376	76	64	**545**	**440**	37,000
				20 State Total	35,381	28,690	2,077,100
				% U.S. Total	**84%**	**84%**	**75%**

The table examines the relative impact of job creation for the top 20 states (Table 4.)

Economic expansion of related industries

If the goals outlined in the PV Roadmap are pursued, the economic impact will spread far beyond the current active firms. Companies currently engaged in manufacturing processes similar to the manufacturing of photovoltaic system components could potentially transfer their capabilities to this new market. For example, a company that makes glass plate could potentially begin making top surface glass for PV modules; a silicon semiconductor company could begin making silicon solar cells.

In order to take a look at the size and location of this potential market, REPP uses an approach based on the **North American Industrial Classification System, or NAICS**, which the U.S. Census Bureau adopted in 1997. The results of this study indicate that 10,179 firms, located across all 50 states, operate in industries similar to the manufacturing of PV components.

VII) Silicon Feedstock Shortage

China's enormous shortage of polysilicon will become the bottleneck for the solar photovoltaic energy industry explosion in the coming years. This was stated in the recently released annual report, Semiconductor **-- China's Solar Energy Market Annual Report 2005-2006**

This has become the bottleneck to hinder the rapid development of the solar PV energy industry. Additionally, the rather high capital and technical requirements of polysilicon projects, only mining productivity beyond one thousand tons of silicon can be economically effective and competitive.

The gap between demand and supply is huge in China. The total demand in 2005 was 2,825 tons while the supply was only 130 tons. Currently PV is growing about 50% per year. Since this growth is faster than anticipated, a temporary shortage in silicon feedstock has occurred. While this situation is not unprecedented, the European Photovoltaic Solar Energy Conference reported on a number of efforts to overcome the situation in the short, mid and long term. Supplies of new solar grade Si, China's low-cost labor will make it a world contender in turning raw silicon (pictured here) into solar modules for the global market.

Silicon: The bottleneck for the solar photovoltaic energy industry
(Figure 14.)

Capacities are projected to meet the additional material requirements by 2007/08. Whether the quantities envisaged will be sufficient to resolve the bottleneck of requiring more than 12,000 metric tons of Si for producing more than 1000 MW of crystalline PV modules remains to be seen at the next European PV conference in 2006.

a) Chinese manufacturing cost advantages

In addition to labor costs that can be less than $200/month per worker, Chinese solar companies also benefit from lower SG&A (Sales, General and Administration or 'cost of doing business') Research & Development, peripheral costs, and tax rate. There is also an expanding solar manufacturing equipment industry that provides equipment at a fraction of the cost of equipment made overseas.

The current generation of Chinese manufactured solar equipment includes module lamination, wafer etch/bath, and mono-crystalline wafer pullers (~$150,000 each). Also there is a growing list of lower cost wet-chemistry suppliers for slurry and aluminum paste. Chinese manufacturing lines tend to be more labor intensive and use more domestic equipment, requiring substantially lower capital expenditure.

In particular, the Chinese module lines do not run automated assembly equipment and instead favor an all-labor approach; the only equipment required are laminators and module testers.
Three Chinese polysilicon manufacturers dominate the domestic landscape. Sichuan Xinguang is still under construction with initial production in 2007, and 2008 planned capacity of 1,250 metric tons. LSCS now has capacity of ~300 tons, and plans 2007 capacity of 1,000 metric tons. ESM currently has annual polysilicon production of ~100 tons. Domestic poly production will not address near-term poly needs, as most production will not come online until 2008. Spot virgin poly prices are now as high as $200/kg, and many Chinese solar OEMs will happily pay $170/kg to secure poly. High-grade scrap (ingot tops and tails) command $150/kg, while lower end scrap (pot scrap) can command $50-$70/kg. All solar companies are using a mix of scrap and virgin poly to keep their blended poly cost at ~$130/kg. Several Chinese solar companies, in anticipation of a future capital market transaction, have been stockpiling poly in the order of hundreds of metric tons.

Sources:
www.renewableenergyaccess.com

20th European Photovoltaic Solar Energy Conference, 6 - 10 June 2005, Barcelona, Spain

http://www.greenjobs.com

Zhao Yuewang, analyst from Analysys International.

Additional information about Silicon Technology, visit the *Silicon Technology* center at:

http://www.dowcorning.com/content/sitech/

b) <u>Alternatives to Silicon Crystalline Cells</u>

Solar's Thin Film and Nanotech Revolution

One scientific discovery of the computer semiconductor industry also has great potential in the photovoltaic (PV) industry: thin-film technology. The "thin film" term comes from the method used to deposit the film, not from the thinness of the film: thin-film cells are deposited in very thin, consecutive layers of atoms, molecules, or ions. Thin-film cells have many advantages over their "thick film" counterparts (polycrystalline cells). For example, they use much less material—the cell's active area is usually only 1 to 10 micrometers thick, whereas thick films typically are 100 to 300 micrometers thick.

Also, thin-film cells can usually be manufactured in a **large-area process**, which can be an automated, continuous production. Several different deposition techniques can be used, and all of them are potentially less expensive than the ingot-growth techniques required for crystalline silicon. Thin film photovoltaic solar cells represent the most promising technology for reducing the cost of solar electrical systems. This technology has the potential to provide low cost solar power by using **non-silicon solar cells**, low cost plastic substrates and through currently available, high volume and inexpensive manufacturing techniques.

The promise of thin film photovoltaics has always been evident. The promise of solar nanotechnology has recently received significant attention. But neither of these technologies has yet to become a major player in the global market. With global silicon constraints driving an intensive search for alternatives, the day of thin film and/or nanotechnology may have finally come. One of the leading technology companies, DayStar, commercially sells non-silicon thin film Copper Indium Gallium diSelenide (CIGS) cells that are deposited, rather than printed, on a stainless foil.

Thin film amorphous (not crystalline) silicon cells made with a roll to roll process on a stainless substrate are available commercially now. The next generation thin-film cells are based on non-silicon semiconductors, which can absorb the same amount of sunlight as crystalline Silicon but in layers that are at least two orders of magnitude thinner, saving tremendous material costs.

These thin film photovoltaic cells consist of layers of a semiconductor material such as CIGS, Copper Indium diSelenide (CIS) or Cadmium Telluride (CdTe), and applied to a low-cost substrate, such as plastic. The economic benefit of thin film PV cells is that they use much less semiconductor material than the crystalline silicon cells, a lower cost substrate and can use much less costly manufacturing methods. Thin film cell manufacturers do not talk about price of their products as the products are generally not available to the consumer market, except in some specialized applications.

By comparison, DayStar is planning on having lower cost, higher volume continuous production facilities operating by the end of 2006 which should reduce their costs to about $2.00 per watt. They also project that in full scale production they can reduce costs to $1.00 per watt. This is based on sales of $18 million for 5.6 MW of panels for the quarter ending June 2005.

The ability to "print" (solution-coat) the most expensive layers of a solar cell onto a low-cost, lightweight, flexible plastic substrates is what makes it possible to reduce manufacturing costs. Printing processes are simple and robust in comparison with other thin-film deposition techniques and enable unprecedented process throughput with roll-to-roll production methods. This process makes it possible to produce solar cells that can deliver as much energy and life expectancy as conventional silicon cells and achieve unprecedented cost and production volume advantages. This results in price competitive photovoltaic cells even though the efficiency of thin film cells is less than for crystalline silicone cells.

DARPA (Defense Advanced Research Projects Agency) in conjunction with the U.S. Department of Energy's National Renewable Energy (NREL) held a competition to select contractors to conduct further development of thin film PV cells. More than 100 leading technology companies competed under this procurement process, with four of them making the final cut and contracts being awarded to: Nanosolar ($10.3 million), Konarka ($6.1 million), Nanosys ($2.3 million) and NREL.

By coating or printing photoactive materials onto a flexible plastic substrate, energy can be absorbed from both the sun and indoor light. In particular, this technology has the potential to provide low cost solar power through currently available, high volume and inexpensive manufacturing techniques based on conventional film based processes such as roll to roll manufacturing. To develop their nanotechnology-enabled solar cells they are collaborating with several United States government agencies.

(Figure 15.)
Non-silicon solar cells: *"these cells are cost-effective (1/3 cost of traditional solar)"*.
Howard Burke, President, Konarka

Konarka develops and produces a unique, carbon-based, light-activated power plastic (*thin film solar cells*) that are inexpensive, lightweight, flexible and versatile. This material makes it possible for devices, systems and structures to have their own low-cost embedded sources of renewable power. By integrating energy generation functionality into everyday devices, Konarka allows manufacturers to offer truly wireless applications. Konarka's material is cost-effective (1/3 of traditional solar), lightweight (1 to 2 oz. per square foot), aesthetically appealing (can be colored and patterned), integrate-able (can be cut to fit), flexible and versatile so as not to increase or otherwise impede the application's form factor.

Konarka's polymer photovoltaic materials are manufactured in a continuous roll-to-roll process that is significantly less expensive and capital intensive than the multi-step assembly of traditional solar cells. This proven process, similar to photographic film, is simple, energy efficient, environmentally friendly, replicable to multiple plants and scalable to high volumes.

This technology seems to be moving in the right direction and unless there are unexpected constraints, or additional R & D challenges, they should have some substantial reductions in the price of solar cells in the next few years. With at least four US companies competing, the chances are good for more breakthroughs. One of the four is DayStar who is claiming their CIGS cells on a stainless steel substrate can be produced for $1.00 per watt.

Sources:
* National Renewable Energy Laboratory http://www.nrel.gov/news/press/2005/1805_quantum_dot.html

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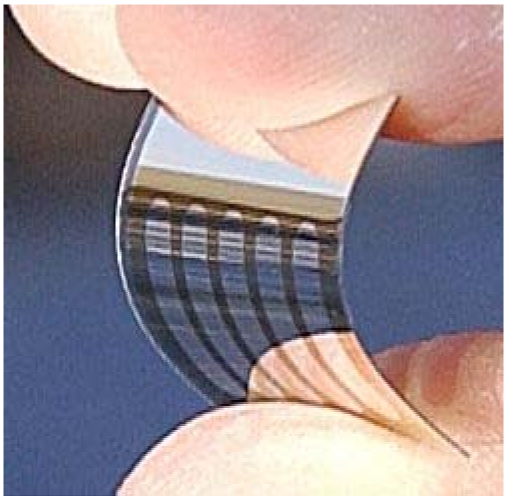
Technology hones the efficiency of sun-powered energy systems. NREL
EERE Solar Energy Technologies Program - Thin Films

c) Self-Assembling' Solar Cells

The new photovoltaics are made from "organic" materials, which consist of small carbon-containing molecules, as opposed to the conventional inorganic, silicon-based materials. The materials are ultra-thin and flexible and could be applied to large surfaces. Scientists from the University of Princeton, especially electrical engineering professor Stephen Forrest are designing, synthesizing and characterizing molecules that will self-organize from solution into coatings about 100 nanometers thick, or about one-thousandth the thickness of a human hair. Molecules in the layer must be very highly ordered to efficiently transport electrical charge.

Made from "organic" materials (Figure 16.)



Structure is one of the keys to that transformation. Patterns of silicon and oxygen repeat over and over again in the silicon crystals that comprise commercially available solar panels.
Most naturally occurring materials, called organics, do not repeat their patterns, but Pentacene does.
Organic solar cells could be manufactured in a process something like printing or spraying the materials onto a roll of plastic. The cells also could be made in different colors, making them attractive architectural elements or they could be transparent so they could be applied to windows. The cells would serve as tinting, letting half the light through and using the other half to generate power. Because of these qualities, researchers have pursued organic photovoltaic films for many years, but have been plagued with problems of efficiency. The first organic solar cell, developed in 1986, was 1 percent efficient - that is, it converted only 1 percent of the available light energy into electrical energy. That number stood for about 15 years.

At present the organic versions have an efficiency of 4 percent, according to the details of the study in the Nov. 29 issue of the journal of Applied Physics Letters,* (see also at the figure below: Best Research cell Efficiency)

Researchers in are now planning to combine the new materials and techniques. Doing so could yield at least 5 percent efficiency, which would make the technology attractive to commercial manufacturers. With further commercial development, organic solar devices would be viable in the marketplace with 5 to 10 percent efficiency, the researchers estimated. "We think we have pathway for using this and other tricks to get to 10 percent reasonably quickly".

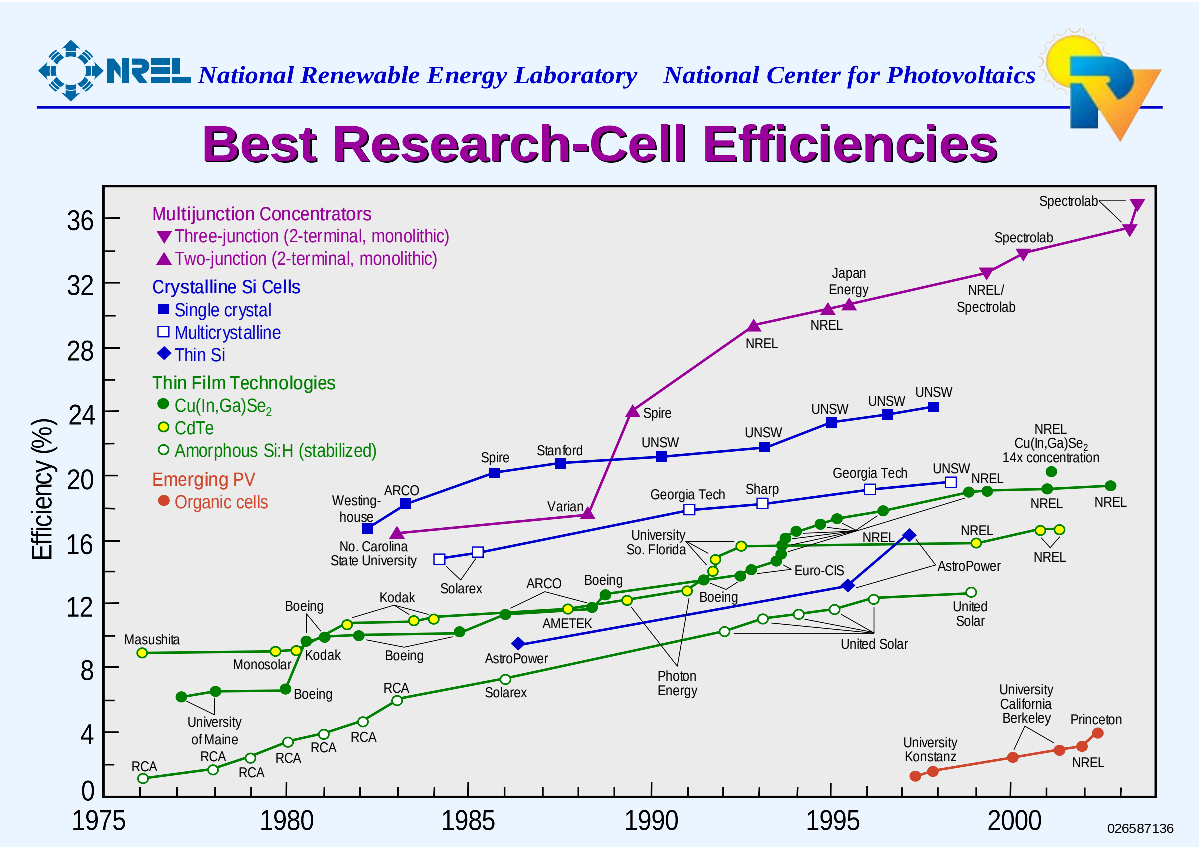
Organic solar cells will be cheaper to make, so in the end the cost of a watt of electricity will be lower than that of conventional materials. The technique the researchers discovered also opens new areas of materials science that could be applied to other types of technology. Solar cells are made of two types of materials sandwiched together, one that gives up electrons and another that attracts them, allowing a flow of electricity. The Princeton researchers figured out how to make those two materials mesh together, like interlocking fingers, so there is more opportunity for the electrons to transfer.

According to the NREL the efficiency of thin film technologies is close to 16%. Compare the Best Research-Cell Efficiencies in Fig 17 below.

Further Information: U.S. Department of Energy Efficiency and Renewable Energy www1.eere.energy.gov

The key to this advance was to apply a metal cap to the film of material as it is being made. The cap allowed the surface of the material to stay smooth and uniform while the internal microstructure changed and meshed together, which was an unexpected result. The researchers then developed a mathematical model to explain the behavior, which will likely prove useful in creating other micromaterials.

(Figure 17.)



http://www.nrel.gov/ncpv/thin_film/docs/kaz_best_research_cells.ppt
* http://scitation.aip.org/dbt/dbt.jsp?KEY=APPLAB

CSC has the best cell efficiency with over 35 percent.

Further Information:

University of Princeton
Department of Electrical Engineering
Prof. Stephen R. Forrest
http://www.ee.princeton.edu/people/Forrest.php

VIII. Concentrating Solar Power (CSP)

300-900 MW Solar Project Planned for Southern California (Figure 18.)

The world's largest solar facility: The New Solar Energy Project Announced by Southern California Edison and Stirling Energy Systems, Inc.

Edison International (NYSE:EIX) subsidiary Southern California Edison (SCE), the nation's leading purchaser of renewable energy, and Stirling Energy Systems announced an agreement that could result in construction of a massive, 4,500-acre, about 7 square miles solar generating station in the Southern California desert. When completed, the proposed power station would be the world's largest solar facility, capable of producing more electricity than all other U.S. solar projects combined. The 20-year power purchase agreement, which is subject to California Public Utilities Commission approval, calls for development of a 300-megawatt (MW) solar project 70 miles northeast of Los Angeles using innovative Stirling dish technology. The agreement includes an option to expand the project to 900 MW.

Planned for Southern California, the world's largest solar facility

Concentrating solar power (CSP) technologies can be a major contributor to our nation's future need for new, clean sources of energy, particularly in the West. A solar dish farm covering 11 square miles hypothetically could produce as much electricity per year as Hoover Dam, and a farm 100 miles by 100 miles in the southwestern U.S. could provide as much electricity as is needed to power the entire country.

National Renewable Energy Lab, 2005

Initially Stirling would build a one-MW test facility using 40 of the company's 37-foot-diameter dish assemblies. Subsequently, a 20,000-dish array would be constructed near Victorville, Calif., during a phased four-year period. The utility-scale Stirling project would provide enough clean power to serve 278,000 homes for an entire year," said SCEC chairman John Bryson. "Edison is committed to facilitating development of new, environmentally sensitive, renewable energy technologies to meet the growing demand for electricity here and throughout the U.S."

Source:

http://www.nrel.gov/csp/

Although Stirling dish technology has been successfully tested for 20 years, the SCE-Stirling project represents its first major application in the commercial electricity generation field. Experimental models of the Stirling dish technology have undergone more than 26,000 hours of successful solar operation. A six-dish model Stirling power project is currently operating at the Sandia National Laboratories in Albuquerque, New Mexico.

Tests conducted by SCE and the Sandia National Laboratories have shown that the Stirling dish technology is almost twice as efficient as other solar technologies. These include parabolic troughs which use the sun's heat to create steam that drives turbines similar to those found in conventional power plants, and photovoltaic cells which convert sunlight directly into electricity by means of semiconducting materials like those found in computer chips.

a) SES Dish Stirling System Technology (Figure 19.)

The Stirling dish technology converts thermal energy to electricity by using a mirror array to focus the sun's rays on the receiver end of a Stirling engine. The internal side of the receiver then heats hydrogen gas which expands. The pressure created by the expanding gas drives a piston, crank shaft, and drive shaft assembly much like those found in internal combustion engines but without igniting the gas. The drive shaft turns a small electricity generator. The entire energy conversion process takes place within a canister the size of an oil barrel. The process requires no water and the engine is emission free.

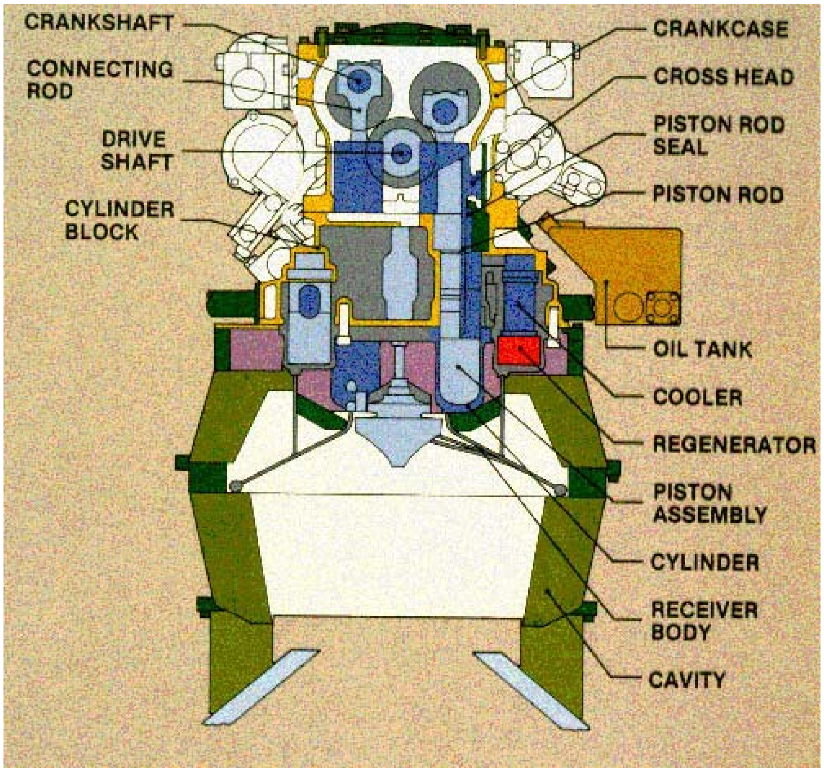
No water is required and the engine is emission free on this SES Dish Stirling System showed above

89 mirror facets are attached to the frame by three-point adjusting mounts at specific points on the subassemblies. It is designed in five subassembly units for ease of transport and installation on site. Two small motors, an azimuth drive and an elevation drive, are attached to the pedestal and programmed to swivel the dish on two axes, following the suns progress across the sky during the day. Each morning, the system wakes up, putting it in position to greet the sun, rather like a robotic sunflower. At the end of the day, the system controller commands the concentrator to tilt down into a “night-stow” position, with the engine at ground level.

Site preparation involves sinking a cement base with an imbedded pedestal to support the dish, with the subassemblies unloaded, bolted together and affixed to the pedestal by two workmen in about four hours. No crane is required. When final alignment adjustments are made at the factory, the facets are locked into place before the system is shipped so as to eliminate the need for adjusting mirror facets at the site. The subassembly design permits units to be transported to an installation site by truck

Source:
http://www.stirlingenergy.com/images.asp?Type=solar

The Stirling engine, net solar-to-electric conversion efficiency reaching 30 percent. Each unit can produce up to 25 kilowatts of daytime power. (Figure 20.)



The Stirling engine's cylinder block incorporates four sealed cylinder assemblies (pistons, piston rods, and connecting rods domes) along with coolers, regenerators and heater heads. Concentrated solar energy heats up self-contained gas (hydrogen) in the Power Conversion Unit, causing the gas to expand into the cylinders, moving the cylinders and generating electricity. There is a 90-degree timing separation between adjacent cylinders and the working gas is exchanged repeatedly back and forth between the same adjacent cylinders. This cycle is repeated over and over as the engine runs at a steady rate of 1,800 rpm (a low-stress, long duty-life regimen for a conventional gasoline engine).

Unlike familiar auto or truck engines, Stirling engines do not rely upon internal combustion to drive the pistons and rotate a crankshaft. In fact, there is no combustion at all. Power is generated by heat transfer from the concentrated solar rays to the working gas in the engine's heater head, which converts the heat energy into mechanical motion. This power runs the electric generator, which produces electricity with an output of 480 Volts and 60 Hertz, so it is already power-conditioned by the generator's interface. The generator of each unit in a utility-scale project is connected by underground wire to a small substation where the power can be transformed into a higher voltage for more efficient transmission across the grid

SES management forecasts sales of its dish solar Stirling system outside the U.S. are likely to be concentrated in Spain, the Mediterranean region, and Australia, because there is strong government commitment to solar in these countries. In Spain, for example, there are Royal and Parliamentary mandates providing price incentives of up to 20 cents per kilowatt-hour (kWh) for solar-generated electricity. In the U.S., solar system sales are backed by incentives and/or requirements for renewable energy technologies in place in several states, including Arizona, California, Connecticut, New Jersey, Pennsylvania, Nevada and Texas. With its superior technology, team and market timing, SES is ready to capitalize on these opportunities as they develop.

SES estimated that this project will generate, in addition to electricity, 3,000 to 5,000 jobs during the construction phase and about 100 to 200 jobs for operation and support of a 500-megawatt plant. Including the replacement component manufacturing and all of the community support requirements, that somewhere between 350 and 600 on-going jobs will be needed at the site and related support.

b) Trends sterling engine

The cost for each prototype unit is about $150,000. Once in production SES estimates that the cost could be reduced to less than $50,000 each, which would make the cost of electricity competitive with conventional fuel technologies.

A solar dish farm covering 11 square miles hypothetically could produce as much electricity per year as Hoover Dam, and a farm 100 miles by 100 miles in the southwestern U.S. could provide as much electricity as is needed to power the entire country. (NREL estimate)

Another application could be to operate as stand-alone units in remote areas off the grid, such as the Navajo reservation, and supply power to several homes or businesses.

Rendering of SES Dish Stirling System used to pump water and support agriculture (Figure 21.)

Stand-alone units have already been demonstrated as an effective means of pumping water in rural areas. With desertification already a serious problem, large scale Solar systems can slow and prevent deserts from spreading.

Desertification of the world spreads 30 square meters every day.

The Sahara Supposition is a proposal to try and Terraform the Sahara Desert; to reclaim it for the benefit of Humanity. This solar desert strategy will attempt to redress the balance.

The dish-Stirling system works at higher efficiencies than any other current solar technologies, with a net solar-to-electric conversion efficiency reaching 30 percent. Each unit can produce up to 25 kilowatts of daytime power. One of the system's advantages is that it is "somewhat modular," and the size of the facility can be scaled up over a period of time. That is compared to a traditional power plant or other large-scale solar technologies that have to be completely built before they are operational.

Sources:

http://www.sandia.gov/news-center/news-releases/2004/renew-energy-batt/Stirling.html
http://www.stirlingenergy.com/solar_overview.htm
http://www.analogzone.com/grnrept23.htm

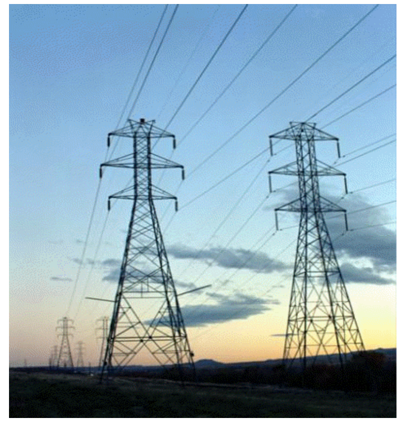
IX. Transmission the essential link

The active use of transmission to replace polluting energy sources by renewable energy sources could eliminate, in 10 to 15 years, about:

1500 million tonnes/year of CO_2

5 million tonnes/year of NOX

15 million tonnes/year of SO_2



Electrical transmission has to be used since electric power must be transported. It is not practical to store electric energy in large quantities. Furthermore, the production resource is fixed for renewable energy such as energy from the desert. Many of the best renewable power resources in the world are located far from the load centre.

As production and consumption places in most cases are separated by great distances, the only possibility to make use of the power is to build transmission lines. From a technical point of view, a considerable amount of power can be transported on ac and dc transmission lines over very long distances. Additionally, between areas separated by water, the use of a direct current system allows a utility to transmit the energy by submarine cables. Research studies show insignificant adverse health effects on human beings or fish.

a) Characteristics of transmission

The type of transmission used depends on the type of generation and distances involved. High voltage transmission is defined today as grids with voltages from 69 kV and above. At lower voltages we use the terminology distribution. Today's interconnected and meshed networks use three phase alternating current, ac, with a frequency of 50 or 60 Hz as the commonly used technique taking advantage of the easy use for transformation between voltage levels. Direct voltage, dc, is used especially for long transmission lines where it gives the advantage of the same power level being transmitted to/on just two conductors.

The higher voltages result in lower losses and economic advantages. But, HVDC (high voltage DC) can also be used for special applications when it is possible or difficult to connect the two networks by an ac transmission, e.g. for stability reasons. The capacity of an 800 kV ac line is around 2000 MW and an anticipated figure for the future are 1200 kV lines is 5000 MW. A realistic maximum distance for an ac transmission is around 1200 km.

The characteristics of transmission lines for moving electric energy mean that there is the potential of using long transmission lines to a larger extent than is the case today. Thereby the proportion of the renewable and cleaner types of generation of electricity is increased and reduces the amount of greenhouse gas emissions. Such bulk power transmissions over long distances can be built at a reasonable cost. The transmission of 2000 MW over 1000 kilometers would cost less than 1 cent/kWh.

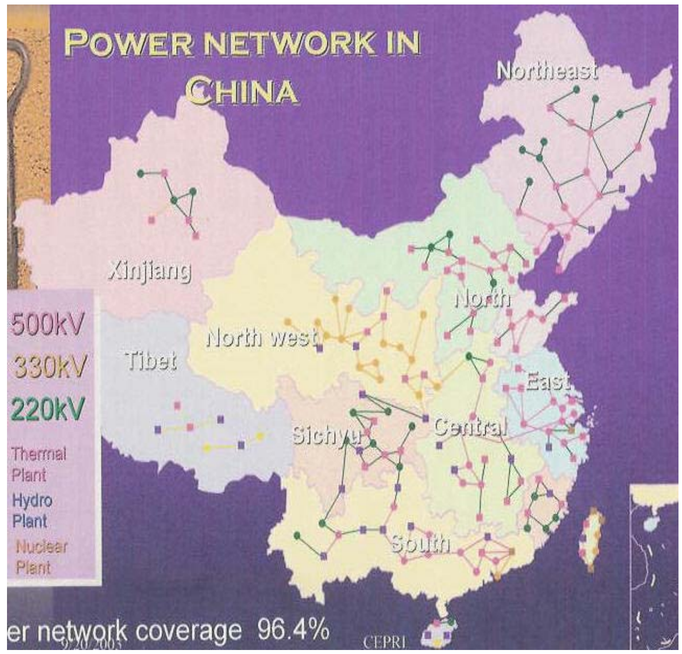
"Restructuring means you'll be able to pick your own power supplier. So if you want to choose renewable energy, for the first time in history you'll be able to do that."

Ralph Cavanagh, **the senior attorney at NRDC and co-director of the Energy Program**

X. Energy source and market

The largest world desert regions are sometimes near existing transmission lines which make it possible to more simply add renewable energy from the desert to these grids.

a) <u>Gobi desert for China</u> (Figure 22.)



The Gobi Desert can feed the energy demand of China by adding solar energy on a large scale to the existing transmission lines. Transmission lines in Baotou, Jining, Hohot are very close to the Gobi Desert. It is possible to add significant renewable solar energy on a large scale from the Gobi Desert to this existing grid to supply the growing energy demand for China. It is also possible with the existing transmission lines to export energy to other countries like Vietnam, Japan and Korea .

Basic facts to China

- China is set to overtake the US as the largest producer of greenhouse gases by 2025 unless current trends are modified.
- 7 of the world's 10 most polluted cities are in China
- Economic losses and health costs due to pollution alone are equal to 8% of China's GDP (source: the World Bank)
- Acid rain in China is widespread, causing severe damage to crops and forests. The particulate cloud is now observed over Japan, the northern Pacific and North America
- 75% of China's energy production is currently from burning coal

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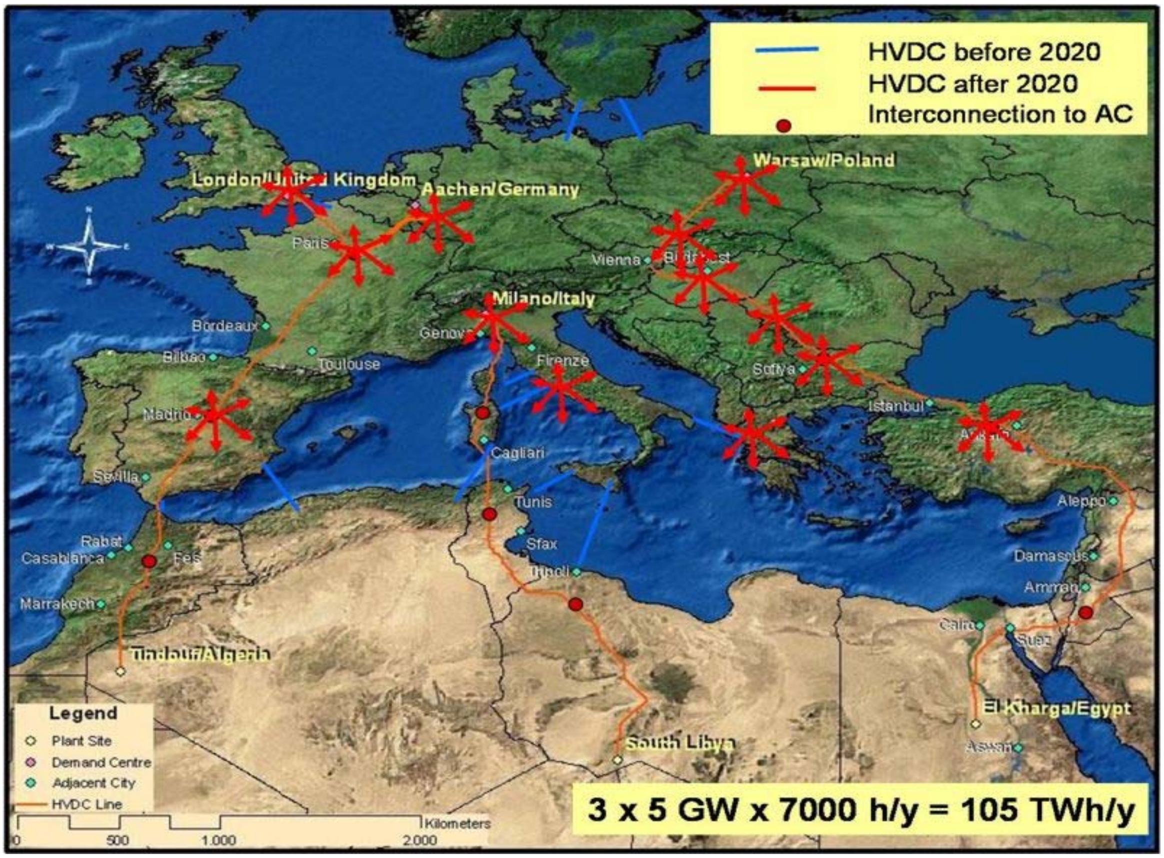
Further information on
http://www.wwfchina.org/english/
http://www.wwfchina.org/english/loca.php?loca=96

The first approach for Gobi Desert

The World Wildlife Fund (WWF) is working to develop a large solar power plant, which would supply power to Dunhuang city, Gansu province. Representatives from China's National Energy Bureau, the solar energy industry, regional and local governments, and WWF recently met to discuss the development of a demonstration project for an **8 MWp grid-connected solar PV photovoltaics plant in the Gobi Desert, Gansu Province.**

b) Concentrating Solar Power for the Mediterranean Region **(Figure23.)**



HVDC-interconnections analysed in the German Aerospace Center DLR-study TRANS-CSP for trans-Mediterranean power transmission.

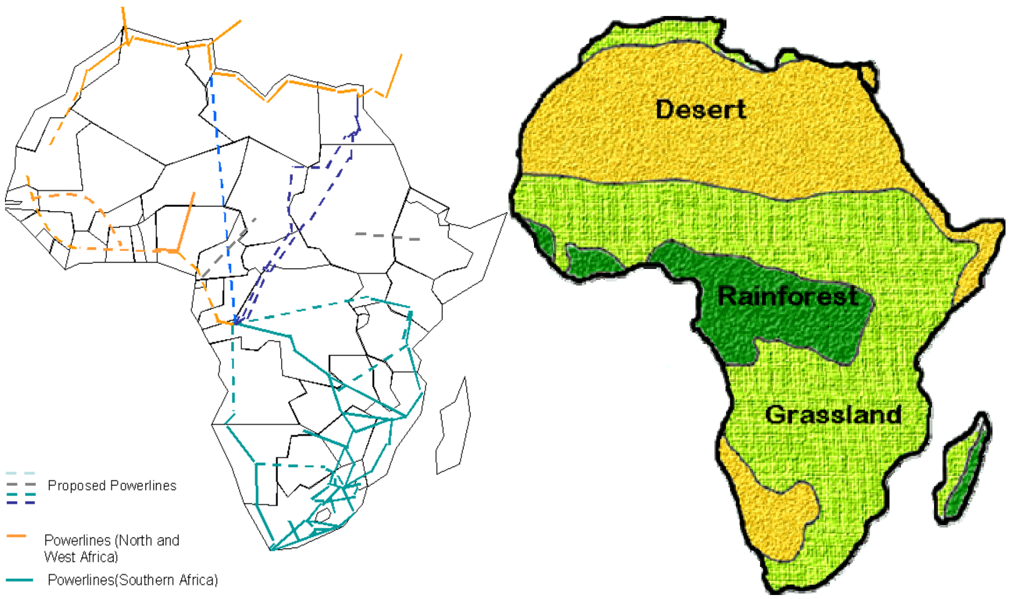
Two studies, called **MED-CSP** (Concentrating Solar Power) for the Mediterranean Region and **TRANS-CSP** (Trans-Mediterranean Interconnection for Concentrating Solar Power), have been commissioned by the former environment minister in the German Government, *Jürgen Trittin*, and the Federal Ministry for the Environment, Nature Conversation and Nuclear Safety (**BMU**). They have been undertaken by a German think tank of the German Aerospace Center (**DLR**) during 2005 and 2006.

This study reviewed renewable energies on a large scale as a strategic lever to shift global energy policies. A strategic partnership between the European Union (**EU**), the Middle East (**ME**) and North Africa (**NA**) is a key element of such a policy for the benefit of all stakeholders.

Further information / source:
German Aerospace Center: http://www.dlr.de/tt/med-csp
http://www.trecers.net
http://www.geni.org/globalenergy/library/technical-articles/transmission/abb-power-systems-a-b/electrical-transmission/index.shtml

c) **POTENTIAL FOR ENERGY INTEGRATION IN AFRICA (Figure24.)**

Solar energy from the Sahara can be connected to the existing powerlines from North and West Africa. (orange lines) To feed parts of the energy demand in central Africa, proposed powerlines have to be build first. (blue lines in diagram) Solar energy from the Namib and Kalahari desert can be connected to the powerlines from Southern Africa (green lines). (Dashed lines are proposes new routes for high-voltage transmission lines.)



Former Soviet President Calls for Global Solar Fund to help developing countries.

"This idea reflects our vision of a way of helping the energy impoverished in the developing world, while creating concentrations of solar energy in cities that could be used to prevent blackouts, and would result in lower electricity bills," "The Global Solar Fund could easily be raised by cutting subsidies for fossil fuels and nuclear energy, to install solar photovoltaic equipment around the planet, thereby driving down the price and creating a mass market for a clean fuel technology."

Mikhail Gorbachev, May 1, 2006
Geneva, Switzerland and Washington, DC

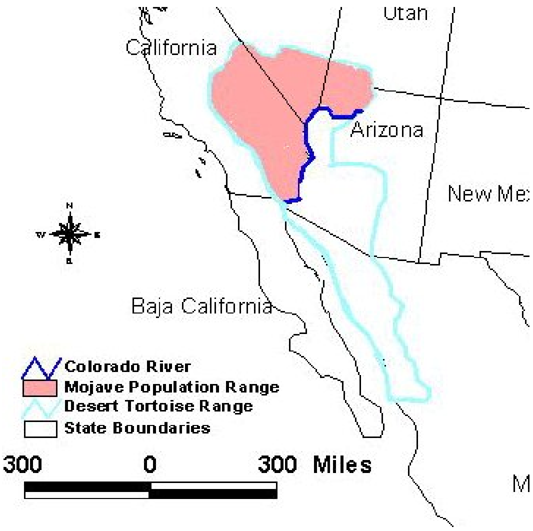
Further Information:
http://www.renewableenergyaccess.com/rea/news/story%3Bjsessionid=0BA2CDC822EAB0C577A61104DF6305F9?id=44774

Source:

http://images.google.com/imgres?imgurl=http://www.esi-africa.com/archive/esi_1_2004/52_1_3.jpg&imgrefurl=http://www.esi-africa.com/archive/esi_1_2004/52_1.php&h=335&w=302&sz=92&tbnid=h935QHXWx_zOtM:&tbnh=115&tbnw=103&hl=en&start=10&prev=/images%3Fq%3Denergy%2Bgrid%2Bafrica%26svnum%3D10%26hl%3Den%26lr%3D%26sa%3DN

d) <u>Mojave Desert for the US</u> (Figure 25.)

The existing Power Lines are along the Mojave Desert. Solar energy form the Mojave Desert can be added to this existing grid of the Western States without significant new investment.



Just 9% of Mojave Desert, a patch of 100 square miles of open space covered with efficient solar panels, could power all the electricity needs of the US.

National Renewable Energy Lab

Visionary engineer, R Buckminster Fuller, sums up the true potential of Very Large Scale Solar Power from the Deserts in his provocative statement:

"There's no energy shortage,
there's no energy crisis,
there's a crisis of ignorance"

Source:

http://www.nrel.gov/solar/

XI. Summary and Conclusion

Transforming the sun’s energy into electricity has evolved from providing power to satellites in space, to remote off-grid village applications, and to plans for large scale systems in the world's deserts. Early schemes for large solar arrays showed the promise of abundant, clean energy. Yet, system costs and low conversion efficiencies kept solar power at the kilowatt scale for the past three decades.

The potential solar resource from desert regions is truly astounding. Several studies show that the entire global electricity demand could be provided from just 4% of the world's deserts. Many of the grand schemes place large arrays around the equatorial regions with high-voltage transmission lines delivering that energy to populated areas in the north and south.

Preventing such ideas were the costs of developing photovoltaic cells and the conversion devices. Now, annual industry growth rates of 20% per year and entry by major energy companies has driven costs down and efficiencies up.

Policymakers can assist the solar industry by cutting subsidies for fossil fuels and nuclear energy, providing tax incentives to solar purchasers, thus driving down the costs and creating a mass market for this clean fuel technology. For example, in the U.S., direct subsidies to nuclear energy amounted to $115 billion between 1947 and 1999 with a further $145 billion in indirect subsidies. In contrast, subsidies to wind and solar combined during the same period totaled only $5.5 billion.

With energy demand projected to double in 30 years, mostly from developing nations, the business-as-usual energy scenarios predict dire consequences for the planet. Growing CO_2 concentrations in the atmosphere are driving climate change, and transitioning to carbon free energy sources is a prime solution. Large solar arrays in deserts (VLS PV and CSP) provide the largest potential renewable energy resource to meet growing energy demands in a sustainable manner.

High-voltage transmission grids can carry the electricity over thousands of kilometers from regions with abundant solar radiation to our cities and industry. This paper offers several examples for the Gobi, Sahara and Mojave Deserts -- and utilities in Southern California are now pursuing 300MW - 900MW VLS photovoltaic (PV) and concentrating solar power (CSP).

The benefits to millions of people through solar energy in desert regions is a sustainable way to solve both environmental and social problems. We see that large solar power systems could one day replace fossil fuels as the main energy source for society.