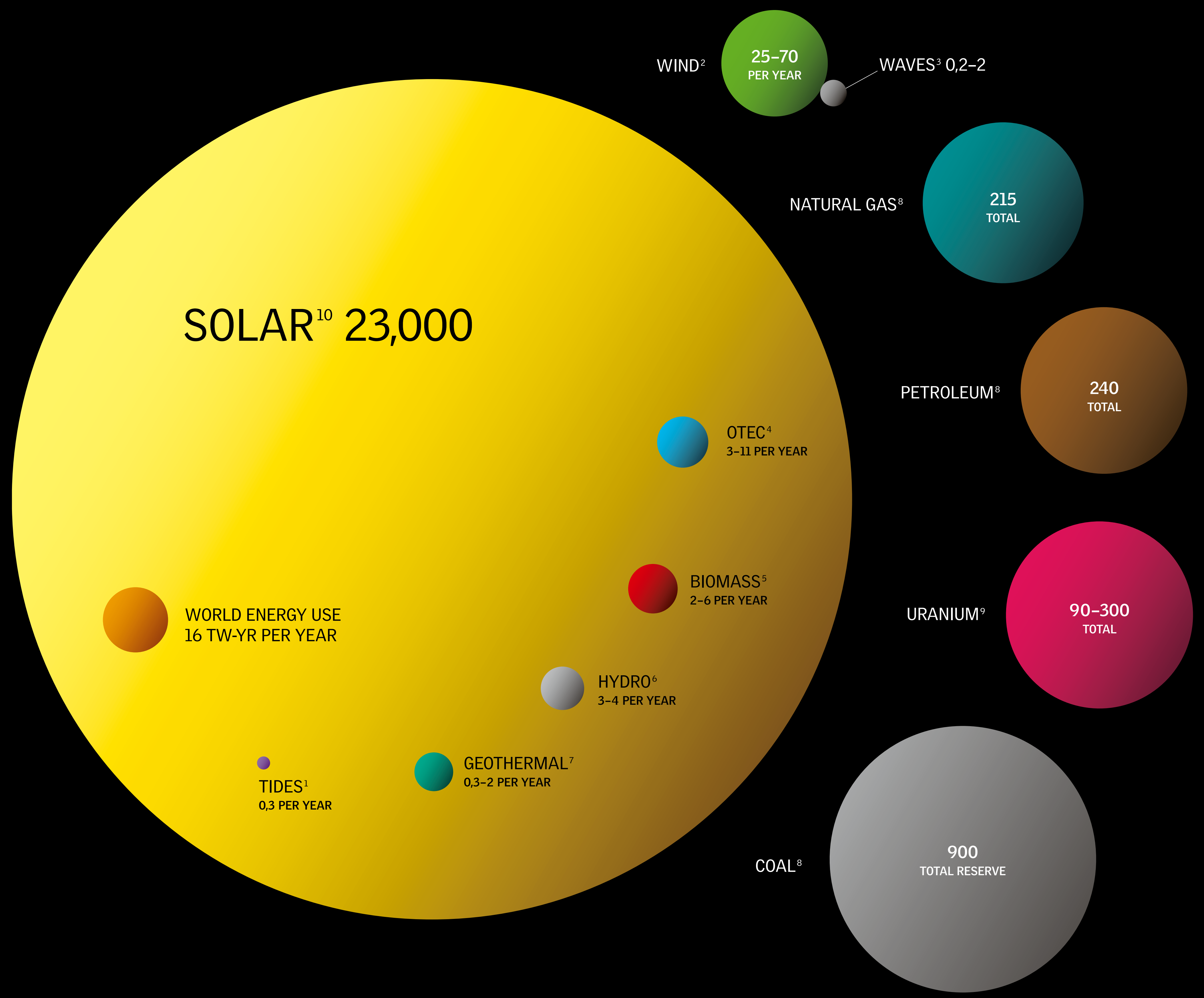
# MAKING THE CASE FOR SOLAR ENERGY

Solar energy is often viewed as a set of niche applications, with a useful, but limited potential. However it is probably the only long-term supply-side energy solution that is both large enough and acceptable enough to sustain the planet's long term requirements.

By Richard Perez




(Figure 1) © R. Perez et al.

# SOLAR POWER

The available solar energy exceeds the world's energy consumption by a factor of 1.500. Fossil fuels like oil and coal alone could fulfil our energy needs for another three or four generations, but would do so at a considerable environmental cost.

1. S. Heckeroth, Renewables.com, adapted from Christopher Swan (1986): Sun Cell, Sierra Club Press
2. C. Archer & M. Jacobson, Evaluation of Global Wind Power – Stanford University, Stanford, CA
3. World Energy Council
4. G. Nihous, An Order-of-Magnitude Estimate of Ocean Thermal Energy Conversion Resources, Journal of Energy Resources Technology – December 2005 – Volume 127, Issue 4, pp. 328–333
5. R. Whittaker (1975): The Biosphere and Man – in Primary Productivity of the Biosphere. Springer-Verlag, 305-328. ISBN 0-3870-7083-4.
6. Environmental Resources Group, LLC http://www.erg.com.np/hydropower_global.php
7. MIT/INEL The Future of Geothermal Energy – Impact of Enhanced Geothermal Systems [EGS] on the U.S. in the 21st Century http://www1.eere.energy.gov/geothermal/egs_technology.html. Note that geothermal is treated here as a renewable resource, with a yearly production rate based on projected installed capacity in 40-50 years exploiting current recovery technologies. The resource is indeed finite (since contained within the earth) but its ultimate potential is considerable and has been estimate at several 10,000 TW-yrs. However its exploitation is contingent on capturing the heat reservoirs stored very deep under the earth's crust and on humanity's willingness to do so.
8. BP Statistical Review of World Energy 2007
9. http://www.wise-uranium.org/stk.html?src=stkd03e
10. Solar energy received by emerged continents only, assuming 65% losses by atmosphere and clouds



# POWER OF THE SUN

IT IS HELPFUL to distinguish between two types of solar energy applications: those which are designed to meet a particular end-use, and those which are universal in nature.

The first group includes such applications as domestic hot water, passive or active heating of buildings, and utilisation of natural light. These applications are indeed 'niche applications' although their scope can be very large (e.g., the penetration of solar hot water systems in countries like Israel, Spain Turkey and especially China[1] is significant). However, the impact of these technologies is limited to meeting their specific end-use, contributing to the general perception that solar is a useful but limited energy resource.

The second group includes technologies designed to generate electricity – i.e., a universal energy carrier that can be stored, transformed and reach virtually any end-use application requiring energy. This group includes photovoltaic (PV) power generation, concentrated solar power (CSP), and wind power generation[2]. This second group holds the key to a very large scale deployment potential that could, in theory, meet all the planet's energy requirements and beyond.

## HUMANITY'S ENERGY REQUIREMENTS

At present the total primary energy consumption of the world is of the order of 480 exajoules[3] per year, amounting to a constant power demand of 16 Terawatts[4]. This consumption is not distributed equally, with rich industrialised countries, such as the United States of America using almost 22% of the planet's energy with only 5% of its population. Growing economic powers China and India are rapidly increasing their demand for energy with a combined consumption now exceeding that of the United States, suggesting that the current worldwide figure is headed for a strong growth. Table 1 reports energy consumption figures for major countries and groups of countries around the world.

Residential and commercial sectors (i.e., largely buildings) account for almost 30% of energy use in OECD countries. While the proportion is smaller in non-OECD countries, the commercial building sector's energy demand growth surpasses all other sectors by far.

## MEETING ENERGY DEMAND

There are two ways to meet worldwide energy demand and its fast anticipated growth:

1. On the demand-side, by acting to reduce, and eventually reverse, the growth rate, using conservation and increasing efficiencies: e.g., better engines, higher efficiency lighting, better insulation, avoiding unnecessary waste; in short smarter, better and smaller. The McKinsey report on climate change[5] indicates that over 40% of the consumption of major consumers like the United States could be met economically by smart conservation and efficiency alone.

2. On the supply-side, by tapping existing and new resources capable of meeting the demand remaining after conservation. Table 3 reports the current contribution of different resources to the planet's supply-side needs.

*Finite supply-side resources:* The lion's share of the today's primary energy comes from fossil fuels with the balance largely met by nuclear, hydroelectricity and biomass. Much of this supply chain is finite, and the world is rapidly moving into a phase where the balance between supply and demand will reach a tipping point. Oil is the first to approach its physical production peak and the inevitable supply-demand imbalance already causes chaotic market fluctuations with a strong underlying price strengthening.

Aside from oil, a look at the proven planetary reserves (Fig 1) of finite resources is quite revealing.

Nuclear energy is often presented as the solution to oil depletion and global warming. Unfortunately, this "silver bullet" view may be too optimistic. Apart from the still unresolved issues of waste management and nuclear proliferation, and apart from the unaccounted need for large, if hidden, public subsidies (e.g., the Price-Anderson Act in the United States[13], protection from terrorism, etc.) the supply of nuclear fuel may be just too small using current and planned nuclear generator technologies[7]. The current pressure on nuclear fuel price, paralleling that of oil, is an indication that supply-demand balance is tightening[8].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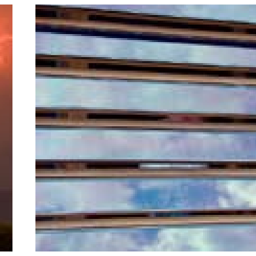
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1. Central or distributed? Using today's electricity grids for both methods of solar power supply would not involve any significant problems.
2. Worldwide, known coal reserves would be alone sufficient to supply the world with energy for the next 2 to 3 generations.
3. Measured in terms of annual power generation, wind power is currently the second most important source of renewable energy after hydroelectric power. In terms of its global potential, however, it comes far behind solar power.
4. Today, buildings consume more than 30 per cent of all energy worldwide. In distributed, solar power supply in the future, they could play an important role as miniature power stations.
5. Solar trough power station in California. Large solar heat power stations such as these are regarded as a highly promising alternative to photovoltaic forms of power generation.

**IMAGE CREDITS**
1: GEOFF TOMPKINSON / SPL / AGENTUR FOCUS
2: THOMAS STEINHAGEN / FOTOLIA
3: KAJ R. SVENSSON / SPL / AGENTUR FOCUS
4: TECHNISCHE UNIVERSITÄT DARMSTADT
5: HANK MORGAN / SPL / AGENTUR FOCUS

The proven reserves of coal are significant and could carry the planet for a good number of years, but probably not for more than 2–3 generations if coal-alone had to carry the planet's energy burden, and, likely, at a huge environmental cost, with, first and foremost, global warming intensification.

While natural gas is considerably more environmentally benign than coal, the reserves are also considerably more limited. The recent trend observed in North America between the number of gas wells drilled and the amount of gas produced may be an early symptom of more pressure to come[9].

*Renewable resources:* Figure 1 compares the yearly potential yield of renewable resources against the finite reserves of conventional energies. It is plainly evident that the magnitude of the solar resource dwarfs any other finite and renewable resources. Note that many of the renewable resources are second and third order byproducts of incoming solar energy, like wind, biomass, hydropower and wave power – just as fossil fuels are byproducts of solar energy stored in the earth over millions of years[10]. Wind energy could probably satisfy the planetary energy requirements if exploited to a substantial portion of its potential. However the yearly, indefinitely renewable supply of solar energy received by the emerged continents alone is more than 30 times larger than the total planetary reserves of coal and 1,500 times larger than the current planetary energy consumption.

The solar resource is well distributed and widely available throughout much of the planet. It is of course more abundant in the tropical belts than it is in the temperate zones[11], but consider that even such a modestly sized, northern, and sometimes cloudy country as Denmark receives a total of nearly 5 TW-year worth of solar energy every year, that is one third of the energy consumption of the entire planet.

It is widely believed that deploying solar energy on a massive scale would utilise too much space. A quick look at the physical reality reveals that this view is not accurate: even, assuming a very conservative rate of 10% conversion[12] from available to useable solar energy, it would take less than one percent of the emerged continent's area to produce all the energy used by the planet today, i.e., an area smaller than the earth's currently [sub] urbanised land – and much of the urbanised landscape can be used for solar harvesting with very little visual or operational impact. The city of New York, for instance, one of the densest energy demand hubs on the planet, could satisfy its entire electric consumption using 60% of its surface, using the same modest 10% conversion efficiency[13] as a reference. Another interesting point of reference is to contrast solar generation area requirements to hydroelectric artificial lakes. In the United States, for instance, artificial lakes occupy 100,000 square kilometres of flooded land to produce only 7% of the county's electrical energy. Only a quarter of that flooded space would be needed to supply 100% of the electricity with photovoltaic power generation.

## A COMPREHENSIVE SOLAR SOLUTION

While stressing that demand-side conservation and efficiency are an inherent part of any solution, a nearly 100% supply-side solar future for the planet is not inconceivable. Given the size of the finite reserves and the size of the renewable solar supply, logic alone would say that such a future is inevitable.

Beyond conservation and efficiency, a comprehensive approach would first involve maximising the utilisation of the direct end-use solar applications that have the highest onsite solar-to-application efficiencies: hot water, daylight, passive heating and passive cooling where climate permits.

But the key would lie in electricity generation via any of the leading direct solar technologies (PV and CSP) or indirect technologies (wind, smart biomass) and in the development of creative solutions and infrastructures to serve the energy and modify it to meet all end-uses.

*Infrastructure:* Two very distinct infrastructural models are envisageable:

(1) Local, decentralised production of solar-derived electricity near points of utilization – largely using PV, but also wind, taking advantage of available space – particularly space that can be used for solar harvesting in addition to a primary role like building envelopes, industrial exclusion zones, transportation right of ways, etc. The resource is large enough in almost every part of the world to fulfil most needs. However, a considerable technological challenge will have to be addressed because the solar renewable resources are intermittent and vary seasonally. Smart, interactive electrical load management and energy storage technologies will have to undergo a fast development phase.

The main attraction of this decentralised deployment model is that it would result in indigenous, highly-secure, and robust energy pathways. Because of the decentralisation of production, demand management, and storage operation, the failure of any one decentralised unit, with built-in minimal stand-alone operation capability, would be insignificant.

The storage panoplies which will have to be developed will range for very short term (capacitors, fly wheels, batteries, load demand response) to mid term (e.g., interactive electric/hybrid cars[14] load/backup management), to long term (e.g., flow batteries, hydrogen, compressed air)

(2) At the other extreme are continental, and possibly planetary super power grids: the basic ideas behind this vision are that some places on the planet receive more solar energy than others (e.g., the world subtropical deserts) and that the average solar yield of the entire planet is nearly constant (i.e., it is always sunny somewhere on planet earth). There are conceptual proposals on the drawing board both in Europe and in America[15] considering this type of solar energy deployment. The approach will necessitate the development of very high voltage, highly conductive DC super power lines, and, more importantly will necessitate a strong and tacit agreement between all involved parties and countries to maintain and protect such a network.

The author's preference is for the first (decentralised) model, but a combination of both could be envisageable - at the very least making use of nearby availability of large solar resources (such as the US southwest deserts providing power to the large cities of the east coast, taking advantage both of the time difference and the solar yield differences).

*Serving all energy needs:* Many demand sectors, transportation in particular, rely on liquid fuel to operate. This issue would require particular attention but the task is not insurmountable: ground transportations could become largely electrical over time through increase electric rail-based mass transportation, the advent of electrical and plug-in hybrids, and new concepts such as Personal Transportation Networks[16]. It is also possible to produce fuel, or fuel equivalents derived from solar/wind electricity – hydrolysis of hydrogen being the most familiar if not the most promising method. New generation of fuel-producing biomass could also be considered for the remaining applications which could not easily rely on electricity directly or indirectly, such as air transport. Although relying on biomass alone for all transportation needs would put an impossibly large burden on food chain and the planetary ecosystem, innovative solar-augmented biomass or bacteria-based fuel producing t echnologies could be reasonably envisaged for applications absolutely requiring liquid fuels.

*A look at the solar industry:* As a reality check, a quick look at the direct and indirect solar industries that are fast emerging throughout the world today indicates that the type of 'big-picture' visions mentioned above already have a strong, if yet still embryonic, head start: Considering the growth of PV, wind, and CSP alone over the last ten years[17] and projecting this growth rate in the future indicates that over half of the new electric generating capacity installed in a country like the United States will come from these renewable resources within 20 years. This growth may not yet be quite sufficient yet given the fossil energy depletion and environmental pressures, but it is already impressive; and suggests that when additional countries and decision makers become aware of the need for a fast transition, a rapid renewable takeoff is not pie in the sky but a real possibility.

The first markets to evolve are, and will be, driven by key underlying forces: (1) The people/policy driven markets exemplified by Germany and Japan that, despite a modest solar resource, have become the largest solar markets in the world today and are building on this experience to invent and develop the technological solutions that will permit increased penetration of solar energy in their energy systems; (2) markets where solar synergies will provide high-value solutions that will attract investment, particularly where a large resource can meet a large quasi-synchronous demand for power – much of the United

The use of solar power is not a new invention. As early as 1981, the 'Solar One' power station was built in Barstow, California. Its 1818 heliostats (reflector mirrors that follow the path of the sun) cover a total area of 51 hectares. In 1996, another 108 heliostats were added to enlarge the power station, which then had a peak electrical output of 10 MW.

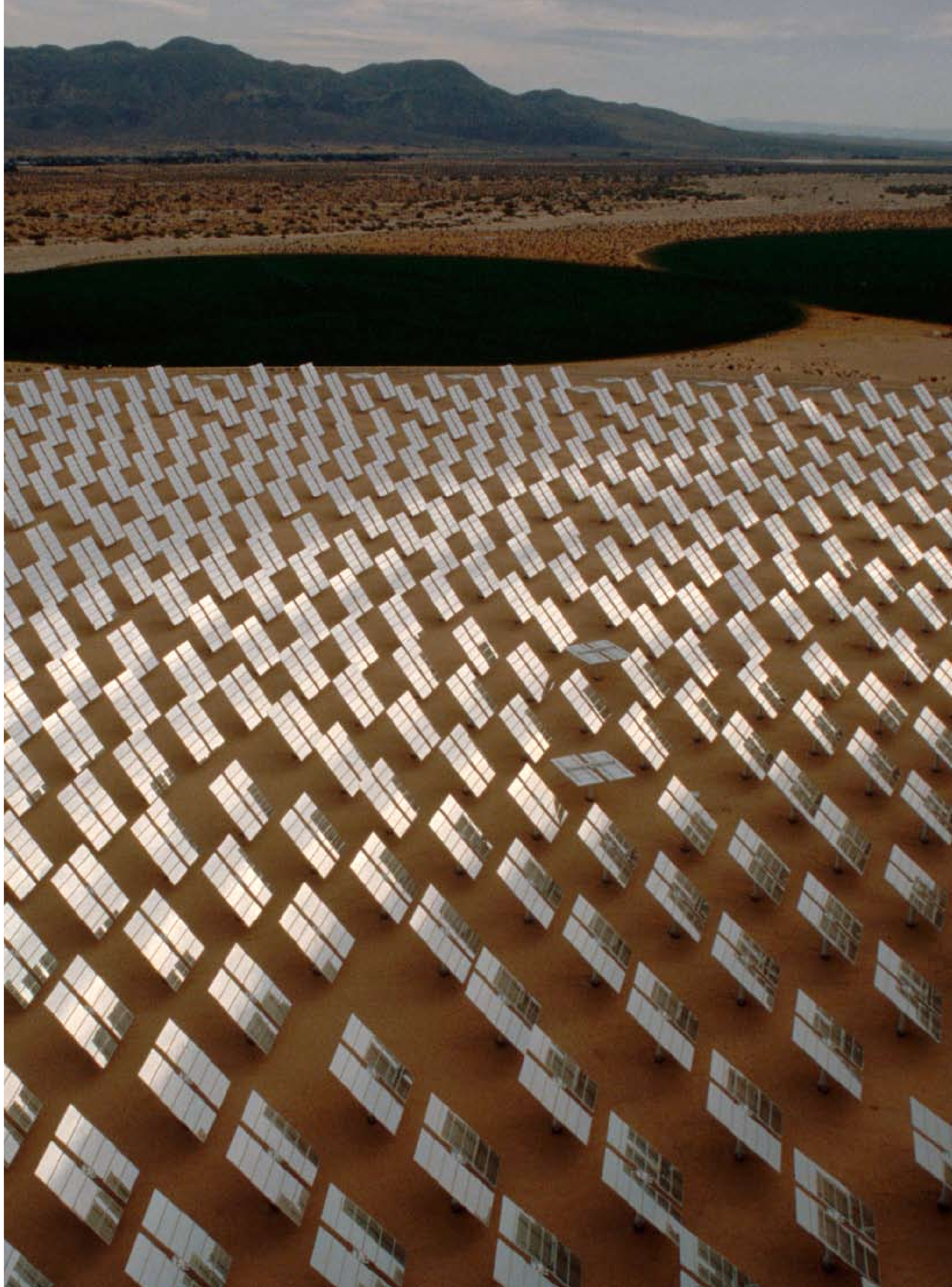

PHOTO: SCANPIX/CORBIS/BOB ROWAN

States constitute such a potential market where the peak electrical demand is driven by air conditioning demand, itself driven by the sun – as a case in point, the analysis of the massive 2004 power blackout in New York and Toronto showed that even a modest solar resource dispersed around the large cities of the northeast would have averted the heat-wave-driven outage at a small fraction of its cost[18]; and (3) given proper investment means, markets where no significant energy generation infrastructure yet exists and where solar energy could leapfrog conventional resources

### HOW MUCH WOULD IT COST?

Of course, switching overnight to solar would incur a seemingly impossibly large financial burden[19]. However, a fast-track growth and complete turnover within 50 years will be affordable, especially as both apparent and real costs of conventional energies escalate. The long term economic soundness of a solar future can be simply expressed in this one fundamental reality: all direct and indirect solar technologies have energy payback of 3–7 years today and are constantly improving, i.e., when operated under average conditions, these technologies will produce more energy in a few years than is used to construct and install them. With operational lifetimes far exceeding their energy pay-back period, these technologies are, in effect, energy breeders capable of powering themselves into growth. Energy payback is a fundamental physical measure of long term economic viability to societies investing in it. For a monetary translation of this physical reality, let's look at an example: an unsubsidised PV installation (i.e., considering the most expensive solar technology) in the north-eastern US (a region with a modest solar resource) valued against current wholesale electricity (i.e., not counting the external costs of fossil fuel depletion and environmental compliance). The financial return of such an unsubsidised installation in this conservative worse case scenario is of the order of 2–3%. While the real return is likely to be much higher when considering true costs beyond current wholesale costs, even this modest 2–3% return represents an attractive societal investment for the long term, considering that this is the most secure, stable and risk-free investment there could be.

### THE ROLE OF ARCHITECTURE

Because buildings represent a large part of the energy consumed by society (nearly 30% in the OECD countries), the role of architecture is fundamental. Buildings can best exploit conversion efficiencies and incorporate most end-use oriented solar application: heat, daylight, cooling, and all these solutions can be developed with creative and attractive designs.

In addition, building envelopes also constitute a primary harvesting surface for the universal solar energy generation technologies, particularly PV. Hence buildings have a fundamental role to play in the supply-side energy chain, not only as electricity generators, but also as active components in a decentralised renewable energy model, serving as load management and energy storage hubs and nodes.

Better than pursing the holy grail of individualised zero energy perfection for showcase buildings at all cost – highly possible in some situations, but difficult in others - it would be preferable to conceive buildings and places to live (big and small, modest and sophisticated) as fully participating in the dispersed energy generation/distribution model, operating as the nodes of a smart energy network, with appropriate controls for load management and storage operation, acting as energy hearts and relays/storage management in the most elegant way during normal operating conditions, but also capable of operating in low-demand emergency modes – i.e., staying alive during any type of power blackouts, or power crisis[20]

**Richard Perez** is Research Professor and Senior Research Associate at the SUNY Atmospheric Sciences Research Center in Albany, New York, USA. Since 1981, he has also been working as a consultant on energy, environment, economics and international matters. He has been an Associate Editor of the Solar Energy Journal since 1995 and published over 120 articles and reports in the fields of solar radiation, renewable energy applications and daylighting. Richard Perez started his academic career by studying electrotechnics and geophysics in Nice and Paris, before he went on to obtain his PhD in Atmospheric Science at the University of Albany in 1983.

**Acknowledgement:** Thanks to Marc Perez for sourcing the data presented in Table 1-3 and in Fig.1.

***Page 17, left top*** **Building envelopes constitute a primary harvesting surface for solar energy, both through solar heat and photovoltaics. Both technologies were combined in an exemplary way in the SOLTAG demo house, developed in 2005 by VELUX.**

***Page 17, left bottom*** **Each year, Denmark alone receives a total amount of energy from the sun that is equal to 1/3 of the total planetary energy consumption. The solar power station in Marstal on the island of Ærø (www.solarmarstal.dk) produces district heating on a large scale. Around 8,000 m² of solar collectors cover approximately 15 per cent of the community's heating requirements.**

***Page 17, right*** **Electricity directly from the roof to the laptop: The prototypes of the energy-independent 'Solar Decathlon' house in Washington (see page 7) made it possible. Each building had to use solar cells to generate the same amount of electricity as or more electricity than its occupants consumed during the same period of time.**

**TABLE 1: Primary energy consumption (TW–yr) and 1995–2005 growth trends for selected countries/regions of the world**

| | 1995 | 2005 | 1995–2005 growth (%) |
|---|---|---|---|
| World | 12.21 | 15.48 | 27% |
| USA | 3.05 | 3.37 | 10% |
| China | 1.17 | 2.24 | 93% |
| Europe | 2.57 | 2.89 | 12% |
| Eurasia | 1.42 | 1.53 | 8% |
| Asia & Oceania | 3.18 | 4.95 | 56% |
| Africa | 0.36 | 0.48 | 36% |
| South & Central America | 0.59 | 0.78 | 33% |
| North America | 3.64 | 4.08 | 12% |
| Middle East | 0.46 | 0.76 | 66% |

SOURCE: US ENERGY INFORMATION AGENCY (2005): INTERNATIONAL ENERGY ANNUAL REPORT

**TABLE 2: Primary energy consumption and projected growth trends for OECD and non–OECD countries**

| | Residential | | Commercial | | Industrial | | Transport | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | TW–yr | % total | TW–yr | % total | TW–yr | % total | TW–yr | % total | TW–yr |
| OECD 2005 | 1.29 | 16% | 0.83 | 10% | 3.18 | 40% | 2.72 | 34% | 8.02 |
| OECD 2030 | 1.58 | 16% | 1.20 | 12% | 3.78 | 37% | 3.59 | 35% | 10.14 |
| projected 05-30 growth | 22% | | 44% | | 19% | | 32% | | 27% |
| No OECD 2005 | 0.94 | 13% | 0.25 | 3% | 4.70 | 64% | 1.49 | 20% | 7.38 |
| No OECD 2030 | 1.72 | 13% | 0.67 | 5% | 8.13 | 60% | 3.01 | 22% | 13.54 |
| projected 05-30 growth | 83% | | 171% | | 73% | | 103% | | 84% |

SOURCE: US ENERGY INFORMATION AGENCY (2007): INTERNATIONAL ENERGY OUTLOOK

**TABLE 3: Primary energy consumption per source and 1995–2005 growth trends for OECD and non–OECD countries**

| | Petroleum | | Natural gas | | Coal | | Hydro | | Nuclear | | Other* | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TW–yr | % total | TW–yr | % total | TW–yr | % total | TW–yr | % total | TW–yr | % total | TTW–yr | % total | TW–yr |
| OECD 1995 | 3.01 | 42.6 | 1.49 | 21.1% | 1.37 | 19.5% | 0.44 | 6.3% | 0.68 | 9.7% | 0.06 | 0.9% | 7.05 |
| OECD 2005 | 3.32 | 41.4% | 1.80 | 22.4% | 1.59 | 19.8% | 0.42 | 5.2% | 0.78 | 9.7% | 0.12 | 1.4% | 8.02 |
| growth 1995–2005 | 10% | | 21% | | 16% | | -5% | | 14% | | 91% | | 14% |
| Non OECD 1995 | 1.76 | 34.6% | 1.22 | 24.1% | 1.59 | 31.3% | 0.40 | 7.9% | 0.10 | 1.9% | 0.01 | 0.2% | 5.08 |
| Non OECD 2005 | 2.34 | 31.8% | 1.80 | 24.4% | 2.51 | 34.1% | 0.55 | 7.4% | 0.14 | 1.9% | 0.03 | 0.4% | 7.38 |
| growth 1995–2005 | 33% | | 47% | | 58% | | 36% | | 47% | | 129% | | 45% |
| Total 1995 | 4.76 | 39.3% | 2.71 | 22.3% | 2.96 | 24.4% | 0.85 | 7.0% | 0.78 | 6.4% | 0.07 | 0.6% | 12.13 |
| Total 2005 | 5.67 | 36.8% | 3.60 | 23.4% | 4.10 | 26.6% | 0.97 | 6.3% | 0.92 | 6.0% | 0.14 | 0.9% | 15.40 |
| growth 1995–2005 | 19% | | 33% | | 39% | | 14% | | 18% | | 98% | | 27% |

SOURCE: US ENERGY INFORMATION AGENCY (2005): INTERNATIONAL ENERGY ANNUAL REPORT

* INCLUDES GEOTHERMAL, BIOMASS, WIND AND SOLAR

PHOTO: ADAM MØRK

PHOTO: MARSTAL FJERNVARME

PHOTO: TECHNISCHE UNIVERSITÄT DARMSTADT

NOTES

1. 70% of the solar world's solar hot water systems are installed in China, occupying a cumulative surface of over 20 million square meters today (i.e., equivalent to the peak power generation of 10 large nuclear power plants).
2. Wind is a by-product of solar energy – the energy from the sun heating the planet is the source of all winds blowing through the planet's atmosphere.
3. One exajoule = 1 billion billion joules or 277 billion kilowatt-hours.
4. One terawatt = 1 trillion Watts. The corresponding energy unit, one terawatt-year, equals 8.67 trillion kilowatt-hours.
5. McKinsey Report on Climate Change: Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost? http://www.mckinsey.com/clientservice/ccsi/
6. Passed in 1957 and renewed several times since, the Price-Anderson Act stipulates that the federal government is the insurer of last resort in case of catastrophic nuclear power accident – this was enacted because no commercial insurer was willing to assume risk liability.
7. Of course this argument would have to be revisited if nuclear fusion or breeder reactors were ever to be commercially developed.
8. The cost of uranium increased by a factor 10 (in US $) between 2002 and 2007 (Financial Time 7/27/07).
9. Gas well drilling activity vs. gas production trends – while until the early 2000s gas production had been highly correlated with the number of wells drilled, it now takes an increasing amount of drilling activity to maintain production - courtesy of Chuck Kutscher, National Renewable Energy Laboratory.
10. The conversion efficiency from the original solar energy that grew the biomass now stored in the form of fossil fuels amounts to less than 1/10th of 1 millionth percent.
11. The difference between the planet's deserts and northern Europe is often overstated: For instance, a photovoltaic collector installed in Copenhagen, Denmark, would generate 'only' 55% less energy than the same collector installed in the Sahara.
12. Today's conversion efficiency is already exceeding 20% for both PV and CSP.
13. Table 2 source: US Energy Information Agency (2007): International Energy Outlook
14. Electric vehicles (EVs) carry a substantial electrical storage capability that could be used interactively with the power grid to absorb or supply energy when not in use. This concept is known as PV-to-Grid.
15. In Europe: The Club of Rome's Trans-Mediterranean Renewable Energy Cooperation, http://www.desertec.org/concept.html and in the USA: K. Zweibel et al., January 2008, "The Solar Grand Plan," Scientific American, 298(1), 64-73, http://www.sciam.com/article.cfm?id=a-solar-grand-plan
16. E.g., see personal rapid transit concepts at http://www.personalrapidtransit.com/, or see ongoing deployment plans in Abu Dhabi at http://www.npr.org/templates/story/story.php?storyId=90042092
17. (wind installed cap approaching 100 GW and PV 10 solar thermal taking off fast)
18. Perez R., B. Collins, R. Margolis, T. Hoff, C. Herig J. Williams and S. Letendre, (2005) Solution to the Summer Blackouts – How dispersed solar power generating systems can help prevent the next major outage. Solar Today 19,4, July/August 2005 Issue, pp. 32-35.
19. As a quick order-of-magnitude check, installing overnight the 40 terawatts of the intermittent PV, CSP, and wind resource necessary to power the planet indefinitely after strong conservation measures could cost anywhere between 50 and 150 trillion US dollars using current technological costs – a huge number, but 'only' 2-3 times larger than the wealth currently held by the planet's top 0.15% richest people.
20. The 1998 Quebec ice storm resulted in thousands of homes and businesses having to abandon their buildings in the middle of winter, resulting in lost business and physical damage from frozen water lines. A study from the Northeast Sustainable Energy Association (NESEA) showed a solar powered critical load system of as little as 1 kW per residence would have carried most buildings through the storm without the need for evacuation.