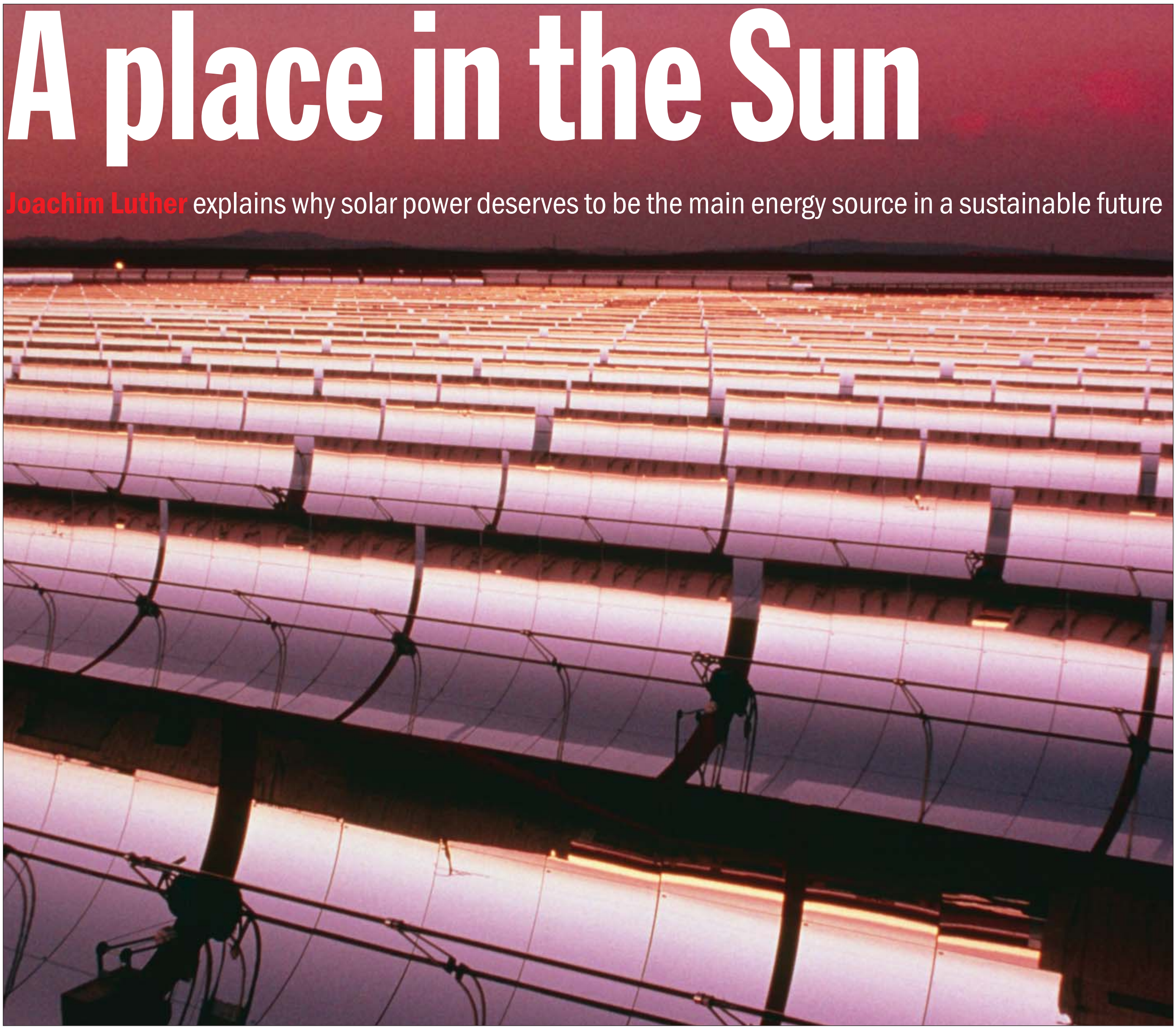
A place in the Sun

Joachim Luther explains why solar power deserves to be the main energy source in a sustainable future



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The dawn of the new century saw the beginning of a paradigm shift in energy policy: from fossil-fuel-based systems towards a sustainable energy supply. The basis for this transformation was laid by science over the last few decades. The man-made causes of global climate change – mainly the emission of greenhouse gases into the atmosphere – will very likely result in non-manageable worldwide disasters if today's methods of energy production are not changed fundamentally. However, we also know that the transformation of the current energy supply into a sustainable system is technologically and economically feasible.

Sustainability is an overused term that has almost lost its useful meaning. However, this concept, as defined by the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992, is a carefully worded and useful guide to the evolution of human civilization. According to the concept, decision-making and implementation processes should promote ecologically, economically and socially sustainable development, and should take into account the needs of future generations. A future-compliant energy system should mainly based on the efficient use of energy and the (sustainable) use of renewable energy sources.

As I see it, nuclear (fission) energy as it is applied today is not socially sustainable – not when the risk of weapon proliferation remains an unsolved problem. Furthermore, the problem of storing extremely long-term waste does not yet have a secure and reliable solution. The sustainability of the next generation of nuclear-fusion power plants is still largely unknown – in particular regarding the recycling of the radioactive containment vessel and the fuel cycle. In any case, such plants will not be available before middle of the century.

It is essential to apply the concept of sustainability without compromises to the use of renewable energy sources. Of course, this requires the careful consideration and evaluation of different ecological and socio-economic aspects. There are, for instance, problems related to land use – such as the competition between food production and energy farming – and issues regarding the use of hazardous materials in the manufacture of new technologies – such as the use of

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Every little counts
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cadmium, a toxic substance, in some thin-film solar-cell technologies (as an alternative to the silicon solar cells that make up more than 90% of today's solar-cell market). These, along with many other problems related to economic feasibility, biodiversity and recycling, have to be examined diligently.

However, such studies also show that renewable energy sources harbour a sufficiently high sustainable potential for the future (even if the global energy demand increases considerably). Wind power and modern biomass systems have a large but limited sustainable potential. Energy sources such as hydro power, geothermal power, ocean waves and ocean currents will also contribute to a sustainable energy-supply system. And, of course, we also have one source of energy that can be practically expanded without limit: solar energy.

Free for all

Solar energy has many advantages. It is available almost everywhere on Earth and it can be converted into electricity, heat and energy for transportation.

The average annual terrestrial solar irradiation varies by a factor of two or less between regions having a substantial human population. For example, the yearly difference in solar-energy input between Algiers and Hamburg is 1.8. In other words, assuming that the cost of solar electricity is inversely proportional to energy input (which is the case for solar cells but not for "solar-thermal" power plants that use mirrors to focus light onto a large volume of hot liquid), the cost of photovoltaic electricity varies less than 100% between these two cities. The annual variation of solar energy is, of course, a bigger issue at higher latitudes, where the amount of sunlight varies much more than in the equatorial regions.

Solar radiation is a highly dispersed form of energy with an average spatial energy density of 100–200 W m^{-2} in highly populated regions (in comparison, a coal fired power plant has approximately 10 000 W m^{-2}). Consequently, the harvesting of solar energy requires the use of large-area technologies. Fortunately, most solar technologies are highly modular. Thus they can be applied to building roofs and facades, and to canopies of parking areas. In many industrialized countries up to 50% of future energy demand could be harvested from areas that are already occupied by buildings and other infrastructure. The rest of the solar electricity input could come from ground-based systems.

Focus of attention
The PS10 solar-thermal plant near Seville in Spain.

Many deserts and semi-arid areas are also suitable for large-scale solar electricity generation. The technologies being applied are solar-thermal power plants and photovoltaics. Of these technologies, solar-thermal power plants have the advantage that thermal-energy storage systems can be integrated into the facilities, thereby enabling the generation of solar electricity generation even at night. The electricity can then be transported to industrialized areas via high-voltage DC transmission (in the future, high-temperature superconducting cables will be a potential alternative). Such projects are currently under investigation in Asia, South-East Asia/Australia and northern Africa/Europe. Of these, the most advanced is the DESERTEC industrial initiative, which plans to install a high-power electrical grid linking the Mediterranean countries and Central Europe. Large-scale solar-electricity plants placed in the arid areas of northern Africa will feed into this grid. This project could lead to an increased electrification of countries in north Africa and to a considerable solar-electricity export from these countries to Europe.

Solar technology

A variety of solar-energy conversion technologies are used to generate electricity, energy for heating and cooling systems, and to power transportation. Electricity is produced via photovoltaics (solar cells) and solar-thermal power plants. Heat energy is supplied by means of solar-thermal collectors (radiation absorbers that heat up fluids like water and even air). Air-conditioning (cooling) can also be powered by solar electricity; in the future, solar heat will be transformed into cold by means of novel thermodynamic processes. Solar-powered transport can be realized by the use of solar electricity stored in batteries or fuels derived from solar energy (e.g. hydrogen). Large-scale application of these solar technologies could cover the majority of our future energy demand.

Of all the technologies that convert renewable energy sources into technically useful energy, photovoltaics (PV) will be the most important. Photovoltaics can be applied almost everywhere on Earth; the technology is highly modular and uses no moving parts for energy conversion; and PV modules can be produced in an ecologically acceptable way. Some 90% of today's annual PV market (6000 MW in 2008) is based on silicon-wafer technologies. The technical lifetime of such photovoltaic installations is longer than 20 years and the energy pay-back time for PV systems in southern Europe is less than two years. During the last decade, the PV market had average growth rates exceeding 30% per year.

New photovoltaic technologies are now emerging. In particular thin-film technologies and concentrator photovoltaic systems (which use optical concentrators and multijunction solar cells based on III–V semiconductor materials, as used for solar cells on satellites). Furthermore, novel concepts of photovoltaic energy conversion are being investigated in laboratories and pilot industrial production lines, including organic cells and nano-structured solar cells.

Although the fuel for photovoltaic energy conversion is free, the efficiency of energy conversion of PV systems is of importance with respect to the economic viability of the installation and its space requirements (which is particularly important in densely populated regions). The overall efficiencies of current PV systems range from 5% (amorphous silicon) and 13% (wafer silicon) up to 23% (pilot installations using the optical concentration of sunlight). There is still much room for improvement.

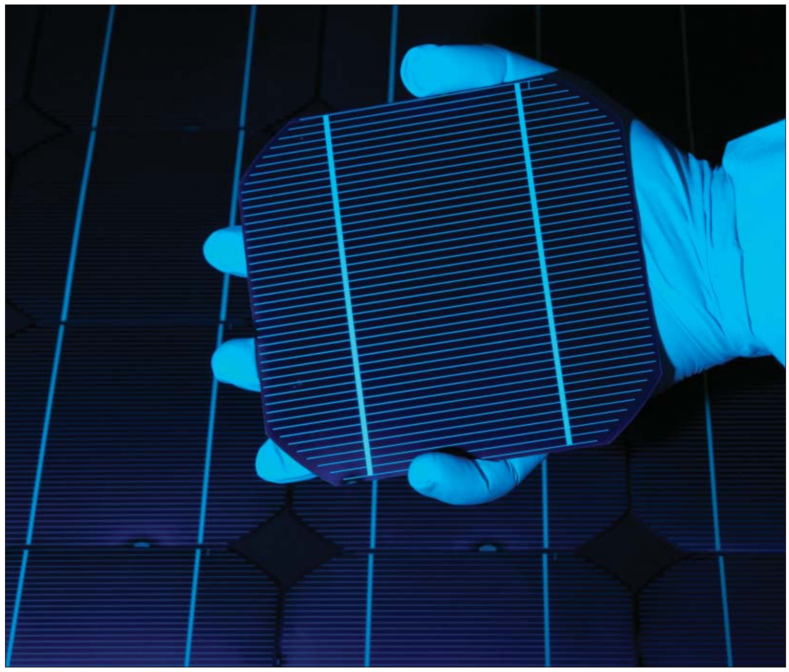
Saving costs

Photovoltaics are a proven and robust technology, but their main drawback is cost. In order to make them cheaper, reliable and steadily growing markets in combination with scientific research are of the utmost importance. For instance, some industrialized countries have embarked on a strategy to foster the PV market. A very successful example of this is the "feed-in tariff": when PV electricity is fed into the grid, a higher price is paid by the electricity utility to the PV system owner than the consumer has to pay the utility company. The difference in price between selling and buying is not subsidized by the government but is spread across all electricity consumers. The higher selling price under the feed-in tariff scheme is generally guaranteed over 20 years, which makes it easy to finance PV systems via bank credits. In order to place a time limit on this scheme, and to foster technological improvements, the feed-in tariff is reduced year on year. This has reduced the cost of PV electricity by almost one order of magnitude in the last decade.

The foreseeable further cost reduction should result in "grid parity" – when the cost of solar electricity is equal to the price of non-renewable electricity – for photovoltaic electricity in the next few years, for example in several southern European countries. Detailed analyses by the European Union's PV Technology Platform have shown that further cost reductions are feasible via higher efficiency in energy conversion, reduced material consumption, the application of low-cost materials, optimized manufacturing and, possibly, the introduction of novel concepts of photovoltaic energy conversion, such as nano-structured and organic (plastic) solar cells.

The efficient use of energy is an indispensable foundation for a sustainable global energy system. For instance, the application of solar-optimized windows, solar-thermal collectors, photovoltaic panels and excellent thermal insulation optimizes the energy-efficiency of the building envelope (roof and facades). Novel systems for heating, air-conditioning and, possibly, energy storage, will also lead to a further reduction in energy demand. Future buildings designed according to such concepts could have an external energy demand that is on average more than 10 times lower than that of buildings today.

In the sustainable energy system of the future, electricity will become by far the most important form of distributed and traded energy. The main reasons are the large reduction in external fuel demand of solar- and energy-efficient buildings, the increasing importance of electricity-powered transport and the massive contribution of solar and wind electricity.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Level pegging
Silicon-wafer solar cells are relatively efficient but are today still relatively expensive to make. The aim is for electricity from photovoltaics to be as cheap as that from non-renewable sources.

Such an electricity supply system will be based on the concepts of smart grids – which incorporate digital information technology to optimize distributed power generation, energy use and innovative energy-storage methods. Very large-area grids – covering one or more continents – will largely level out unpredictable variations in distributed power generation and, in part, the annual and seasonal variations in the supply of electricity from renewables. Furthermore, load management on the grid by smart technologies will largely match electricity supply and demand. Distributed energy storage in loads (for example storage in refrigerating systems) will facilitate load matching. Any remaining negative balance in the electricity supply system could be overcome by storing energy from renewable sources (for example in the form of hydrogen) and via the sustainable use of fossil fuels, since a limited amount of carbon-dioxide emissions from the production of electricity can be absorbed by the oceans.

Transforming today's energy system into a sustainability system will, of course, require substantial financial investments. For instance, a detailed study for the German government in 2003 showed that it will amount to approximately 2% of global GDP during this century. This is a huge investment but it is one that has to be made because the alternative – a non-sustainable energy system – will result in non-acceptable consequences (and considerably higher social costs).

The benefits of a sustainable energy system are obvious: protection of the natural life-support system; eradication of energy poverty in developing countries; promotion of peace by reducing the dependence on regionally concentrated energy resources; and increased security of energy supplies. Political will and a suitable global financing scheme are required to transform today's energy-supply system into a sustainable one. ■

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