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Publisher
Michael K. Rasmussen

VELUX Editorial team
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Re-write
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Art direction & design
Stockholm Design Lab ®
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Nina Granath
Björn Kusoffsky
www.stockholmdesignlab.se

Photography
Torben Eskerod and
Susanne Wellm
except images on p. 103-104, 107
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Website
www.velux.com/da

E-mail
da@velux.com

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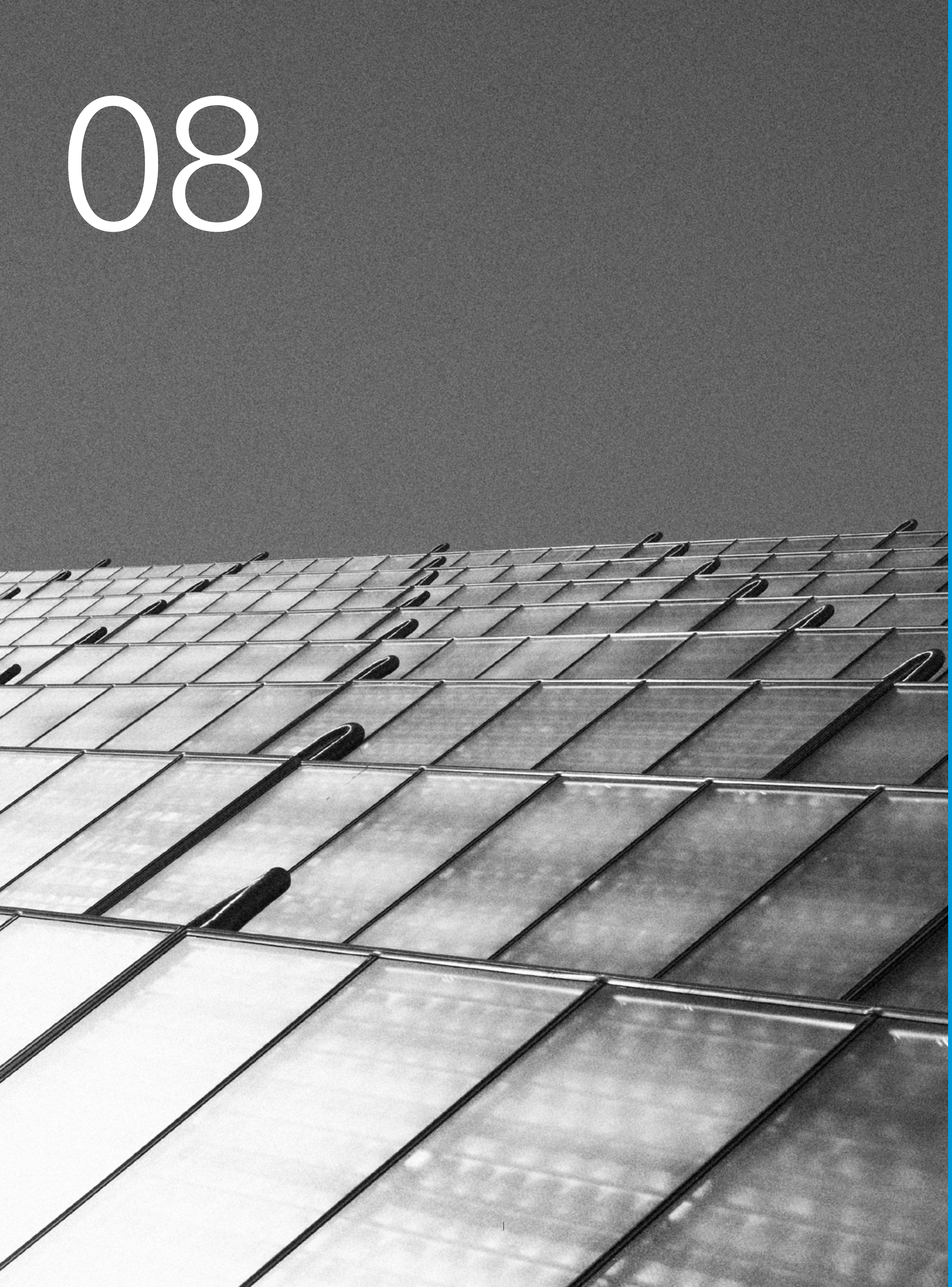


RENEWABLE ENERGIES
OUR SOLAR FUTURE

Every day, the Earth receives 1,500 times as much energy from the sun as mankind consumes. A fully solar-powered future of the world's cities is, therefore, by no means inconceivable. Efficiency measures and 'secondary' renewables such as wind and biomass will assist in the energy transition to come, but ultimately, the greatest promise lies in a combination of large-scale solar power plants and small-scale, building-integrated, solar energy uses.

By Richard Perez

WHY?

World energy consumption will have grown by another two thirds by 2050. At the same time, all energy reserves – except renewable energies – are limited; so is nuclear energy, which relies on the conversion of uranium. But climate change is providing the most powerful stimulus for restructuring our energy supplies; CO_2 emissions can be halved by 2050 only if the use of renewables is promoted alongside greater efficiency.

WHAT?

What are the renewable energies sources with a future? Wind power alone could cover mankind's needs, but its use is already approaching the limits in many countries. Biomass should be restricted to uses for which burning processes are essential. This leaves the sun as the main provider of energy; it gives the industrialised states alone 1,500 times more energy than mankind consumes at the moment.

HOW?

The question to be asked about solar energy provision is not whether supply should be centralised or decentralised; the two concepts have to be taken together if requirements are to be met. Energy provision will have to come from renewable sources, in the future even more than now. This means that the buildings we build or refurbish today must be based on a carbon-neutral energy supply from sources such as solar panels, and be provided with adequate storage facilities for heat and electricity.

At present, the total primary energy consumption of the world is of the order of 480 exajoules[1] per year, amounting to a constant power demand of 16 Terawatts[2]. 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. The US Energy Information Agency anticipates that worldwide demand will reach 23 Terawatts by 2030 and trend to 28 by 2050. Over three quarters of the growth is expected to take place in non-OECD countries, occurring primarily in commercial and transportation sectors.

Unfortunately such 'official' predictions by national and international agencies also anticipate that the bulk of this growth will be met by coal, with renewable energies playing only a side role. However, a fundamental look at the energy resources of the planet suggests that this business-as-usual outlook may be both short-sighted and unrealistic.

MEETING ENERGY DEMAND

There are two ways to meet worldwide energy demand and its 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 and avoiding unnecessary waste; in a few words: smarter, better and smaller. The McKinsey report on climate change[3] 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 1 shows the current contribution of different resources to the planet's supply-side needs.

RENEWABLE OR FINITE RESOURCES?

The figure on the opposite page compares the one-year potential supply of renewable resources against the finite reserves of conventional energies.

Fossil fuels: apart from their environmental impacts, Figure 1 suggests that the recent 'boom-bust' volatilities in oil and gas markets are early symptoms of their finiteness when demand begins to outstrip supply. As for coal, while reserves are vast, they are not infinite and would last at most a few generations if this became the predominant fuel, notwithstanding the environmental impact that will result from such exploitation if now elusive 'clean coal' technologies do not fully materialise.

Nuclear energy is not the global warming 'silver bullet' claimed by some. Reserves of uranium are large, but they are far from limitless. Setting aside all the long term environmental and proliferation unknowns associated with this resource, there would simply not be enough nuclear fuel to take over the role of fossil fuels – the rise in the cost of uranium that paralleled, and even exceeded, that of oil from 1997 to 2008 is symptomatic of this reality. Of course this statement would have to be revisited if an acceptable breeder technology or nuclear fusion became deployable. Nevertheless, short of fusion itself, even with the most speculative uranium reserves scenario and assuming deployment of advanced fast reactors and fuel recycling[5], the total finite nuclear potential would remain well below the one-year solar energy potential.

The solar resource: it is plainly evident that the magnitude of the solar resource dwarfs any other finite and renewable resources. 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[6], 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. Nothing could be further from reality: assuming a 30% solar-to-useable energy conversion rate (certainly achievable by 2050[7]), less than one half of one percent of the emerged continent's area would be sufficient to produce all the projected energy used by the planet. This is 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. Consider the city of New York, for instance, arguably one the densest energy demand hubs on the planet: together with smart demand-side operational efficiencies, New York City could certainly be solar self-sufficient electrically by 2050 using only 20% of its surface, i.e. the size of its current roof space.

Another interesting point of reference is to contrast solar generation area requirements with 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 country's electricity. By contrast, with 30% PV efficiency, under two tenths of that flooded space would be sufficient to produce all the electricity in the US.

Other renewables: how about wind power, hydropower, biomass/biofuels, marine currents, waves, ocean thermal energy conversion (OTEC), geothermal, and tides? First it is worth noting that, with the exception of tides and geothermal, all the renewable resources are second and third-order by-products of incoming solar energy – just as fossil fuels are by-products of solar energy stored in the earth over millions of years. These renewables are, indeed, concentrated forms of solar energy, which makes them more economical to exploit in the short run, especially hydropower. As such they will have an important role to play initially. However, as by-products, their potential is considerably smaller than that of the primary solar resources.

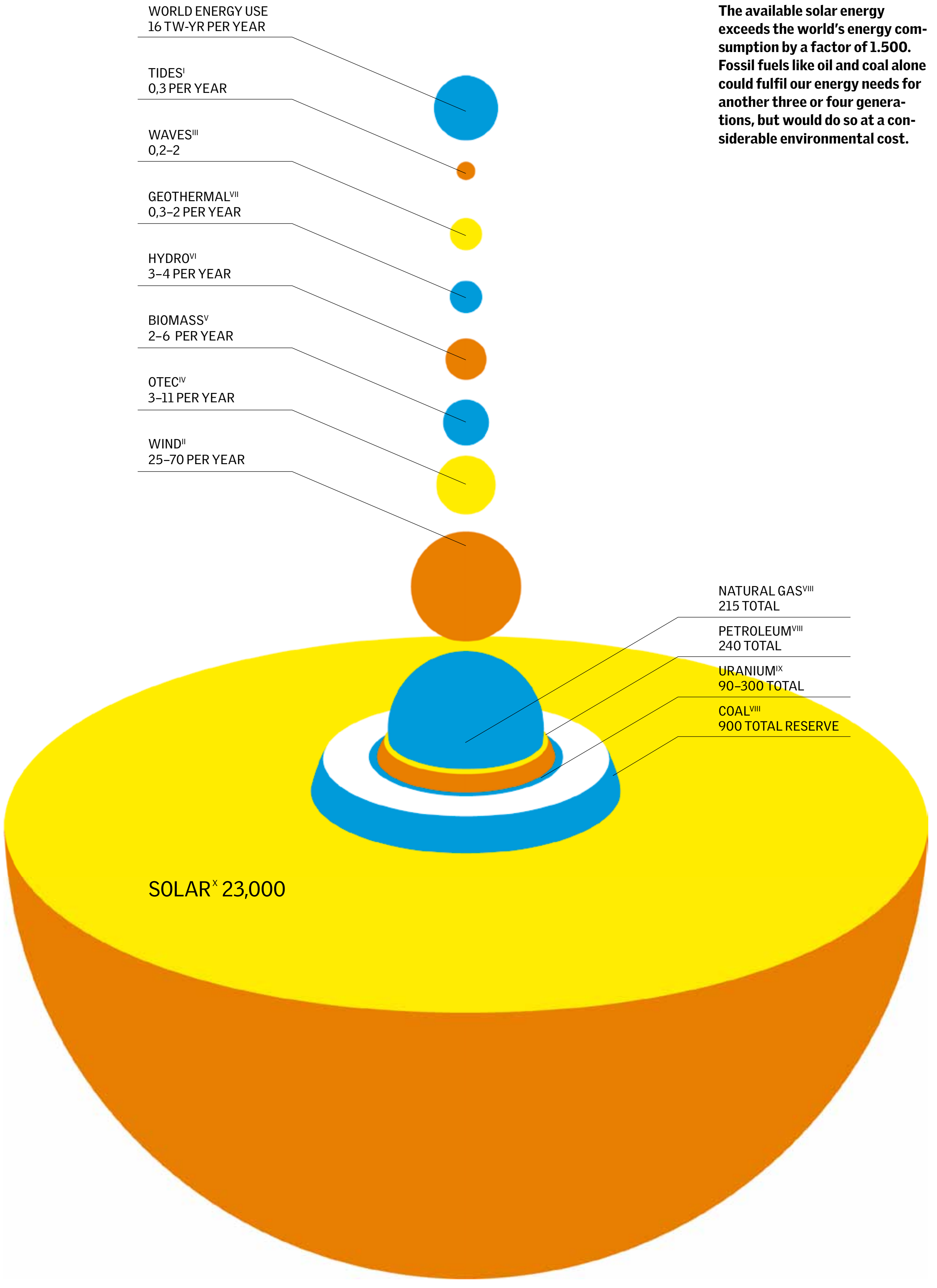
Wind energy could probably satisfy all of the planetary energy requirements with some room to grow if exploited to a substantial portion of its potential, but none of the other renewables, alone, could. The current explosive growth of the wind power industry – the largest installed incremental electricity generating capacity in 2008 in OECD countries – is certainly an expression of this potential and of the resource's current economic advantage over direct solar energy conversion. Hydropower is nearly maxed out in most OECD countries, with some good opportunities left in the rest of the world (e.g., the Mekong river in south-western China), but the environmental price of further developing this resource is not trivial. OTEC, marine currents, and tides also certainly offer promising localised economic opportunities. However, these resources are not scalable to levels that would satisfy planetary energy demand, while the environmental side effects of their massive exploitation could be far-reaching. Concerning biomass and biofuels, the rise in food cost that paralleled the 2008 rise in oil prices is symptomatic of the underlying reality that crops for energy, while certainly providing lucrative opportunities for some, cannot become a replacement to fossil fuels. Biofuels will certainly have a role to play, but will have to be reserved for those applications where high energy density liquid fuels will remain unavoidable for the foreseeable future such as air transportation.

A COMPREHENSIVE RENEWABLE ENERGY SOLUTION

While stressing that demand-side conservation and efficiency are an inherent part of any solution, a nearly 100% supply-side renewable 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 solar approach will first involve maximising the utilisation of the direct end-use solar applications which have the highest on-site solar-to-application efficiencies: hot water, daylight, passive heating and passive cooling where climate permits.

But the key will lie in electricity generation via any of the leading direct solar technologies – PV and concentrating solar power (CSP) – supplemented initially by indirect solar technologies (wind, smart bi-



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.

omass), and in the development of creative solutions and infrastructures to serve the energy, transform it, and store it as needed to meet all end-uses.

Infrastructure: two very distinct infrastructural models are envisageable:

1. Local, decentralised production of solar-derived electricity near points of utilisation – 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 largest renewable resources (solar and wind) 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 that will have to be developed will range from very short-term technologies (capacitors, flywheels, batteries, load-demand response) to mid-term (e.g. interactive electric/hybrid cars[8] 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. 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 in both Europe and in America[9] considering this type of solar energy deployment. The approach will necessitate the development of very high voltage, highly conductive 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.

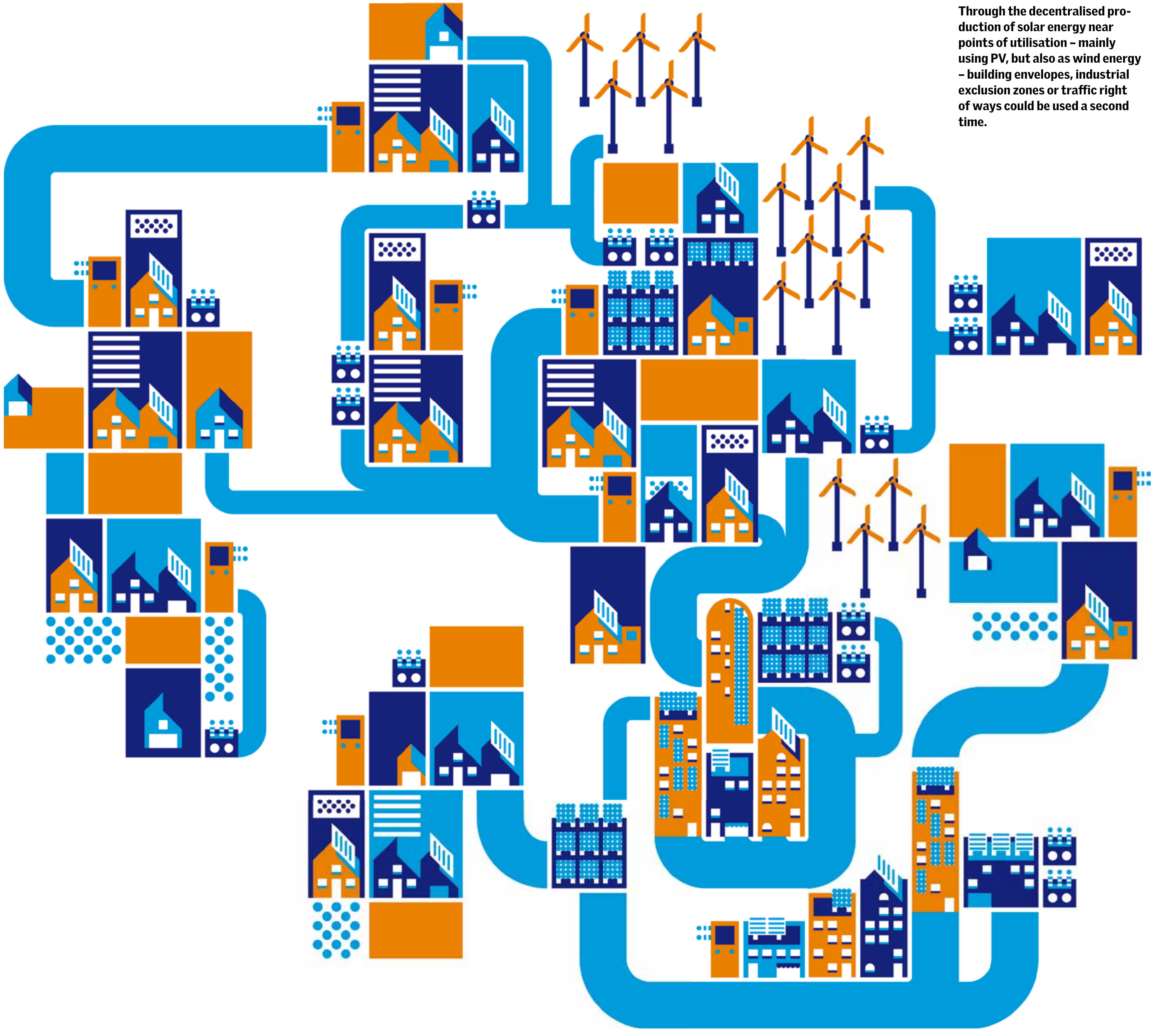
The future will likely be a combination of both fully decentralised systems and subcontinental-scale networks with centralised generators. The good thing is that the two approaches are not incompatible and could even be complementary. Large corporations and utilities will probably prefer centralised applications because of economy of scale and similarities with the current electric production/distribution system. In this scenario, wind energy – largely centralised, or semi-centralised by nature[10] – will play a major role initially. Ultimately, the decentralised systems should flourish and prevail as technology costs fall, and, more importantly, the value and resiliency of on-site generation can be fully captured. As discussed below, the costs of producing clean renewable energy and its value are still largely disconnected entities in the current business environment, although this question is already being addressed in some embryonic form via incentives such as feed-in tariff (FIT)[11] legislation proposals patterned after that of Germany, with highest value given to decentralised solar applications[12].

Serving all energy needs from renewables: because of the universal nature of electricity produced by direct and indirect solar technologies, the great majority of energy demand sectors will be adequately served, albeit with some adaptation/evolution. Transportation in particular currently relies on fossil liquid fuels. A shift to renewables will require particular attention but the task is not insurmountable: by 2050, ground transportation will have become largely electrical through increase of electric rail-based mass transportation, the advent of all-electric vehicles and plug-in hybrids – e.g. spearheaded by projects such as BetterPlaces[13] designed from the onset to exploit renewable energy – and new concepts such as Personal Transportation Networks[14]. 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. The so-called 'second generation' biomass should be reserved for the remaining applications that could not easily rely on electricity directly or indirectly, such as air transport and, to a lesser extent, water transport.

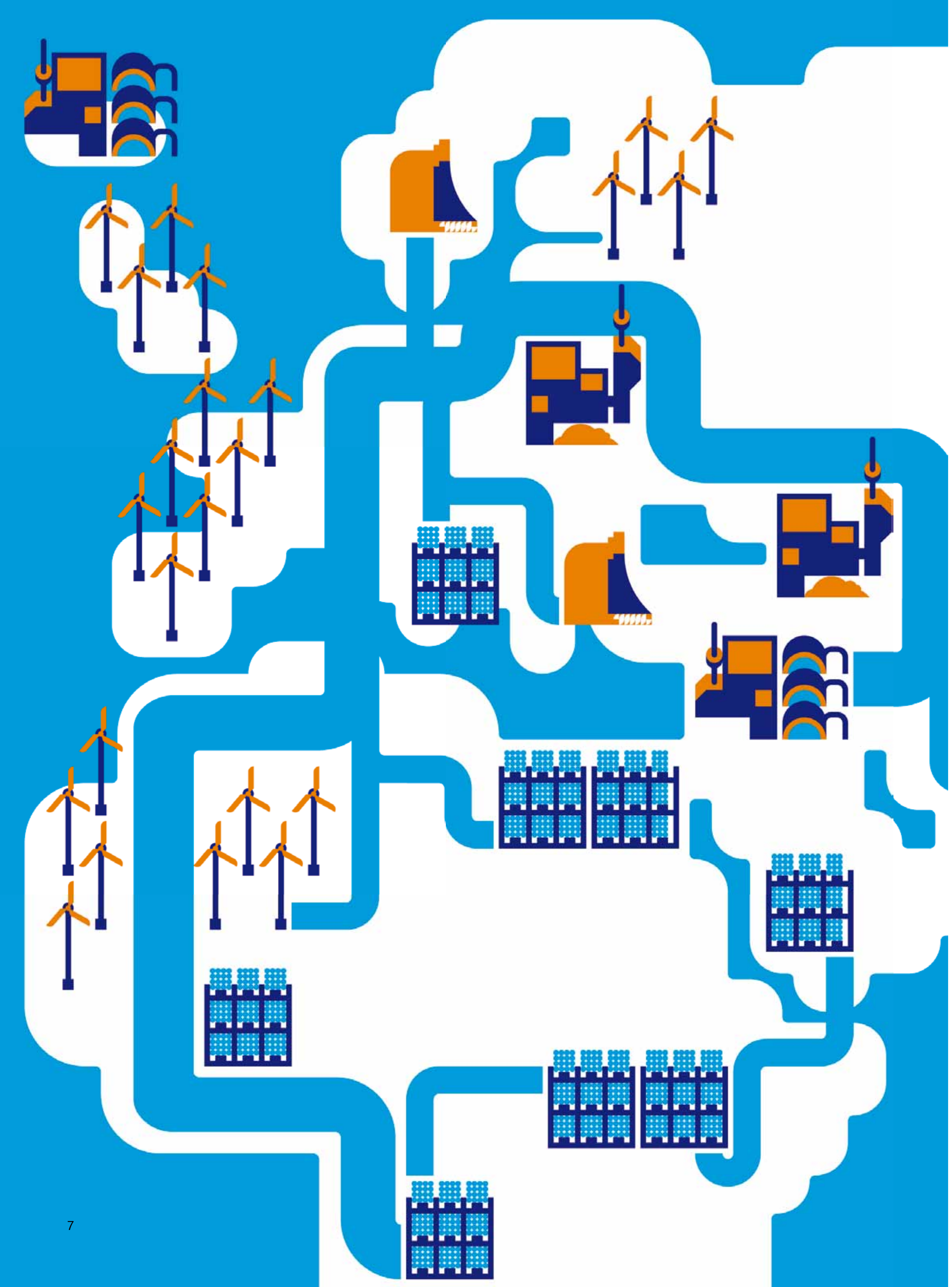
A reality-check check – the growth of the wind and solar industries: a quick look at the direct and indirect solar industries that are fast emerging throughout the world today indicates that the 'big-picture' renewable visions discussed in this article already have a strong head start. Considering the growth of PV, wind, and CSP alone over the last ten years[15] and projecting this growth rate in the future indicates that the majority of the new electric generating capacity installed in the world will come from renewable resources in less than 20 years. This growth rate may not 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 and switchover is not pie in the sky but a likelihood – and rapid change of awareness is taking place here and now. For a long time confined to visionary leaders such as Germany, Denmark or Japan, the drive for renewables that caught up in the rest of Europe is now gathering momentum in the United States, driven by a new administration. At the same time, China, which became the world's largest PV producer in 2008, edging Germany out of first place, has just adopted a major upward revision of its renewable energy deployment plans, including 100 GW of land-based wind generation by 2020.

HOW MUCH WILL IT COST?

Of course, switching overnight to direct/indirect solar would incur a seemingly impossibly large financial burden[16], a point often raised by detractors of renewable energies. 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. In the end, what will matter is the value proposition offered by solar and renewables, not the cost. If value exceeds cost, then there is no question that renewables will be the way to go, and many indicators point in that direction. The price we pay in our energy bills today simply does not include all the costs incurred by society: two major costs that are not yet included, as they should be, are the costs associated with the degradation of the environment (chiefly global warm-



Through the decentralised production of solar energy near points of utilisation – mainly using PV, but also as wind energy – building envelopes, industrial exclusion zones or traffic right of ways could be used a second time.



ing) and the depletion of finite energy resources[17]. Other un-incurred costs, more site-specific in nature, include power grid reliability and security, as well as the lost value opportunities of job creation[18] and economic growth associated with the advent of renewables. It is important to note that as societies, we are already paying for these un-incurred energy costs and lost opportunities one way or the other, but not yet via direct energy bills – through taxes, insurance premiums, military budgets, and by borrowing heavily from our descendants. Once the value proposition is fully integrated – and common sense says it will by 2050 – it will become evident that it is much less expensive to generate electricity directly or indirectly from the sun, even after including the storage/management technologies needed for their high penetration, than by using finite and polluting resources. At that point, the incentives used today to level the playing field, such as FITS, will no longer be needed.

In essence, 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 an energy payback of 3–5 years today and are constantly improving, i.e. when operated under average conditions these technologies 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 us look at a worst-case example: a totally unsubsidised PV installation (the most expensive solar technology today, likely to be 2–3 times cheaper in 20 years) in the north-eastern US (a region with a modest solar resource) valued against current wholesale electricity (a 'rock-bottom' number excluding all the grid support, fuel depletion, environment and business growth values mentioned above). The financial return of this conservative worst-case scenario is of the order of 2–3% per year, which still represents an attractive long-term societal investment, knowing that this is the most secure, stable, and risk-free investment there could be. The real return to society will, of course, be much higher.

HOW WILL CITIES LOOK IN 2050?

To the passing observer, cities will probably look very much as they do today. They will simply be much more electrified, both on the demand and supply sides. We will have shifted away from (fossil?) fuels, especially for transportation. Exhaust and noise levels will be considerably reduced, and so probably will congestion: a by-product of conservation associated with smarter (i.e. smaller) electric personal vehicles, the advent of exchange programmes like the Parisian vélib'; consider that even New York, home of the giant gas-guzzling yellow taxi cabs, will see its fleet turned over completely to hybrids by 2012.

Many buildings particularly in cities' suburbs will have become net energy producers from both higher operational efficiencies and use of available solar energy-harvesting surfaces, as well as energy management/storage hubs at the nodes of smart electrical grids. However, their appearance from the street need not change much from today's. Load management and storage facilities, required to manage the flow of renewables, will not be conspicuous, and could be embedded in the framework of residential, commercial and industrial districts. Just to give an idea of the sizes involved, picture a highly efficient, daylit, two-storey, two-apartment residential building with a footprint of 100 m^2 in northern Europe. Its roof space will produce more electrical energy than needed by the occupants for all uses, including commuting and transportation. The year-round energy storage needed to sustain a 100% combination of grid-interactive solar, wind and hydropower would be substantial but not inconceivable. Using a promising sustainable flow-battery technology, the physical size of the load management and storage facilities required for the above two-apartment building would be a two-metre cube that could be located just about anywhere on the smart power grid.

Richard Perez is a Research Professor at the SUNY Atmospheric Sciences Research Center in Albany, New York, and sits on the Advisory Board of the GW Solar Institute at GW University in Washington, DC, 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 on solar radiation, renewable energy applications and daylighting. In 2008, Richard Perez received the Villum Kann Rasmussen Foundation's Daylight & Building Component Award.

***Opposite page:* International supply networks for renewable energy in which every form of energy is used where it occurs in concentration are a practical addition to decentralised energy production. One organisation that is pursuing this kind of objective is the Desertec Foundation, which will bring solar-derived electricity from the Sahara to Central Europe.**

TABLE 1: Primary energy consumption per source and 1995–2005 growth trends for OECD and non–OECD countries[4]

	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