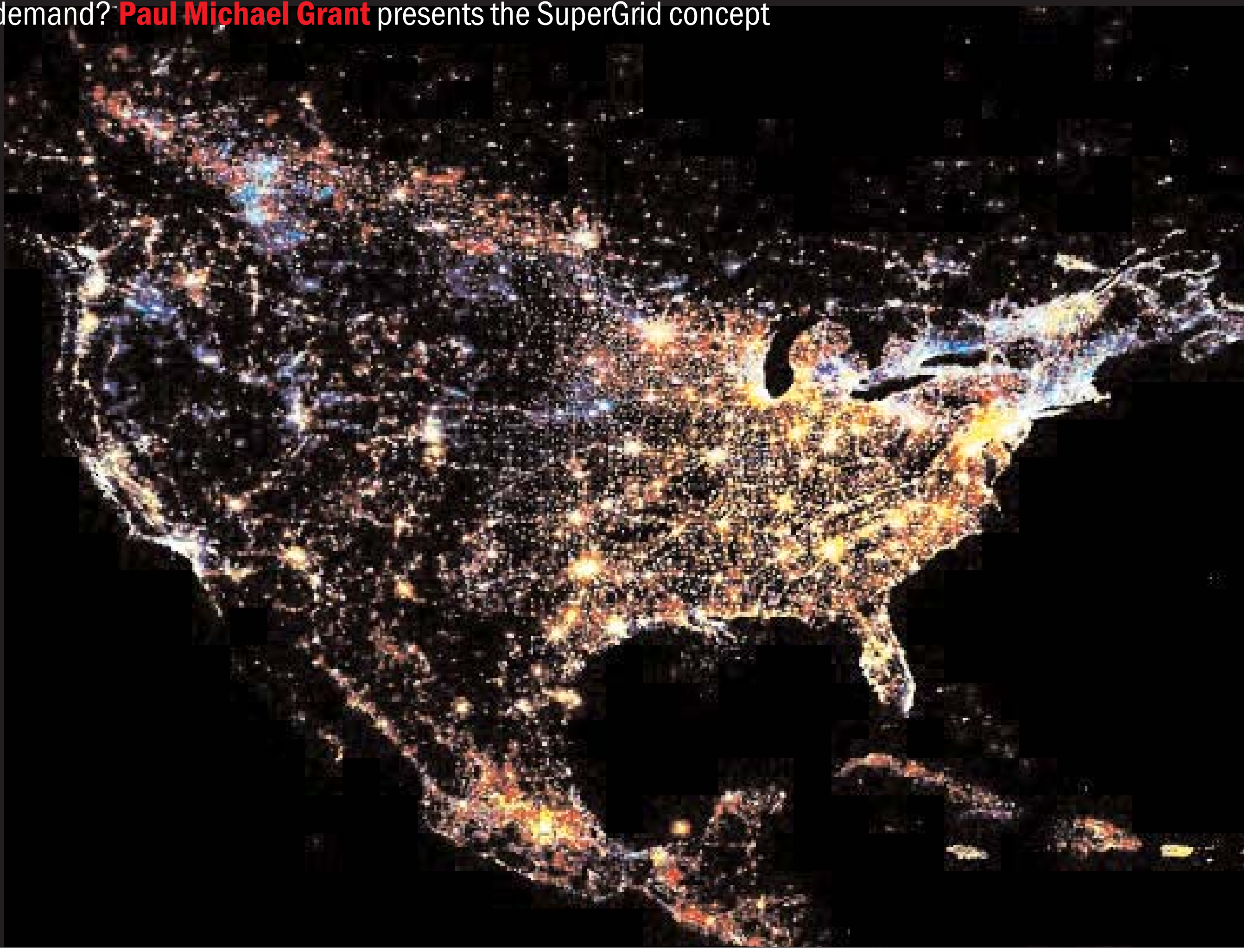
Extreme energy makeover

With the world's population expected to reach 10 billion by 2050, how will we cope with the energy demand? Paul Michael Grant presents the SuperGrid concept



According to a report by the US Department of Energy (DOE), world energy consumption is expected to grow from its present level of about 120 EWh (120×10^{18} watt-hours) per annum to well over 180 EWh by 2025, a rise of more than 50%. Moreover, many demographers predict that the world's population will approach 10 billion by mid-century, with global industrialization rates far outpacing those of the US. As the entire planet aspires to reach a Western standard of living, the DOE predicts that the current energy consumption rate, 63 EWh per year in the industrialized nations and 55 EWh in emerging countries, will evolve towards 80 EWh and 97 EWh, respectively.

How to supply and configure the energy economy and infrastructure for such a world is perhaps the principal long-term challenge facing civilization in the 21st century. A major component of the challenge will be attaining this energy goal in the most environmentally benign and least eco-invasive manner possible. To paraphrase the titles of several popular reality-TV programmes of recent years, an "extreme makeover" will be required. But whereas these entertainment productions addressed radically changing the physical appearance of people and houses, this article will consider what may be necessary to transform the world energy culture and economy to accommodate the challenge – in other words, how to effect an "extreme energy makeover".

A principal uncertainty in this social equation is how much further the Earth's remaining fossil fuel reserves can be exploited. The link between the observed increase in global temperature and concomitant increase in carbon-dioxide emissions (currently 6000 million tonnes of carbon emitted per year and expected to reach 10 000 by 2025) remains controversial, but all agree that it is physically plausible. The coming decades are likely to see an internationally agreed upon "no regrets" policy adopted that severely restricts the use of fossil fuels for both transportation and the production of thermal and electrical energy. It would be most wise for humanity not to oxidize every remaining atom

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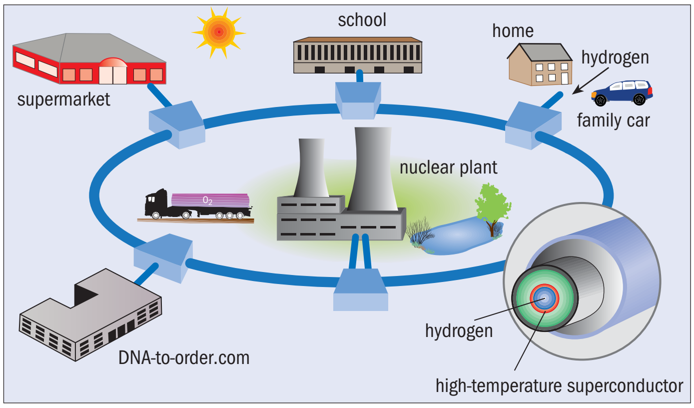

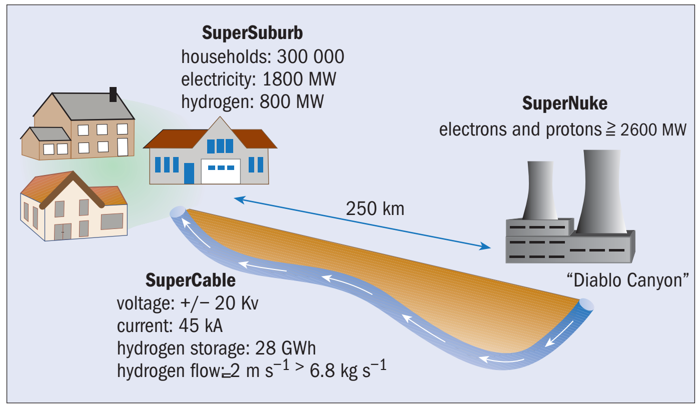

Superstars The figure above left depicts a light-industrial, commercial/residential complex powered by nuclear-generated "hydricity" delivered over a hydrogen-cooled SuperCable using high-temperature superconductivity wires. The "sun" represents the presence of photovoltaic roof panels as an adjunct power source, and the "pond" by the nuclear plant represents the processing of sewage and other organic waste. Note the hydrogen-powered truck transporting "waste" oxygen resulting from the electrolysis of water, which can be sold for commercial purposes or used to process or combust locally produced biowaste. DNA-to-order.com represents a hypothetical biotech firm of the future. Above right is conceptual depiction of the SuperSuburb and its baseline hydricity power supply and distribution to 300 000 end-users based the energy consumption of the author's family household and provided by a "SuperNuke" of the approximate capacity of the Diablo Canyon facility located on the California coast 250 km south of San Jose. On the opposite page is an example of a continental SuperGrid. This figure is simply illustrative, not literal. Various rearrangements can be imagined and visualized to accommodate US regional political interests.

of carbon in the Earth's crust.

One major harbinger of this trend is the effort currently under way globally to develop technologies to replace hydrocarbons with hydrogen as surface vehicular transportation fuel. In 2003 I estimated, as an example of the enormity of this challenge, that the production of sufficient quantities of hydrogen to replace the then-current annual consumption of petroleum in cars and trucks in the US alone, either by electrolysis or thermal splitting of water or methane, would require additional power production equivalent to roughly 420 GW, which is one-third of the nation's electricity generation capacity, currently about 1.3 TW (*Nature* **424** 419) . Given the massive amounts of carbon dioxide that would be need to be captured should this hydrogen be generated either directly or indirectly from fossil fuels, and given the enormous land areas needed for biomass, wind or solar required in its place, one is brought to the conclusion that only nuclear power can feasibly enable a complete hydrogen-transportation economy in developed and developing nations. An expansion of nuclear power for electricity and hydrogen production worldwide must be accompanied by the creation of a new international organization capable of ensuring, by armed force if necessary, that the actinide materials employed are not diverted, from mine to enrichment through reprocessing and breeding, for military purposes.

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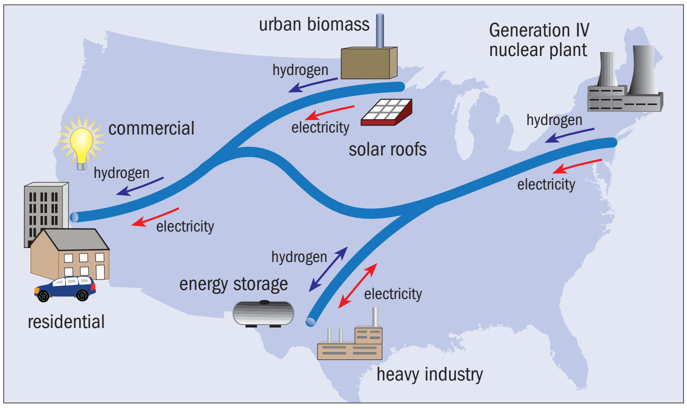
The SuperCity

I have a vision of an energy society based on a symbiosis of nuclear power generation of hydrogen and electricity, dubbed hydricity, distributed via a "SuperCable" employing high-temperature superconductors cooled by cryogenic hydrogen. The latter would also be used as an intrinsic power agent at the end delivery point in addition to electricity.

An urban embodiment is suggested in the form of a light-industrial, commercial/residential "SuperCity". The "boundary conditions", or ground rules, are that the technologies employed be carbonless and non-eco-invasive – that is, to impress as small a footprint as possible on the environment and ecology. This latter requirement makes massive-scale renewables, such as wind, solar and biomass, unecessary, but not industrial–commercial–residential solar photovoltaics on roofs, as one has to live and work somewhere and the land area deployed is thus available for dual use. Similarly, by necessity, community provision is needed for the disposal of both sewage and discarded food, which can subsequently be converted into methane to generate hydricity. I estimate that perhaps 85% of the energy requirements of SuperCity can be provided by nuclear-generated hydricity, abetted by an additional 15% from solar power and biowaste. Finally, all the technologies required for SuperCity already exist or are on the immediate horizon – no new breakthroughs or discoveries are needed.

In order to quantify the SuperCity concept, I undertook a detailed study of a "SuperSuburb" modelled using data that describe the energy consumption of a typical family home – mine – in a Silicon Valley residential community such as San Jose. The study takes into account individual residential electricity requirements for appliances, lighting, air conditioning and cooking, and hydrogen for the storage of electricity and personal transportation (50 000 km per year per family). Not included are community-support services such as shopping centres, electric rail rapid transport and street lighting.

In 2004 and 2005, I collaborated with Chauncey Starr from the Electric Power Research Institute and Thomas Overbye from the University of Illinois on an extension of the SuperCable concept to encompass an entire continent, essentially comprising a continental SuperGrid (2006 *Scientific American* July pp76–83). The figure on the opposite page shows how this concept might apply to the "lower 48" states of the US. However, similar scenarios can be constructed for China, India, South America, existing East–West European energy corridors and the Middle East – in particular Saudi Arabia, as that nation moves from oil to



nuclear and solar. Particularly interesting is Canada, where several gas-pipeline construction projects are already under consideration, principally the Mackenzie Valley Pipeline, which would run from the Arctic fields near Inuvik 1220 km south to Alberta and the US transporting 18 GW (thermal) of natural gas, planned to start construction in 2010, the energy equivalent to China's Three Gorges hydroelectric generation. When this gas crosses the US–Canada border, some 23% will be combusted to generate electricity. When the Delta gas fields are depleted, why not plan to construct a Generation IV nuclear plant on the site to generate hydricity that would be sent southward over a SuperCable to be laid in the same right of way already developed for the natural-gas pipeline?

A quixotic dream?

Are SuperCities, SuperSuburbs and SuperGrids, although in principle feasible with today's emerging technologies, merely quixotic dreams? As mentioned earlier, the various technologies required are already available. The eco-impact of transmission corridors would be about the same as a current oil or gas pipelines. Regarding cost, it is estimated that the 1220 km Mackenzie Valley Pipeline, including supporting pumping stations, will cost about $18 000m, to which would be added SuperCable materials and packaging, which I estimate to be approximately $6000m over an equivalent distance. The footprint required for hydricity generation by nuclear power is far less than for fossil fuels and especially renewables, but it is more expensive than the former. Estimates of the costs of future Generation IV plants run from $1400 per kW to $4000 per kW (for comparison, coal plants capitalize at $800 and natural gas at $450).

Having said this, it is important to point out that the energy economy, unlike most of the private sector, is driven by a multitude of factors in addition to technology. The next round of iGadgets will succeed in the marketplace only if they are smaller, run faster and cooler, cost less and create an addicted user community. Technology is, at best, only 50% of the energy equation, the remaining terms being driven by social and political policies together with public perception, which is often not guided by sound science (witness, for example, the irrational fear of electromagnetic fields emanating from overhead transmission lines). A thorough energy makeover must also find ways to address these other, non-technical factors. That will arguably be a far more difficult challenge. ■