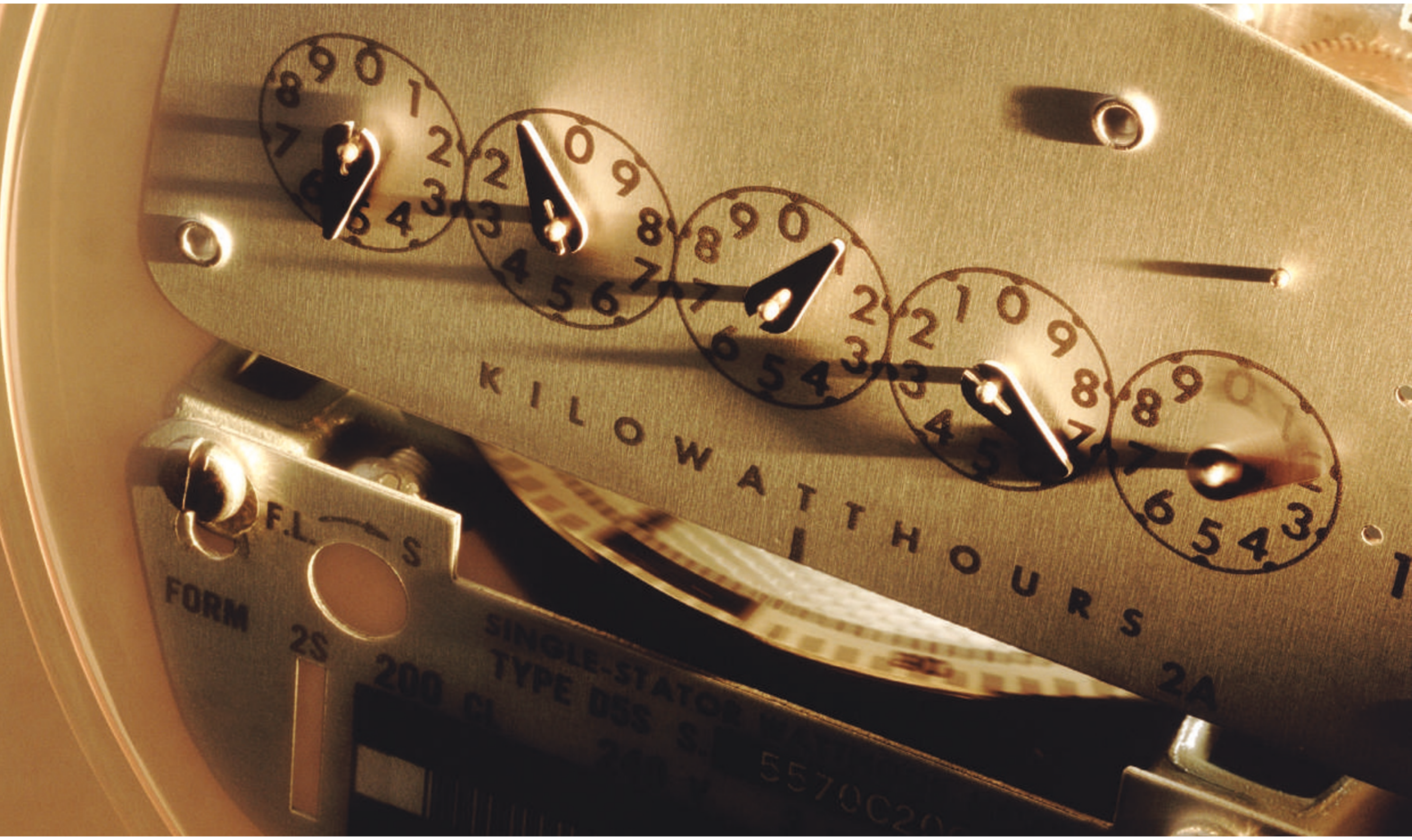
SUPER SAVERS

Energy efficiency is one of the least flashy but most promising ways to cut carbon dioxide emissions. In the first of two features, **Declan Butler** explores the energy-saving possibilities of an intelligent electrical grid. In the second, **Zoë Corbyn** looks at how labs can cut their energy use.



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Meters to manage the future

"Switch off the washing machine or dryer for the next 3 minutes, and let me buy, at 10 cents per kilowatt hour, 20% of your solar energy output." Such instant electronic transactions between electricity distributors and smart electric meters in millions of homes and businesses are set to add some badly needed intelligence to the electricity grid, bringing greater efficiency and reliability.

Ways that humanity can adapt their use of energy to the realities of global warming tend to focus either on supply — renewable technologies such as solar power — or demand, personal abstinence of various sorts. But there is untapped potential in the space between supply and demand — the mundane world of energy distribution. Making the electrical grid more efficient would offer benefits on the demand side, by helping users to consume less energy, and in terms of supply, by providing better ways to handle the intermittent and distributed nature of alternative energy sources.

The humble electric meter might seem an unlikely place to start a revolution. But today's centralized grid, which has electricity fanning out from a few large generators across transmission lines to end users, is mostly dumb. Utility companies have detailed data on events at the power plant or on their transmission line, but once the electricity radiates out to the community they have no idea where it goes, let alone how to manage it.

Smart meters change that by providing data on what is happening in every corner of the grid at any instant. Utilities in Europe and the United States are rolling out millions of meters that send real-time data on the electricity use of individual homes and businesses via the Internet, or along the electricity supply. In turn, these meters can receive real-time data on grid conditions, load and pricing.

The meters are a stepping stone to smart grids, which would provide a modern, distributed network of computing and telecommunications — a dynamic 'energy Internet'. And just as the Internet triggered an explosion of innovative technologies and services, not least the Web, new and more efficient electricity services will flow from smart grids.

"Smart meters are the harbinger of the future," says Steven Hauser, vice-president of strategy at GridPoint, the first company to sell such energy management systems direct to

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consumers. "They are the breakthrough that has helped utilities understand that you can see what's happening on the network right down to the customer level," he says.

Enel, an Italian electricity company based in Rome, is the world's biggest user of smart meters. It has installed more than 30 million meters since 2001, mostly to improve billing. In the United States, the world's largest consumer of electricity, California is one of many states following suit. By 2011, Pacific Gas & Electric, which serves northern and central California, will have supplied its 9.3 million customers with smart meters, and Southern California Edison is rolling out 5 million.

The latest meters are built to meet smart grid standards designed to ensure that all networks and devices speak the same language — the grid equivalents of the data-transfer protocols that made the Internet possible. The standards are being driven by a swarm of research efforts, including the US Department of Energy's (DoE) GridWise programme, and the European Union's SmartGrid initiative.

On the supply side of the efficiency ledger, smarter devices and richer data will facilitate the development of sophisticated energy-management software. A smart grid can accommodate a greater diversity of fuel supplies and, in particular, intermittent energy sources, such as wind and the Sun, says Kevin Kolevar, director of the DoE's Office of Electricity and Energy Assurance.

"Smart meters are the harbinger of the future."
— Steven Hauser

A centralized grid is inefficient and costly. Only a third of the fuel energy burnt in power plants ends up as electricity, with half lost as waste heat, and a further 8% lost along long-distance transmission lines. Moreover, 20% of generating capacity exists only to meet peak demand, so it runs just 5% of the time and provides just 1% of supply. The grid is often congested because it relies on a few high-traffic arteries. The congestion amplifies the inefficiency because if the utility cannot redirect power from efficient sources, they have to turn to costlier, dirtier and more inefficient sources to meet peak demand.

A more distributed grid, by its very architecture, can improve efficiency by matching local supply with demand. With multiple decentralized energy sources, electricity can be generated close to the point of use, avoiding the losses and congestion that result from long-distance transmission. Some of the most efficient energy sources are small turbines powered by natural gas, or biogas, which use waste heat to provide heat and hot water to the local area, and convert energy with 70–85% efficiency.

The world leader in decentralized power, Denmark, now generates half its electricity through decentralized grids, with combined heat and power accounting for 80% of local-area heating, and wind power about 20% of all electricity. As a result, its carbon dioxide emissions have tumbled from 937 grams per kilowatt hour in 1990, to 517 grams per kilowatt hour in 2005. Denmark began its push towards decentralization two decades ago, before smart-grid technology was available, relying mostly on tough regulations to force the change.

The key to Denmark's success was standing up to the utility companies, says Henrik Lund, an expert in energy systems at Aalborg University. For instance, the government required that energy companies buy back electricity from consumers at 85% of the price. Lund recalls being told by the utilities in the 1980s that it was not technically possible for more than 10% of electricity to be provided by wind power. The country wouldn't be where it is now, he says, if they had taken statements from the utility companies as fact.

This is an important lesson for the smart-grid movement. Although the infrastructure for intelligent grids is falling into place, overcoming institutional and market barriers remains a major issue, says Kolevar. "Many utilities have a disincentive to push distributed generation, as generally it is the customers who are the biggest beneficiaries, with the utilities seeing lower sales."

Resistance to distributed generation can be seen in the development of 'net-metering' laws, which oblige US utilities to allow consumers to sell energy back to the grid. Forty states have implemented such laws, but by 2004, just 15,200 US customers were taking advantage of the rules, 13,000 of whom were in California, according to the Network for New Energy Choices, a New York-based advocacy group.

In a survey the group published in November, the fingerprints of utility companies were found in nearly all the state laws. Indiana forbids commercial and industrial companies from taking part, for example, whereas Arkansas pays such poor rates for consumer-generated electricity that only three customers have participated since its launch in 2001. California emerged among the best, but even here the state has capped solar-energy generation at 2.5% of utilities' peak demand, arguing that it needs to assess its impact on the grid.

But the regulatory environment continues to change. The 2005 Energy Act requires that all federal buildings be equipped with two-way metering and energy-management systems by 2012, creating a huge potential market. Eventually, all states will be expected to offer net-metering and time-based pricing. And with the traditional grid straining under peak load, utility companies are waking up to distributed generation and storage as being vital to meet future demand, says Kolevar.

Companies are also emerging to exploit the new regulations. GridPoint's device, for example, can manage a residential solar panel or windmill, store generated energy in a battery that holds 12 kilowatt hours of electricity,

Plug in, turn on...sell out

"Forget hydrogen, forget hydrogen, forget hydrogen." James Woolsey, a former CIA director, reckons that there's a faster and cheaper way to solve America's energy problem — plug-in electric cars, acting as a massive distributed battery for the electricity grid.

K. KENNELL/ZUMA PRESS/NEWSCOM

Woolsey, founder of Set America Free, an organization based in Washington DC that advocates the reduction of US dependence on oil, was speaking in January 2006 at the launch of Plug-In Partners, an advocacy group led by the city of Austin, Texas. Its members have already pledged to buy almost 10,000 cars for municipal fleets.

The idea is to replace millions of gas guzzlers with electric vehicles that are powered by off-peak mains electricity. Millions of vehicles could be charged without building any new power stations, as existing plants rarely run at full capacity. Part of the stored energy could then be sold back to the grid at periods of peak demand.

Integrating vehicles and the electricity grid, the two largest consumers of energy, makes a lot of sense, according to a study published last month by the Pacific Northwest National Laboratory. It concluded that the existing grid capacity could power 217 million light-duty vehicles (three-quarters of the light-duty fleet).

Moreover, because the light-duty vehicles consume 97% of the petrol supply, switching to plug-in hybrid electric vehicles (PHEVs) could save 6.5 million barrels of oil a day — or half of US imports. The scheme would require running power plants at higher constant levels, but because they are more efficient than car engines, the net balance would be a 27% reduction in greenhouse-gas emissions.

PHEVs are similar to today's electric car, but they have bigger and more expensive batteries to cover average daily driving needs (53 kilometres), with a fuel engine kicking in for longer trips. Assuming that PHEVs would cost US$6,000 to $10,000 more than a regular car, the study estimated a user would recover the investment in 5–8 years. Those economics would improve further once batteries could be mass produced, says Steven Letendre, an expert in vehicle-to-grid economics at Green Mountain College in Vermont.

The snag is that for now, very few PHEVs are available. Only one small company, AC Propulsion in California, currently makes them, although General Motors, Toyota and DaimlerChrysler, are working on prototypes. "The real key to making PHEVs work is the vehicle — they must be attractive in terms of performance and cost to the US consumer — or the high penetrations we studied will not come to pass," says Robert Pratt, one of the authors of the study. A 24 January executive order by US President George W. Bush may give PHEVs a federal boost, by requiring US agencies to adopt them as soon as their life-cycle costs become comparable to those of gas-fuelled vehicles.

Without such incentives, or with continued hikes in oil prices, Pratt reckons that it could take 20 years before PHEVs make a serious dent in the US vehicle fleet. Woolsey thinks that they still make much more sense than the hydrogen economy, which requires changing the entire energy and transport structure. By comparison, he said, PHEVs demand "a bigger battery, and yes, an infrastructure investment: an extension cord. Every family would need an extension cord." **D.B.**

and then buy and sell to the grid depending on price. The battery also provides 8–12 hours of backup supply for a typical home.

The units contain no one technological breakthrough, admits Hauser, but instead pull existing devices together into a single box and add clever software. The climate is now ripe for such units, he says, owing to increasingly friendly legislation. Gridpoint units are not cheap, ranging from $6,000 to $16,000, but buyers will benefit from a 30% income tax credit on the purchase price through the 2005 Energy Act (with a $2,000 cap for residential customers), and could shave 10–15% off their electricity bills.

"Many utilities have a disincentive to push distributed generation."
— Kevin Kolevar

With appropriate regulation, real-time pricing should increase the competitiveness of renewable energies and of storage because local producers could sell power when prices are highest during peak demand and purchase it at the lower rates during off-peak periods. The overall effect would be to flatten out the load and price curve, and shave demand at peak hours, says Kolevar. The extra capacity offered by a distributed market should also mean that fewer of the inefficient central generators would need to be built.

Capacity demands can also be buffered by energy storage systems. A suite of distributed storage technologies are available, including fuel cells, flywheels, superconducting magnetic energy storage and advanced batteries, but they have never been used or tested on a large scale. Smart grids should change the economics in their favour.

Electricity storage is another area in which GridPoint is trying to turn theory into practice. It has signed a deal with the power company Cogentrix, headquartered in North Carolina, and is in discussion with others to test thousands of its units as a backup supply to ease demand on the grid at peak periods.

Even the idea of using plug-in hybrid vehicles as distributed energy storage is now being taken seriously, says Kolevar (see 'Plug in, turn on...sell out'). It was previously considered a research area, but Kolevar sees real interest in the idea, adding that what is now needed is a "large and definitive" demonstration project .

Another hoped-for result of real-time pricing is that homeowners and businesses will reduce their energy consumption. Typical wholesale electricity prices vary wildly, even over the course of a day, but consumers are usually charged a flat rate calculated as an average estimate over months. Smart meters can, however, make decisions that are based on real-time pricing information and the user's preset choices, such as to turn down the air conditioning if the price goes above a certain level.

Market research says that introducing such price information will encourage consumers to use less electricity overall, not just at peak periods, although these ideas still need to be tested in the marketplace. The Pacific Northwest National Laboratory in Richland, Washington, is testing a GridWise system to send real-time pricing via the Internet every 5 minutes to 200 homes on Washington's Olympic Peninsula. Heating and use of other appliances is adjusted automatically according to the pricing and usage preferences set by the users. Although the results are not yet in, preliminary data show that customers have responded well to the system and are highly responsive to the price, with consumption falling by more than 10% at peak times, says Donald Hammerstrom, a project manager for GridWise at the Pacific Northwest National Laboratory.

Experiments like this would have been unthinkable a few years ago, when an infrastructure for grid data and communications did not exist, says Hauser. With intelligent grids now emerging, the stage is set for a wave of innovation that will generate, store and manage electricity more efficiently, resulting in energy production and consumption that are less polluting and more cost-effective. ■

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