L.E.K.

SPECIAL REPORT

THE FUTURE OF ENERGY

JASON ALDEN

This report grew out of various projects that L.E.K. Consulting has recently undertaken for participants in the energy value chain. Our clients turned to us for help in deepening their understanding of several key trends within the energy sector, so that they could refine their strategy with these opportunities and challenges in mind. It soon became clear that we were unusually well-positioned to analyse these trends: in the last decade alone, L.E.K. has conducted over 700 energy-related projects. These have involved every imaginable sub-sector, including oil and gas exploration, production and services; processing and energy-related equipment; nuclear energy; smart grid infrastructure; wind, solar, biomass and hydropower.

This wide-ranging involvement in the energy sector has clarified for us just how rapidly it's changing, and how dramatically these changes will affect companies in diverse fields — from industrial giants to utilities to providers of energy equipment and services. In the pages that follow, we look at ten of the most important energy trends that companies need to examine. For example, the recent geopolitical crisis in Ukraine has reignited worries about energy security. We're also undergoing epochal changes in technology, which will transform electricity grids, energy storage, the availability of natural gas, and the competitiveness of renewables. Meanwhile, China and India are becoming not just huge consumers, but leading producers of energy.

This report isn't intended to be the final word on these and other energy trends, but to spark further discussion. The report draws heavily on the expertise of three consultants in L.E.K.'s global energy team — Florian Funke, Clare Chatfield and Karin von Kienlin — who embody our rigorous analytical approach to solving problems and identifying opportunities in this sector. Here, they help to highlight the issues that will define the future of energy.

John Goddard
Senior Partner and
Head of L.E.K. Consulting Europe

The Future of Energy

THESE TEN TRENDS WILL TRANSFORM THE ENERGY WORLD, ALTERING THE WAY WE PRODUCE, DISTRIBUTE AND CONSUME EVERYTHING FROM FOSSIL FUELS TO RENEWABLES

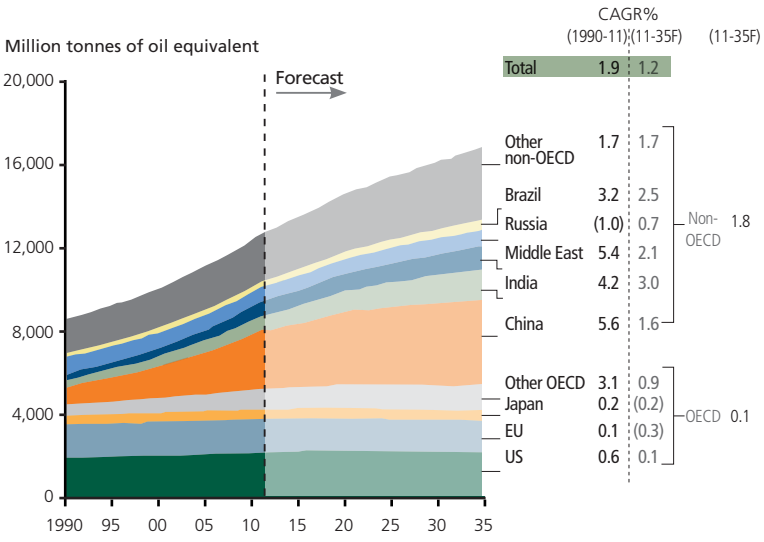
1 Energy Demand Will Shift Inexorably To The Developing World

By 2035, the International Energy Agency expects China to consume about 80% more energy than the United States. That's an extraordinary indication of just how dramatically the patterns of global energy consumption are changing. Indeed, the IEA predicts that at least 90% of the world's growth in energy demand will come from non-OECD countries over the next two decades. Initially, China will be the main driver of this growth, but India is expected to assume the lead around 2025. At the same time, we will also see rising energy demand from other non-OECD countries such as Brazil, Indonesia, Thailand, Saudi Arabia, Egypt, South Africa and Nigeria.

What we are witnessing here is a seismic shift in the way the world consumes energy. Gone are the days when OECD countries such as the U.S., Germany and Japan were the main drivers of global energy growth. As the graphic on this page shows, demand for energy in Japan and the European Union is actually forecast to contract between 2011 and 2035. By contrast, visit any of the booming metropolises of Asia and you can see with your own eyes the powerful forces driving this economic megatrend. These include rapid growth in GDP per capita, massive urbanisation, a population boom, and rising personal incomes.

One of the most powerful forces fuelling this shift in energy demand to the developing world is the relentless rise of the megacity. Today, 28 cities have a population of over 10 million, up from just two cities 30 years ago. By 2025, there will be as many as 37 cities with 10 million inhabitants, and 22 of these will be in Asia. These megacities will require enormous quantitites of energy for new office towers, malls, public transportation systems, desalination plants, and countless other forms of development.

Primary energy demand by region in the IEA base scenario* (1990-35F)



Note: *The IEA New Policy Scenario is IEA's base scenario that assumes all policy commitments and those recently announced are implemented albeit in a cautious manner
Source: IEA World Economic Outlook (November 2013)

Chinese cities such as Shanghai need vast supplies of energy

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Meanwhile, as personal incomes rise across the developing world, so too will demand for cars and residential conveniences such as air conditioners and washing machines. Increasingly, electricity will provide the energy for residential consumption, replacing wood, waste and other non-marketed energy sources.

To meet all of this additional demand, the developing world will require vast investments in energy-related infrastructure. Major industrial engineering companies from the developed world will play a pivotal role. Western companies have had some success in the oil and gas sector. However, Western suppliers in the power generation sector are increasingly being replaced by Asian equipment manufacturers and engineering, procurement and construction contractors. Despite the intense competition, more and more companies will focus their attention on these buoyant markets, compensating for the less-thrilling growth prospects of the developed world.

2 Coal And Oil Face A Mounting Threat From Natural Gas And Renewables

Rumours of the death of fossil fuels have been greatly exaggerated. Coal is still the world's most widely-used source of energy, accounting for more than 40% of global power generation. As for oil, it still accounts for almost a third of the world's energy consumption.

But the dominance of coal and oil is starting to wane, and this process will accelerate over the next two decades. By 2035, coal's share of global generation is expected to slip to 33%. The importance of oil will also be challenged, given a combination of high prices, potentially depleting reserves, the

rising cost of exploration and production, and environmental concerns. Governments are under acute pressure to reduce carbon emissions by imposing more regulatory constraints, and this will buoy the prospects of cleaner fuels.

While coal and oil will come under growing pressure, one fossil fuel will continue to win market share: natural gas. The IEA predicts that it will account for almost a quarter of world energy demand in 2035, making this the Golden Age of Gas. One key advantage is that gas is cleaner than other hydrocarbon fuels, making it an appealing option

The Future of Renewable Energy

Clare Chatfield

Q: What's driving the shift towards renewables, and how dramatic will it be?

A: Several fundamental drivers are pushing us towards renewables. First, there's the general move towards having a cleaner environment. Second, there's regulation because of this growing awareness of the need for a cleaner planet. Third, evolving technology has reduced the cost of renewables relative to other types of energy. But there are constraints, too. Putting hydro aside, most renewables are distributed in nature, which adds complexity to the task of getting electricity to end users. Also, most renewables are intermittent, hence the need for backup energy sources, some of which aren't environmentally friendly.

Q: When will renewables become price competitive with fossil fuels?

A: Each renewable type is at a different level of maturity. It also depends on what country we're talking about. But onshore wind is probably the most developed renewable and is already competitive in some cases. Then comes solar PV, then probably offshore wind. Then you get to emerging technologies like tidal: it's not at a commercial point yet, but I do believe in tidal. It's not permanent in its presence, but you can rely on it. Biomass isn't competitive today and depends on positive government regulation and subsidies. But the technology is developing fast and it will reach grid parity at some point. Certain countries have provided huge subsidies for different renewables, which explains why places like Germany and Spain have such a high proportion of renewables in their energy mix. You have to help these new technologies become competitive. But ultimately there has to come a point where those subsidies are reduced and where these technologies are on a par with more traditional forms of electricity.

Q: How does the future look for wind and solar energy?

A: Onshore wind is a reasonably advanced technology. As the turbines get larger, it's become a real industry, and we'll see further growth in Asia. But there's a saturation point. In highly populated countries with a relatively small surface area, there's a limit to how many wind turbines you can have, and most people don't want them next to their homes. With offshore wind, you don't have the same problems over permission and you can respond to much greater energy needs. Offshore wind has huge potential in Europe. But these are much bigger constructions, and the investments are enormous. Your average utility or developer doesn't fully understand the risks. There's also a big issue over the transmission of electricity from offshore turbines to land, which is a blocking point for tidal energy, too. As for the solar industry, it's suffered badly from the financial crisis, but solar energy will develop very strongly in the future. The distributed nature of solar PV makes it particularly interesting for countries like India that have problems with their transmission and distribution networks, allowing them to equip areas that aren't connected to the grid. That's a very powerful advantage for solar.

Q: How key is Asia to the future of renewables?

A: The Chinese are absolutely at the forefront of developing renewables. They've been developing vast amounts of capacity for wind components and turbines and have gone very heavily into solar PV. Renewables are massively on the Chinese government's agenda. The Indians also have renewables on their agenda but it takes much longer to get things through there. In the future, much of the growth in renewables will come from Asia because it has such huge energy needs.

***Clare Chatfield,** a Senior Partner at L.E.K. Consulting, leads the company's Energy & Environment Practice.*

CHINAFOTOPRESS/GETTYIMAEGS

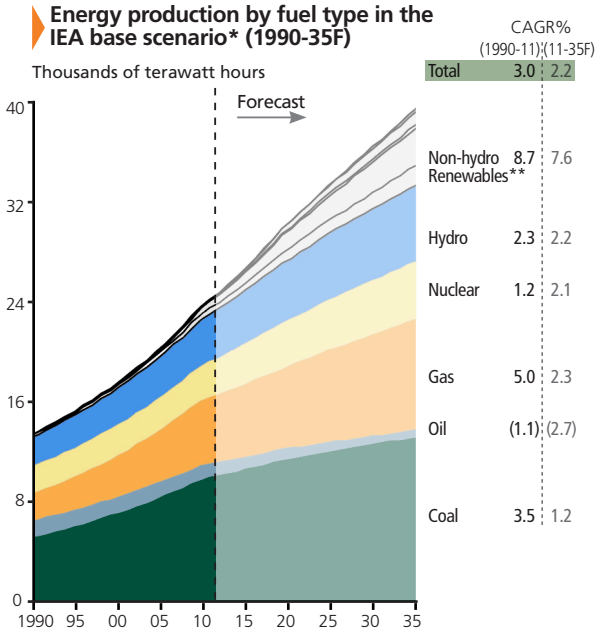
Flood water is released from spillways of China's Three Gorges Dam

in sectors such as industry and transportation. China, which faces particular pressure to confront its pollution problems, is expected to account for 30% of the growth in global demand for natural gas. Concerns about energy security will add a further incentive for governments to embrace gas. There is also a growing void to fill now that nuclear energy is losing favour in Europe and elsewhere: for example, Germany plans to retire all of its nuclear plants by 2022. Natural gas is also plentiful, thanks partly to North America's shale boom, so its price should remain attractively low.

The shift away from coal and oil will be a boon for renewable energy, too. By 2035, renewables are forecast to become the world's second-largest source of electricity, after coal, with 31% of the market. (For more on renewables, see our interview with Clare Chatfield on page 5.) Hydropower is the leading source of renewable energy and will continue to grow steadily. But non-hydro renewables such as wind, biomass, solar, geothermal and tidal power are poised to grow even faster as China, India, the U.S. and other countries diversify their energy mix. By 2035, non-hydro renewables could account for 15% of global energy production.

None of this is fatal to coal and oil, which still boast a significant cost advantage over renewables such as offshore wind, tidal and geothermal. But as green technology improves and environmental pressures intensify, these historically dominant fossil fuels will come under greater and greater threat.

Energy production by fuel type in the IEA base scenario* (1990-35F)



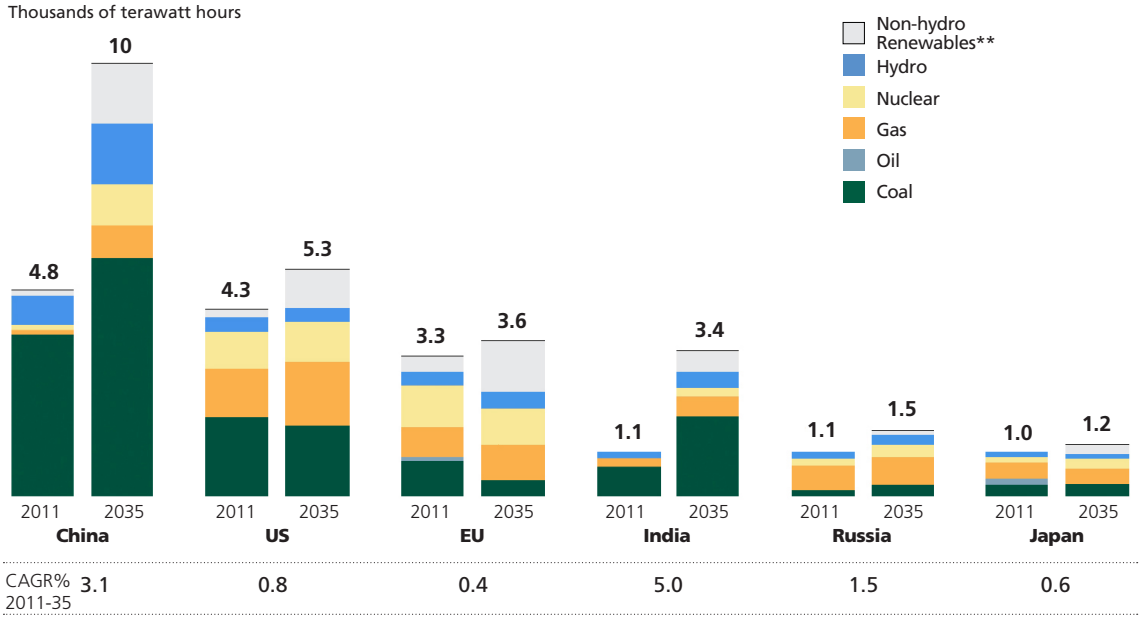
Note: *The IEA New Policy Scenario is IEA's base scenario that assumes all policy commitments and those recently announced are implemented albeit in a cautious manner; **includes biomass/ waste, geothermal, solar PV, CSP and tidal

Source: IEA World Economic Outlook (November 2013)

3 China and India Will Become Major Energy Producers

Shoppers are used to inspecting the labels on clothing and other retail goods, only to find that familiar phrase: 'Made in China'. But what about energy? Are we entering an era when a growing proportion of the world's energy will also be made in China? Increasingly, the answer is yes.

Energy production by region and fuel type in the IEA base scenario* (2011 vs. 35F)



Note: *The IEA New Policy Scenario is IEA's base scenario that assumes all policy commitments and those recently announced are implemented albeit in a cautious manner; **includes biomass/ waste, wind, geothermal, solar PV, CSP and marine

Sources: IEA World Energy Outlook (November 2013)

Already, China is the world's largest producer — and importer and consumer — of coal, which meets more than two-thirds of the country's primary energy demand. But China's energy needs are expanding so rapidly that its use of coal will surge for many years to come. Indeed, by 2035, the IEA expects China's coal-fired generation to exceed the current level of generation from all sources of energy in the U.S. and Japan combined.

At the same time, China's concerns over pollution will also drive massive growth in its use of renewable energy, including hydropower, onshore wind and solar PV. By 2020, renewables are expected to provide more than 40% of the nation's incremental output, aided by strong policy support and financial incentives. China is also expanding its nuclear capacity: according to the IEA, the country is currently constructing 29 nuclear reactors, in addition to the 17 units already in operation. Meanwhile, China is expected to bring online another 60 gigawatts of gas-fired capacity by the end of its current five-year plan in 2015, reflecting the government's push to use natural gas as the preferred source of energy to fuel the nation's urbanisation.

India, too, possesses an almost insatiable hunger for energy — and, like China, it's poised to become an increasingly important producer. By 2035, India's coal-fired generation is expected to more than double, primarily to meet new demand. But the country will also need to boost its imports of natural gas in the short to medium term.

For foreign companies, these are tough markets to crack. The well-known risks in India include political uncertainty, corruption, and bureaucratic red tape. The opportunities in China's energy sector are enticing, but the barriers to entry are high, since the government has increasingly sought to localise its supplier chain. Still, in 2011, shale gas was classified as a separate 'mineral resource', which means that China's national oil companies will not hold exclusive exploration rights. This may signal that the government intends to grant more access to foreign businesses. That openness would be a striking measure of the scale of investment and expertise required to meet China's surging energy needs.

4 Developed Nations Must Find The Will And Money To Modernise Their Energy Infrastructure

The best word to describe the developed world's energy infrastructure is 'old.' Actually, better make that 'decrepit.' Take coal-fired power plants. They are built to last about 30 years, after which they typically need to be retired, retrofitted, or replaced. By the end of 2012, almost two-thirds of the coal-fired capacity in OECD countries was over 30 years old. By contrast, in non-OECD countries, nearly three-quarters of the coal-fired capacity is less than

20 years old. This age gap reflects a broader problem for the developed world: overall, about 40% of all power plants in the U.S. and the E.U. are already past their thirtieth birthdays. Meanwhile, the International Energy Agency estimates that, by 2035, around half of today's electric grid infrastructure in Western countries will be 40 years old.

This will give rise to a powerful trend over the coming decades: the widespread replacement of outdated power plants and grid infrastructure across the developed world. The scale of what's required is staggering. For example, the IEA estimates that at least 60% of the grid infrastructure in Europe, Russia and the U.S. will need to be replaced by 2035.

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An ageing power plant in the U.S. reflects the developed world's need for new energy infrastructure

That's joyous news for engineering contractors, equipment manufacturers and others in the infrastructure business — not least, Western companies that are particularly well-positioned to meet the enormous needs of the U.S. and European market. It's also a major opportunity to build new plants and infrastructure that are more efficient and environmentally friendly. But it's ominous news for cash-strapped governments, which must foot the immense bill for replacing this inadequate infrastructure in order to maintain current production levels. The U.K. alone must spend an estimated £200 billion on energy infrastructure over the next ten years to rebuild its power distribution and generation capacity. Similarly, the European Commission estimates that the EU must spend about 1.1 trillion Euros between 2013 and 2020 to meet its energy infrastructure needs.

In the U.S., where natural gas is now increasingly plentiful, many coal-fired plants will be replaced with gas-fired generation. Still, the American Society of Civil Engineers predicts that the investment gap for refurbishing or replacing distribution and transmission infrastructure will rise to $94 billion by 2020. As for Japan, Asia's largest developed economy, an estimated 54% of its current generating capacity will need to be replaced by 2035. All of the country's nuclear reactors were shuttered in the wake of Fukushima plant disaster, adding urgency to the task of upgrading Japan's now infamous energy infrastructure.

The vexing question for the developed world is how to pay for this massive infrastructure replacement cycle. In the end, this will require the summoning of considerable political will. Engineers can predict with some precision how long a power plant can operate before it falls apart. Alas, it's harder to predict how long it will take for politicians to confront — let alone resolve — these difficult financial challenges.

5 Developing Nations Must Bridge Their Infrastructure Gap

Demand for energy will surge in developing markets over the next two decades, driven by rising GDP per capita, rapid population growth, and pell-mell urbanisation. For example, in developing Asia, the International Energy Agency predicts that energy consumption will almost double by 2030. In China alone, energy demand per capita is expected to rise by 40% in that time. This soaring demand will place intense pressure on energy-related infrastructure.

This challenge is all the more acute, given the inadequacy of much existing infrastructure in the developing world. In parts of Africa, Asia and Latin America, there is a dire need for investment in basic urban utilities. Many developing countries also have poorly-maintained and inefficient grids, with transmission and distribution losses of up to 30%. Another place where the infrastructure gap is particularly wide is in the unplanned perimeters of emerging megacities — not least in India, where

millions lack access to electricity and where blackouts are a recurring problem for industry. As for China, its urban infrastructure is relatively well-developed, but it's paying an environmental price for its reliance on coal. To address this, the government plans to invest heavily in higher-efficiency coal-fired plants, while also tripling the use of renewable generation between 2011 and 2035.

Financially, it won't be easy to meet these colossal infrastructure needs. The IEA says the world will need $1.6 trillion a year of investment in energy-supply infrastructure until 2035; it estimates that 61% of that investment is needed in non-OECD nations. Access to financing is a widespread problem, and developing nations must compete for investment with developed nations that are perceived as less risky. In countries as diverse as India and Indonesia — both of which have suffered from chronic underinvestment in infrastructure — the private sector remains wary, while the public sector is hobbled by severe funding constraints.

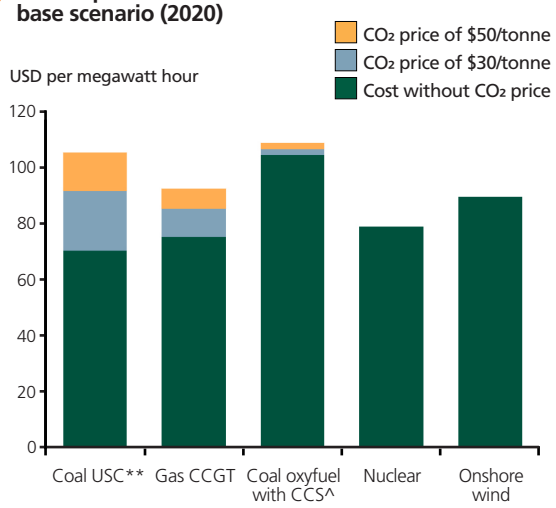
In the short term, one clear beneficiary of the infrastructure gap is the temporary power industry. Aggreko, a supplier of temporary power solutions, predicts that demand for temporary power will rise by 10-15% annually. Stop-gap solutions abound, with many countries resorting to power plant technologies that are sub-scale and environmentally harmful. This provides an opportunity for equipment manufacturers to offer packaged solutions for the short to medium term that are more sustainable.

To succeed, Western equipment suppliers must understand the nuances of local needs and pressures in these challenging markets. In many cases, the best route will be to forge partnerships — whether with regional or local governments, national utilities, master planners of sustainable developments, or specialist providers of integrated energy solutions. One thing is for sure: the need for cost-effective and sustainable infrastructure solutions has never been greater.

6 Green Policies And Regulations Will Proliferate In Response To Climate Change

Like it or not, the prognosis is for more stringent regulations and policies to combat climate change.

Typical levelised cost by plant type and carbon price* in the OECD in the IEA base scenario (2020)



Notes: * Levelised cost is cost per unit of electricity generation, taking into account all associated costs over the lifetime of the asset;
** Ultra Super-Critical; ^ Carbon Capture and Storage

Source: IEA World Energy Outlook (2011)

The overriding aim: to curb greenhouse gas emissions by promoting greater energy efficiency and supporting the development of alternative energy sources. The impact will be dramatic. For example, carbon policies will ultimately drive up the cost of fossil-fuel generation, while making natural gas and renewables more competitive. Companies in energy-related sectors such as power generation, industry, transportation and construction will have to navigate an increasingly complex regulatory and policy landscape to prosper in this arena.

The commitment to address global warming varies considerably from country to country. Still, the trend towards greater regulation is inevitable as the environmental risks of inaction become clearer. The United Nations Climate Change Framework has established a structure for a coordinated response to climate change, including the imposition of stricter emissions standards and better enforcement of emissions regulations. In 2009, participants at the Cophenhagen summit specifically agreed on the need to prevent the average global temperature from rising more than two degrees celsius above pre-industrial levels.

To help achieve these goals, governments have made an array of pledges — some more credible than others — to reduce carbon emissions. For example, China has pledged to cut emissions to

40-45% below the 2005 level by 2020, while the U.S. has pledged a 17% reduction below the 2005 level. A myriad of energy-related policy initiatives has also been announced or implemented. In 2013, the U.S. government outlined a climate action plan that included a mandate to the Environmental Protection Agency to develop tougher regulations for carbon emissions from power plants. New gas-fired plants would be allowed to emit no more than 500kg/Mwh. However, even the most efficient coal-fired plants can't produce electricity without emitting 700kg/Mwh. To comply, new plants would have to be outfitted with carbon capture and storage devices.

As for the E.U., it has committed to reducing emissions by 20% from 1990 levels by 2020, along with a goal of using renewables for 20% of energy consumption. The U.K. has also joined France, Germany, and Italy in calling for a binding reduction of emissions by at least 40% from the 1990 level by 2030. These ambitious targets could help to spur enormous investments in low-carbon technology.

Meanwhile, all eyes are on China, given its unsurpassed energy needs and the scale of its environmental worries. China's 12th five-year plan on National Economic and Social Development showed the government's intensifying focus on energy conservation and environmental protection: for example, it set a binding target of cutting energy consumption per unit of GDP by 16% by 2015. The challenge for China and others is to balance the imperative of sustaining economic growth with a mounting awareness among policymakers that the perils of climate change may be too extreme to ignore.

7 Worries Over Energy Security Will Intensify

The recent turmoil in Ukraine and Crimea has reignited concerns about energy security, reminding many governments how vulnerable their countries are to supply disruptions. Russia, which annexed Crimea in March, supplies the EU with almost a quarter of its gas, much of which transits Ukraine. Russia has also displayed again its willingness to use energy as a political weapon: Gazprom, the Russian energy behemoth, recently announced a massive rise in the price it charges Ukraine for gas — the latest in a series of energy-related conflicts between the two countries.

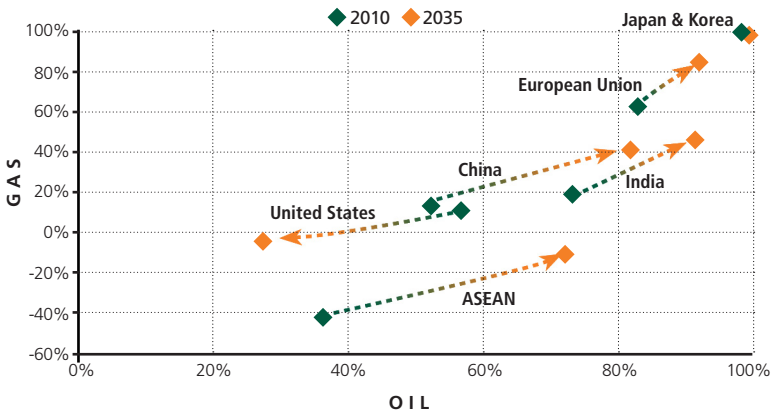
This geopolitical instability is disconcerting for various energy importers, which now wonder if they, too, are overly reliant on Russian energy. For example, Germany imports nearly 40% of its gas from Russia. That's a serious concern, given Germany's attempts to shift away from nuclear energy. It cannot hope to fill this nuclear void unless it can rely on a steady supply of Russian oil and gas.

Russia is hardly the only concern for energy importers. A hefty portion of the world's energy comes from geopolitical hotspots, including Iran, Iraq and Saudi Arabia. The lesson is clear: it's never

VINCENT MUNDY/BLOOMBERG/GETTY IMAGES

The Trans-Siberian Pipeline in Ukraine is a key route for Russia's natural gas exports to Europe

Net oil and gas import dependency* in selected countries in the IEA base scenario



Note: * Import dependency is calculated as net imports divided by primary demand for each fuel
Source: IEA World Energy Outlook (2012)

been more important for countries to diversify their sources of energy by cultivating new suppliers and securing access to alternative pipeline routes.

This is a particularly pressing issue for the EU. Its demand for gas is forecast to grow by 1% annually until 2035, yet its gas production is expected to drop by 1.4% annually. That shortfall is spurring anxious discussions about the need to boost domestic production, diversify external supplies, and establish a non-Russian and non-Iranian pipeline system to bring gas to Europe from the Caspian region and Central Asia. This rising demand for new pipelines is likely to provide lucrative opportunities for companies in energy-related construction, manufacturing and financing.

China is also nervous about its deepening dependence on energy imports. Over the next two decades, its reliance on imported gas will rise. It's also expected to import more oil than the entire EU by 2020. Eager to reduce this dependence on fossil fuels, China wants to expand its use of renewables and increase its unconventional gas exploration and production. This will create significant investment opportunities in energy sectors that provide an alternative to fossil fuels.

While many countries are scrambling to bolster their energy security, the U.S. is well-positioned to profit from rising overseas demand, thanks to its unconventional oil and gas boom. Indeed, the U.S. is expected to become a net exporter of gas by 2017. One major opportunity will be for companies that can help to construct or operate the new LNG terminals required to export America's increasingly abundant energy resources.

8 Technological Advances Herald A New Era Of Energy Efficiency

New technologies promise to bring much greater efficiency to key aspects of the energy arena, including the extraction of oil and gas, power generation, and consumption.

One vital area of progress is the on-going development of enhanced oil recovery (EOR) techniques to increase the amount of crude extracted from oil fields. These methods include injections of steam, gas, chemicals or CO2. By increasing recovery rates in conventional reservoirs, EOR technologies could release 300 billion barrels of oil on top of current resource estimates, says the IEA, though progress has been hindered so far by relatively high costs. These advances in recovery technology are much-needed, given how energy-intensive the extraction process is in many parts of the world. As oil and gas fields mature, there's a growing reliance on deep-water drilling and unconventional resources such as shale gas, in which production typically requires a lot of energy.

New technologies will also enhance the efficiency of power generation, both from renewable and non-renewable sources. There's a wide range of innovative technologies in the pipeline. Much of the focus is on improving generation efficiency with the help of higher-temperature gas turbines. Meanwhile, coal remains the world's largest source of power, so it's also vital to develop technologies that improve the efficiency of coal-fired plants. The main technologies adopted in this area involve supercritical and ultra-supercritical pulverised coal combustion. These techniques will continue to gain greater traction, despite relatively high capital costs.

Another key area in which we will see major efficiency advances is in the way energy is consumed. Over the coming years, homes will become increasingly energy efficient, particularly in highly urbanised economies like the U.S. A recent study by ExxonMobil predicts that residential energy intensity will drop by around 15% by 2040, thanks to

energy-saving lights and appliances and improved insulation.

But it's not just residential consumption that will become vastly more efficient. Architects in many OECD countries are creating commercial buildings that offer zero-energy consumption. Indeed, from 2018, it will be compulsory for new government buildings in the EU to come close to these zero-energy standards. The transportation sector will also see dramatic progress in terms of efficiency. For example, by 2040, hybrid vehicles are expected to account for about 35% of the world's light-duty vehicle fleet, up from less than 1% in 2010. With support from regulations that mandate greater efficiency, such technologies will have a transformative impact on the use of energy.

9 The Quest For Large-Scale, Low-Cost Energy Storage

The use of intermittent renewable energy is rising around the world. In the next four years alone, global intermittent renewable capacity is expected to soar by about 450GW, with much of this energy derived from wind and solar sources. The question is: how can this fluctuating supply of energy be stored in an economically viable way so that utilities can use it when they need it most?

Pumped-hydro storage is currently the only proven, large-scale technology in the market

DR.G.SCHMITZ

A wide array of storage solutions will be required to meet this challenge. For example, solar power is strongest at midday, but electricity demand peaks in the early morning and early evening. This creates a need for short-term electricity storage lasting several hours. In other cases, it's necessary to store energy for several days when the wind has stopped blowing or the sun has stopped shining. There are also situations in which electricity supply exceeds demand — for instance, in the middle of the night, when usage is low. Storage systems could potentially capture that surplus power during the night, then release it into the grid at times of peak demand.

Chris Floyd, *formerly Business Development Director of Rolls-Royce, is a consultant and a member of L.E.K.'s industrials executive network.*

Pumped hydro storage, which is currently the only proven, large-scale technology available, accounts for about 140GW of capacity worldwide. The IEA estimates that demand for electricity storage could easily reach 350-500GW by 2050. Others have forecast that the electricity storage market could grow six-fold to around $20 billion a year by 2030. But if the cost of storage is too high or the technology is unsatisfactory, utilities will find alternative ways to deal with the problem — for example, by restricting the amount of intermittent renewables on the grid or by generating more surplus capacity.

The trouble with pumped hydro is the shortage of suitable locations, since this process requires a mountain with a lake or reservoir beside it. Furthermore, in Europe it's hard to gain the necessary planning permission, while many other parts of the world lack sufficient water. Still, there's more potential for pumped hydro in the U.S. and especially China, where the sensitivities of local residents are less of an obstacle.

Other new technologies also show promise, particularly compressed air storage using underground caverns, and pumped heat storage which stores energy in tanks filled with high temperature crushed rock. It's too early to predict which of these two rival approaches will win out, and it may be years before useful commercial products hit the marketplace. Lithium batteries also have potential

for larger-scale storage, if costs can be reduced; and there are other early-stage technologies involving everything from hydrogen to liquid air to superconducting magnets. Whatever the approach, the ultimate challenge is to drive down costs and increase efficiency so that storage provides a financially competitive solution.

—By Chris Floyd

10 The Energy Value Chain Will Be Transformed

Traditionally, the energy business worked something like this: a small number of major companies operated large-scale plants located near huge deposits of fossil fuels; gas and electricity generated by these centralised plants was

A Smarter Future: Why Meters Matter

Karin von Kienlin

One of the most powerful trends in energy is the move towards a smart grid. Smart meters are an essential component within this new infrastructure. These electronic devices collect detailed data about customers' energy consumption and relay it instantly to the utility. This helps utilities to balance energy supply and demand.

In the past, this wasn't such a pressing concern, since utilities enjoyed an almost limitless supply of energy from fossil fuels, nuclear power and renewables. But the pressure to meet demand has intensified for various reasons: nuclear energy has lost favour, creating a void that must be filled with other sources, including wind and solar energy, which are only intermittently available from decentralised sources; ageing infrastructure has caused costly outages in the U.S.; and booming economies such as China and India are struggling to meet their rising energy needs. This mounting pressure on utilities is especially acute at times of peak demand. Smart meters offer a clearer picture of how much electricity they will need to supply, helping them with everything from short-term planning to making more targeted investment decisions.

Increasingly, utilities are also incentivising consumers to use energy at off-peak times — for example, by waiting till night-time to run washing machines and dishwashers. In Germany and elsewhere, customers have been paying less for some time when using energy outside peak hours. Other countries will follow suit, abandoning the notion that there should be one price for electricity no matter when it's consumed. By providing customers with timely and transparent information about their own consumption, smart meters should also encourage them to pare back their overall usage, thereby reducing the need to build more power plants.

Many governments are passing regulations to promote the use of smart meters. The EU has mandated an 80% market penetration for smart meters by 2020, and widespread roll-outs have been implemented or are underway in Italy, France, the U.K., and Scandinavia. Attitudes towards smart meters differ depending on the particular country's needs. In Germany, the move away from nuclear power makes it all the more important to invest in smart meters as a way of providing more energy with less input. In China, smart meters offer a much-needed way of maximising supply to help meet overwhelming demand. In the U.S., funding for smart meters and other smart grid technology is driven partly by concerns over the unreliable infrastructure that has led to blackouts in states like California.

Nonetheless, skeptics wonder if smart meters provide a big enough pay-off to justify the high cost of implementing these roll-outs. Smart meters might help to cut the average residential electricity bill by, say, 20%. But utilities worry about recouping the steep upfront cost of installing these new meters, and regulators may need to let them raise electricity prices to cover this added expense. Still, the long-term benefits of smart meters are hard to deny, despite the short-term pain of paying for the switch to this more advanced technology.

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sold through long-term contracts; this energy was then transmitted to customers, whose passive role was simply to receive and consume it. However, every aspect of this energy value chain will be transformed as we move deeper into the smart-grid era.

For a start, those large-scale plants responsible for the centralised generation of energy will increasingly give way to distributed and localised generation. One reason is that it's more cost-effective than ever to produce energy with smaller units that use renewables such as solar PV. Independent power producers (IPPs) will gain greater prominence as the owners and operators of these smaller facilities, which will generate power for sale to utilities, governments and end users. These IPPs will focus heavily on using renewables to generate intermittent capacity for the grid, and the electricity system will have to become more flexible to harness this new capacity.

Energy trading is another area of the value chain that's changing. In the past, gas and electricity were primarily sold through long-term contracts. But we are now seeing the emergence of regional hub markets in Germany and elsewhere, which can help to balance supply and demand. If one part of a country has more wind, for example, a hub market can use that extra capacity to meet demand in another area with less wind capacity. This ability to aggregate fluctuations in supply and demand will become more important as intermittent renewables gain a larger share of the energy mix.

Tesla's electric sports cars mark an era of rapid technological innovation in the world of energy

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The transmission of energy is also shifting. The old model involved a simple, one-way flow of power from centralised generation plants to distribution networks. Increasingly, energy will not just flow out of power plants but will also flow into them. Distributed renewables will play a vital role in providing this backflow of energy. Data and communication equipment is also being installed within the transmission infrastucture, enabling smart-grid technologies to monitor and control the electricity system in ways that enhance efficiency and reduce transmission losses.

Likewise, energy distribution systems will also become more flexible. Instead of power flowing in one direction from the grid to users, there's a move towards two-way systems featuring embedded data, sensing and automation hardware. With the help of smart meters, utilities will collect data on users' energy consumption and react accordingly — for example, turning consumers' smart appliances on and off remotely in response to the real-time balance between energy supply and demand.

Meanwhile, consumers will also be able to take a more active role in their own energy consumption and management. For example, they will use solar panels and other micro-generation technologies to produce their own energy, even reselling the surplus back into the grid. In other words, localised energy will go mainstream as the traditional value chain recedes into history. ■

*This report is based on research by **Florian Funke,** a partner in L.E.K. Consulting's London office who focuses on the energy sector and related equipment markets.*

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