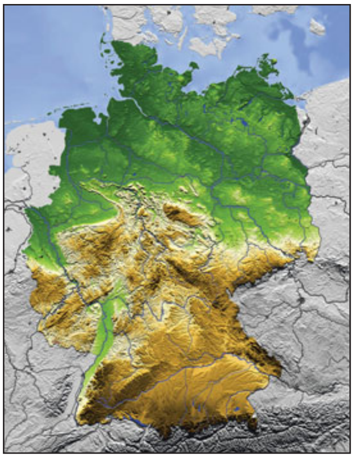

Germany's Energiewende pushes for renewables

By **Angela Saini**
Feature Editors
Steve Brick and Ferdi Schüth

Much of the world's focus may be on new power plants in Asia, but Germany also has ambitious energy plans of its own. The *Energiewende* (energy transformation) is the country's plan to move away from nuclear power and fossil fuels on such a scale that it has been described as Germany's largest post-war infrastructure project.

The idea was proposed in the 1980s, before becoming policy at the turn of the century. The goal is for 80% of electricity and 60% of primary energy consumption to be sourced from renewables by 2050. Nuclear power will be phased out by 2022. This shift requires not only more solar and wind, but new power lines and more energy storage. Its success will hinge on the latest technologies, including new materials.

So far, the Energiewende has made steady progress. The proportion of electricity generated by renewables has risen from 6% to almost a quarter in the space of a decade (in the United States, by comparison, 13% of electricity comes from renewables, and 22% across the world as a whole, according to the Renewables 2014 Global Status Report). But it has come at a high cost: hefty financial subsidies to the renewables industry, and high consumer electricity prices. The challenge for policymakers, according to Stephen Brick, senior fellow in climate and energy at The Chicago Council on Global Affairs, will be to make the system work with lower or no tariffs.

The main purpose of the Energiewende is an environmental one. To that end, greenhouse gas emissions have fallen by 23.8% since 1990. Ferdi Schüth, a German chemist and director of the Max Planck Institute for Coal Research, however, notes that "a substantial part of this reduction is due to the replacement of the very inefficient energy infrastructure of East Germany after reunification." In 2013, emissions rose by just over a percent after new lignite-fired power stations were installed to take advantage of Germany's abundant supplies of brown coal.

A study published this spring in the journal *Energy & Environmental Science* by Stanford researchers showed that it is possible for renewables to produce more energy than that used to manufacture and operate them and store what they produce. On the scale of the Energiewende, however, there are many technical obstacles. "Proportionally, the more renewables you put on, the more challenging it will be," said Sally Benson, head of the Global Climate and Energy Project at Stanford University, and one of the co-authors of the Stanford study.

Prime among the problems associated with grid-scale renewables is intermittent supply: neither wind nor solar can provide constant power. In the worst case, this may mean that Germany will need to resort to a higher proportion of fossil fuels than planned. Another option is for consumers to be encouraged to use less energy during times of lower supply, such as by using smart controls on household appliances.

Germany similarly looks to the rest of Europe to meet its storage needs, partly by using Swiss and Scandinavian pumped hydropower. It also stores energy domestically using pumped hydropower and, on a small scale, conventional "power-to-gas," which involves water electrolysis to produce hydrogen. Pilot power-to-gas projects storing wind energy include a 2 MW unit opened in Falkenhagen in eastern Germany in 2013, and more recently a 6 MW unit for the automobile manufacturer, Audi, in Werite, Lower Saxony.

Another possibility for the future is battery storage. A multimillion-Euro research funding scheme provided by the Energiewende has supported materials research in Germany, including into batteries. The electronics company, Bosch, for example, has started work on high-energy traction batteries for electric vehicles. The challenge, as far as grid-scale renewables are concerned, is cycle life, said Benson. Most battery research and development usually focuses on electronics and automobiles, which do not need to last as long as grid storage.

Elsewhere in the world, there are efforts to prove that battery storage can cope with grid-scale energy production. In West Virginia (USA), for example, power company AES Corporation has built the world's largest lithium-ion battery farm, holding enough electricity to power 5,000 homes. General Electric has also developed a novel grid-scale energy storage system based around its Durathon sodium-metal halide batteries.

However, not everyone is convinced that the storage problem can be solved within the timescale that Germany has set for itself. Jon Samseth, a physics professor in Norway—from where neighboring countries already borrow pumped hydropower for storage—and vice president of the international body, Scientific Committee of Problems of the Environment, said that this hurdle alone could make the Energiewende impossible.

At the same time as meeting this formidable storage challenge, Germany is

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working to improve its grid network—a vital part of the country's renewables infrastructure especially when, as is already the case sometimes, there is excess wind production. Power transmission and distribution losses in Germany are just 4%, leaving little room for improvement. However, there are ways of increasing capacity, and with 2,800 kilometers of extra transmission lines being installed, there is also scope for the next-generation of materials to play a part in new sections of the grid.

This year, the French cabling company, Nexans, installed a kilometer-long underground superconducting cable between two large transformers in the German city of Essen. Capable of carrying five times as much power as a normal copper cable, this type of cable also reduces transmission losses to almost zero.

A major drawback is that the cable must be maintained at –200°C using a thin cooling jacket filled with liquid nitrogen, said Jean-Maxime Saugrain, Nexans Technical Vice President. Mike Ross, managing director of superconductor power systems at American Superconductor Corporation, said, "We have had such cooling systems operating for more than a decade. The key technical challenge is optimizing the cryogenic system to make it as low-cost and efficient as possible for our applications."

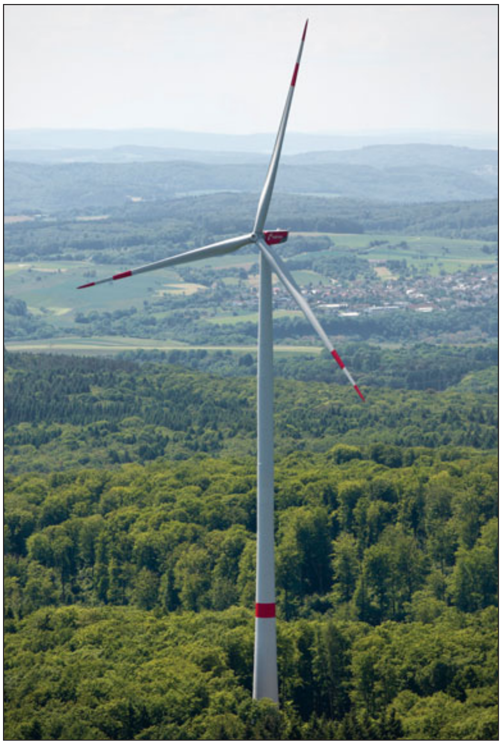
The main reason for using this technology, Saugrain said, is that superconducting cables can move a large amount of power at a low voltage, reducing the need for city-center transformers.

Over long distances, away from urban centers, overhead lines remain the better option. One of the main requirements of these parts of the grid is to transfer energy between coastal and offshore wind parks in northern Germany to the industrial parts of southern Germany, where nuclear plants are due to be decommissioned.

By way of a solution, German Chancellor Angela Merkel has backed plans to replace existing AC transmission lines with high-voltage direct current (HVDC) lines between the north and south. Among the benefits, as well as higher capacity, is that HVDC lines allow one to more precisely control the direction and magnitude of the power transmitted. The major problem with HVDC is in making multiple connections because of the difficulty in switching sections on and off. For that, more effective circuit breakers are needed that can cope with high DC voltages.

As for renewable generation itself, there are also challenges. There is a theoretical maximum efficiency achievable by wind turbines of around 59%, determined by aerodynamic limits, and "wind turbines have been operating within a few percent of this limit for decades," said Jim Platts, a wind turbine expert at the Institute for Manufacturing at the University of Cambridge.

"Materials development on wind turbines has been hugely important, but I would say that much of that work has been done, and what now matters is the wider application of what has come out of that work," he said.



Wind turbine at a wind farm in Hesse, Germany, with a capacity of 2.4 MW (courtesy of Nordex).

One area for improvement, Platts said, is in wind turbine towers, which are becoming proportionally taller to capture the better wind speeds higher above the ground. Traditionally made of steel, which has a limited fatigue life, he advocates a move to composites. Fiber-reinforced composites are already used for turbine blades, and Platts believes this could push wind turbine lifespan beyond 20 years to as long as 40 years.

Solar photovoltaic (PV) cells have also benefited from a huge fall in price in the last three years, because of a "gigantic oversupply by Chinese manufacturers," according to Eicke Weber, director of the Fraunhofer Institute for Solar Energy Systems and a professor of solar energy at the University of Freiburg in Germany.

Most PV cells in Germany, as in the rest of the world, are standard crystalline silicon, with efficiencies below 20%, usually 16–18%. There is a theoretical limit on the efficiency of all standard crystalline silicon solar cells of around 30%. Although PV cells with efficiencies above 40% exist, their high cost only makes them appropriate in "blue sky" regions with high amounts of direct sunlight—not in Germany.

As far as standard cells go, said Weber, there are a number of materials efforts in progress. One key development would be to find a cheaper alternative to silver, a critical material inside PV cells. Another technology under early research is the organic PV cell, which is both transparent and flexible, and potentially low cost.

In the end, there remains a possibility that the Energiewende will fail. As far as materials science is concerned, this will also require fresh research as the need emerges for other clean technologies. Germany may need to turn further to its significant coal reserves, which may precipitate a need for "clean coal."

However successful the Energiewende turns out to be, Germany's unique experiment brings with it important lessons for the rest of the world. As Benson notes, "There are challenges associated with being the first." □

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