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Renewable Energy Supply Chains:

Delivering on the Promise of Green Energy

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RENEWABLE ENERGY SUPPLY CHAINS: DELIVERING ON THE PROMISE OF GREEN ENERGY

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ABSTRACT: *Clean and renewable energy sources such as wind and solar are by nature intermittent and located far away from consumer demand. Given constraints such as these, the challenge is how to design new supply chain systems for cost-effective renewable energy delivery to end consumers. There is an urgent need for solutions as governments and power companies invest more in green energy. Without a robust supply chain to deliver supplies, renewables will not be commercially viable.*

Introduction

The case for increasing our reliance on renewable sources of energy such as wind and solar has never been stronger. Recent market fluctuations and geo-political concerns highlight the shortcomings of oil as an energy source. In addition, there are powerful environmental arguments in favor of 'clean' alternatives to oil. In the U.S., President Obama has made it clear that his administration intends to make significant investments in renewables. While this upsurge in support is laudable there is a serious gap in our knowledge of green energy: how it can be delivered reliably to end consumers.

Up until now, much of the research on renewable energy has been focused on making its production economically viable. This work has been fruitful and generation costs are dropping. In the past 20 years, larger rotors and increasing reliability have reduced the unsubsidized cost of wind energy from over $0.20/kWh to approximately $0.05/kWh. Solar energy costs are also dropping rapidly, though they are still higher than wind.

In contrast, renewable energy delivery has received relatively scant attention from the research community, yet this is an area that requires urgent attention. The fact is that renewable energy sources do not come in crude form mined from the earth; they are derived from capricious forces of nature that have to be transformed into electricity.

Once the electricity is generated, it must either be transported via the electrical grid or transformed into another form, e.g., hydrogen via electrolysis, which is then transported to geographic areas of demand. The problem is that the existing infrastructure — neither the electrical grid nor the pipelines for hydrogen — was not designed to accommodate renewable energy sources. Yet without an efficient supply chain to deliver these renewables, they will not become economically viable.

MIT CTL and the MIT-Zaragoza Program in Spain, in collaboration with Acciona, one of the world's leading generators of wind power, are addressing this shortfall with a research program that is focused on the supply chain for renewable energy sources. Much work remains to be done, but the research has yielded some important insights into how an irregular source of clean energy can be turned into a steady supply.

The Nature of Supply

Renewable energy flows from cycles of nature that are not predictable and cannot be located where convenient. The uncertainty and remoteness of renewable electricity generation represent two major challenges for existing Electricity Grid Systems (EGS), that were constructed to deliver predictable electricity generation over short distances.

First, integrating alternative sources of energy such as wind and solar into grid systems is difficult owing to their intermittent nature. The electrical grid requires an exact balance of supply and demand in real-time. However, forecasting supply levels for wind- and solar-generated power is as uncertain as forecasting the weather- literally. If Mother Nature does not cooperate with the supply plan laid out for the wholesale markets, then reserve generation is required to

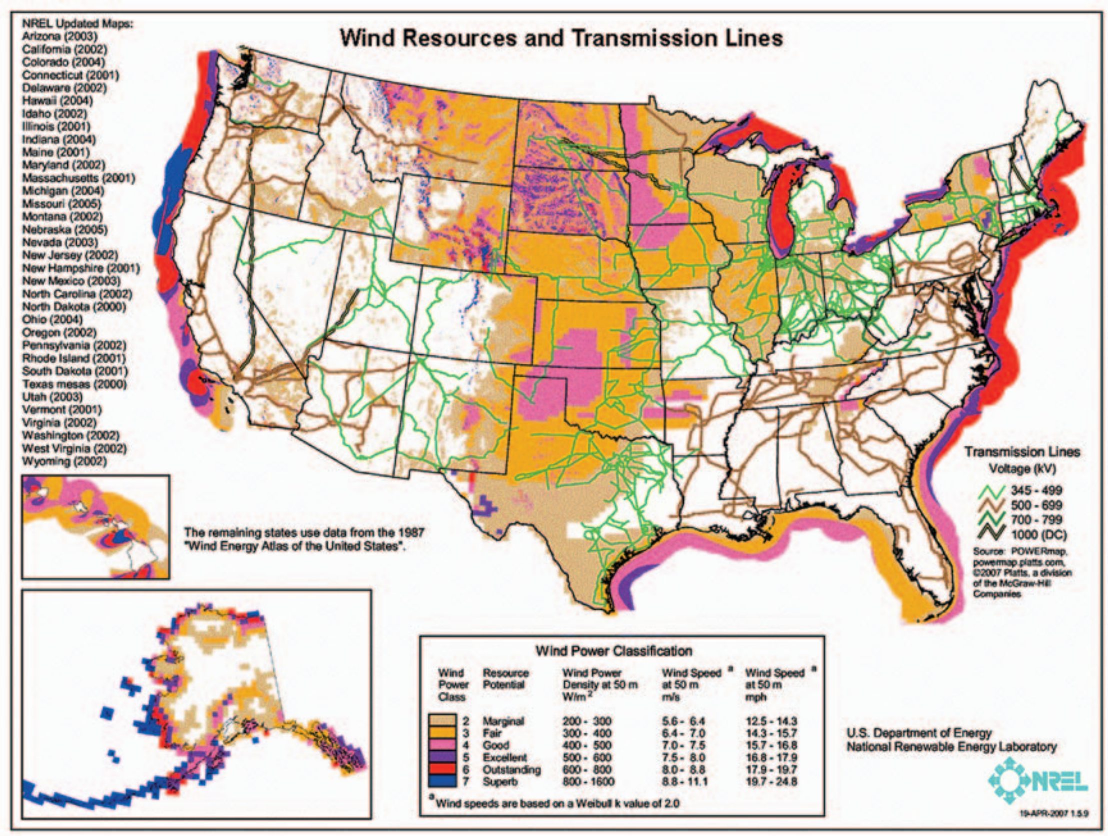

FIGURE 1
SOURCE: HTTP://WWW.NREL.GOV/WIND/SYSTEMSINTEGRATION/IMAGES/HOME_USMAP.JPG

meet the commitment. Natural gas generation is typically the backup source of electricity used to meet supply shortfalls or unexpected peak demand. These "spinning reserves" must be running even if the gap is not realized.

Second, economically viable wind and solar generation is geographically dependent on places where the wind blows strongly and the sun shines brightly (see Figure 1 for an example of wind). Often these locations are far from the population centers that create the demand. Furthermore, these locations are not likely to be close to existing transmission lines, especially not high-capacity lines. This creates a chicken-and-egg situation where transmission capacity is only built based on generation needs, but a generator cannot finance construction without viable transmission options.

A Peak at Demand

A third challenge for wind generation is that most demand occurs during the day when the wind speeds are lower (see examples in Figure 2). The misalignment of supply-demand peak, in combination with the variability and uncertainty mentioned above, means that electrical grid operators offer access to renewable sources that is typically much lower than the potential capacity at top wind sites.

Additionally, while stationary applications such as heating and lighting are fully connected to the grid, cost-effective applications for the transportation sector are still in development. New technologies, such as plug-in hybrid or fuel cell vehicles, are still too costly for mass adoption, though the gap is closing. Mobility demand could absorb much of this off-peak, low-cost wind energy by scheduling battery recharge or hydrogen electrolysis at these times.

Matching Supply and Demand

To address this misalignment of supply and demand, it is worthwhile exploring established supply chain concepts such as forecasting, demand shaping, requirements planning, network design, and inventory and distribution management. These methods have been developed for other industries, but might be adaptable to the needs of renewable energy supply. Sophisticated models are needed to develop systems that holistically address spatial, variable, and temporal challenges.

Typically, supply chains handle a mismatch between supply and demand by carrying inventory. The buffer enables enterprises to shift supply to match demand on a short- or long-term basis. In renewable applications various technologies could be deployed to store the inventory of wind-generated electricity: water reservoirs, compressed air, flywheels, batteries, and hydrogen, for example. Each of these possibilities offers a different set of cost and dynamic performance options, that could meet different objectives for renewable energy supply

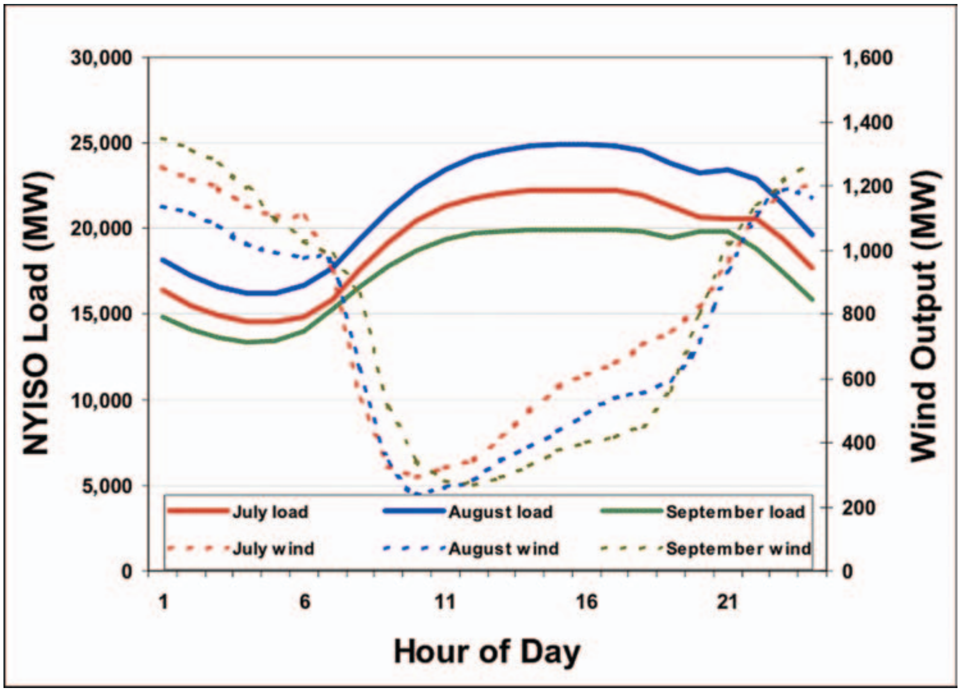

FIGURE 2

SOURCE: GE ENERGY CONSULTING. "THE EFFECTS OF INTEGRATING WIND POWER ON TRANSMISSION SYSTEM PLANNING, RELIABILITY, AND OPERATIONS," MARCH 4, 2005. HTTP://WWW.UWIG.ORG/NYSERDAPHASE2.PDF.

ranging from smoothing out hourly uncertainties to correcting seasonal variations.

A master's thesis project underway at MIT CTL is developing policies based on inventory management approaches in traditional supply chains, to make the delivery of wind-generated electricity over the existing EGSs more predictable and profitable. The policies will utilize nodal pricing data for the wholesale electricity markets in ISO-New England, the regional power system operator, to determine the best times and locations for charging and discharging the storage device. Simulation models will be used to test the efficacy of these policies, and create profitability measures that will be compared with the storage technology investment to assess economic viability.

Regarding the spatial challenges of moving large quantities of remote, renewable energy to populated areas, network design models could be used to optimize grid enhancements, especially in determining where to make the significant investments in long distance transmission lines and where to locate storage technologies. Shadow prices from the network optimization assess the marginal benefit from additional transmission capacity between any pair of nodes and/or storage capacity at a particular node. Furthermore, portfolio analysis could assess how well geographical diversity of energy sources reduces system variability and uncertainty.

Case Study: Hydrogen from Wind

To help clarify how these ideas might be applied in practice, the MIT-Zaragoza Program research team has mapped out a distribution network for hydrogen fuel. The example employs a spatial-temporal model in the context of hydrogen production from wind energy that would be used to fuel vehicles. Splitting water via electrolysis, when coupled with renewable energy sources, has far fewer air pollution impacts than do fossil-fuel sources of hydrogen. The work project is being developed in collaboration with Acciona Energy, the world's largest developer of wind parks, to help the Spanish government to understand how these energy sources might serve future markets.

The MIT-Zaragoza Program received a three-year research grant from the Government of Spain for systems modeling and analysis of the hydrogen supply chain. The expected result is a comprehensive decision support model for strategic evaluation of various technologies for production, storage, and distribution of hydrogen, and for the assessment of infrastructure development as a phased rollout.

Motor vehicle transportation represents the largest potential market for hydrogen fuel. Hydrogen fuel cells have been tested in public fleets such as city busses, and there are some new test installations with private cars in California. Fuel cells offer promising applications for green transportation, providing, of course, that drivers have ready access to filling stations. In addition, the demand for hydrogen would enable companies such as Acciona to fully develop the capacity of the most promising wind locations in Spain, which until now have been limited by the grid demand.

The research team is looking at a number of scenarios. Initially, demand would likely be focused in fleet applications, where large numbers of vehicles refuel at central locations. Next, the team assessed distribution to a network of hydrogen filling stations on the outskirts of densely populated areas. The installations could then be rolled out to the main highway arteries between cities and large towns.

An optimization model determines the type and level of activity in each network node, and the associated flows of electricity and/or hydrogen fuel between these points. Hydrogen is transported via pipeline or truck (in compressed gas or liquid form) from the electrolysis site to the fueling station. The decision where to locate the electrolysis sites determines how far the energy is transported in the form of electricity and how far in the form of hydrogen. The capacity of the grid and estimated congestion affect this decision. An example of a solution to this problem is shown in Figure 3.

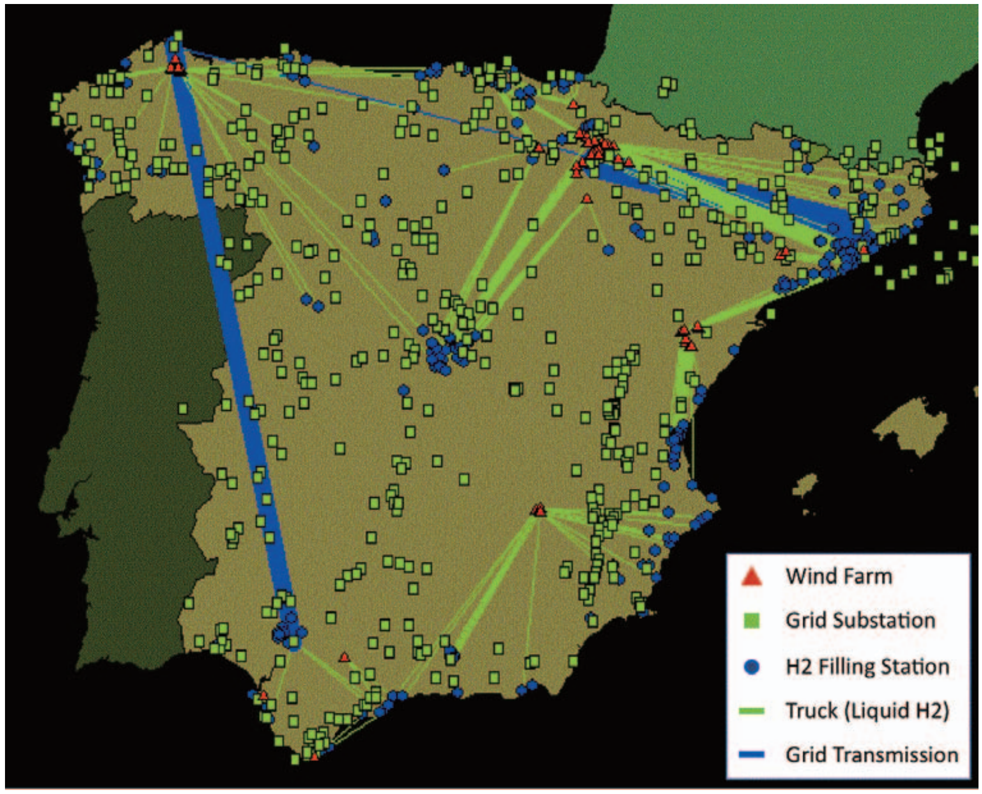

FIGURE 3
SOURCE: MIT CENTER FOR TRANSPORTATION & LOGISTICS AND MIT-ZARAGOZA PROGRAM.

Initial results exploring the tradeoff between transporting hydrogen and utilizing the grid have raised further questions. Information from the model regarding the marginal benefit of capacity throughout the grid can inform strategic decisions of when and where to expand transmission lines. Furthermore, the modular aspect of both the windfarm and electrolyzer capacity enables flexibility in scaling production to meet uncertain demand growth. Insights developed for the phased development of renewable generation and transmission extend beyond the hydrogen application that is the focus of the immediate investigation.

Ongoing Work

The research on hydrogen supply chains in Spain is scheduled for completion in Spring 2010. The work provides some valuable insights into the delivery challenges faced by the energy industry and governments as they ramp up the development of green energy sources. It also offers some preliminary solutions, but clearly, a great deal more work has to be done before robust supply chains for renewable energy can be built.

MIT CTL and the MIT-Zaragoza Program plans to launch a second phase of the research in 2009, that will delve deeper into the supply chain issues and provide more detailed solutions for specific applications. The research is of vital importance to both commercial generators and government agencies at a time when investments in green energy are set to rise sharply. The MIT team is currently recruiting government and corporate research sponsors for the program’s next phase.

NEXT STEPS

For more information on the Renewable Energy Delivery (RED) research project and how to join, contact Dr. Jarrod Goentzel at goentzel@mit.edu, or at +1-617-253-2053.