II.I.3 WinDS-H_2 Model and Analysis

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Objectives

- Identify the scenarios, time frames, and regions of the U.S. in which wind turbines that generate both electricity and hydrogen are likely to become economical.
- From a market perspective, optimize wind system concepts that produce electricity and hydrogen, today and in the future.

Technical Barriers

This project addresses the following technical barrier from the Hydrogen Production section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- T. Renewable Integration

Approach

- Expand the National Renewable Energy Laboratory's (NREL's) WinDS model to include hydrogen production, storage, and transport.
- Evaluate the market potential for hydrogen from wind under different scenarios using the new WinDS-H2 model.

Accomplishments

- Developed the WinDS-H2 model, a multi-regional, multi-time-period model of capacity expansion in the electric sector and hydrogen production from wind in the U.S.
- Established a base case scenario to provide an initial basis on which to judge the capabilities of the model and to move forward in improving the assumptions and data.
- Completed the first sensitivity case, which investigated the impact of reduced fuel cell cost on market potential.

Future Directions

- Update results with revised geographic information system (GIS) wind resource data. The revised data incorporates additional land exclusions that reduce the wind resource estimates used in the intial WinDS-H2 analyses.
- Assess different scenarios of markets and costs; for example, a more optimistic scenario for future hydrogen transport costs.
- Continue to refine model and data inputs.
- Expand model capabilities to include additional sources of hydrogen.

Introduction

Today, the most promising renewable electric technology for hydrogen production is wind energy. Wind is promising for several reasons: it is cost effective at many sites today, there is a large U.S. wind resource, hydrogen can provide a form of storage for the intermittent wind resource, and wind resources are spread through many regions of the country, reducing the hydrogen transportation and distribution infrastructure requirements.

Analyzing the market potential for hydrogen production from wind is complicated due to both wind and hydrogen intricacies. The market potential of wind depends on a host of factors unique to wind including wind resources, transmission access, and integration of the intermittent generation into the electric grid. The market potential of hydrogen from wind depends not only on such wind issues, but also on the complexities of hydrogen production, storage, and transport, and competition with hydrogen produced from other resources. To address these complexities, NREL has modified its WinDS model to include hydrogen.

Approach

This is the first progress report on the WinDS-H2 analysis effort. WinDS is a multi-regional, multi-time-period, GIS, and linear programming model, designed to address the principal market issues related to the penetration of wind energy technologies into the electric sector. These principal market issues include access to and cost of transmission, and the intermittency of wind power. WinDS addresses these issues through a highly discrete regional structure, explicitly accounting for the variability in wind output over time (25 two-year periods from 2000 to 2050), and consideration of ancillary services requirements and costs.

The modified WinDS model, WinDS-H2, is expanded to include the production of hydrogen from three competing technologies—wind, steam methane reforming (SMR), and distributed electrolysis (DE) powered by electricity from the grid—along with storage and transportation of hydrogen. The wind-hydrogen system configuration is illustrated in Figure 1.

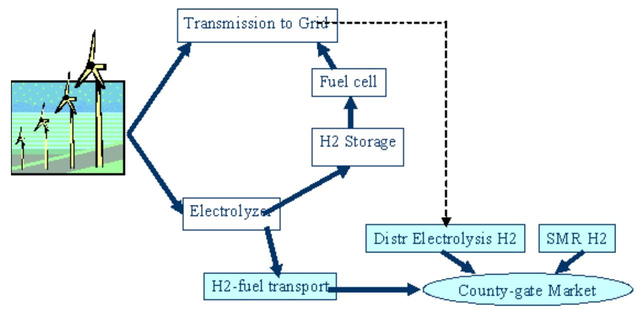

Figure 1. Hydrogen Components in WinDS-H2

WinDS-H2 assumes that a market for hydrogen fuel exists in each city throughout the nation, and that hydrogen is one of many alternative fuels that can be used to meet the demand for transportation fuels. WinDS-H2 determines how much of the demand will be met by hydrogen supplied by each of the three competing sources of hydrogen – wind, SMR, and DE. If none of them can make a profit at the exogenously specified hydrogen price, then none will provide hydrogen in that city and the transportation fuel demand will have to be met by an alternative fuel. Since all three hydrogen sources provide hydrogen at the city-gate, the infrastructure or costs associated with storing and moving the hydrogen to the end-use point of consumption (the service station) is modeled within WinDS-H2.

Hydrogen from Wind: The hydrogen produced by a wind farm can be used either as hydrogen fuel which is shipped to the city-gate hydrogen fuel market or at the wind site within a fuel cell. The wind farm can also produce electricity which goes directly to the grid at the time of generation. Additionally, the wind farm electrolyzers can use grid power during off-peak periods. When a wind farm is installed, WinDS-H2 optimizes the fraction of the capacity in the wind farm which will generate electricity for direct use on the grid, with the remaining fraction of the capacity in the wind farm allocated to the production of hydrogen. The electrolyzer(s) at the wind farm are assumed to operate whenever the wind blows using power provided by the dedicated wind turbines. The hydrogen is assumed to either be transported immediately for use as a fuel or stored at the wind site until it is needed to power a fuel cell during peak demand times. Storage is sized for one day of output from the fuel cell. Fuel cells at the wind site are assumed to operate only during the peak electric demand portion of the day and only when there is transmission capacity available; for example, if the wind farm is generating at full capacity there will not be transmission capacity available for any generation by the fuel cell.

Hydrogen from SMR and DE: The SMR and DE systems are assumed to be located at the city-gate; that is, close to load to take advantage of economies of scale and to minimize fuel distribution requirements. Both the SMR and DE are assumed to operate around the clock. The electricity required to operate the DE system adds to the load (and the reserve margin requirements) of the grid. The cost of the electricity consumed by the DE is assumed to be captured by the endogenous cost of generating and transmitting wholesale electricity within WinDS, plus an adder for the cost of distributing power to an industrial user.

Transport of Hydrogen: Hydrogen produced from wind within a region can either be used in the region or shipped to another region. The model assumes the cost of shipping hydrogen from one region to another is composed of a fixed cost that is invariant with respect to the distance (for example, the cost of liquefying hydrogen for shipment in a tanker) and a variable cost that increases proportionately with the distance (for example, the cost of building a pipeline or driving a tanker).

Results

A limited number of cases have been simulated with the WinDS-H2 model: a no-hydrogen case, the base case, and a reduced fuel cell cost case. These results (obtained during model validation) are preliminary but give an idea of the types of possible analyses and results.

No Hydrogen Case: This case is simply the base case of the WinDS model - a case in which hydrogen production is not simulated. It is useful as a point of comparison to see the impact of including hydrogen as an option for wind production. In this case, wind provides about 149 gigawatt (GW) of capacity in 2050, far larger than today's 6 GW. This growth is

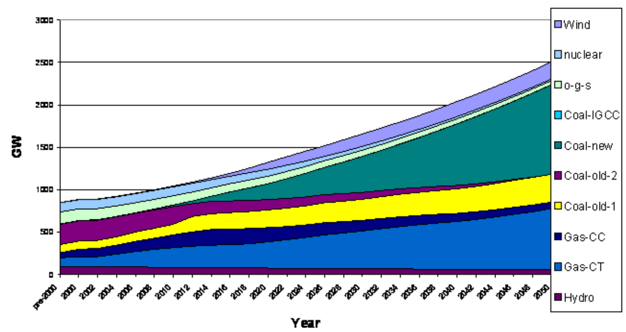

Figure 2. National Electricity in the Base Case

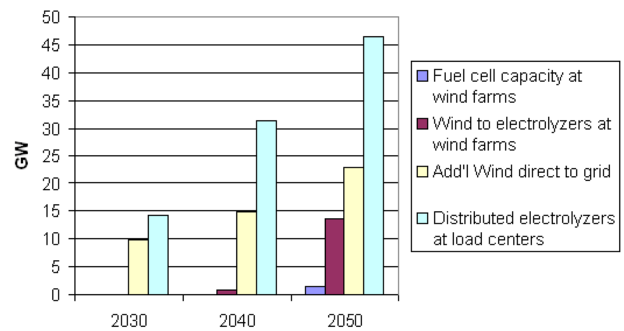

Figure 3. Capacities in the Base Case

largely attributable to improvements in the cost and performance of wind turbines.

Base Case: As shown in Figures 2 and 3, by 2050 the installed wind capacity providing power directly to the grid increases by 23 GW compared to the no-hydrogen case. This increase is at least partially enabled by 1.4 GW of fuel cells built between 2040 – 2050 that firm up some of the additional wind to the grid. However, in 2050 the bulk of the additional wind tied directly to the grid can be attributed to the increased national annual electric load of 384 TeraWatt-hr (TWh) induced on the grid by the 46 GW of distributed electrolyzers at the city-gate.

The wind capacity in Figure 2 is only the wind capacity that provides electricity directly to the grid. It does not include the 13.6 GW of wind capacity that fuels electrolyzers at wind farms, nor does it include the 1.4 GW of fuel cell capacity that backs up the wind to the grid from nine wind sites. These nine wind sites are in regions with high quality winds that by 2050 will be extensively developed.

Wind is also used in very limited amounts in the base case to produce hydrogen as a transportation fuel. The transportation fuel demand is initially met by hydrogen produced from natural gas-fired steam methane reformers. Later, as gas becomes more expensive and the steam methane reformers are retired, distributed electrolyzers and hydrogen fuel from wind begin to enter the market. However, in most regions, the hydrogen sources are too expensive and cannot compete at the assumed hydrogen market price of $2.00/kilogram (kg). In these later years, the remaining transportation fuel demand must be met by sources other than hydrogen.

Sensitivity Case 1 – Reduced Fuel Cell Cost: We examined the possibility that fuel cell costs might drop below the program goal for stationary fuel cells to $200/kWe. In this case, the number of fuel cells installed at wind sites would grow to 93 gigawatt electric (GWe) by 2050. These fuel cells would be supplied with hydrogen by 52 GWe of electrolyzers, which also contribute 1.4 billion kg of hydrogen for use as transportation fuel. Compared to the base case, these fuel cells lead to an increase in the amount of wind energy that is supplied directly to the grid; more wind can be built for the grid since it is firmed by the fuel cells and because the fuel cell output must be transmitted on lines largely paid for by new wind capacity tied directly to the grid.

Conclusions

If the hydrogen program reaches its technology cost performance goals by 2010, a limited amount of wind energy will be an economic source of hydrogen at $2/kg at the city-gate. However, should the cost of fuel cells fall below the costs of combustion turbines, substantial wind-hydrogen capacity might be installed to increase the availability of electricity generated from wind power. This would not only provide additional capacity credits to wind power, but would also reduce ancillary service requirements induced by wind power, minimize surplus wind generation at times of low electric demands, and increase the loading on transmission lines built to carry wind power.

Transportation costs for hydrogen will have to be significantly reduced before wind-produced hydrogen will be a major source of transportation fuel. If natural gas prices rise to the point that SMR is not the preferred production option, large distributed electrolyzers at centralized locations are likely to be less expensive sources of hydrogen than hydrogen transported from wind farms.

FY 2004 Publications/Presentations

1. Short, W., Heimiller, D., and Berlinski, M., 2004, *Assessment of the Role of Wind Energy in the Production of Hydrogen: Market Models and Technology Opportunities*, Paper presented at the National Hydrogen Association Annual Meeting, Los Angeles, CA, April 2004.