XI.9 Resource Analysis for Hydrogen Production

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Fiscal Year (FY) 2012 Objectives

- Understand the hydrogen production requirements for a future demand scenario
- Estimate low-carbon energy resources required to meet the future scenario demand
- Compare resource requirements to current consumption and projected future consumption
- Determine resource availability geographically and on a per kg hydrogen basis
- Estimate fuel cell electric vehicle (FCEV) miles traveled per quad of resource

Technical Barriers

This project addresses the following technical barrier from the Systems Analysis section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(C) Inconsistent Data, Assumptions and Guidelines

Contribution to Achievement of DOE Systems Analysis Milestones

This project will contribute to achievement of the following DOE milestone from the Systems Analysis section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- Milestone 1.9 (Systems Analysis Task 1: Perform Studies and Analysis): Complete analysis and studies of resource/feedstock, production/delivery, and existing infrastructure for technology readiness. (4Q, 2014)

FY 2012 Accomplishments

- Incorporated updated renewable energy resource potential data used for hydrogen production potential estimates [1].
- Updated conversion efficiencies based upon revised Hydrogen Analysis (H2A) production case studies.
- Revised demand scenario to meet an illustrative FCEV market share projection by 2040.
- Incorporated new resource data on fossil and uranium resources from the Energy Information Administration (EIA).
- Incorporated new energy consumption projections based upon EIA forecasts.
- Updated resource maps for biomass, wind and solar energy hydrogen production potential.

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Introduction

The widespread adoption of hydrogen vehicles would result in a shift in reliance on fuels produced from petroleum to reliance on other primary energy resources. The present study examines the degree to which these other resources would be consumed with respect to: (1) the existing resource base, and (2) projections of future consumption by FCEVs in 2040. Hydrogen can be produced from any primary energy resource. Rather than predicting the mix of resources that may be relied upon given future policy, technology, and market dynamics, this study examines a series of simple scenarios in which 50% of a future hydrogen demand level is derived from any one of six primary energy resources: natural gas, coal, nuclear (uranium), biomass, wind and solar (photovoltaic [PV] with electrolysis). In addition to estimating total resources required in 2040, resource maps of production potential by county have been updated to match new resource assessment results for biomass, wind and solar [1] as well as updated H2A production conversion efficiencies [2]. The projected increase in consumption of each resource in 2040 is determined as a percentage of projected consumption in the 2012 Annual Energy Outlook (AEO) Reference Case for future energy consumption [3].

Approach

A demand scenario is developed in which 100 million FCEVs have been deployed by 2040. We assume that these FCEVs travel, on average, 12,000 miles per year and achieve an on-road fuel economy of 60 miles per kg of hydrogen, which is roughly equivalent to 60 miles per gallon of gasoline [c.f., 4]. This results in a demand of 20 million metric tonnes (MMT) of hydrogen in the year 2040. For our resource consumption scenarios, we examine requirements for each resource to provide 50% of this total demand, or 10 MMT of hydrogen per year by 2040. Table 1 lists the resources examined, conversion processes, resource required per kg of hydrogen produced (in physical units), production efficiency and the number of FCEVs that would be supported by conversion of one quad of each resource. In all calculations we only consider production efficiencies and do not account for additional conversion losses or energy inputs required for storage and delivery of the hydrogen between the point of production and dispensing at the hydrogen refueling station. The influence of conversion losses from these additional supply chain phases on resource requirements will vary between resource types; this influence is omitted here for the sake of simplicity [5,6,7].

To place resource requirements in context, we compare them with estimates of energy resources available today (e.g., reserves or annual potential) and projected consumption in 2040. Resource availability estimates are taken from multiple sources. Resource estimates for natural gas, coal and uranium are from the Energy Information Administration's Annual Energy Review 2012 [8], and biomass, wind and solar resource potentials are from a recent update of renewable resource potential [1]. Projected consumption is determined based upon a linear extrapolation of demand trends between 2025 and 2035 reported from the AEO 2012 Reference Case. Hydrogen production conversion efficiencies, shown in Table 1, are taken from the updated H2A Production Case Studies [2,9].

TABLE 1. Primary energy resource, conversion process, physical units per kg hydrogen, production efficiency and FCEVs supported per quad

Resource	Conversion Process	Resource per kg hydrogen produced (physical units)		Production Eff. (E_{out}/E_{in}, HHV)	Million FCEVs per quad
Natural gas	SMR	143	scf	86%	37
Coal	Gasification	9.8	kg	61%	26
Uranium	Nuclear fission	0.35	mmBtu	35%	15
Biomass	Gasification	13	kg (bone-dry)	60%	26
Wind	Electrolysis	46	kWh	86%	37
Solar	PV or ThChem	46	kWh	86%	37

Notes: SMR = steam methane reforming; PV = photovoltaic; Production efficiency is the energy of the hydrogen produced (Eout) divided by the energy of the primary resource input to the production process (Ein) on a higher heating value (HHV) basis; Uranium efficiency refers to the heat energy input used in a turbine; million FCEVs supported per quad of energy resource converted assumes 12,000 vehicle miles traveled/year and 60 miles per kg hydrogen.

Results

Analysis results for non-renewable resources are summarized in Table 2 and results for renewable resources are summarized in Table 3. The tables show total resource availability, current consumption in 2012, projected consumption in 2040, and the quantity of resource needed to produce 50% of projected hydrogen demand in 2040. The increase in projected consumption is indicated in the last column, shown as a factor calculated using the following equation:

$$\text{Increase Factor} = \frac{\text{Projected} + \text{Needed for 50\%}}{\text{Projected}}$$

This factor result can also be read as a percentage. The additional hydrogen required to produce 50% of projected demand in 2040 would require the following percentage increases in projected consumption: 5% increase in natural gas, 10% increase in coal, 44% increase in nuclear, 33% increase in biomass, 153% increase in wind, and a 575% increase in solar. Figure 1 places current and projected consumption values on an equivalent energy basis to further highlight relative reliance of each resource to meet 50% of projected demand in 2040. Additional resources needed for hydrogen production are shown as a stacked bar on top of projected AEO consumption in 2040. It should be noted that these projected consumption values are based upon business-as-usual policy and technology input assumptions. Arguably, any scenario resulting in 100 million FCEVs by 2040 would include policy and market factors that would likely also

TABLE 2. Hydrogen production resource potential for non-renewable resources

Carbon Neutral Resource	Availability [a]	Current Consumption (2012) [b]	Projected Consumption (2040) [a]	Needed to Produce 50% of all Hydrogen	Increase in Projected Consumption
Natural Gas	2,543 trillion cubic feet (total technically recoverable resources)	25 trillion cubic feet	27 trillion cubic feet	1.4 trillion cubic feet	1.05
Coal (with sequestration)	441 billion tonnes (demonstrated reserve base)	870 million metric tonnes/year (all grades)	992 million metric tonnes/year (all grades)	98 million metric tonnes/year	1.10
Nuclear	6,077 million pounds at <$50/lb (reserves and estimated additional resources)	102 GWe	120 GWe	53 GWe	1.44

Notes: (a) availability values are from Annual Energy Review 2010, (b) current and projected consumption values are from AEO 2012 Early Release, Reference Case.

TABLE 3. Hydrogen production resource potential for renewable resources

Carbon Neutral Resource	Availability [a]	Current Consumption (2012) [b]	Projected Consumption (2040) [b]	Needed to Produce 50% of all Hydrogen	Increase in Projected Consumption
Biomass	Between 0.4-1.1 billion dry tonnes/year	160 million metric tonnes/year	389 million metric tonnes/year	130 million metric tonnes/year	1.33
Wind	3,750 GWe (nameplate capacity, not power output)	130 billion kWh	300 billion kWh	460 billion kWh	2.53
Solar (PV)	32,300 GWe (capacity, full U.S.)	2.15 billion kWh	80 billion kWh	460 billion kWh	6.75

Notes: (a) availability values are from a forthcoming NREL report [1], and high biomass estimate is based upon the recent Billion Ton Study, (b) current and projected consumption values are from AEO 2012 Early Release, Reference Case.

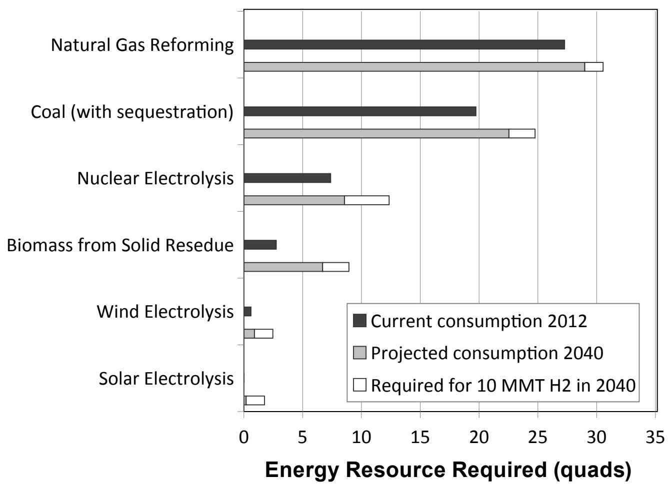

FIGURE 1. Current and projected resource consumption compared to resource requirements to provide 50% of hydrogen demand in 2040.

influence consumption of these resources for other end uses. For example, if a high penetration of FCEVs arises within a carbon-constrained future, it might be expected that all resource consumption values would be lower due to energy efficiency measures and that lower-carbon resources (e.g., nuclear and renewables) would increase in relative use due to greater market pull.

Renewable hydrogen production potential estimates at the county level, previously reported by Milbrandt and Mann [10], have been updated based upon updated conversion efficiencies and resource estimates for biomass, wind and solar resources. Updated resource estimates for biomass, wind and solar are based upon a consistent basis for technical potential, rather than market, economic or theoretical physical potential [1]. This spatial representation of production potential provides insight into which regions may rely upon different hydrogen supply pathways, especially in carbon-constrained scenarios or market conditions that result in a premium on low-carbon hydrogen.

Several important factors must be considered to better understand the spatial aspects of this resource production potential:

- Biomass resources will evolve over time in response to various market forces and policy constraints. Technical availability may increase significantly beyond what has been estimated for "current" potential today. Market availability may prove to be more of an issue than technical availability, in part due to competition among end uses.
- A more detailed time series model would capture plant production efficiency increasing over time and with economies of scale. This may result is slightly higher resource requirements due to inefficiencies of older vintage plants.
- Previous studies suggest that wind farms that generate both electricity (for baseload transmission) and hydrogen (during peak peak supply) may prove economically favorable. This may also alter our technical resource potential estimates.
- Fuel economy of FCEVs is a critical input, especially when comparing resource requirements among multiple vehicle types and fuel pathways.

Conclusions and Future Directions

Hydrogen production requirements for a future demand scenario to 2040 have been estimated with respect to natural gas, coal, nuclear (uranium), biomass, wind and solar resources. Providing 50% of hydrogen demand in 2040 would require relatively small increases in projected consumption of natural gas (5%) or coal (10%) resources, and more significant increases in projected consumption of nuclear (44%), biomass (33%), wind (153%), and solar (575%) resources. Future work would consist of the following:

- Compare resource use across multiple fuel types (e.g., biofuels or electricity).
- Assess regional variations in resource potential with respect to regional demand.

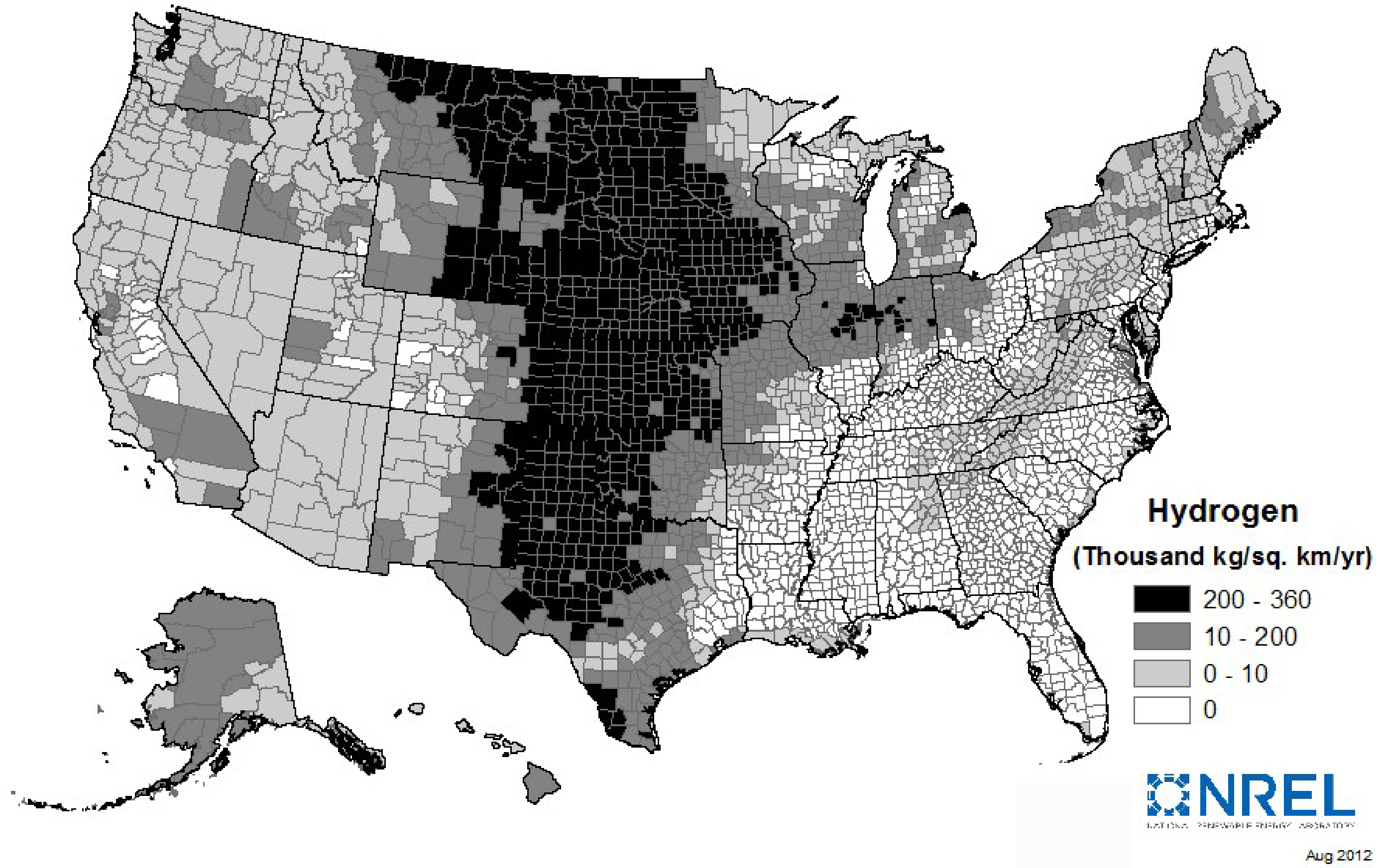

FIGURE 2. Hydrogen potential from onshore wind resources. This analysis represents potential generation form onshore wind turbines at 80 m height above ground, with a power density of 5 MW/sq. km. It excludes environmental and land use areas, and areas with slope greater than 20%.

- Contribute to resource-constrained scenarios of transportation energy use.
- Incorporate estimates of non-light-duty vehicle fuel demands, such as aviation biofuels.
- Contribute to supply curve calculations for low-carbon scenarios.

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