Resource Analysis for Hydrogen Production

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Project ID: AN026

Overview

Timeline	Barriers
Project Start Date: October 2009 Project End Date: September 2012 Percent Complete: 65%	4.5 E. Unplanned Studies and Analysis • Response to DOE request
Budget	**Partners**
Total project funding – DOE share: $65,000 – Contractor share: none Funding received in FY11: $15k Funding for FY12: $25k	Interactions / collaborations • Internal to NREL only Project lead: M. Melaina • Project team: M. Penev and D. Heimiller

Resource Analysis for Hydrogen Production

Analysis involves estimating energy resources required to support part of the demand generated by 100 million FCEVs in 2040

- Fuel Cell Technologies Program
- Industry input in the development of H2A
- Program experts on technical resource potential

Analysis Framework

Data:

- H2A v3 Production Case Studies
- EIA 2012, Annual Energy Outlook, Early Release
- EIA 2011, Annual Energy Review, 2010
- NREL Resource Potential Report, forthcoming

→

Models & Tools

- H2A v3 Production Case Studies
- SERA vehicle stock model

→

Studies & Analysis

- Hydrogen Resource Potential
- Long-term Analysis
- Environmental Analysis

→

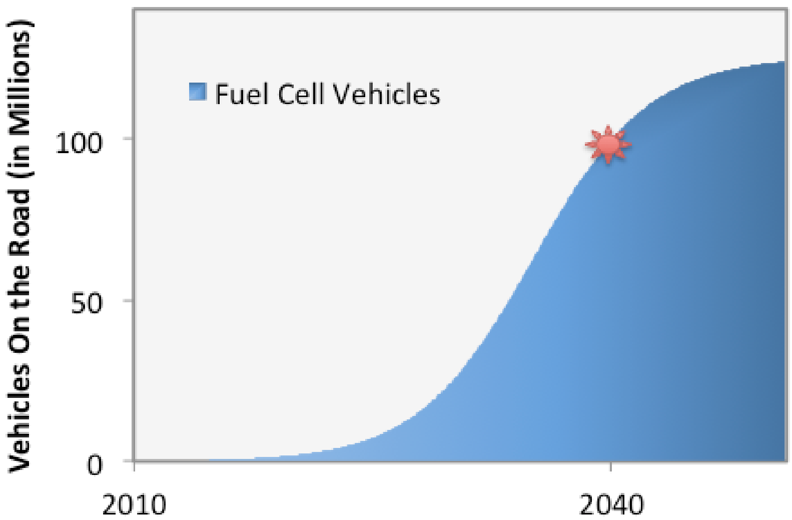
Outputs & Deliverables

Resource Potential Report

Objectives 1 & 2

1. Understand the hydrogen production requirements for a future demand scenario

- Demand Scenario for 2040
  - 20 million tonnes* hydrogen
  - Approx. 100 million fuel cell electric vehicles (FCEVs)



2. Estimate low-carbon energy resources required to meet the future scenario demand

- Estimate the hypothetical resources needed to supply 50% (10 million tonnes H2) of the 2040 demand from each of the following energy resources:
  - Natural Gas
  - Coal (with CCS)
  - Nuclear
  - Biomass
  - Wind
  - Solar

* 1 tonne = 10^3 kg

Objectives 3 - 5

Relevance [2]

3. Compare resource requirements to current consumption and projected future consumption

4. Determine resource availability geographically and on a per kg hydrogen basis

5. Estimate fuel cell electric vehicle miles traveled per quad of resource

Technical Approach: Demand & Production

Simple energy balance calculations are used to determine resources required to produce hydrogen from multiple sources to meet demand generated by 100 million FCEVs in 2040

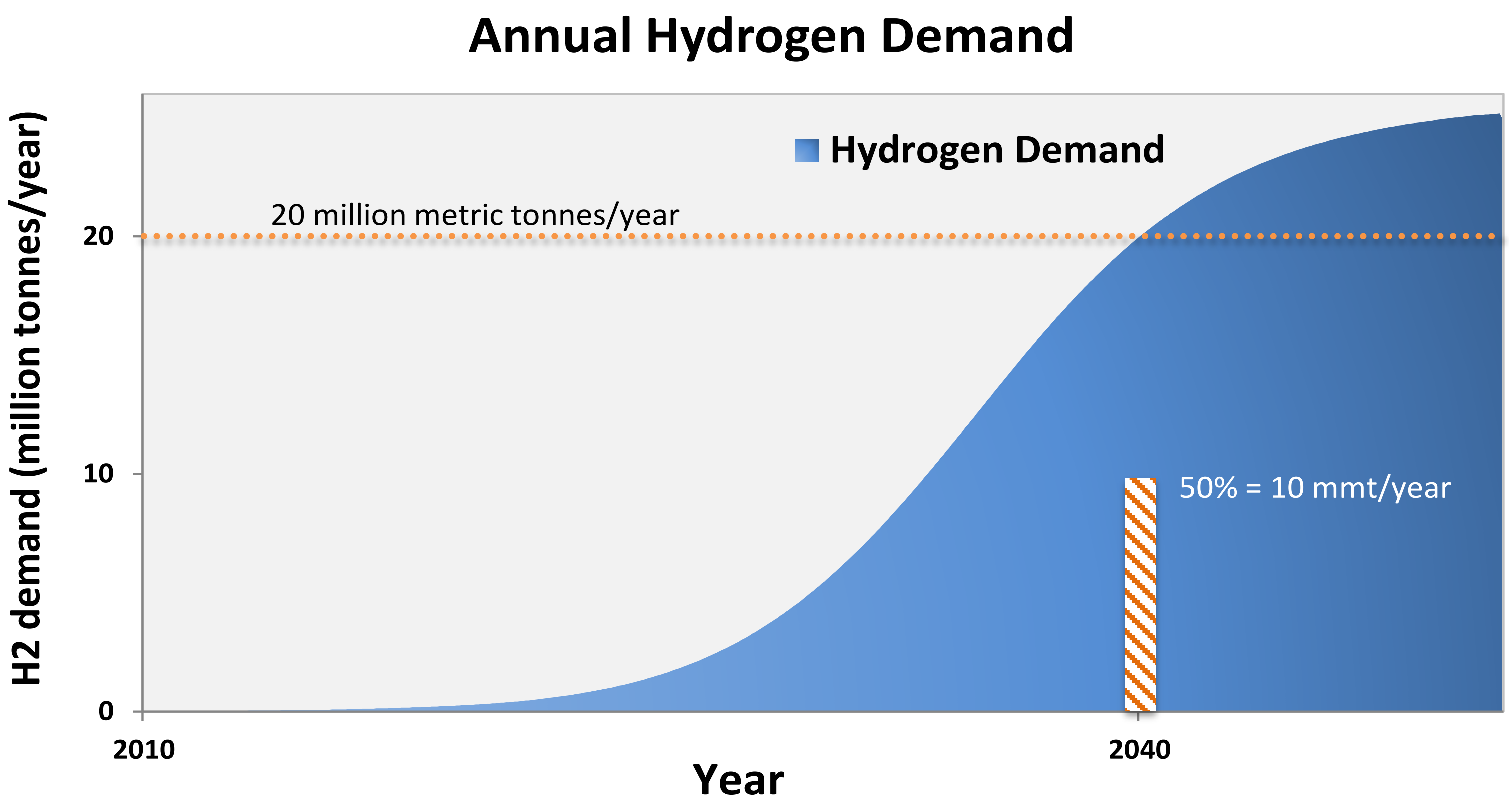
- Basic parameters include production efficiency, vehicle miles traveled and average FCEV fuel economy
- The SERA stock model has been used as basis for total national demand (SERA = Scenario Evaluation and Regionalization Analysis model)
- Temporal and spatially disaggregated details for the same scenario can serve as a baseline for future SERA scenario work

The mix of production sources in 2040 is not estimated here. Instead, we estimate what would be needed for any single resource examined to provide 50% of total demand.

Analysis is for plant-gate hydrogen production potential only

- Storage and delivery pathway efficiencies are not taken into account
- The efficiency of delivery pathways would vary regionally and between resource types, but these are best analyzed within a dynamic cost optimization framework (as has been done elsewhere using the SERA model)

Providing 50% of total demand from each respective energy resource



Basis:

- 12,000 annual miles travelled
- 60 miles/kg hydrogen
- 100 million total vehicles
- 50% = 10 million tonnes hydrogen per year

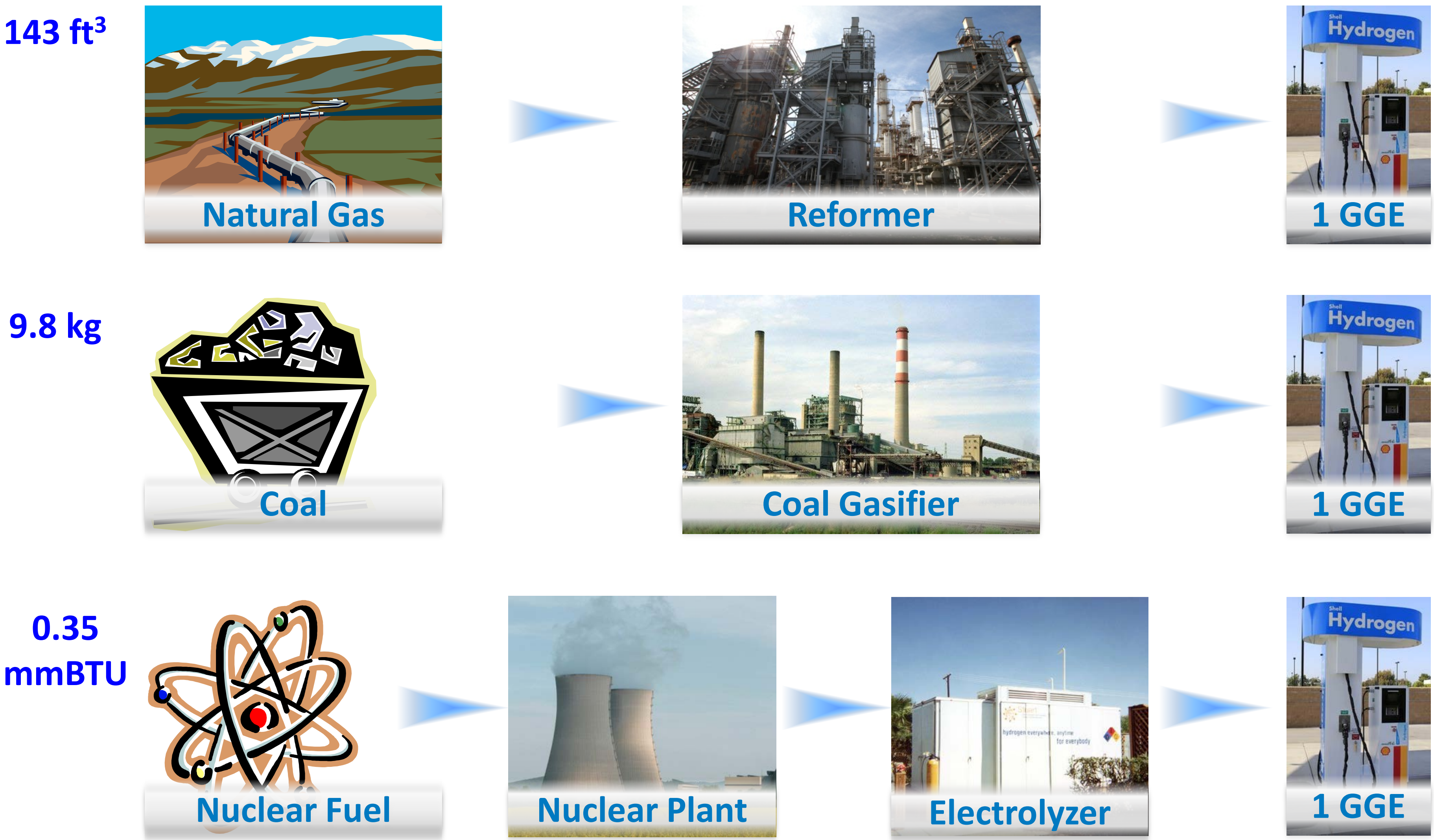
The adoption curve shown is an example only. An urban-based, spatially disaggregated curve with detailed early market take-off dynamics has been developed using the SERA model.

Conversion efficiencies for non-renewable feedstock (per 1 kg)

Approach [3]

(1 kg hydrogen is approx. 1 Gallon of Gasoline Equivalent [GGE])

Most values are taken from H2A Case Studies



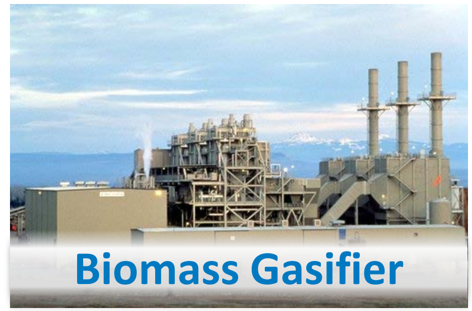
Conversion efficiencies for renewable feedstock (per 1 kg)

Approach [4]

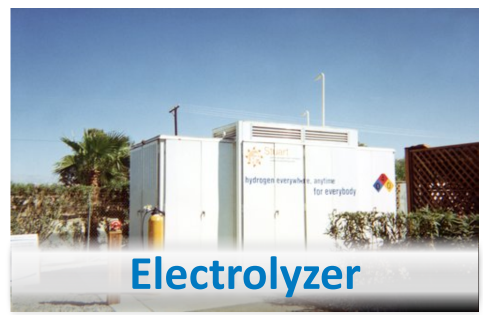
(1 kg hydrogen is approx. 1 Gallon of Gasoline Equivalent [GGE])

Most values are taken from H2A Case Studies

13 kg
bone-dry



46 kWh



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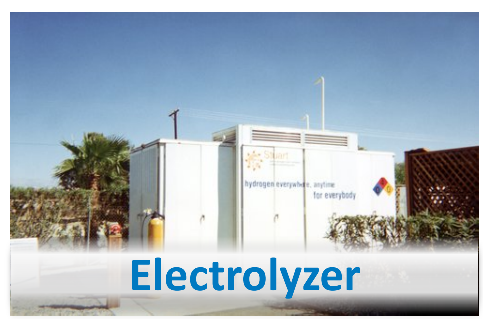
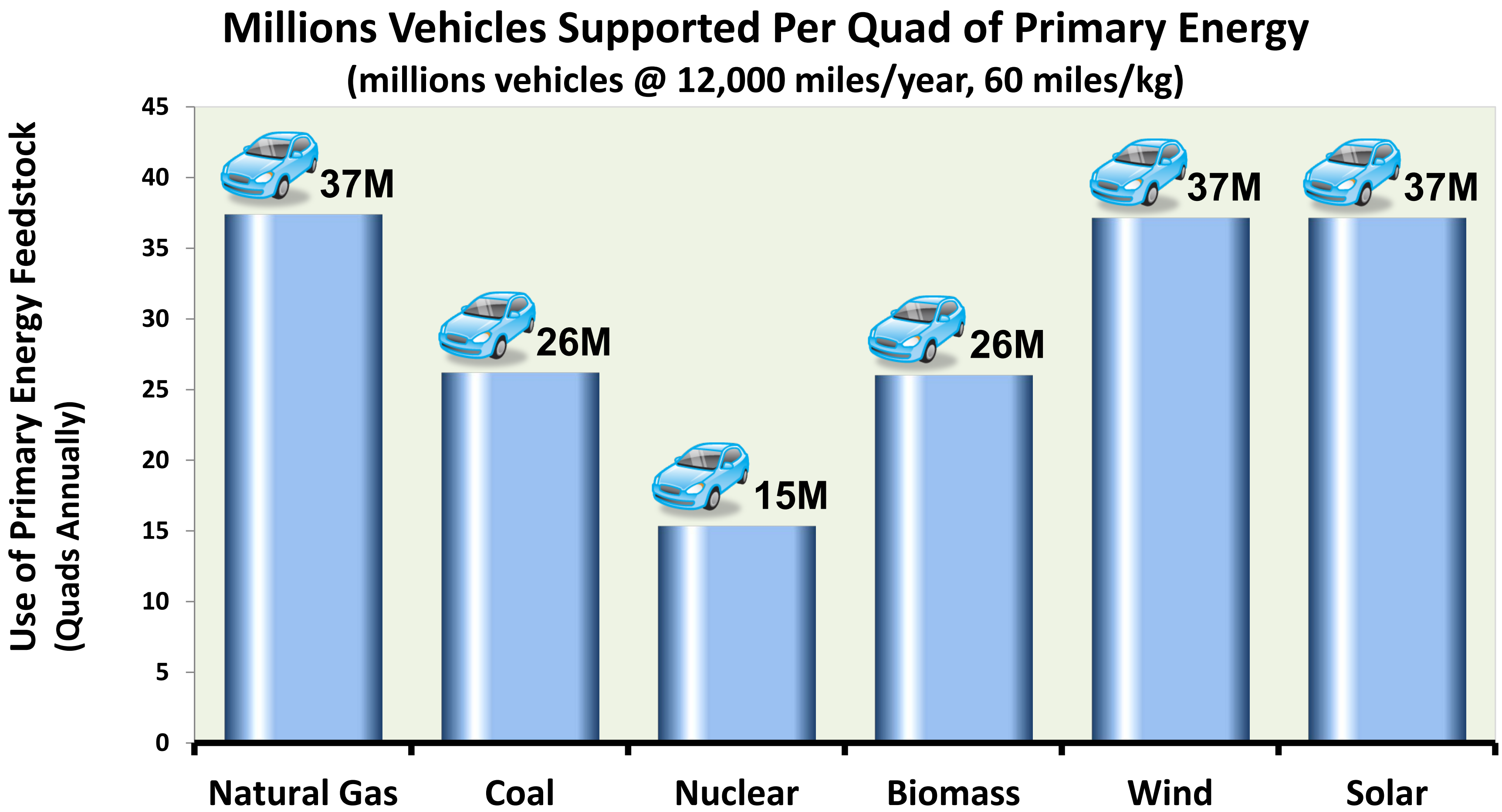


Resource Utilization Effectiveness

Accomplishments and Progress [1]



Estimates can serve as a basis for more complete comparisons of effective use of primary energy resources within transportation or other sectors

Production via Non-Renewables

Accomplishments and Progress [2]

Carbon Neutral Resource	Availability [a]	Current Consumption (2012) [b]	Projected Consumption (2040) [a]	Needed to Produce 50% of all Hydrogen	Increase in Projected Consumption
Non-renewable pathways					
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 & estimated additional resources)	102 Gwe	120 Gwe	53 GWe	1.44

[a] Availability values are from Annual Energy Review 2010.
[b] Current and projected consumption values are from AEO 2012 Early Release.

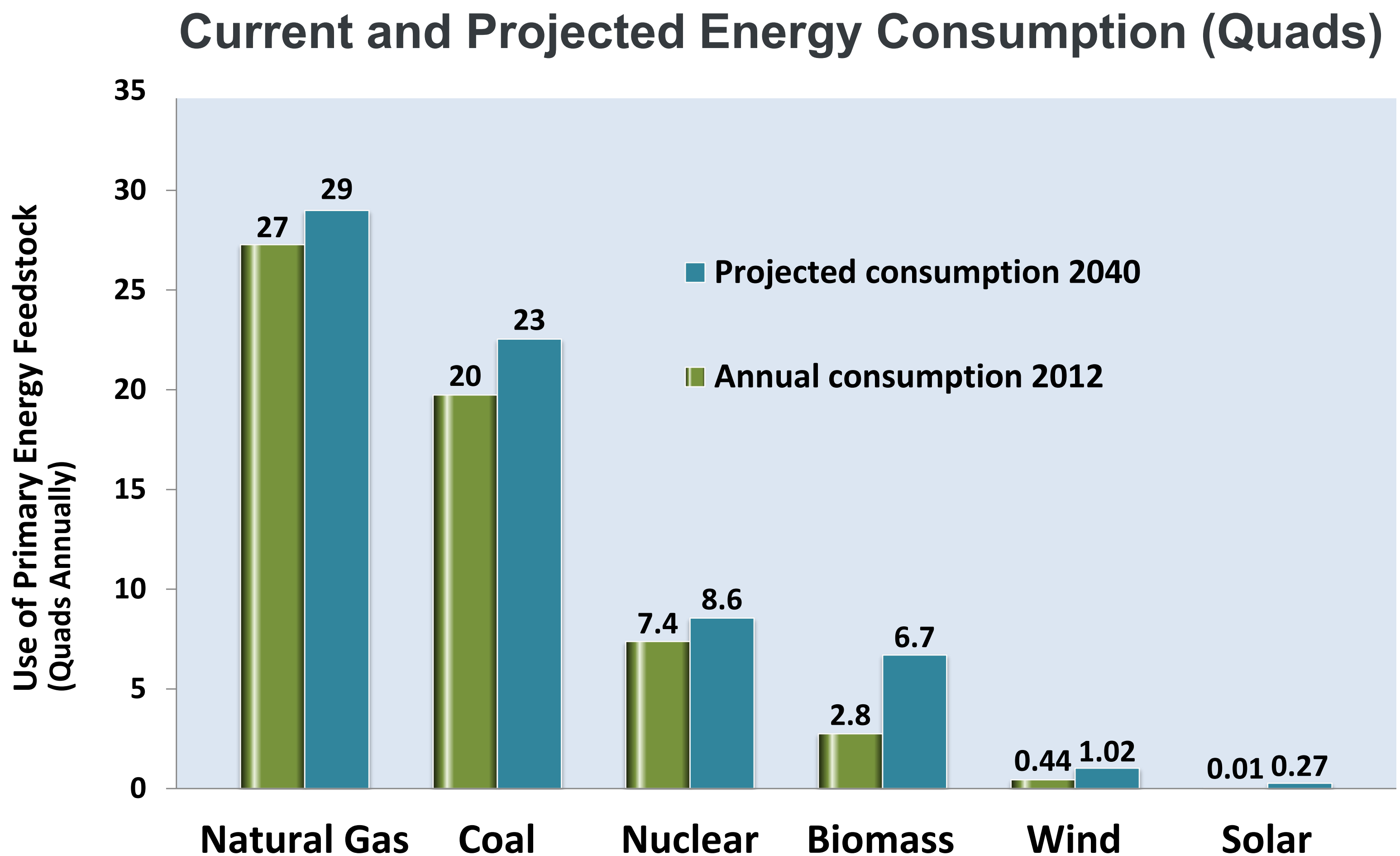
Production via Renewables

Accomplishments and Progress [3]

Carbon Neutral Resource	Availability [c]	Current Consumption (2012) [b]	Projected Consumption (2040) [b]	Needed to Produce 50% of all Hydrogen	Increase in Projected Consumption
Renewable pathways					
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 (Photovoltaic and Thermochemical)	32,300 GWe (capacity, full U.S.)	2.15 billion kWh	80 billion kWh	460 billion kWh	6.75

[b] Current and projected consumption values are from AEO 2012 Early Release.
[c] US Renewable Energy Technical Potential Report, NREL Publication, forthcoming. High biomass estimate is based upon recent update to the Billion Ton Study.

Increase in Projected Consumption

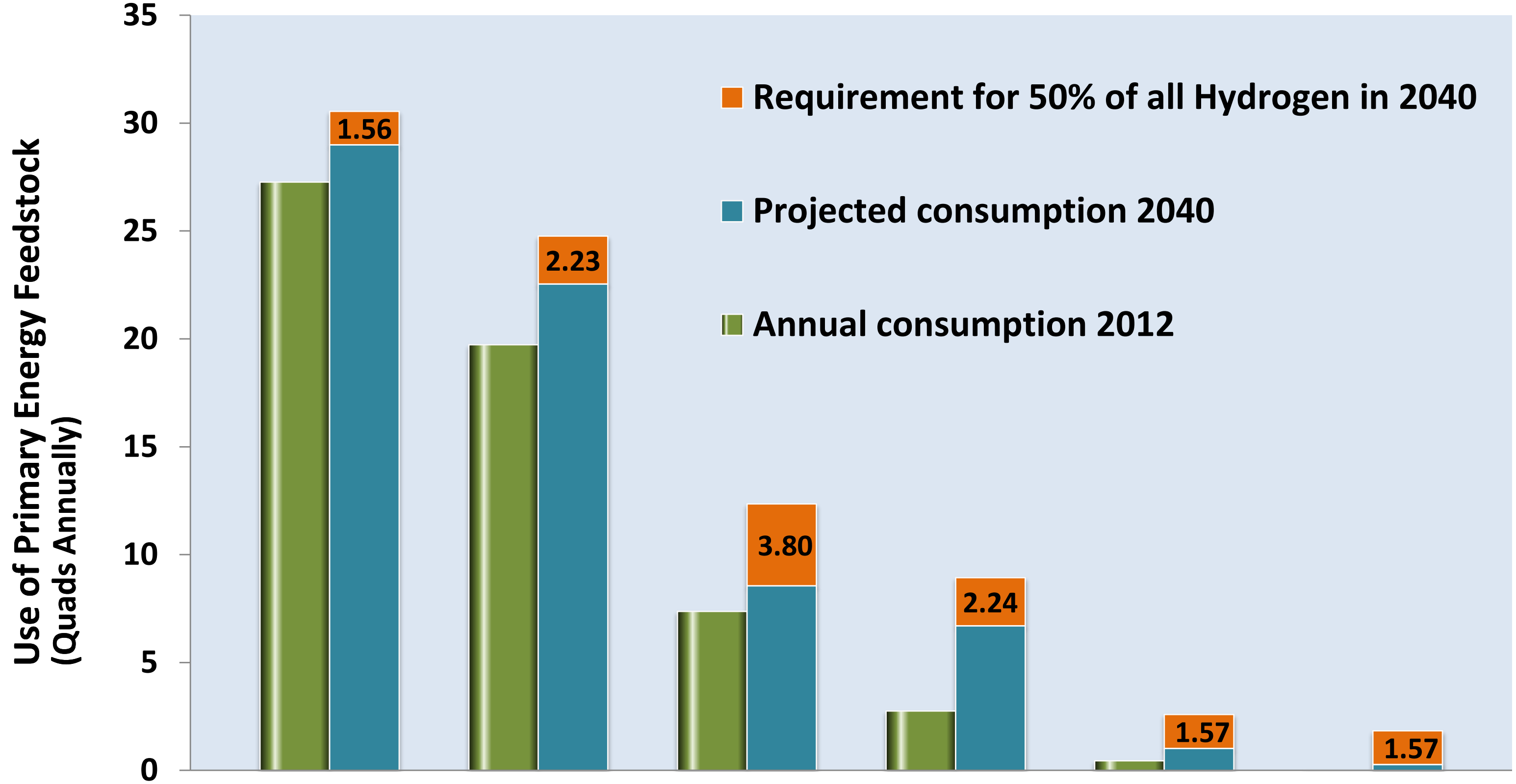


Providing 50% of hydrogen demand from each of these resource types would increase projected consumption in 2040. But to what degree?

Percent Increase in Projected Consumption by Supplying Hydrogen

Accomplishments and Progress [5]

Percent Increase = (Projected + Required for 50% hydrogen)/Projected



	Natural Gas	Coal	Nuclear	Biomass	Wind	Solar
Percent Increase	1.05%	1.10%	1.44%	1.33%	2.53%	6.75%

Results: Updated Calculations for Technical Resource Potential

Accomplishments and Progress [6]

Resource potential maps and GIS data have been updated using new H2A conversion efficiencies and resource potential results

Market Potential
(policy, competition, etc.)

Economic Potential
(projected costs)

Technical Potential
(constraints, performance)

Theoretical Physical Potential
(energy content of resource)

Resource Potential Quantity

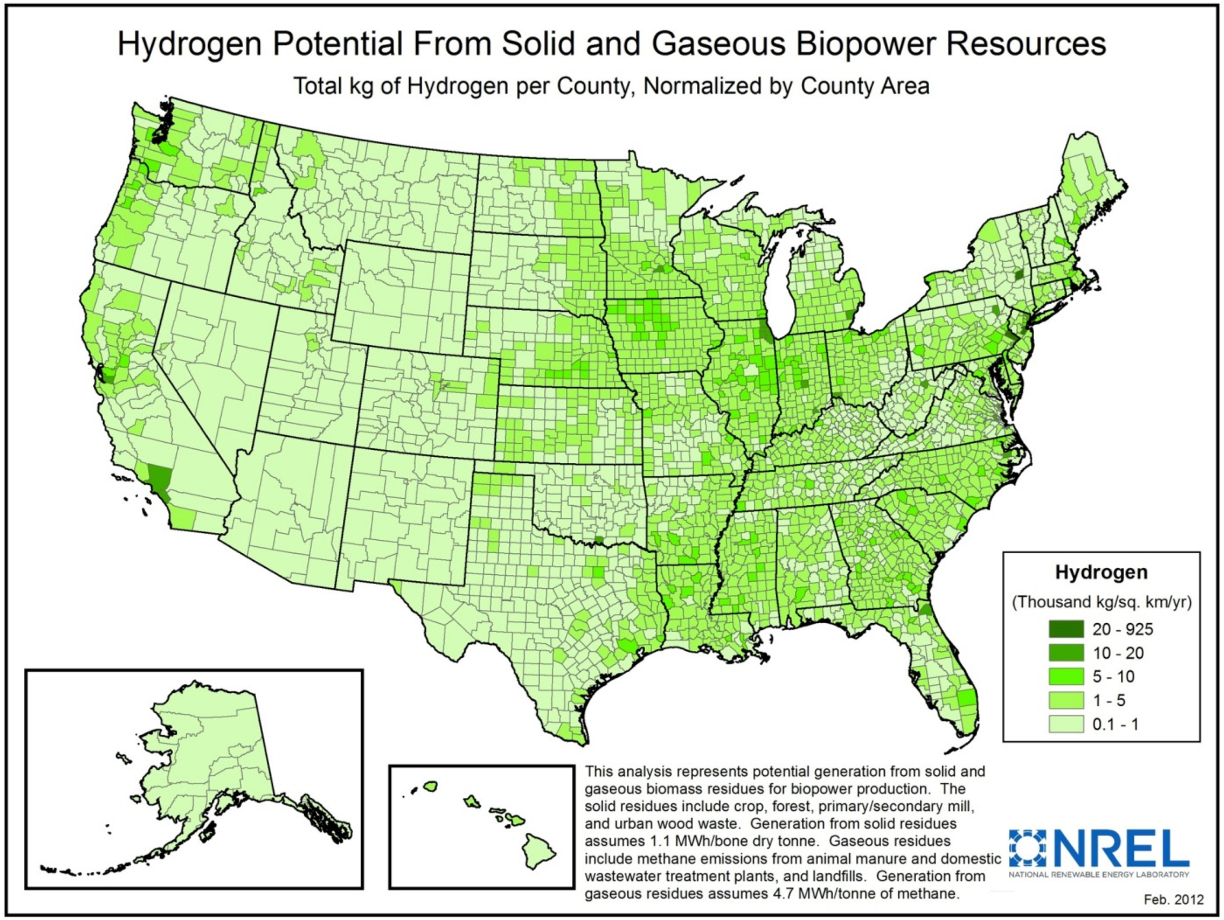
Our revised estimates of hydrogen production potential from renewable energy resources are based upon an updated and consistent calculation of *Technical* potential

- Many studies of renewable energy resource potential have been completed. Many are inconsistent.
- Our estimates are based upon ongoing work to compare the *Technical Potential* (see figure) consistently across renewable energy technologies
- Figure is based upon a forthcoming NREL report

Results: Hydrogen from Biomass

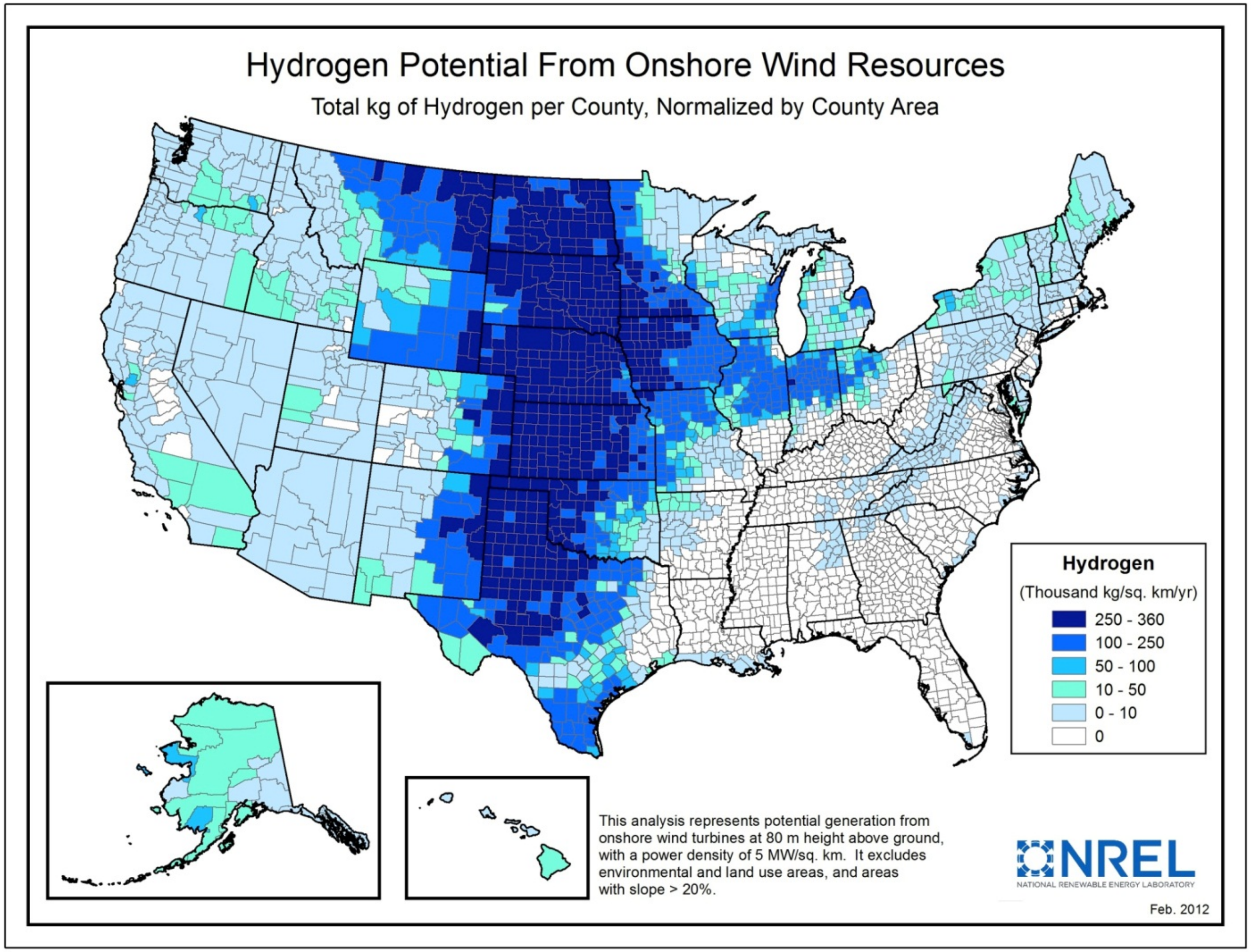
Accomplishments and Progress [7]

Updates are based upon estimates of current biomass resources that could also be used for biopower applications



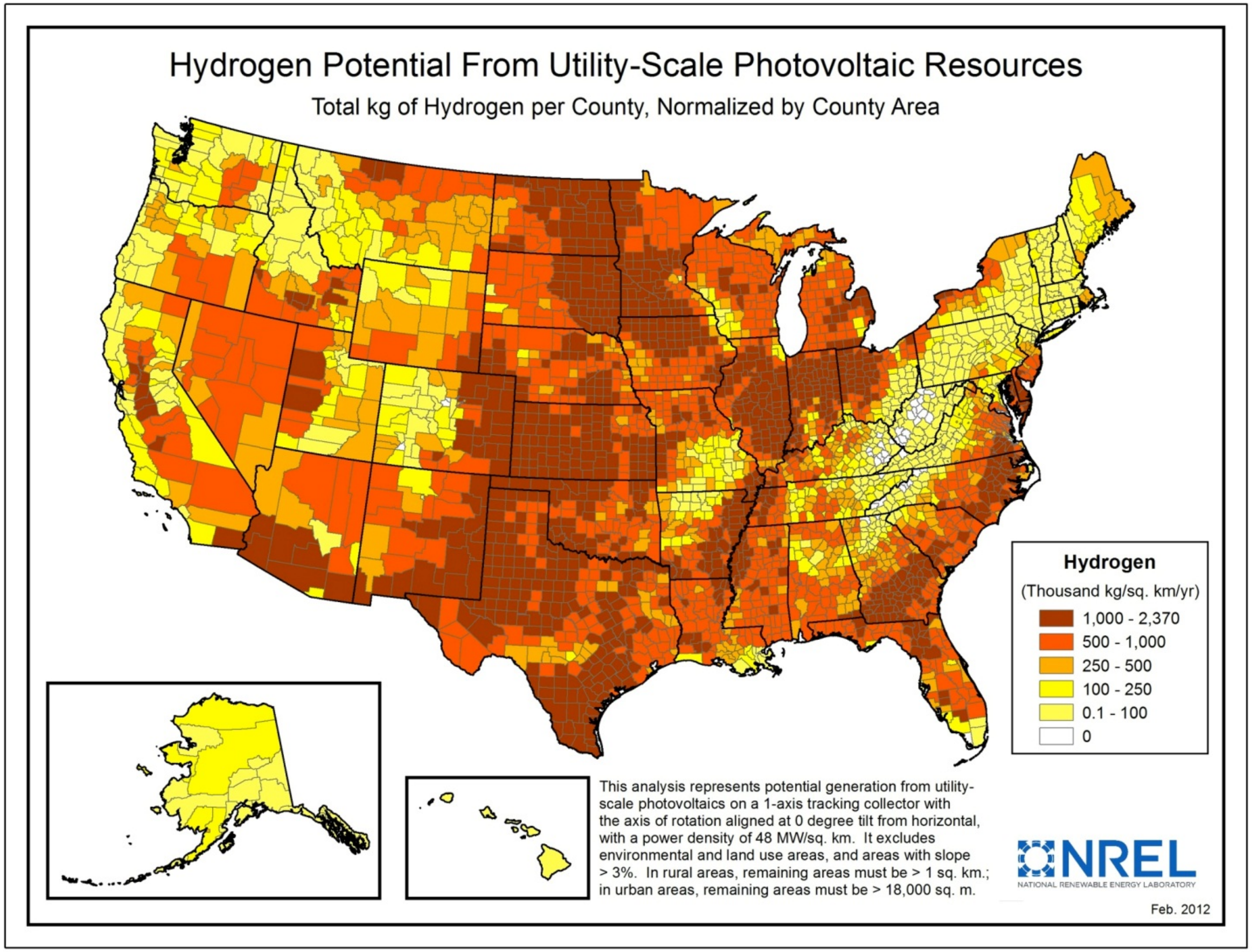
Results: Hydrogen from Wind

The distribution of wind resources raises the question of optimally transmitting wind as electricity or hydrogen. This is an ongoing analysis topic.



Results: Hydrogen from PV

Revised solar PV potential data take into account more realistic technology performance assumptions, including tracking and system footprint



Collaboration

- **H2A conversion rates were determined by way of extensive stakeholder collaboration and expert review**
  - H2A Case Studies have gone through multiple reviews since 2005 and were originally developed by a collaborative group of “Key Industrial Collaborators” (KIC)
- **Input assumptions and data sources have been reviewed with respective NREL program analysts**
- **Results of the analysis will be submitted to a peer-reviewed journal**

Continued Resource Analysis

Proposed Future Work [1]

A summary report will be published on the present analysis

Future work would consist of the following

- Compare resource use across multiple fuel types
- Examine regional variations in resource potential and availability
- Contribute to resource constrained scenarios of transportation energy use
- Include non-light duty vehicle transportation demands (ex: shipping, heavy-duty, air)
- Contribute to supply curve calculations for low carbon scenarios

Project Summary

Relevance
- Expanding use of natural gas significantly could raise issues of resource availability
- Projected future production efficiencies can be relied upon to examine resource needs for different types of low-carbon energy resources

Approach
- Simple energy balance equations; updated geographic resource data

Technical Accomplishments and Progress
- Multiple resource estimates have been updated and compared to recent projections from AEO 2012 (Early Release)
- GIS resource maps have been update with both new resource/technology potential and with new hydrogen production efficiencies (H2A Case Studies)

Collaboration
- H2A models vetted by industry; internal NREL collaborations on resource potential

Proposed Future Research
- Rely upon resource assessment as a metric for future scenario analysis

Technical Backup Slides

Conversion Assumptions & Comments

SUPPORTING INFORMATION

	H2 Total production demand	10.0	million metric tonnes
Biomass	Required biomass from H2A	13.0	kg biomass/kg H2
	Biomass	130	million metric tonnes
	Biomass energy content	17,200,000	BTU/metric tonne
	Tons per quadrillion BTU	58.1	
Coal	Required coal from H2A, future coal with sequestration	9.80	kg coal/kg H2
	Required coal	98.0	million metric tonnes
	Coal energy content	20,608,570	BTU/ton
	Coal energy content	22,717,061	BTU/tonne
	Millions tons coal per quad	44.0	
Natural Gas	Natural gas use	156,000	BTU/kg
	Gas BTU content	1,089	BTU/ft3
	Gas required	1.43	trillion ft3
	Trillion ft3 per quad	0.918	
Wind Power	Wind electrolysis electricity use	46.0	kWh/kg
	Energy needed	460.0	Billion kWh
	GWh per quad	293,071	
	Billion kWh per quad	293	
Solar Power	Solar electrolysis electricity use	46.0	kWh/kg
	Energy needed	460.0	Billion kWh
Nuclear Power	Nuclear electrolysis electricity use	46.0	kWh/kg
	Nuclear power needed	52.5	GW average (nuclear)
	Nuclear capacity factor	1.00	GW produced/GW installed
	Nuclear installed capacity	52.5	GW installed
	Nuclear electric efficiency*	0.350	Electricity produced per nuclear thermal power
	Waste heat use**	0.063	Waste heat used per nuclear thermal power
	Total nuclear efficiency	0.413	Total energy used for H2 production per nuclear thermal power
	Nuclear usage per kg H2	325,031	BTU/kg H2
Vehicles	Hydrogen energy content	1.35	Quads
	Fuel efficiency	70.0	miles/kg H2
	Annual VMT per vehicle	12,000	miles/year
	Total vehicles supported	58.3	million vehicles

* Assuming 35% efficient steam cycle

** Using waste heat for steam generation for high temperature electrolysis