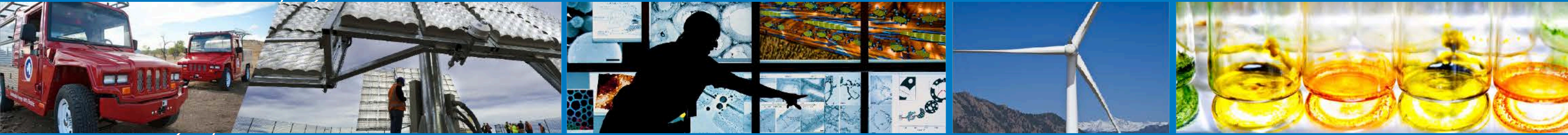
Hydrogen and Fuel Cells for IT Equipment



Jennifer Kurtz

March 9, 2016

The Green Grid Forum

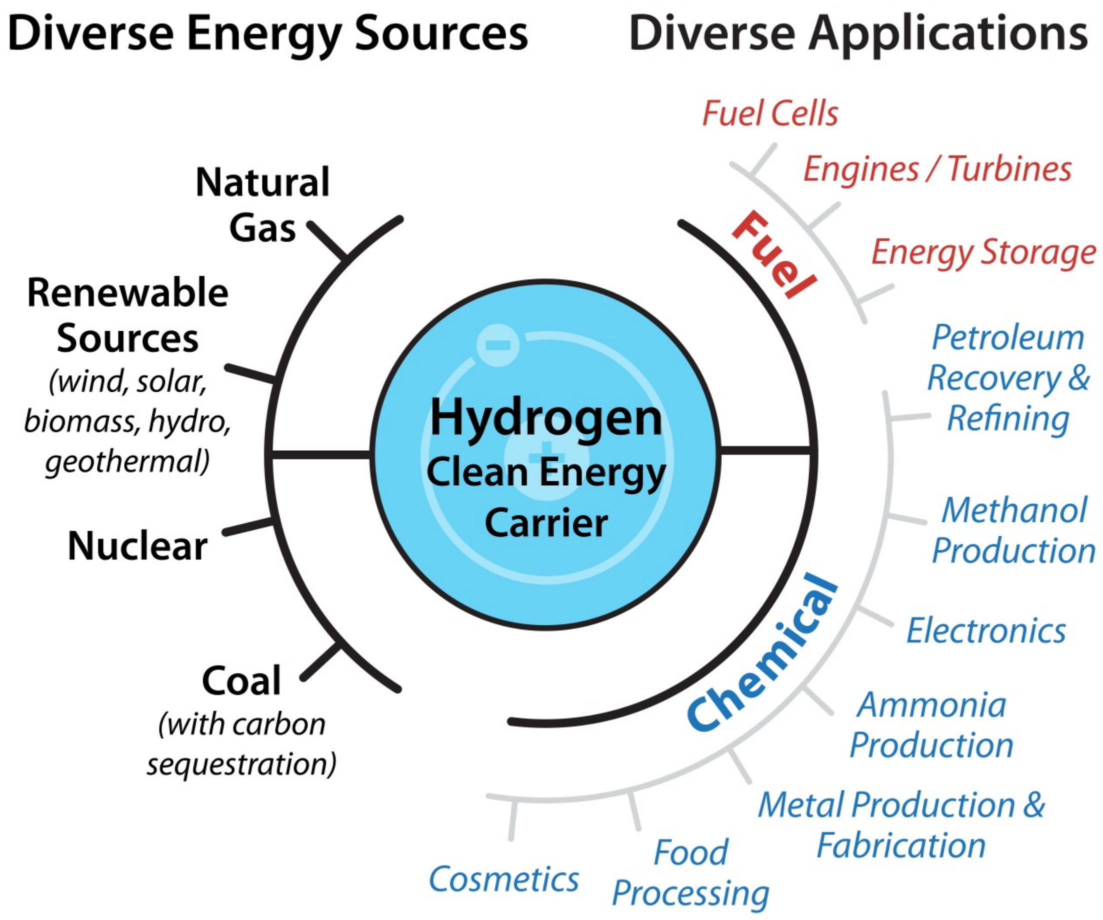
Seattle, Washington

NREL/ PR-5400-66610

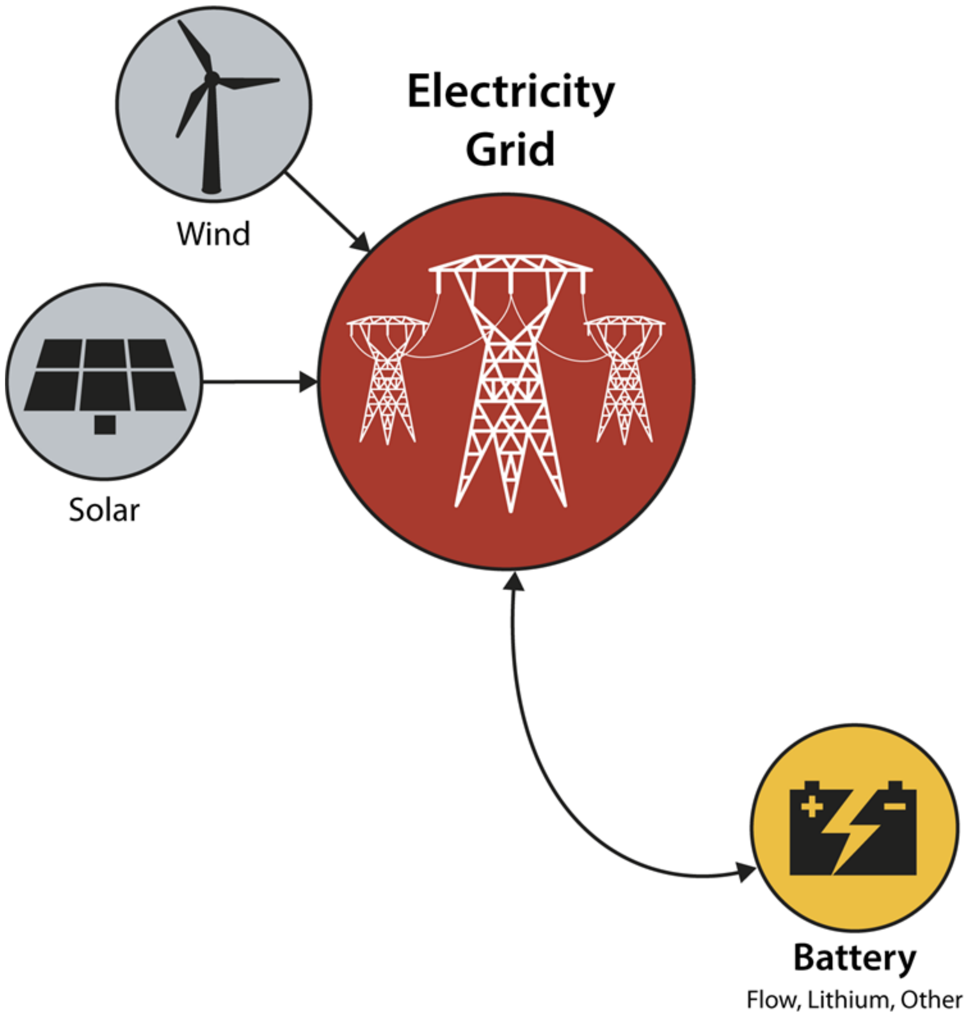
Why Hydrogen with IT

Challenges:

- Climate change
- Transportation and stationary/grid demands
- Renewable energy intermittency



Hydrogen as a Key Part of Solution



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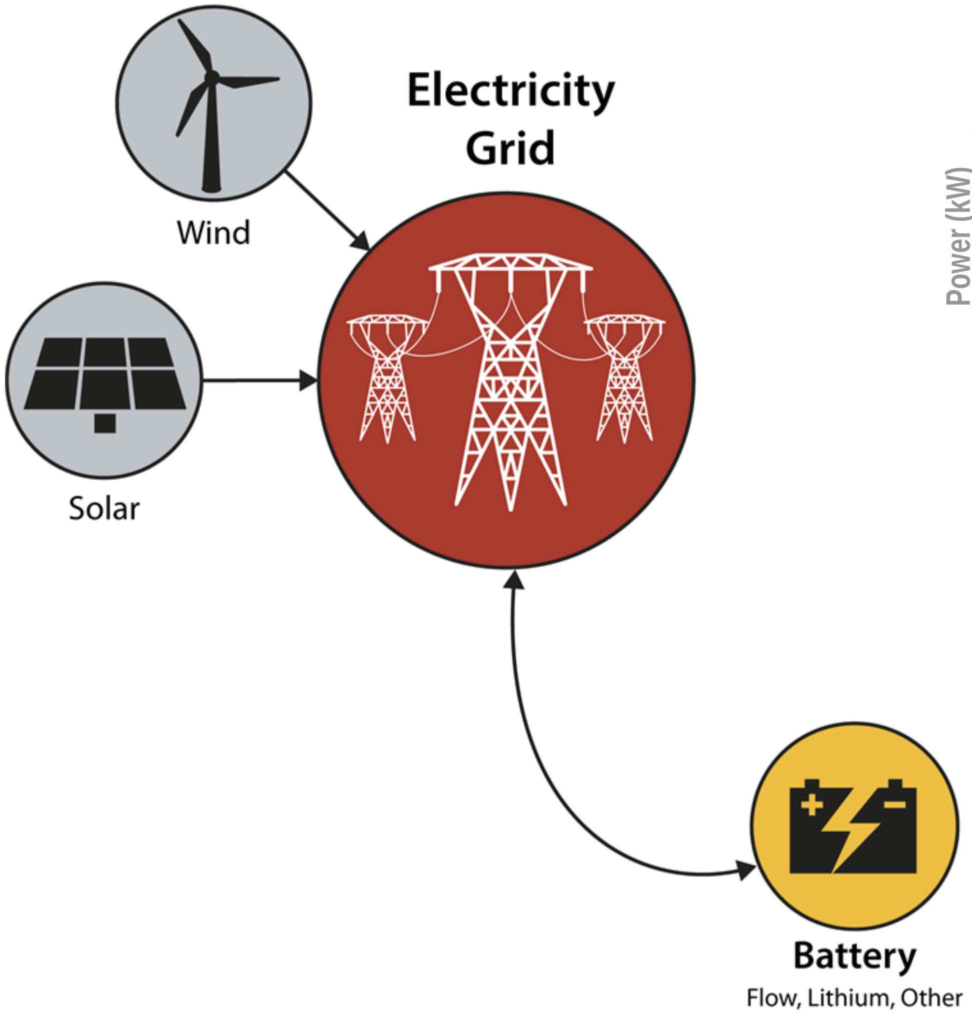
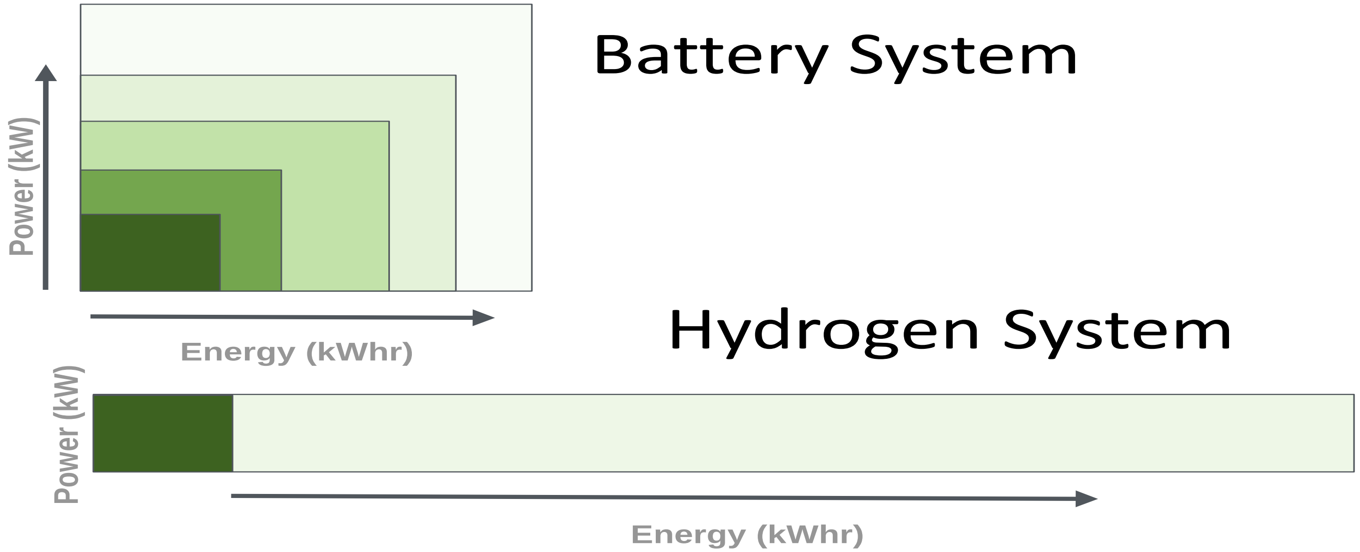
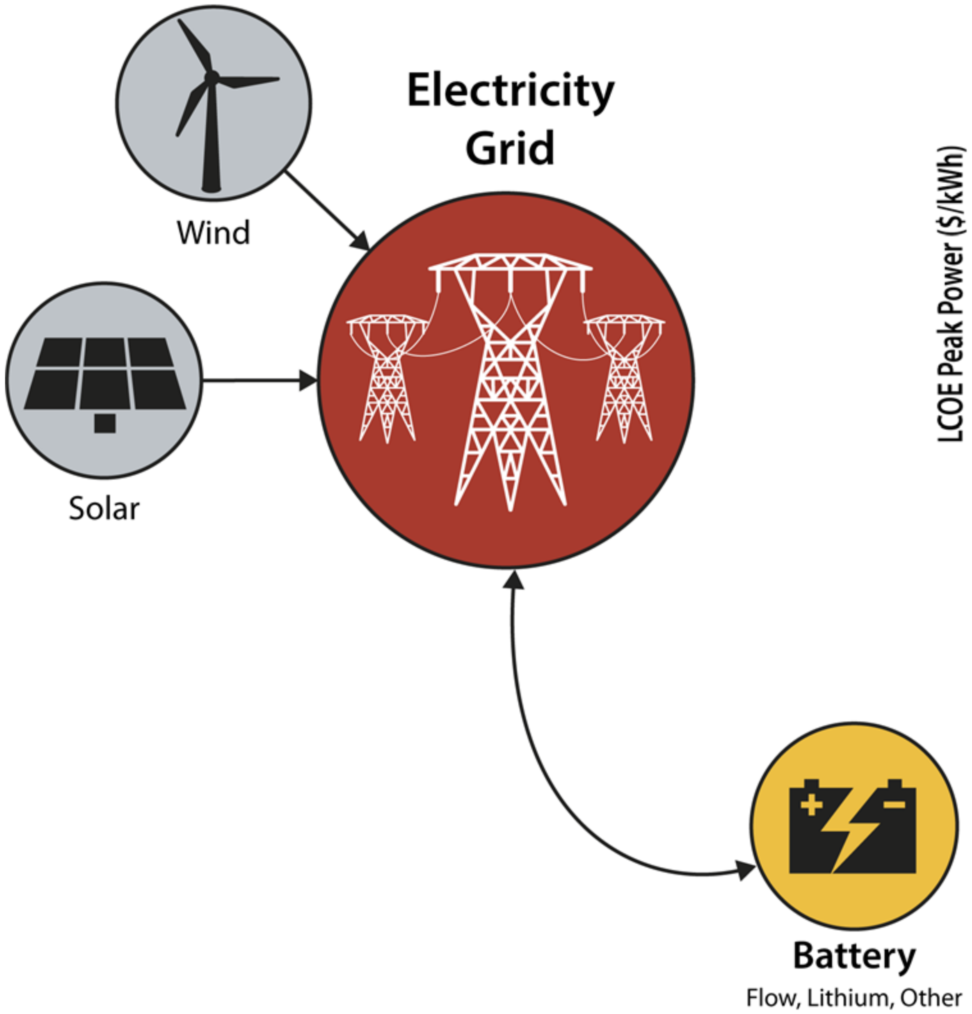
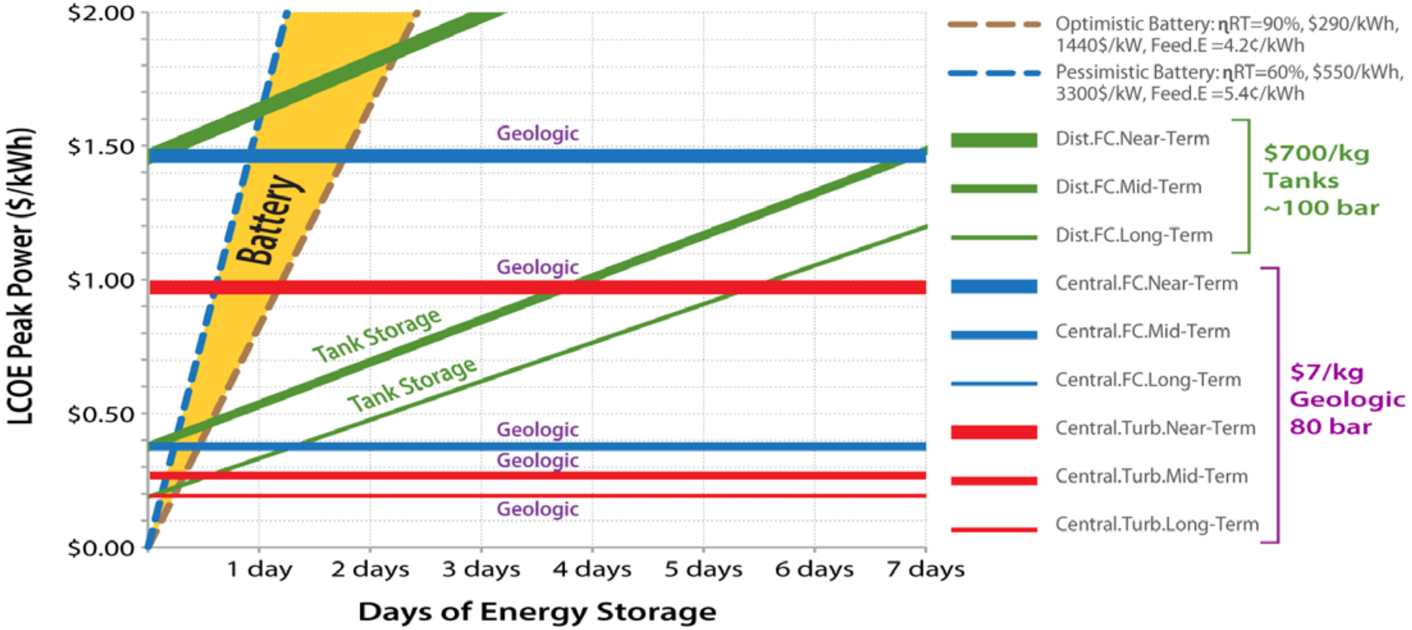


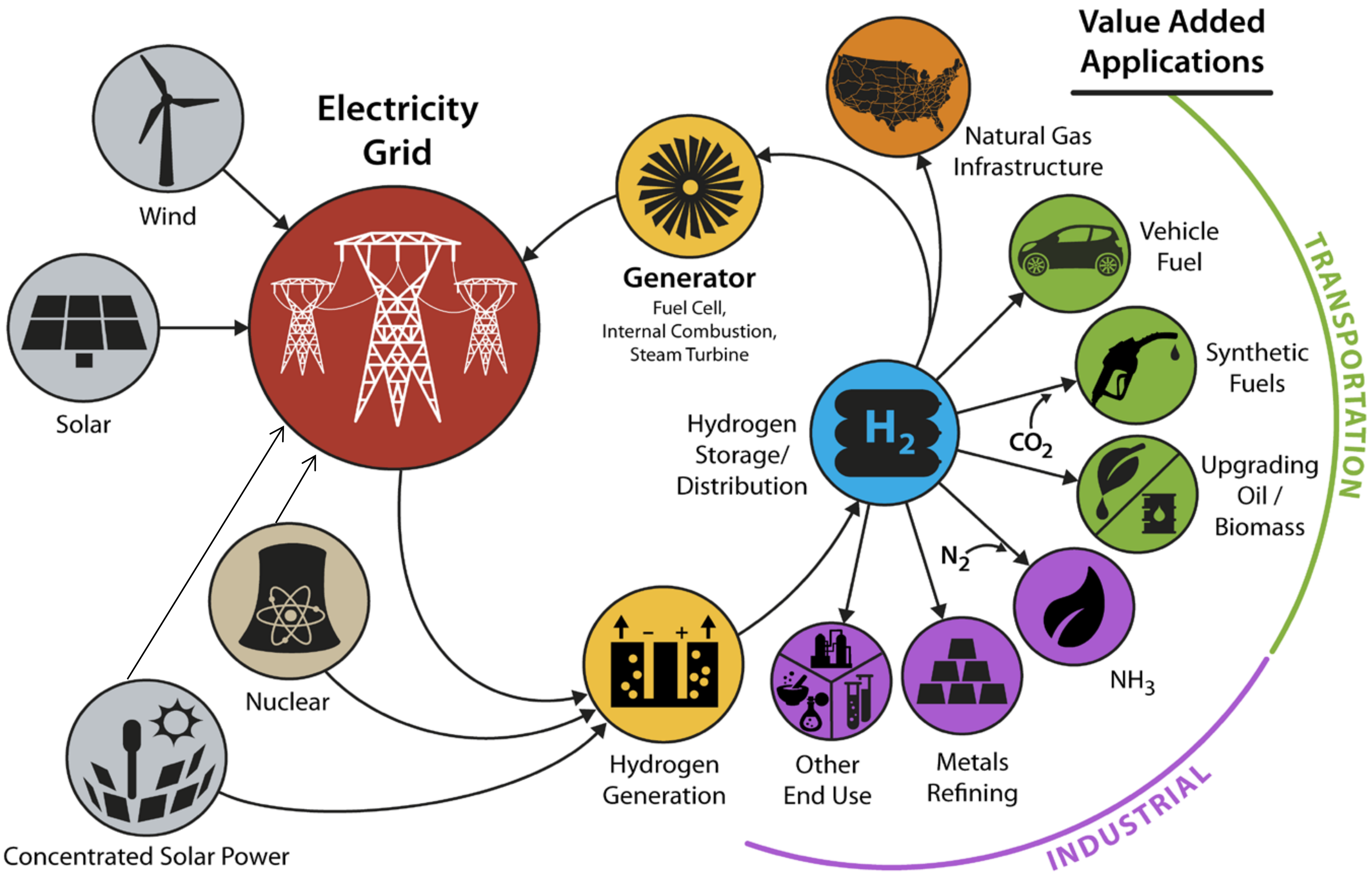


Hydrogen as a Key Part of Solution





Hydrogen as a Key Part of Solution

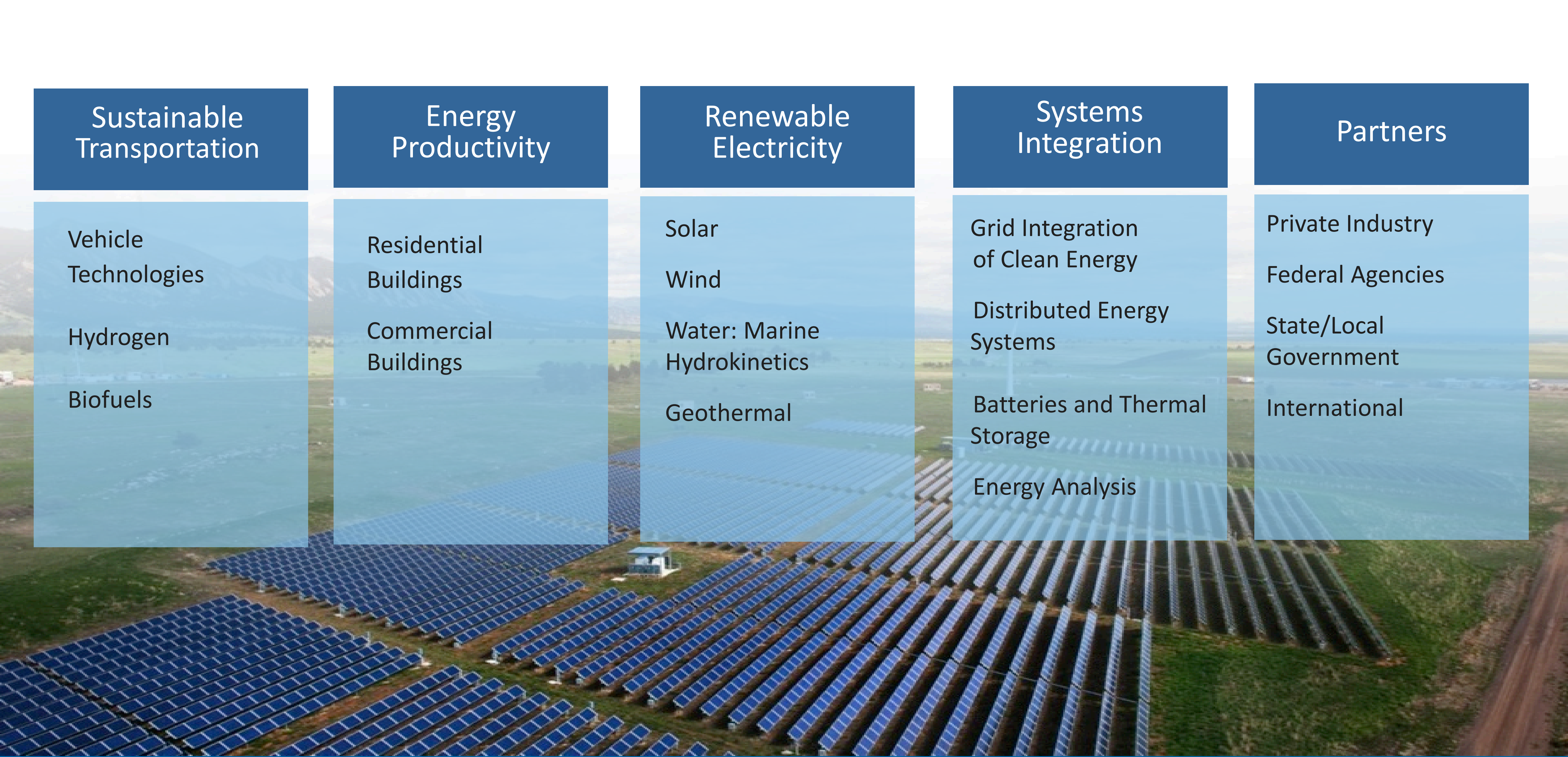


NREL Laboratory Snapshot

Only National Laboratory Dedicated Solely to Energy Efficiency and Renewable Energy

- Leading clean-energy innovation for more than 37 years
- ~1,760 employees with world-class facilities
- Campus is a living model of sustainable energy
- Economic impact at $872M nationwide
- Owned by the Department of Energy
- Operated by the Alliance for Sustainable Energy

Scope of NREL Mission



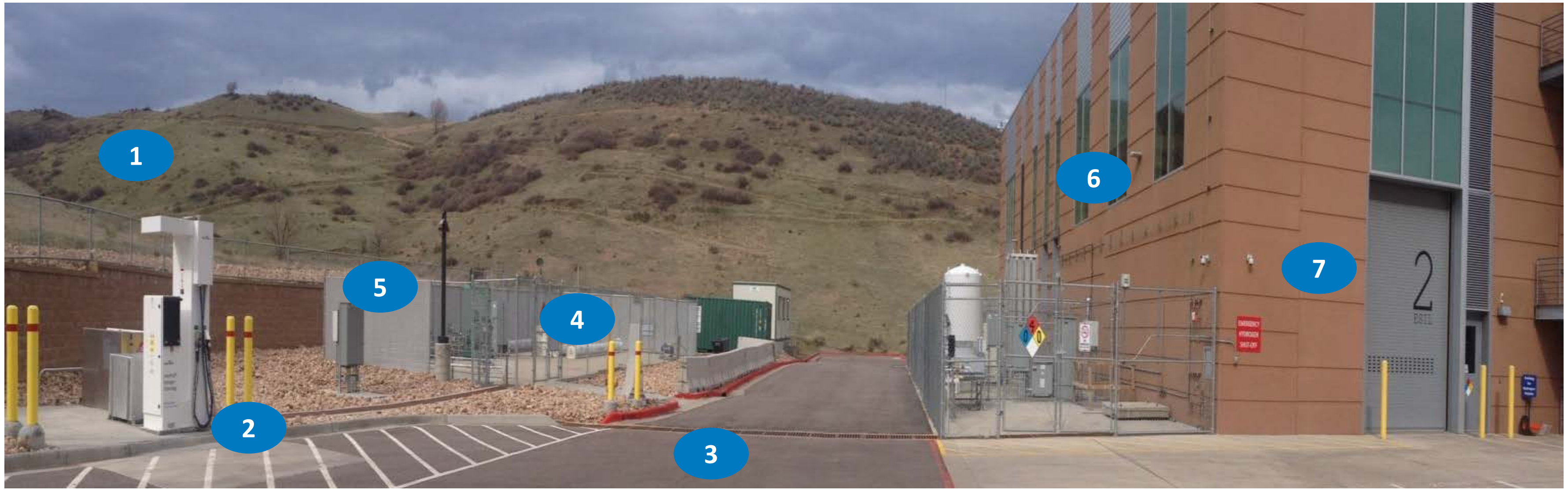
Sustainable Transportation	Energy Productivity	Renewable Electricity	Systems Integration	Partners
Vehicle Technologies	Residential Buildings	Solar	Grid Integration of Clean Energy	Private Industry
Hydrogen	Commercial Buildings	Wind	Distributed Energy Systems	Federal Agencies
Biofuels		Water: Marine Hydrokinetics	Batteries and Thermal Storage	State/Local Government
		Geothermal	Energy Analysis	International

NREL Fuel Cell and Hydrogen Technologies Program

- Hydrogen production and delivery
- Hydrogen storage
- Fuel cells
- Fuel cell manufacturing R&D
- Technology validation
- Market transformation
- Safety, codes and standards
- Systems analysis

NREL's Integrated Hydrogen Infrastructure R&D

Energy Systems Integration Facility (ESIF)



Distributed Energy Resources Test Facility (DERTF)

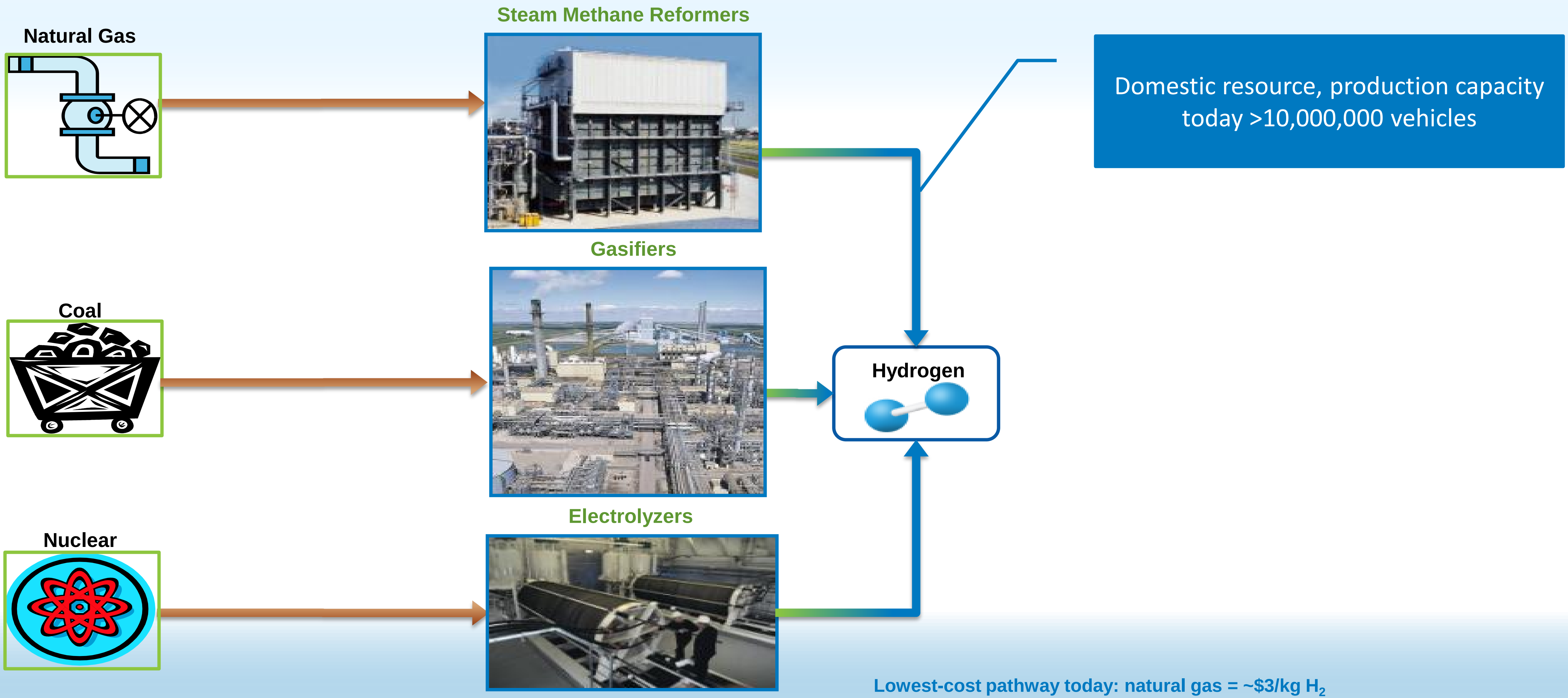
Hydrogen infrastructure R&D capabilities and current projects

1. Hydrogen infrastructure codes and standards development
2. HySTEP device testing, FCEV fueling
3. House hydrogen supply
4. Component testing integrated with a station – compressors and sensors
5. Hydrogen infrastructure testing with NFCTEC data collection
6. Accelerated component testing on a benchtop – pressure relief devices and hose reliability testing
7. Integration – renewable electrolysis, grid integration, power-to-gas, MHE-to-building demonstration

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

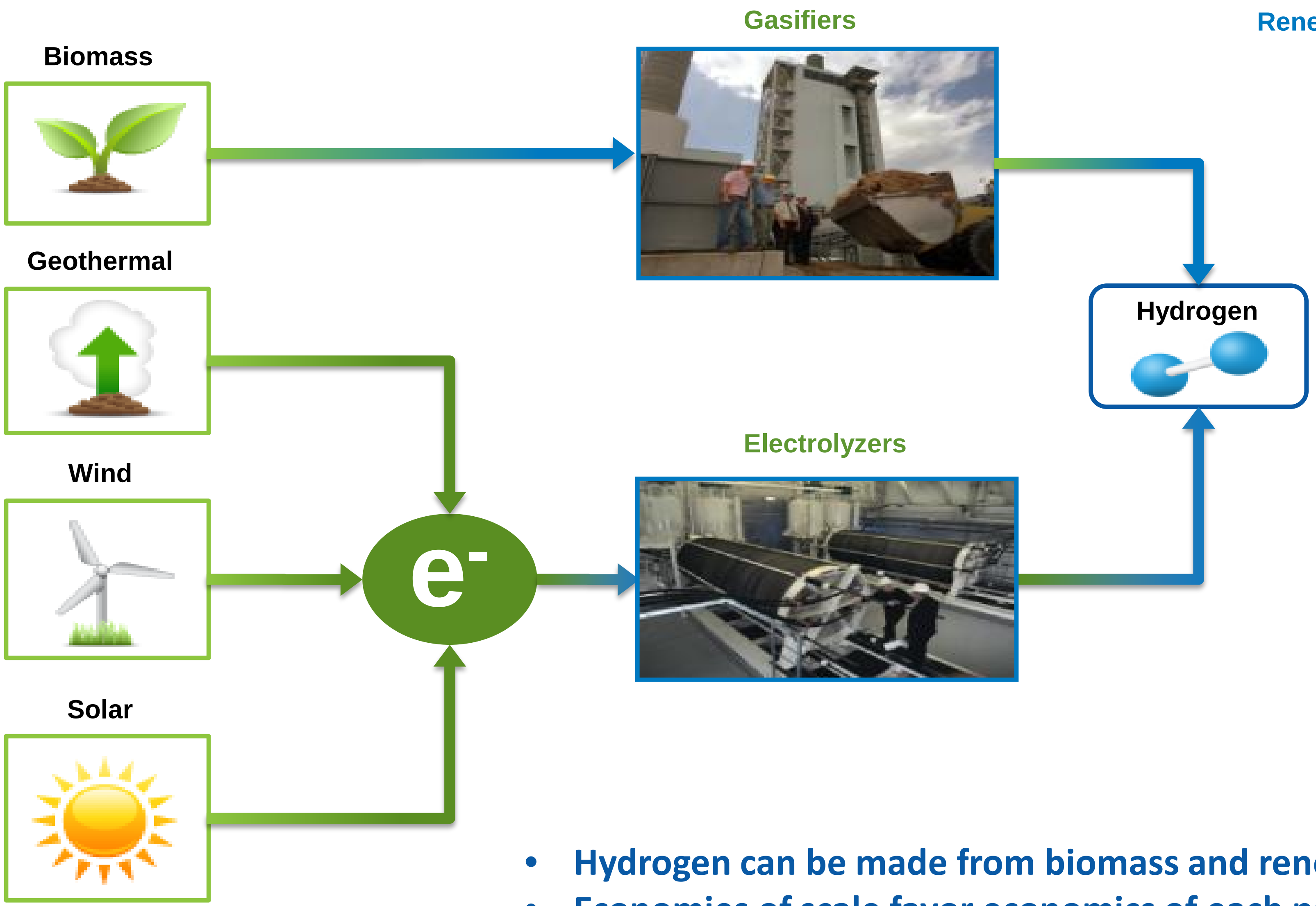
Hydrogen Pathways

Non-Renewable Hydrogen Pathways



Lowest-cost pathway today: natural gas = ~$3/kg H_2

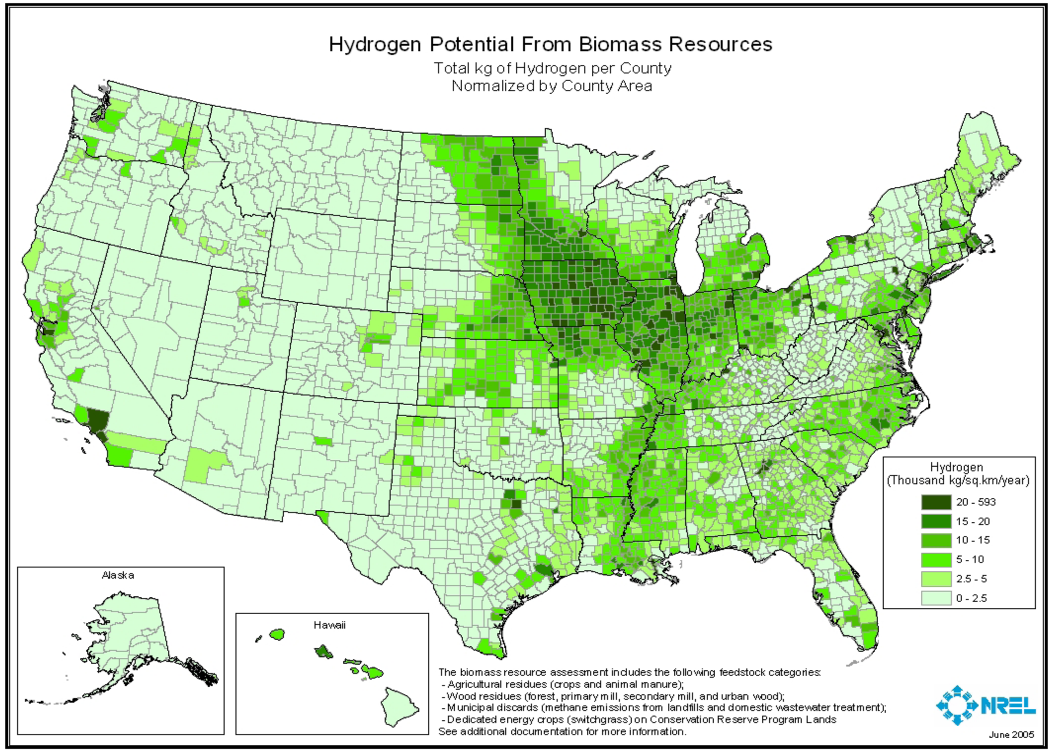
Advancing Renewable Hydrogen Pathways

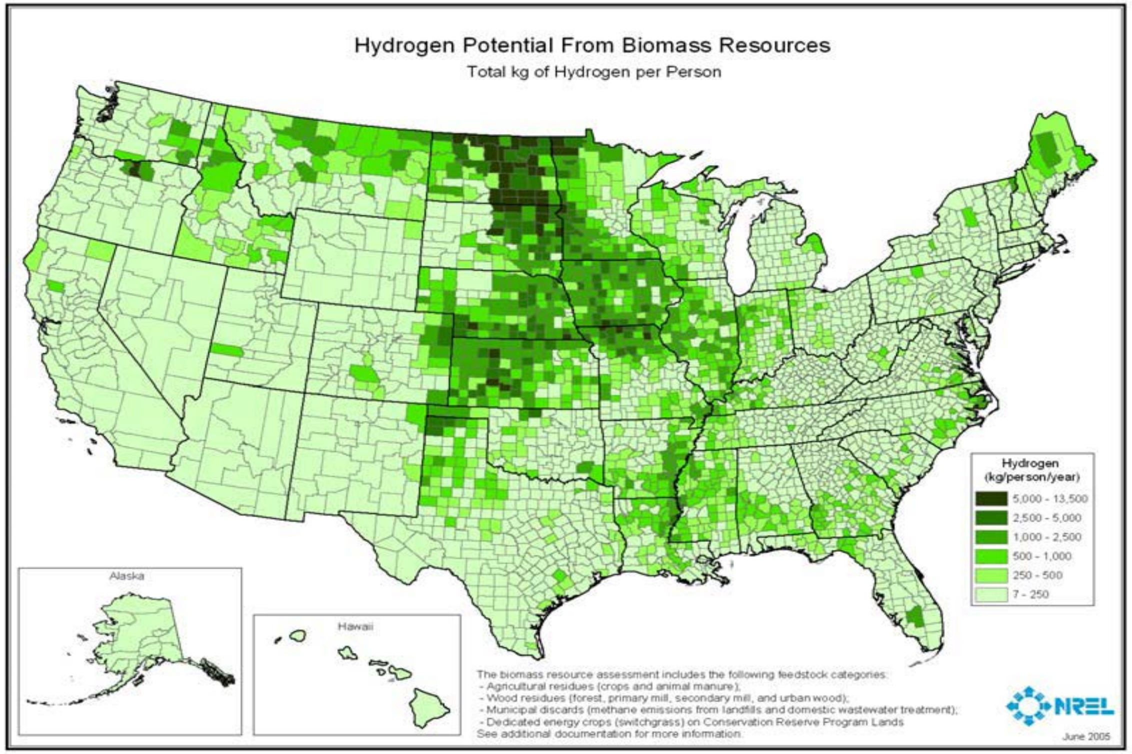


- Hydrogen can be made from biomass and renewable electricity
- Economies of scale favor economics of each pathway

U.S. Biomass Resource Maps

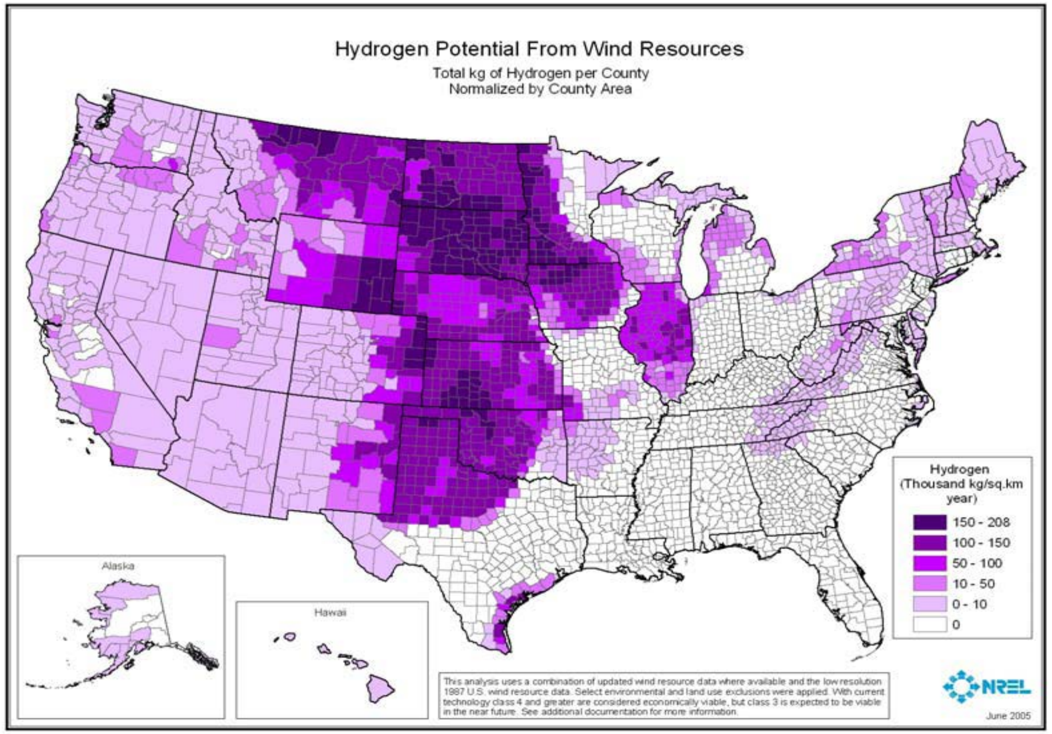
Total Biomass Potential:
30,000 million kg H_2/year

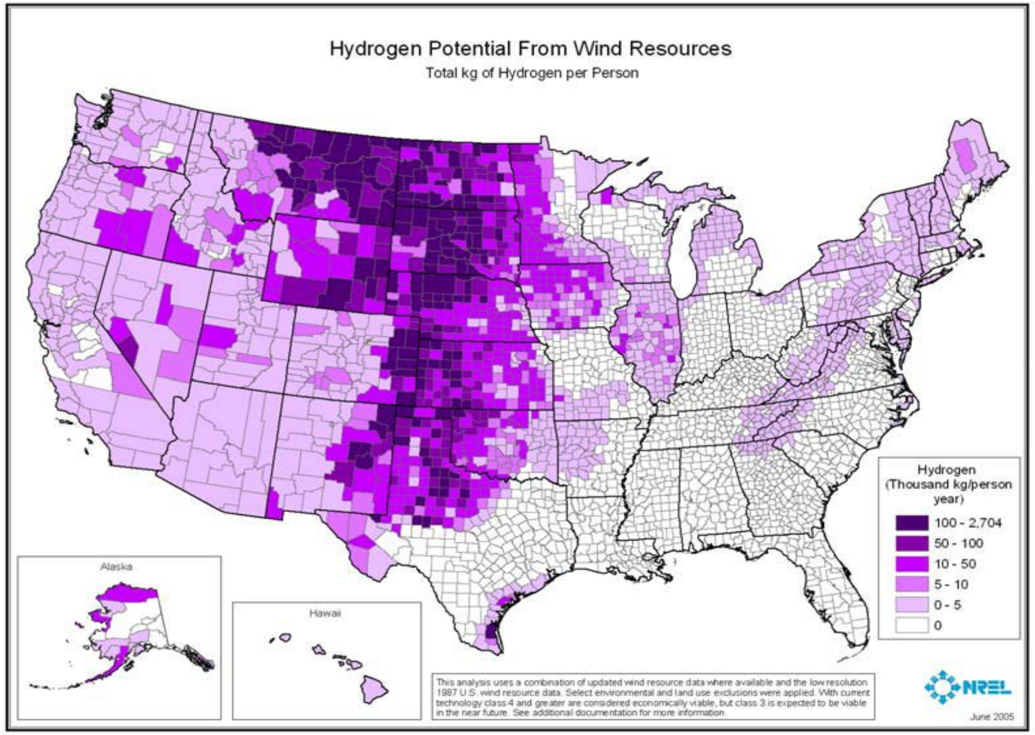




U.S. Wind Resource Maps

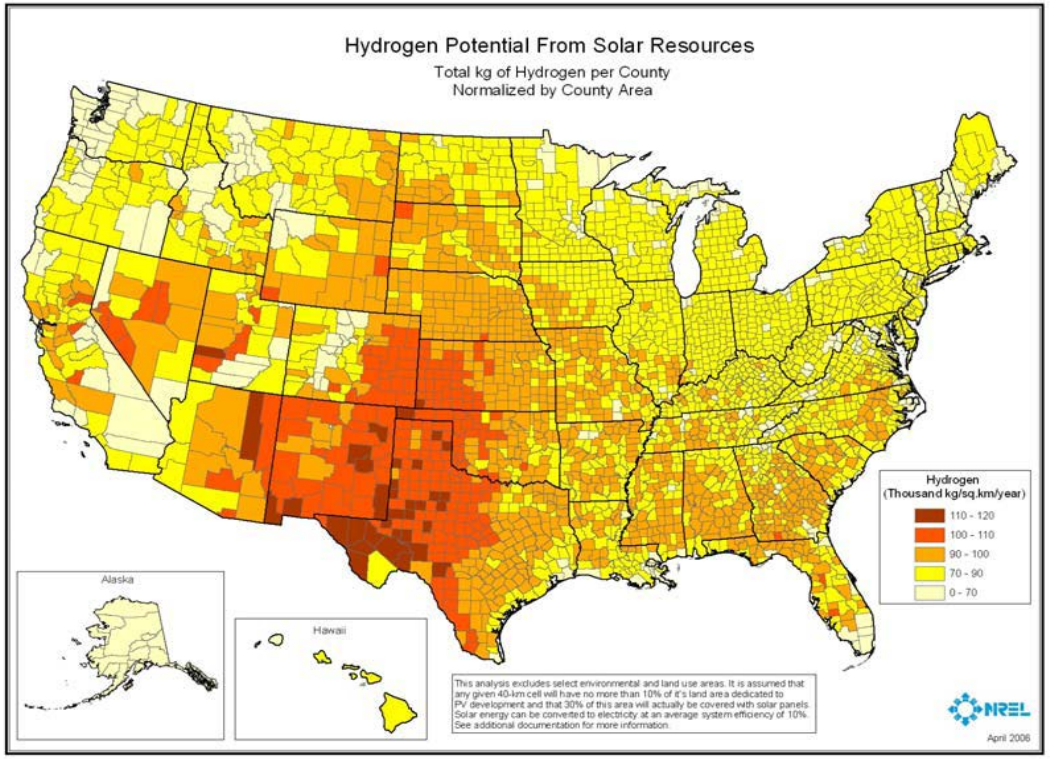
Total Wind Potential:
273,000 million kg H_2/year

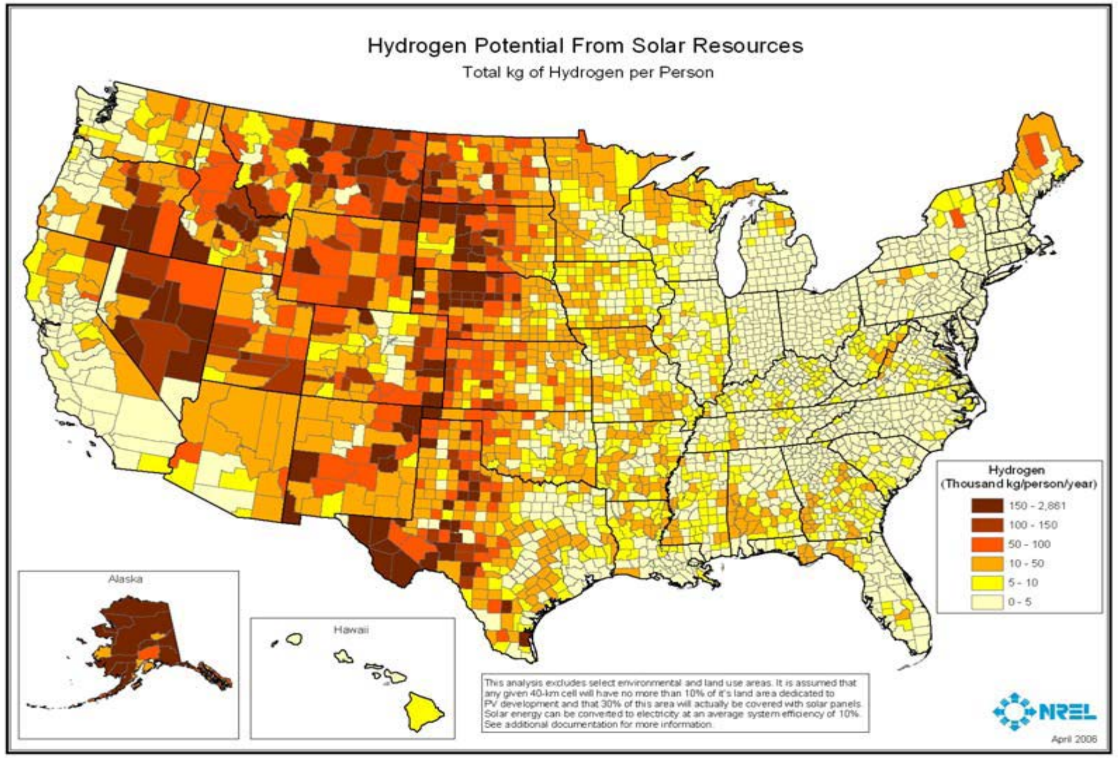




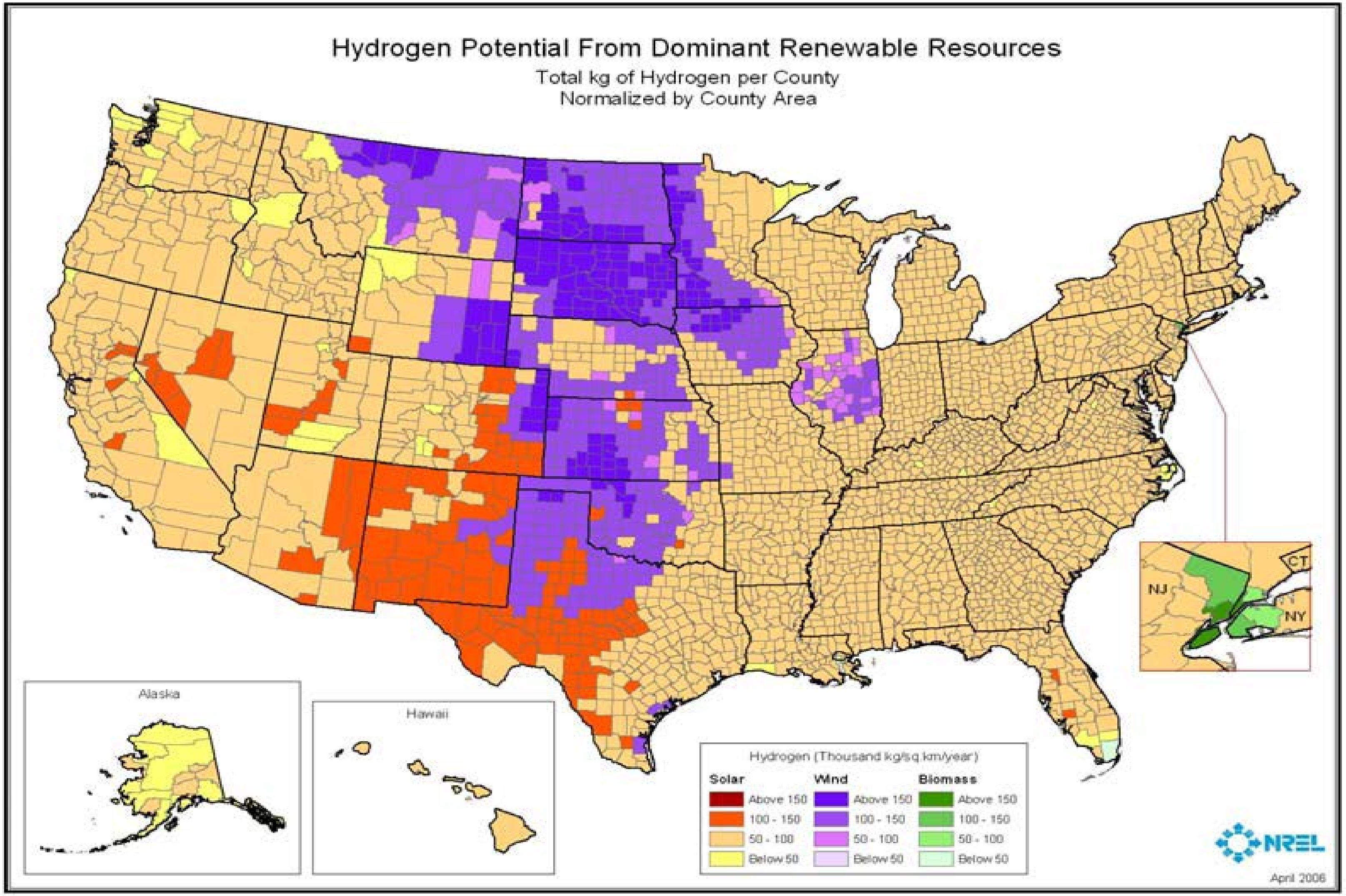
U.S. Solar Resource Maps

Total Solar Potential:
717,000 million kg H_2/year





Hydrogen from Renewable Resources Could be Made in All 50 States



Total Renewable Potential:
1,020,000 million kg H_2/year

Wind-to-Hydrogen Small Scale Testing

http://www.nrel.gov/hydrogen/proj_wind_hydrogen_animation.html

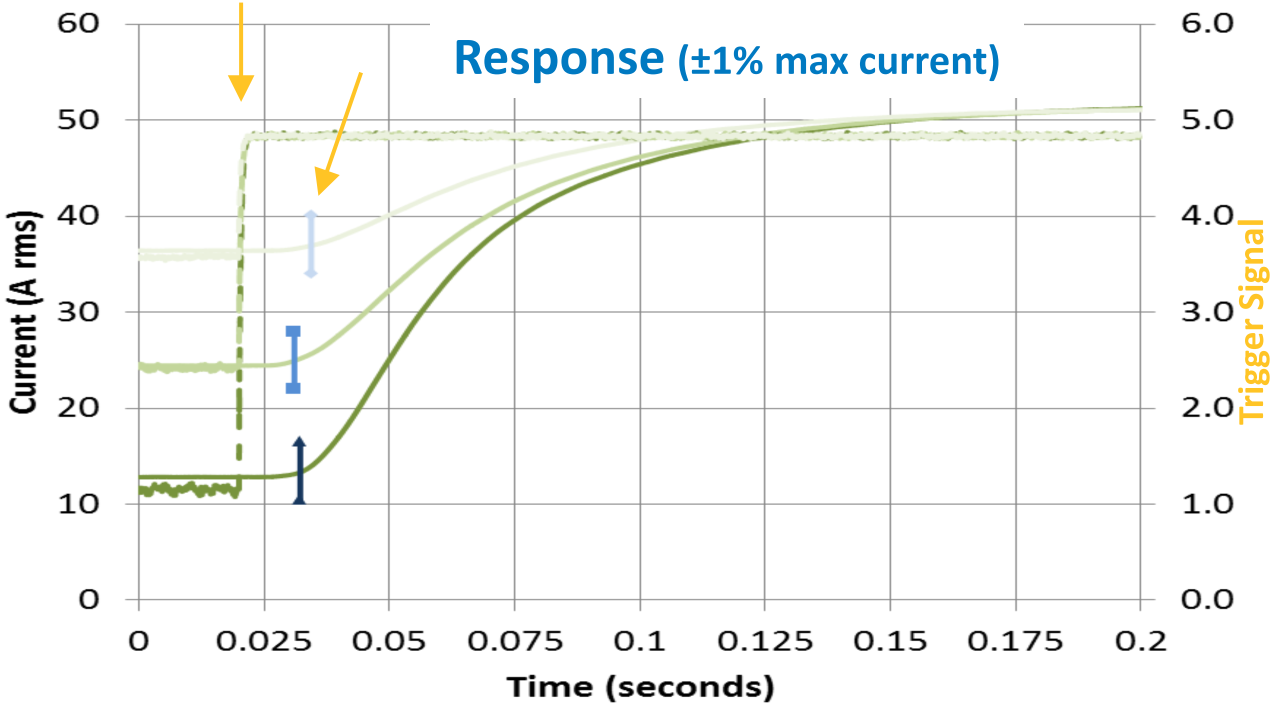
Electrolyzer Response Time

Electrolyzer systems can rapidly change their stack power to support grid stability

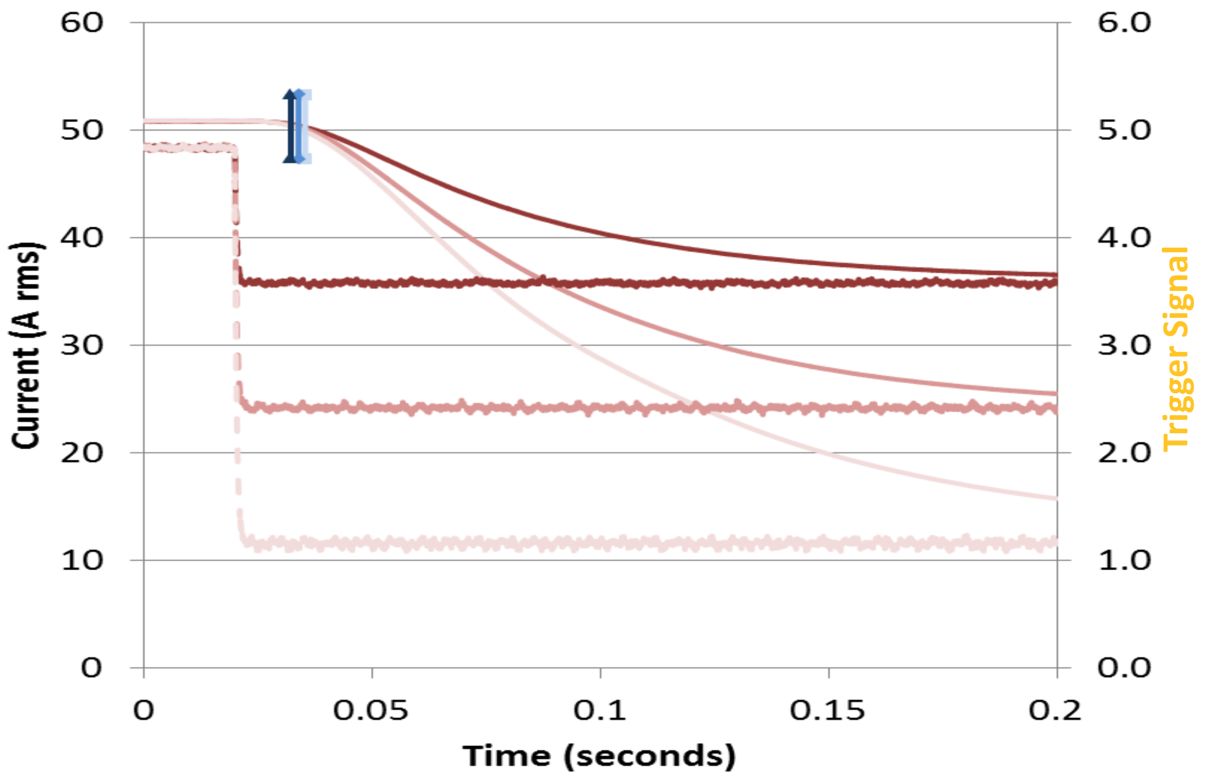
Stack power ramped up and down (PEM system data shown)

Ramp Up: 25%, 50%, and 75% →100%

Trigger at 0.02 seconds

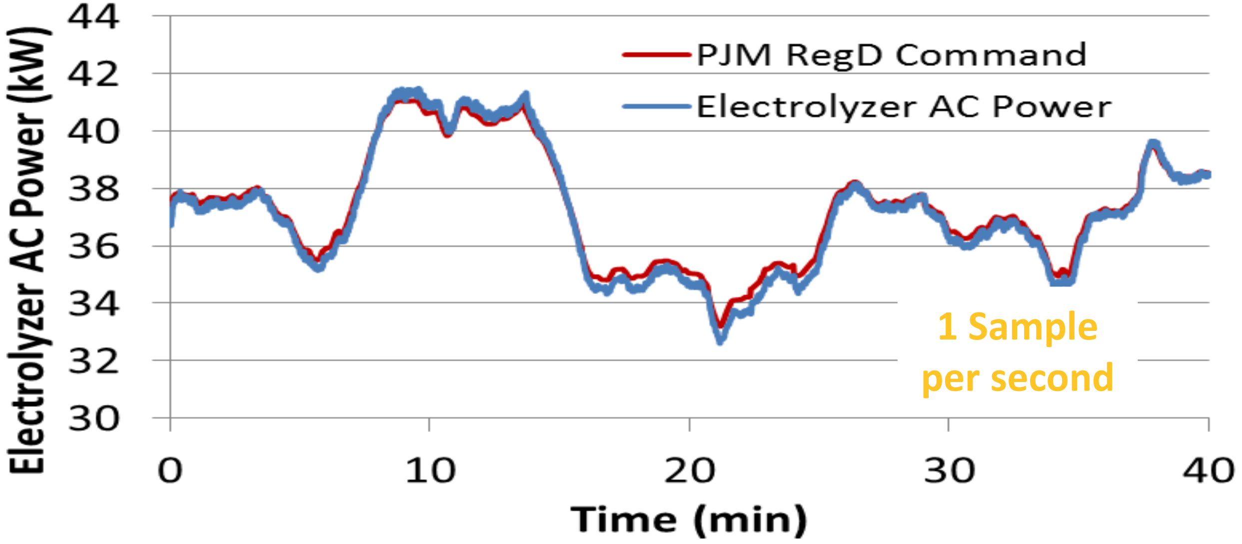


Ramp Down: 100% → 75%, 50% and 25%



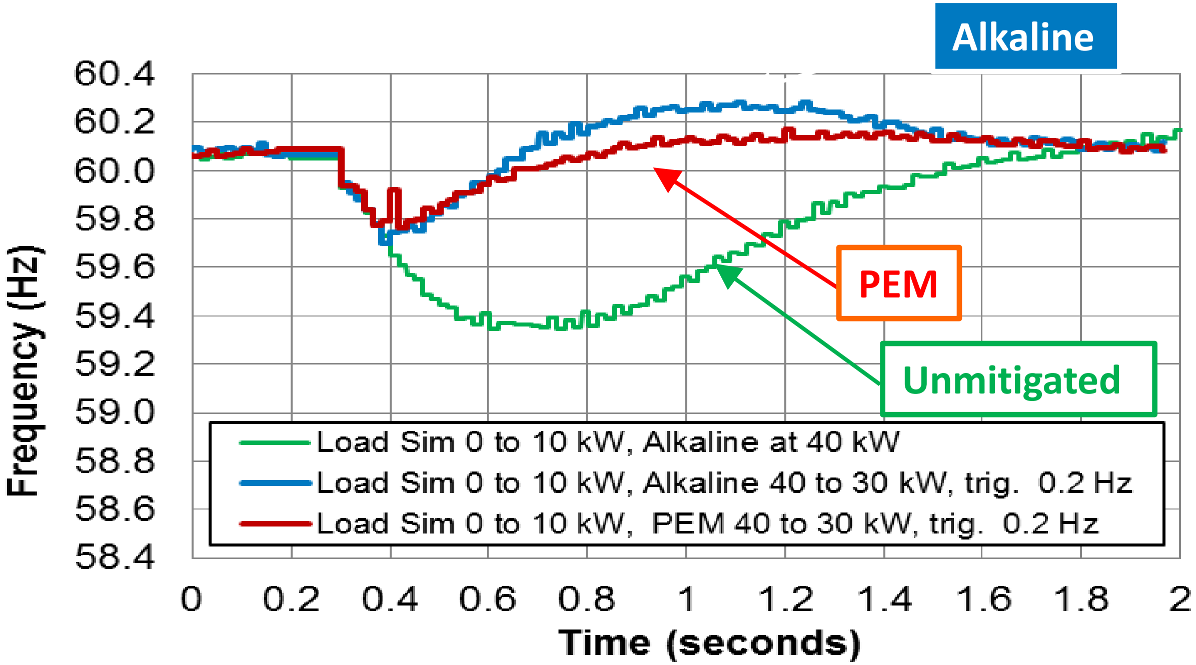
Electrolyzer Regulation Tests

Electrolyzers can respond to rapidly varying input signal



Frequency Regulation

Tested frequency response using a microgrid



Source: Harrison K., Mann M., Terlip D., and Peters M., NREL/FS-5600-54658

Electrolyzer Stack Test Bed

Located at NREL's Energy Systems Integration Laboratory

- AC-DC power supplies capable of 2,000 ADC and 250 VDC
- Built through INTEGRATE project
- Flexible platform for large active area stack testing

System efficiency improvements in electrolyzer balance of plant

Goal is to improve system efficiency:

- Drying losses in variable operation with NREL's variable flow drying technique
- Optimize balance of plant based on variable stack power

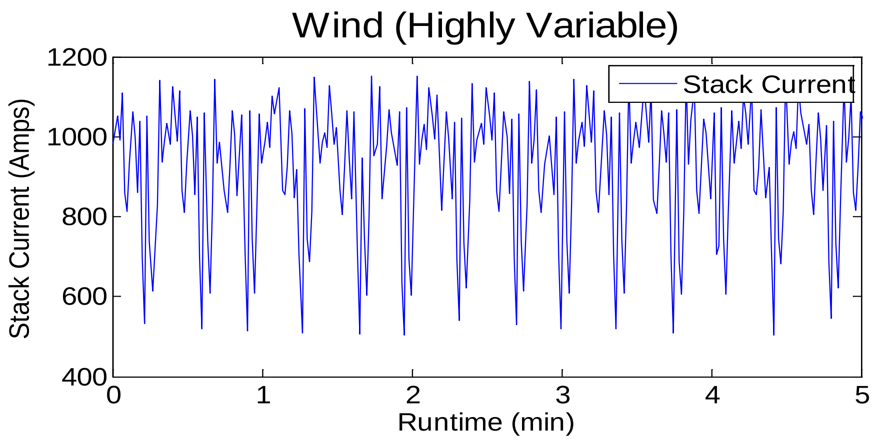
First testing completed with Giner Inc.

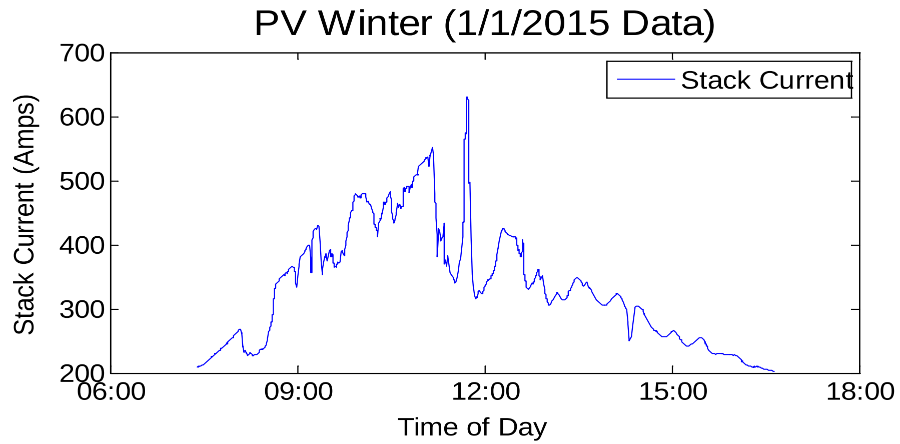
- Three 150-kW PEM stacks
- IV-Curves were collected at stack temperature of 70°C
- Individual cell voltages were collected at different current and stack pressure levels

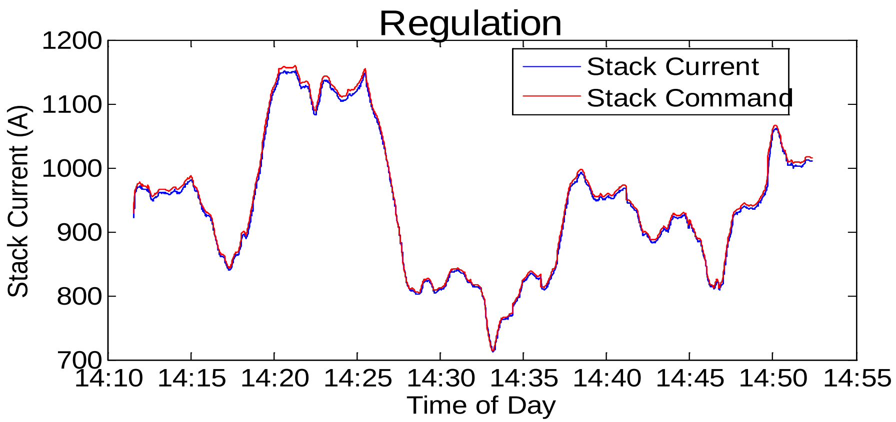
Simulating Renewable and Regulation Profiles

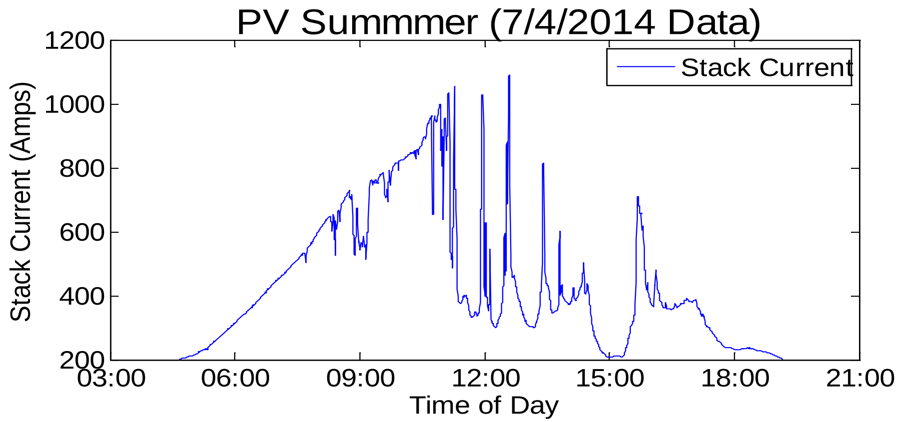
Ability to program profiles into the stack test bed

- Examples of renewable and regulation profiles
- Ran profiles with 120-kW stack from Proton









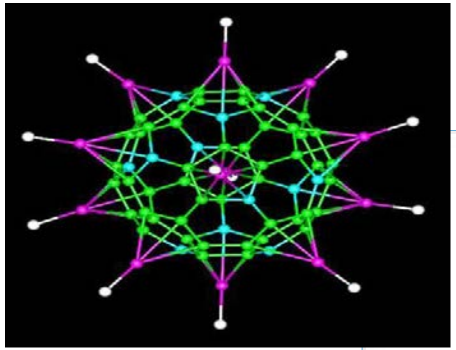
Hydrogen Storage

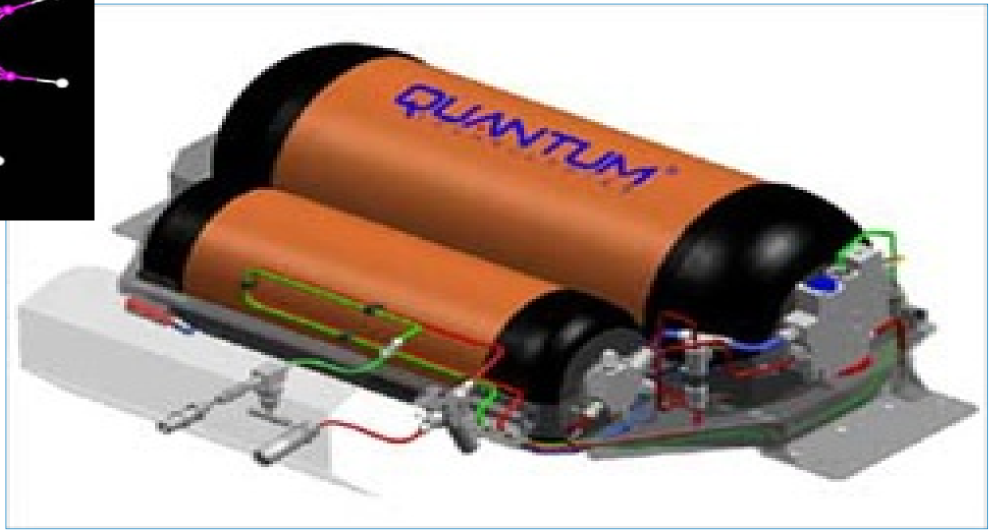
Materials testing and characterization

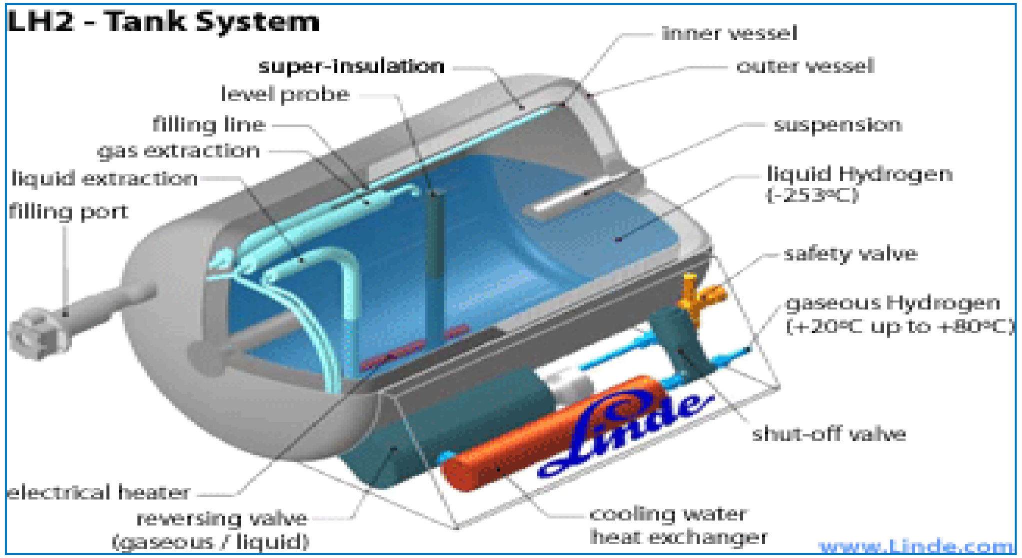
Validation of hydrogen storage measurements

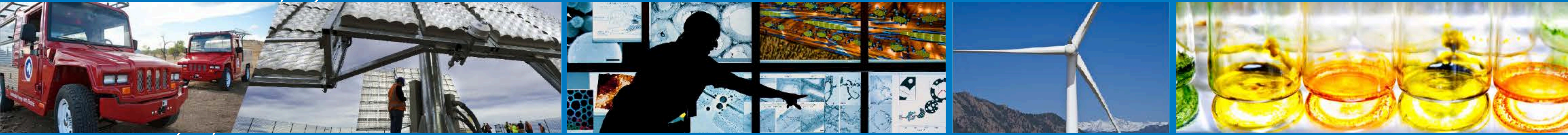
Development of advanced materials

Storage system design, analysis, and modeling



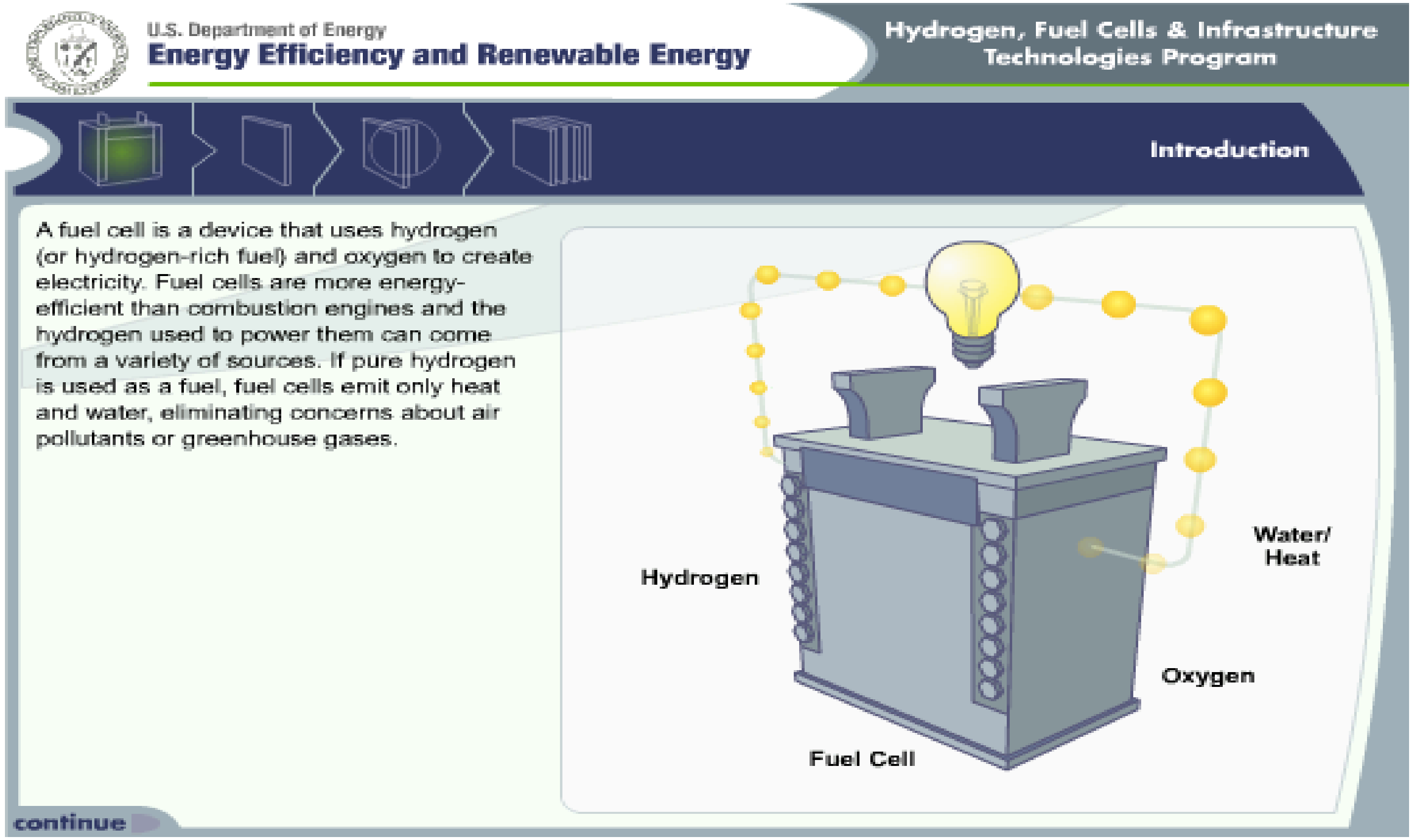






Fuel Cell Operation

Fuel Cell Operation



http://energy.gov/eere/fuelcells/fuel-cell-animation

National Fuel Cell Technology Evaluation Center (NFCTEC)

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Leading Clean Energy Innovation

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Hydrogen Production & Delivery
Hydrogen Storage
Manufacturing
Market Transformation
Safety, Codes, & Standards
Systems Analysis
Technology Validation
-Fuel Cell Electric Vehicles
-Fuel Cell Buses
-Early Fuel Cell Markets
-Fuel Cell Technology Status
-Hydrogen Fueling Infrastructure
-Stationary Fuel Cell Systems
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Fuel Cell and Hydrogen Technology Validation

Technology validation is defined as confirmation that component and system technical targets have been met under realistic operating conditions. The NREL technology validation team works on validating hydrogen fuel cell electric vehicles; hydrogen fueling infrastructure; hydrogen system components; and fuel cell use in early market applications such as material handling, backup power, and prime-power applications. The team also analyzes the current status of state-of-the-art laboratory fuel cell technologies, with a focus on performance and durability. This work supports the Department of Energy's hydrogen and fuel cell technology validation activity.

Interactive Map Shows Cost of Producing Hydrogen from Wind

NREL analysis reveals the cost of producing hydrogen from wind-based water electrolysis at potential sites across the United States.

1 2 3 4

Technology validation projects involve gathering extensive data from the systems and components under real-world conditions, analyzing this detailed data, and then comparing results to technical targets. While the raw data is protected by NREL, analysis results are aggregated into public results called composite data products. These public results show the status and progress of the technology, but don't identify individual companies.

Click on the application type to see project highlights, analysis results, and detailed reports and presentations from the hydrogen and fuel cell technology validation efforts underway at NREL.

Vehicles — CARS
Buses — BUSES
Forklifts — FORKLIFTS
Backup Power — BACKUP POWER
Stationary Power — PRIME POWER
Infrastructure — INFRASTRUCTURE
Laboratory Stacks — STACK

Subscribe to the biannual Fuel Cell and Hydrogen Technology Validation newsletter, which highlights recent technology validation activities at NREL.

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Did you find what you needed?

Yes No

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

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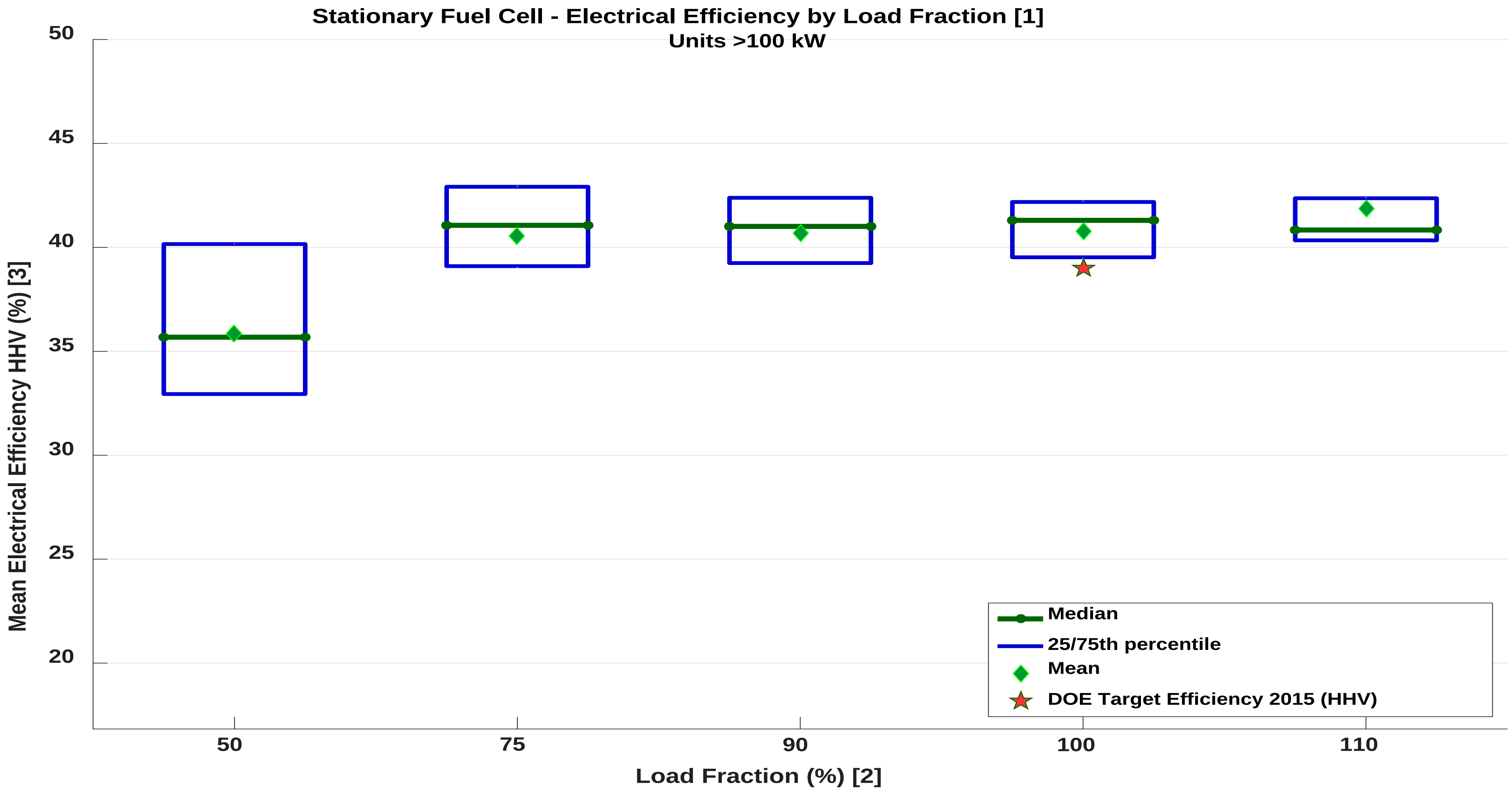
http://www.nrel.gov/hydrogen/proj_tech_validation.html

Confirmation of component and system technical targets

Technology validation in real-world settings

Evaluation, optimization, and demonstration in integrated energy systems

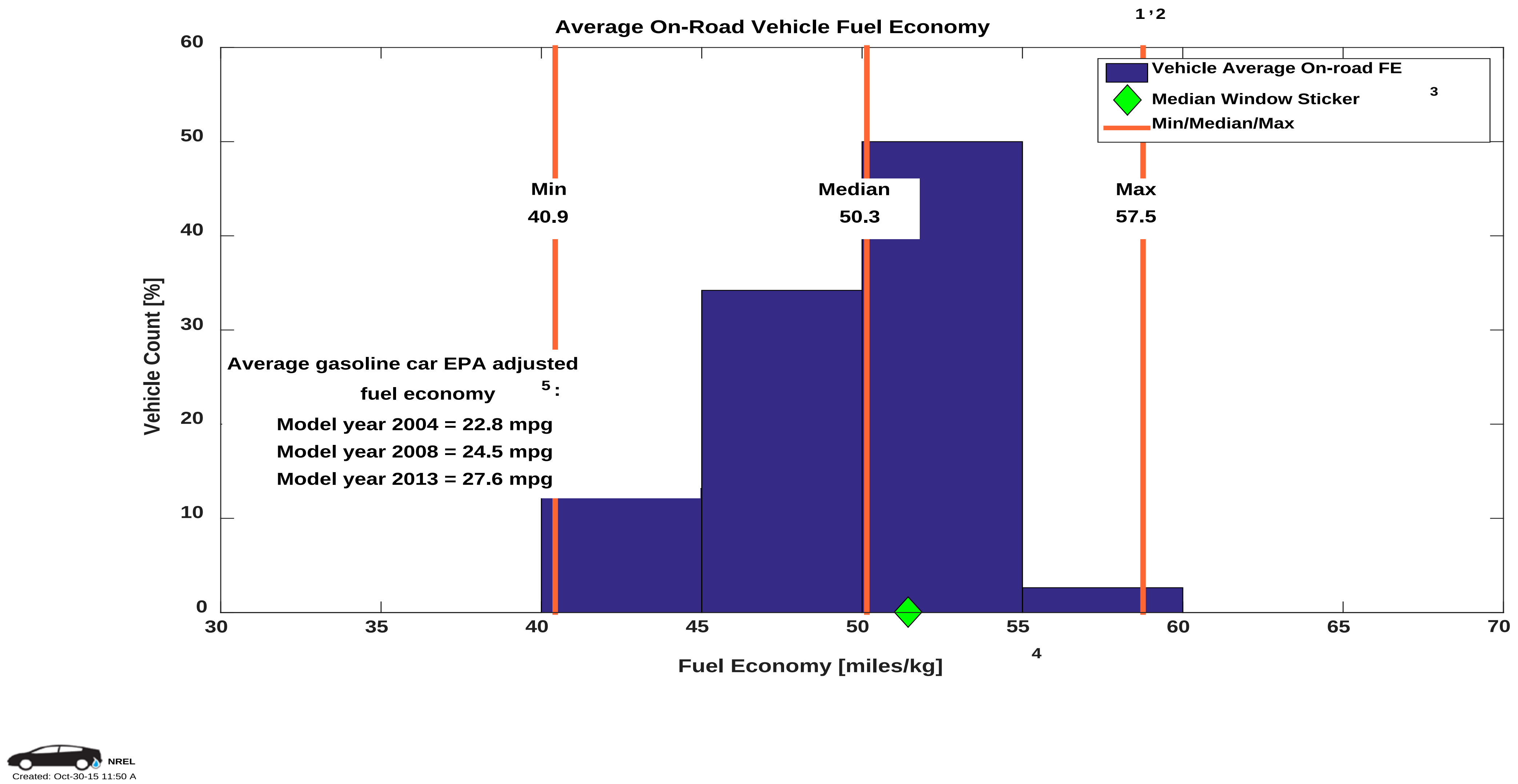
Electrical Efficiency by Load Fraction for Units >100 kW



NREL cdp_stat_33
Created: Nov-19-15 7:53 AM | Data Range: 2001Q2-2015Q3

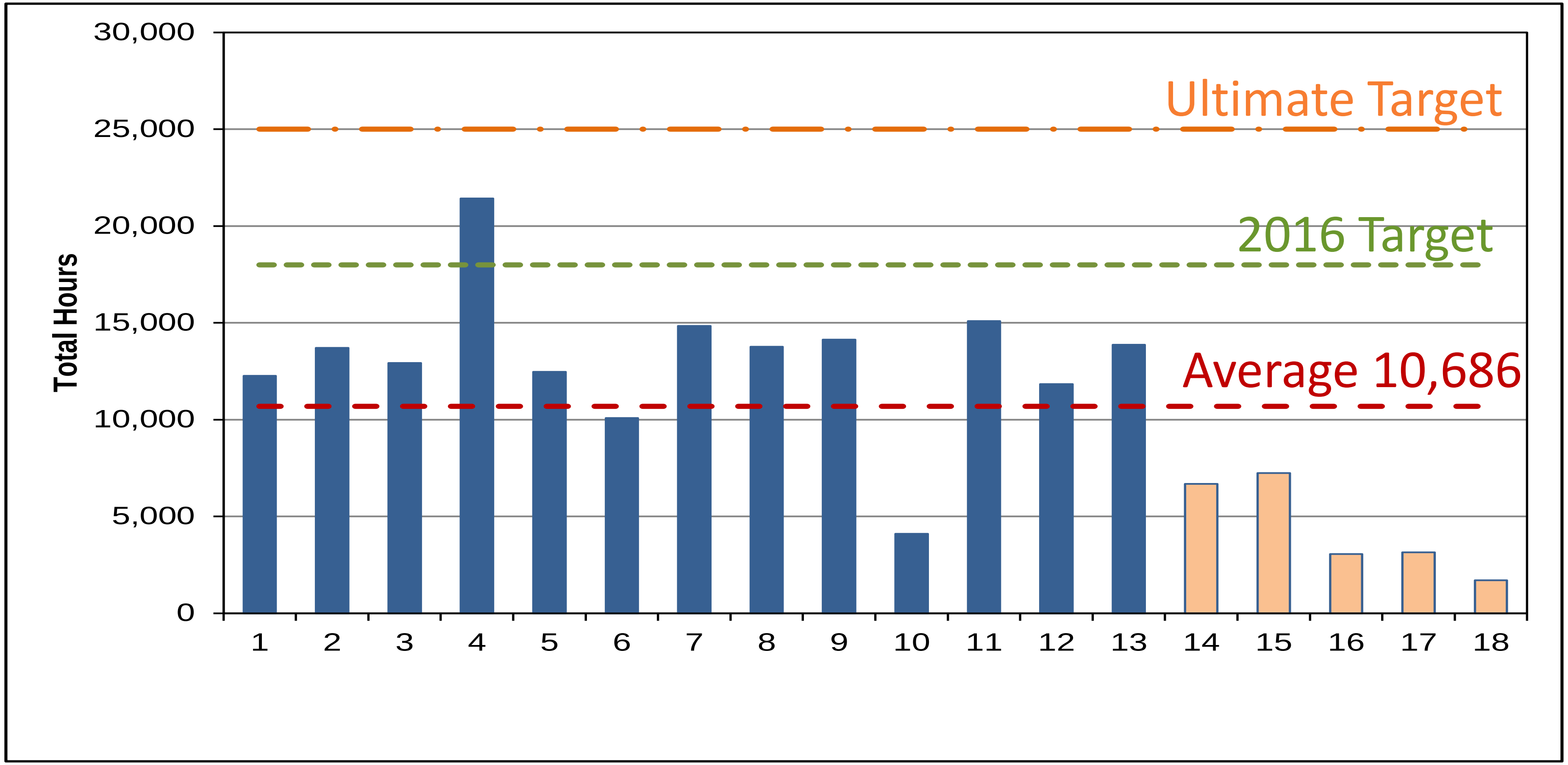
[1] Voluntarily supplied data for units > 100 kW
[2] Load fraction is the ratio of electrical output per rated capacity of the fuel cell unit. Efficiency data points for each load fraction are +/- 2% of the target load fraction.
[3] Mean efficiencies by unit are calculated as the percentage of electrical power output to higher heating value of fuel input. The natural gas higher heating value used is 48.956 MJ/kg and the lower heating value used is 44.294 MJ/kg.

On-Road Fuel Cell Vehicle Fuel Economy



Accumulated Hours on Each FCPP (12/2015)

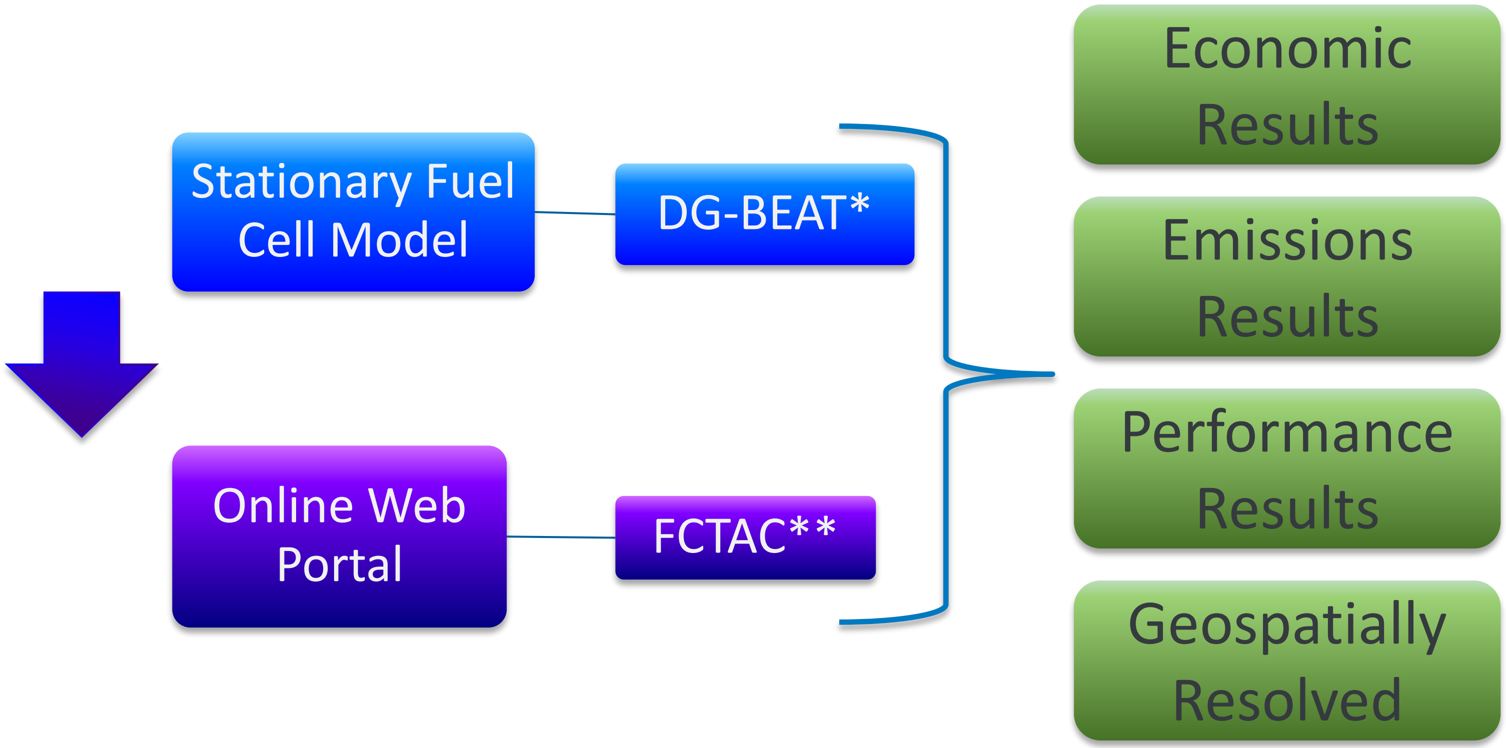
FCPP:
Fuel cell power plant



- **Includes 18 FCPPs from two demos**
- **Top FCPP: 21,422 hours (AC Transit)**
- **67% of FCPPs (12) have surpassed 10,000 hours**

Stationary Fuel Cell Modeling

Objective: Creation of tools that will enable research of the benefits of stationary fuel cells as a component in a modernized energy infrastructure and aid early market growth for the industry

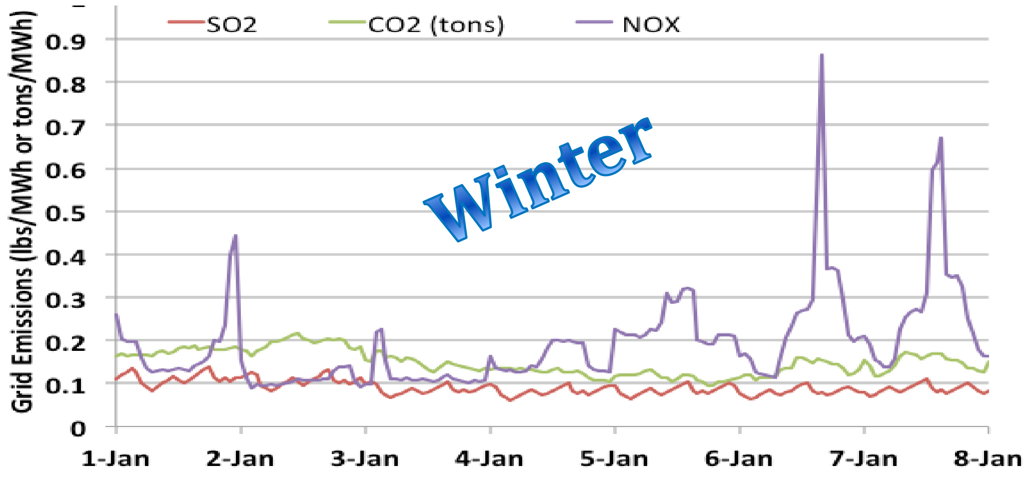


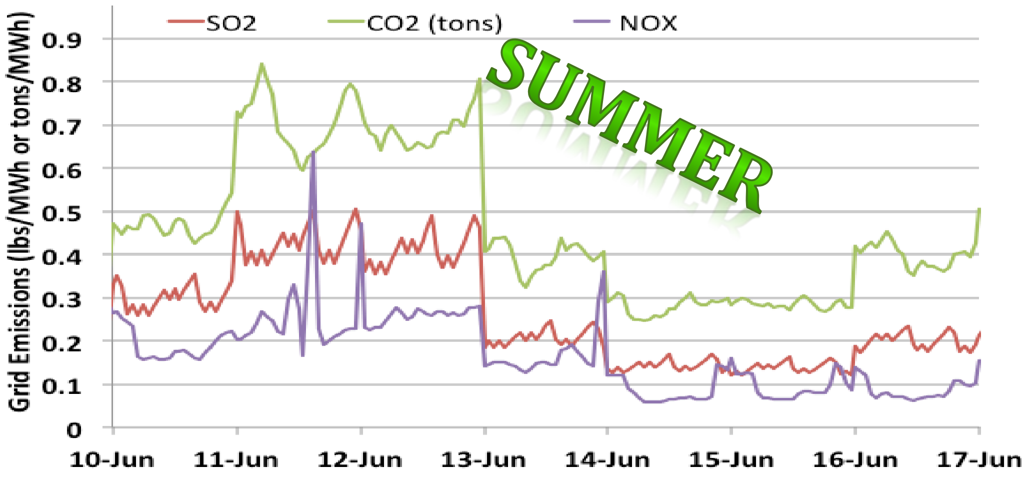
The results can examine:
- Fuel cell sizing
- Fuel cell controls
- Regional cost implications
- Regional emissions
- Real or ideal building profiles
- Assess building or campus
- Inform market potential

* **D**istributed **G**eneration – **B**uild-out **E**conomic **A**ssessment **T**ool
** **F**uel **C**ell **T**ool for **A**ssessing **C**osts

Regional Emissions Reporting and Control

- ➢Hourly emissions profiles can vary radically in different seasons and days, details that annual emissions alone cannot show
- ➢President Obama's EO 13514 mandates 40% reduction in greenhouse gas (GHG) emissions





Expectation that sum of daily and seasonal variations corresponds to annual totals

- ➢ **Hourly emissions data by state (GHGs such as CO_2, SO_2, NO_x)**
  - ✧ EPA Acid Rain Program and SIP NO_x Program
  - ✧ NO_x projected from daily totals by combustion power plant hourly emissions of CO_2
- ➢ **Comparison to annual factors from eGrid**
  - ✧ Annual emissions factors from the hourly profiles within ±5% of eGRID values
  - ✧ Annual total generation within 10% of state totals from eGRID for 48 states*

* Exceptions are California and Texas (55% and 70% of total, respectively)

Accomplishments: FCTAC – Online Web Portal

- Easily read results, visual and tabular

Analysis Information for Your Facility

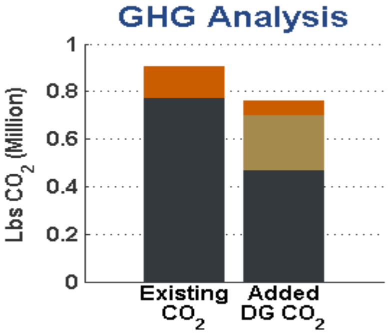
Climate Zone: Baltimore (ASHRAE 4A)

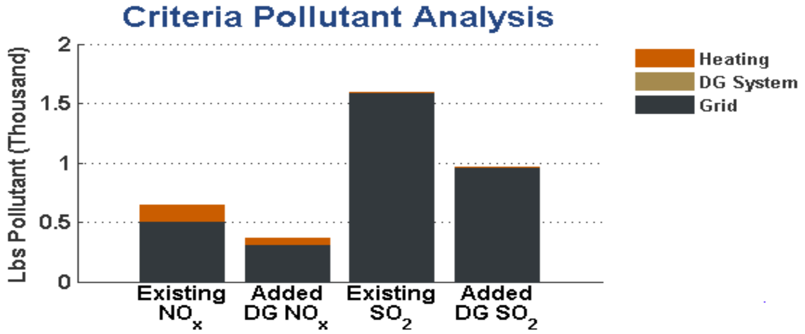
eGrid Zone: SERC Virginia/Carolina

System Size: 35kW HTFC

Analysis Period: 20 years

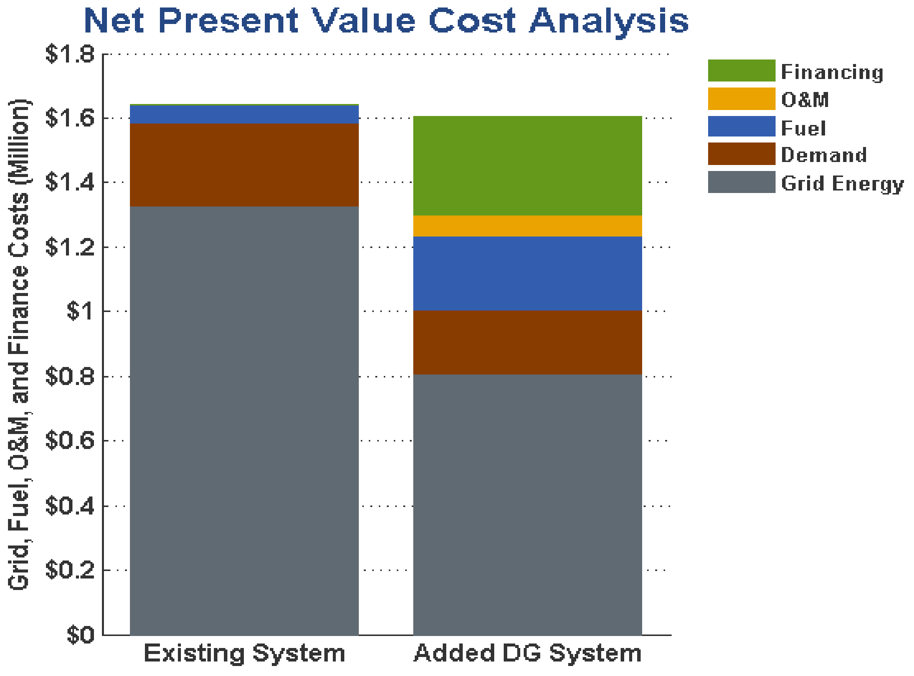
Payback: 15 years





Annual GHG and Pollutant Production (lbs)

	CO_2		NO_x		SO_2	
	Existing	Added DG	Existing	Added DG	Existing	Added DG
Heating	125,184	53,375	134	57	1	0
DG System	0	233,297	0	3	0	0
Grid	776,901	471,769	510	310	1,590	965
Total	902,085	758,441	644	370	1,591	965



Net Present Value Cost Analysis (US$)

	Existing System	Added DG
Finance	$0	$304,874
O&M	$0	$65,294
Fuel	$56,103	$229,988
Demand	$254,178	$196,954
Grid	$1,329,502	$807,348
Total	$1,639,783	$1,604,458

$35,325 reduction (2%) over the 20 year analysis period.

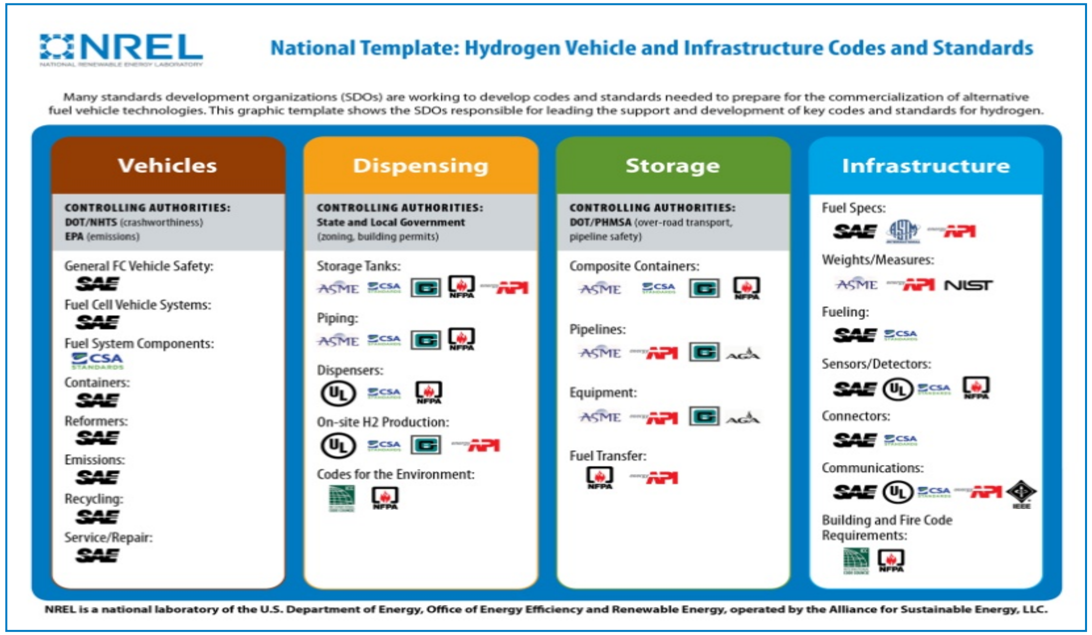
Safety

Safety, Codes, and Standards

Guidance on safe operation, handling, and use

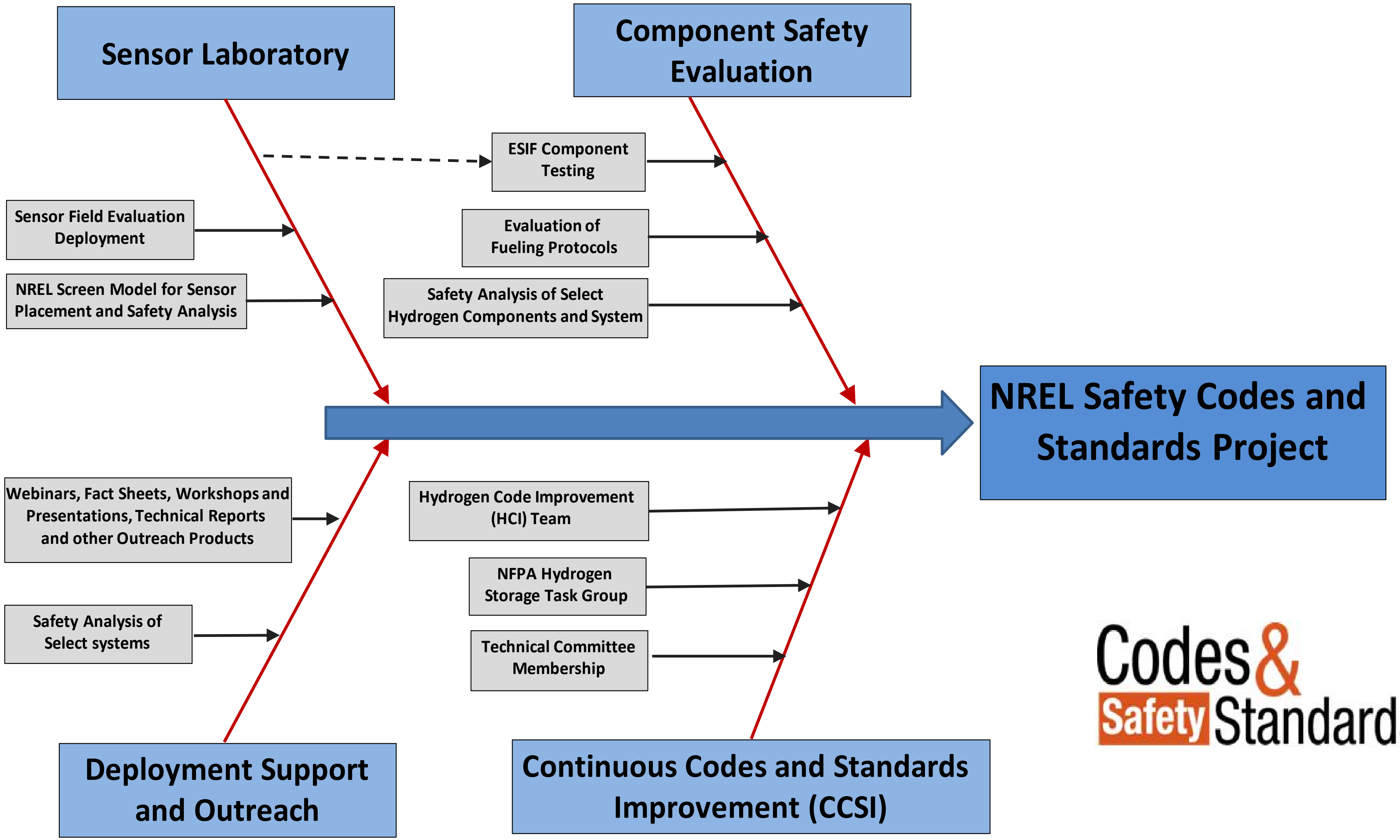
Safety testing and sensors

Vehicle, equipment, and building codes and standards



Top and middle photos by Keith Wipke, NREL; bottom photo by Dennis Schroeder

NREL Safety Codes and Standards Project Structure



Codes & Safety Standards

Stationary Fuel Cell Safety

Key Points and Documents

- Fuel cell contains very little hydrogen
- The hydrogen storage presents a greater safety concern
- Codes and standards well established to address both the fuel cell and hydrogen storage
- NREL supporting development of safety guide publish ~June 2016
- NFPA 853 Standard for the Installation of Stationary Fuel Cell Power Systems
- CSA FC1 – fuel cell operation and performance
- NFPA 2 Hydrogen Technologies Code – hydrogen storage

Hydrogen and fuel cells complement intermittent renewable power for carbon-free data centers

Learn more at www.nrel.gov/hydrogen

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.