Zero Carbon Systems with Renewable Hydrogen

to

Senate Hydrogen & Fuel Cell Caucus

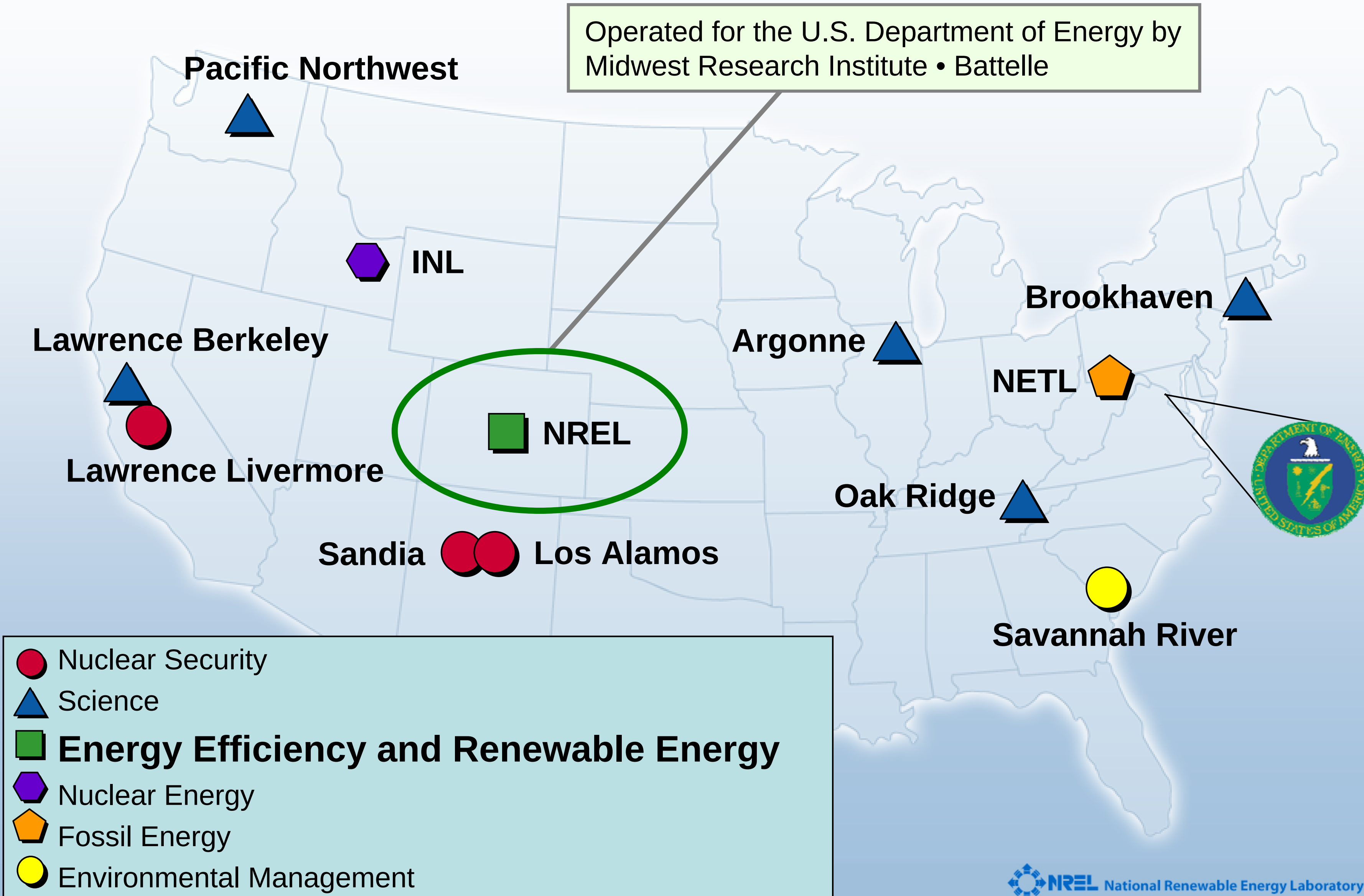
Dirksen Senate Office Building/G-11

April 16, 2008

Dr. Dan E. Arvizu

Director, National Renewable Energy Laboratory

Major DOE National Laboratories



National Renewable Energy Laboratory
What Makes Us Unique?

- Only national laboratory dedicated to renewable energy and energy efficiency research and development
- Research spans fundamental science to technology solutions
- Collaboration with industry and university partners is a hallmark of our laboratory
- Research is market relevant – aimed at transfer and deployment of technologies to industry and the market

NREL Energy Efficiency and Renewable Energy Technology Development Programs

NREL R&D Portfolio

Efficient Energy Use

- Vehicle Technologies
- Building Technologies
- Industrial Technologies

Renewable Resources

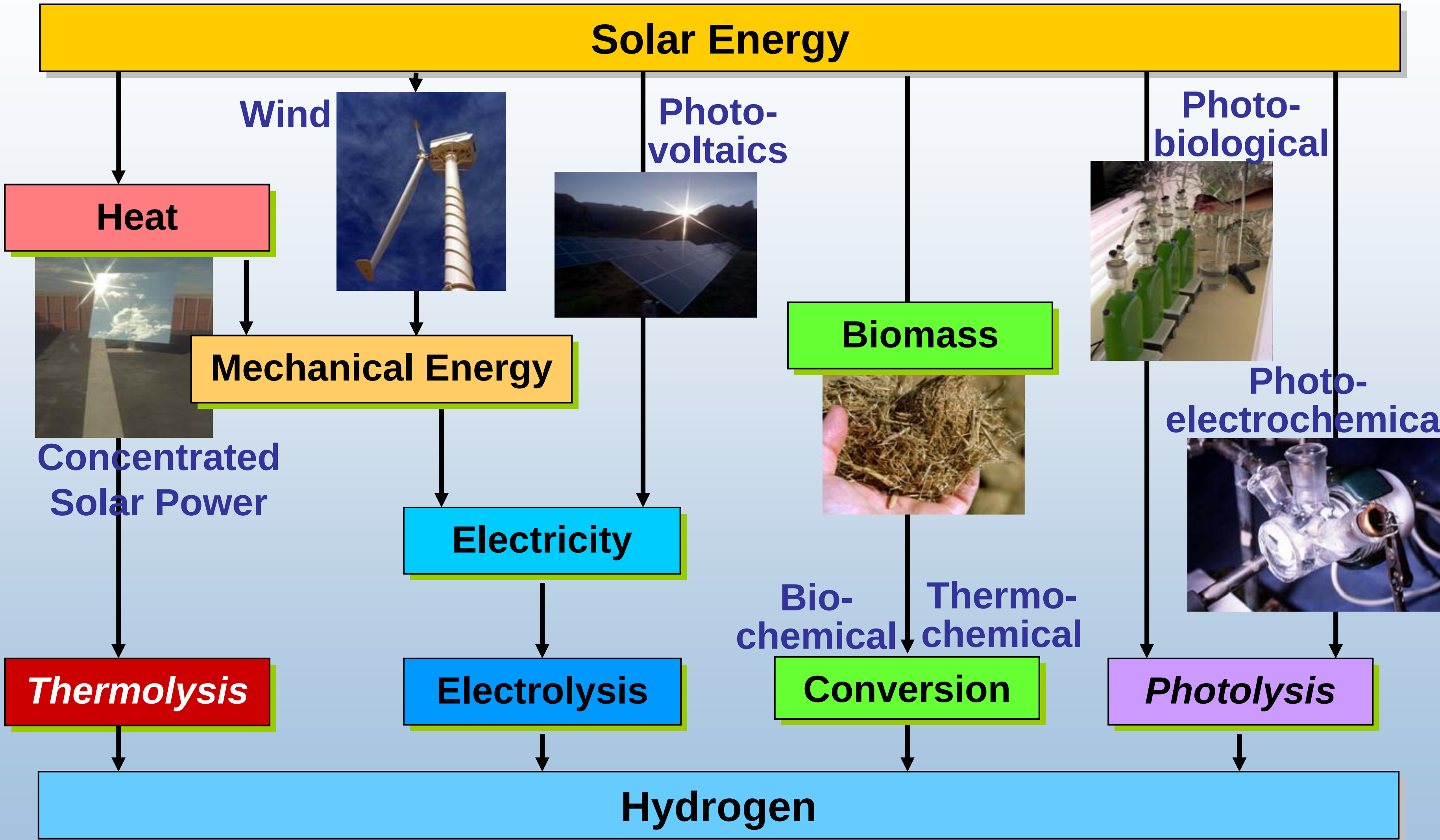
- Wind
- Solar
- Biomass
- Geothermal
- Renewable Hydrogen

Energy Delivery and Storage

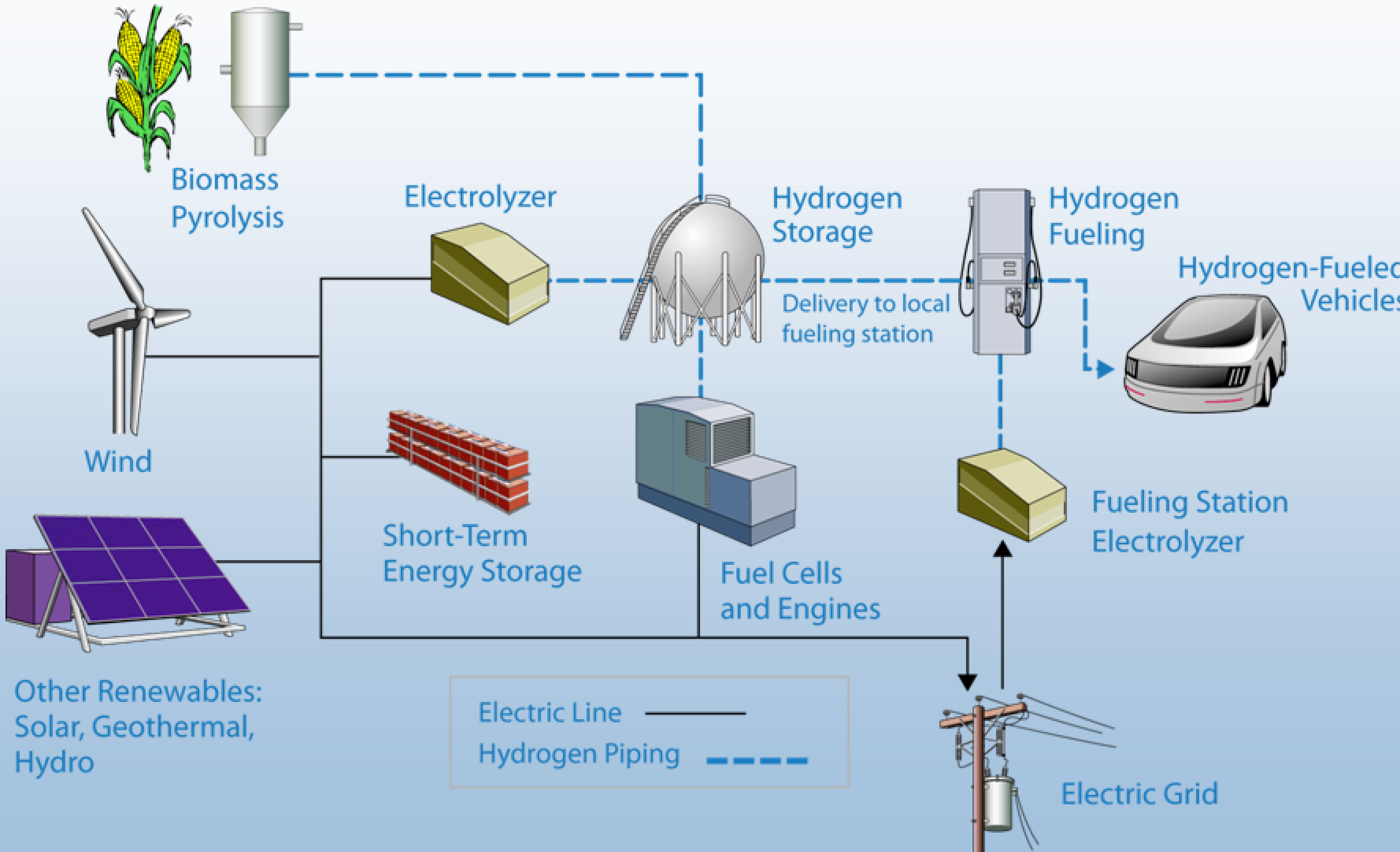
- Electricity Transmission and Distribution
- Alternative Fuels
- Hydrogen Delivery and Storage

Foundational Science and Strategic Analysis

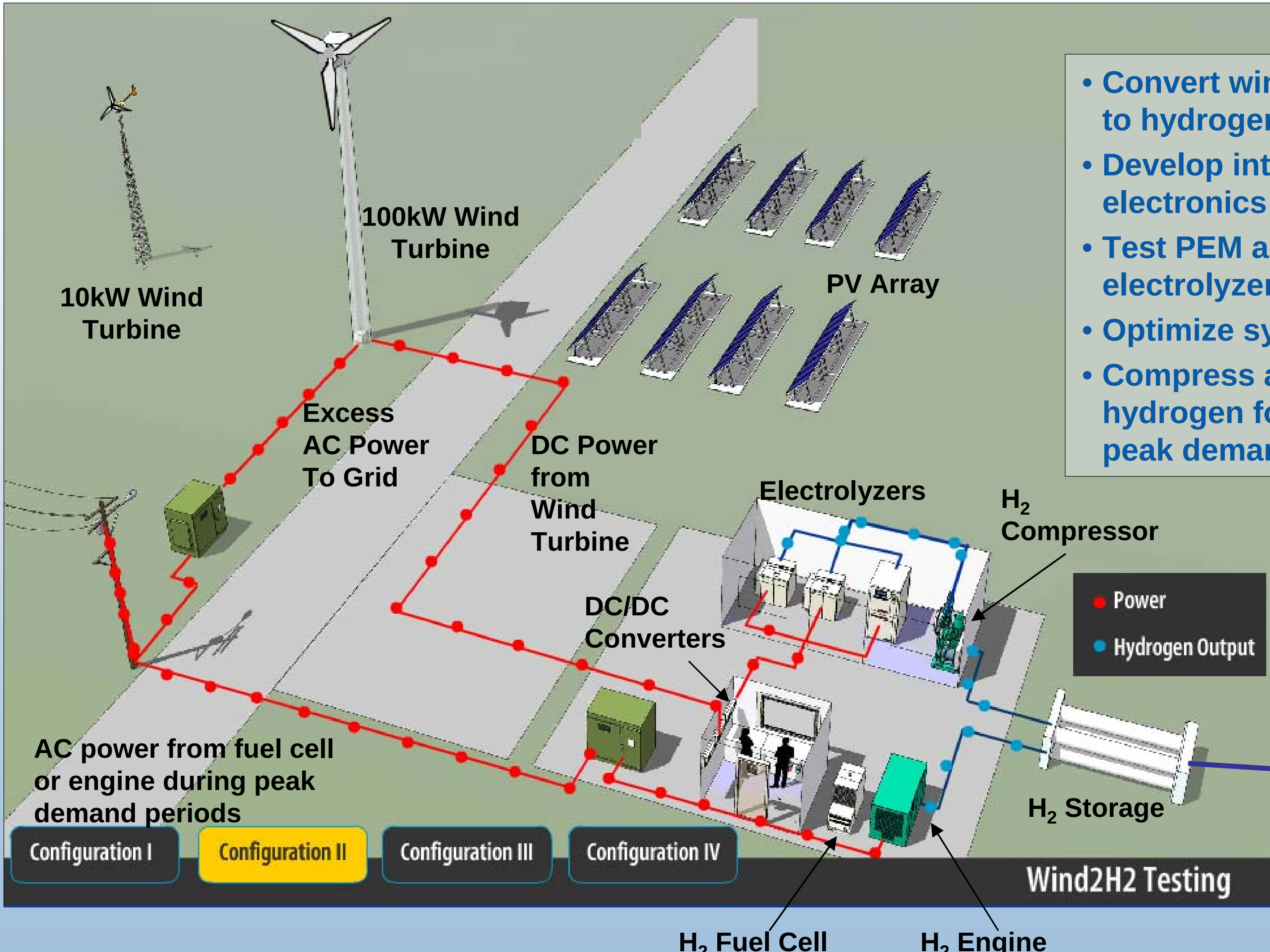
Renewable Energy Paths to Hydrogen



Example Renewable Hydrogen Systems

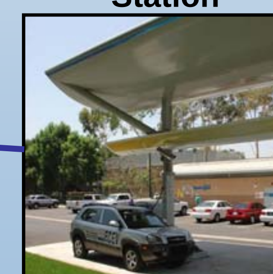


NREL/Xcel Wind-to-Hydrogen Project

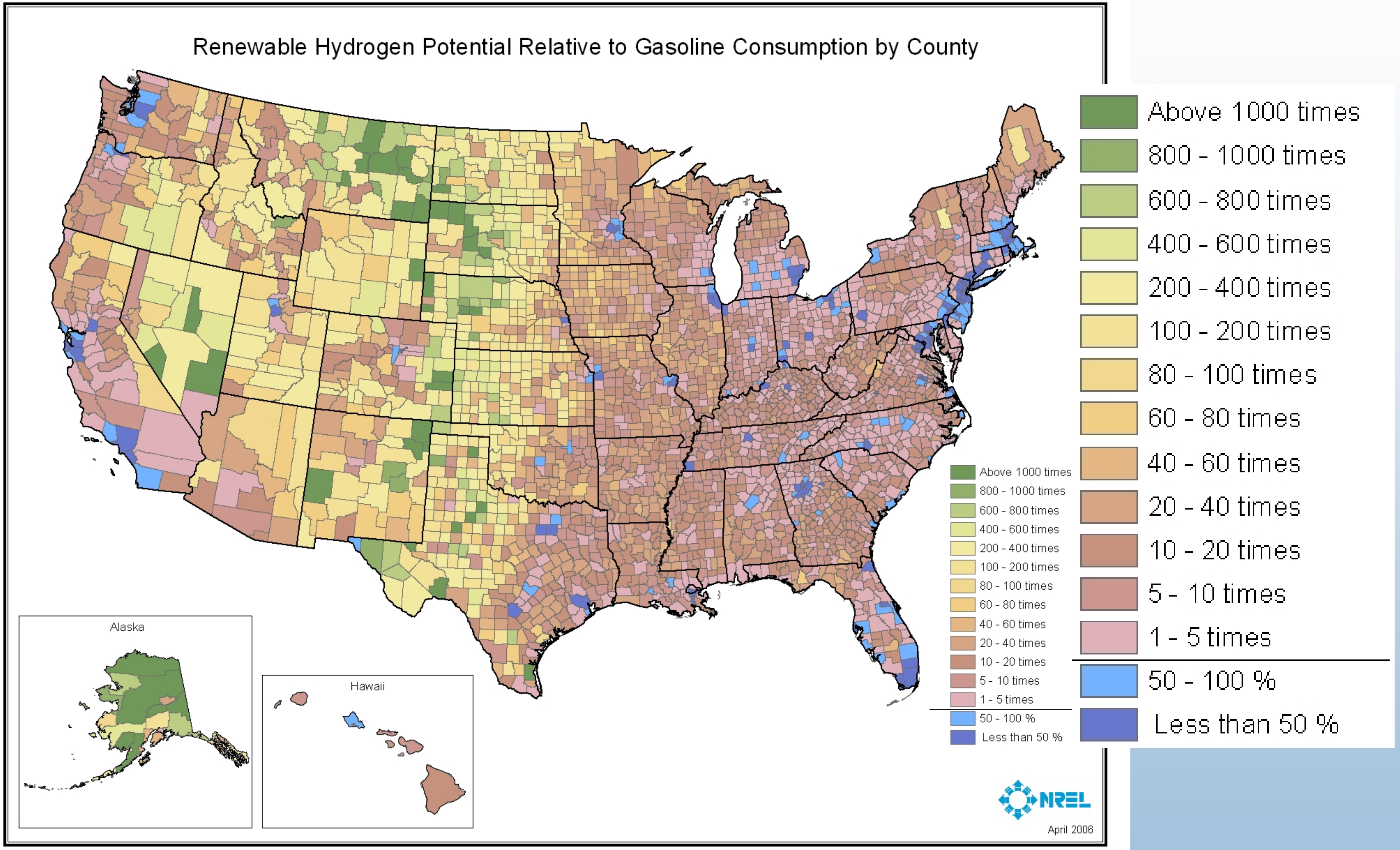


- Convert wind and solar to hydrogen
- Develop integrated power electronics
- Test PEM and alkaline electrolyzers
- Optimize system controls
- Compress and store hydrogen for use during peak demand

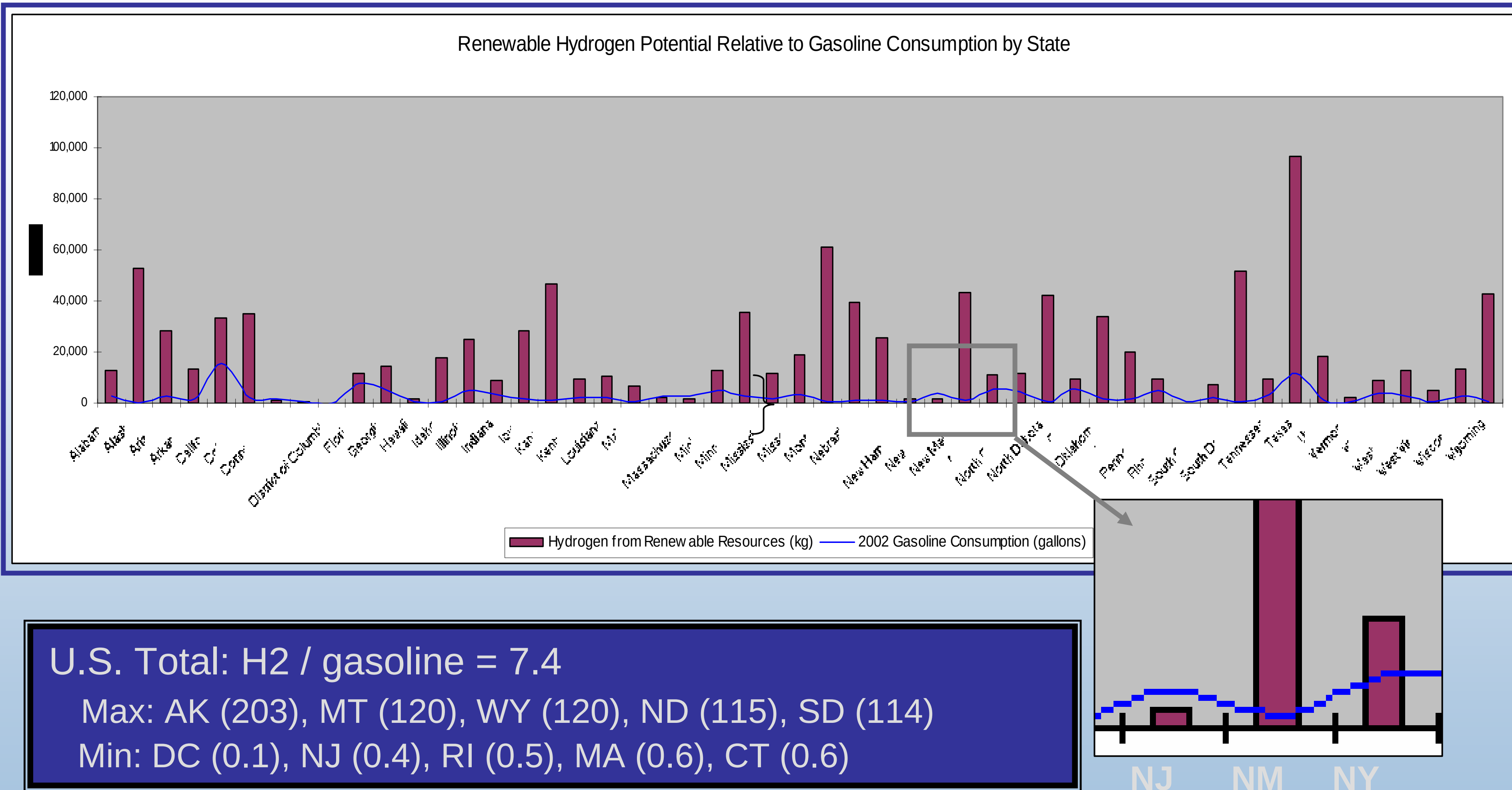
FCV Refueling Station



Total Renewable Hydrogen Potentail



Renewable Hydrogen Potential by State



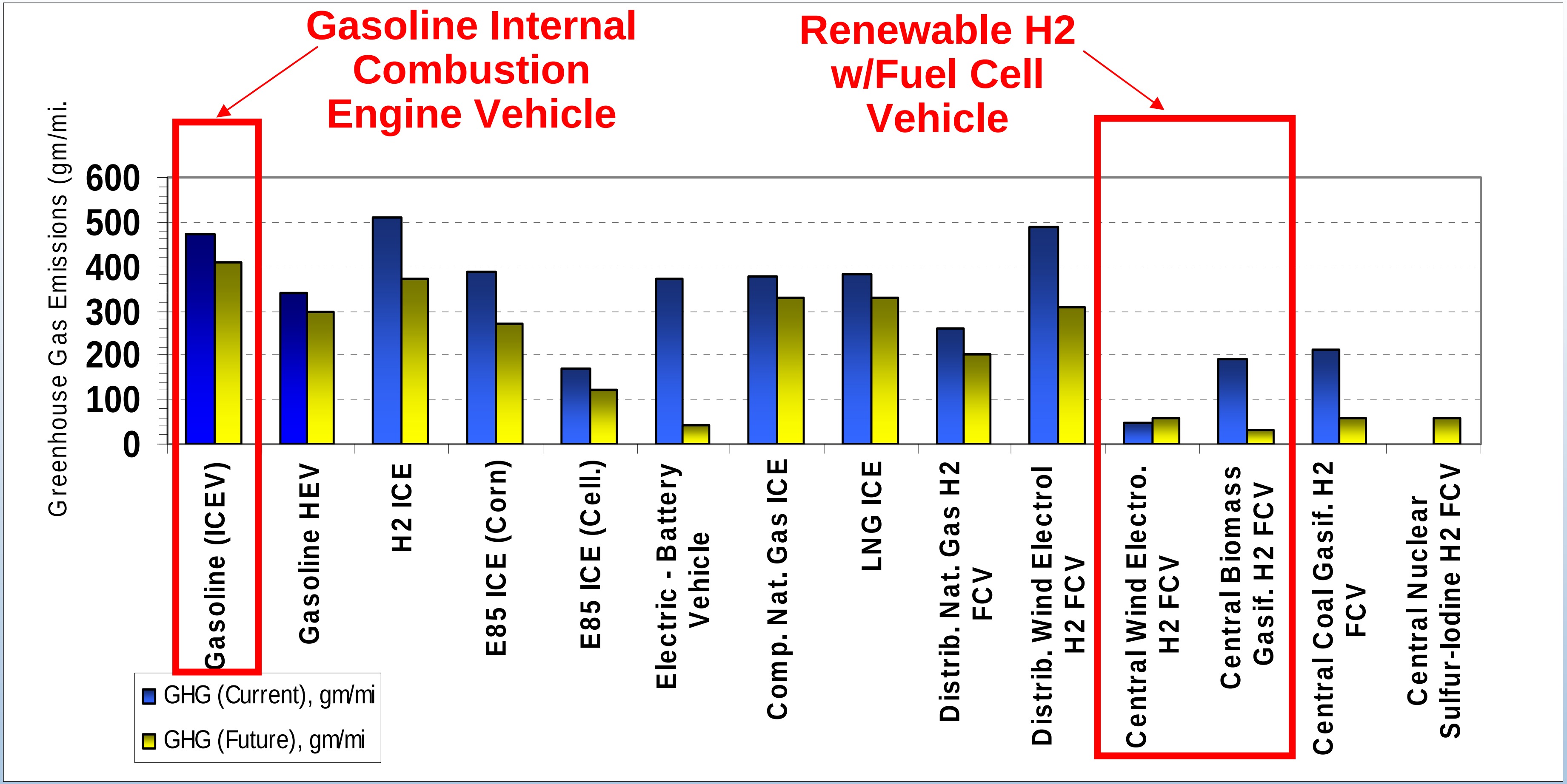
U.S. Total: H2 / gasoline = 7.4

Max: AK (203), MT (120), WY (120), ND (115), SD (114)

Min: DC (0.1), NJ (0.4), RI (0.5), MA (0.6), CT (0.6)

Energy equivalent basis (gge): no advantage given to hydrogen for higher fuel cell efficiency, which would increase ratios of hydrogen over gasoline

Well-to-Wheels Greenhouse Gas Emissions

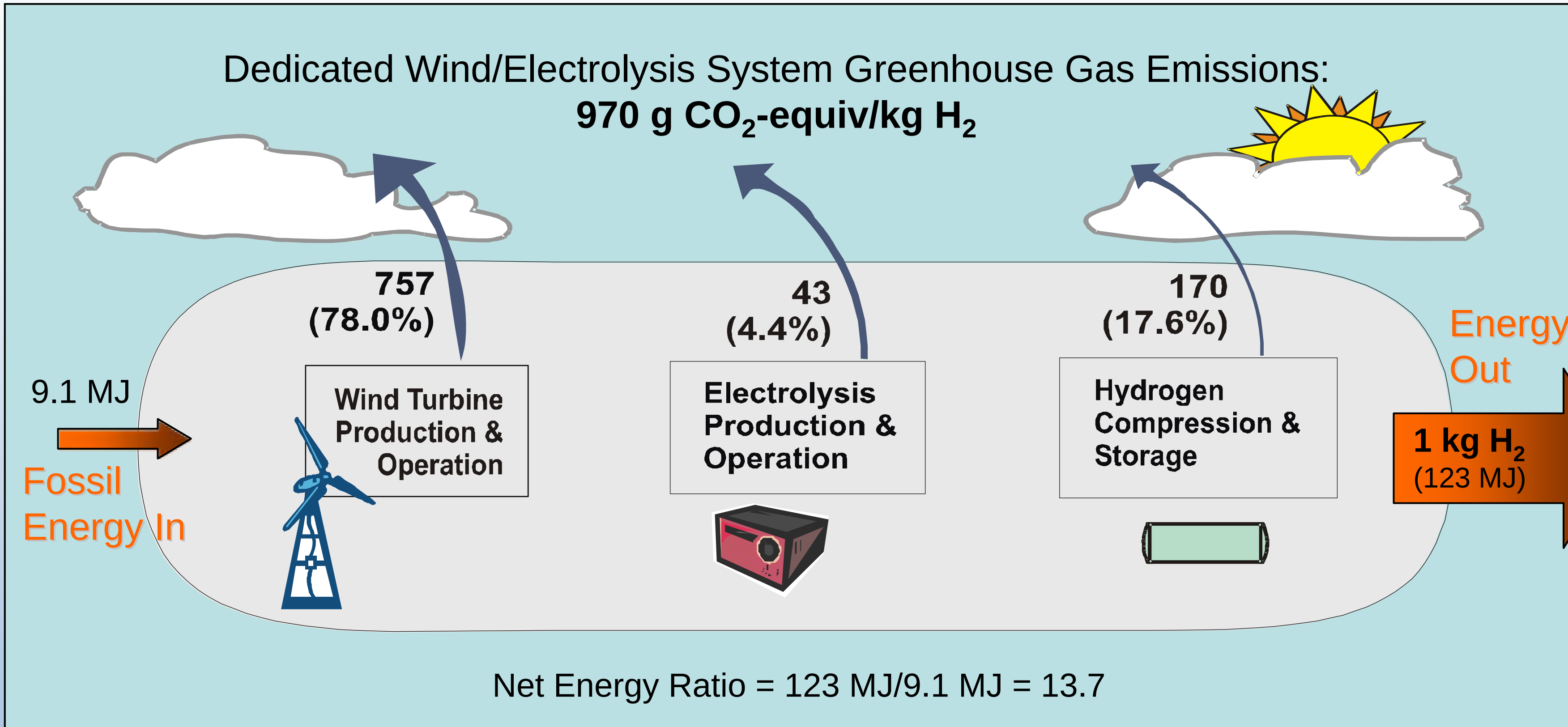


Vehicle Fuel Economy used in the analysis, mpgge

	Gaso. ICE	Gaso.HEV	H2 ICE	Nat. Gas ICE	FCV HEV
2005	24	34	29	24	57
2015	28	39	34	28	66

Sources: H2A and ANL/GREET models

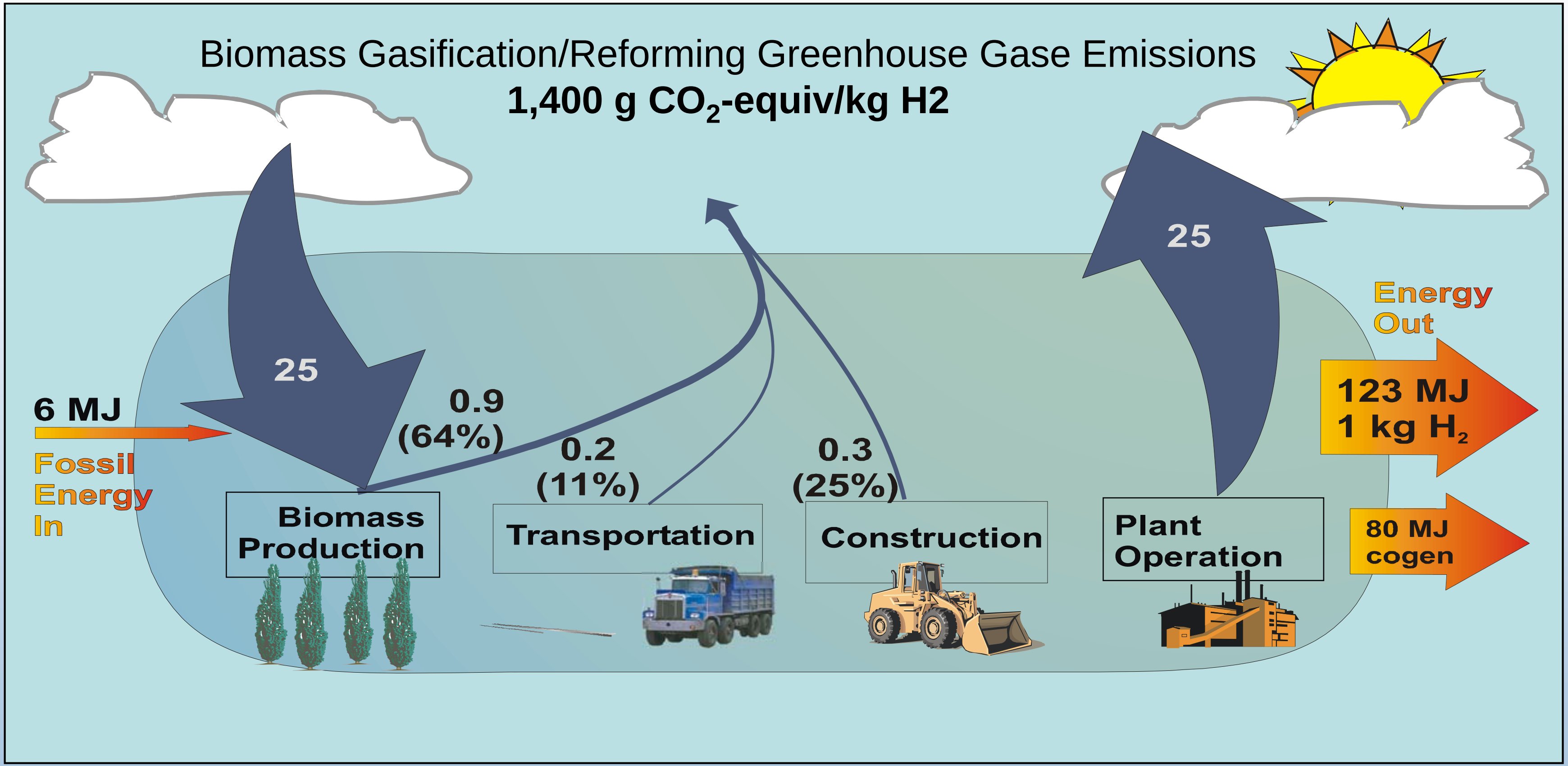
Environmental Impacts of Wind-Electrolysis Hydrogen Production System



For Gasoline and ICE Vehicle:
Greenhouse Gas Emissions = **11,500 g CO_2-equiv/kg H_2**

Sources: NREL and ANL/Greet

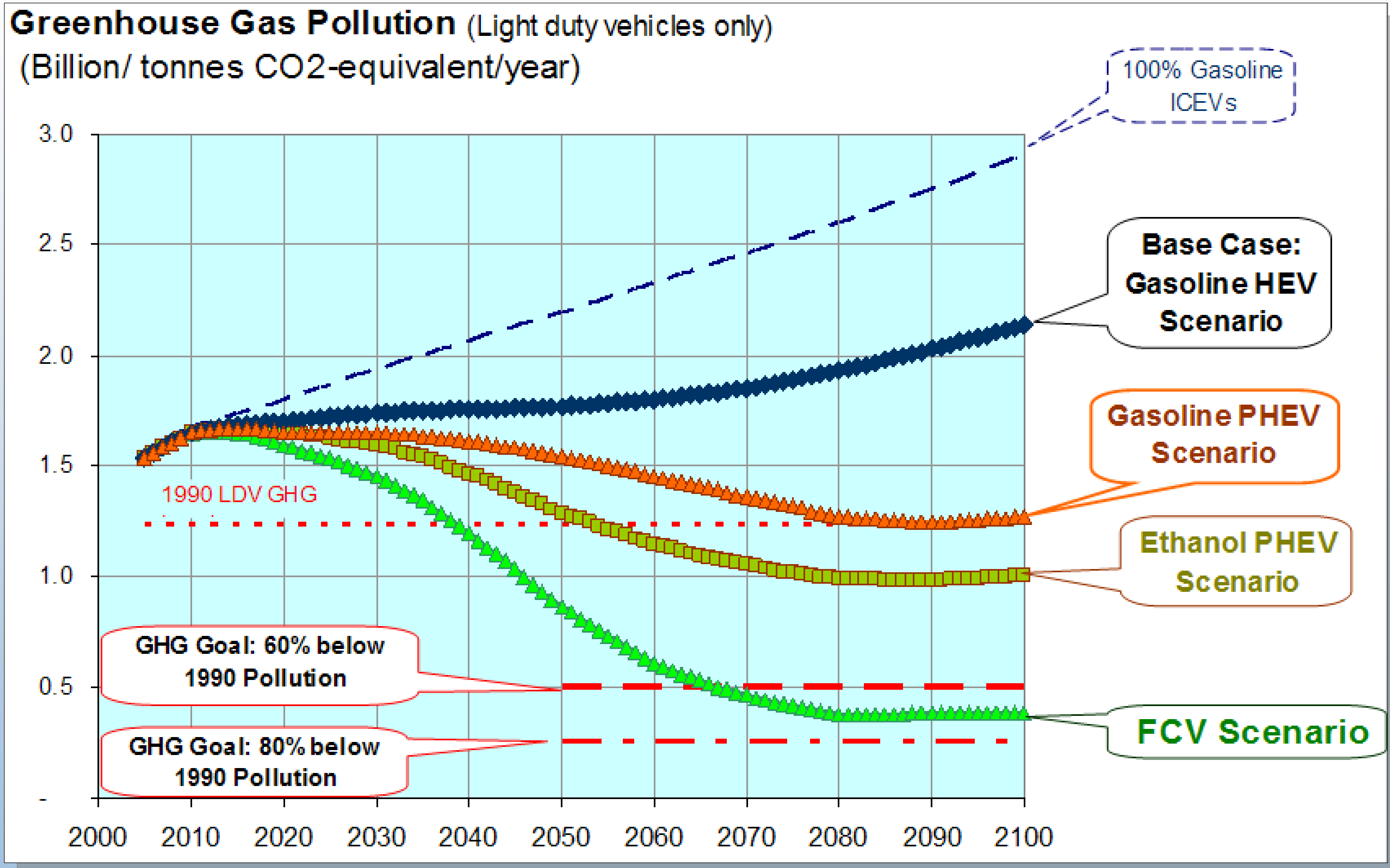
Environmental Impacts of Thermochemical Biomass to Hydrogen Processes



For Gasoline and ICE Vehicle:
Greenhouse Gas Emissions = **11,500 g CO_2-equiv/kg H_2**

Sources: NREL and ANL/Greet

CO2 Emissions – Technology Comparison



Source: C. E. (Sandy) Thomas, Ph.D., H2Gen

DOE Hydrogen Production Cost Progress

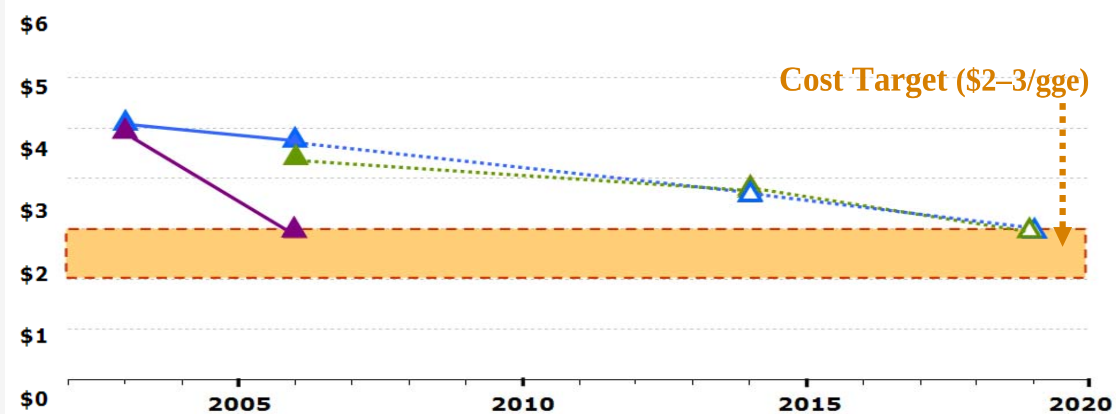
Cost of Hydrogen (Delivered) — Status & Targets

(in $/gallon gasoline equivalent (gge), untaxed)

NEAR TERM: **Distributed Production**

→ *Hydrogen is produced at station to enable low-cost delivery*

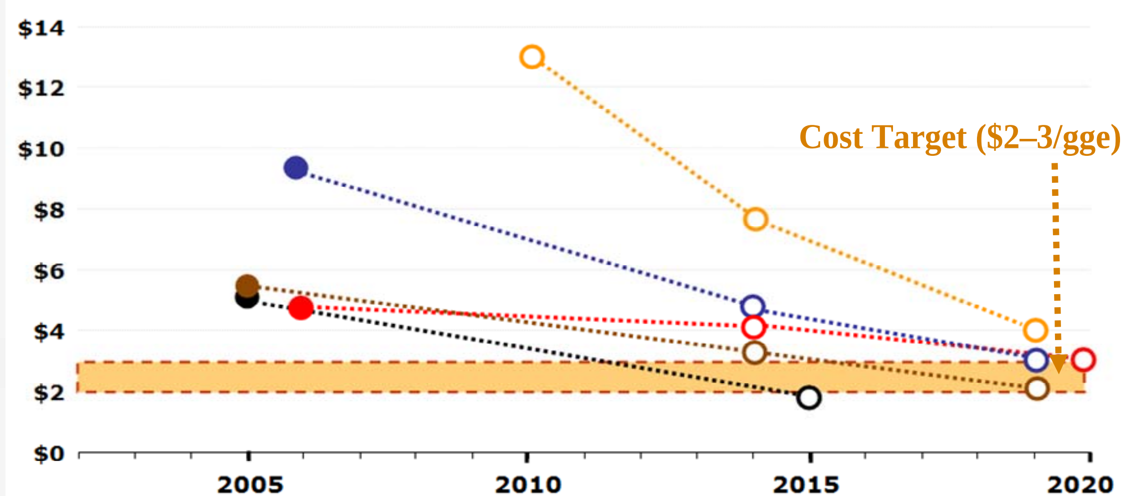
- ▲ Distributed Natural Gas
- ▲ Distributed Electrolysis
- ▲ Distributed Bio-Derived Renewable Liquids



LONGER TERM: **Centralized Production**

→ *Large investment in delivery infrastructure needed*

- ● Biomass Gasification
- ● Coal Gasification with Sequestration
- ● Solar High-Temperature Thermochemical Cycle
- ● Central Wind Electrolysis
- ● Nuclear



Source: EERE Hydrogen and Fuel Cells Program

DOE FY09 Hydrogen Budget Drivers

Technology Barriers

Hydrogen Production Cost *

(One cost-competitive pathway required for critical path. Target: $2 – 3 /gge — *met by distributed reforming of natural gas*)

Hydrogen Storage Capacity & Cost

(Targets: 2.7kWh/L, 3kWh/kg, and $2/kWh)

Fuel Cell Cost and Durability

(Targets: $30 per kW, 5000-hour durability)

Economic & Institutional Barriers

Safety, Codes & Standards Development

Delivery Infrastructure

Domestic Manufacturing and Supplier Base

Public Awareness & Acceptance

Critical Path Barriers for Fuel Cell Vehicle Technology Readiness in 2015

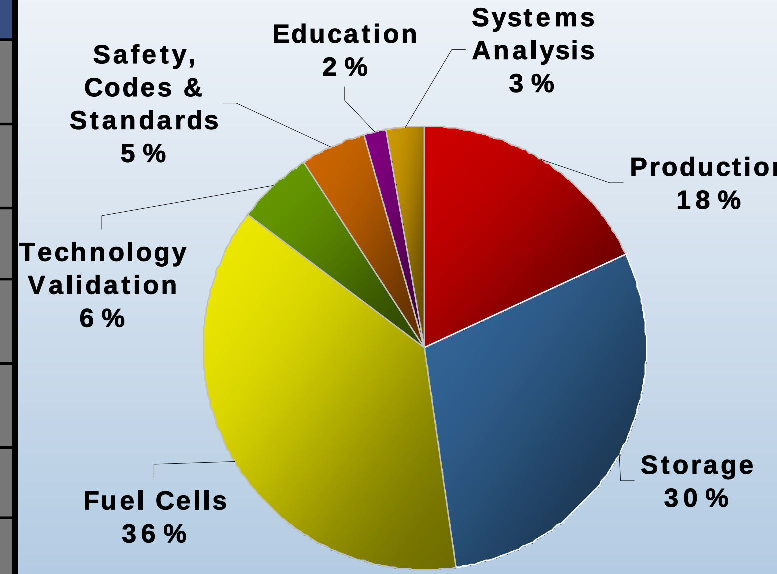
****Critical Path for hydrogen cost is one cost-competitive production pathway. Multiple pathways are needed for longer-term energy security and sustainability.***

Source: EERE Hydrogen and Fuel Cells Program

DOE FY09 Hydrogen Budget Request by Sub-Program Area

Activity	Funding ($ in thousands)					
	EERE (HFCIT)	EERE (VT)	FE (coal)	NE (nuclear)	BES (science)	TOTAL
Hydrogen Production			11,430	16,600	20,133	48,163
Hydrogen Storage	59,200				20,134	79,334
Fuel Cells	79,300				20,133	99,433
Technology Validation		14,789				14,789
Safety, Codes & Standards		12,238				12,238
Education		4,000				4,000
Systems Analysis	7,713					7,713
TOTAL	146,213	31,027	11,430	16,600	60,400	265,670

$40M in FY08



Source: EERE Hydrogen and Fuel Cells Program

Summary

- **Hydrogen/Fuel Cell Vehicles offer a near-zero GHG transportation pathway**
  - Well-to-Tank: Hydrogen production/storage/delivery is near-zero GHGs when produced from renewable energy sources
  - Tank-to-Wheels: FCVs produce no GHGs – only water vapor exhaust
- **Renewable hydrogen resource is sufficient to provide U.S. transportation needs in long term**
- **Primary barrier to renewable hydrogen is cost**
  - Some of the pathways are getting close to competitive
  - But, the game-changing technologies need continued R&D
- **Balanced R&D program is needed which both**
  - Introduces hydrogen and FCVs to early markets in order to stimulate the infrastructure – even with non-optimum technologies
  - Acknowledges the criticality of the longer term hydrogen production goals and keeps that R&D funded and viable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