Many Pathways to Renewable Hydrogen

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Power Gen: Renewable Energy & Fuels 2008

by

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Why Renewable Hydrogen?

- Virtually any primary energy source can be turned into hydrogen opening up the possibility of hydrogen becoming a universal fuel.
- Renewable Hydrogen contributes to our National energy objectives

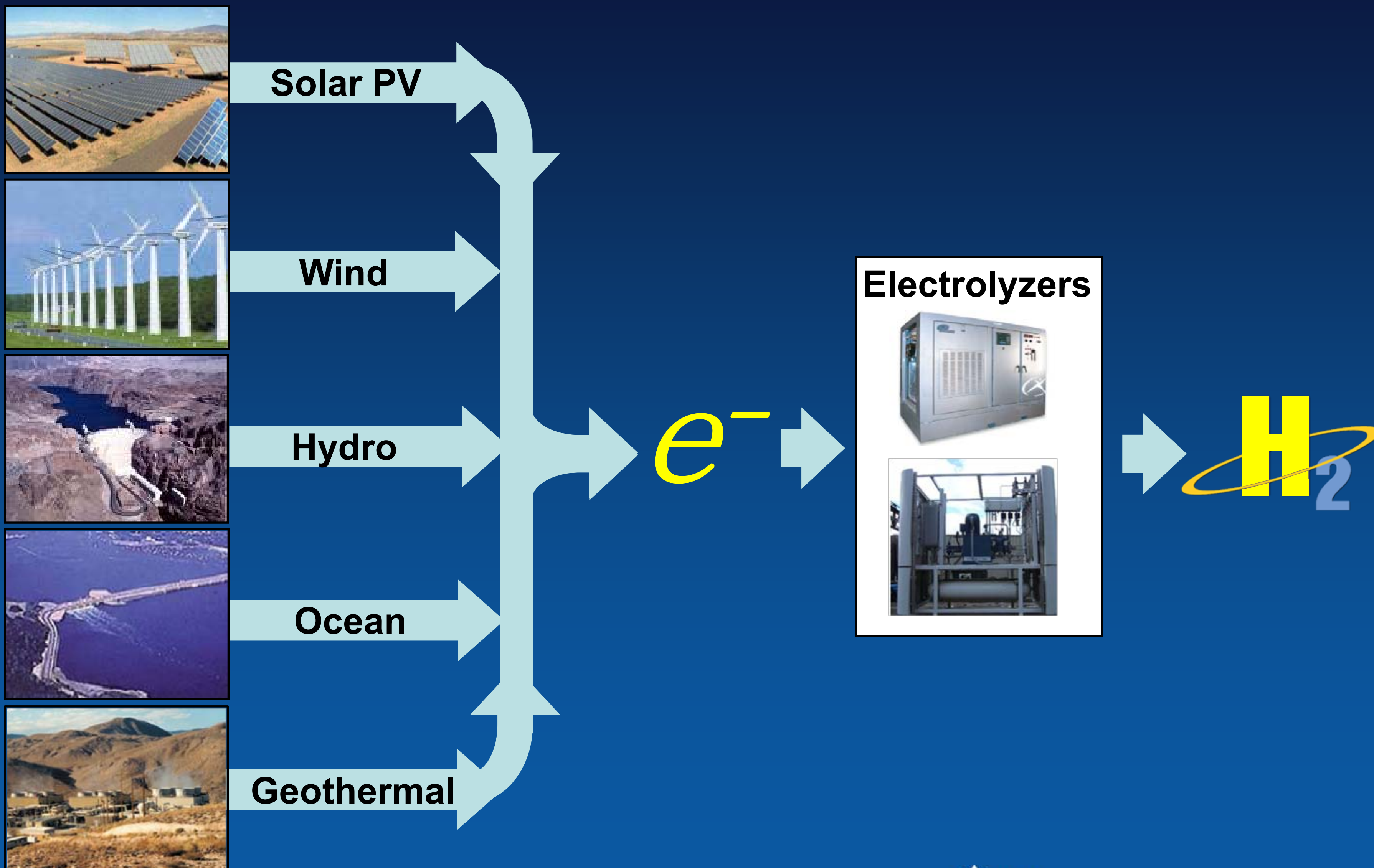
Energy Security

Environmental Stewardship

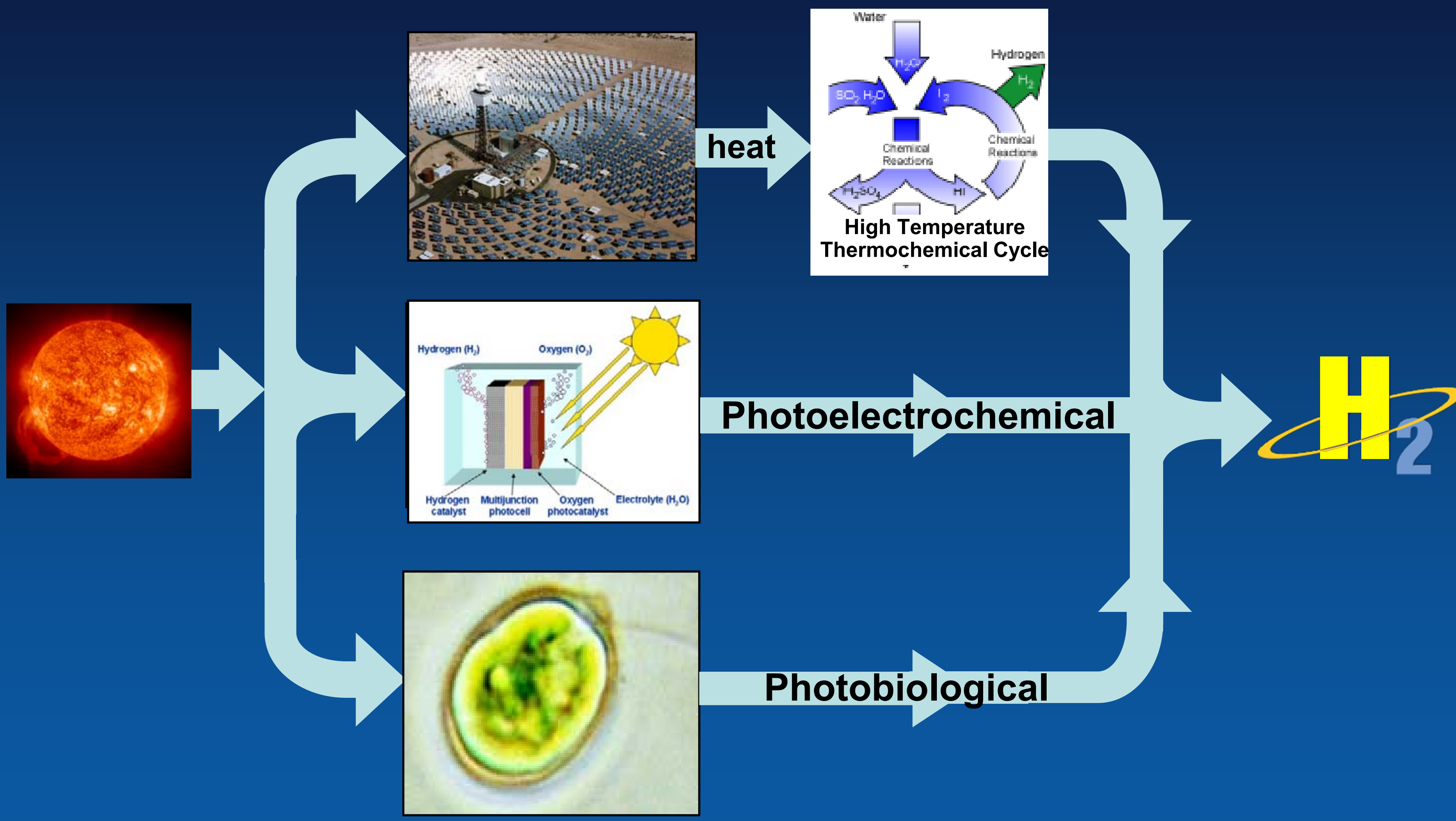
Economic Competitiveness

- Using hydrogen as an energy vector helps mitigate the intermittency of renewable energy sources by providing opportunities for storage.

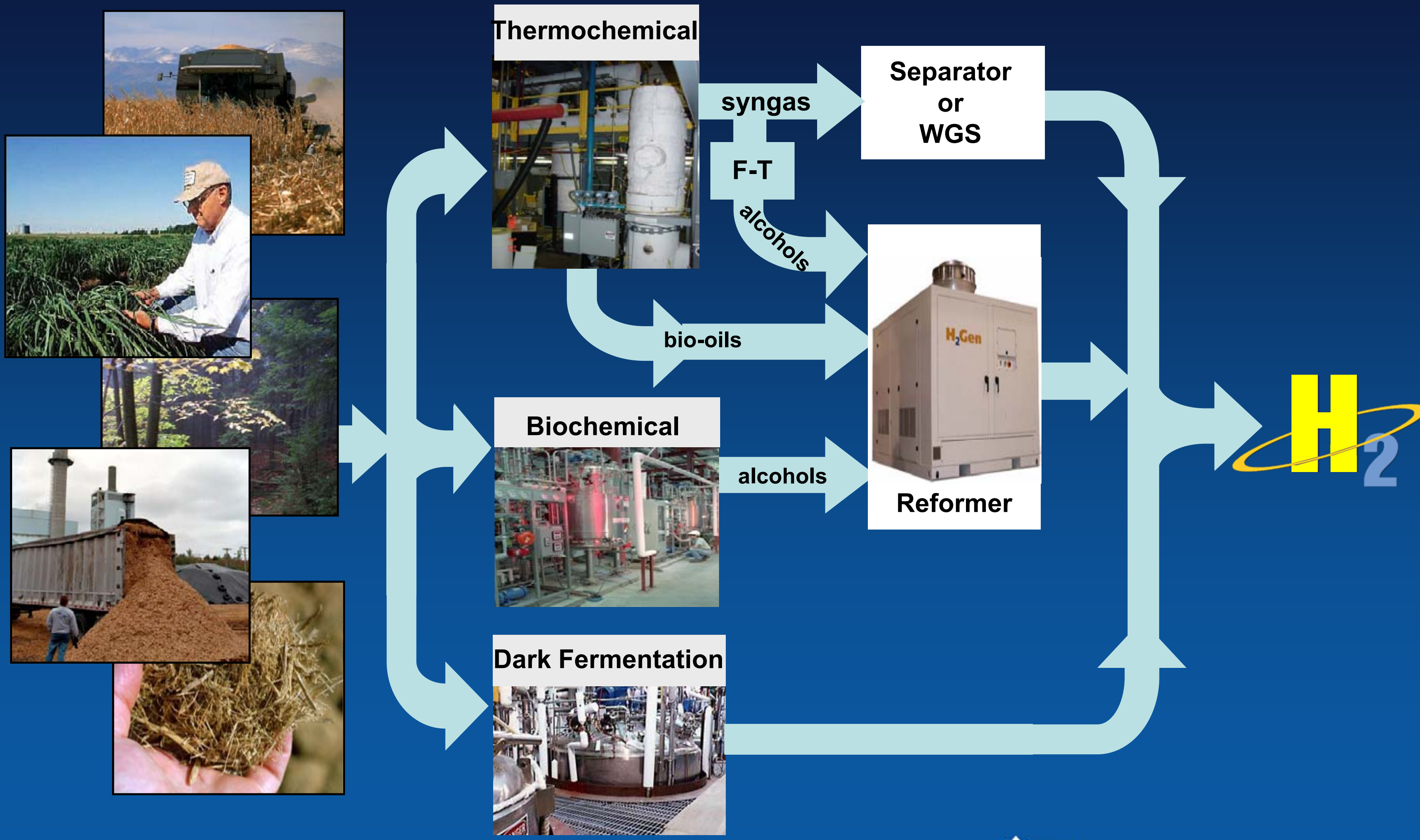
Electrolysis Pathways

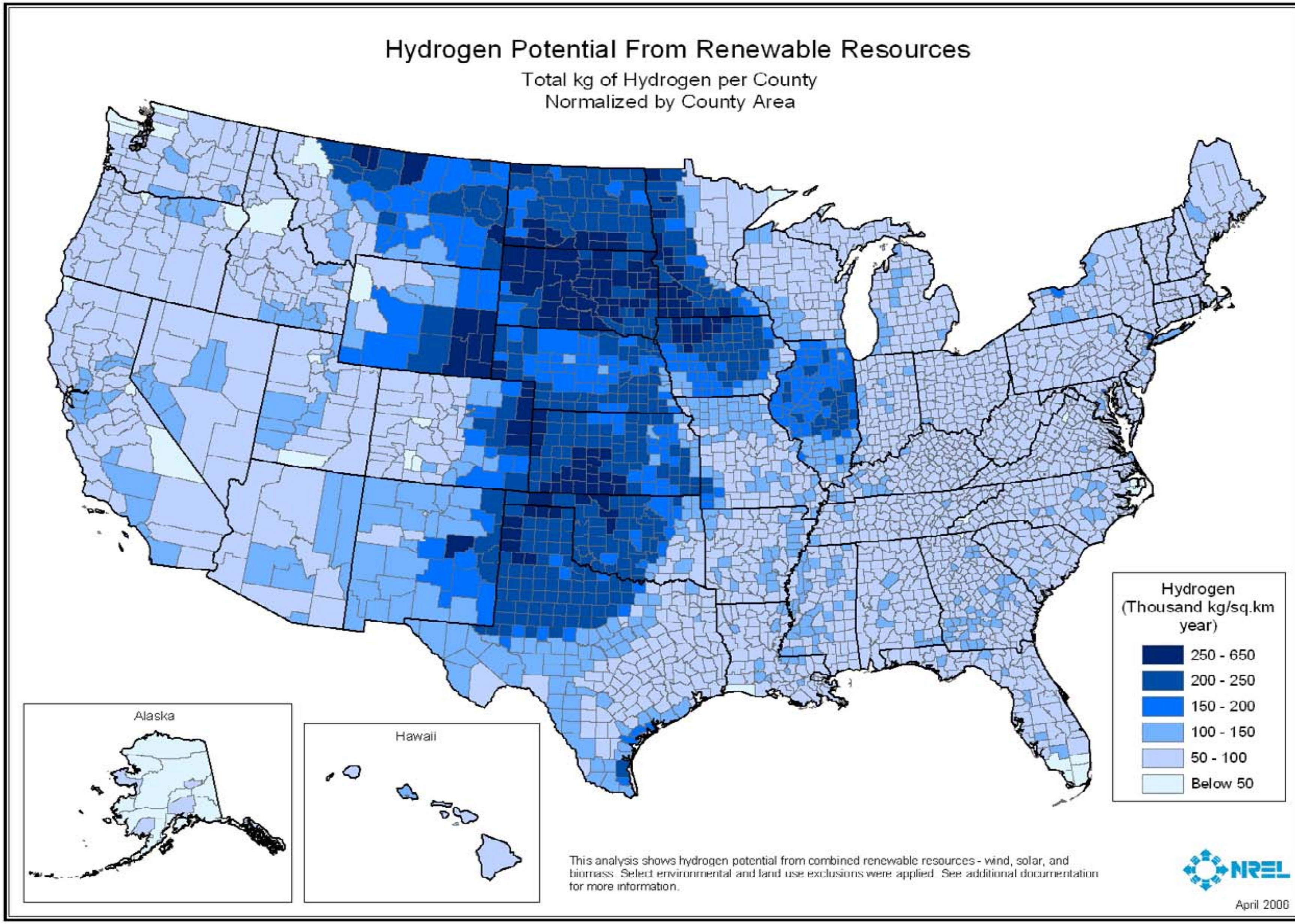


Non-PV Solar Pathways



Biomass Pathways




Hydrogen Potential From Renewable Resources
Total kg of Hydrogen per County
Normalized by County Area
Alaska
Hawaii
Hydrogen
(Thousand kg/sq.km year)
250 - 650
200 - 250
150 - 200
100 - 150
50 - 100
Below 50
This analysis shows hydrogen potential from combined renewable resources - wind, solar, and biomass. Select environmental and land use exclusions were applied. See additional documentation for more information.
NREL
April 2006

Barriers to Implementation

- General / Marketplace
  - Viewed as long term – *20 to 30 years out*
  - Hydrogen use viewed with trepidation by public
  - Current hydrogen production costs higher than conventional fuels
- Technological
  - Numerous technical challenges for each of the renewable pathways
  - Limited industry interest and investment in R&D

NREL Supports DOE's Hydrogen Program Goals for 2015

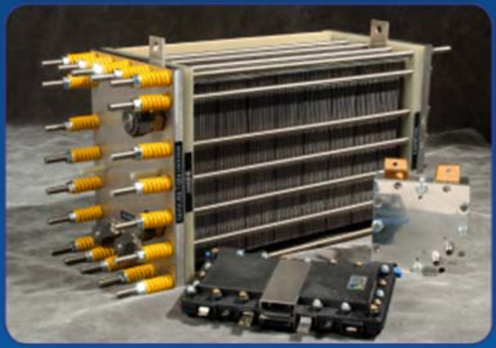
Production

$2.00 - 3.00/kg
(pathway independent)

Onboard Storage

300 mile range

Fuel Cell



$30/kw

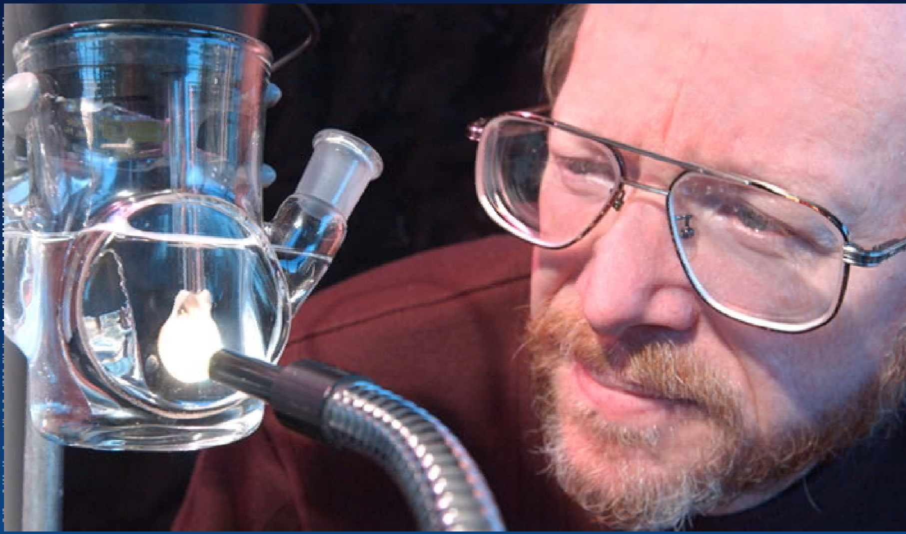
NREL Hydrogen Technology Thrusts

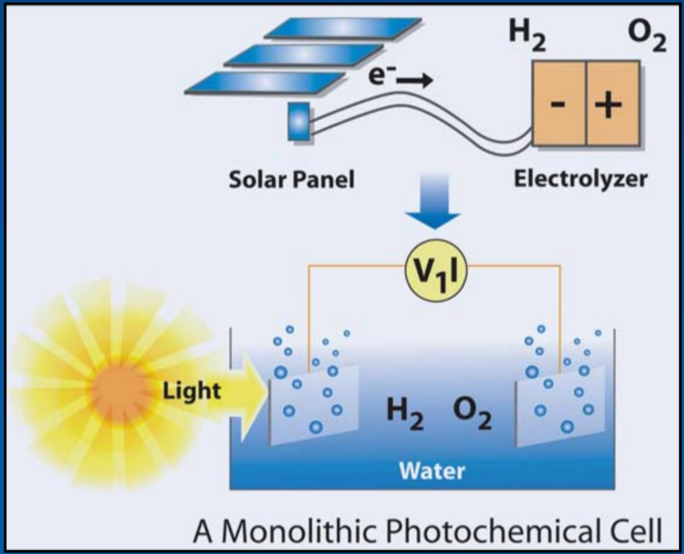
- Hydrogen production
- Hydrogen delivery
- Hydrogen storage
- Hydrogen manufacturing
- Fuel cells
- Technology validation
- Safety, codes, & standards
- Analysis

H_2 Production: Photoelectrochemical

Photoelectrochemical materials are specialized semiconductors that use energy from sunlight to dissociate water molecules into hydrogen and oxygen.

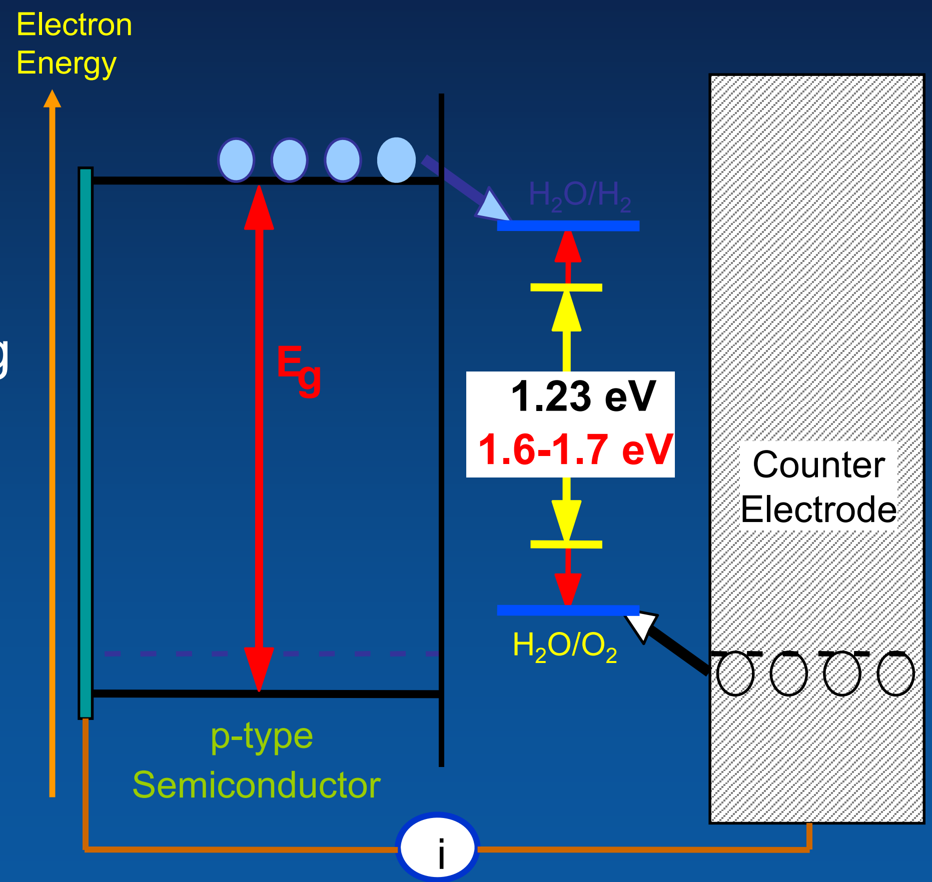
Work involves identifying and developing durable and efficient photoelectrochemical materials, devices, and systems.





Semiconducting Materials Research

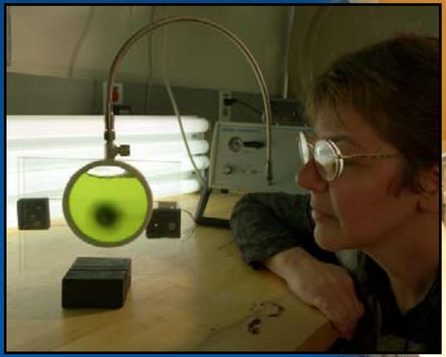
- Targeted material characteristics
  - Band gap absorbs major portion of solar spectra
  - Durable (10-year lifetime) in aqueous solution
  - Able to drive water-splitting reaction
- Current materials under consideration
  - Metal oxides (TiO_2, WO_3, Fe_2O_3, ZnO)
  - Group III-V materials ($GaInP_2$, GaNP)
  - Thin films (SiC, CuInSSe, SiN)



H_2 Production: Photobiological

Hydrogen is produced from water using sunlight and specialized microorganisms such as green algae and cyanobacteria.

These microorganisms consume water and photoproduce hydrogen as a byproduct of their natural metabolic processes.



H_2 Production: Fermentation

Fermentation technologies are used to convert renewable biomass resources such as corn stover, sugarcane residue, and switch grass into hydrogen.

Work is investigating **the** direct fermentation of cellulose and hemicellulose as feedstock for hydrogen production.

Hydrogen Production from Corn Stover

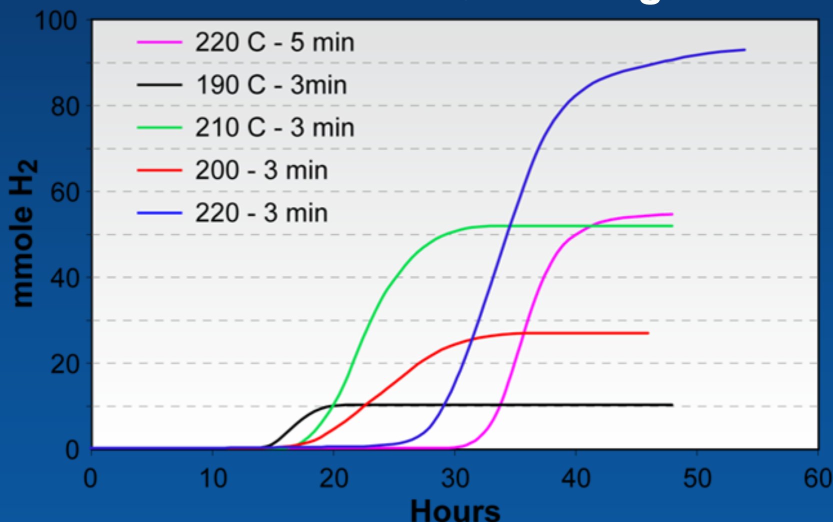
Steam explosion

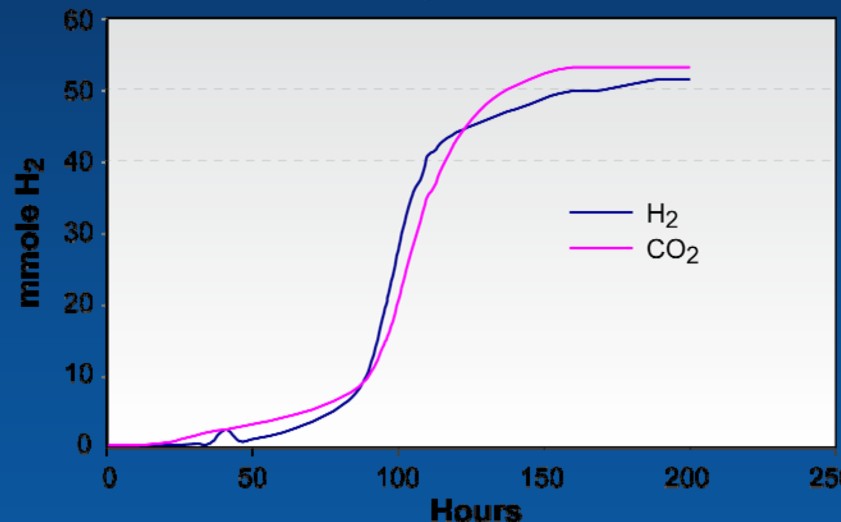
Hemicellulose

Lignocellulose

Sewage sludge

Clostridium thermocellum





H_2 molar yield: 2.8
260 ml H_2/ hr / reactor

H_2 molar yield: 2.2
45 ml H_2/ hr / reactor

H_2 Production: Biomass Pyrolysis

Biomass pyrolysis produces a liquid product—bio-oil—that contains a wide spectrum of components that can be efficiently produced, stored, and shipped to a site for renewable hydrogen production.

H_2 Production: Biomass Gasification

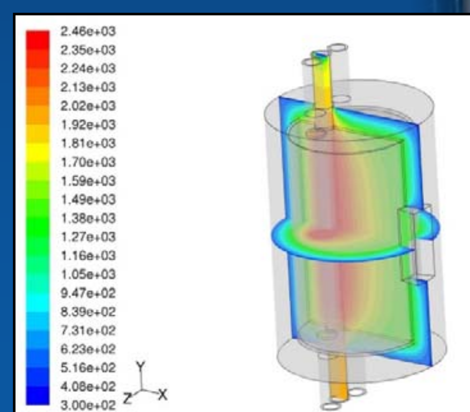
Biomass is converted into syngas—a gaseous mixture of CO, hydrogen, and other compounds—by applying heat in the presence of steam and oxygen.

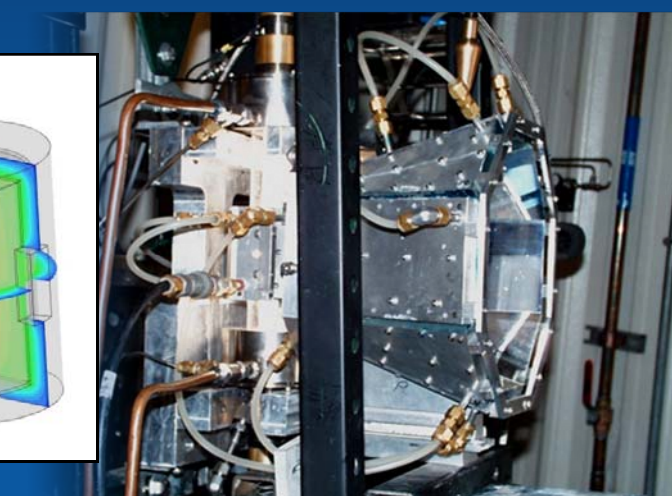
Work is addressing gasification yields, gas compositions, and contaminant removal for centralized hydrogen production.

H_2 Production: Solar Thermochemical

A solar concentrator uses mirrors to capture and focus sunlight to produce temperatures up to 2,000°C.

This high-temperature heat drives thermochemical water-splitting reactions that produce hydrogen.



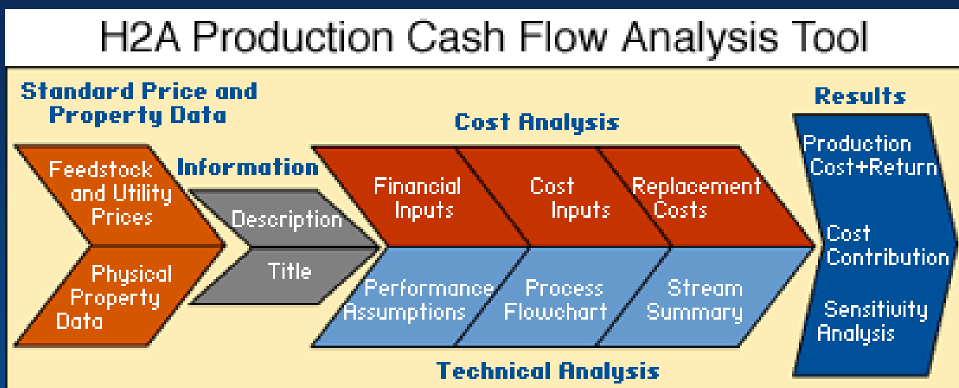


DOE Top-Level Cost Goals

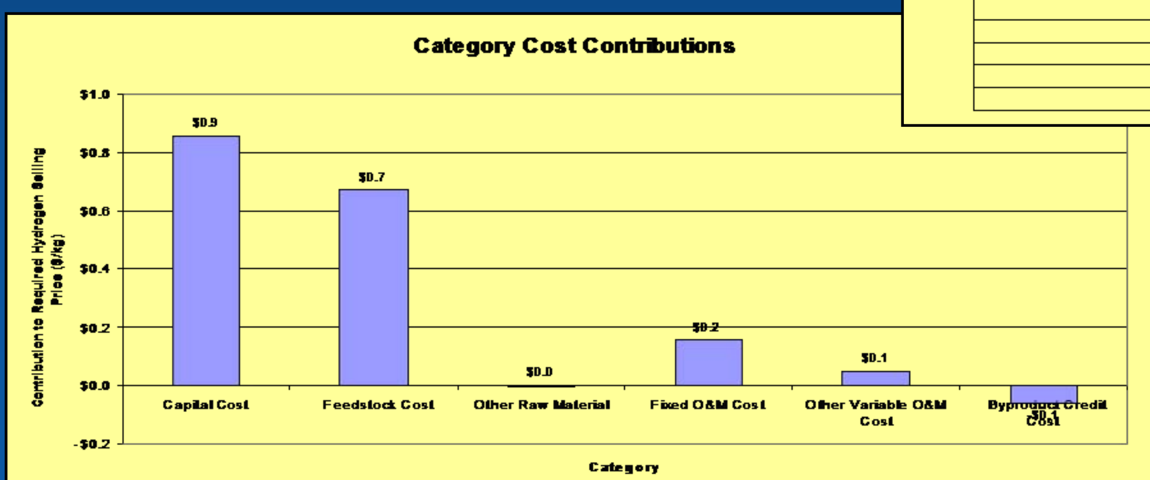
Goal \ Year	2012	2017	2018
Distributed reformation of biomass-derived renewable liquids	$3.80/gge (delivered, untaxed) at the pump	<$3.00/gge (delivered, untaxed) at the pump	
Distributed electrolysis	$3.70/gge (delivered)	<$3.00/gge (delivered)	
Central wind electrolysis	$3.10/gge at plant gate ($4.80/gge delivered)	<$2.00/gge at plant gate (<$3.00/gge delivered)	
Biomass gasification	$1.60/gge at the plant gate (<$3.30/gge delivered)	$1.10/gge at the plant gate ($2.10/gge delivered)	
High-temp Solar thermochemical cycles		$3.00/gge at the plant gate ($4.00/gge delivered)	Verify the potential to be competitive in the long term
Photoelectrochemical and photobiological			Verify the feasibility to be competitive in the long term

H2A Cash Flow Model

- http://www.hydrogen.energy.gov/h2a_analysis.html



	Base Case	H2A Guidelines
Reference $ Year (in half-decade increments)	2000	2000
Assumed Start-up Year	2005	2005, 2015, 2030
After-Tax Real IRR (%)	10%	10%
Depreciation Type (MACRS, Straight Line)	MACRS	MACRS
Depreciation Schedule Length (No. of Years)	20	20
Analysis Period (years)	40	40
Plant Life (years)	40	40
Assumed Inflation Rate (%)	1.90%	1.90%
State Income Taxes (%)	6.0%	6%
Federal Income Taxes (%)	35.0%	35%
Effective Tax Rate (%)	38.9%	
Design Capacity at 100% Capacity (kg of H2/day)	-	
Operating Capacity Factor (%)	90%	Varies according to case
Plant Output (kg H2/day)	-	
Plant Output (kg H2/year)	-	
% Equity Financing	100%	100%
% Debt Financing	0%	0%



H2A Production Cases
(Currently Available on Web)

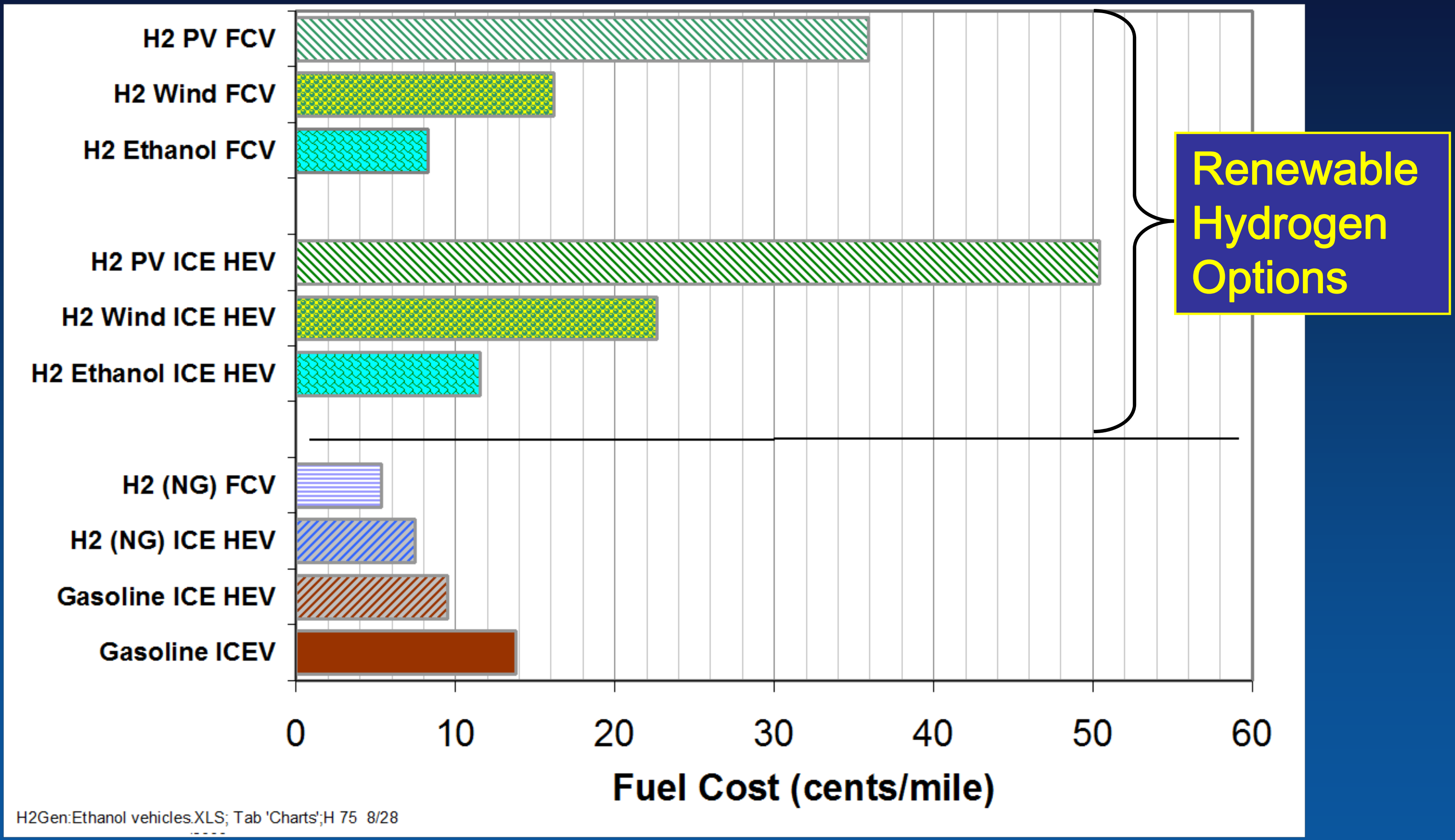
Central Production of Hydrogen (>50,000 kg/day of hydrogen)

- **Coal: Hydrogen Production w CO_2 Sequestration**
- **Coal: Hydrogen Production w/o CO_2 Sequestration**
- **Natural Gas: Hydrogen Production w CO_2 Sequestration**
- **Natural Gas: Hydrogen Production w/o CO_2 Sequestration**
- **Biomass Gasification for Hydrogen Production**
- **Wind Electrolysis: Hydrogen Production only**
- **Wind Electrolysis: Hydrogen and Electricity Production**

Forecourt Production of Hydrogen

- **Natural Gas Reforming** (100 kg/day)
- **Natural Gas Reforming** (1500 kg/day)
- **Electrolysis via Grid** (100 kg/day)
- **Electrolysis via Grid** (1500 kg/day)

Fuel Costs per Mile



H2Gen:Ethanol vehicles.XLS; Tab 'Charts';H 75 8/28 /2006

Assumptions: Gasoline = $2.90/gallon; Ethanol = $1.50/gallon; PV = 20 cents/kWh for 7 hours/day; Wind = 5 cents/kWh for 12 hours/day; Gasoline-HEV fuel economy = 1.45 X ICEV; H2-HEV fuel economy = 1.71 x ICEV; FCV fuel economy = 2.38 X ICEV
[DOE cost parameters: 11% annual capital recovery, 90% capacity factor, NG = $3.97/MBTU (HHV), Electricity= 7 cents/kWh]

Way Ahead

- Need for more H_2 users to stimulate market
  - Stationary/portable fuel cell users
  - Fuel Cell vehicles and transit buses
  - Federal/State governments in role of early adopters
- More industry involvement in demos and R&D
- Federal/State policies and incentives
- Universal set of Codes and Standards
- Ramp up education efforts
  - C&S Officials
  - Federal & State officials (DOTs & EPAs)
  - First responders

Diverse Energy Sources . . .