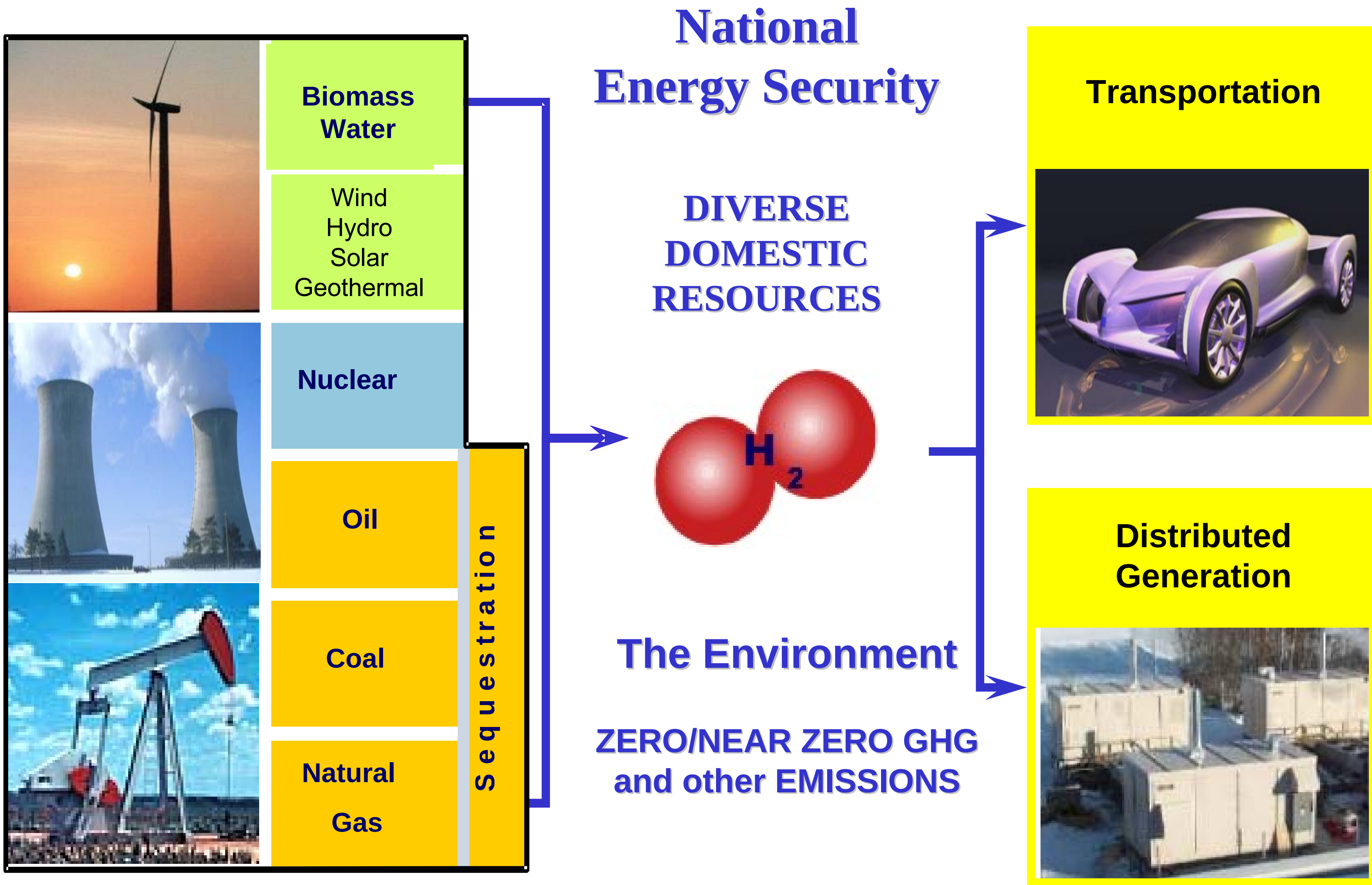
수소 생산 및 배달

미국 에너지성

Why Hydrogen



Production Feedstock/Process Options

Coal

- Supply: 5,780 Quads recoverable reserves
- Process options: central production from gasification
- Cost: Current: $0.90-1.80/kg

  Projected: $0.50-1.10/kg
- Requires sequestration and near-zero other emissions

Production Feedstock/Process Options

Natural Gas

- Supply:
  - 188 Quads proven reserves
  - Currently importing 15% of our needs
- Process Options
  - Central Reforming
    - Cost: Current: $0.60-1.00/kg   Projected: $0.40-$0.90/kg
    - Requires sequestration
    - Lowest cost current route
  - Distributed Reforming
    - Cost: Current: $4.00-$6.00/kg   Projected: $1.50-$3.00/kg
    - Lowest cost current route for delivered hydrogen
    - Very sensitive to NG price
    - GHG emissions unavoidable

Production Feedstock/Process Options

Biomass

- Supply
  - 6-10 Quads/yr. currently possible
  - Could be much more with biotech advancements
- Feedstock Cost and Infrastructure are Key Issues
- Central Production Process Options
  - Gasification
    - Cost: Current \$2.00-\$4.00/kg   Projected: \$1.00-\$3.00/kg
  - Fermentation
    - Relatively unexplored
  - Anaerobic Fermentation → Methane → Hydrogen
    - Agriculture, MSW or industrial sites
    - Existing biomass "collection" infrastructure
    - Co-Gen power and hydrogen possible
    - Sensitive to scale of operations and required distribution infrastructure

Production Feedstock/Process Options

Biomass

- Central/Distributed Process Options
  - Trades hydrogen delivery costs for liquid carrier costs plus reforming
  - Fermentation → Ethanol → Hydrogen
    - Fungible transition from ethanol fuel
    - Cost ??
  - Gasification → Syngas → Methanol (Ethanol) → Hydrogen
  - Pyrolysis → Bio-Oil → Hydrogen
  - Sugar Hydrogenation → Sugar Polyols (e.g., Sorbitol)→ Hydrogen

Water: Electrolysis

- Distributed and central production
- Requires non-GHG emitting clean power: wind, solar, geothermal, hydroelectric, nuclear, fossil with sequestration
- Supply:
  - Essentially unlimited
  - Need purified water

Production Feedstock/Process Options

Distributed Electrolysis

- Cost: Current: $4.00-$8.00/kg   Projected: $2.50-4.50/kg
- Electricity cost is the driver/controlling
- Eliminates hydrogen delivery costs and infrastructure

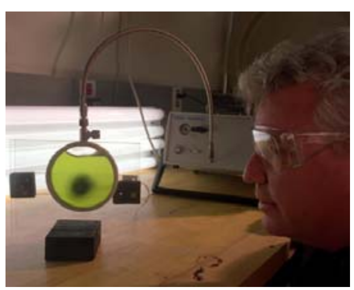
Central Electrolysis

- Cost: need better analysis
- Enables more efficient use of intermittent renewables
- Enables more efficient use of off peak power availability
- High temperature steam electrolysis may be more efficient
- Requires hydrogen delivery

Production Feedstock/Process Options

Water: Photolytic Production

- Supply: Unlimited
- Central Production Utilizing Photosynthetic Organisms (Algae)
  - Cost: Current ~$200/kg Projected: <$5.00/kg
  - Requires breakthroughs in biotechnology and systems engineering
  - Land area requirements or ocean operations
- Central or Distributed Direct Photoelectrochemical Production
  - Cost: Current: N/A Projected: <$3.00/kg
  - Requires breakthroughs in materials
  - Intermittent: diurnal cycle
  - The ultimate system if successful: renewable, unlimited, <u>simple</u>



Production Feedstock/Process Options

High Temperature Thermochemical Water Splitting

- Process Options
  - High temperature (500-1000 C) central production utilizing advanced nuclear energy heat source (or other source) and S-I or CaBr (or other) cycles
  - Ultra-high temperature (1000-3000 C) water splitting chemical cycles utilizing concentrated solar energy
  - Direct water splitting
- Unproven Chemical Cycles
- Materials Issues

Summary

Route	$/kg Current	$/kg Projected	%EE WTP[1]	GHG WTW Reduc.[1,2]
Coal: Central Gasification	$0.90-1.80	$0.50-1.10	_	High W/Sequest.
Coal: C/D Gasification/Reforming	_	_	_	Low-Medium
NG: Central Reforming	$0.60-1.00	$0.40-0.90	62%	61%
NG: Distributed Reforming	$4.00-6.00	$1.50-3.00	60%	High
Biomass: Central Gasification	$2.00-4.00	$1.00-$3.00	_	High
Biomass: Central Fermentation	_	_	_	High
Biomass: Central Ferm./Methane/Hydrogen	_	_	_	High
Biomass: C/D Gasification/Methanol or Ethanol/Hydrogen	_	_	_	High
Biomass: C/D Pyrolysis	_	_	_	High
Biomass: C/D Ferm./Ethanol/Hydrogen	_	<$3.00	41% Total 92% Fossil	98%
Biomass: C/D Sugar Hydrogenation/Polyols/Hydrogen	_	_	_	High

Summary

Route	$/kg Current	$/kg Projected	% EE WTP[1]	GHG WTW Reduc.[1,2]
Water: Electrolysis: Distributed	$4.00-8.00	$2.50-4.50	28% Grid 68% Renew.	(22%) Grid ~100% Renew.
Water: Electrolysis: Central		_	_	Low: Grid High: Renew.
Water: Central Photolytic: Organisms (e.g. algae)	~$200	<$5.00	_	High
Water: Central or Distributed Photolytic: Photoelectrochemical	_	<$3.00	_	High
Water: Central HT Splitting Chemical Cycles	_	<$2.00	_	High
Water: Central U-HT Splitting Chemical Cycles	_	_	_	High
Water: Direct Water Splitting	_	_	_	High

1. The estimates, except for the distributed water electrolysis case using renewable electricity, are from "Guidance for Transportation Technologies: Fuel Choice for Fuel Cell Vehicles, Final Report prepared by Arthur D. Little for U.S. Department of Energy, February 6, 2002, http://www-db.research.anl.gov/db1/cartech/document/DDD/192.pdf. The distributed water electrolysis estimates are from Wang, M., "Fuel Choices for Fuel-Cell Vehicles: Well-to Wheels Energy and Emissions Impacts," *Journal of Power Sources*, **112(1):** 307-321, October 2002.
2. GHG well-to-wheels reduction is the reduction of GHG emissions as compared to the emissions from standard/today's gasoline ICE.

Potential Scenarios

Short Term

- Distributed: NG, Liquids (including biomass derivatives), Electrolysis
- Central NG, Coal and Biomass
- Renewable Power: Wind, Solar, Hydro, Geothermal
- Central Coal with Sequestration
- Photolytic: Photoelectrochemical, Photosynthetic organisms
- Thermochemical Water Splitting Nuclear, Solar, Other

Long Term

Hydrogen Delivery

Hydrogen Delivery: Develop cost effective, energy efficient delivery technologies for hydrogen to enable the introduction and long term viability of hydrogen as an energy carrier.

Barriers

- Lack of hydrogen/carrier infrastructure options analysis
- Capital cost of hydrogen pipelines
- Cost of hydrogen compression and liquefaction
- Cost of gas or liquid truck or rail transport
- Hydrogen capacity and cost of known solid or liquid carriers.
- Chemical carriers (i.e. ethanol, bio-oils, naphtha) require two processing operations

Delivery Options

- End Game
  - Pipeline Grid
  - Other as needed for remote areas
    - Breakthrough Hydrogen Carriers
    - Truck: HP Gas & Liquid Hydrogen
  - Electrolysis and Distributed reforming of NG, Renewable Liquids (e.g. ethanol etc.)
- Transition
  - Electrolysis and Distributed reforming of NG, Renewable Liquids (e.g. ethanol etc.), other liquids
  - Truck: HP Gas & Liquid Hydrogen
  - Regional Pipeline Grids
  - Breakthrough Hydrogen Carriers

Technoeconomic Analysis

- Basic economic analysis of individual processes to produce or deliver hydrogen
  - Project by project basis: Project Team or other resources
  - H2A Core effort

- Timeframe: 2005, 2015, 2030
- Most better known routes to hydrogen
- Consistent, comparable, transparent approach
- Central Production
  - Coal Gasification
  - NG Reforming
  - Biomass Gasification
  - Nuclear: S-I, HT Steam Electrolysis
  - Wind Electrolyis

- Forecourt/Distributed
  - Dispensing Only
  - NG Reforming
  - Electrolysis
  - Ethanol Reforming
  - Methanol Reforming

- Delivery: Hydrogen Pipeline, Tube Trailer, Liquid Truck
  - Components
  - A few basic metropolitan and interstate cofigurations

Infrastructure: Transition & End Game

- In what scenarios (under what conditions) will the hydrogen economy succeed?
- How do individual technologies affect the transition to and functioning of the system?
- How do alternative energy sources affect the transition to and functioning of the system?
- How will the evolution of the system over time and geographically affect costs and benefits?
- What is the role for policy in the transition and maintenance of the hydrogen economy?
- What are the costs and benefits (including the global macroeconomic effects) of a hydrogen economy?

Infrastructure: Transition & End Game

- FY04 Plan: Learn by Doing
  - Insert some hydrogen pathways and FCVs into TAFV (ORNL) model
  - GIS level modeling of infrastructure in the mid-west (Joan Ogden)
  - Metropolitan infrastructure modeling (Tellus)
  - All energy systems modeling (LLNL)
  - Small region/U.S. modeling (WINDS: NREL)
  - Infrastructure NPV analysis (TIAX)
  - Delivery options analysis (Solicitation)
  - Transitions analysis (Solicitation)