The Conversion Project

IHTDF: International Hydrogen Transmission Demonstration Facility

Bill Leighty, The Leighty Foundation
Alvin Duskin, The Conversion Project

Windpower 2003, 18-21 May, Austin, TX
• Great Plains Wind: Huge, Stranded

• Big Market: Hydrogen Fuel, not Grid

• Accelerate Conversion
How shall we bring the large, stranded, Great Plains wind to market?
Total USA Wind Resource Estimate: PNL-7789 (1991)

USA electric energy consumed in year 2000 =~ 3,500 TWh (billion kWh)

<table>
<thead>
<tr>
<th>State</th>
<th>TWh / year</th>
<th>MW (nameplate, at 40% CF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Dakota</td>
<td>1,210</td>
<td>345,320</td>
</tr>
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<td><strong>TOTALS</strong></td>
<td><strong>9,900</strong></td>
<td><strong>2,840,000</strong></td>
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<td>Idaho</td>
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Example Flowgate Interfaces
MAPP – Mid-continent Area Power Pool

Map of Mid-continent Area Power Pool (MAPP) with states and flowgate interfaces labeled.

- MHEX
- NDEX
- FTCAL
- WNE_WKS
- MNEX
- ECL-ARP
- NI_WUMS
- COOPER_S

Key states: Manitoba, Saskatchewan, Montana, Wyoming, South Dakota, North Dakota, Minnesota, Wisconsin, Illinois, Missouri, Nebraska, Iowa, Kansas, Colorado, Missouri.
# Exporting From 12 Windiest Great Plains States

Number of GH2 pipelines or HVDC electric lines necessary to export total wind resource

Wind energy source: PNL-7789, 1991

* at 500 miles average length

<table>
<thead>
<tr>
<th>State</th>
<th>AEP, TWh</th>
<th>Wind Gen MW (nameplate) (40% CF)</th>
<th>6 GW 36&quot; GH2 export pipelines</th>
<th>$ Billion Total Capital Cost *</th>
<th>3 GW export HVDC lines</th>
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<td><strong>2,849,316</strong></td>
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<td><strong>890</strong></td>
<td><strong>$ 534</strong></td>
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Harvesting Stranded Great Plains Wind

- Extant grid: insignificant
- New electric lines
  - HVAC
  - HVDC
  - Double – six – phase (Osborne, MISO)
- New hydrogen gas pipelines
- “E-Pipe”, EPRI “continental supergrid”
  - superconducting LVDC
  - 100 GW electric
  - 100 GW liquid hydrogen
  - Rock tunnel 100 m subsurface
Superconducting “Energy Pipeline”
Paul Grant, EPRI
~ 100 GW electrical + 100 GW LH2
Natural Gas Pipelines in Shield Tunnel
ALL Denmark’s energy from wind

- ALL energy -- elec, oil, gas -- replaced by wind
- Prof. Bent Sorensen, Roskilde Univ, DK
- World Hydrogen Energy Conference, June 02, Montreal
- Convert fraction to H2, store in two extant salt caverns
- USA do same? Vehicle fuel?
The Conversion Project

• Gasoline **costs** too much, as vehicle fuel
• GAO study: “full cost”
• Wind is lowest-cost renewable
• Wind-source hydrogen cost less?
• Yes? Major PR, education campaign
• “Renewable Energy Hydrogen Production Act”
  – Initiate in Congress
  – Build transmission
  – Subsidize renew - hydrogen fuel production
• Convert from oil-source to renew-source fuel
THINK: Multi-GW scale, beyond “Cherry Picking”

- Best wind sites
- Close to transmission
- No-cost transmission: access, wheeling
- Limited: game over soon
- Wind must pay ALL transmission costs:
  - “stranded”
  - CF problem
- Wind “cost” doubles?
4,000 MW of Nameplate Wind Generation
53 x 53 grid 500 m spacing
2,809 wind generators at 1,400 kW each
~ 850 sq km ~ 350 sq mi
“Distributed Collection”

4,000 MW of Nameplate Wind Generation

150 x 19 grid
500 m spacing

2,850 wind generators at 1,400 kW each

~ 750 sq km
~ 300 sq mi
Cost of Dakotas Wind Energy in Chicago
$ US per kWh in year 2010

Total Transmission Costs and Losses
Wind Generated Unsubsidized COE
"Electrical Transmission" Scenario

Wind Generators
Collection System
North Dakota
Wind Generators

AC to HVDC Converter Station

1,000 miles
+/ - 500 kv HVDC

HVDC to AC Converter Station
"STIFF" AC grid
End users

Chicago
Bishop, CA

Left: 3,000 MW HVDC (Pacific DC Intertie, PDCI)  Right: HVAC
High Voltage
Direct Current Transmission

**North Dakota wind needs**
115 new lines
at 3,000 MW each

**Twelve Plains states wind needs**
890 new lines
at 3,000 MW each

**SIEMENS**
HVDC line
+/- 500 kv
Used Only 20% of North Dakota’s Wind Potential!

All of Iowa’s Electricity
Natural Gas
Petroleum

23 New 3 GW 500 kv HVDC electric lines
How much can we upgrade capacity of extant ROW and structures, with “no net loss of perceived or real safety or tranquility”?

Zion nuclear plant: 2 of 3 tower systems

HVDC potential: 6 bipoles @ 3,000 MW = 18,000 MW
Distribution Problem!

Back-Up Power

Hydrogen Generation

Vehicle Fueling

Stuart Energy
“Hydrogen Energy Station”
Hydrogen Transmission Scenario

- Low-pressure electrolyzers
- “Pack” pipeline: ~ 1-2 days’ storage = 120 GWh

Storage: 120 GWh

1,000 miles Hydrogen Gas Pipeline 36" diameter ~ 1,000 psi

Wind Generators

Electrolyzers

Compressors

AC grid Wholesale

End users Retail

Generators ICE, CT, FC

Cars, Buses, Trucks, Trains

Liquefy

Aircraft Fuel
Tabletop Solar-Hydrogen Demo

Hydrogen is NOT a clean, abundant energy source!

Storage: 120 GWh

1,000 miles Hydrogen Gas Pipeline 36" diameter ~ 1,000 psi
• Energy carrier
• Energy storage
• Fuel
• NEVER a source

Hydrogen is NOT a clean, abundant energy source!

Lyn Harrison
“Hydrogen Transmission” Scenario
Hydrogen Fuel Delivery
High-pressure electrolyzers

Wind Generators
High-press Electrolyzers
Wind Generators

Storage: 120 GWh

1,000 miles
Hydrogen Gas Pipeline
18 - 36" diameter
~ 1,000 psi

Generators ICE, CT, FC
Cars, Buses, Trucks, Trains
Liquefy

AC grid Wholesale
End users Retail
Aircraft Fuel
Twelve Great Plains states wind needs ~ 400 H2 gas Pipelines

6,000 MW each
36” diameter, 65 bar
“We know how to pipeline hydrogen” Air Products
~ 10,000 miles of GH2 pipeline, worldwide

Air Products H₂/ CO Pipeline - Texas Gulf Coast

HYDROGEN
CO
SYNGAS
Air Products Facilities

Approx. 60 Miles
Composite Reinforced Line Pipe (CRLP)

42” diameter
3,400 psi
.75” X70 steel
.75” composite

NCF Industries and TransCanada Pipelines

ASME International Pipeline Conference and Exposition, Calgary, AB, Canada, October 02.
Composite – Reinforced Line Pipe (CRLP)
3,400 psi, .75” X70 steel plus .75” composite

NCF Industries and TransCanada Pipelines
ASME International Pipeline Conference and Exposition,
Calgary, AB, Canada, October 02.
Norsk Hydro Electrolyzers
2,000 kW each
Compressor
Reciprocating
Natural gas

3,000 hp
Electric Motor
Drive
“Hydrogen Transmission” Scenario

- **Electricity delivery**
- **Low-pressure electrolyzers**
- **Pack pipeline:** ~ 1-2 days’ storage = 120 GWh

Wind Generators

Electrolyzers

Compressors

Generators

ICE, CT, FC

AC grid

Wholesale

End users

Retail

Storage: 120 GWh at 1000 - 500 psi

1,000 miles
Hydrogen Gas Pipeline
36" diameter
~ 1,000 psi
Annual Profit / Loss

Wind Energy Generation, Transmission
Wholesale Delivery of Electricity
With PTC; Wind Capital Cost = $ 700 / kW
“Hydrogen Transmission Scenario”
Collection Topology Options:
Electrolyzer and Rectifier Location

PE: Power Electronics
**Pipeline Delivery Nodes**

- **Simple**
- **Low cost**
- **Large or small**
- **Closely spaced**

Diagram:

- **10 MW Windplant + Electrolyzers**
  - Compressor
  - Meter, gas quality control
  - Shutoff Valve
  - Pipe Flange
  - 12" Hydrogen Gas Pipeline

- **5 MW Biomass Plant**
  - Compressor
  - Meter, gas quality control
  - Shutoff Valve
  - Pipe Flange
"Wind Power – Hydrogen Hybrid Systems and Natural Gas Pipeline Systems in Northeast Asia"

K. O’Hashi, Nippon Steel

M. Hirata, Shibaura Institute

K. Ono, Kyoto University
Windpower - Hydrogen Hybrid Systems

By Dr. K. O’Hashi 20 Dec 99

Source: “Overview of the Transportation of Wind-Generated Hydrogen Using Natural Gas Pipeline Network in Northeast Asia” August, 2000

By: Asian Pipeline Research Center, Shibaura Institute of Technology
2002 USA gasoline use

- 130 billion gallons / year
- Over half imported
- Price =~ $ 1.80 gallon
- Cost = ??
- HFCEV’s double mileage:
  - 65 billion “GGEE”
  - One-fourth of Great Plains wind
- Don’t wait for fuel cells! ICE – hybrids, Ford “U”
Model “U”
Hydrogen-fueled, ICE hybrid
The gas is only $1.39. The aircraft carrier is $470. The tank is $125. The stealth fighter is $330. The gas mask is $45 and the gun adds $30 a gallon.
“External” costs of gasoline

• Supply security
  – Military
  – Interruptions
  – Foreign policy bias

• Climate change
  – Property loss: severe weather
  – Property loss: sea level rise
  – Agriculture
  – Forests
  – Diseases advance

• Air pollution
  – Health degradation
  – Corrosion

• Water pollution: surface, ground, oceans

• Tanker spills

• Habitat & species loss, from exploration

• Future generations deprived of abundant oil

• Other?
What does gasoline really COST?

- Pump price .................................................. $ 1.70
- Supply security
  - Military ....................................................
  - Interruptions .............................................
  - Foreign policy ..........................................  
- Climate change
  - Property loss: severe weather ......................
  - Property loss: sea level rise .......................  
  - Agriculture .............................................
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  - Diseases advance ....................................
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- Water pollution: surface, ground, oceans .......
- Tanker spills ............................................
- Habitat & species loss, from exploration ..........  
- Future generations deprived of abundant oil ..... $  

Total COST $
The Conversion Project

- Gasoline **costs** too much, as vehicle fuel
- GAO study: “full cost”
- Wind is lowest-cost renewable
- Wind-source hydrogen costs less?
- Yes? Major PR, education campaign
- “Renewable Energy Hydrogen Production Act”
  - Initiate in Congress
  - Build transmission
  - Subsidize renew - hydrogen fuel production
- Accelerate conversion from oil to wind-hydrogen
The Phoenix Project

• “Shift from oil to hydrogen with wartime speed”
• All USA energy as hydrogen from wind
• USA independent of all fossil, nuclear fuels
• Total conversion in 10 years
• Mass-production of wind generators will greatly lower windpower cost
• Don’t wait for fuel cells—convert ICE’s to H2, both extant and new
• New fed “Fair Accounting Act”
  – Eliminate fossil, nuclear subsidies
  – Tax gasoline with “external cost” carbon tax
  – Tax credits to convert gasoline ICE cars to H2
• www.phoenixproject.net; www.h2pac.org
Bald Eagle Power Company Inc.  
Offshore Long Island, NY

- Applied for ACOE permits:
  - Offshore, shallow continental shelf
  - 402 sq miles, 9 sites, S shore
  - Public Notice expected mid-03

- “Seahorse™” wind farms, 7,000 MW
- All wind energy converted to hydrogen offshore
- 1 billion kg hydrogen per year: fuel all LA cars
- Demo Phase I: ~20 MW
- Phase II: Max 1,925 turbines, 3.6 MW each
Areas where the average wind speed is greater than 18 mph, the water depth less than 100 ft., and that are outside the state’s three-mile limit and shipping lanes.
Hydrogen Fuel Cost in Chicago
No PTC subsidy

Wind-generated electricity in ND $0.045 / kWh
Hydrogen conversion and 1,000 miles transmission 0.052 / kWh

Wholesale price of GH2 fuel in Chicago, end-of-pipe $0.097 / kWh
Equivalent per-gallon-gasoline-energy price * $3.49 / gal
Distribution and fuel station cost $0.79 – 1.45 / gal

Retail price of GH2 fuel in Chicago $4.28 – 4.94 / gal
Drive train efficiency ratio: FCEV / ICEV = 2
Equivalent retail price GH2 fuel per vehicle-mile $2.14 – 2.47 / gal

* 1 GJ = 278 kWh; 1 gallon gasoline = 0.13 GJ (HHV) = 36 kWh @ $0.08 / kWh = $2.89 / gallon
HHV means higher heating value of hydrogen.
GH2 means compressed gaseous hydrogen
Hydrogen Fuel Cost in Chicago
With PTC subsidy

Wind-generated electricity in ND $ 0.045 / kWh
Fed PTC (production tax credit subsidy) ( .017 )
Subsidized wind energy in ND 0.028
Hydrogen conversion and 1,000 miles transmission 0.052

Wholesale price of GH2 fuel in Chicago, end-of-pipe $ 0.08 / kWh
Equivalent per-gallon-gasoline-energy price * $ 2.89 / gal
Distribution and fuel station cost $ 0.79 – 1.45 / gal

Retail price of GH2 fuel in Chicago $ 3.68 – 4.34 / gal
Drive train efficiency ratio: FCEV / ICEV = 2
Equivalent retail price GH2 fuel per vehicle-mile $ 1.84 – 2.17 / gal

* 1 GJ = 278 kWh; 1 gallon gasoline = 0.13 GJ (HHV) = 36 kWh @ $ 0.08 / kWh = $ 2.89 / gallon
HHV means higher heating value of hydrogen.
GH2 means compressed gaseous hydrogen
What does gasoline really COST?

• Pump price .............................................. $ 1.70

• Supply security
  – Military ............................................. ______
  – Interruptions .................................... ______
  – Foreign policy .................................. ______

• Climate change
  – Property loss: severe weather ............... ______
  – Property loss: sea level rise ................. ______
  – Agriculture ...................................... ______
  – Forests .......................................... ______
  – Diseases advance ............................... ______

• Air pollution
  – Health degradation ............................. ______
  – Corrosion ........................................ ______

• Water pollution: surface, ground, oceans ........ ______

• Tanker spills ........................................ ______

• Habitat & species loss, from exploration ........ ______

• Future generations deprived of abundant oil .... ______

Total COST $
The Conversion Project

- Gasoline costs too much, as vehicle fuel
- GAO study: “full cost”
- Wind is lowest-cost renewable
- Wind-source hydrogen costs less?
- Yes? Major PR, education campaign
- “Renewable Energy Hydrogen Production Act”
  - Initiate in Congress
  - Build transmission
  - Subsidize renew - hydrogen fuel production
-Accelerate conversion from oil to wind-hydrogen
Competition for renewable-source hydrogen fuel

- From NG by SMR (steam methane reformation)
- From coal by gasification, with CO2 sequestration
- Nuclear: electricity, heat
“Zero Emissions” Coal Synergy

- ND, MT, WY are wind and coal states
- Oxygen byproduct of electrolysis to “zero emissions” coal gasification plants
- 4,000 MW windplant produces –
  - ~ 3.1 million tons O2 per year
  - value ~ $ 19.17 / ton at coal plant
  - $ 59 million per year delivered O2
- Share transmission; CF improve?
- Is “zero emissions” coal “clean”?
- Will CO2 sequestration work?
The coal gasification process

Coal gasification involves dismantling the molecular structure of coal and reassembling the resultant hydrogen and carbon as methane.

The heart of the synfuels plant is a building containing 14 gasifiers. The gasifiers are cylindrical pressure vessels 40-feet high with an inside diameter of 13 feet.

Each day 16,000 tons of lignite are fed into the top of the gasifiers. Steam and oxygen are fed into the bottom of the coal beds causing intense combustion (2,200 degrees Fahrenheit). Resulting hot gases break down the molecular bonds of coal and steam, releasing compounds of carbon, hydrogen, sulfur, nitrogen and other substances to form a raw gas that exits the gasifiers. Ash is discharged from the bottom of the gasifiers.

The raw gas goes to the gas cooling area where the tar, oils, phenols, ammonias and water are condensed from the gas stream. These byproducts are sent on for purification and transportation. Other byproducts are stored for later use as boiler fuel for steam generation.

The gas is moved to a cleaning area where further impurities are removed. Some of these substances with additional refining could become valuable byproducts in the future.

Methanation is the next step. Methanation takes place by passing the cleaned gas over a nickel catalyst causing carbon monoxide and most remaining carbon dioxide to react with free hydrogen to form methane. Final cleanup removes traces of carbon monoxide.

The gas is then cooled, dried and compressed, entering the pipeline with a heating value of 975 Btu per cubic foot.

“Raw gas” : H₂ + CO₂ + CO + CH₄ + H₂O
Hydrogen Fuel Cost in Minneapolis
From Dakotas Gasification Company (DGC) Lignite

Lignite – source GH2 * at DGC plant, Beulah, ND @ 1 atm $ 4.44 / Mscf
GGEE * = $ 1.58 / gal

Volume: 55 billion scf / year = 56 million gallons gasoline
(Assume C-sequestration, included in cost)

Annual and 400 miles transmission pipeline and compression costs
$350 M pipeline @ 12% CRF = $ 42 M
Pipeline O&M = $ 5 M
Compression energy = $10 M
Total annual cost = $ 57 M / 56 M gallons = $ 1.02 / gal

Wholesale price of GH2 fuel in Minneapolis, end-of-pipe $ 2.60 / gal

Distribution and fuel station cost $ 0.79 – 1.45 / gal

Retail price of GH2 fuel in Minneapolis $ 3.39 – 4.05 / gal

Drive train efficiency ratio: FCEV / ICEV (gasoline) = 2
Equivalent retail price GH2 fuel per vehicle-mile $ 1.70 – 2.03 / gal

* GH2 means compressed gaseous hydrogen
* GGEE = gallon of gasoline energy equivalent: H2 = 325 Btu / scf; gasoline = 116,000 Btu / gal
IHTDF

- **International Hydrogen Transmission Demonstration Facility**
- Pilot-scale pipeline system
- Can we deliver renewable-source H2 fuel to major urban markets for $2.00 / gallon-gasoline-energy-equivalent?
- Necessary: critical path to conversion?
Estimated Average Annual Wind Speeds
Typical average wind speeds on well exposed sites at 50 m above ground

Iowa Energy Center
This map was generated from data collected by the Iowa Wind Energy Institute under Iowa Energy Center Grant No. 93-04-02. The map was created using a model developed by Brover & Company, Andover, MA.

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IHTDF

- Pilot scale renewables-hydrogen system
  - Generation
  - Collection
  - Transmission
  - Storage
  - Distribution, end users
  - Synergy: O2, seasonal
- ~ 10 – 100 MW
- 50 - 100 km pipeline
- Defining it reveals R+D to precede it
- Next steps:
  - Finish the H2 vs HVDC study
  - Propose RFP
IHTDF

- Multiple renewables sources
- Demonstration, through “back yards”
- Allay public fears of H2
- Building it proves feasibility, acceptance
- Operating it proves
  - technology maturity
  - economics
  - safety
- $ 40 – 50 million investment
- Upper Midwest location?
Why hydrogen transmission for Great Plains wind?

- Lower cost / kWh than electric?
- Nascent market: vehicle fuel
- Can’t build 900 new 3 GW electric lines
- Storage
- Underground: more secure, acceptable, permittable?
How shall we bring the large, stranded, Great Plains renewables to market?

- Delivered COE: can renewables compete?
- Whole-system design, optimization:
  - Generation
  - Collection
  - Transmission
  - Storage
  - Distribution
  - End-use
  - Intelligence: control, integrate
The Conversion Project

- Gasoline costs too much
- Wind-hydrogen costs less?
- Accelerate conversion

IHTDF: International Hydrogen Transmission Demonstration Facility -- pilot scale conversion

Your card: mail you CD

Bill Leighty, The Leighty Foundation
bill@eagle.ptialaska.net

Alvin Duskin, The Conversion Project
End Windpower 2003
Leighty
21 May 03
The following slides are supplemental or redundant
"Stranded": no transmission
Electricity: 24,500 MW wind by 2020

New Clean Power Capacity (MW)

4,474

“Repowering The Midwest”
ELPC, Feb 01
Alliance Pipeline: CDN-USA
$US 3.5 billion (’97-00)
1 Dec 00 startup
2,988 km (1857 miles)
36”, 1740 psi (115 bar)
1.5 Bcfd (16 GW)
Compression = 407 MW
"ALCAN" Route: Proposed Alaska Highway Gas Pipeline Project

Foothills Pipe Lines Ltd.
Canada
North American Natural Gas Pipeline Infrastructure

Bcf: billion cubic feet per day, border capacity
U.S. Supply and Market

[Map of North America showing various supply and market areas, such as Alaska North Slope Supply, Mackenzie Delta Supply, Alberta Hub, PNW Market, California Market, Midwest Hub, Eastern Canada Market, Henry Hub, and Gulf Coast Supply.

Graph showing EIA Demand Forecast with categories for Industrial, Electric Power, Residential, and Commercial. X-axis represents years from 2000 to 2020, and Y-axis represents Bcf/d.]
Natural Gas Price at which Pipeline Hydrogen Cost Equals Cost of Hydrogen from SMR (steam methane reformation)

18 - NC: 18" diam pipe, no compressors
36 - NC: 36" diam pipe, no compressors
36 - C: 36" diam pipe, compressors
Norsk Hydro Complete Electrolyzer Plant, KOH
265 MWe capacity
$ 570 / kWe input, 70% efficiency
“Electrical Transmission” Scenario

- VSC’s at North Dakota source;
- Multiple VSC entry points

Variable-voltage, Variable-frequency buses

Squirrel-cage Induction Generators

North Dakota

VSC #1

Vv, Vf

AC - HVDC

LCC

HVDC - AC

"STIFF" AC grid

Chicago

1,000 miles HVDC line

- Voltage-Source Converter stations in ND, 300 - 500 MW each
- Line-Commutated Converter station in Chicago, 1 - 3 GW
Are large-scale GH2 pipelines --

- Economical for harvesting renewables?
- Economical for long-distance transmission?
- Permittable? Insurable? Financeable?
- Bankable: part of the “hydrogen economy”?
- Safe?
- Acceptable to the public? Located where?
- Capable of valuable energy storage?
- A mature technology? What R+D needed?
- Part of USDOE “Hydrogen Roadmap”? 
How shall we bring the large, stranded, Great Plains renewables to market?

- **Electricity**
  - HVDC (high voltage direct current)
  - HVAC, double-six-phase
- **Gaseous hydrogen (GH2) pipelines**
- **Superconducting “Energy Pipeline”**
  - EPRI -- Electric Power Research Institute
  - “Continental Supergrid”
  - 100 GW LVDC electricity plus 100 GW LH2
How shall we bring the large, stranded, Great Plains renewables to market?

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- Whole-system design
Collection and Transmission: Large-scale Stranded Renewables

- Delivered COE: can renewables compete?
- Multi – GW (1,000 MW)
- Great Plains
  - 12 windy states
  - Wind lowest-cost renewable
  - Big: 10,000 TWh / year
- Beyond “cherry picking” wind: must pay for transmission
- Wind, biomass synergy
  - Dry, wet biomass
  - Oxygen byproduct of electrolysis
  - Share transmission
  - Seasonal complement
- Coal gasification synergy
  - ND, MT, WY
  - Oxygen byproduct of electrolysis
  - Share transmission
Collection and Transmission: Large-scale Stranded Renewables

- Hydrogen pipeline option -- GH2
  - End-run around electricity bottleneck ?
  - Lower cost than electricity ?
  - More acceptable, permittable ?
  - Energy storage valuable
  - Vehicle fuel, not “grid”

- NHTTF: National Hydrogen Transmission Test Facility -- or IHTTF (International... )
“Hydrogen Transmission” Scenario

- Electricity delivery
- Low-pressure electrolyzers
- Pack pipeline: ~ 1-2 days’ storage = 120 GWh

Storage: 120 GWh at 1000 - 500 psi

1,000 miles
Hydrogen Gas Pipeline
36" diameter
~ 1,000 psi
“Hydrogen Transmission” Scenario

- **Electricity delivery**
- **High-pressure electrolyzers**
- **Pack pipeline:** ~ 1-2 days’ storage = 120 GWh

Storage: 120 GWh at 1000 - 500 psi

1,000 miles
Hydrogen Gas Pipeline
36” diameter
~ 1,000 psi
“Hydrogen Transmission” Scenario

Hydrogen Fuel Delivery
High-pressure electrolyzers
Mid-line Compressors

Wind Generators
High-pressure Electrolyzers
Wind Generators

Storage: 120 GWh

Mid-line Compressors Needed?

1,000 miles
GH2 Pipeline
18 - 36" diameter
~ 2,000 psi

Generators
ICE, CT, FC

End users
Wholesale
Retail

Cars, Buses, Trucks, Trains
Liquefy
Aircraft Fuel
"Hydrogen Transmission" Scenario

Hydrogen Delivery with Coal Synergy

- Coal Gasification Plant
- Compressors
- Water-shift Reaction
- CT, ICE
- Reactors
- Generators
- Grid
- Chemicals
- AC Grid
- Wholesale
- End Users
  - Retail
- Cars, Buses, Trucks, Trains
- Liquefy
- Aircraft Fuel
- Wind Generators
- Electrolyzers

- H2O
- H2
- O2
- H20
- CO2

- 1,000 miles
- Hydrogen Gas Pipeline
- 18 - 36" diameter
- ~ 1,000 psi
- Sequestration?
Dry Biomass
At $40 / dry ton, agricultural and forestry residues increase, and energy crops become competitive
Total ~190 M dry tons / year =~ 840 TWh / year gross
Dry Biomass

At $50 / dry ton, total biomass resource increases almost 50%
Total ~300 M dry tons / year =~ 1,300 TWh / year

Janet H. Cushman, Marie Walsh
Oak Ridge National Laboratory
How shall we bring the large, stranded, Great Plains renewables to market?

- **Electricity**
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- **Liquid hydrogen (LH2) rail cars**
- **Superconducting “Energy Pipeline”**
  - EPRI -- Electric Power Research Institute
  - “Continental Supergrid”
  - 100 GW LVDC electricity plus 100 GW LH2
- **Distribution expand**
- **Whole-system design**
“Repowering the Midwest” adjunct study

• Transmission systems
  – HVDC electricity
  – Hydrogen gas pipeline
• Deliver wholesale electricity
  – Chicago
  – Twice year 2000 hourly price
• Cost Model
• Profit Model
• Year 2010 technology, $US 2001
• 9 scenarios
• Further study catalog
Cost Model Results

Drives Profit Model

Simple CRF (capital recovery factor),
not DCF (discounted cash flows)
Profit Model Results

Profit: Revenues > Costs
Annual Transmission Costs and Energy Losses, $ Million

- Fixed Charge: Capital Recovery
- Electrolyzers O&M
- Electrolyzer Losses
- Compressor Energy
- Electric Transmission Losses
- Electric Transmission System O&M
- Pipeline System O&M

H2-A, H2-B, H2-C, ELEC-D, ELEC-E, ELEC-F, ELEC-G

$0, $100, $200, $300, $400, $500, $600, $700

ch 5
Annual Revenues, with Oxygen Sales, With PTC

Million $ 2001

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<th></th>
<th>Electricity</th>
<th>Oxygen</th>
<th>PTC</th>
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<tr>
<td>18-NC-CT</td>
<td>$100</td>
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</tbody>
</table>
Annual Loss
Wind Energy Generation, Transmission
Wholesale Delivery of Electricity
With PTC; Wind Capital Cost = $950 / kW
"The Conversion Project"

- Gasoline COSTS too much, with “externalities”
  - Human health
  - GW, GCC
  - Military, war, security
  - Other environmental
  - Trade balance
  - Deplete resources – future generations
  - Other social, political, human
- Renewable-source H2 fuel will cost less than gasoline
- GAO study to reveal full costs of gasoline, H2
- PR, advertising campaign to arouse public
- Accelerate conversion from gasoline to renewable-source H2
- Great Plains advocates help define The Conversion Project
- Wind-source Hydrogen for Vehicle Fuel
- The Conversion Project; The Phoenix Project
- IHTDF: International Hydrogen Transmission Demonstration Facility
Vision for the Hydrogen Economy: ... Hydrogen is flexible, affordable, safe, domestically produced, used in all sectors of the economy, and in all regions of the country.

• Effective design and implementation of a hydrogen-based energy system requires a “whole system” approach.

• A greatly expanded distributed infrastructure will be needed...

• Government / industry partnerships for technology demonstration and commercialization... Public-private production demonstrations are essential.

• ... will include mid-sized community systems... and pipeline delivery for longer distances

• Multi-state delivery demonstrations and showcases
Why Hydrogen Transmission?

- New farm-to-market road system for energy
- End-run around electricity transmission bottleneck?
- Lower cost than electric transmission?
- Add greater value? Energy storage; source synergy
- Profitable?
- Wind energy market may be---
  - Not electric grid
  - H2 fuel for transport and distributed generation (DG)
- Underground pipeline:
  - More acceptable;
  - More permittable;
  - More secure, than electricity transmission?
Northern Great Plains Opportunities

*R+D needed*

- Gathering, transmission, distribution
  - Engineering, economic models: System optimization
  - Pipeline design: materials, collection topology, node components
  - Costs, long-term

- Electrolyzers
  - MW scale
  - > 2,000 psi output
  - > 90 % efficiency
  - < $ 250 / kWe capacity, installed
  - < $ 0.001 / kWh O&M cost
  - Integrated with wind generator design

- Large-scale underground GH2 storage: seasonal, smoothing

- Output smoothing over large catchment area:
  - wind, continental scale
  - ISET study: wind, Europe + North Africa

- Polygeneration from O2-blown coal gasification, with C-sequestration,
  in near-zero-emissions plants (Williams, Princeton)

- CO2 sequestration: permanent, low-cost (~ $ 0.01 / kWh)
  - Depleted oil + gas fields
  - Deep geologic
  - Soils
  - Mineralized and backfilled: Mg carbonates, etc.
Pipelines will distribute hydrogen to high-demand areas…

Testing and validation should be ongoing.

Create a public demonstration hydrogen village.

Demonstrations that integrate production technology with other elements of the hydrogen infrastructure, including a market use, will be more cost effective.

Increase demonstrations significantly. Demonstrations should showcase the near-term availability of multiple alternative technologies for distributed generation…

Technology demonstrations and hydrogen pilot projects can help to uncover problems and compile empirical data to better estimate the costs and benefits of infrastructure requirements for transition to a hydrogen economy.
The IHTDF will:

1. Help us decide under what circumstances large-scale, cross-country collection and transmission of renewable-source energy in GH2 pipelines will be technically and economically attractive;

2. Demonstrate the probable long-term costs of such GH2 pipeline systems for “stranded” renewable resources.

3. Demonstrate economic and technical synergy among renewable GH2 sources—wind, biomass, and perhaps others, embracing:
   a. Availability and output variations at hourly to seasonal time scales;
   b. Stockpiling and dispatch, especially of biomass;
   c. Possibly “zero emissions” coal gasification.

4. Demonstrate “distributed collection” (DC) of diverse, dispersed, diffuse renewable resources, large and small, continuously along the GH2 pipeline ROW via frequently-spaced GH2 gathering input points; design and test the system topology and components to accomplish this.

5. Demonstrate the pipeline as an energy storage medium;

6. Discover pressure range limits and management techniques; develop economic valuation models for this storage.

7. Investigate and prove feasibility and cost of large-scale geologic storage of GH2, along pipeline ROW, in:
   a. Extant natural gas storage structures, as available;
   b. Other geological formations.
The IHTDF will:

8. Bring GH2 production, transmission, and use out of the laboratory and out of established industrial reservations, and into farmers' fields, across private and public lands, to utilization at a major research university campus and USDOE laboratory (in the case of Iowa State University and Ames Laboratory).

9. Encounter and solve public and professional misunderstanding, apprehension, and impediments in:
   a. Land use and zoning;
   b. Perception of hydrogen systems: design, function, and safety;
   c. Codes and standards;
   d. The insurance and banking industries

10. Induce codes, standards, and insurance problem resolution via operating experience on a “real project”.

11. Encounter and solve novel ROW acquisition problems.

12. Estimate feasibility and costs of scale-up to multi-GW, long-distance, cross-country GH2 gathering and transmission pipeline systems; project what the cost of diverse Great Plains renewable energy resources, delivered at long distances as GH2, could be.
The IHTDF will:

13. Verify long-term:
   a. O+M costs;
   b. System component degradation;
   c. Integrity inspection methods, especially for hydrogen corrosion and embrittlement of steel.

14. Be a dynamic test bed for evolving technology in GH2 collection and transmission:
   a. Electrolyzers
   b. Compressors
   c. Meters, valves
   d. Gas quality monitoring, control, leak detection, and shutdown systems
   e. Software for modeling, management, and control
   f. Pipeline inspection and integrity

15. Be a dynamic test bed for evolving technology:
   a. Wind energy conversion equipment optimized to feed electrolyzers;
   b. Electrolyzers
   c. Biomass energy conversion to GH2

16. Demonstrate “Distributed collection” (DC) is the complement to “distributed generation” (DG)

17. Encourage industry to:
   b. Invest in GH2 production, collection and transmission, and distribution, from renewable energy sources and possibly from “zero emissions coal”:

18. Reveal energy policy implications for a carbon-free energy economy.
Ameron
Steel Strip Laminate (SSL) Pipe
Ameron
Steel Strip Laminate (SSL) Pipe

Glass Reinforced Epoxy Outer Jacket
Helically Wound Steel Strip Layers
Glass Reinforced Epoxy Inner Liner
Ameron
Coil-Lock joining system

- Highest pressure rating
- Can be field tested at assembly
- Double O-ring with injected sealant for critical applications
- Can be disassembled (even if sealed)
Focus on

• Large stranded Great Plains wind resource
  – Stranded
  – Enough to supply all USA energy
• End of “cherry picking” era for large wind projects: must pay full cost of transmission
• H2 transportation fuel may be a bigger market than grid electricity for wind (over next 20 years?)
• Accelerated conversion: Gasoline to renewable-source H2
  – Gasoline now costs too much; External costs: GAO study
  – Energy insecurity of importing > half our transportation fuel
  – Climate insecurity of burning fossil fuels in Carnot engines
  – Build transmission to bring Great Plains wind to markets: twice the NHS investment
  – Phoenix project: wartime speed
• Solar-H2 demo on tabletop
The Conversion Project

- Gasoline *costs* too much, to continue to use for vehicle fuel, when the myriad “external costs” are included
- A General Accounting Office (GAO) study will be required to credibly reveal and compare the full costs of gasoline, and of hydrogen fuel, to confirm the above; members of Congress need to request this study.
- Benign-source (from indigenous, renewable energy sources, and perhaps others) hydrogen fuel will *COST* less than gasoline
- Therefore, we need to accelerate our conversion from gasoline to renewable-source, or other benign-source, hydrogen for vehicle fuel
- A large PR and advertising campaign will arouse public opinion, to generate the political will to compel the Conversion.
- Then, large capital investments will be needed to harvest diverse, distant, dispersed renewable energy resources; to convert this energy to hydrogen fuel; to transmit and distribute the fuel to urban markets
- Drafting and initiating legislative action in the U.S. Congress on “The Renewable Energy / Hydrogen Production Act” which would subsidize the production of hydrogen from renewable sources of energy to make hydrogen competitive with gasoline, diesel, and jet fuel.
President Bush deserves credit for focusing on hydrogen in his recent State of the Union Address, but the Bush Administration is waiting to replacing internal combustion engines with fuel cells, and he proposes to make the hydrogen primarily from toxic and non-renewable fossil and nuclear fuels, which involves significant R&D. As such, with the Bush Administration's approach, the hydrogen economy will be many decades - if not centuries - into the future.

Because of the exponential nature of the global energy and environmental problems, we cannot afford to wait for nuclear fusion or fuel cells to be developed. Moreover, because hydrogen is a "universal fuel," it can power any existing vehicle or appliance, including SUVs, trucks, planes and spacecraft, as well as any remaining Model T Fords -- or a Coleman stove on a mountain-top. Moreover, hydrogen can be made with any source of electricity and water, which is found at every gas station, as well as every home. Thus filling up with pure hydrogen will be easier - and much safer - than using gasoline and other hydrocarbon fuels where the hydrogen is chemically bonded to carbon. Consider the following:

1. The Phoenix Project is the only realistic 5 or 10-year plan that would allow the U.S. to shift from fossil and nuclear fuels to wind-powered hydrogen production systems, which would include modifying every existing vehicle - including aircraft - to use hydrogen fuel.

2. Approximately 12 to 15 million one-megawatt wind-powered hydrogen production systems will create 100% of U.S. energy requirements (i.e., 100 quads). Given that wind systems are similar to automobiles from a manufacturing perspective, and given that 17 million vehicles are manufactured in the U.S. each year, the needed wind systems could and should be built and installed within a 5 or 10-year period.

3. The Phoenix Project plan will supercharge the economy and employ millions of Americans as the U.S. rapidly becomes energy independent of fossil and nuclear fuels. Indeed, the U.S. will rapidly become a Saudi Arabia-class energy exporter of a completely non-toxic, pollution free fuel that is inexhaustible.

4. Congressional Hearings are needed in order to enact Fair Accounting Act legislation that will serve as the "trigger mechanism" for shifting to a hydrogen economy. This legislation will transfer federal subsidies from fossil and nuclear fuels to clean hydrogen technologies, including the necessary automotive conversion kits and an interstate superconducting hydrogen pipeline system that would also efficiently carry electricity.

5. The hydrogen from wind systems will have a production cost of about $2.00 per equivalent gallon of gasoline, but while gasoline will get increasingly expensive in the future as oil reserves are depleted, the wind-powered hydrogen production costs will continue to be reduced as more and more engineers focus on optimizing the hydrogen production technologies.
“We know how to pipeline hydrogen” Air Products
~ 10,000 miles of GH2 pipeline, worldwide

Air Products H₂/CO Pipeline - Texas Gulf Coast

Approx. 60 Miles

Approx. 60 Miles

HYDROGEN
CO
SYNGAS
Air Products Facilities