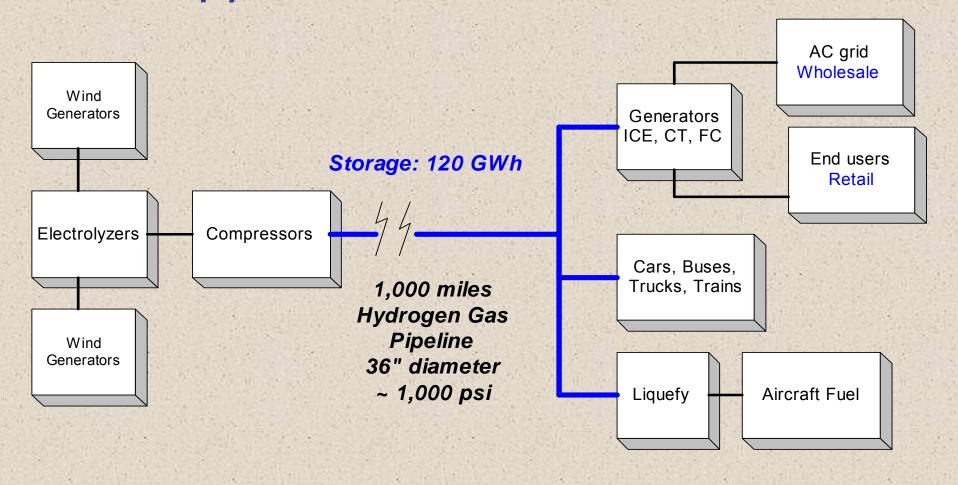
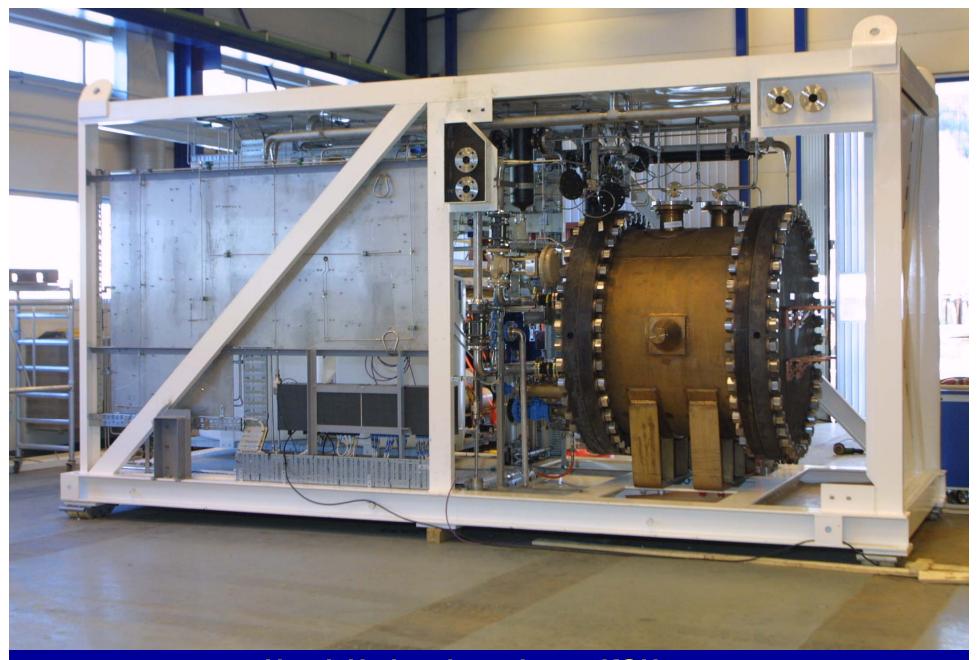


Solar Hydrogen Energy System

Hydrogen Transmission Scenario

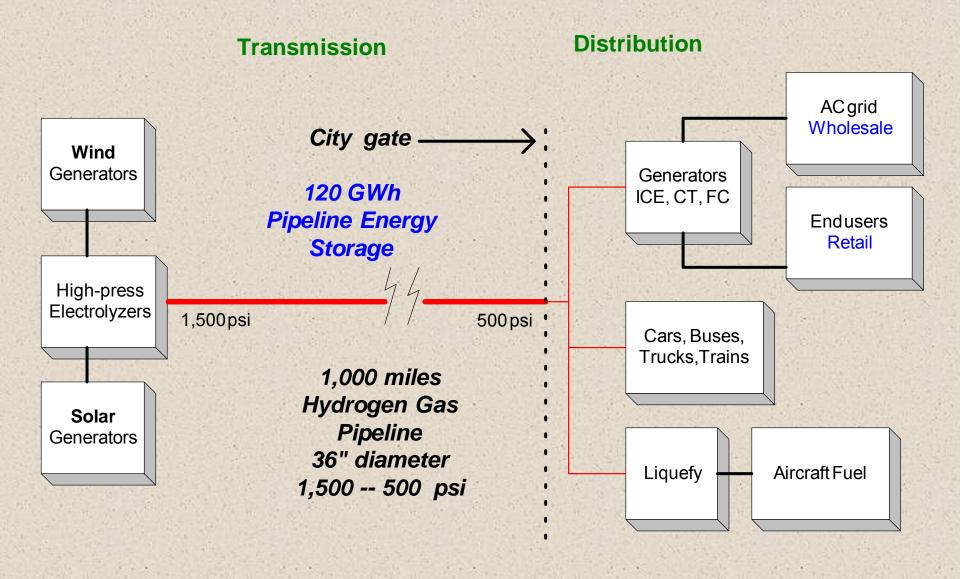
- Low-pressure electrolyzers
- · "Pack" pipeline: ~ 120 GWh

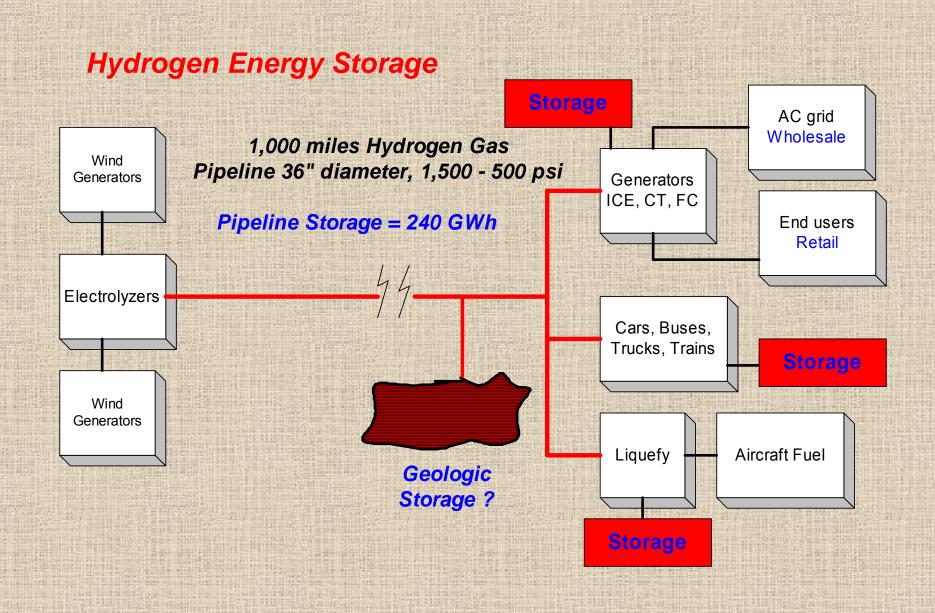


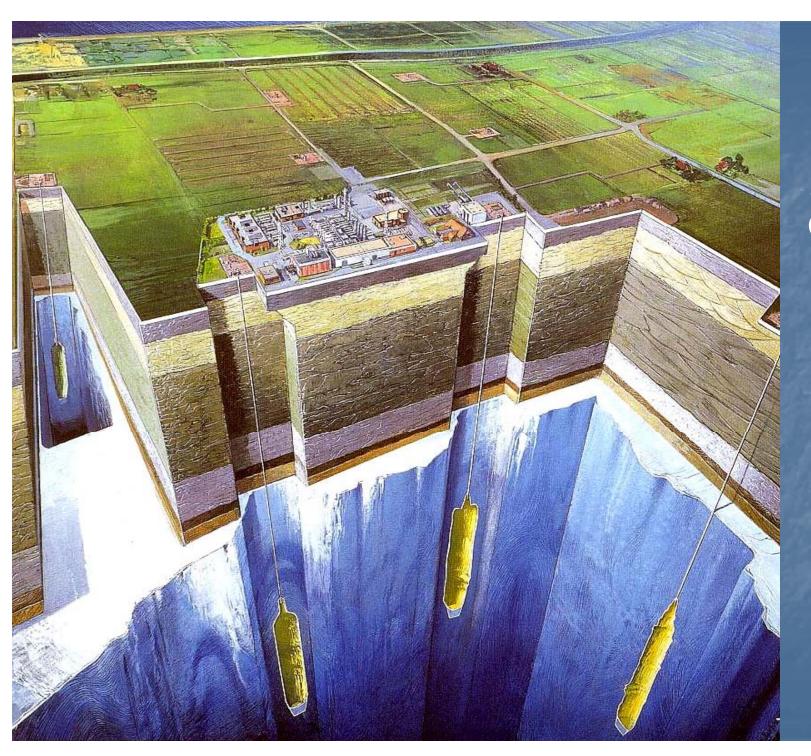


Norsk Hydro electrolyzer, KOH type 560 kW input, 130 Nm3 / hour at 450 psi (30 bar)

Hydrogen Transmission Scenario

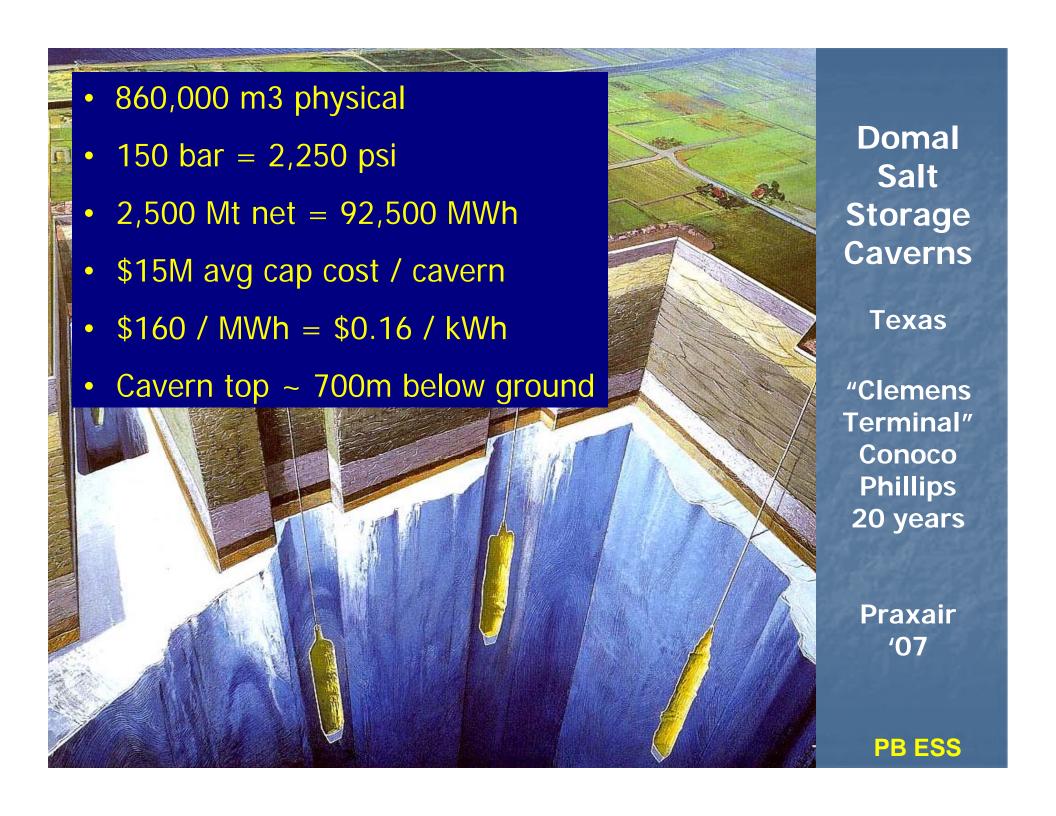


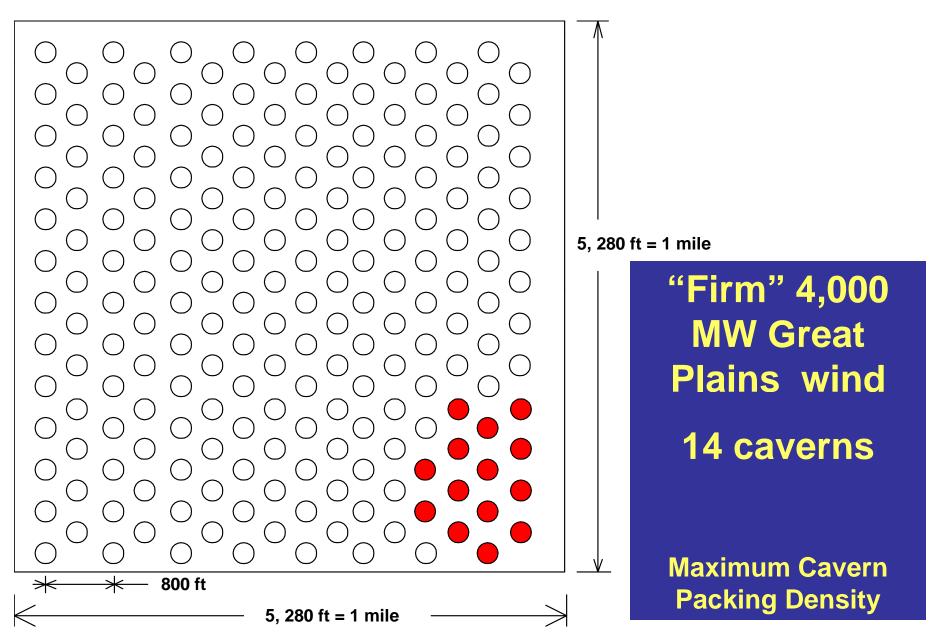




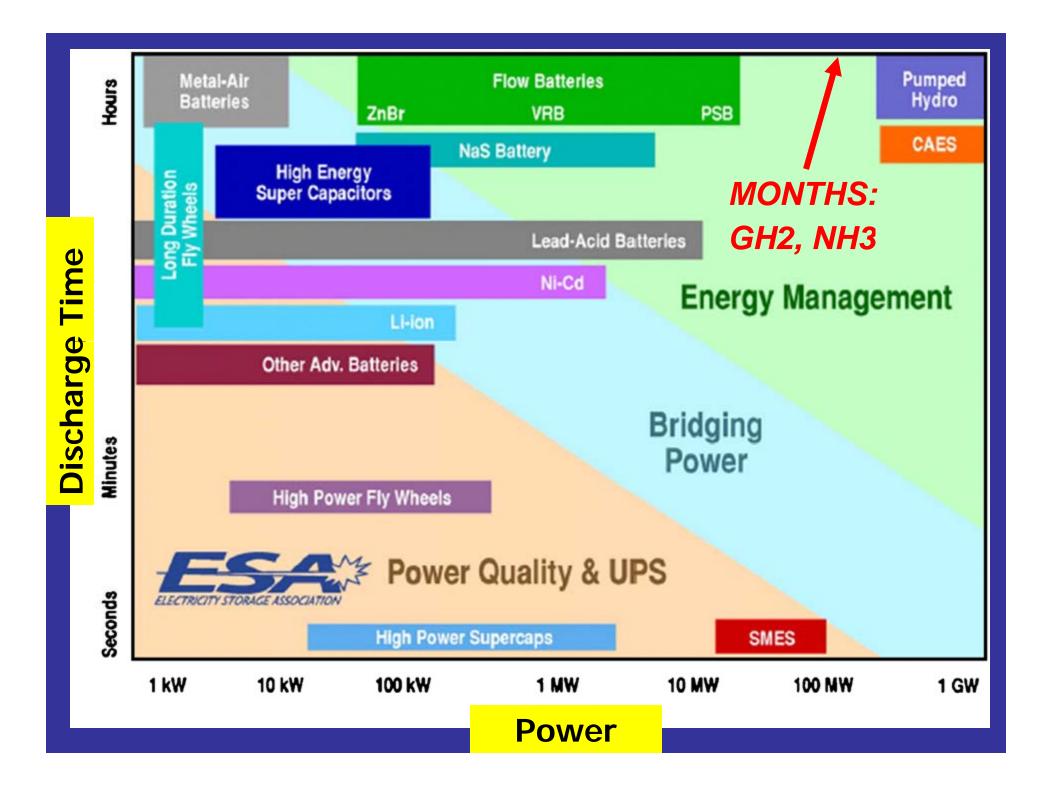
Domal Salt Storage Caverns

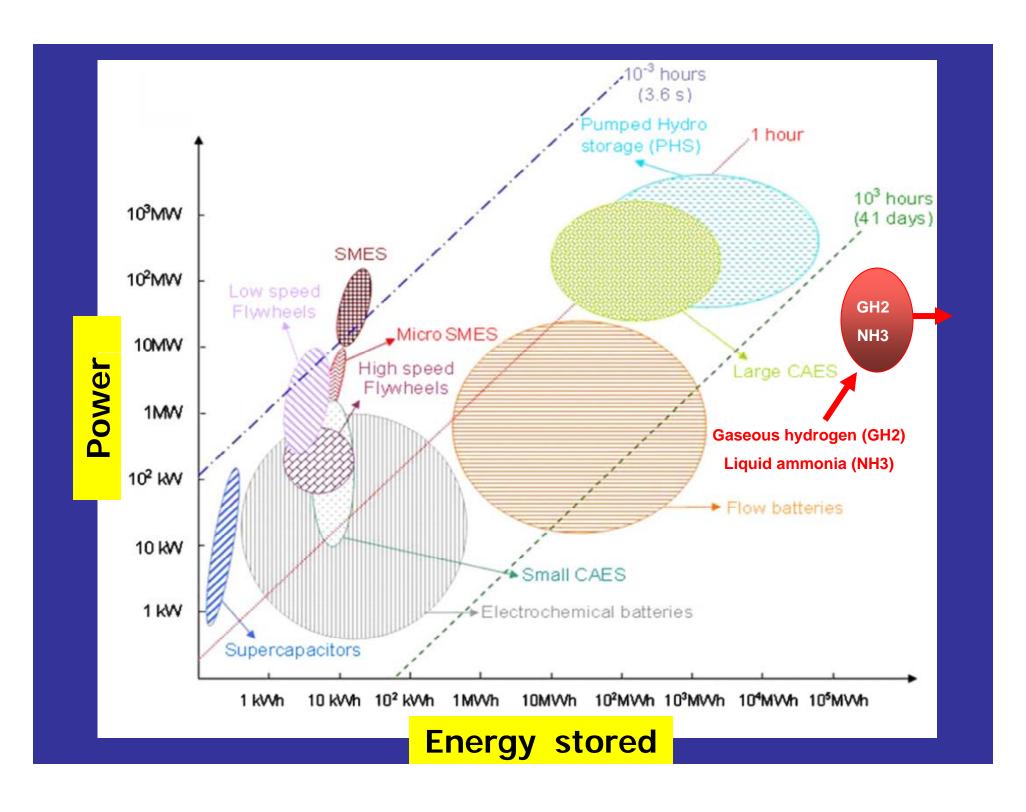
PB ESS

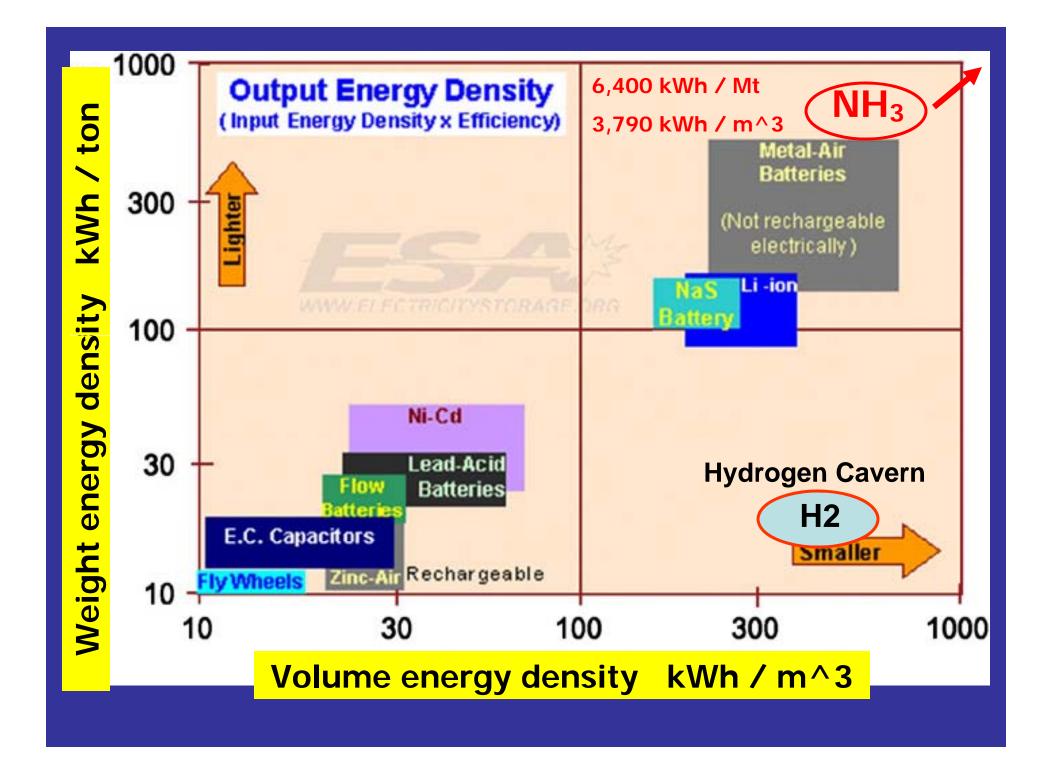


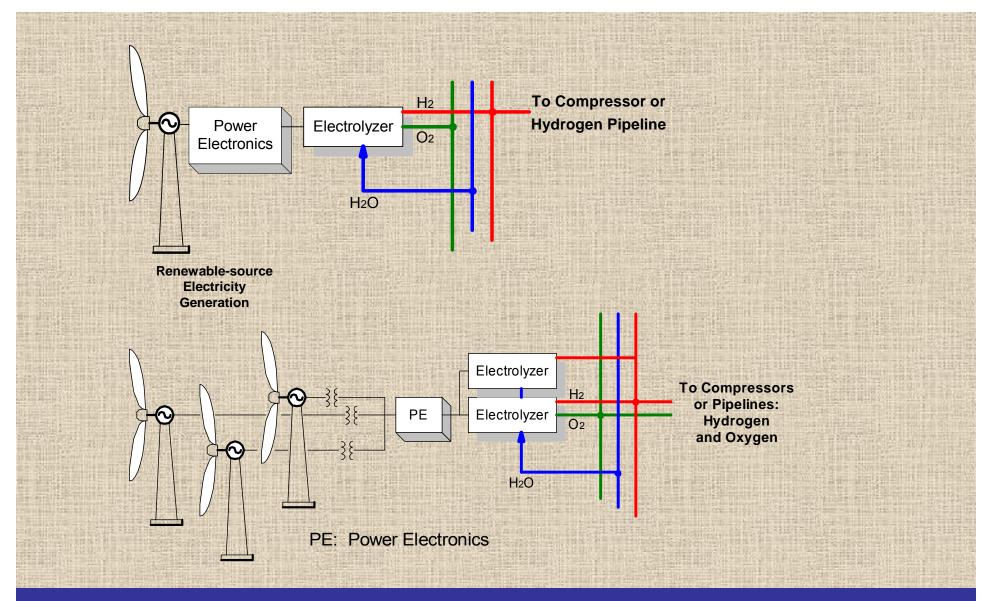


 $(8 \times 13) = 104 + (8 \times 12) = 96$ Total = 200 caverns per square mile Each cavern is 200 ft diam, with minimum 200 ft web separation.



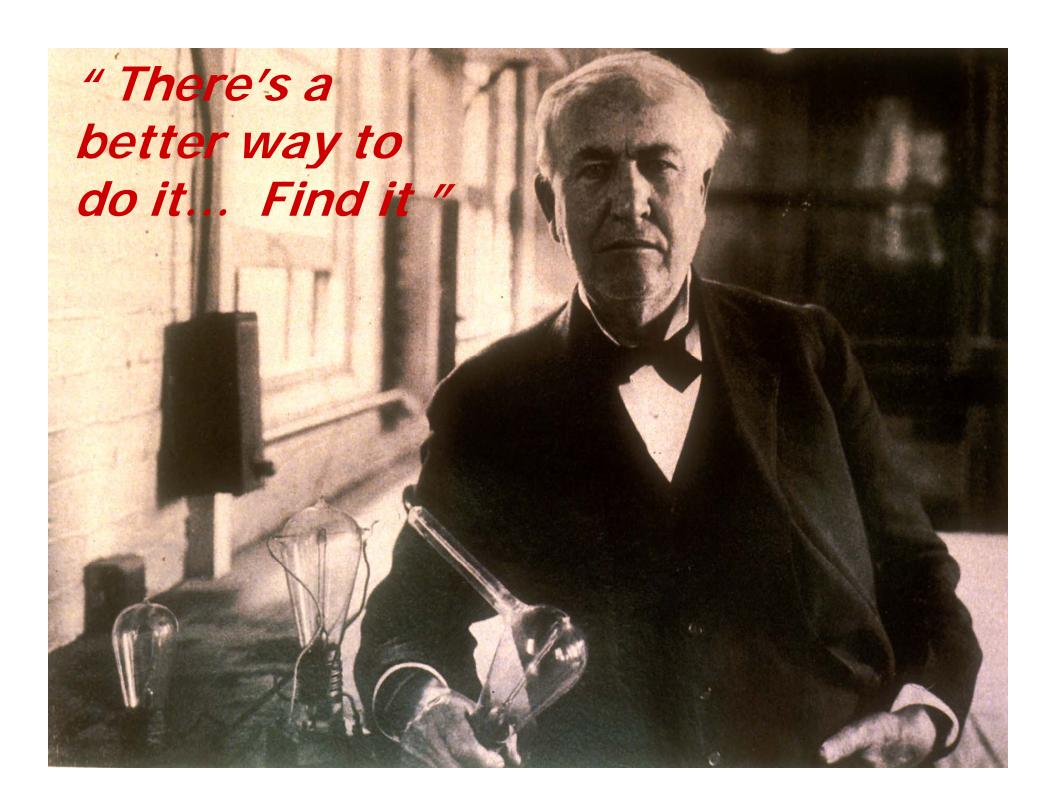






Topology Options: H₂ and O₂ Production and Gathering from Renewable Energy Generation





MUST Run the World on Renewables – plus Nuclear?

- Emergencies:
 - Climate change
 - Ocean acidification
 - Energy prices
 - Energy security
- Quickly invest:
 - Conserv + efficiency
 - GW-scale renewables
 - Beyond electricity grid
 - Hydrogen, ammonia, ?



Opportunity: Extraordinary, not promising ARPA-E "GRIDS" FOA

• ARPA-E:





Advanced Research Projects Agency – Energy

GRIDS:

Grid-Scale Rampable Intermittent Dispatchable Storage

FOA:

Funding Opportunity Announcement

Opportunity: Extraordinary, not promising "GRIDS" FOA

- 5 page concept paper due 1 Apr 10
- 23 Apr: "... not encouraged to submit..."
- "Full App" due 24 May 10
- Funding announced ??
- Goal: \$100 / kWh capital cost
- H2 cavern storage: \$0.20 / kWh

Opportunity: Extraordinary, not promising GRIDS

- Grid-scale Rampable Intermittent Dispatchable Storage (GRIDS)
- ... widespread deployment of ... grid-scale energy storage
- ... develop revolutionary new storage systems
 ... which are modular ... widely implemented at any location across the power grid
- ... focusing on technology prototyping and proofof-concept R&D efforts

Opportunity: Extraordinary, not promising AASI * Concept Paper, 1 Apr 10

- Assemble Collaborative
- Conceive, design, bid
- Renewables hydrogen pipeline pilot plant
 - Renewable resources
 - Transmission pipeline
 - Destination end-users for GH2 fuel
 - Cavern GH2 storage, if available
- Bid: credible RFP or RFQ release
- Responses: cost, feasibility, further work
- R&D&Demonstration: polymer-metal line pipe

^{*} Alaska Applied Sciences, Inc. (AASI)

Opportunity: Extraordinary, not promising AASI Concept Paper Budget:

```
$ 400 K Pilot plant pipeline
```

\$ 200 K Polymer – metal line pipe

\$ 480 K ARPA-E cash

\$ 120 K Applicants in-kind

Opportunity: Extraordinary; not promising

- "Full Application" to ARPA-E
- 24 May deadline; foot in door
- Join AASI as co-applicant
- If ARPA-E declines:
 - Collaborative founded
 - Proceed? Resources?

1: Adequate Renewables

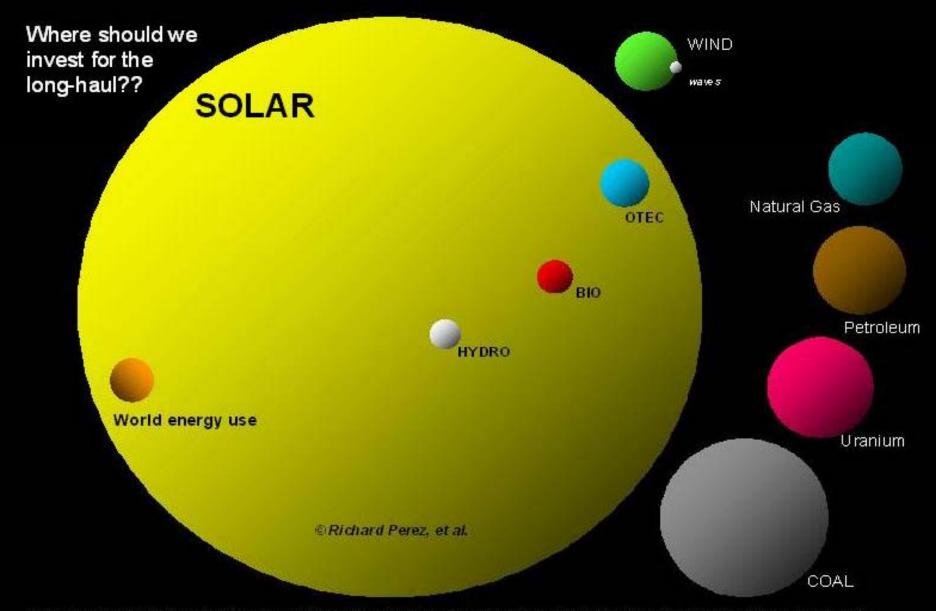
- Run the world; humanity's needs
- "Distributed" and "Centralized"
- Affordable, benign
- Diverse, synergistic
- Richest are "stranded"
 - Far from markets
 - No transmission

MUST Run the World on Renewables – plus Nuclear?

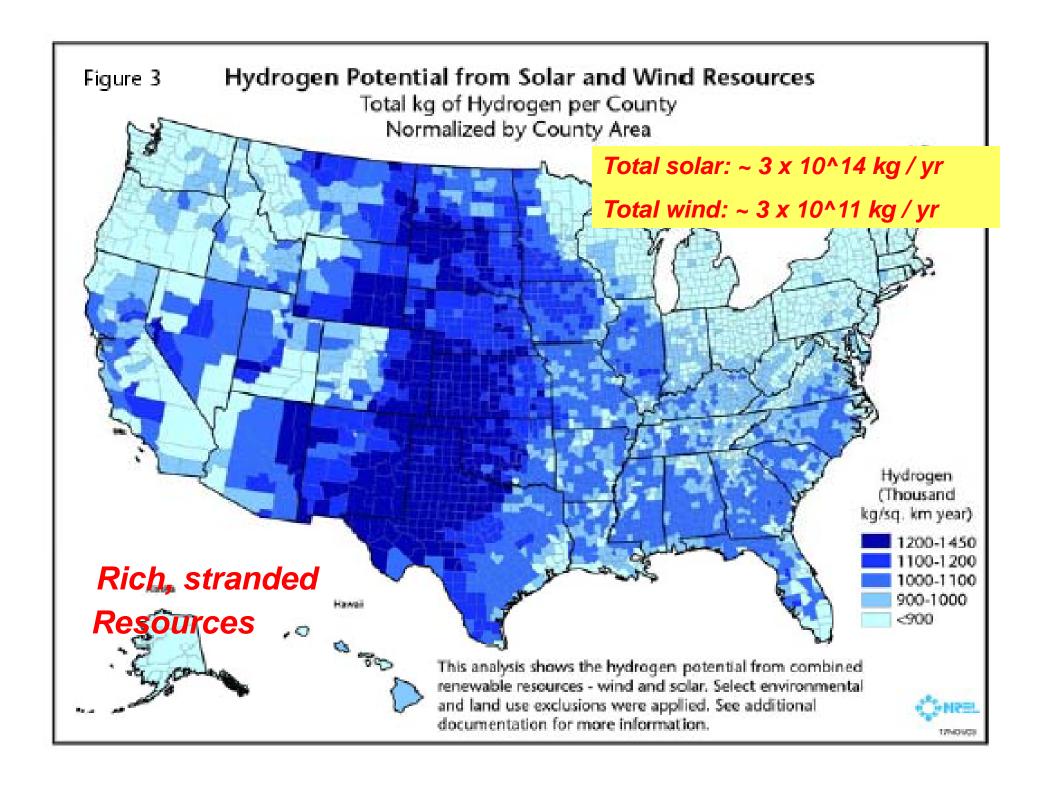
- Climate Change
- Ocean acidification
- Demand growth
- Depletion of Oil and Gas
- Only 200 years of Coal left
- Only Source of Income:
 - Sunshine
 - Tides
 - Meteors and dust
 - Spend our capital ?

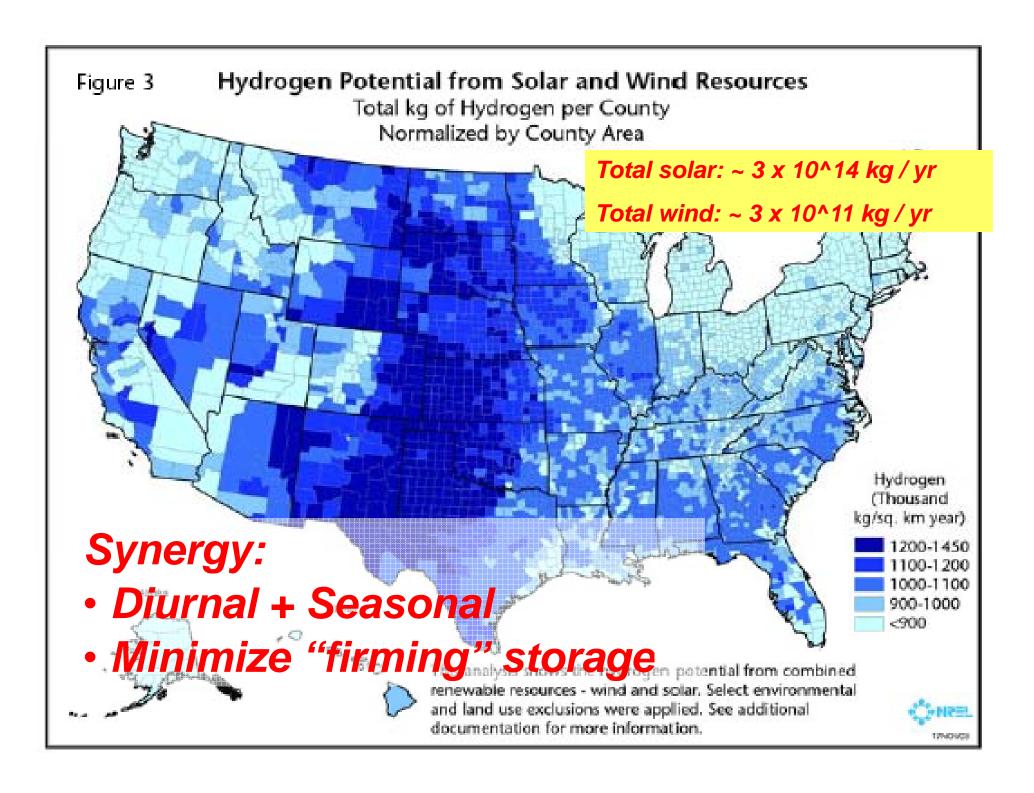


Comparing the world's energy resources*



^{*}yearly potential is shown for the renewable energies. Total reserves are shown for the fossil and nuclear "use-them, lose-them" resources. Word energy use is annual.





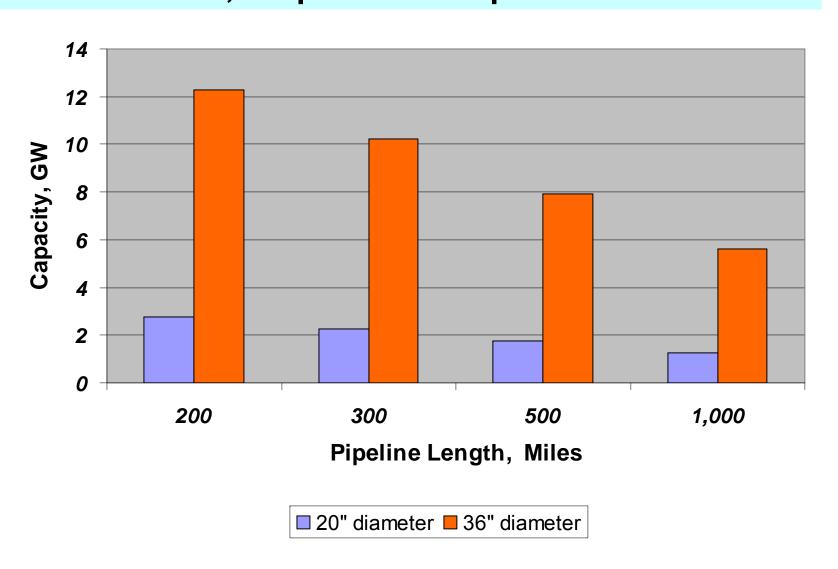


Exporting From 12 Windiest Great Plains States

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

State	AEP, TWh	Wind Gen MW (nameplate) (40% CF)	6 GW 36" GH2 export pipelines	\$ Billion Total Capital Cost *	3 GW export HVDC lines	\$ Billion Total Capital Cost *
North Dakota	1,210	345,320	50	50	100	60
Texas	1,190	339,612	48	48	100	60
Kansas	1,070	305,365	43	43	100	60
South Dakota	1,030	293,950	41	41	100	60
Montana	1,020	291,096	41	41	90	54
Nebraska	868	247,717	35	35	80	48
Wyoming	747	213,185	30	30	70	42
Oklahoma	725	206,906	29	29	60	36
Minnesota	657	187,500	26	26	60	36
Iowa	551	157,249	22	22	50	30
Colorado	481	137,272	19	19	40	24
New Mexico	435	124,144	17	17	40	24
TOTALS	9,984	2,849,316	401	\$ 401	890	\$ 534

Compressorless 20", 36" GH2 Pipeline Capacity 1,500 psi IN / 500 psi OUT



Capital Cost per GW-mile

Electricity: Capacity

KV MW \$M / MW-mile

• SEIA: 765 5,000 1.3

345 1,000 2.6

• AEP-AWEA 765 5,000 3.2

Consensus? 2.5

Hydrogen pipeline:

36", 100 bar, 500 mi, no compress 0.3

(100 bar = 1,500 psi)

2: When we realize these as emergencies:

- Global Warming, Rapid Climate Change
- Energy Security and Cost
- Peak Oil and Natural Gas

We must quickly invest in:

- Energy conservation, efficiency
- GW-scale new energy supplies:
 - CO₂ emissions free
 - Indigenous
 - Both distributed, centralized

3: Shortest path to benign, secure, abundant energy

- Renewables
 - Diverse
 - Diffuse
 - Dispersed
- Centralized:
 - Large, rich; lower cost than distributed?
 - But stranded (no transmission)
- Gaseous hydrogen (GH2) pipelines
 - Conversion, gathering
 - Transmission
 - Storage: tanks, salt caverns
 - Distribution
- Geologic storage "firms"
- Pilot plants needed:
 - Every major new industrial process
 - IRHTDF

3: Shortest path to benign, secure, abundant energy

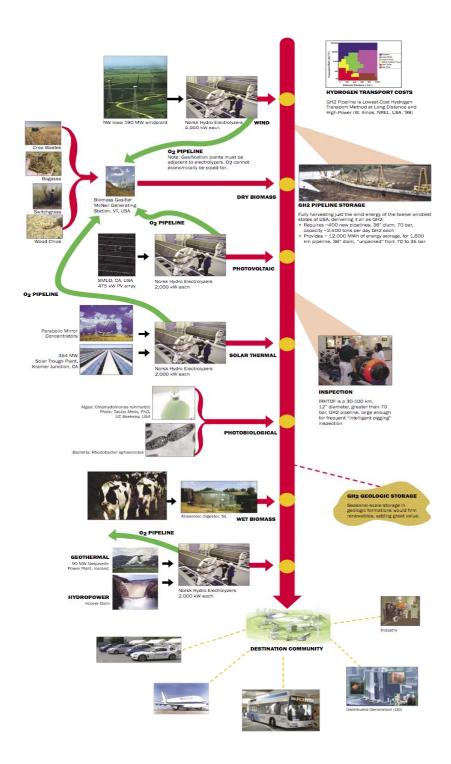
- Anhydrous Ammonia (NH3) pipelines, tanks
 - Conversion, gathering
 - Transmission
 - Storage: tanks
 - Distribution
 - Carbon steel: no HE
- Pilot plants needed:
 - '08 Farm Bill Sec 9003:
 - "Renewable Fertilizer Research"

4: Hydrogen's principal value

- NOT fuel cell cars
- Gather, transmit, store:
 - Large-scale, diverse, stranded renewables
 - FIRM time-varying-output renewables
 - Pipeline transmission, storage
 - Geologic storage
 - "Renewables Nuclear Synergy …", C. Forsberg
- Benign, if from renewables
- Global opportunity
- Hydrogen "sector", not "economy": Systems
 - Transportation fuel: ground, air
 - DG electricity, CHP, retail value

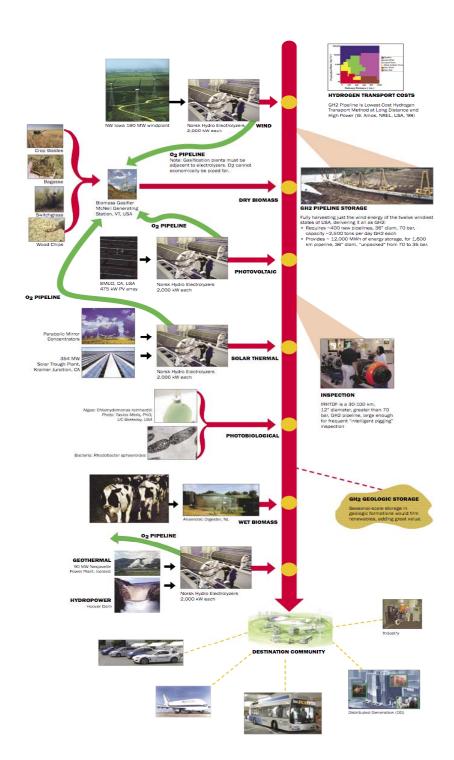
5: Pilot plants needed

- Every major new industrial process
- Diverse, large-scale, stranded
- Renewables-source systems
- IRHTDF
- Papers: Japan, Canada, IPHE
- Systems



Pilot-scale Hydrogen Pipeline System: Renewables

- Diverse
- Dispersed, diffuse
- Large-scale
- Stranded
 - Remote
 - No transmission

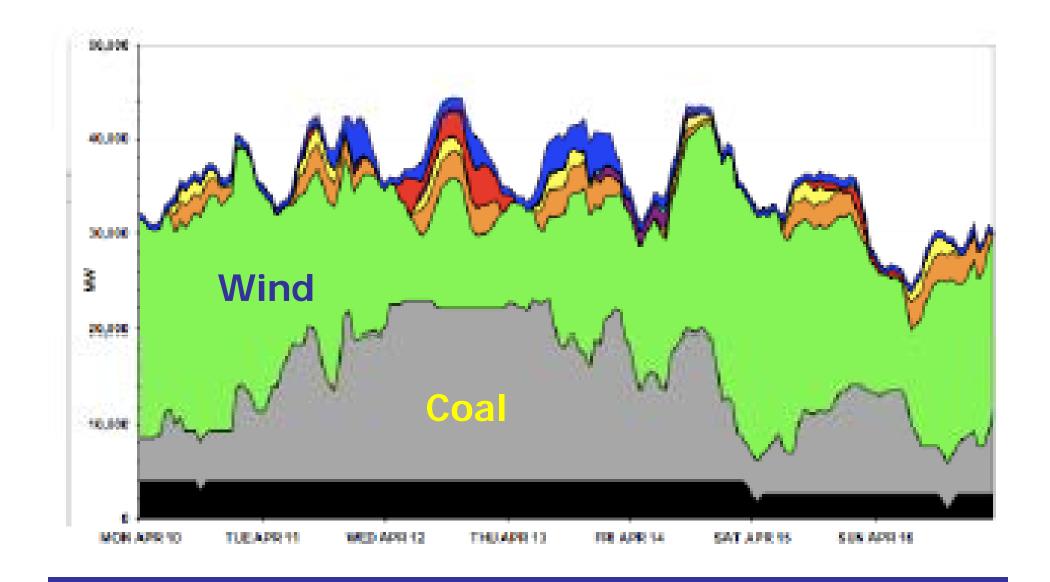


International Renewable Hydrogen Transmission Demonstration Facility (IRHTDF) Pilot plant

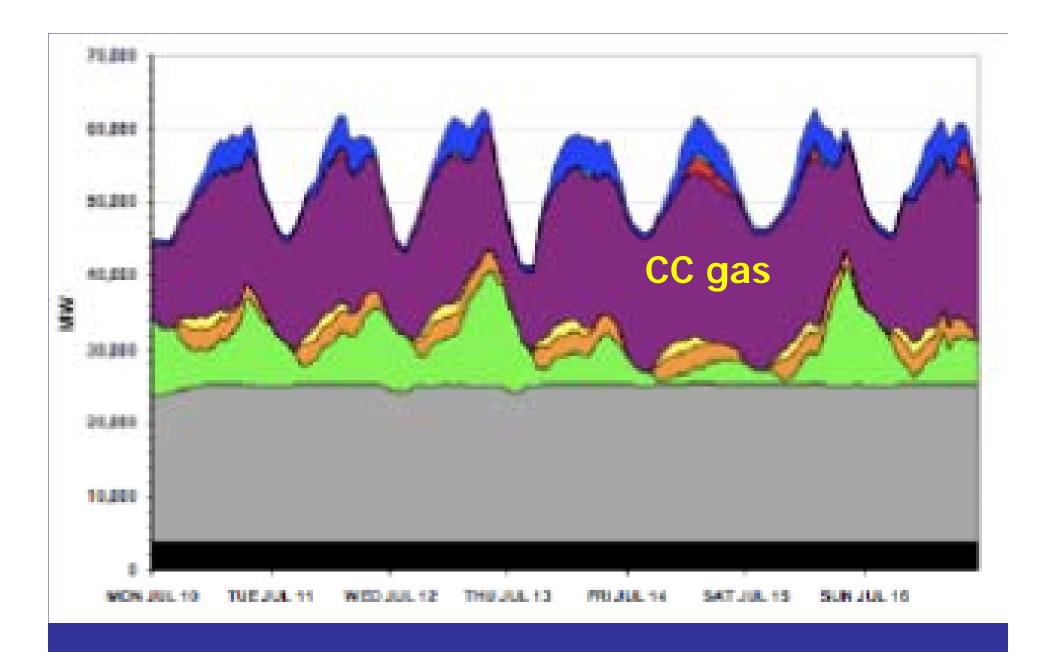
Global opportunity:
IPHE project?

Trouble with Renewables

- Diffuse, dispersed: gathering cost
- Richest are remote: "stranded"
 - High intensity
 - Large geographic extent
- Time-varying output:
 - "Intermittent"
 - "Firming" integration + storage required
- Distributed AND centralized



WWSIS: April week: 30% RE



WWSIS: July week: 30% RE

Wind seasonality, Great Plains

Normalized to 1.0

• Winter 1.20

• Spring 1.17

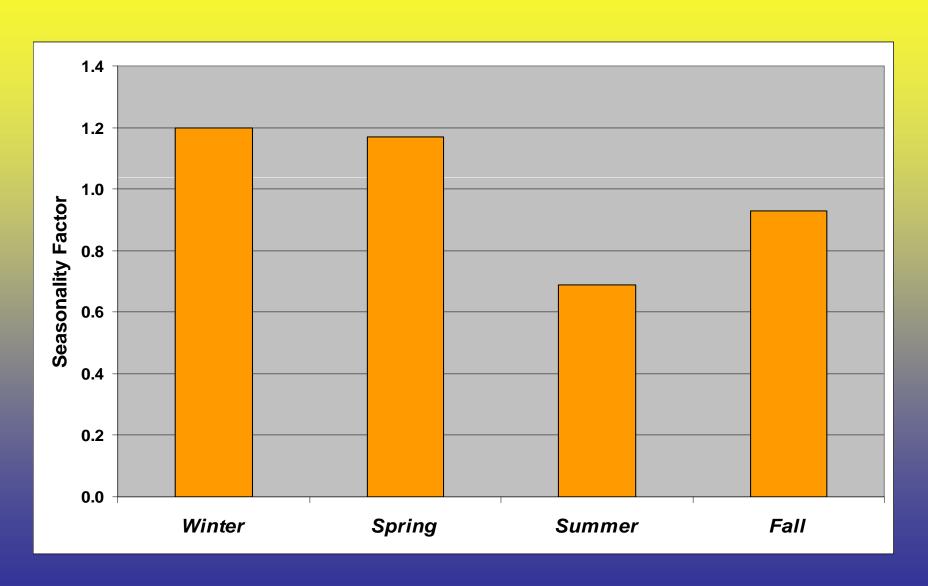
• Summer 0.69

Autumn 0.93

Source: D. Elliott, et al, NREL

Wind Seasonality, Northern Great Plains

Normalized to 1.0 per season

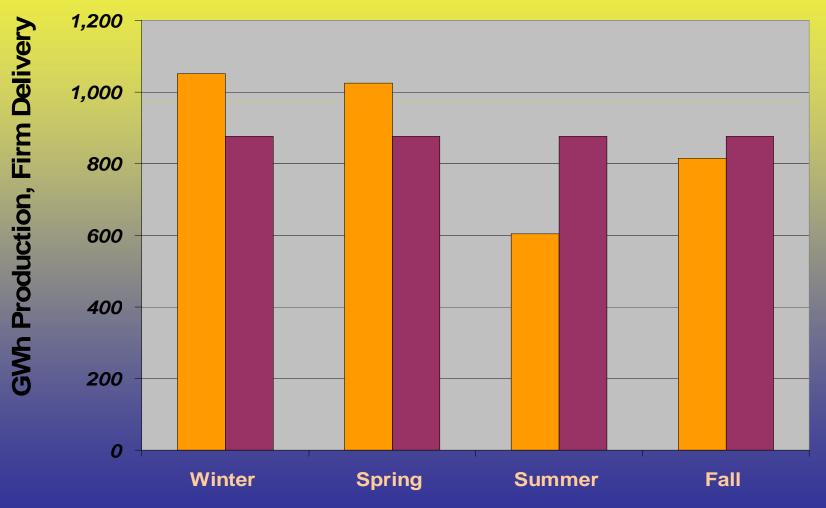


Wind Seasonality, Northern Great Plains

1,000 MW windplant: AEP = 3,500 GWh/yr

"Firm" goal = 875 GWh / season Storage: 320 GWh per 1,000 MW wind

Source: NREL, D. Elliott



Optimistic: Total Installed Capital Cost 1,000 mile Pipeline "Firming" GH2 cavern storage

Windplant size 1,000 MW [million]
Wind generators \$ 1,000
Electrolyzers 500
Pipeline, 20" 1,100
storage caverns [4]
Caverns @ \$10M ea 40
Cushion gas @ \$5M ea 20
TOTAL \$ 2,660

Cavern storage: ~ 3 % of total capital cost

320,000 MWWh Annual firming, 1,000 MW wind

- CAES (compressed air energy storage)
 - O&M: \$46 / MWh typical
 - Iowa: Power = 268 MW

Energy capacity = 5,360 MWh

Capital: 268 MW @\$800 / kW = \$214 M

@ \$40 / kWh = \$13 Billion

@ \$1 / kWh = \$325 Million

- VRB flow battery
 - O&M: 80% efficiency round-trip
 - Capital: \$500 / kWh = \$160 Billion

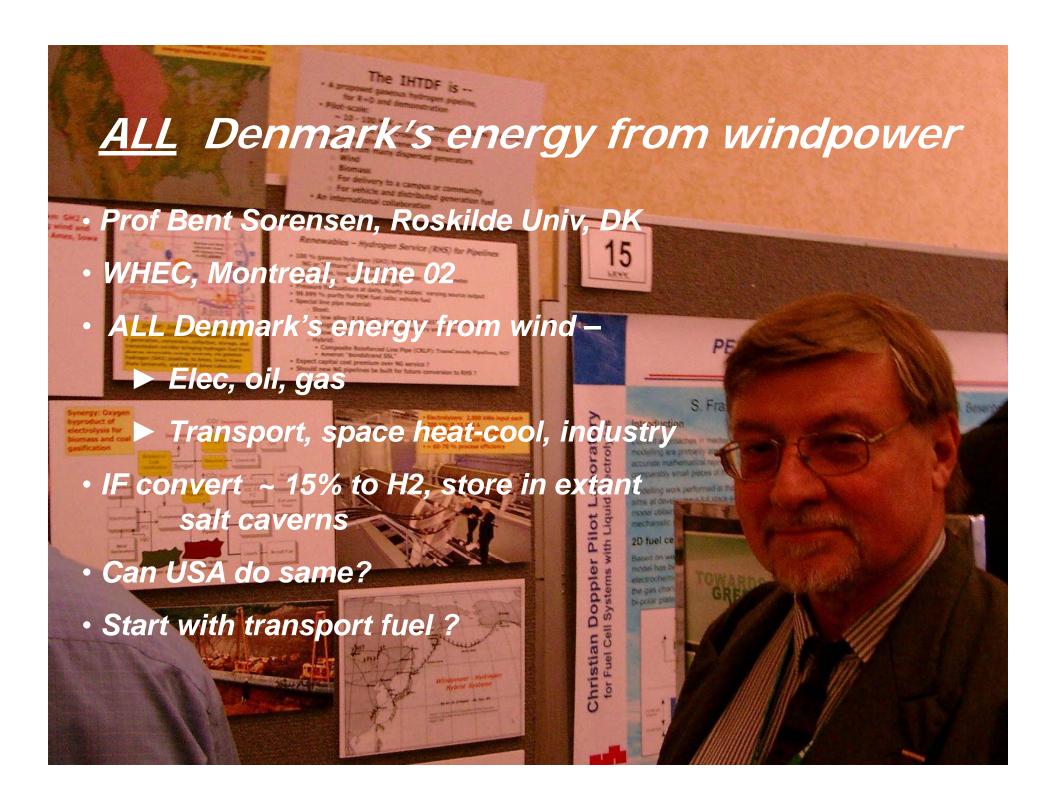
Trouble with Renewables - Electricity Transmission

- Grid nearly full
 - New wind must pay for transmission
 - Costly: AC or DC
- Low capacity factor (CF) or curtailment
- Costly "firming" storage: CAES, VRB
- Overhead vulnerable: God or man
- Underground: Only HVDC
- FERC no interstate jurisdiction
- Wide ROW
- NIMBY: site, ROW delay + cost



Trouble with GW - scale Wind

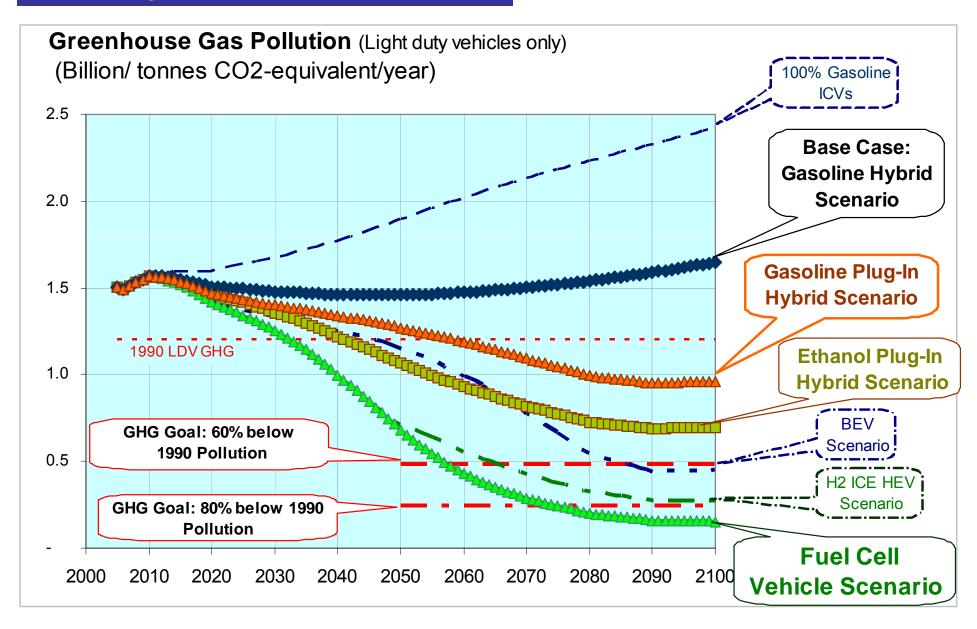
- "Cherry-picked" windplants:
 - Best wind sites
 - Low-cost transmission access
- Depend on PTC: \$ 0.02 / kWh
- No storage: smoothing or firming
- Grid integration: instability, cost

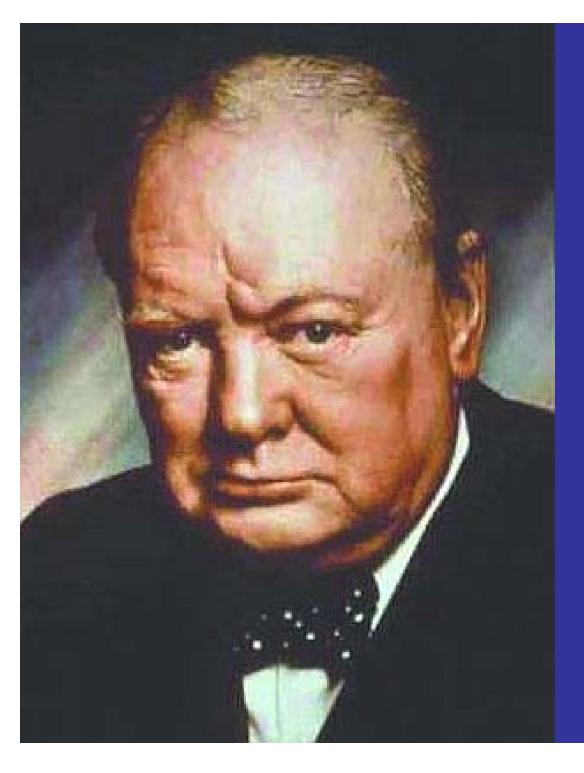


CA: 20% of "cars" hydrogen fueled by 2030

- 20% of 45M vehicles = 9M
- @ 78 mpg = 78 miles / kg H2
- 12,000 miles / year = 150 kg H2 / year
- 1,800 M kg H2 / year = 1.65 M tons H2 fuel / year
 @ 50 kWh / kg electrolysis at windplant gate:
 - 82,500 GWh / year
 - @ 40% CF = 23,000 MW nameplate wind
 - Requires 3 GH2 pipelines, 36", 500 miles long
 - PLUS @ 4 caverns / GW = 92 storage caverns,
 to firm the supply at annual scale

Sandy Thomas '08-09





"Americans can be counted on to always do the right thing –

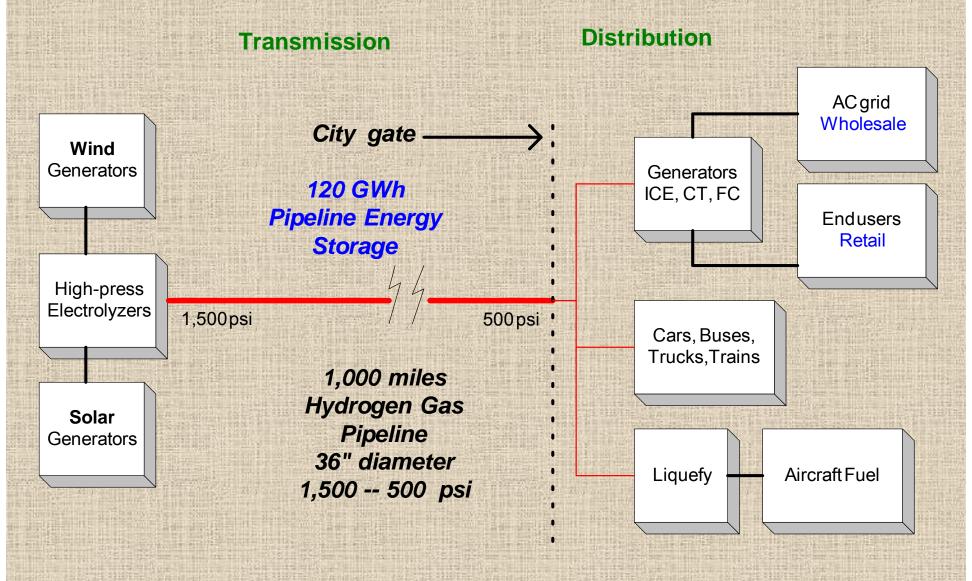
but only after they have tried everything else "

Winston Churchill

The dog caught the car.

Dan Reicher

Compressorless system: No geologic storage





Composite Reinforced Line Pipe (CRLP)

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

NCF Industries and TransCanada Pipelines

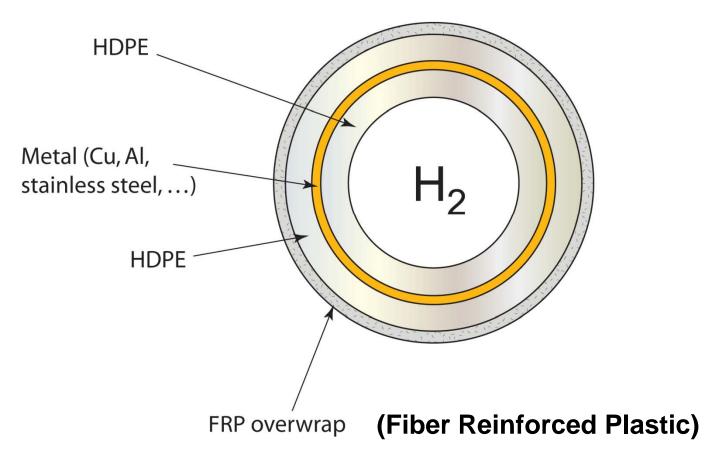
ASME International Pipeline Conference and Exposition, Calgary, AB, Canada, October 02.



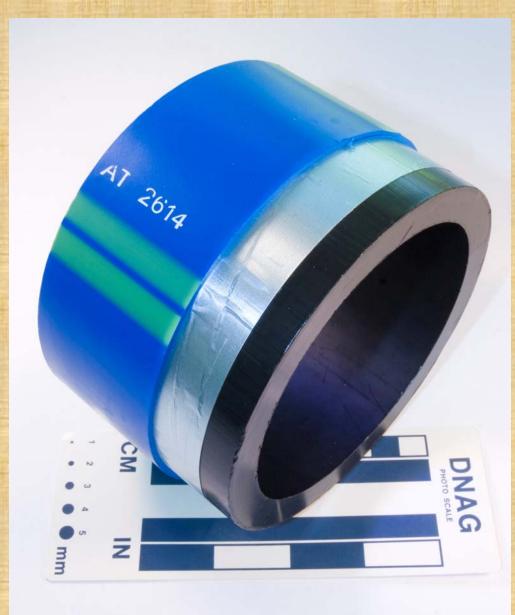
CRLP™ is a trademark of NCF Industries, Inc.

CRLP™ is manufactured under license from NCF Industries, Inc. U.S. and Foreign patents have been issued and are pending.

HDI Polymer - Metal Pipe Technology: Transverse Cross-Section



Polymer - Metal Line Pipe



HDPE +
Al foil
H2 barrier

4" ID

- Hydrogen Discoveries, Inc. (HDI)
- Smart Pipe, Houston

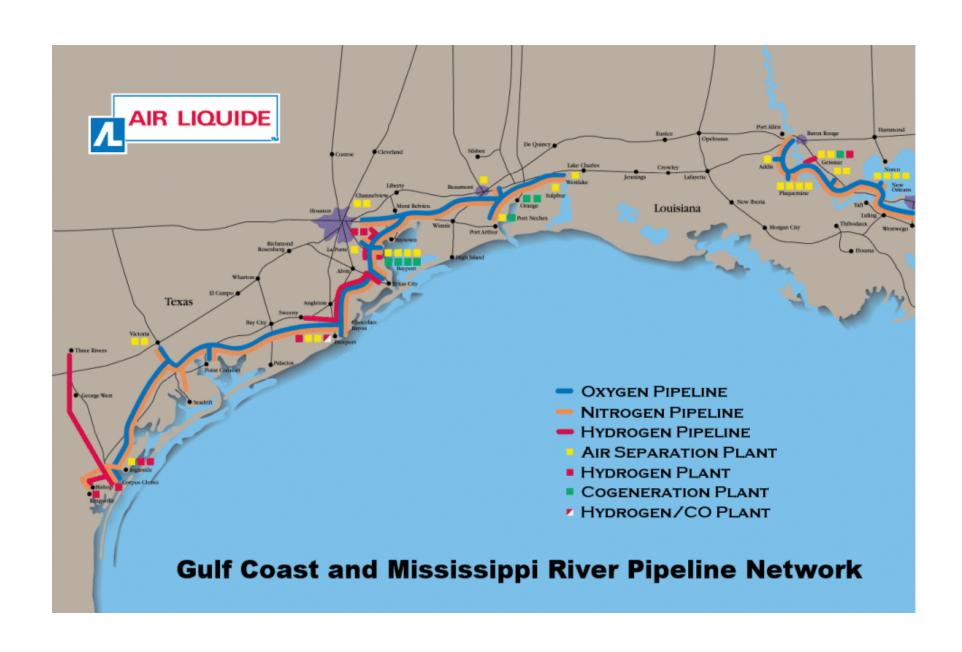






Smart Pipe, Houston

- On-site fab, continuous
- Unlimited length
- FRP (fiber-reinforced plastic)



Air Products Company

REFINERY ACTIVITY
LOS ANGELES BASIN, CALIFORNIA

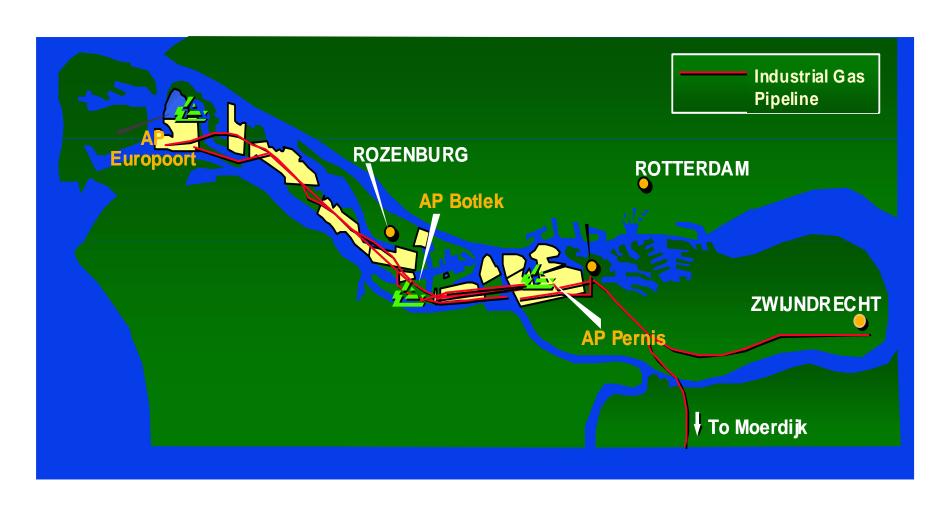


"We know how to pipeline hydrogen" Air Products ~ 10,000 miles of GH2 pipeline, worldwide

Air Products H₂/ CO Pipeline - *Texas Gulf Coast*

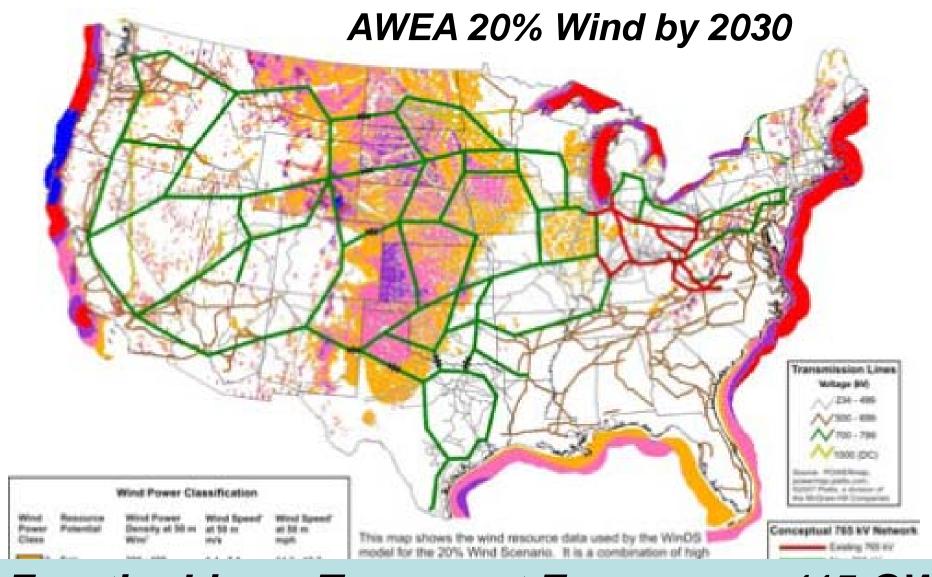


Rotterdam Pipeline System



Industrial Gas H2 Pipelines: avoid HE, HCC

- Low-alloy steel
- Constant pressure
- Low-pressure:
 - -30% SMYS (Spec Min Yield Strength)
 - Natural gas: 80% SMYS
- Short distance
- Industrial corridors

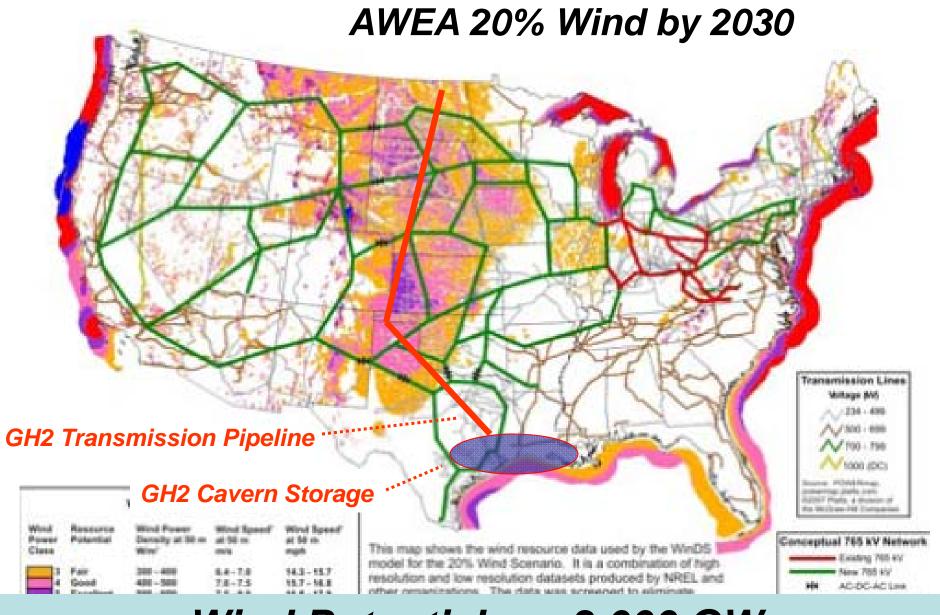


Frontier Line + Transwest Express ~= 115 GW
Wind Potential ~= 3,000 GW



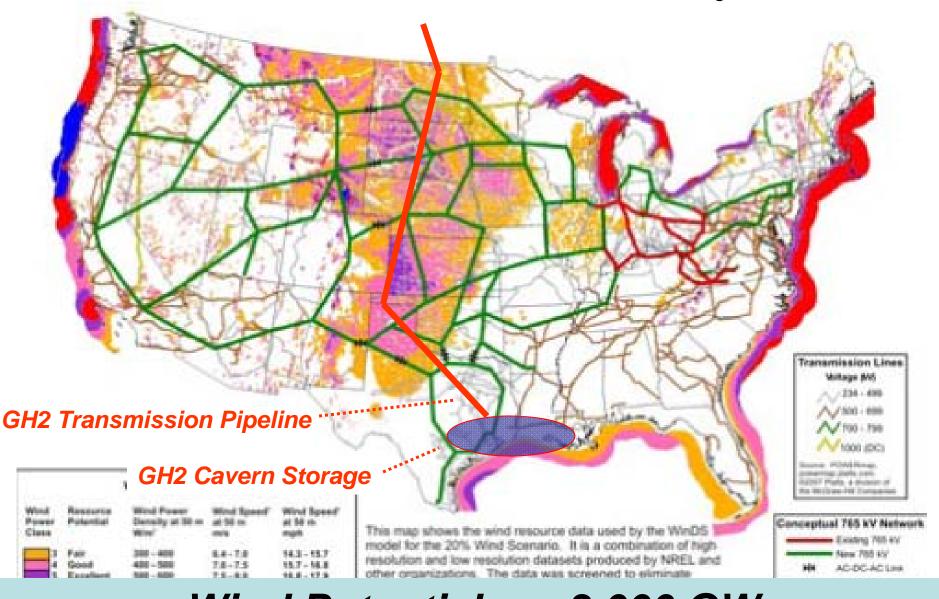
Renewable-source GH2 geologic storage potential.

Candidate formations for solution-mined, salt caverns



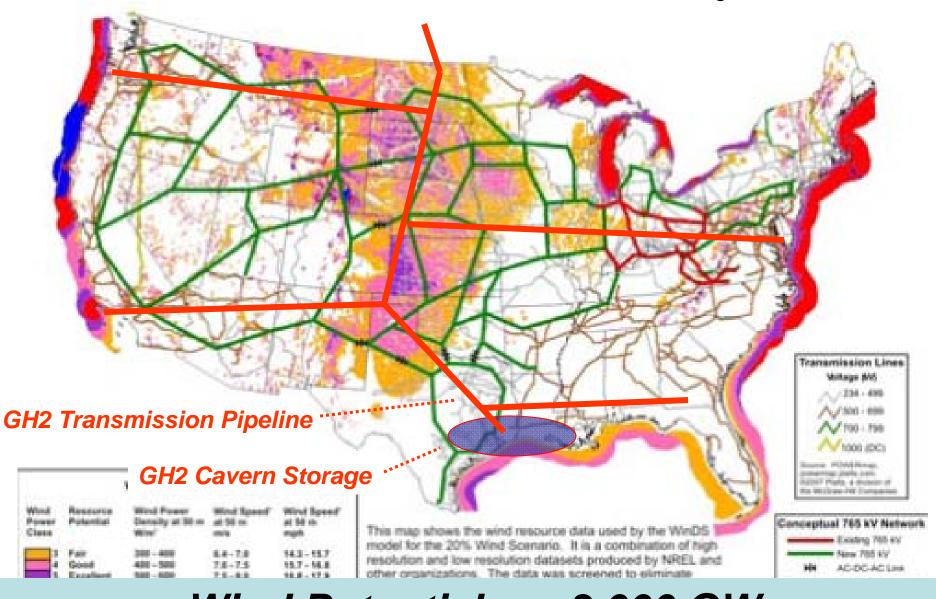
Wind Potential ~= 3,000 GW

AWEA 20% Wind by 2030



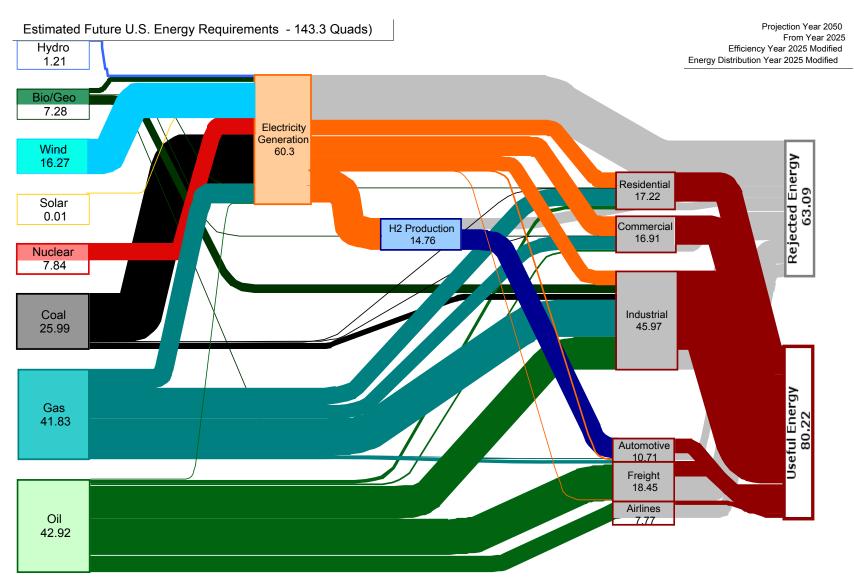
Wind Potential ~= 3,000 GW

AWEA 20% Wind by 2030

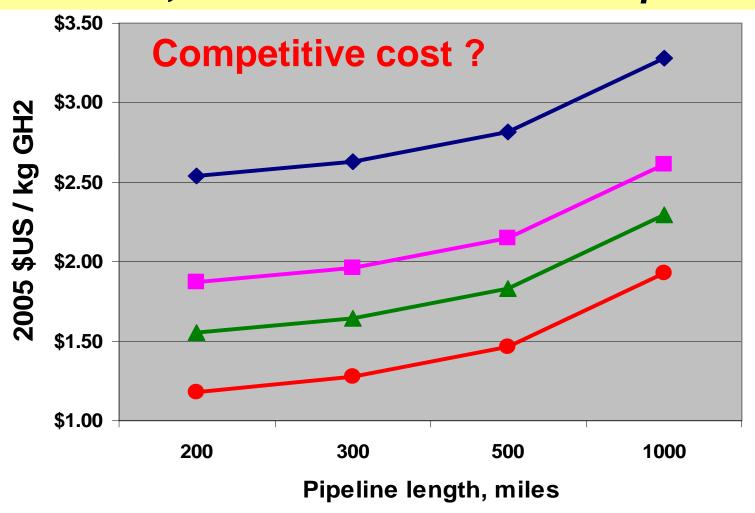


Wind Potential ~= 3,000 GW

Estimated **2050** energy use (H₂ fleet using wind electrolysis)

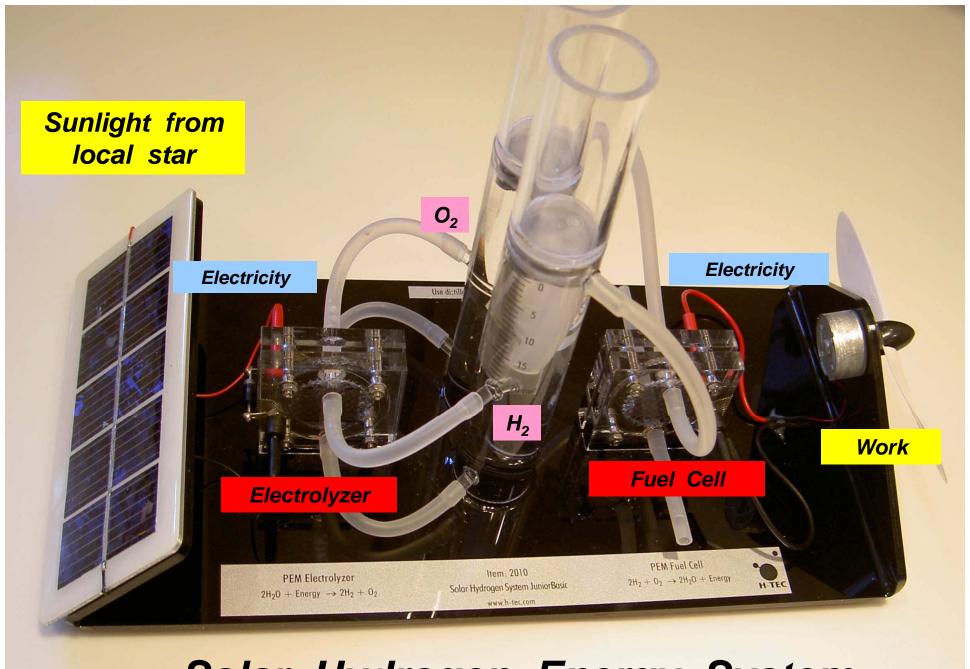


OPTIMISTIC City-gate GH2 cost @ 15% CRF, 20" pipeline, from 2,000 MW Great Plains windplant

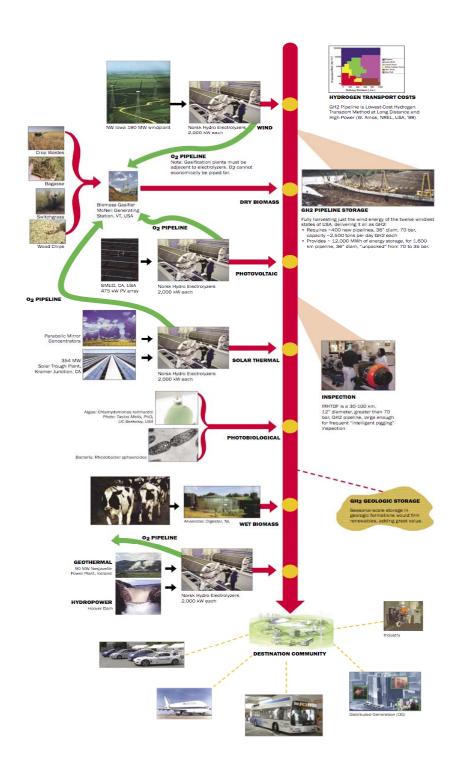


IRHTDF

- Pilot plant: Every new industrial process
- IPHE project ? Global
- Renewables-hydrogen system
 - Generation
 - Conversion
 - Collection
 - Transmission
 - Storage
 - Distribution, end users
 - Synergy: O₂, seasonal

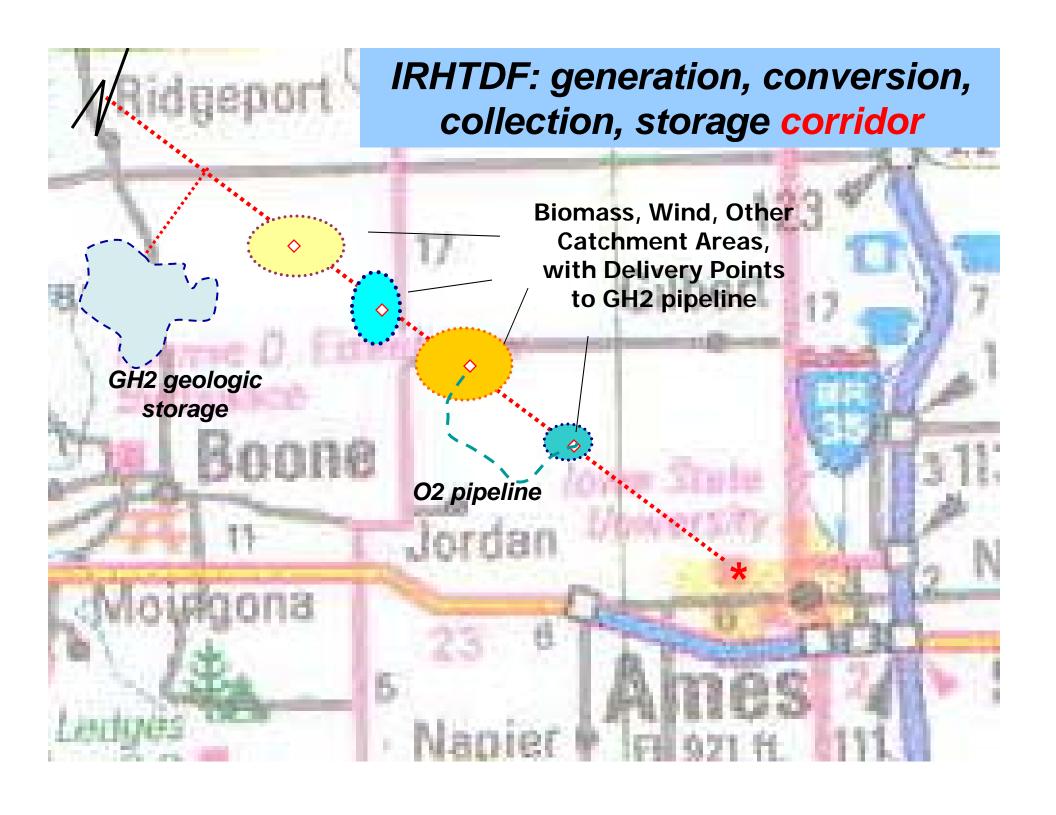


Solar Hydrogen Energy System

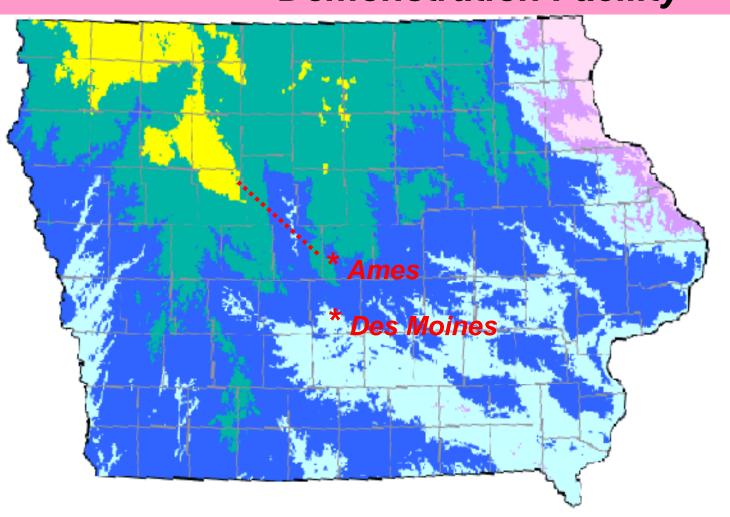


International Renewable Hydrogen Transmission Demonstration Facility (IRHTDF) Pilot plant

Global opportunity: IPHE project



IRHTDF International Renewable Hydrogen Transmission Demonstration Facility



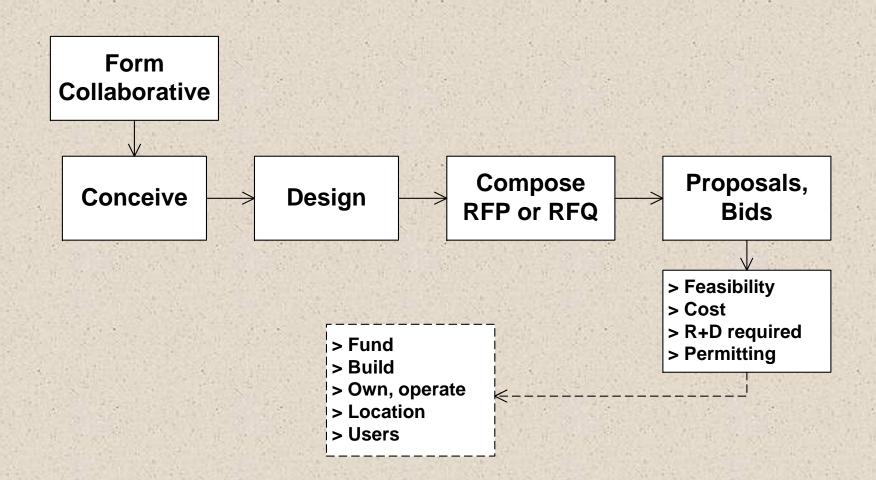
>19.0	>8.5
17.9-19.0	8.0-8.5
16.8-17.9	7.5-8.0
15.7-16.8	7.0-7.5
14.5-15.7	6.5-7.0
13.4-14.5	6.0-6.5
12.3-13.4	5.5-6.0
<12.3	<5.5

Iowa Energy Center

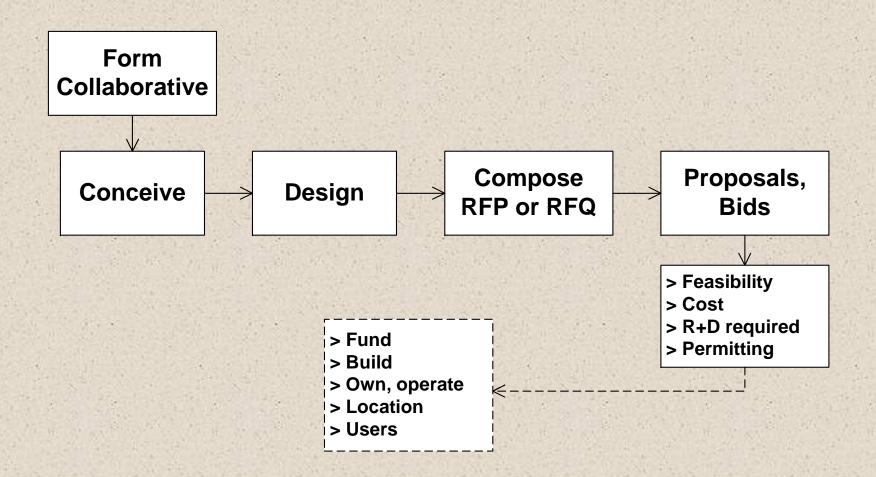
This map was generated from data collected by the Iowa Wind Energy Institute under Iowa Energy Center Grant No. 93-04-02. The map was created using a model developed by Brower & Company, Andover, MA.

Copyright © 1997, Iowa Energy Center. All rights reserved. This map may not be republished without the written consent of the Iowa Energy Center.

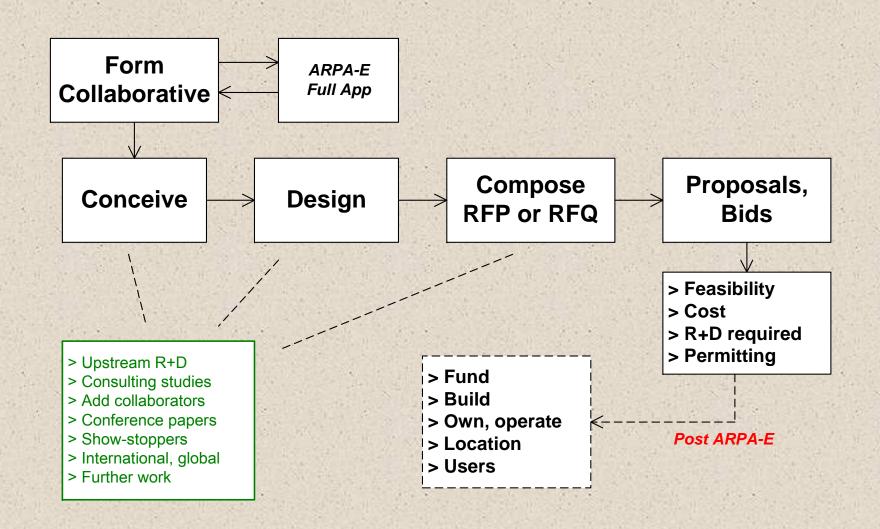
IRHTDF Process



ARPA-E Full Application Process



ARPA-E Full Application Process

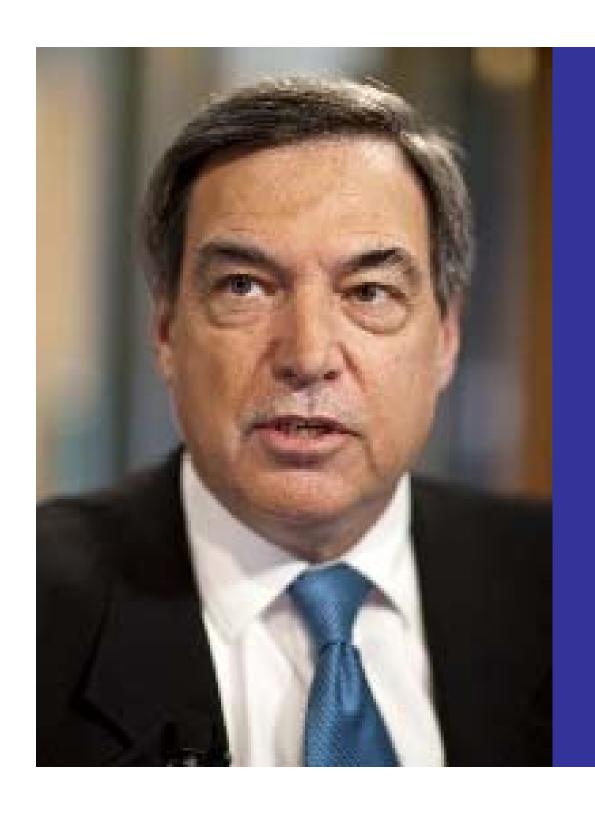


IRHTDF, ARPA-E Outcomes

- 1. Discover and demonstrate:
 - a. Tech + Econ feasibility, advantages RE-H2 systems
 - b. Upstream R+D needed
 - c. Collaborators, funders, users
- 2. Report results to world energy community
 - a. Technology
 - b. Costs, benefits, synergies
 - c. Extrapolate to large-scale
- 3. Encourage investment
 - a. Improve and proliferate renewable energy sources
 - b. Known cost, benefits
 - c. Proven market for H2 fuel
 - d. New NG pipelines as RE-H2-capable
- 4. Model for designing larger RE-H2 systems
- 5. Accelerate C-free global future

Opportunity: Extraordinary; not promising

- Full application to ARPA-E
- Foot in door: 24 May deadline
- Join AASI as co-applicant
- If ARPA-E declines:
 - Collaborative founded
 - Proceed? Resources?



Jon Wellinghof FERC* Chairman

About new coal + nuclear plants:

"We may not need any, ever"

NY Times, 22 Apr 09

* FERC = Federal Energy Regulatory Commission

Opportunity: NOW

- Aside from ARPA-E
- H2 industry back on track
- Begin pipeline pilot plant process
 - Autos Sept 09 memo: Ready in '15
 - Gulf oil disaster
 - Energy GCC bills in Congress
 - Econ recovery



GW-scale Transmission + Storage Options

- Electricity: HVAC, HVDC
 - CAES compressed air energy storage
 - Vanadium Redox battery (VRB Power Systems)
 - Sodium-sulfur battery
 - PHEV (distributed)
- Gaseous Hydrogen (GH2)
 - Pipeline
 - Geologic: salt caverns (man-made)
- Liquid Hydrogen (LH2)
 - Pipeline, truck, rail car, ship
 - 1/3 energy to liquefy Ammonia (NH3) liquid
 - Tank, refrigerated, 10K 60K ton
- Liquid ammonia, NH3: steel tanks
- Liquid synthetic HC's zero net C
 - Pipeline, tank, truck, rail car, ship
 - Geologic: salt caverns (man made)
- "Energy Pipeline", EPRI: LH2 in pipeline, SC LVDC electric
- Chemicals
 - Hydrides
 - AI Ga ← → Alumina