Running the World on Renewables

Energy Expo, IRENEW
UNI, CEEE, Cedar Falls, IA
13 Sept 08

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The Leighty Foundation
Juneau, AK
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1958: NE Iowa Science Fair, SCI, 9th grade

1961

12th grade

NE Iowa

Science

Fair

SCI

Collins Radio

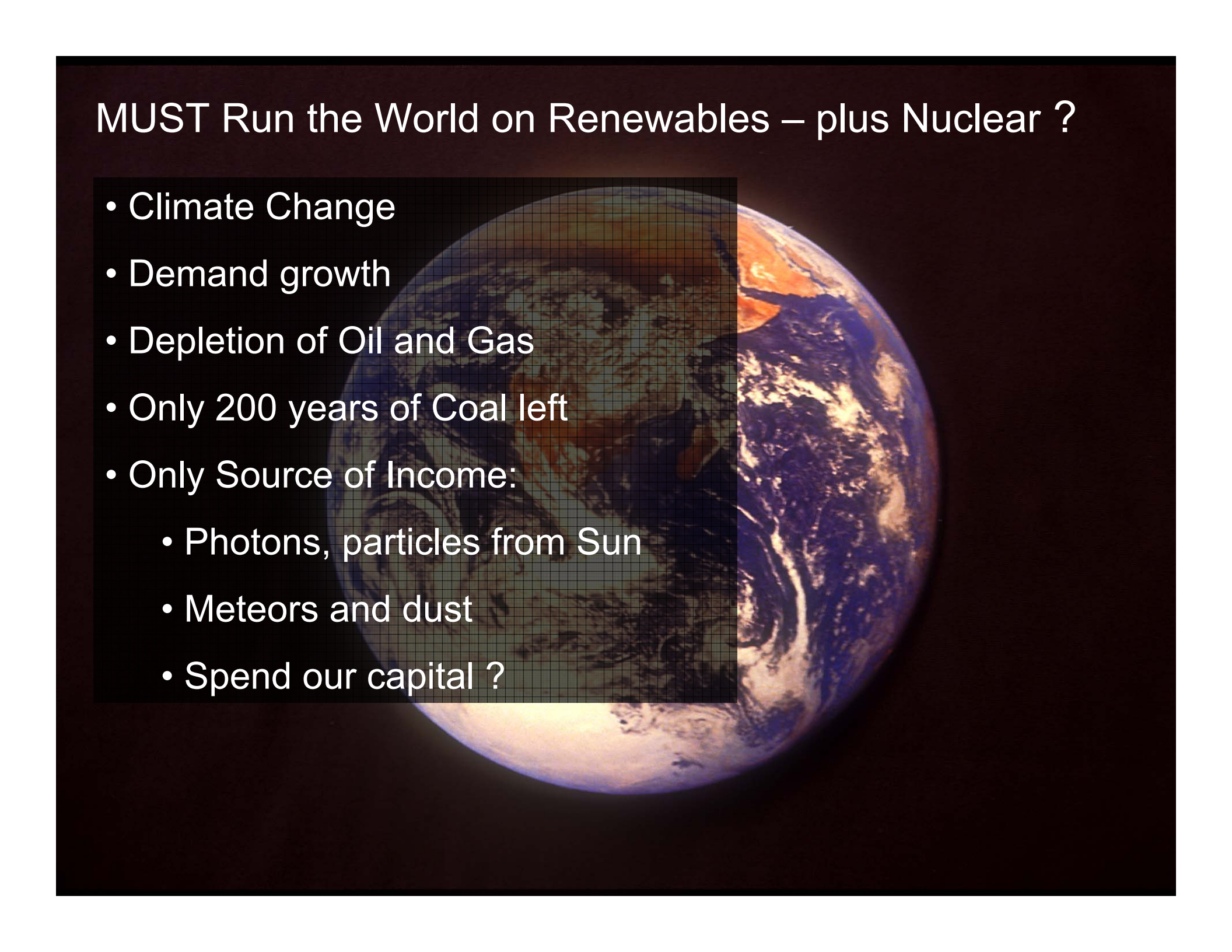
Field Engineer

Vietnam

’68

MUST Run the World on Renewables – plus Nuclear ?

MUST Run the World on Renewables – plus Nuclear ?

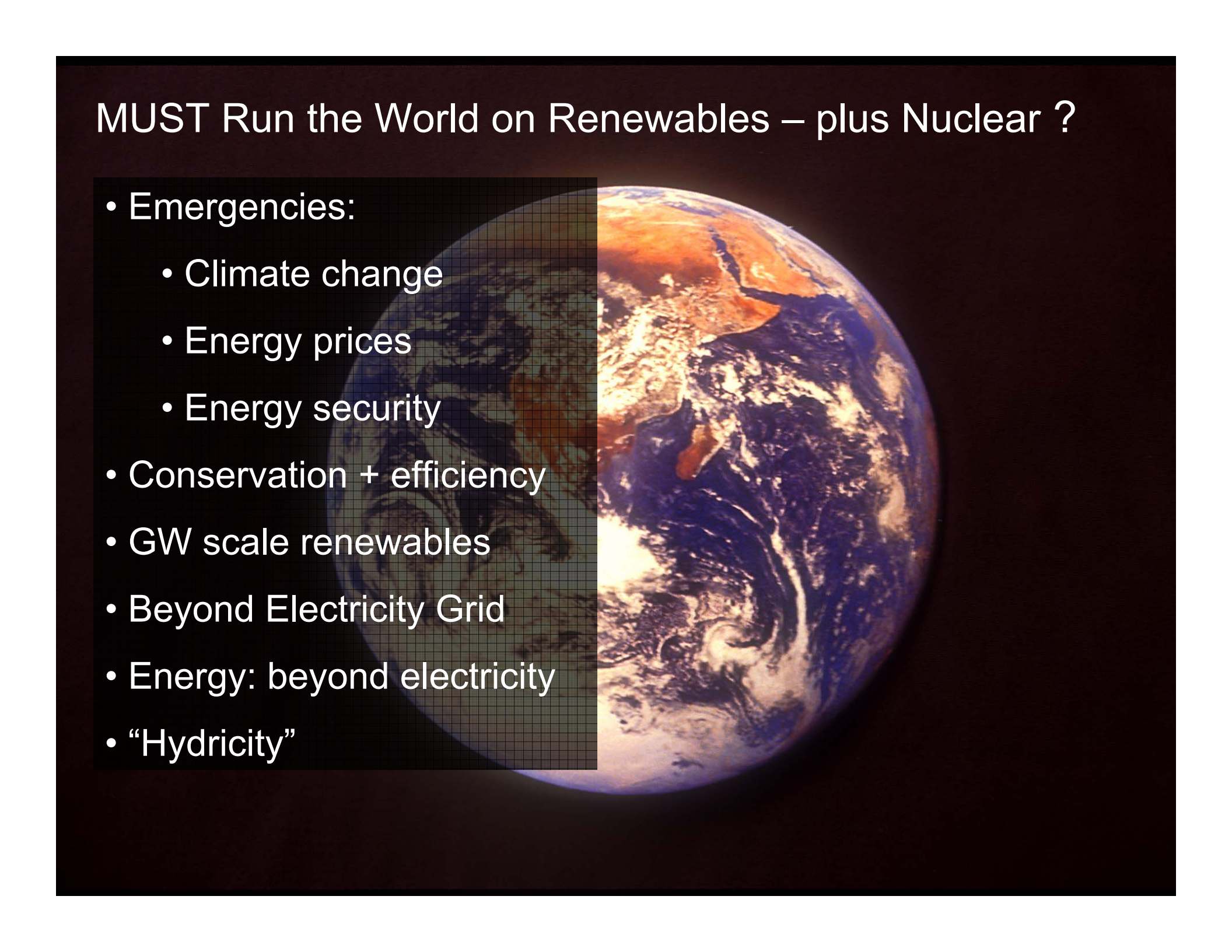


- Climate Change
- Demand growth
- Depletion of Oil and Gas
- Only 200 years of Coal left
- Only Source of Income:
  - Photons, particles from Sun
  - Meteors and dust
  - Spend our capital ?

Earth's only source of income: Solar radiation, dust

MUST Run the World on Renewables – plus Nuclear ?

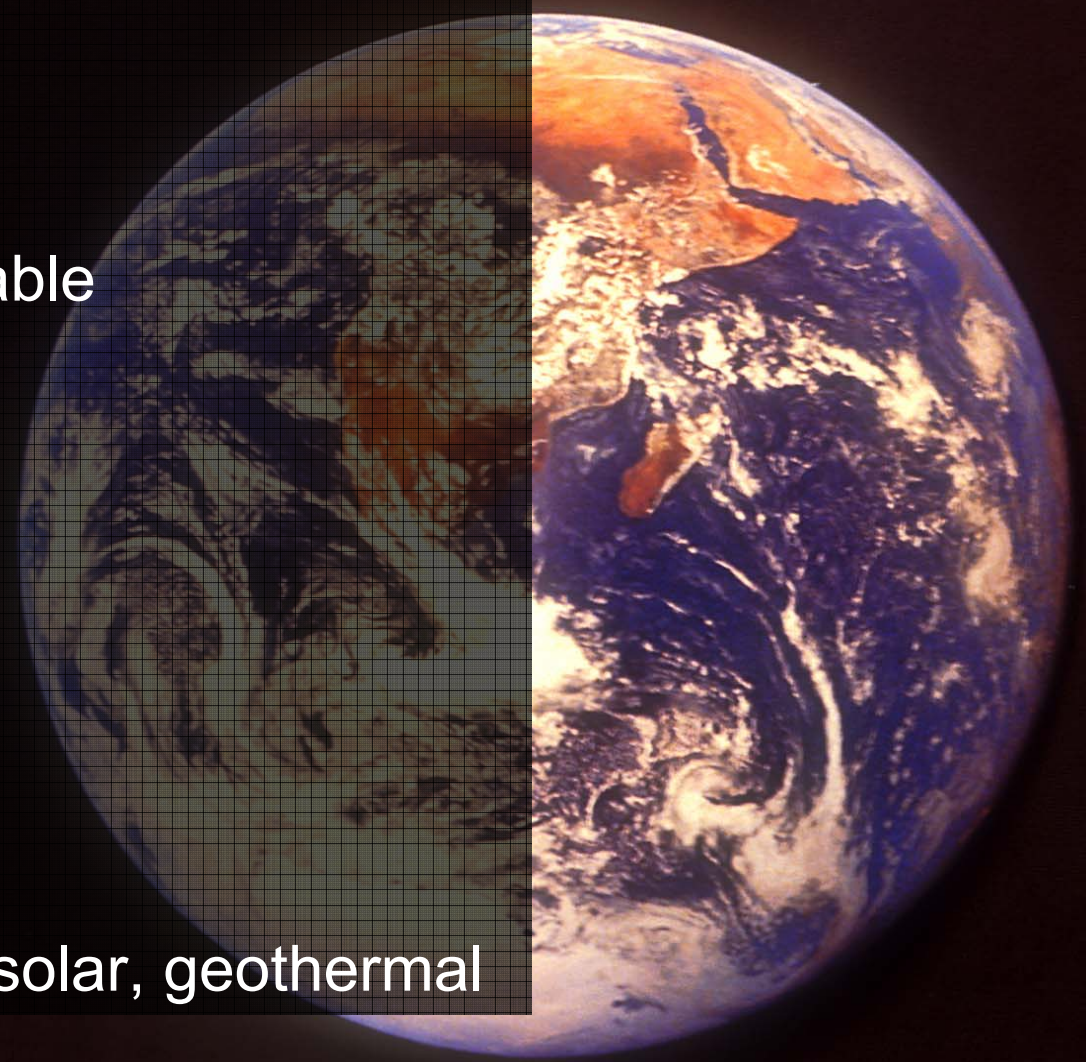
- Emergencies:
  - Climate change
  - Energy prices
  - Energy security
- Conservation + efficiency
- GW scale renewables
- Beyond Electricity Grid
- Energy: beyond electricity
- “Hydricity”




Mendenhall Glacier
Juneau, Alaska 2005

MUST Run the World on Renewables – plus Nuclear ?

- Global
- Indigenous
- Firm: available
- C-free
- Benign
- Abundant
- Affordable
- Equitable
- Perpetual: solar, geothermal

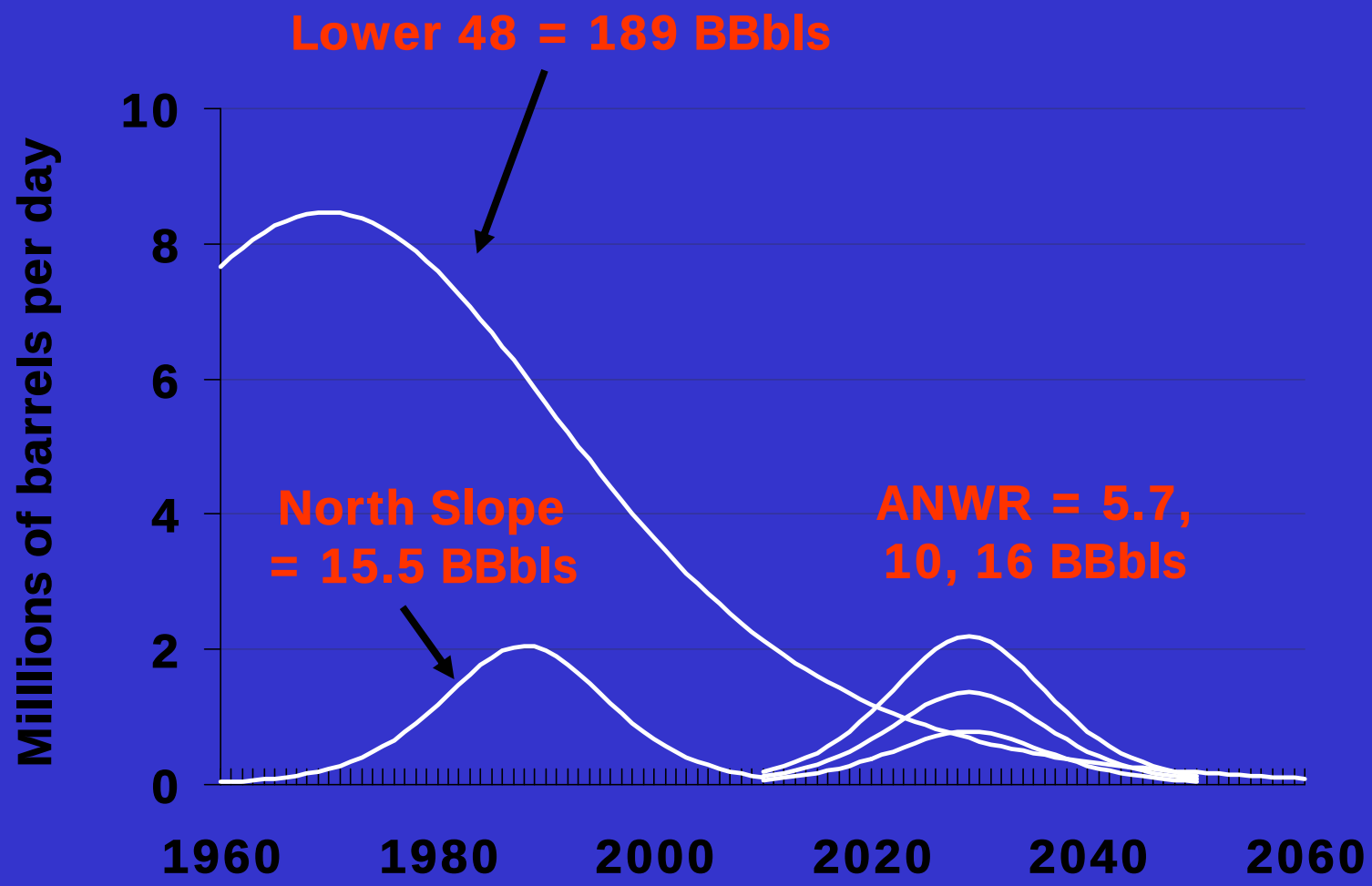


Titusville, PA

1859

First oil well in USA

US total crude oil production



Arctic National Wildlife Refuge (ANWR)

* 1002 Area

Proposed ANS* Gas Pipeline

"ALCAN" Alaska Highway Route

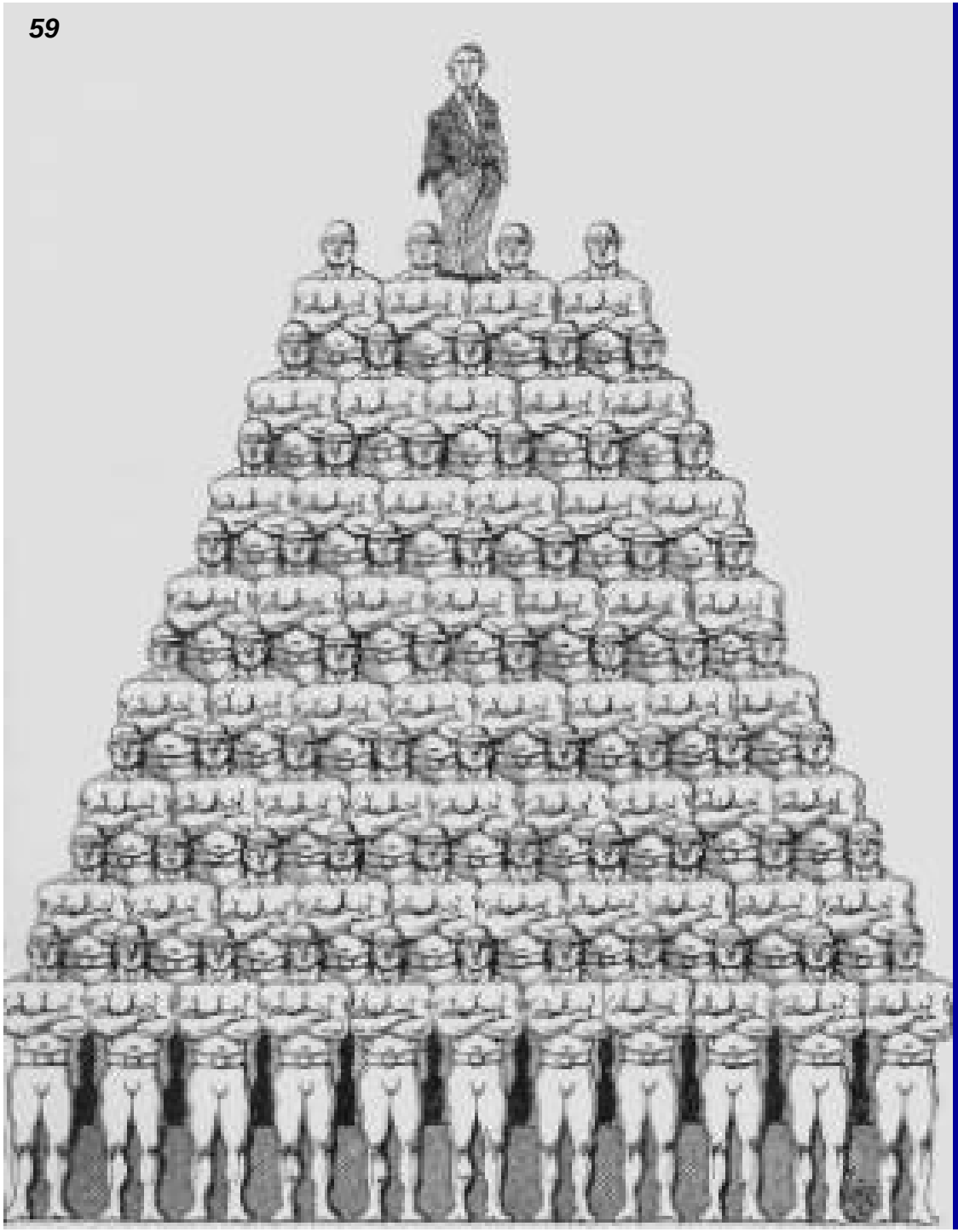
TransCanada Pipelines

* Alaska North Slope

"America is addicted to oil."

Jan 31, 2006, State of the Union, Pres. Bush

Humanity is addicted to energy



Energy Slaves

Lance Armstrong

2002

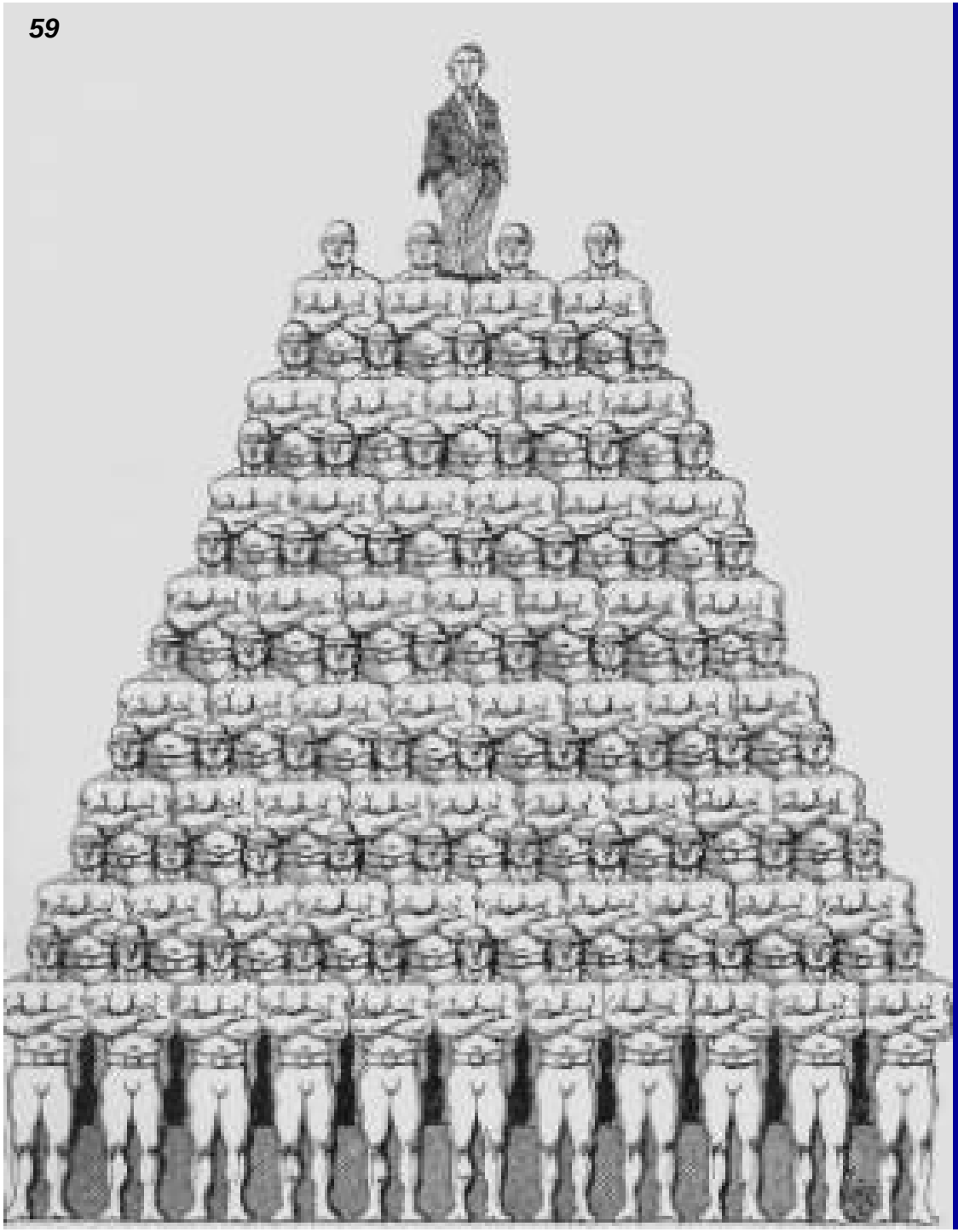
Peak 500 Watts

Average 250 Watts

3 kWh per day

(12 hour day)

746 Watts = 1 hp



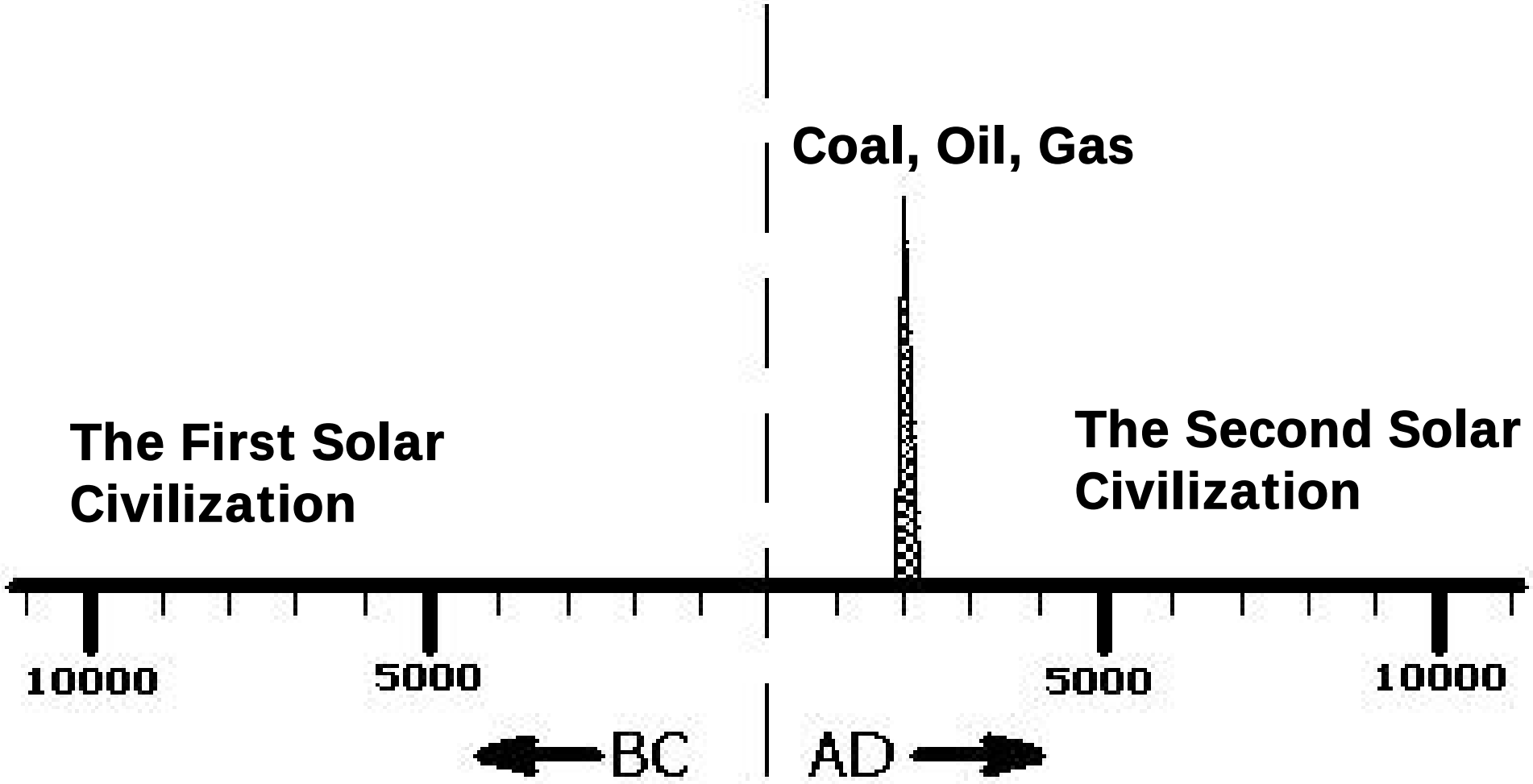
Energy Slaves

USA:

35 Lance Armstrongs per person

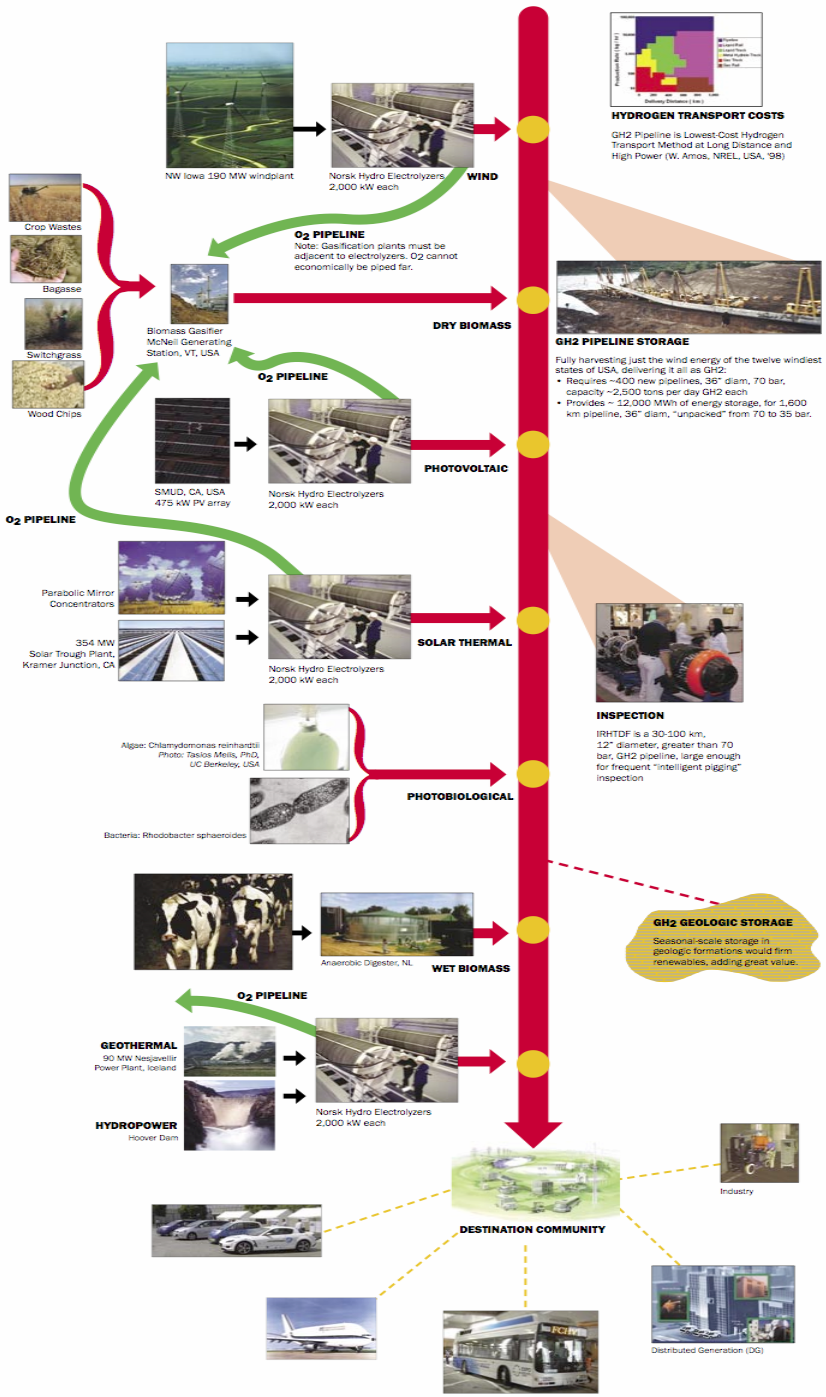
24 / 7

The Fossil Fuel Age: a "Blink of an Eye" between the First and Second Solar Civilizations



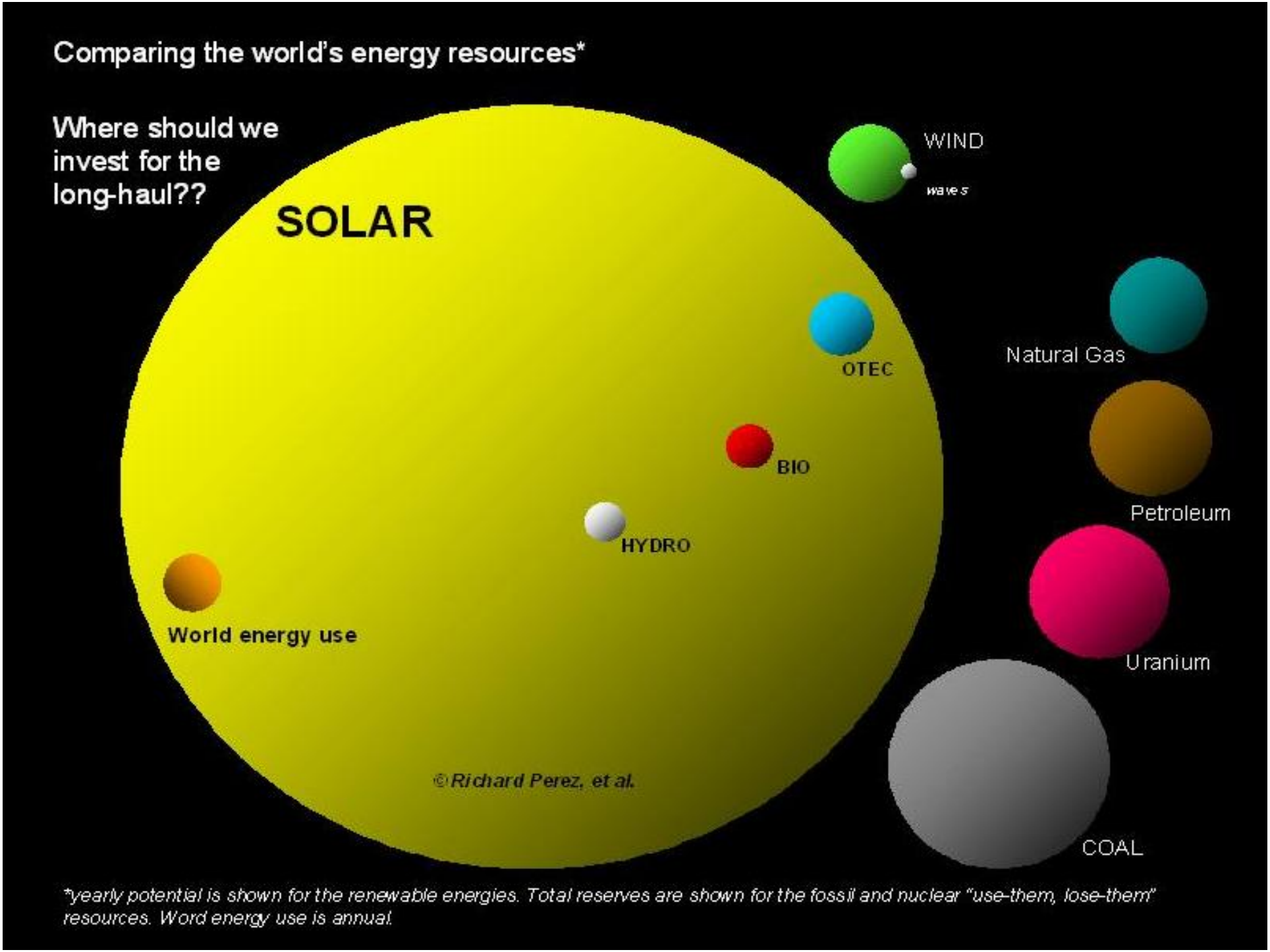
The First Solar Civilization

One-fourth of farm's solar energy harvest goes to the draft animals



The Second Solar Civilization

- Diverse
- Benign
- Renewable
- Remote
  - Electricity
  - Hydrogen


Comparing the world's energy resources*
Where should we invest for the long-haul??
SOLAR
WIND
waves
OTEC
BIO
HYDRO
World energy use
Natural Gas
Petroleum
Uranium
COAL
© Richard Perez, et al.
*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.


Running the World
on Renewables

Watch our language !

"Run"

6. To move freely and without restraint
8. To take part in a race or contest
12. To ply between places
19. **To operate or function**
35. **To perform or accomplish**
46. To operate or drive
50. To manage or conduct

…

67.

1: Adequate Renewables

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

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
- Large, new energy supplies:
  - CO_2 – 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
- Pilot plants needed:
  - Every major new industrial process
  - ’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"
  - 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**
- **Posters: Japan, Canada, IPHE**

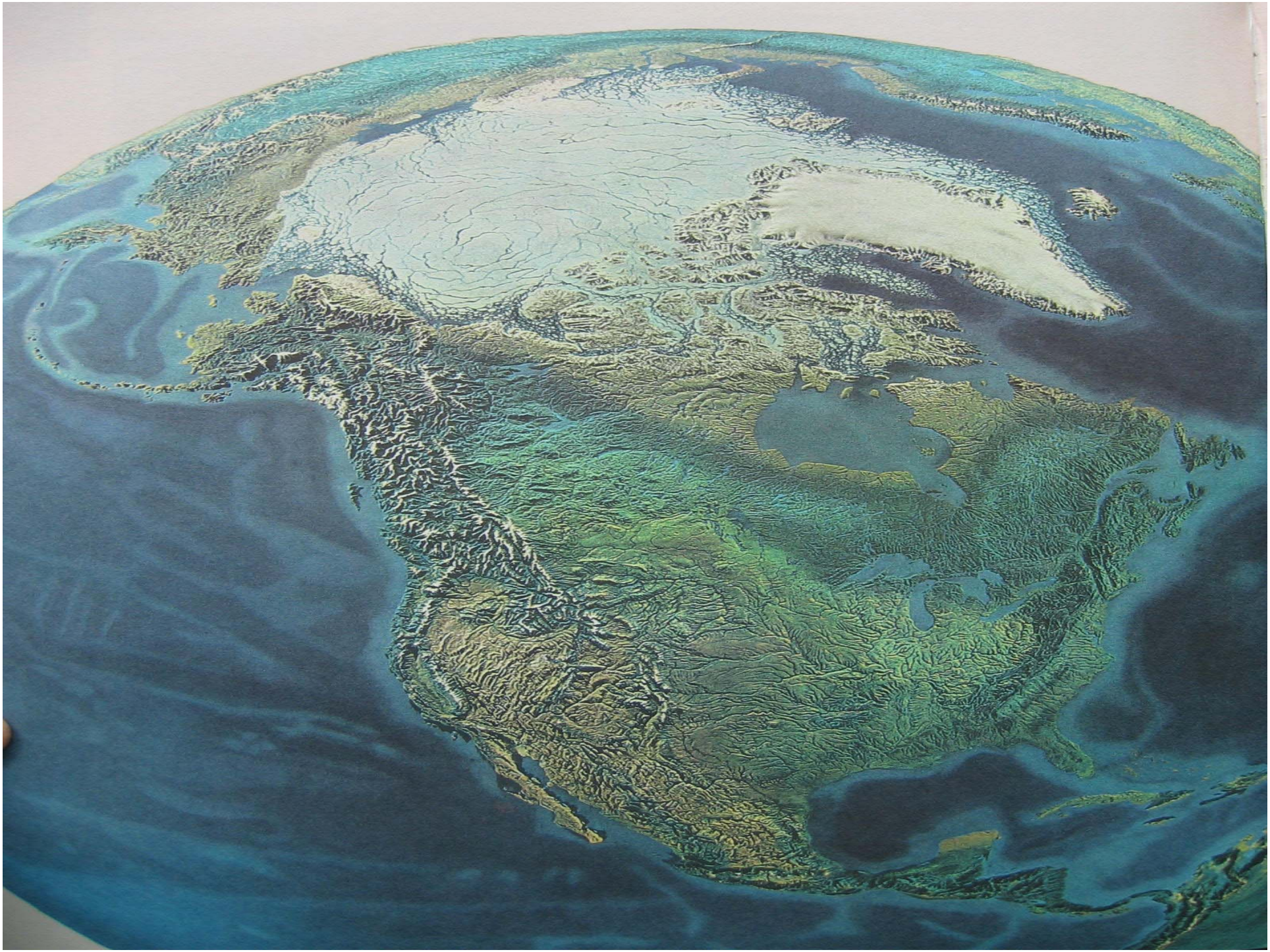
Focus

- **All energy – beyond electricity**
- **Centralized**
- **Diverse renewables**
- **GW scale (1,000 MW)**
- **“Firm” at seasonal-scale**
- **Five hypotheses**

1: Adequate Renewables

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

Global Opportunity



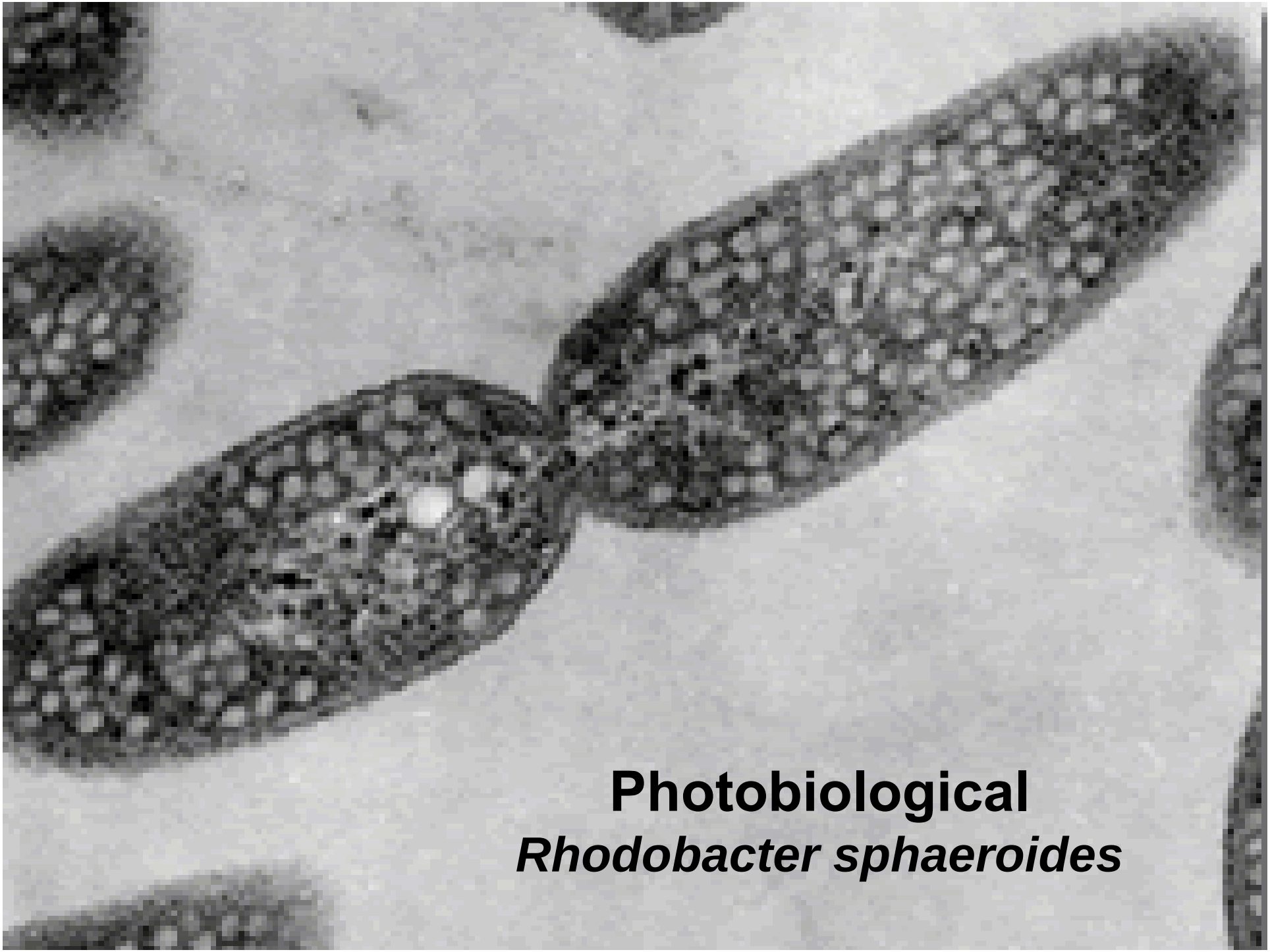

Wind
Powering
America
Diverse !
NW Iowa 190 MW windplant

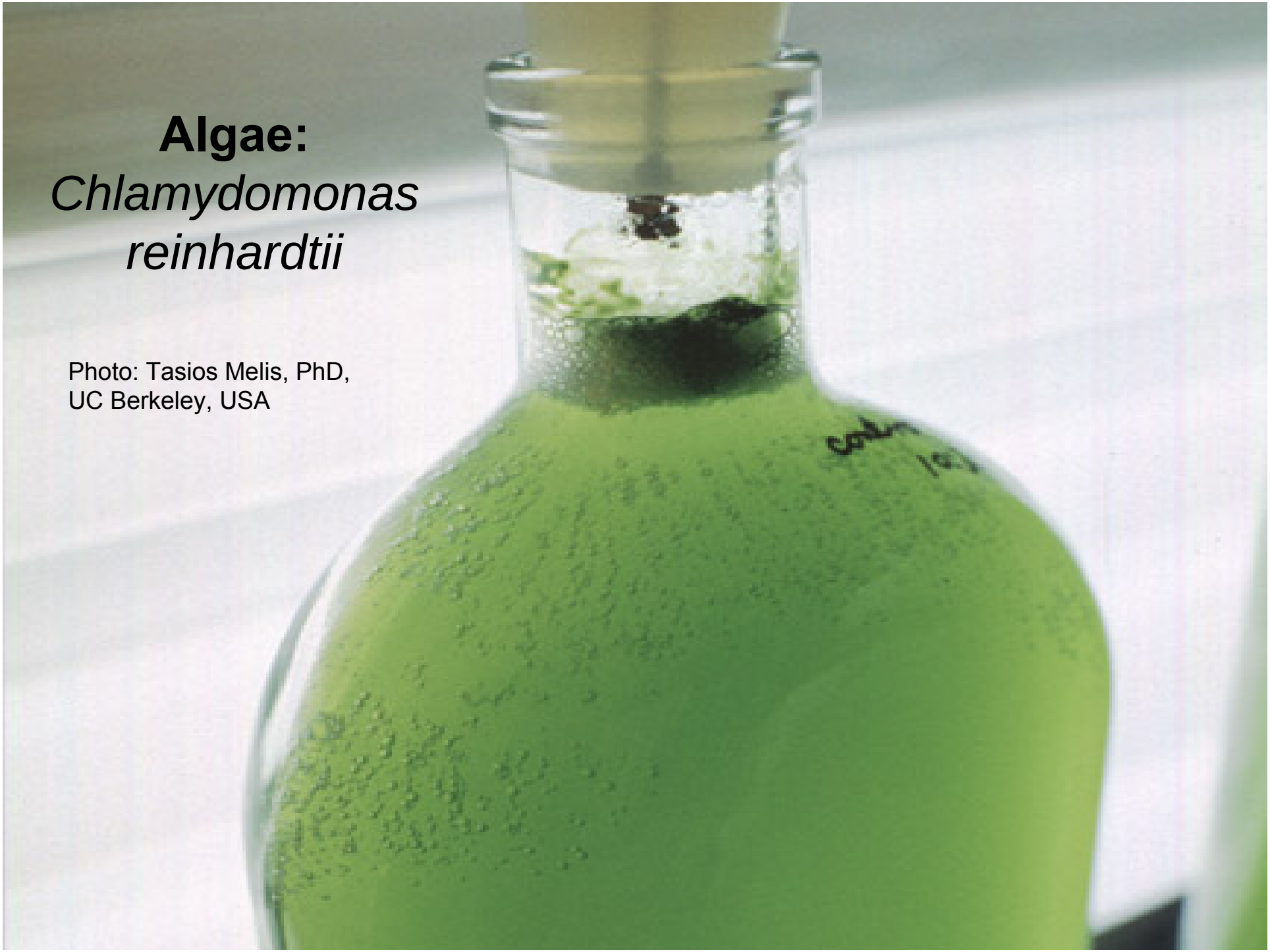
Hydro

Hoover Dam

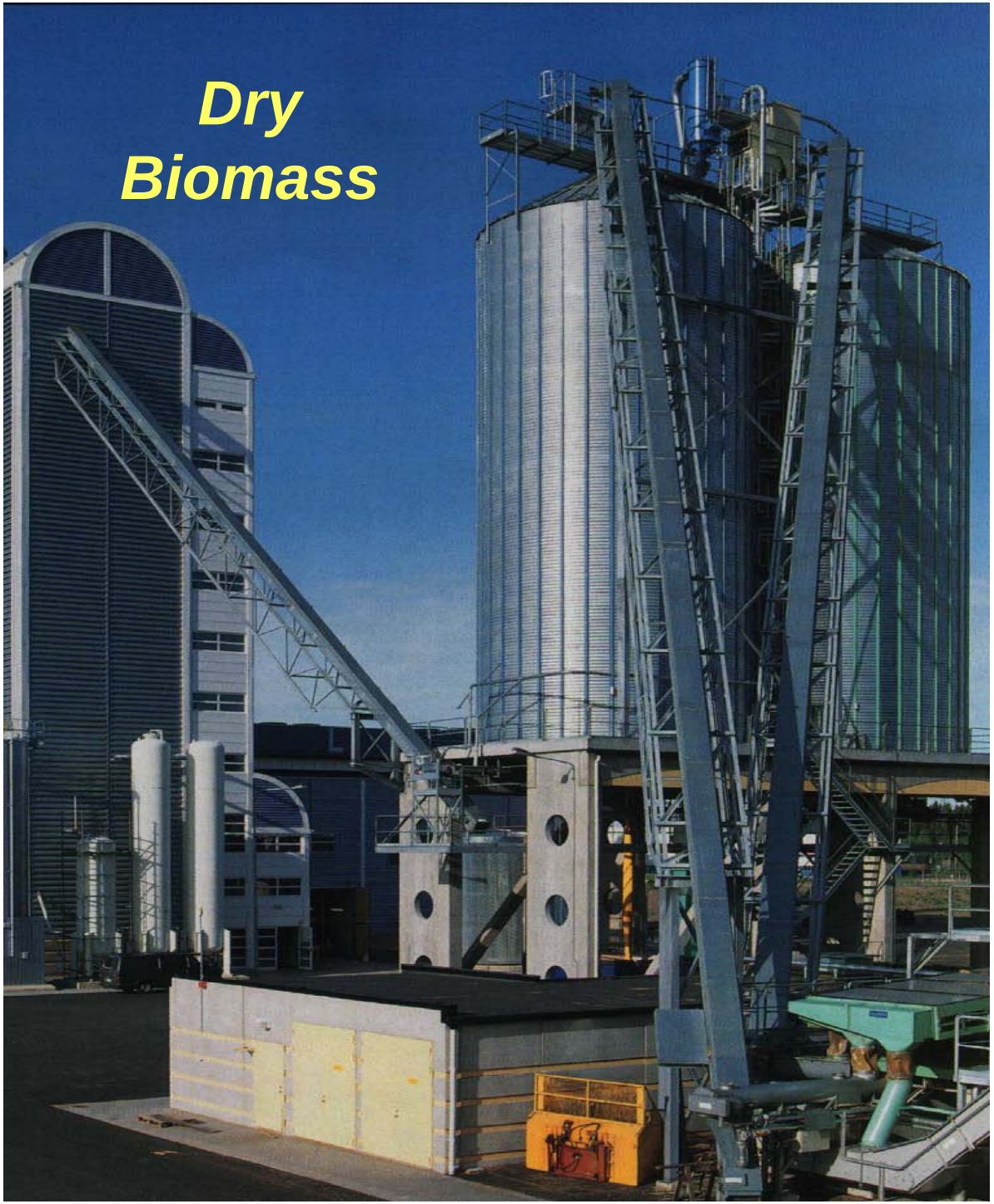
Geothermal:

Nesjavellir Power Plant, Iceland; 90 MW

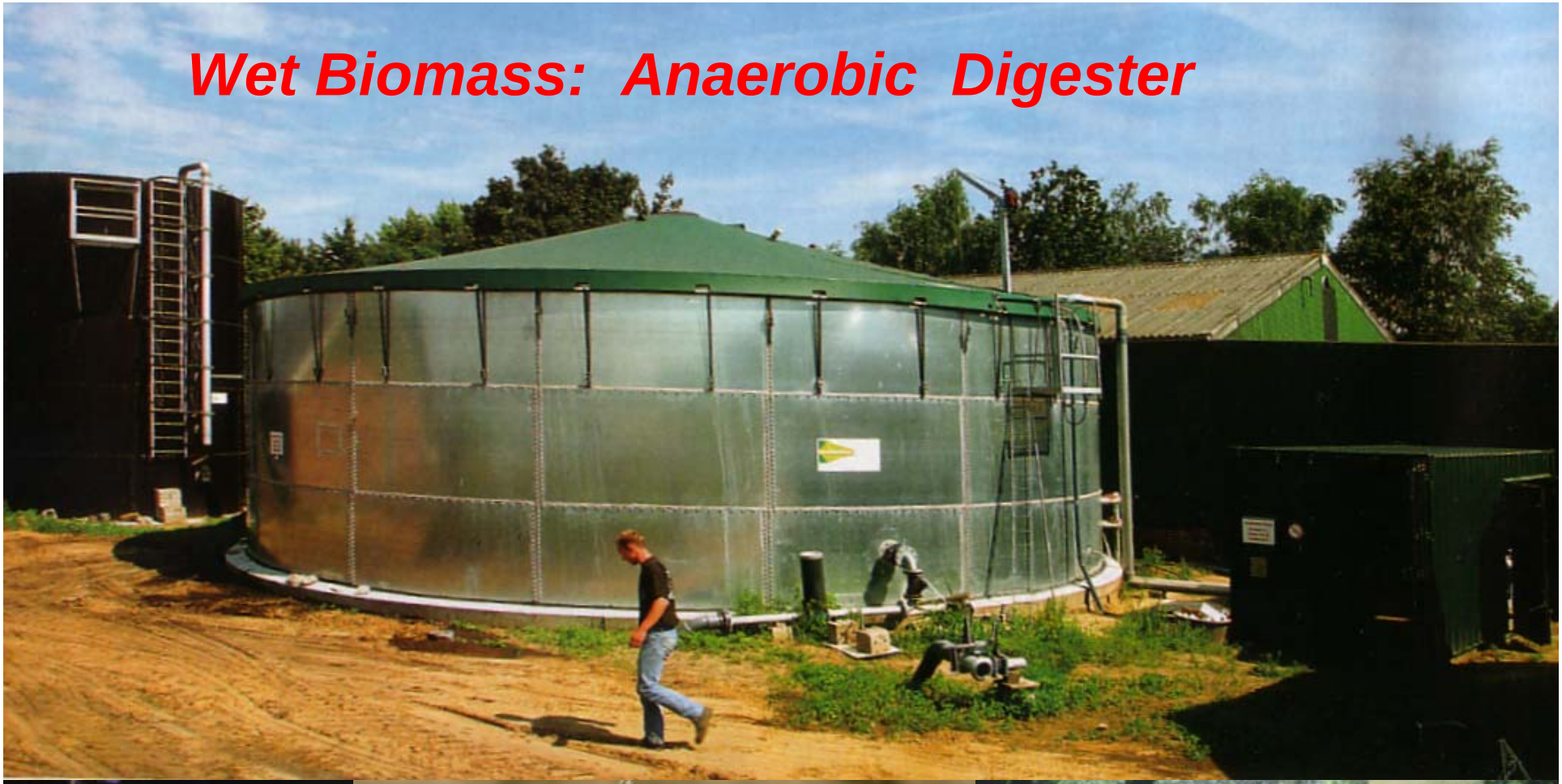

Photobiological
Rhodobacter sphaeroides

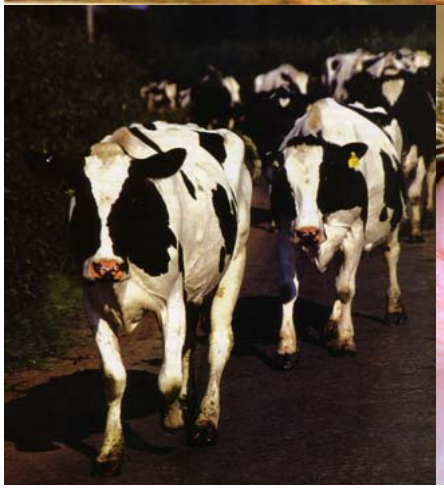

Algae:
Chlamydomonas reinhardtii
Photo: Tasios Melis, PhD,
UC Berkeley, USA

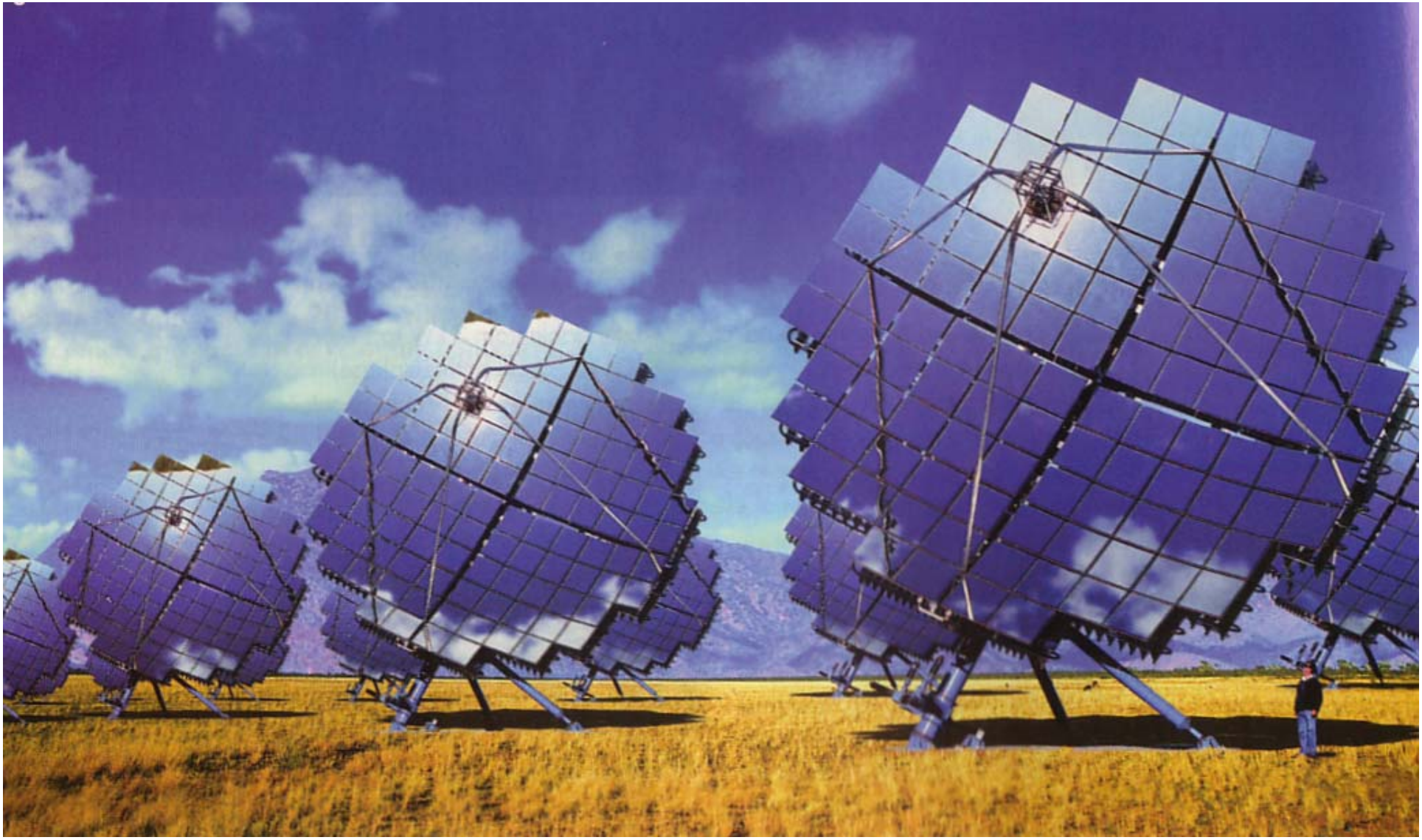
Dry Biomass



Wet Biomass: Anaerobic Digester







Solar thermal

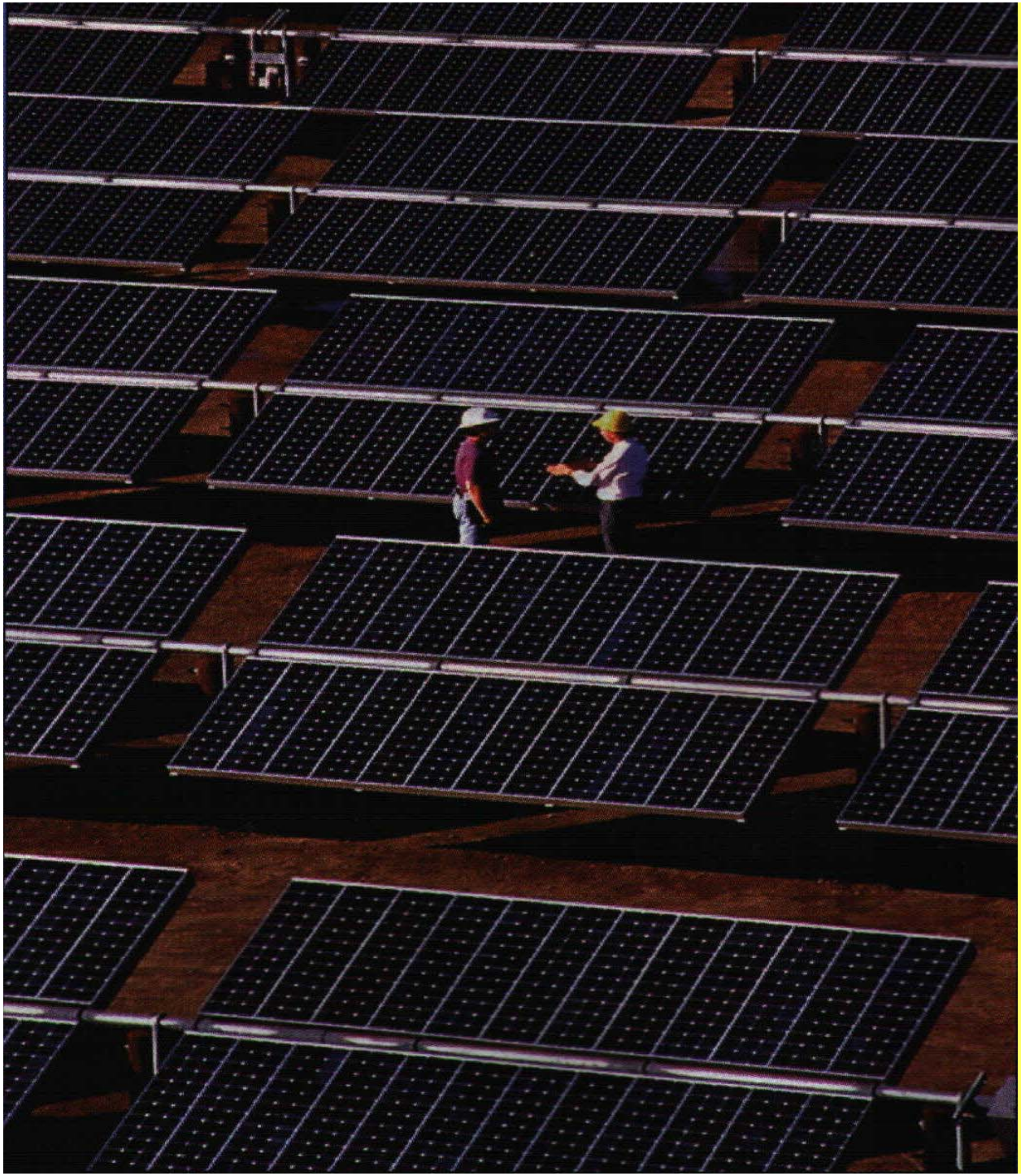
Stirling Energy Systems, Inc.

Model solar thermal power plant, NM Completed May 05

Parabolic Trough

Concentrating Solar Power (CSP)

CA, Spain



Photovoltaic

(PV)

Small

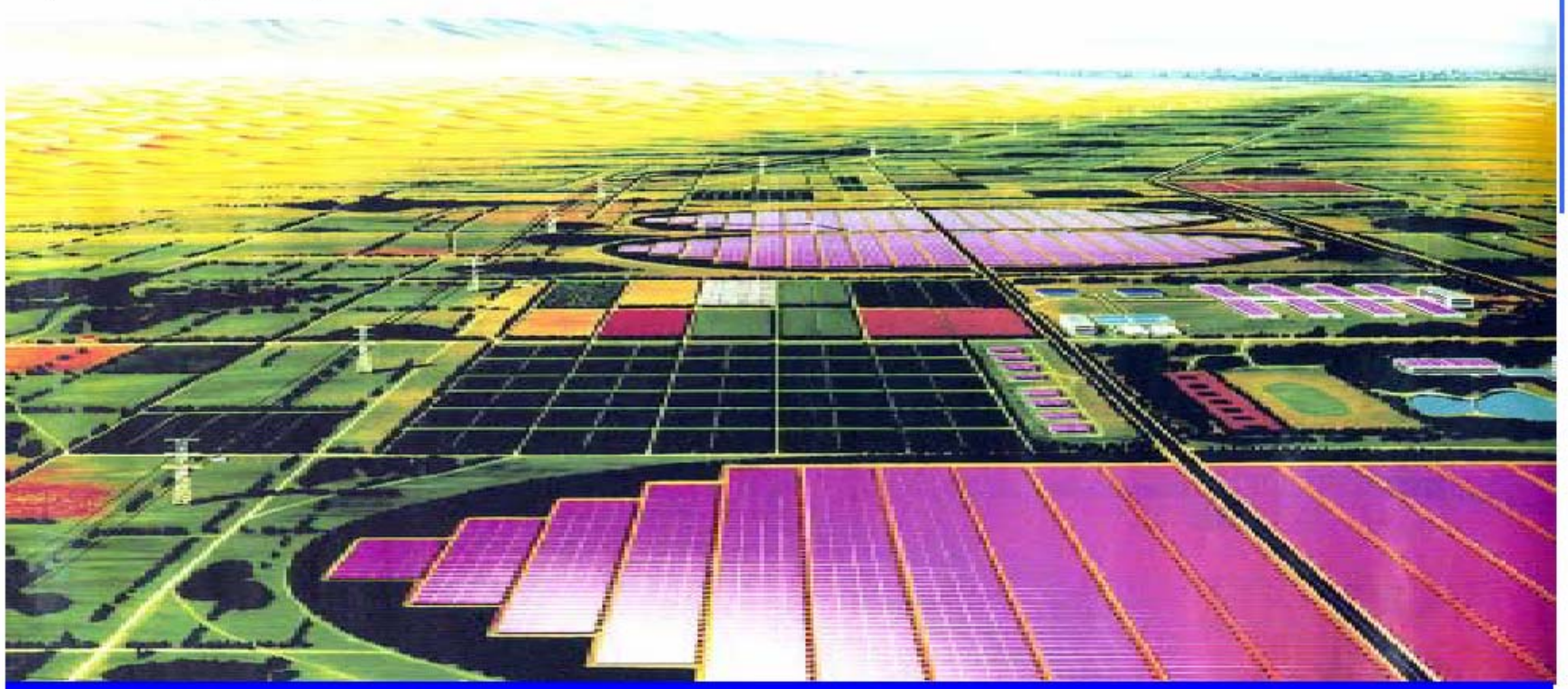
Medium

Large

Example: Vision of a bright future

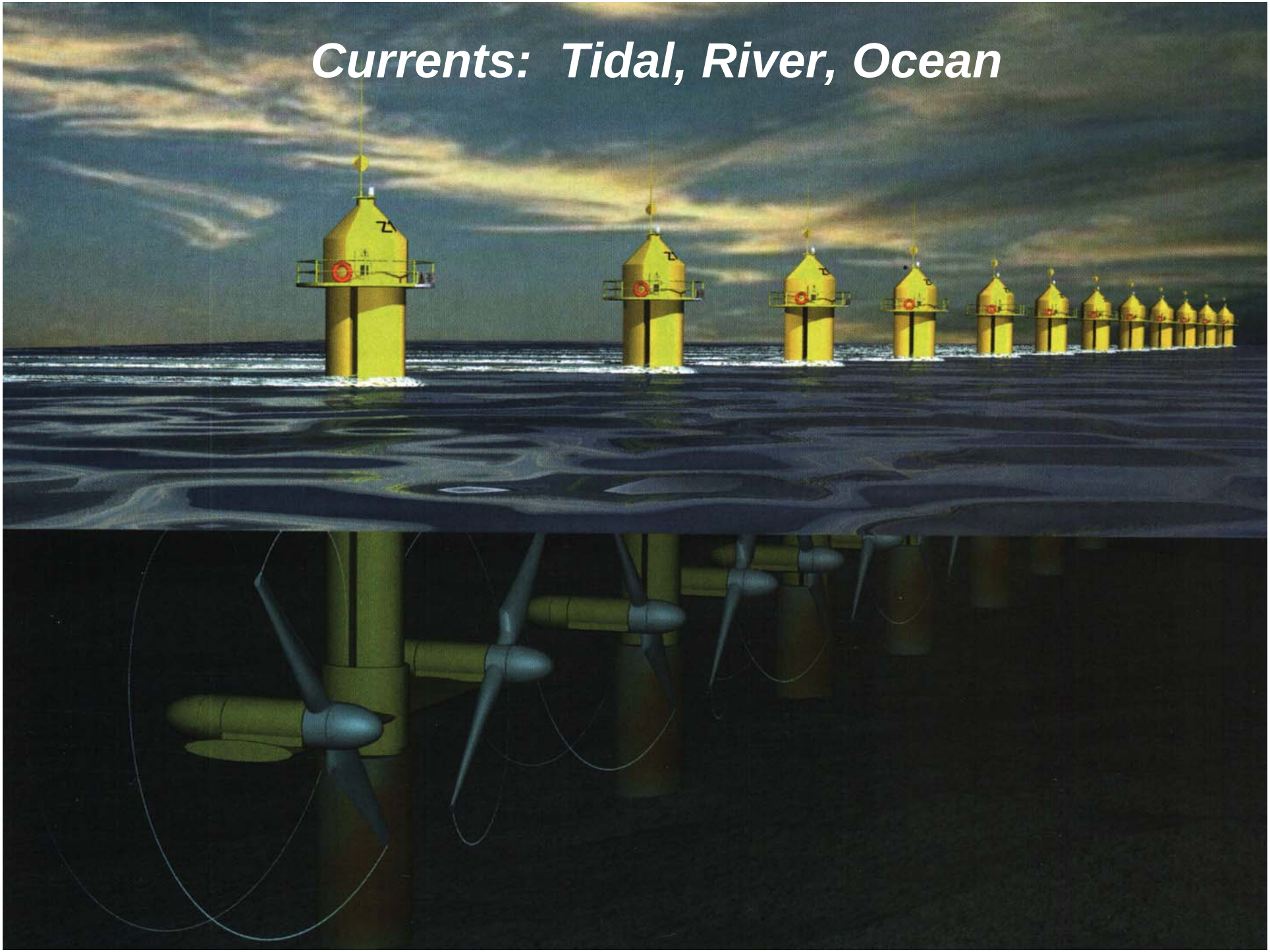
*The Silk Road Genesis Project**

**proposed by Sanyo*



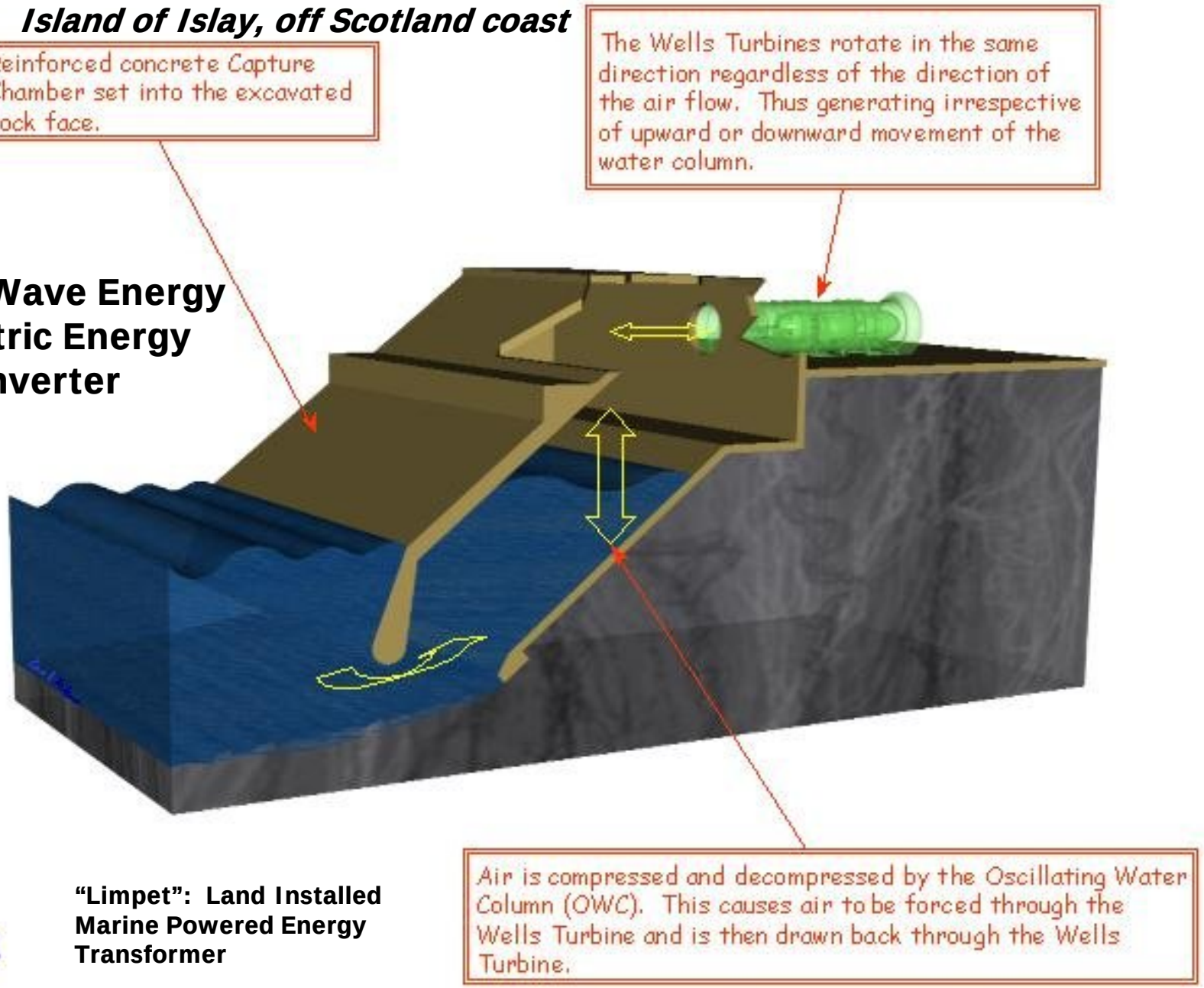
Vision of solar farms in China along the historic silk road to cover $^{1}/_{3}$ of China's energy demand in 2030

Currents: Tidal, River, Ocean



"LIMPET", Island of Islay, off Scotland coast

500 kW Wave Energy to Electric Energy Converter



UK

Wavegen

"Limpet": Land Installed Marine Powered Energy Transformer

pelamis wave power

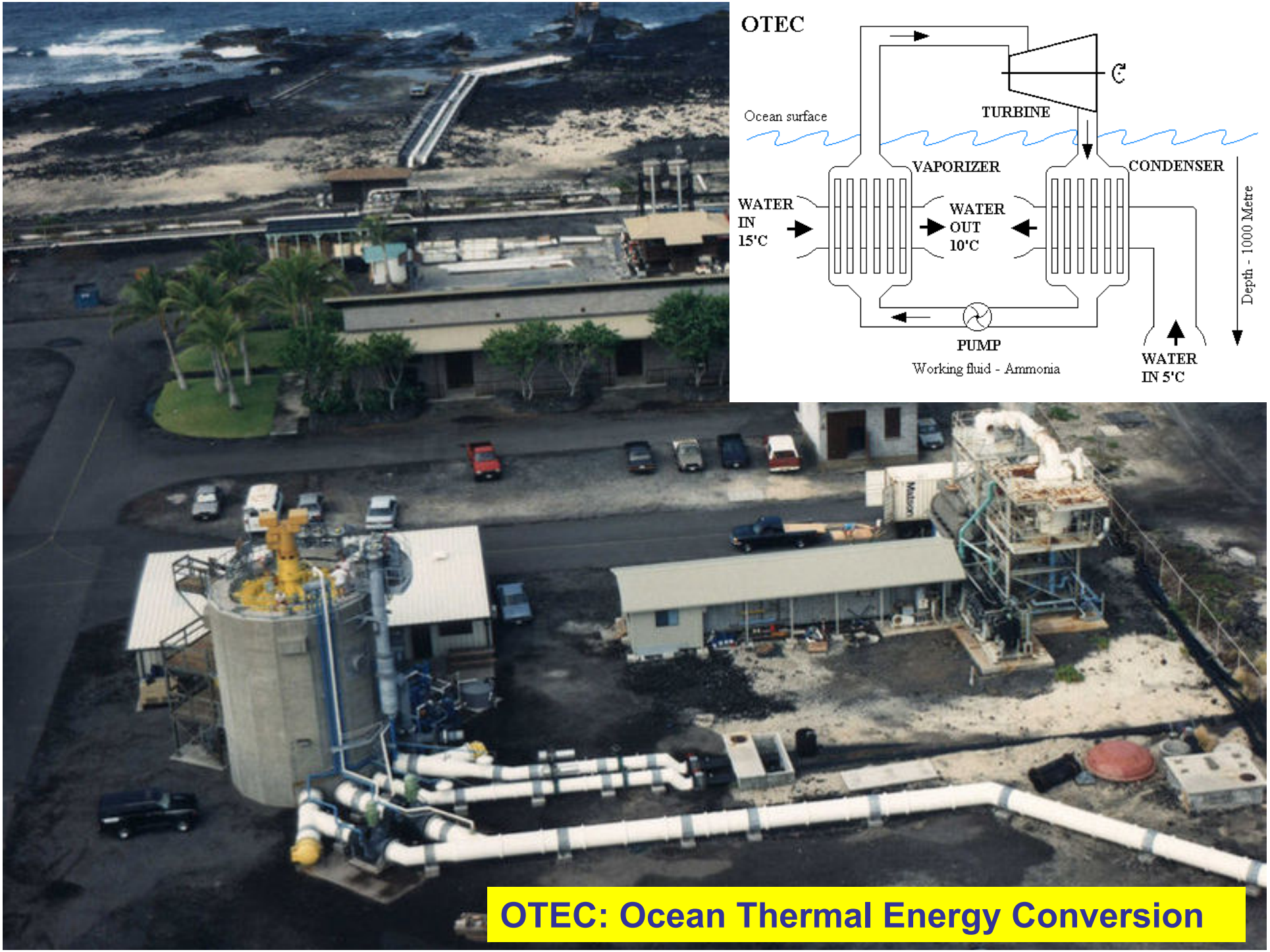




Pelamis Wave Power is the new name for Ocean Power Delivery. A new Pelamis Wave Power website is coming soon but if you would like to visit the Ocean Power Delivery site in the meantime please follow the link below.

FURTHER INFORMATION | OCEAN POWER DELIVERY

Pelamis Wave Power Ltd . 104 Commercial Street . Edinburgh . EH6 6NF . Scotland . T: +44 (0)131 554 8444 . F: +44 (0)131 554 8544 . E: enquiries@pelamiswave.com


OTEC
Ocean surface
TURBINE
VAPORIZER
CONDENSER
WATER IN 15'C
WATER OUT 10'C
Depth - 1000 Metre
PUMP
Working fluid - Ammonia
WATER IN 5'C
OTEC: Ocean Thermal Energy Conversion


The Great Plains Wind Resource
PACIFIC OCEAN
ATLANTIC OCEAN
Gulf of Mexico

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

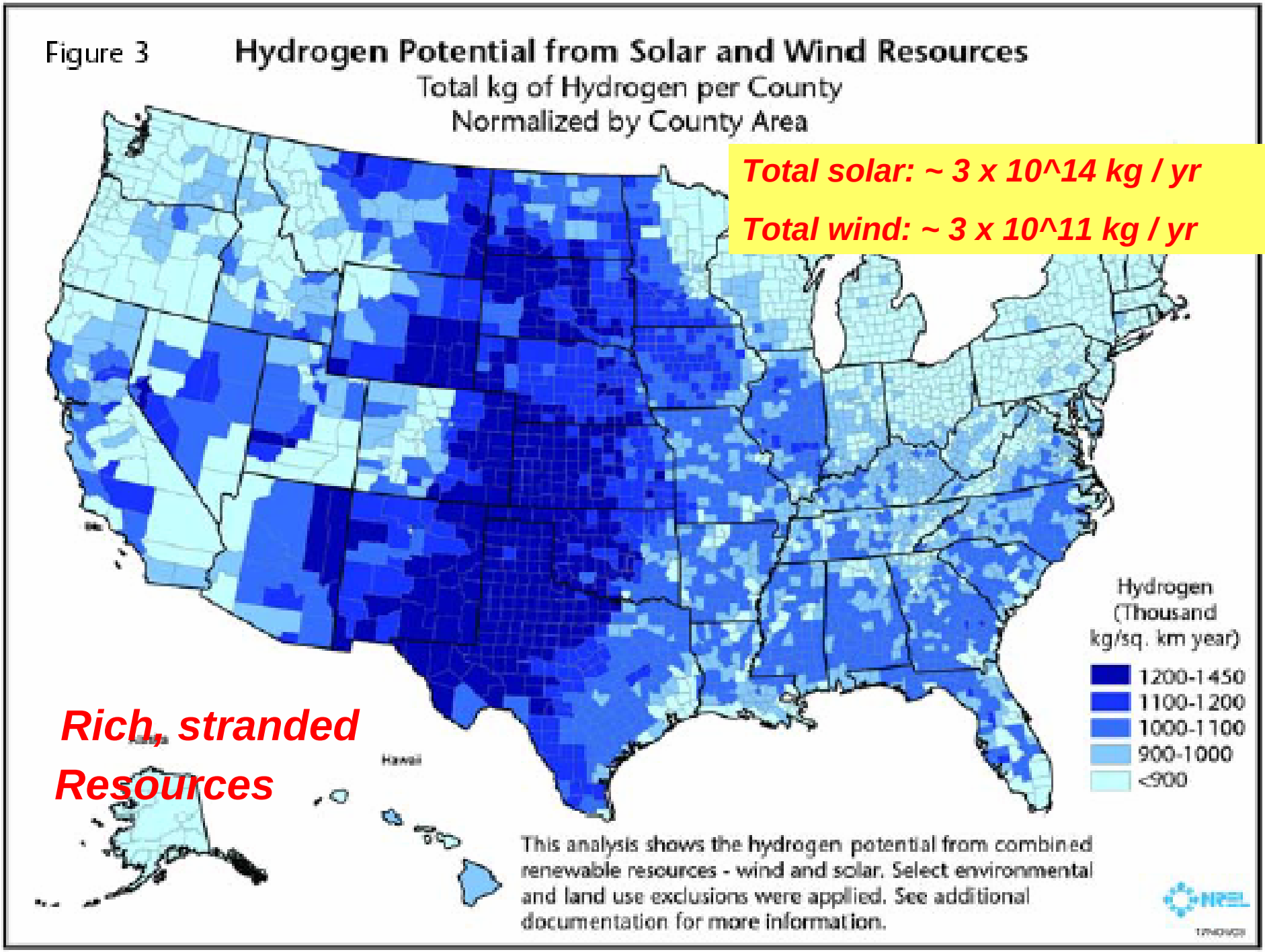


Figure 3
Hydrogen Potential from Solar and Wind Resources
Total kg of Hydrogen per County
Normalized by County Area
Total solar: ~ 3 x 10^14 kg / yr
Total wind: ~ 3 x 10^11 kg / yr
Rich, stranded Resources
Hydrogen (Thousand kg/sq. km year)
1200-1450
1100-1200
1000-1100
900-1000
<900
Hawaii
This analysis shows the hydrogen potential from combined renewable resources - wind and solar. Select environmental and land use exclusions were applied. See additional documentation for more information.
NREL

Iowa Wind Potential

Annual energy production, TWh	**550**
Installed wind generation, MW	**157,249**
Export electric lines	**50**
Export electric lines cost	**$ 30 billion**
Export hydrogen pipelines	**20**
Export hydrogen pipelines cost	**$ 20 billion**

Trouble with Renewables

- Diffuse, dispersed: gathering cost
- Richest are remote: “stranded”
- Time-varying output:
  - “intermittent”
  - “firming” storage required
- Transmission:
  - low capacity factor (CF) or curtailment
  - NIMBY
- Distributed or centralized ?

Trouble with Renewables - Electricity Transmission

- **Grid nearly full**
  - **New wind must pay for transmission**
  - **Costly: AC or DC**
- **NIMBY**
- **Low capacity factor or curtailment**
- **No storage: smoothing or firming**
- **Overhead towers vulnerable: God or man**
- **Underground: Only HVDC**

Trouble with GW-scale wind today

- **Lowest-cost renewable ?**
- **Electricity only**
- **Grid nearly full**
  - **New wind must pay for transmission**
  - **Costly: AC or DC**
- **No storage: smoothing or firming**
- **“Cherry-picked” windplants, to date**
  - **Best wind sites**
  - **Low-cost transmission access**
- **Depend on fed PTC: $ 0.019 / kWh**

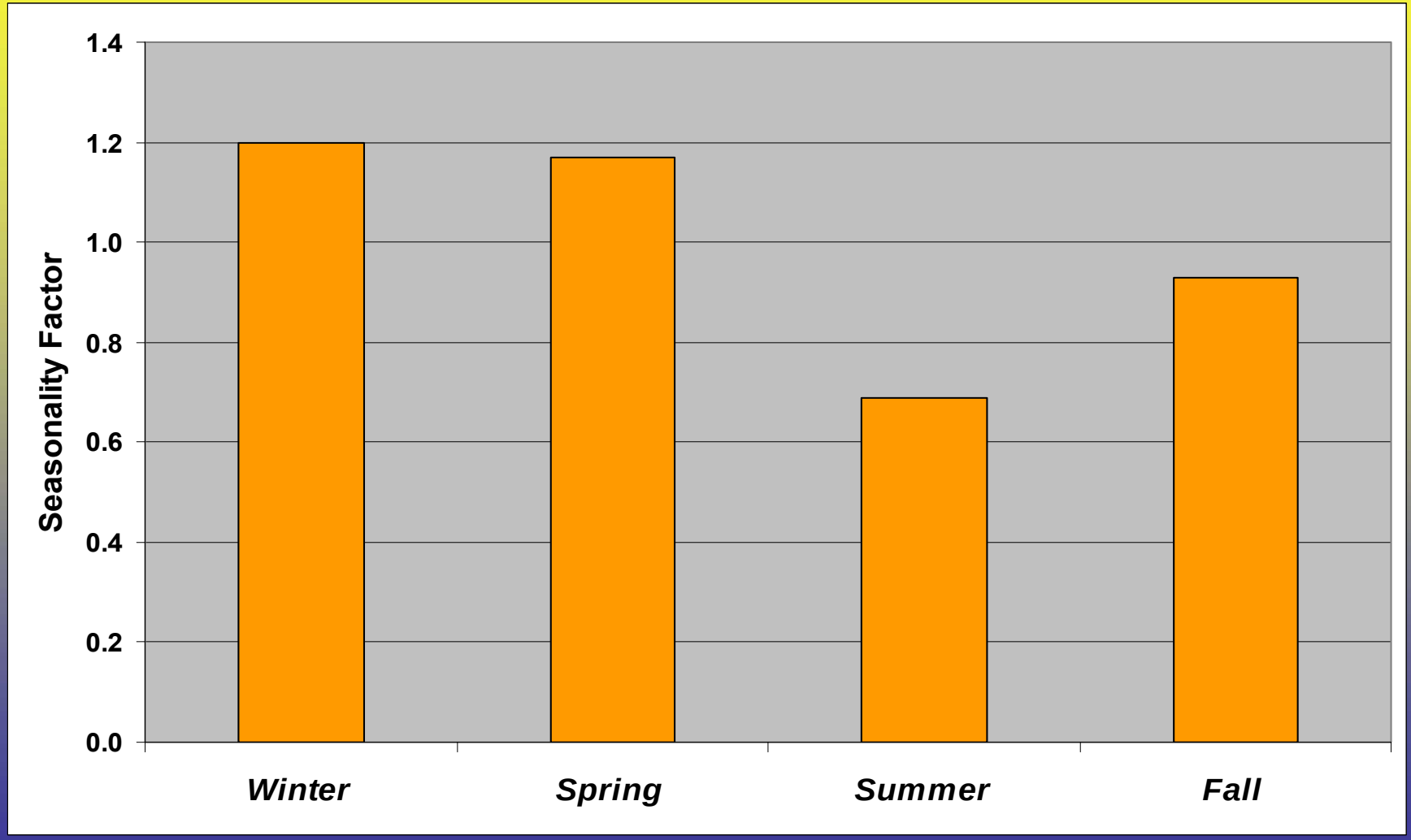
Wind seasonality, Great Plains

- 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



"Firm" energy worth more

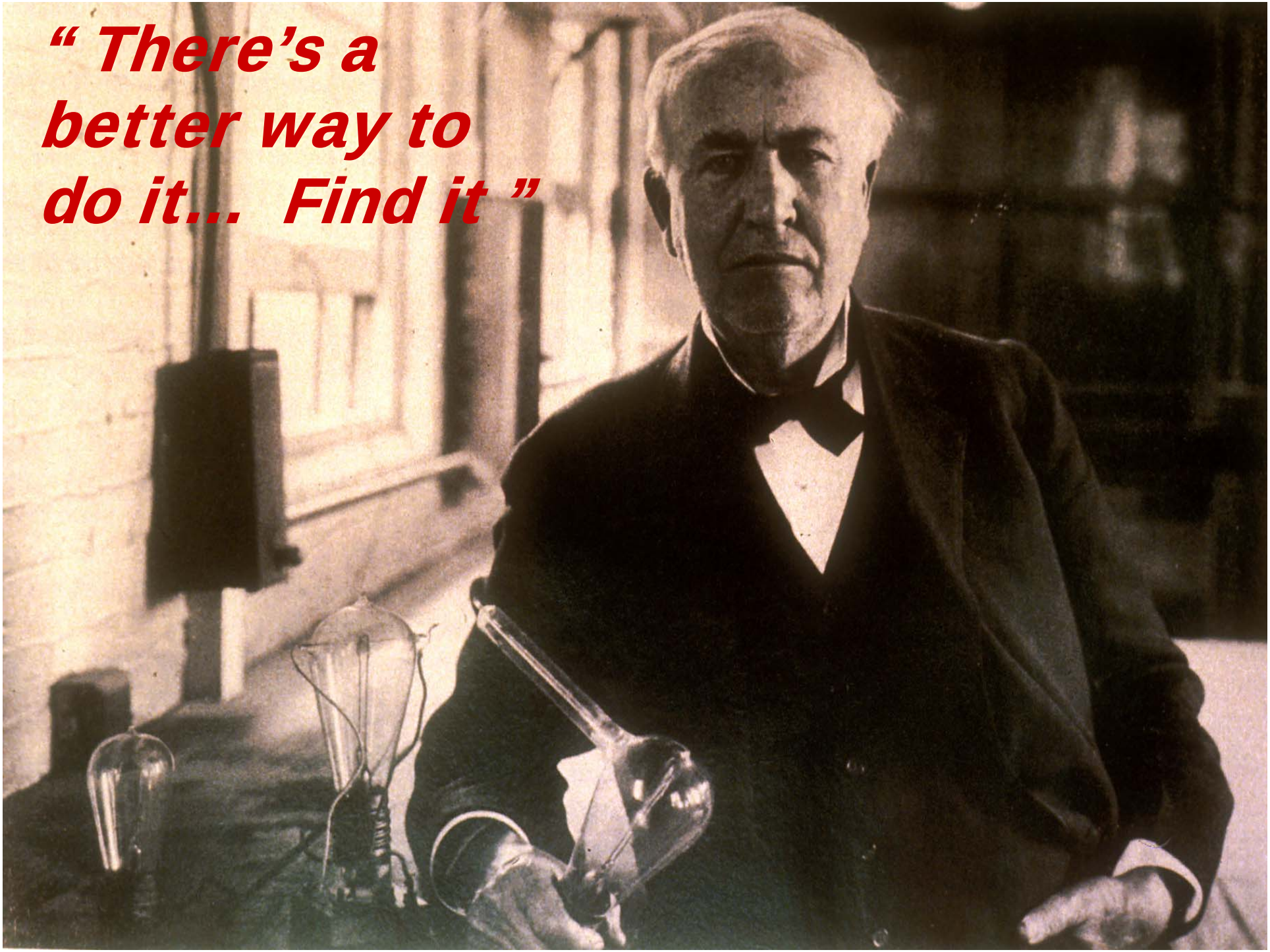
- **Every hour, every year**
- **Strategically: indigenous, secure**
- **Market price**
- **Dispatchable**
- **Bankable large projects**
- **Risk avoidance: rapid climate change**

Energy Storage Alternatives

- Batteries
  - Lead-acid
  - Nickel-cadmium
  - Lithium ion
  - Sodium sulfur
- Flow batteries (FBES)
- Pumped hydro (PHS)
- Thermal (TES)
- Compressed air (CAES)
- Chemical
- Flywheel (FES)
- Superconducting magnetic (SMES)
- Supercapacitors
- NEW
  - Hydrogen in caverns: “Hydricity” (FC-HES)
  - Ammonia in tanks

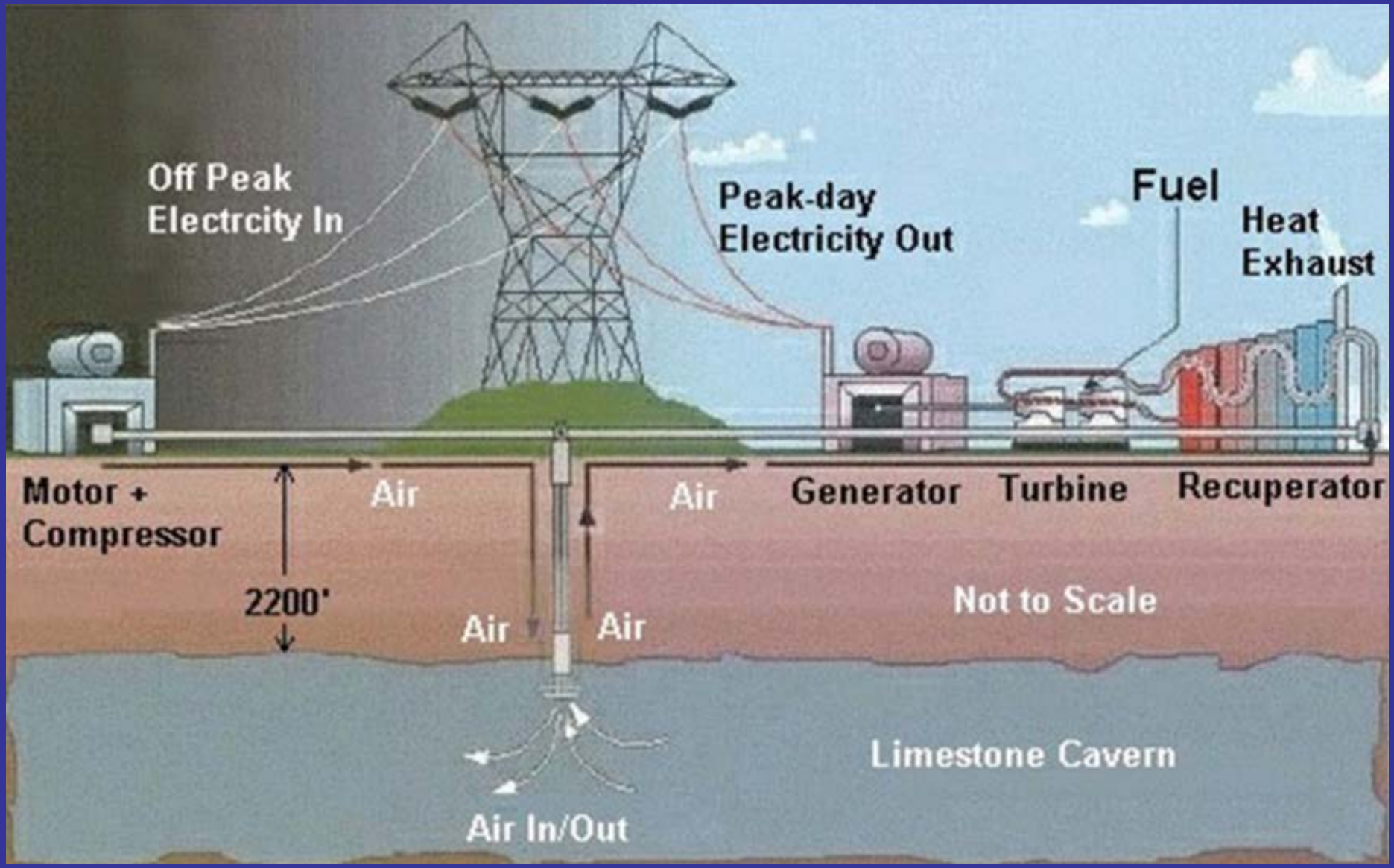
Annual – scale "Firming"
Great Plains Wind

- **Potential, 12 states, ~50% land area:**
  - **10,000 TWh = 100 quads = entire USA energy**
  - **2,800,000 MW nameplate**
- **Seasonality:**
  - **Summer minimum**
  - **Spring – Summer maximum storage**
  - **"Firming" energy storage,**
    per 1,000 MW wind = 450 GWh


“ There’s a
better way to
do it… Find it ”

Compressed Air Energy Storage (CAES)

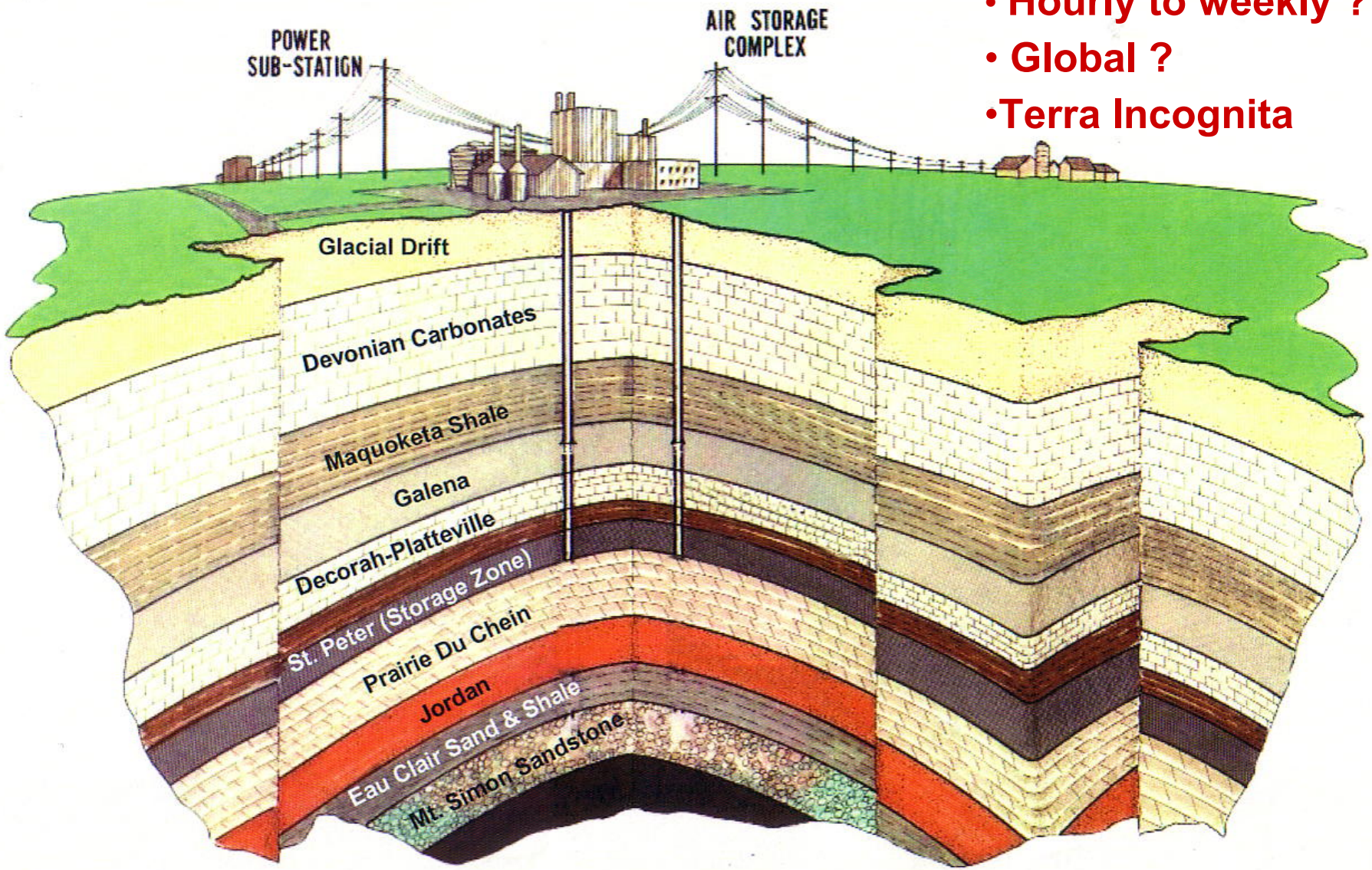
Requires: Right geology + Fuel

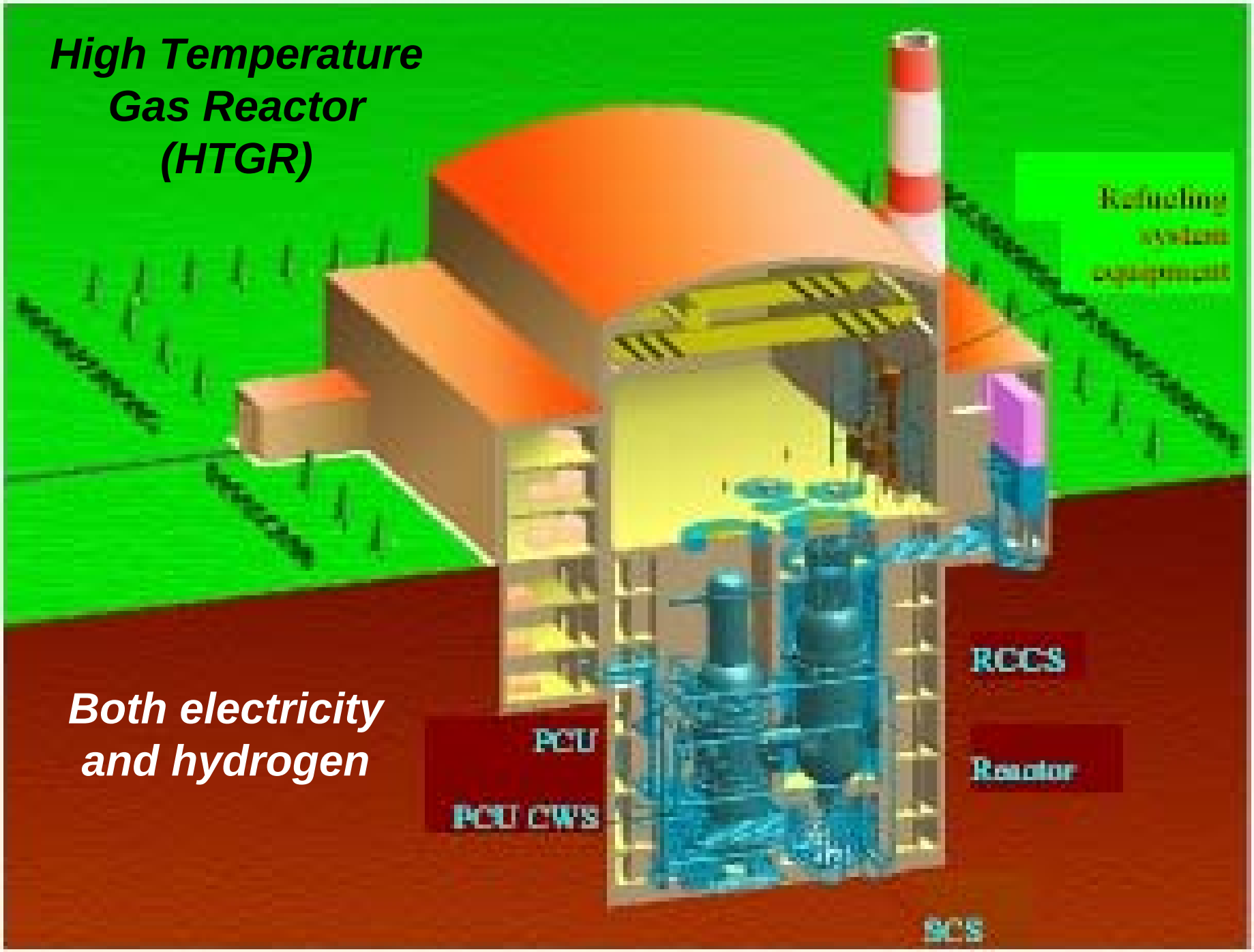


Compressed Air Energy Storage (CAES)

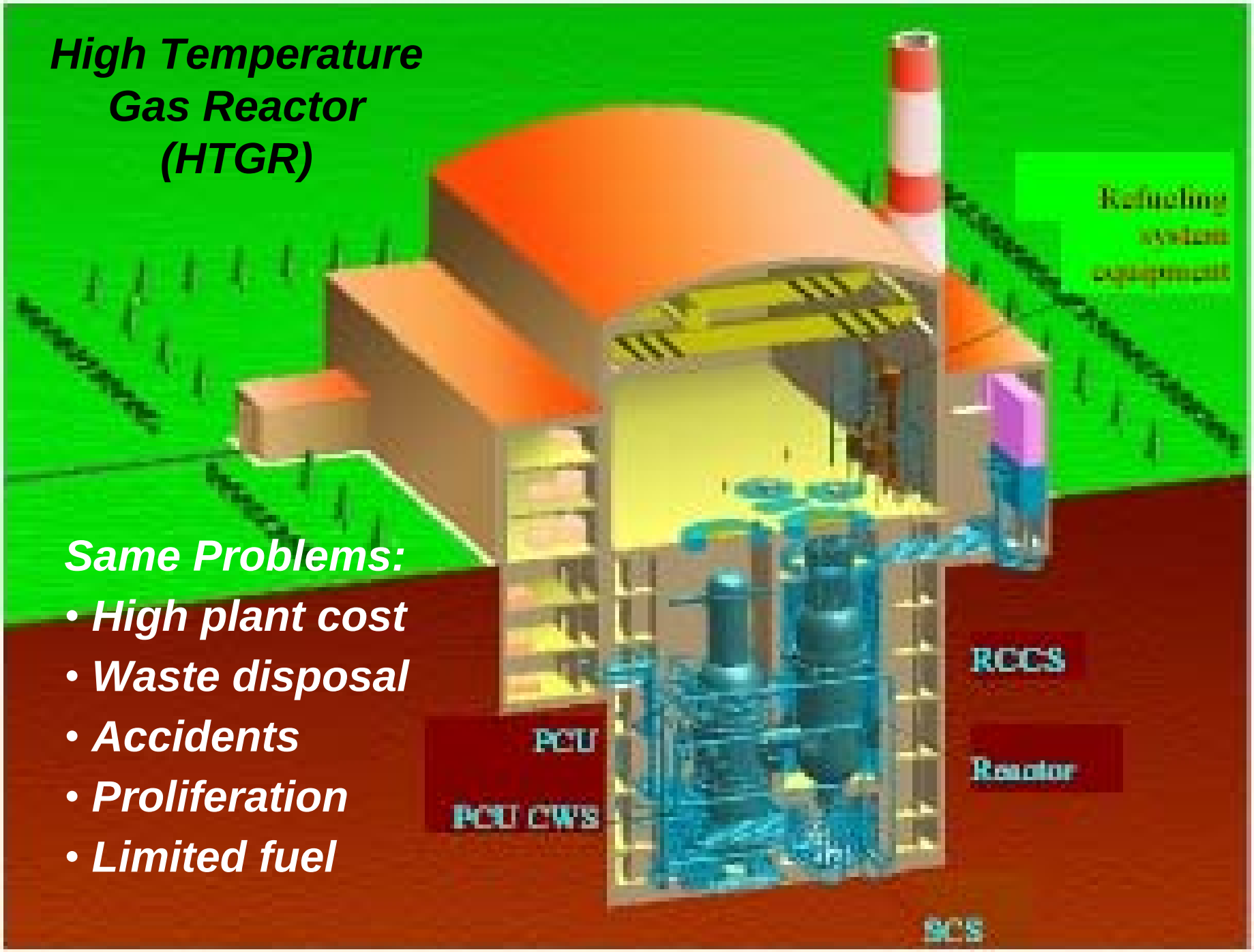
Iowa Energy Storage Park: Geology

- **Hourly to weekly ?**
- **Global ?**
- **Terra Incognita**



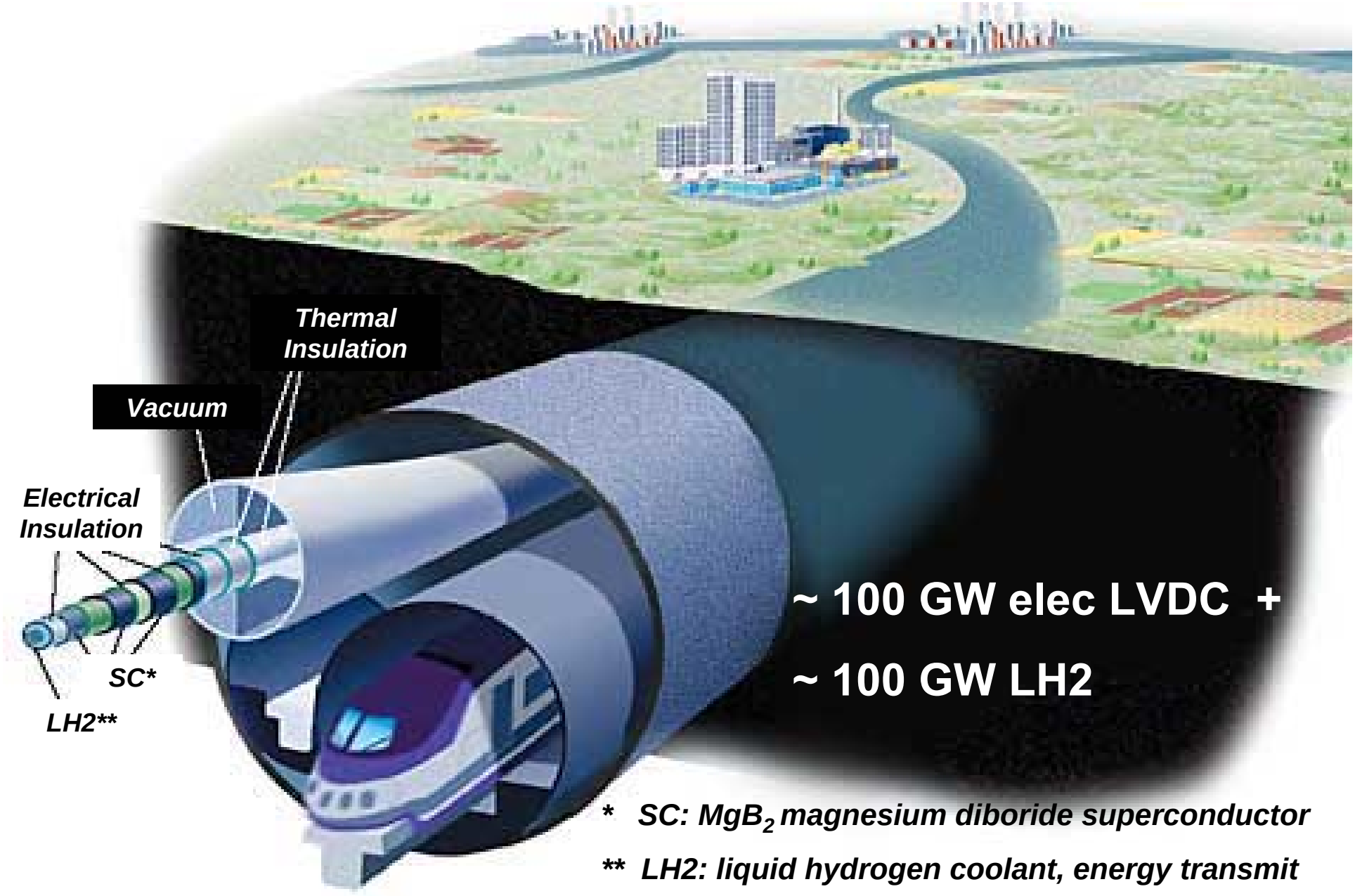

High Temperature
Gas Reactor
(HTGR)
Both electricity
and hydrogen
RCCS
PCU
Reactor
PCU CWS
SCS

High Temperature Gas Reactor (HTGR)



Same Problems:

- ***High plant cost***
- ***Waste disposal***
- ***Accidents***
- ***Proliferation***
- ***Limited fuel***



* SC: MgB_2 magnesium diboride superconductor

** LH2: liquid hydrogen coolant, energy transmit

Continental Supergrid – EPRI concept "Energy Pipeline"

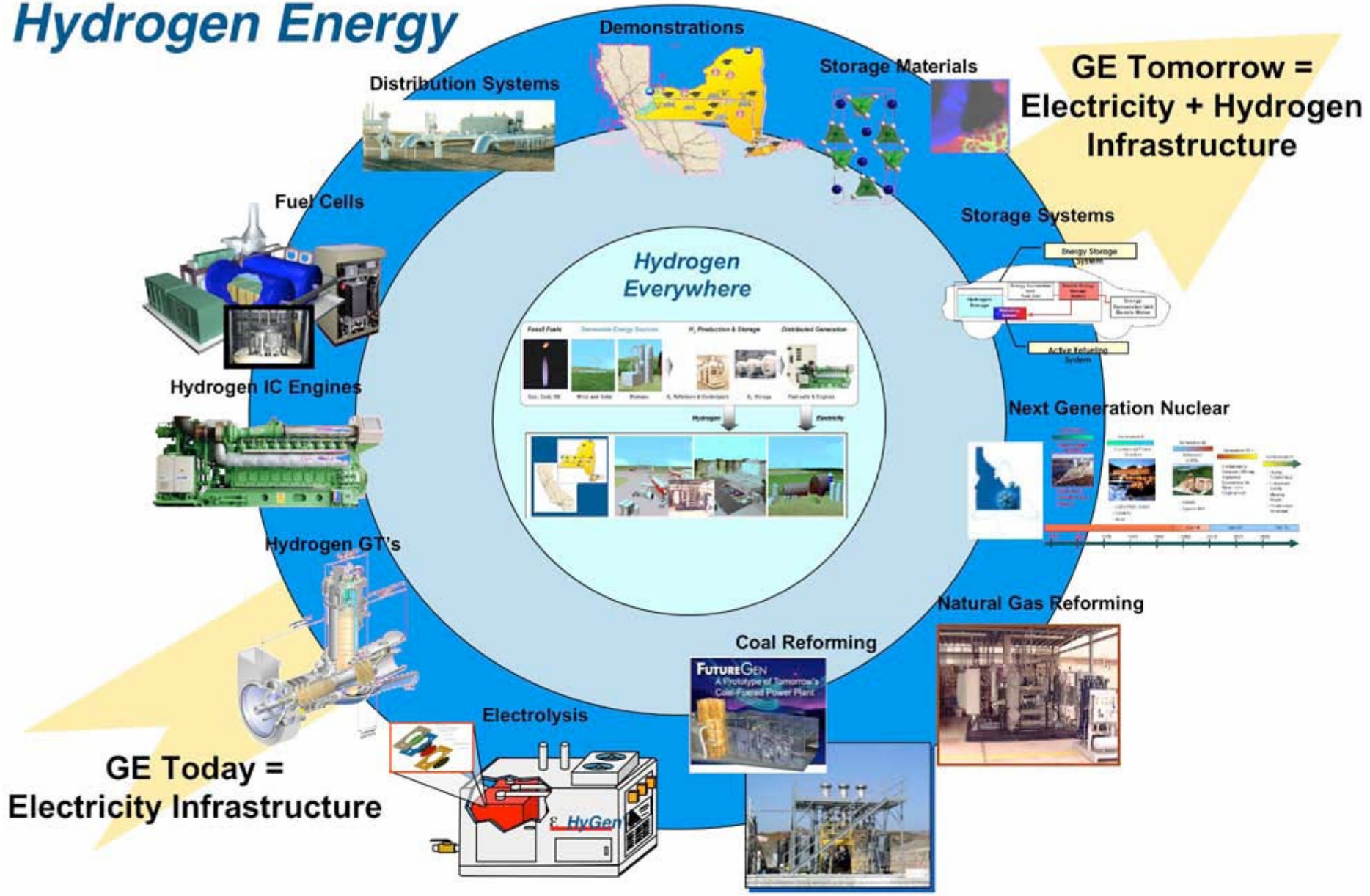
"Hydrogen and electricity become the primary currencies in the future energy economy"

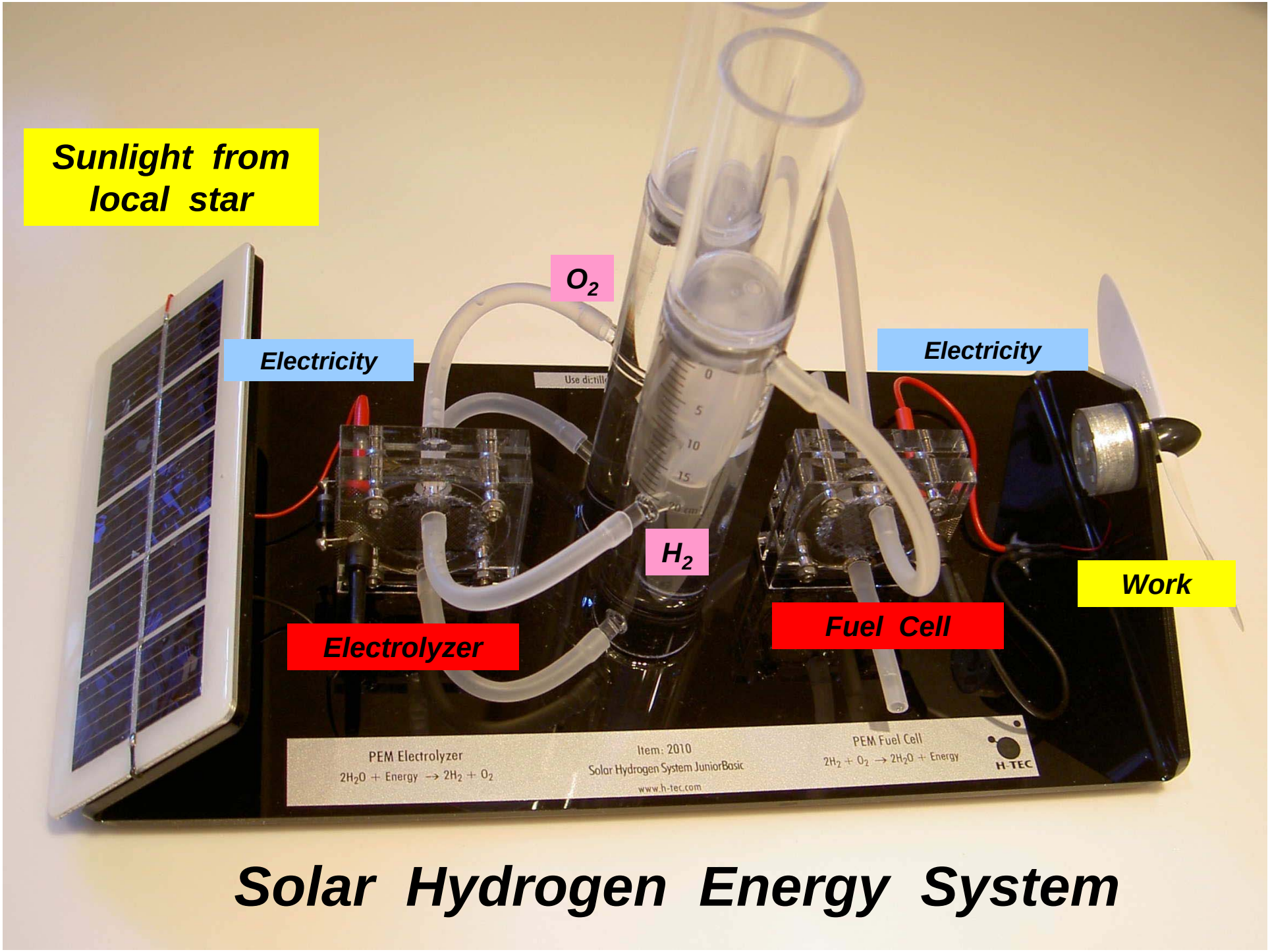
Utility electrolysis vision

- MW-scale utility electrolyzers
- Affordable capital investment:
  Total system cost considerations
- Off-peak, wholesale electricity: Operated by utility
- Distributed, substation level operation
- Tightly integrated with electrical grid

Dan Smith
GE Global Research, 2004

Hydrogen Energy



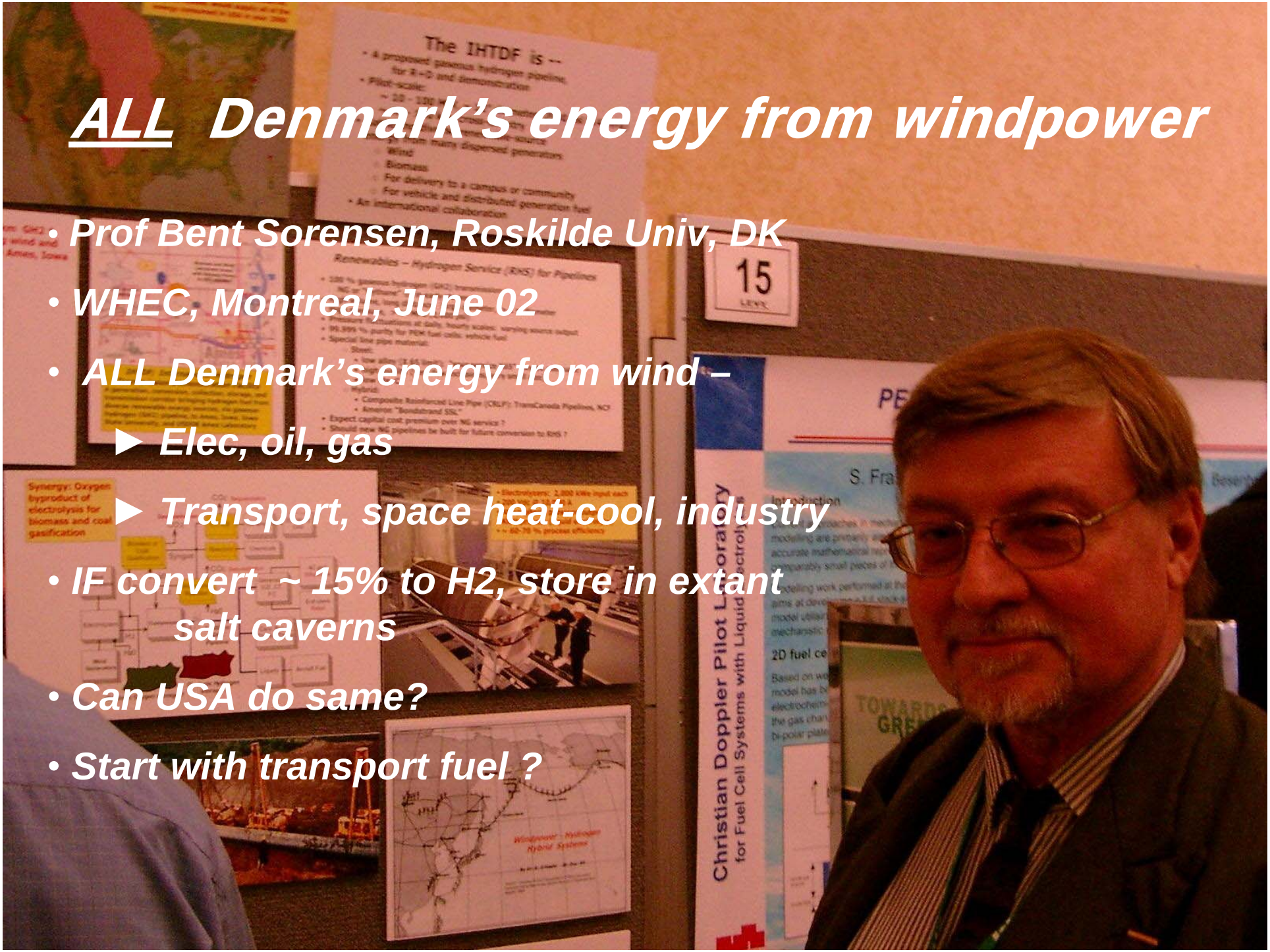


Solar Hydrogen Energy System

Hydrogen Fuel Cell

Proton Exchange Membrane (PEM) type

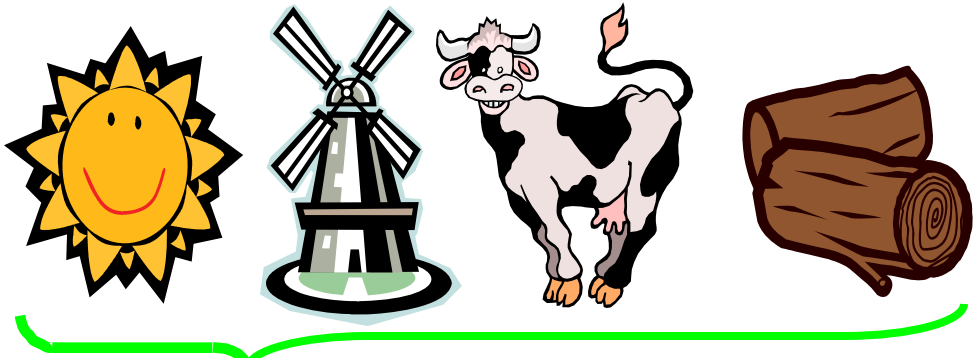
Hydrogen (H2) combines with Oxygen (O2) to make electricity + heat + water (H2O)



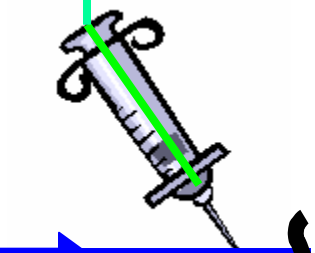
ALL Denmark's energy from windpower

- Prof Bent Sorensen, Roskilde Univ, DK
- WHEC, Montreal, June 02
- ALL Denmark's energy from wind –
  - ► Elec, oil, gas
  - ► Transport, space heat-cool, industry
- IF convert ~ 15% to H2, store in extant salt caverns
- Can USA do same?
- Start with transport fuel ?

EC: The NATURALHY concept



H2

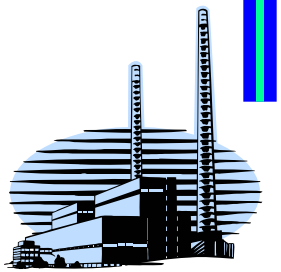


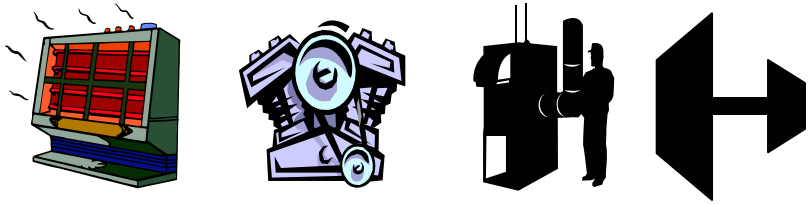
N.G.

Full H2-area

NATURALHY:

- ***Breaks "chicken-egg" dilemma***
- ***Bridge to sustainable future***



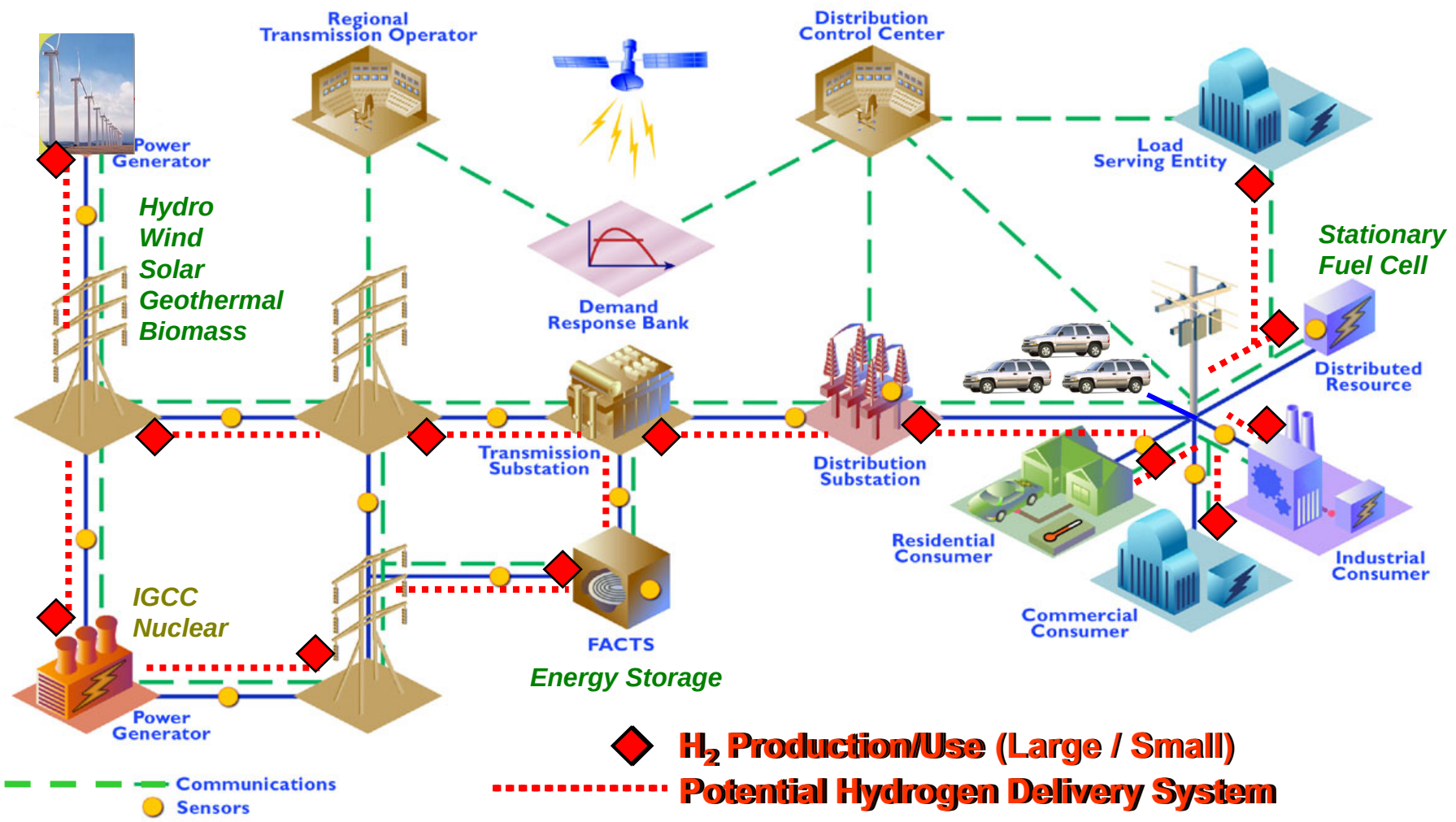


Prepared by
O. Florisson
Gasunie

Hydrogen, Fuel Cell Running on water ?


www.qtww.com
Hydrogen - fueled
2005 Prius
ICE Hybrid

Energy System of the Future



Frank Novachek, Director Corporate Planning

EPRI

Xcel Energy®

Dick Kelly (Xcel) and Dan Arvizu (NREL) shake hands after pushing button to light H2 sign and dedicate system

National Wind Technology Center

Golden, CO

2006

Xcel – NREL Wind – Hydrogen Demo

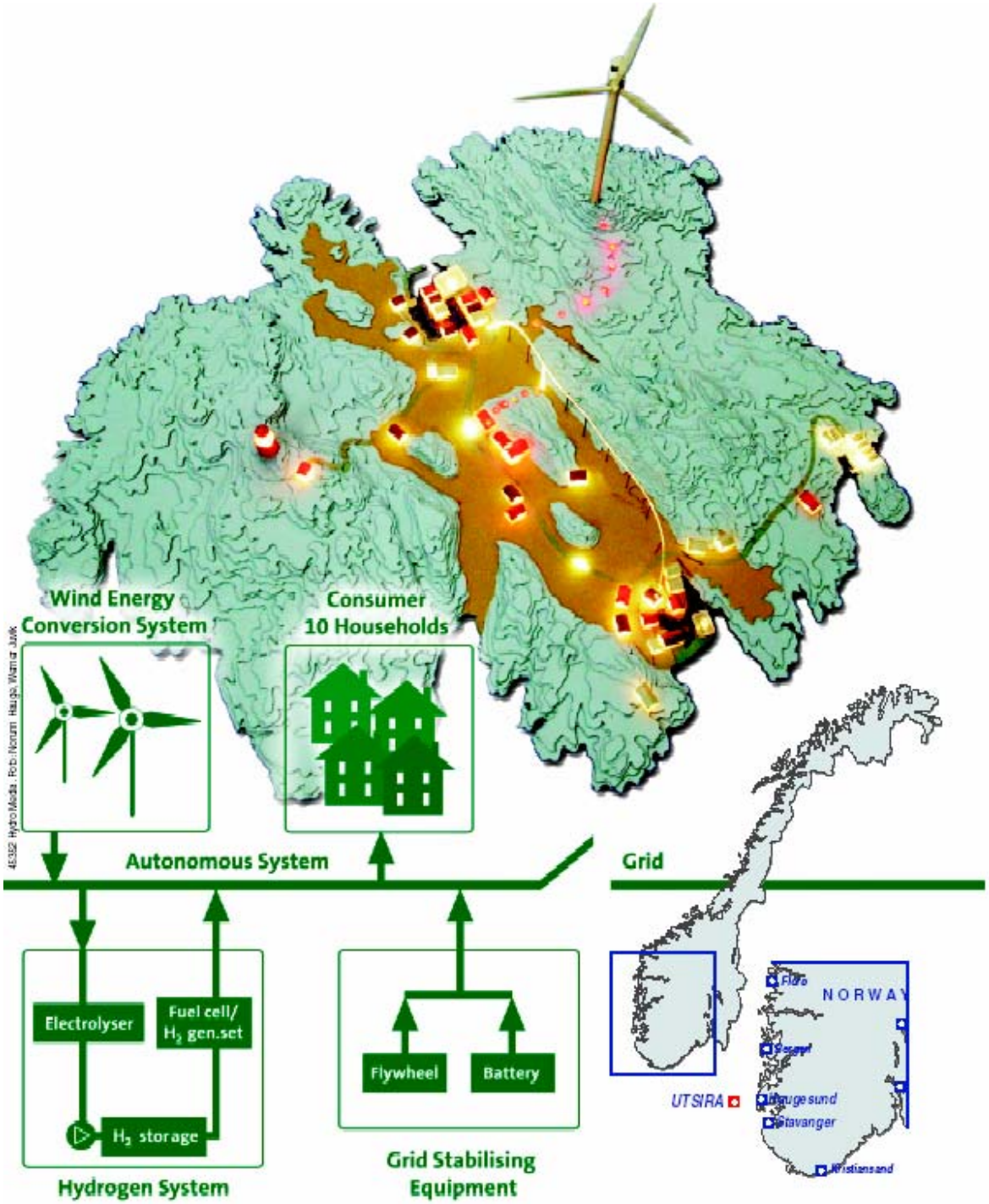
DVD available

Mark Udall (US Rep CO) discusses project with Dan Arvizu (NREL), Dick Kelly (Xcel), and John Mizroch (DOE)

Xcel Energy®

Hydrogen Utility Group (HUG)

Utsira Island, Norway



Utsira Island

Norway

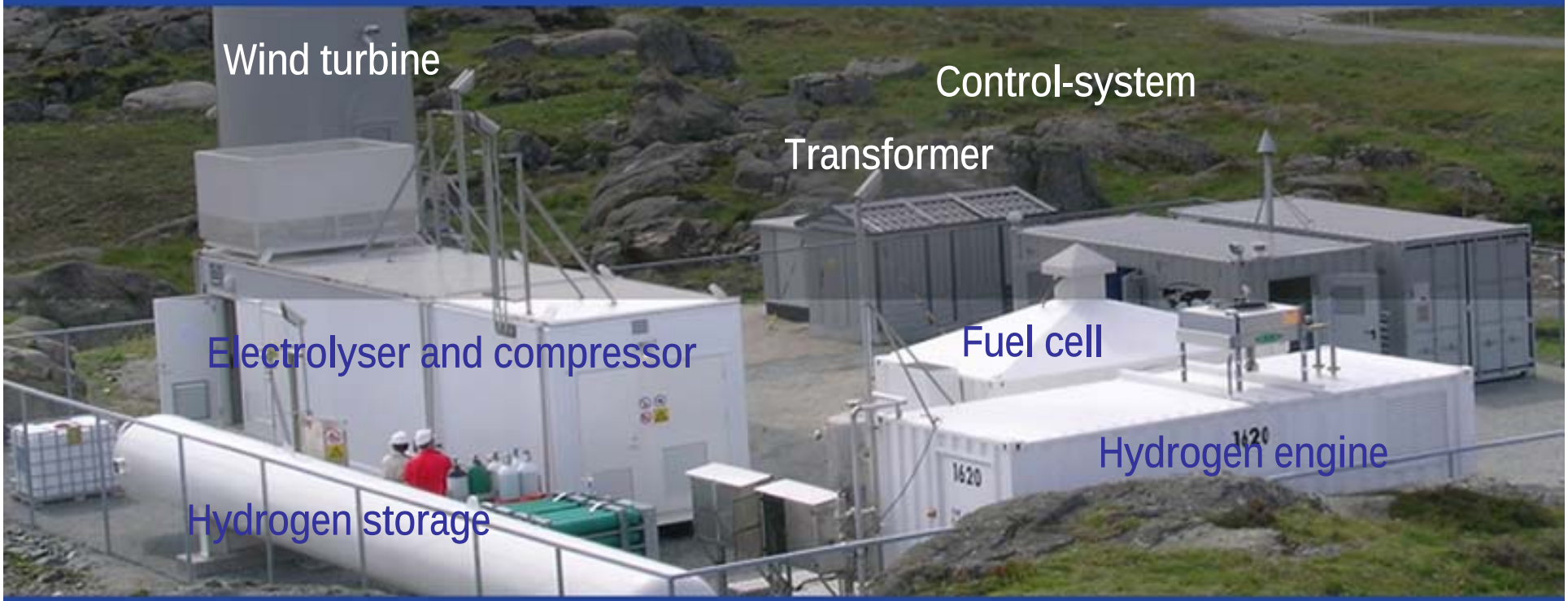
Wind – Hydrogen Autonomous System

Replaces aging electricity cable from mainland

Utsira Island, Norway. 200 people. Isolated wind – hydrogen.

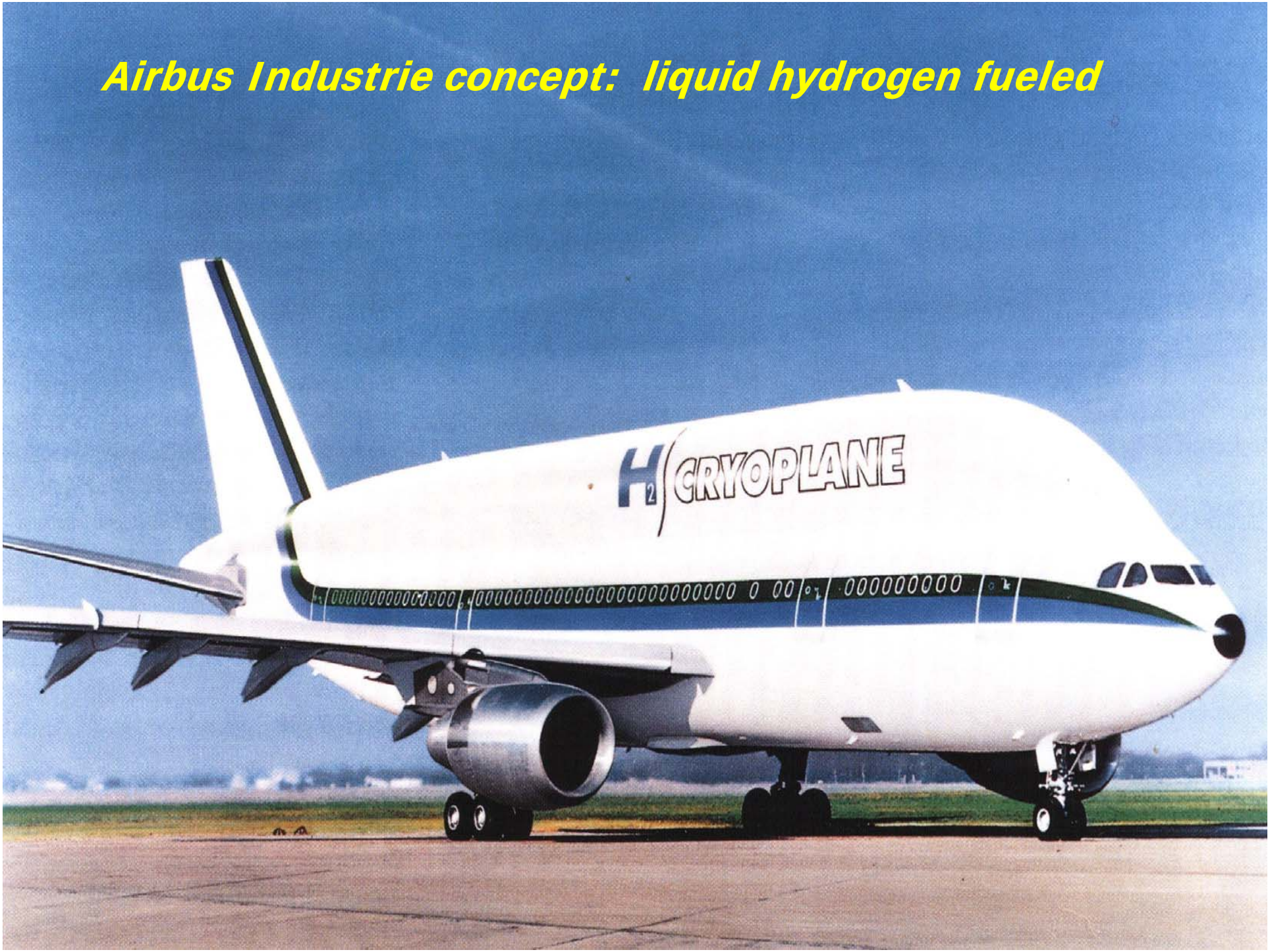
The wind – hydrogen plant at Utsira

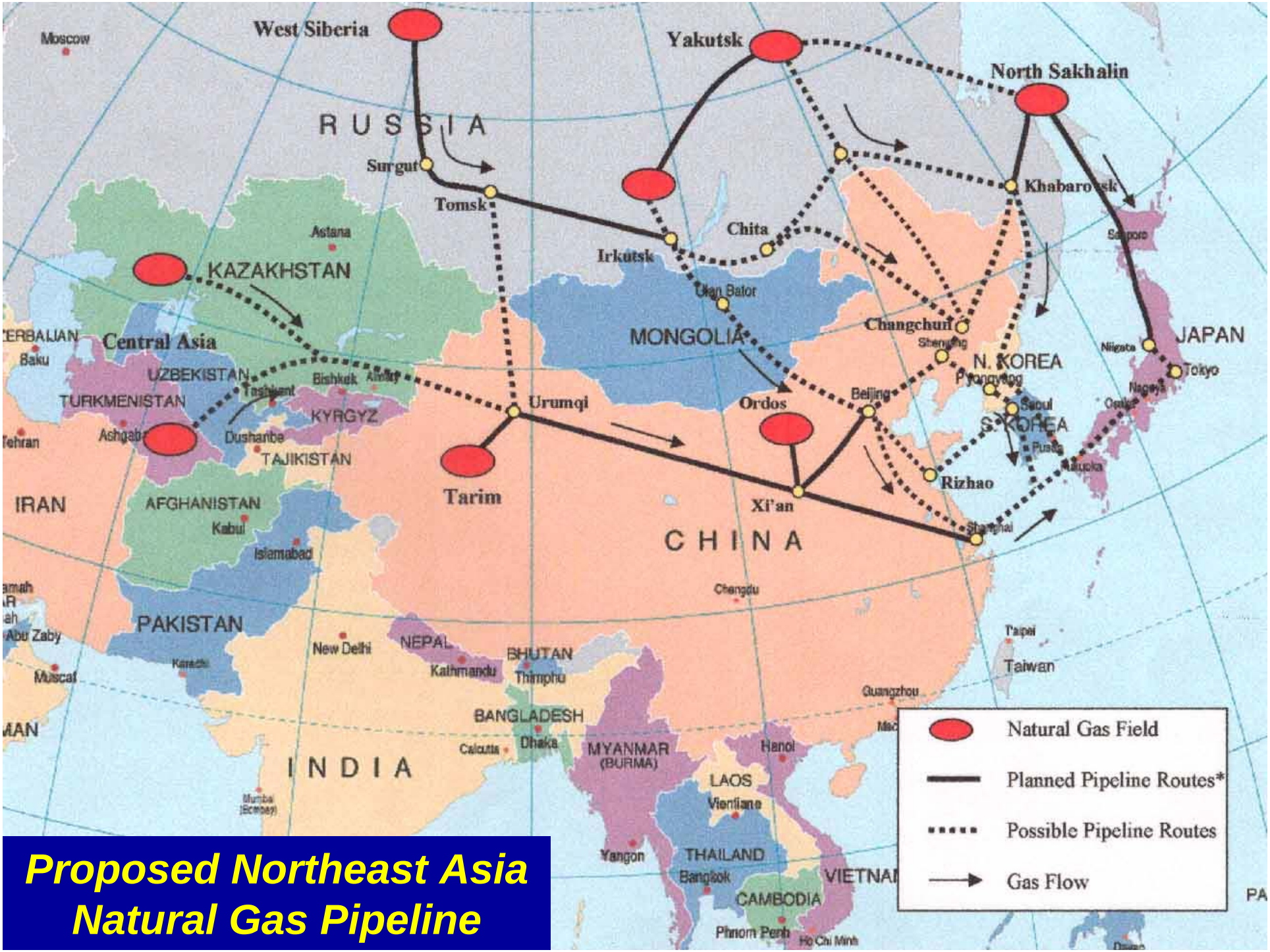
A vision becoming reality



HYDRO

Airbus Industrie concept: liquid hydrogen fueled

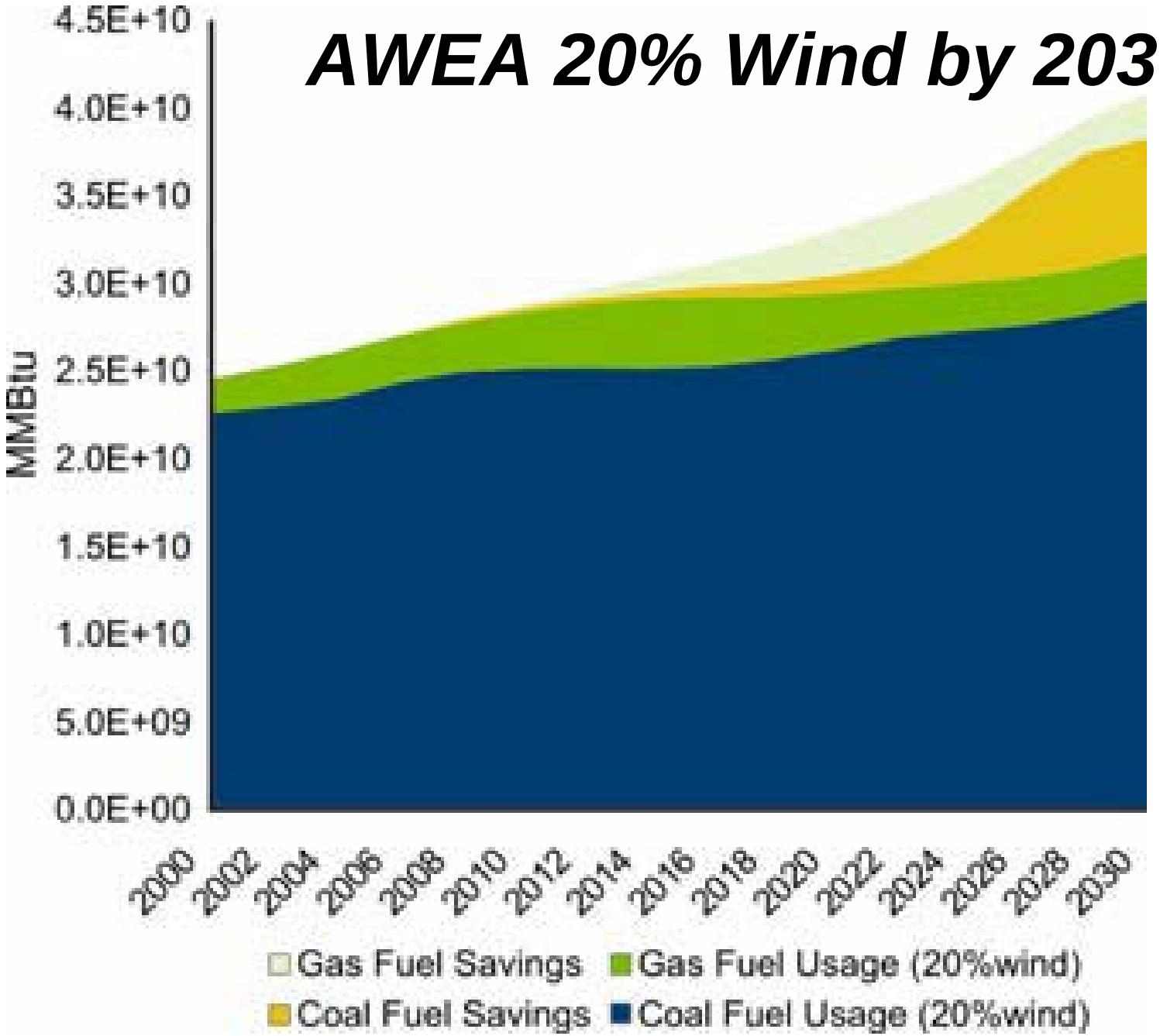



West Siberia
Yakutsk
North Sakhalin
RUSSIA
Moscow
Surgut
Tomsk
Irkutsk
Chita
Khabarovsk
Astana
KAZAKHSTAN
Central Asia
Ulan Bator
MONGOLIA
Changchun
Shenyang
JAPAN
Niigata
Tokyo
N. KOREA
Pyongyang
Beijing
Ordos
Urumqi
Tarim
Xi'an
Rizhao
Shanghai
S. KOREA
Seoul
Pusan
UZBEKISTAN
TURKMENISTAN
KYRGYZ
TAJIKISTAN
Tashkent
Bishkek
Dushanbe
Ashgabat
Tehran
IRAN
AFGHANISTAN
Kabul
Islamabad
PAKISTAN
Chengdu
CHINA
Abu Zaby
Muscat
New Delhi
Karachi
NEPAL
Kathmandu
BHUTAN
Thimphu
BANGLADESH
Dhaka
Calcutta
INDIA
Mumbai (Bombay)
MYANMAR (BURMA)
Yangon
LAOS
Vientiane
Hanoi
THAILAND
Bangkok
CAMBODIA
Phnom Penh
Ho Chi Minh
VIETNAM
Guangzhou
Taipei
Taiwan
Natural Gas Field
Planned Pipeline Routes*
Possible Pipeline Routes
Gas Flow
Proposed Northeast Asia
Natural Gas Pipeline

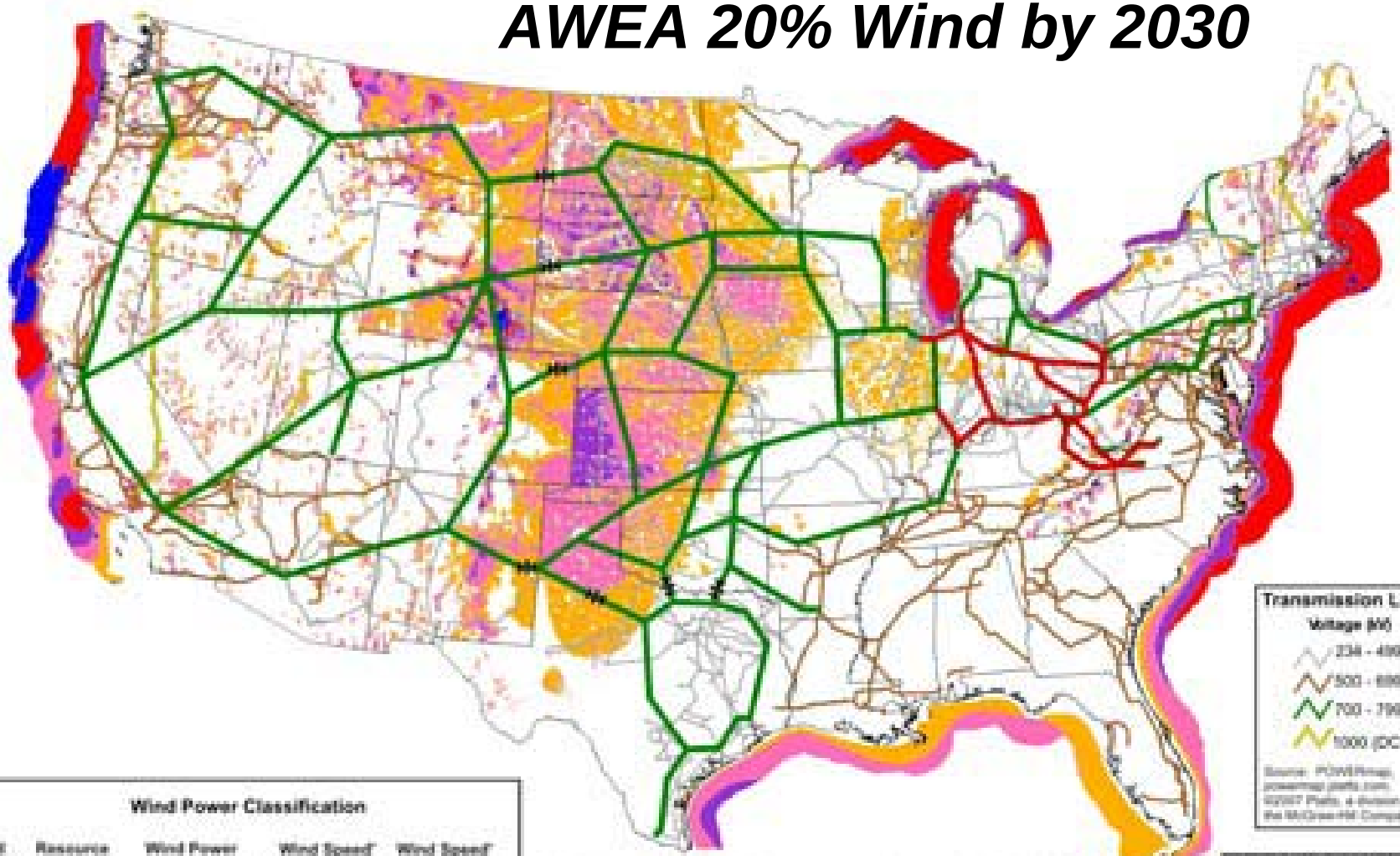
Pickens Plan

- Bold, large-scale, motivates thinking
- GW scale: economies
- Underestimates
  - Transmission
  - Grid integration, thermal plant abuse
  - Firming storage needed
- Disregards Hydrogen demand
  - Gulf Coast refineries
  - Transport fuel
- New turbine manufacturers, designs ?

AWEA 20% Wind by 2030



AWEA 20% Wind by 2030



Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m²	Wind Speed* at 50 m m/s	Wind Speed* at 50 m mph
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

* Wind speeds are based on a Weibull k value of 2.0

This map shows the wind resource data used by the WinDS model for the 20% Wind Scenario. It is a combination of high resolution and low resolution datasets produced by NREL and other organizations. The data was screened to eliminate areas unlikely to be developed onshore due to land use or environmental issues. In many states, the wind resource on this map is visually enhanced to better show the distribution on ridge crests and other features.

Transmission Lines

Voltage (kV)

- 230 - 499
- 500 - 699
- 700 - 799
- 1000 (DC)

Source: POWERmap, powermap.platts.com, ©2007 Platts, a division of the McGraw-Hill Companies

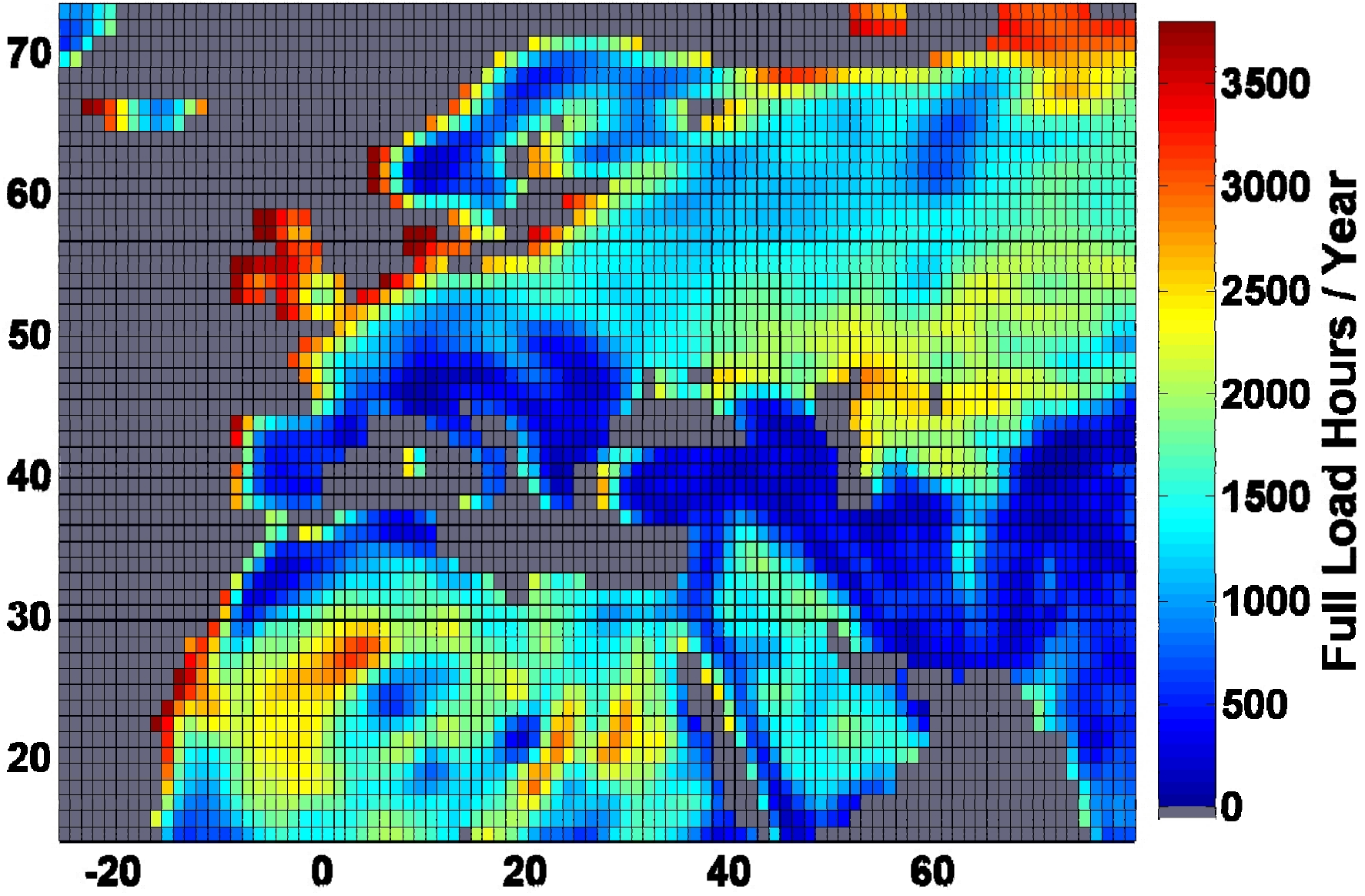
Conceptual 765 kV Network

- Existing 765 kV
- New 765 kV
- AC-DC-AC Link

Source: American Electric Power (AEP)

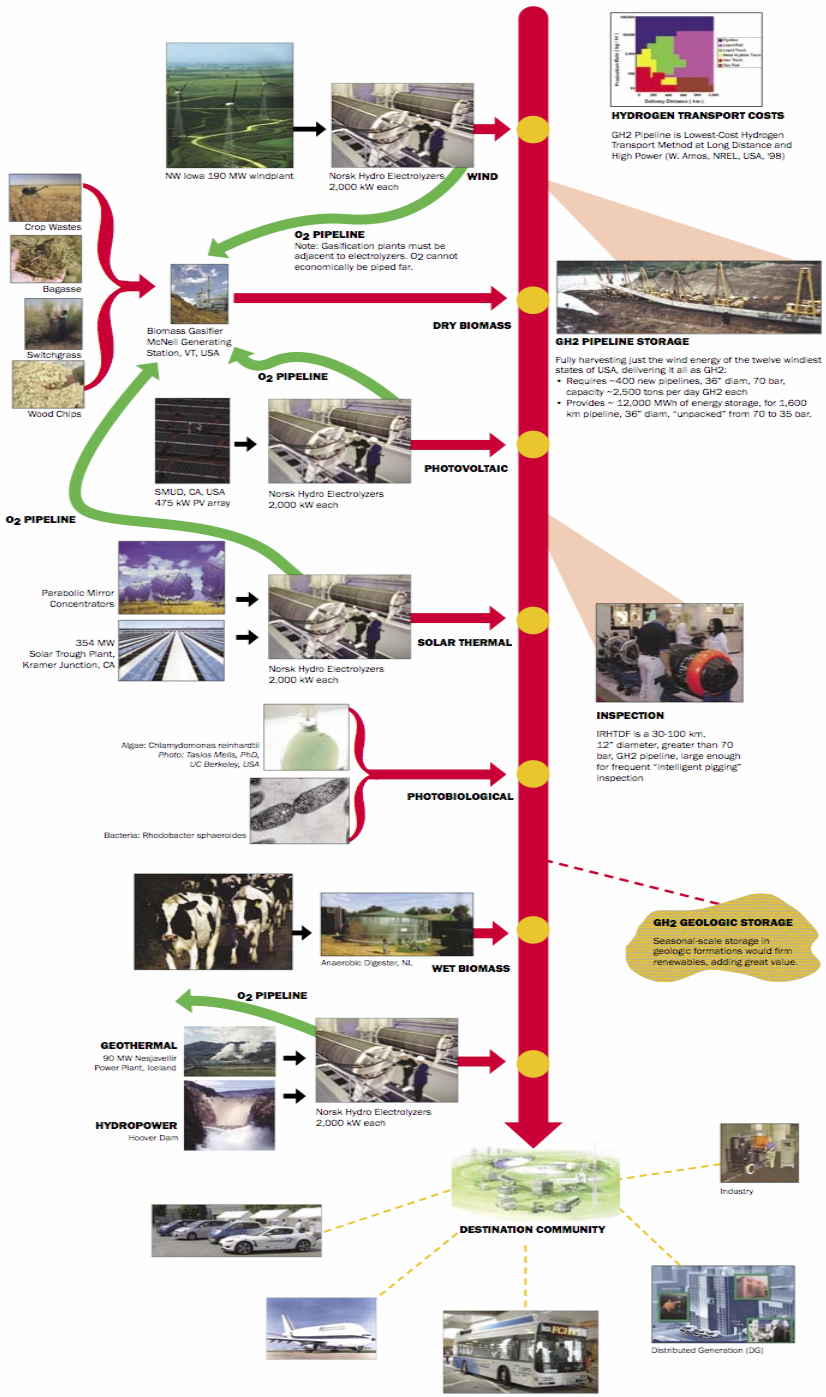
“Wind Huge Catchment Area”

ABB, ISET Kassel, Windpower 01



1: Adequate Renewables, IF

1. **"Efficient" capture + conversion equipment**
   - **Technical**
   - **Economic**
   - **Low "plant gate" COE**
2. **Transmission**
3. **"Firming" storage**
4. **Optimum CF via good system design**
5. **Competitive delivered COE**

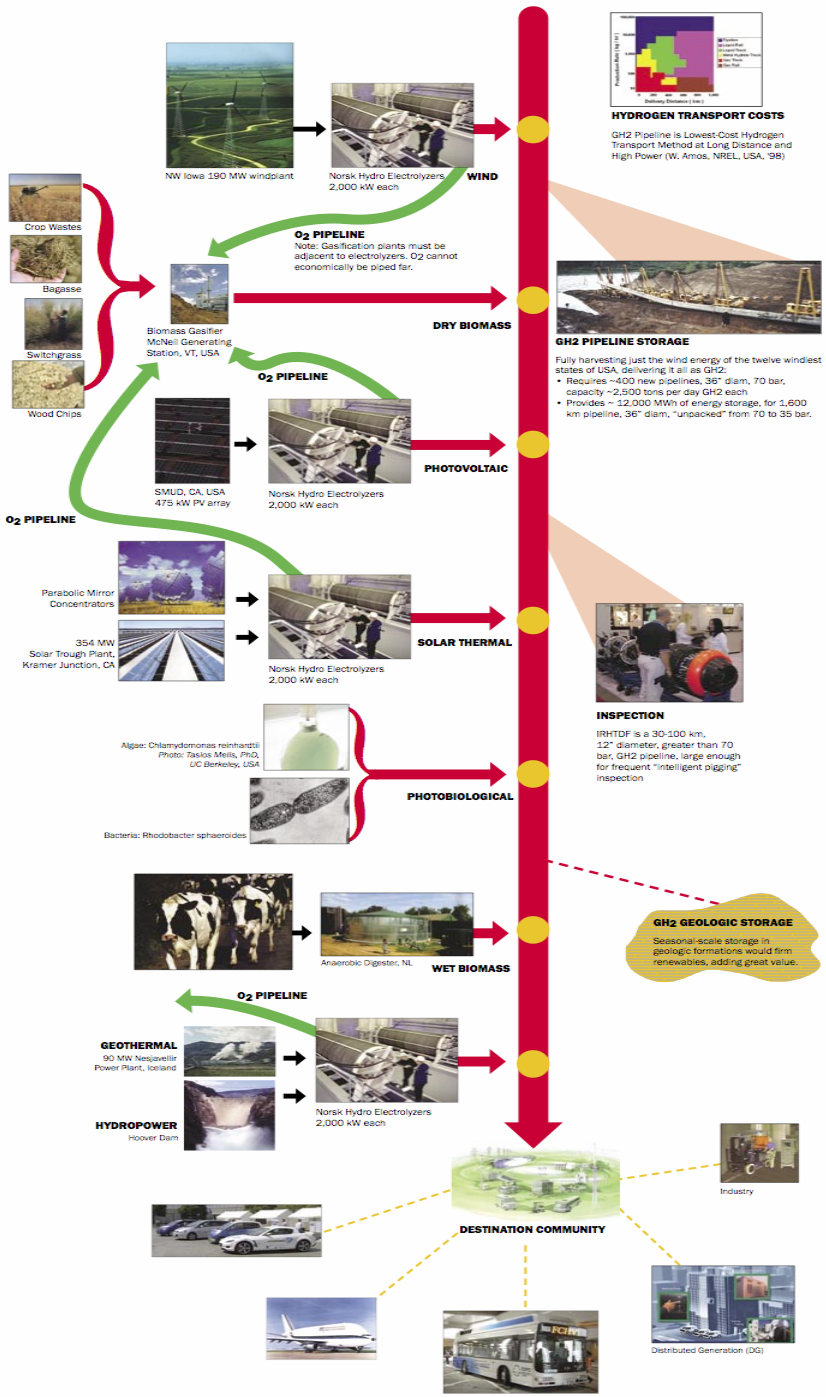


International Renewable Hydrogen Transmission Demonstration Facility

(IRHTDF)

Pilot plant

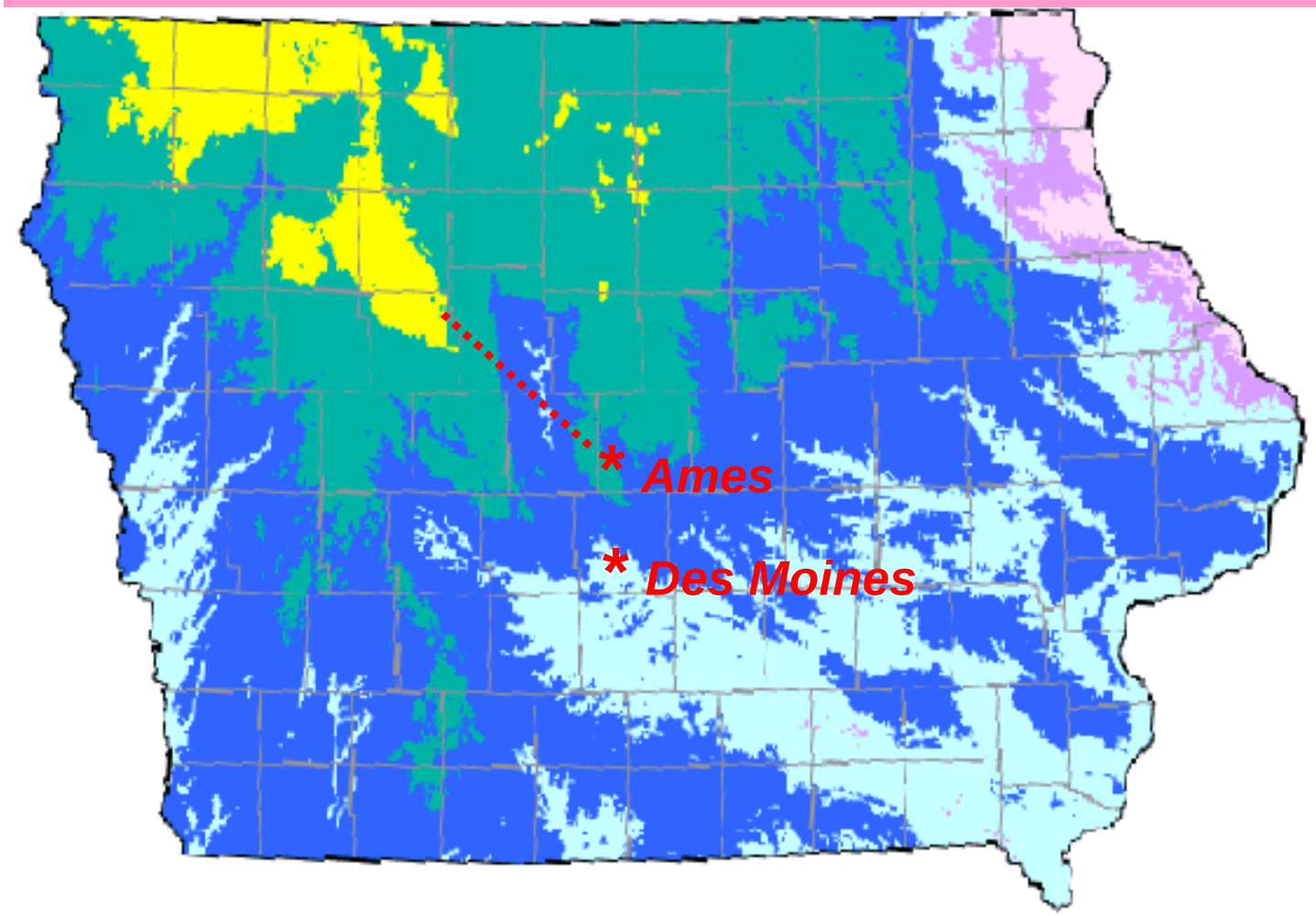
Global opportunity: IPHE project



Pilot-scale Hydrogen Pipeline System: Renewables

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

IRHTDF
International Renewable Hydrogen Transmission Demonstration Facility



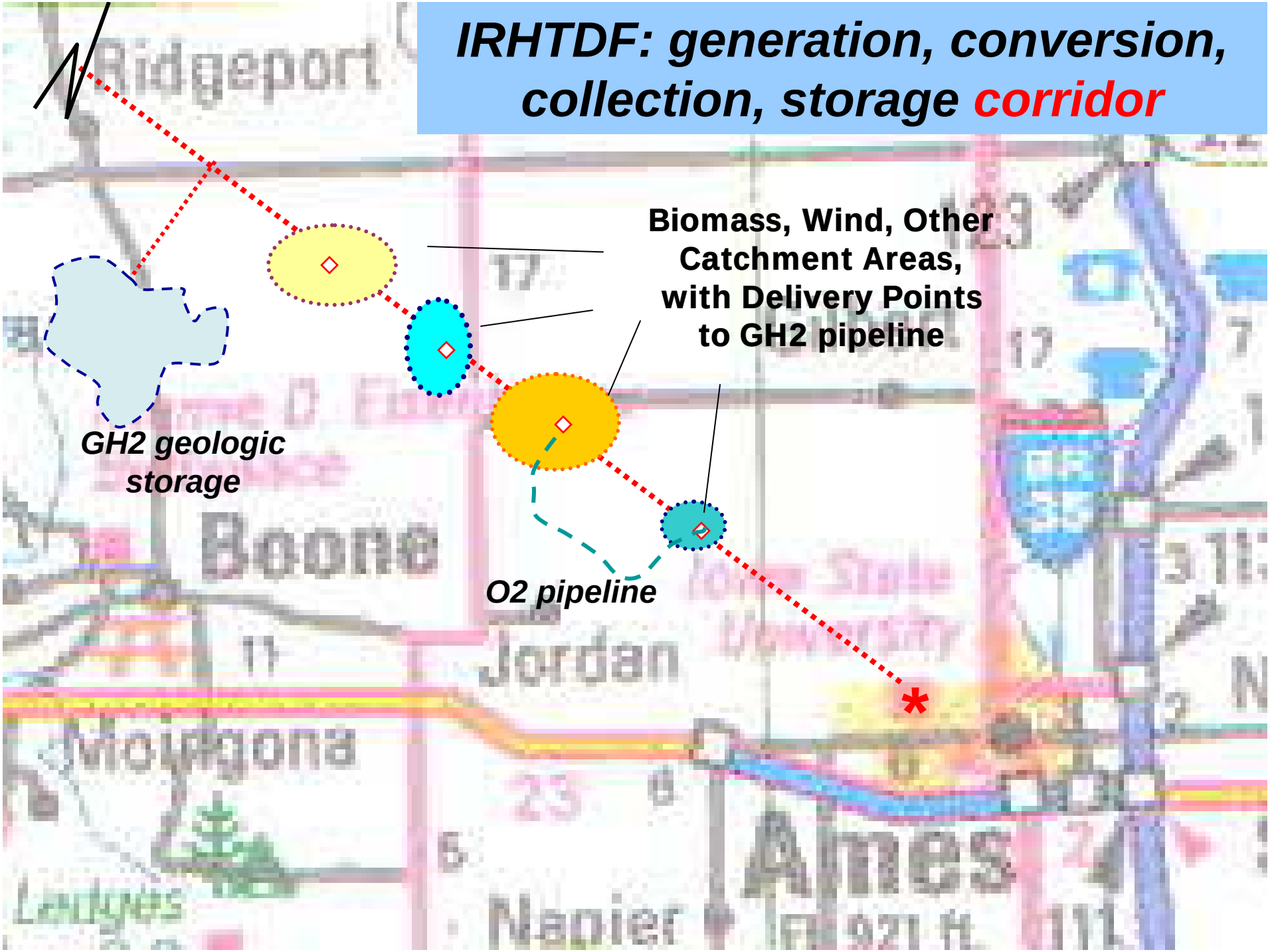
>19.0		>8.5
17.9-19.0		8.0-8.5
16.8-17.9		7.5-8.0
15.7-16.8		7.0-7.5
14.5-15.7		6.5-7.0
13.4-14.5		6.0-6.5
12.3-13.4		5.5-6.0
<12.3		<5.5

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.

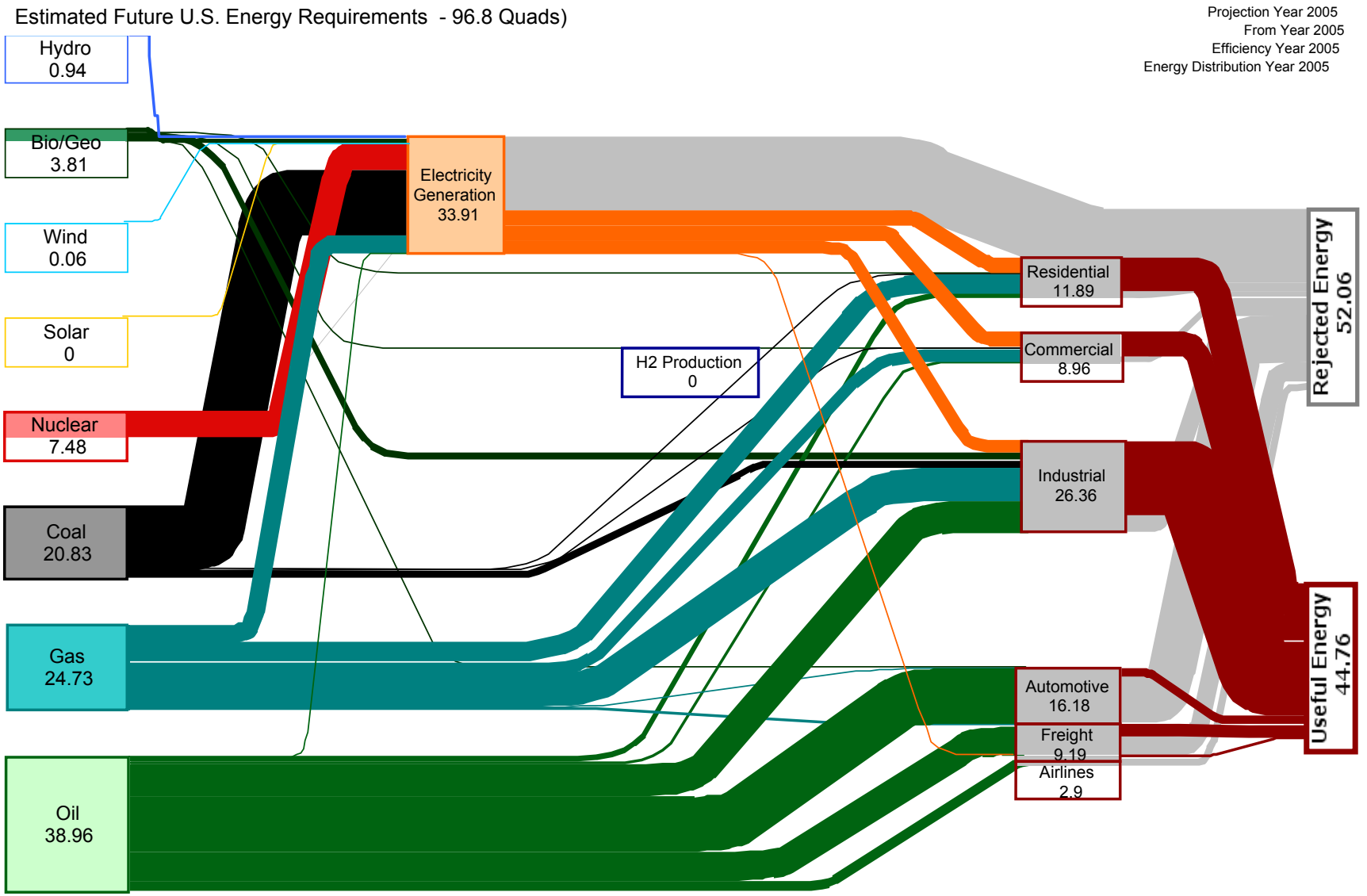
Iowa Energy Center, 2521 Elwood Drive, Suite 124, Ames, IA 50010-8263 Phone: (515) 294-8819 Fax: (515) 294-9912

IRHTDF: generation, conversion, collection, storage corridor

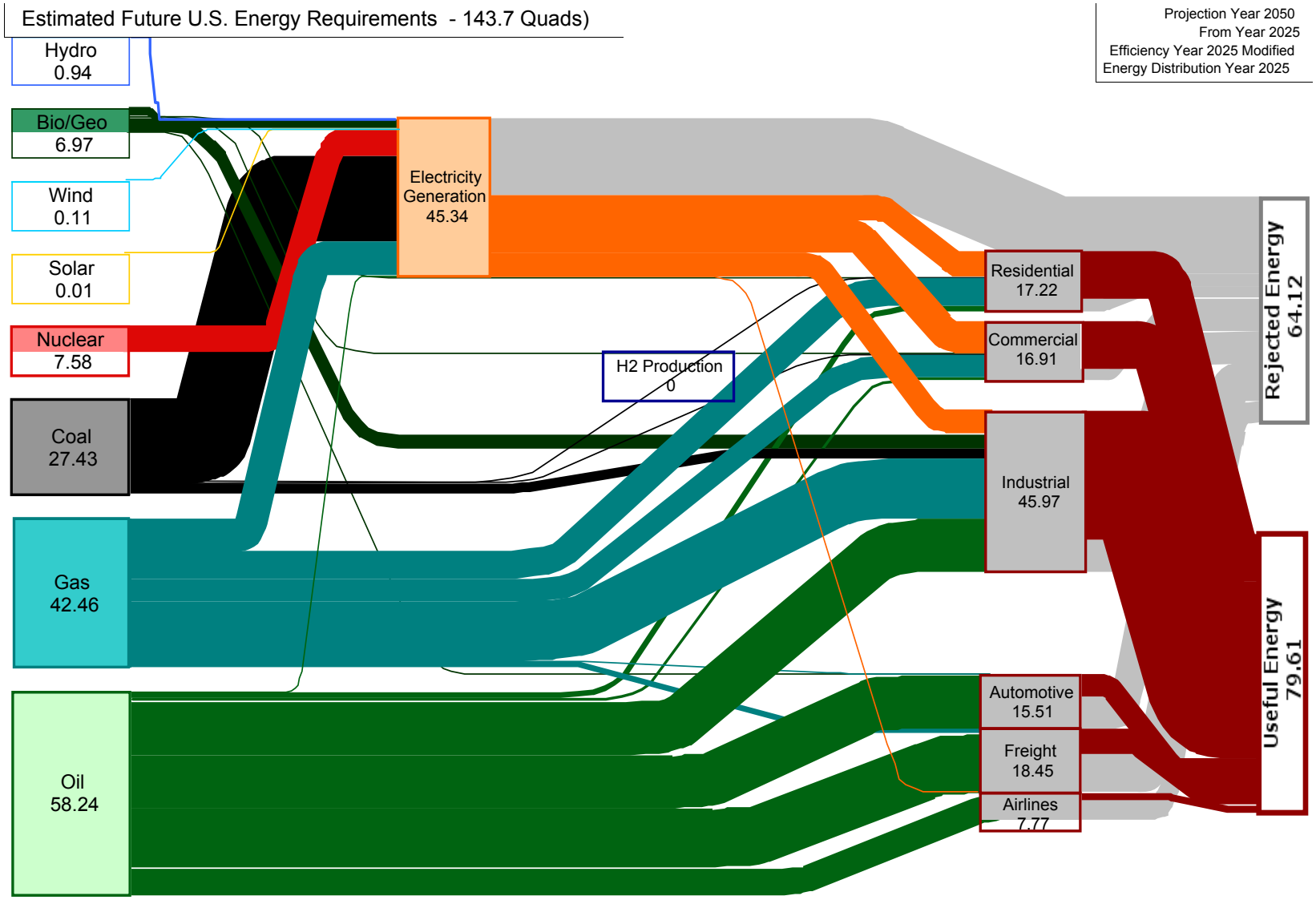



Back-up Power System
Fleet Fueling
Community Fueling
Home Fueling
ACME ELECTRONICS
Industrial Application
Primary Electricity
Hydrogen
Hydrogen-Generated Electricity
H_2 Generation Module
H_2 Storage Module
Power Module
Fuel Dispensing Module
Personal Energy Station (PES)
PES Storage Module
Hydrogen Tank

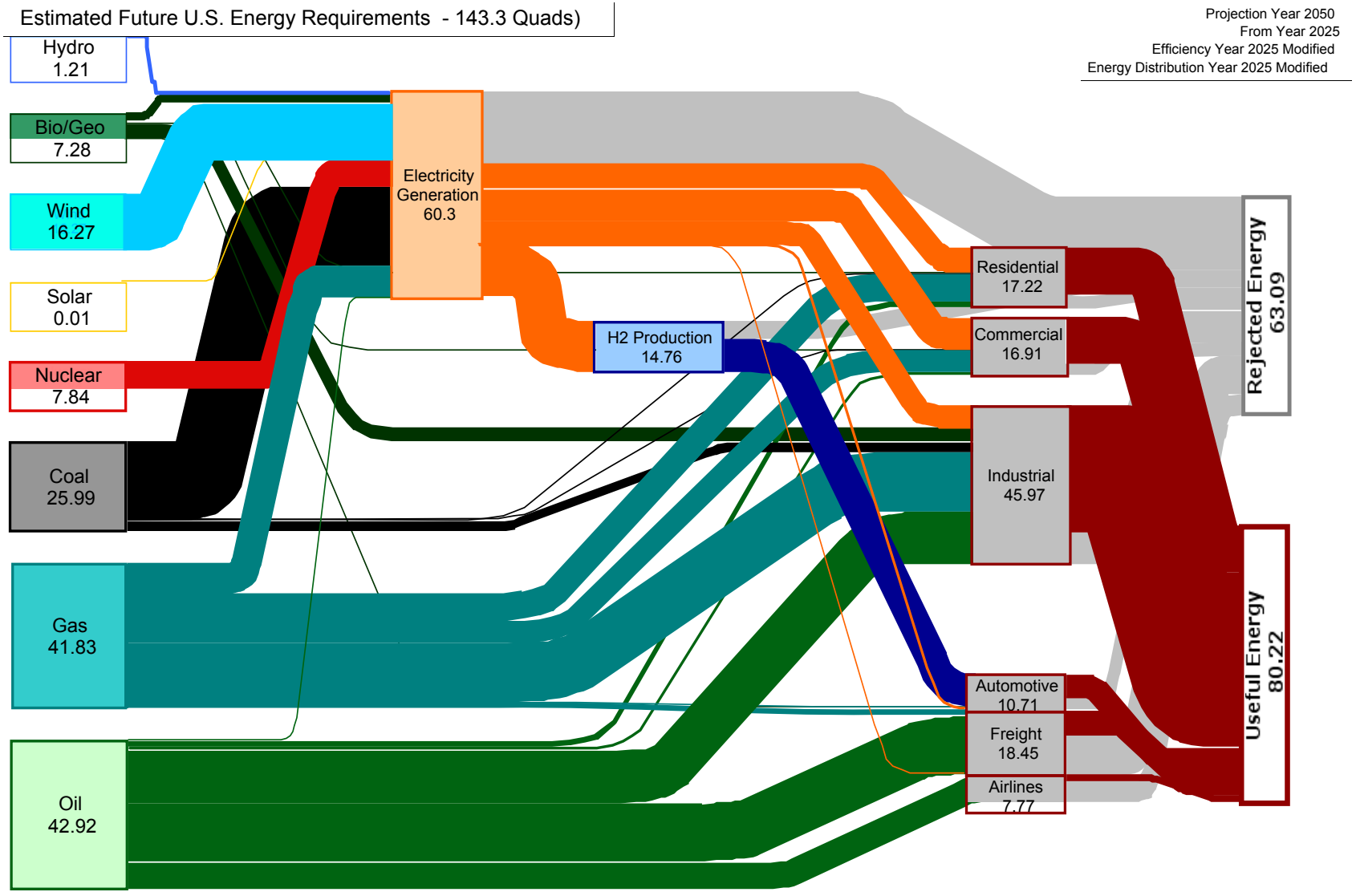
DOE-EIA: Estimated **2005** US energy use



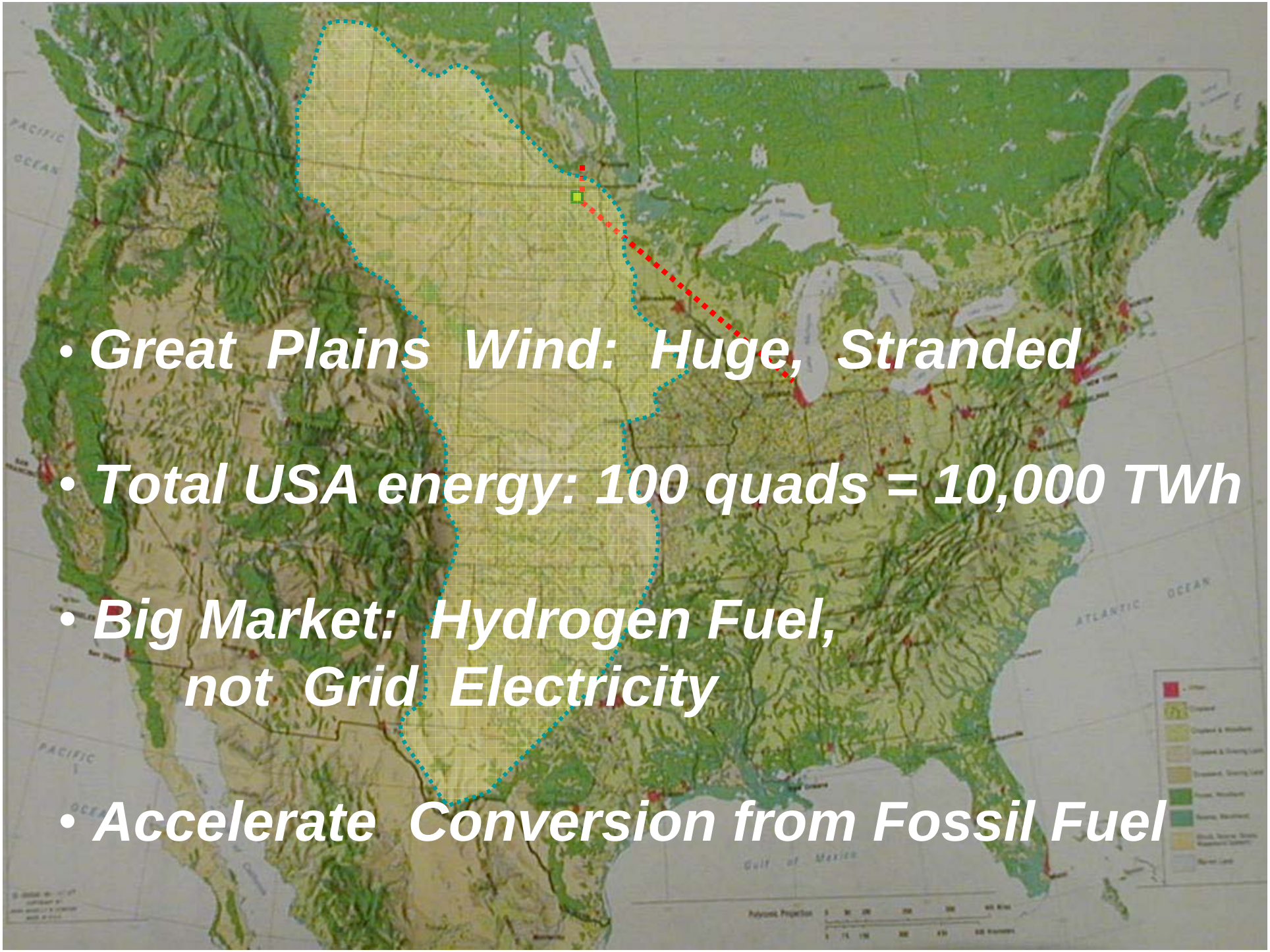
Estimated **2050** energy use (50 mpg hybrid, 50% efficient grid)



Estimated **2050** energy use (H_2 fleet using wind electrolysis)




The Great Plains Wind Resource
How shall we bring the large, stranded, Great Plains renewables to market ?


• Great Plains Wind: Huge, Stranded
• Total USA energy: 100 quads = 10,000 TWh
• Big Market: Hydrogen Fuel,
not Grid Electricity
• Accelerate Conversion from Fossil Fuel

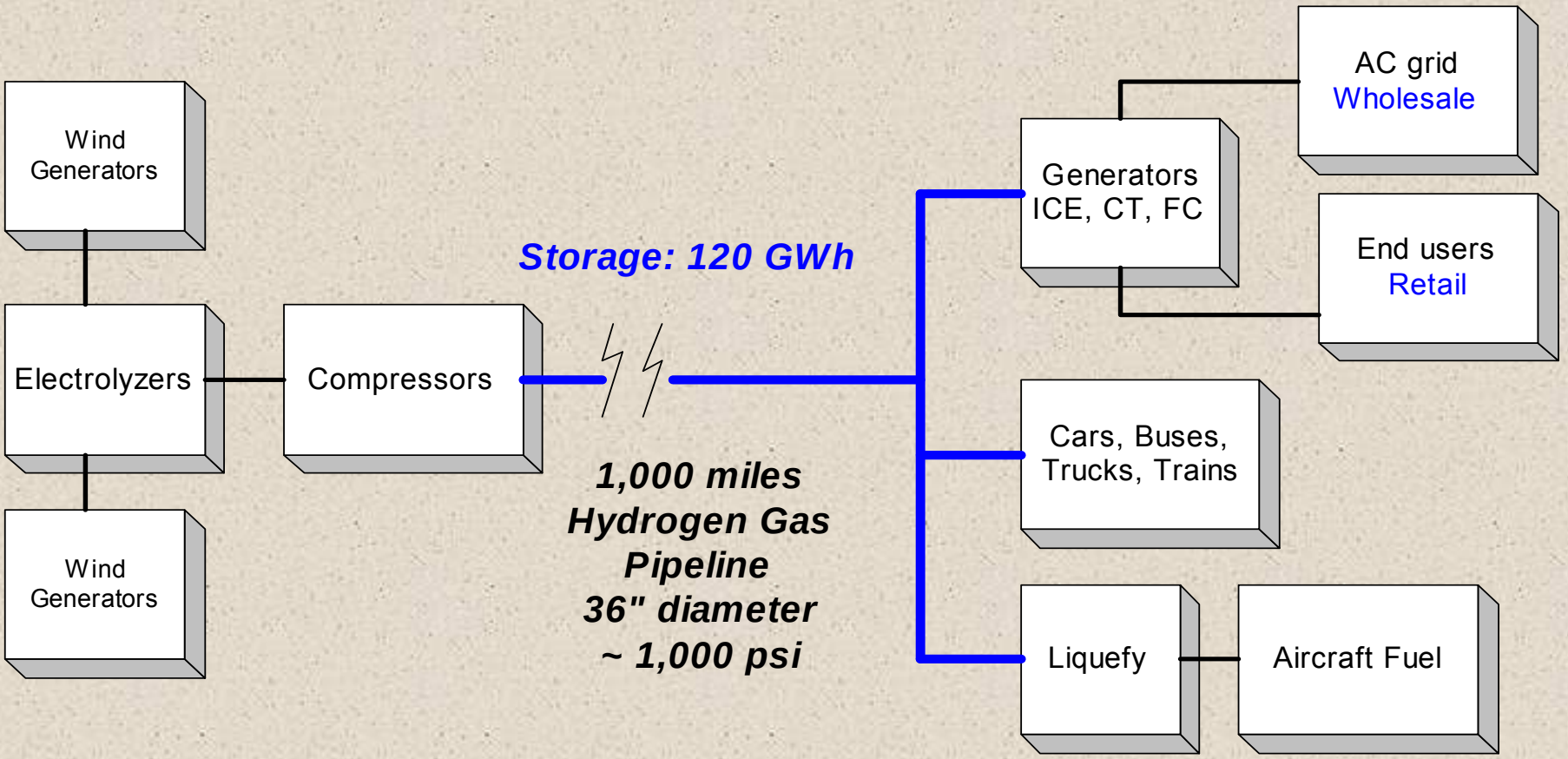
Hydrogen is NOT a clean, abundant energy source.

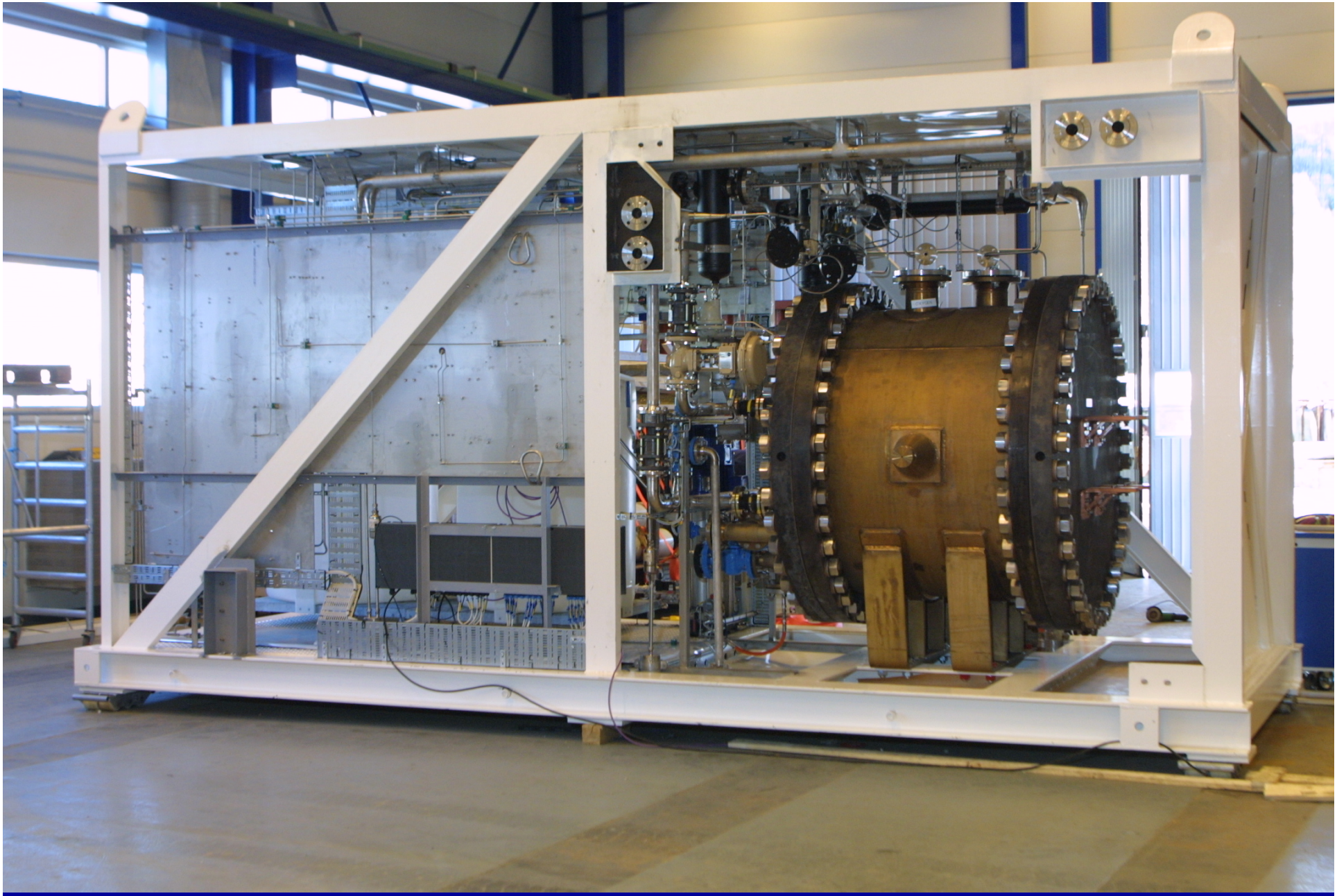
IS:

- **Energy carrier**
  - **Gathering**
  - **Transmission**
  - **Distribution**
- **Storage medium**
- **Fuel**
- **As clean as its source**

Hydrogen Transmission Scenario

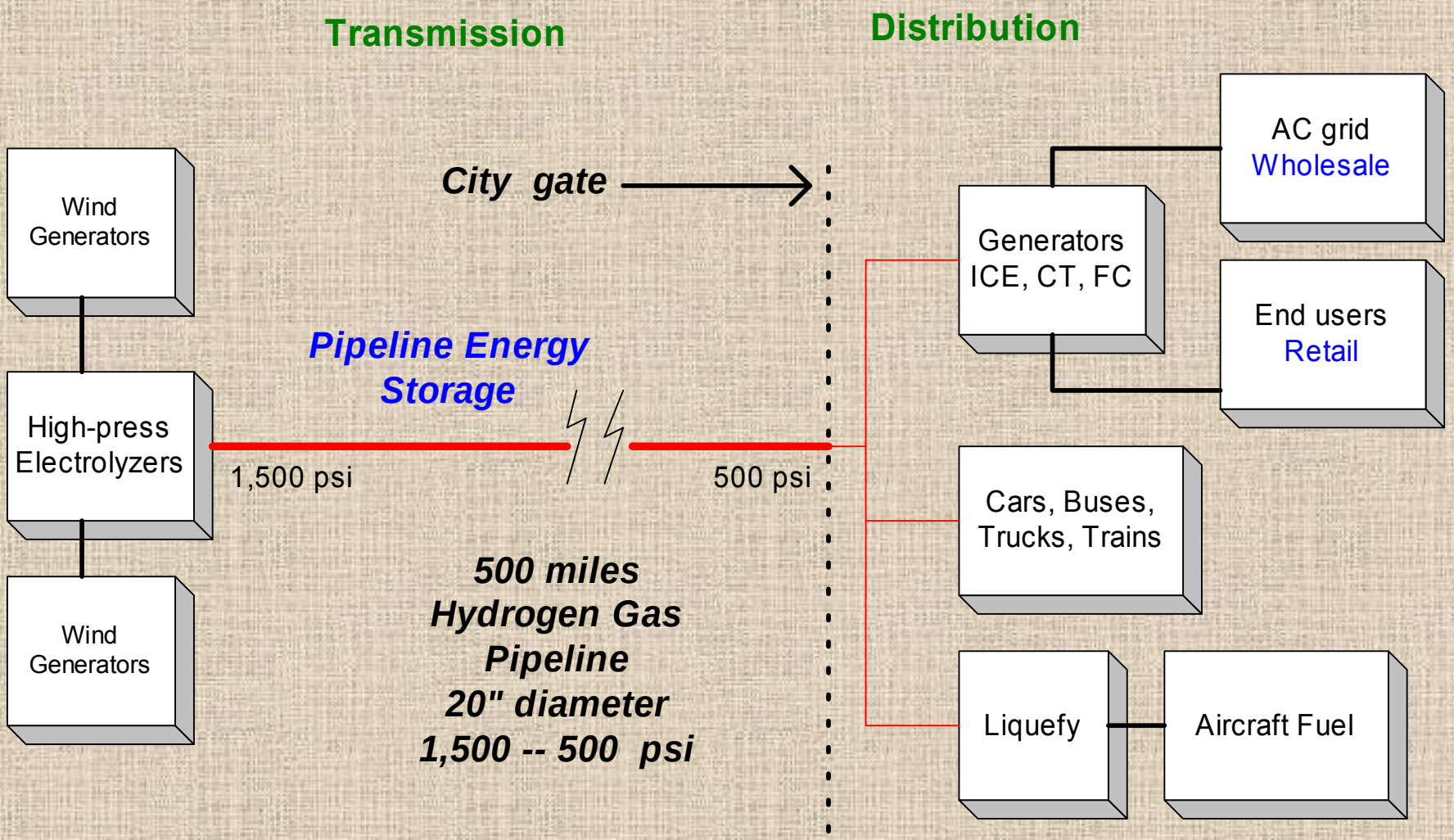
- *Low-pressure electrolyzers*
- *"Pack" pipeline: ~ 1-2 days' storage = 120 GWh*



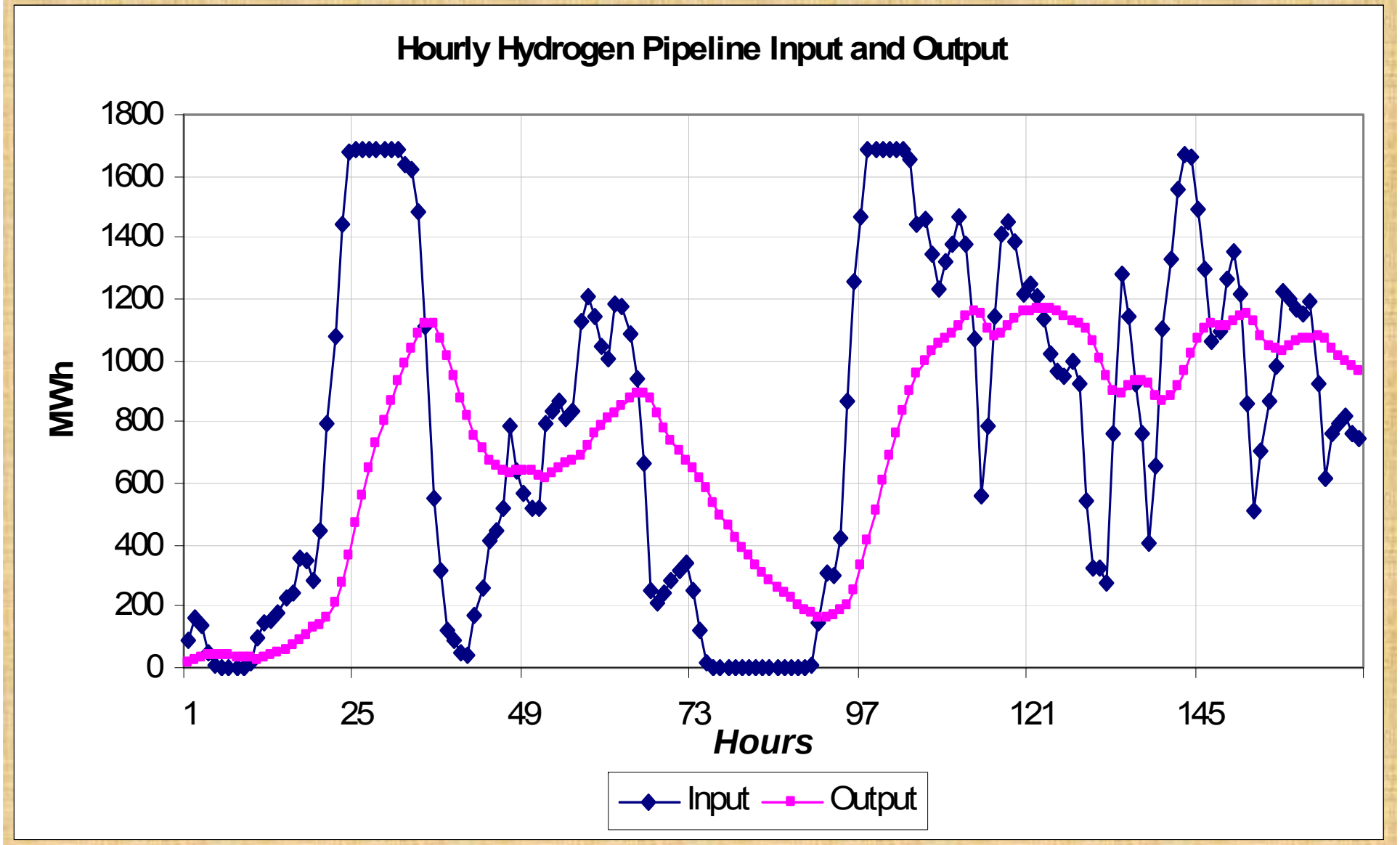


Norsk Hydro electrolyzer, KOH type
560 kW input, 130 Nm3 / hour at 450 psi (30 bar)

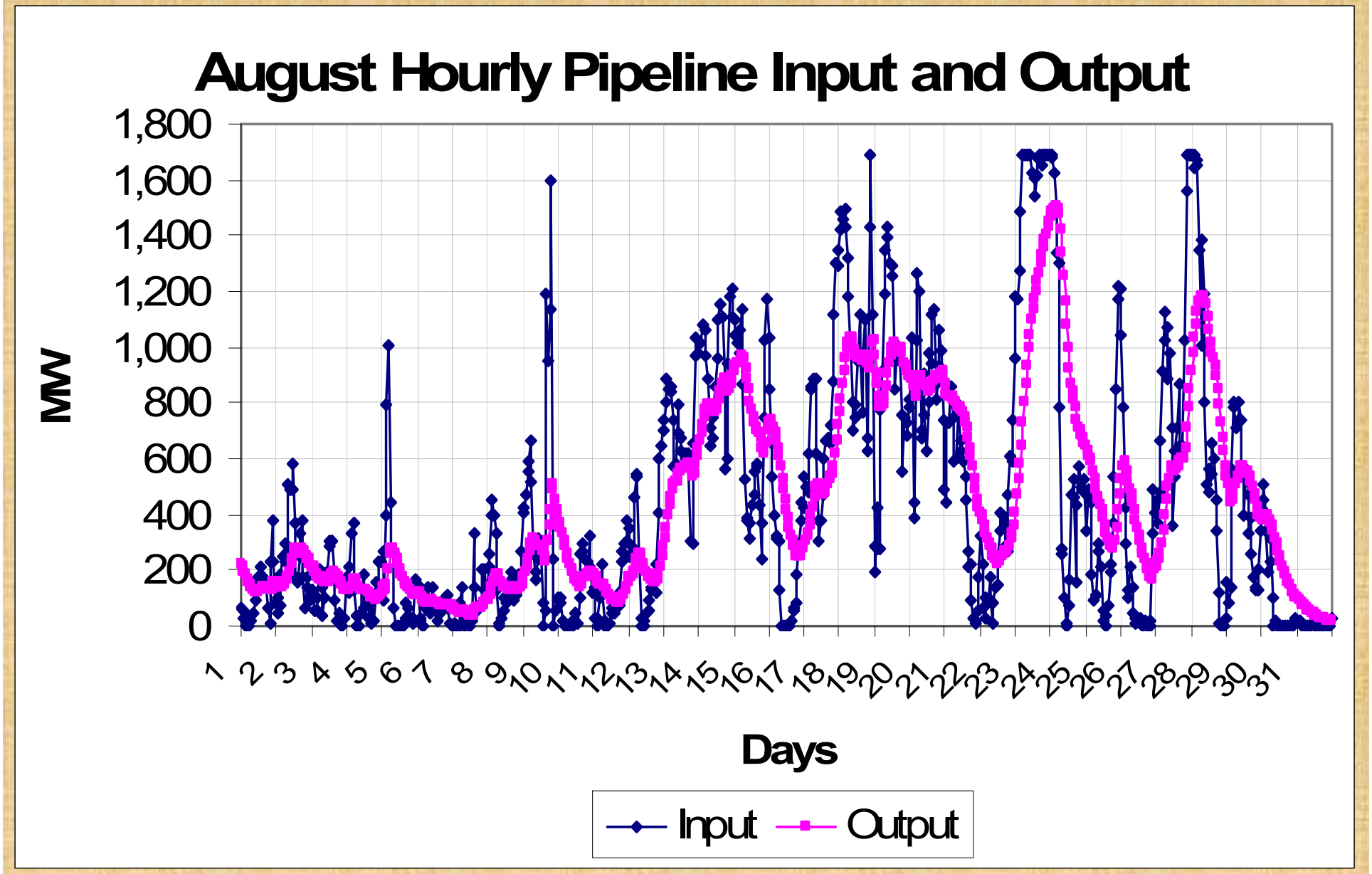
Compressorless system: No firming storage



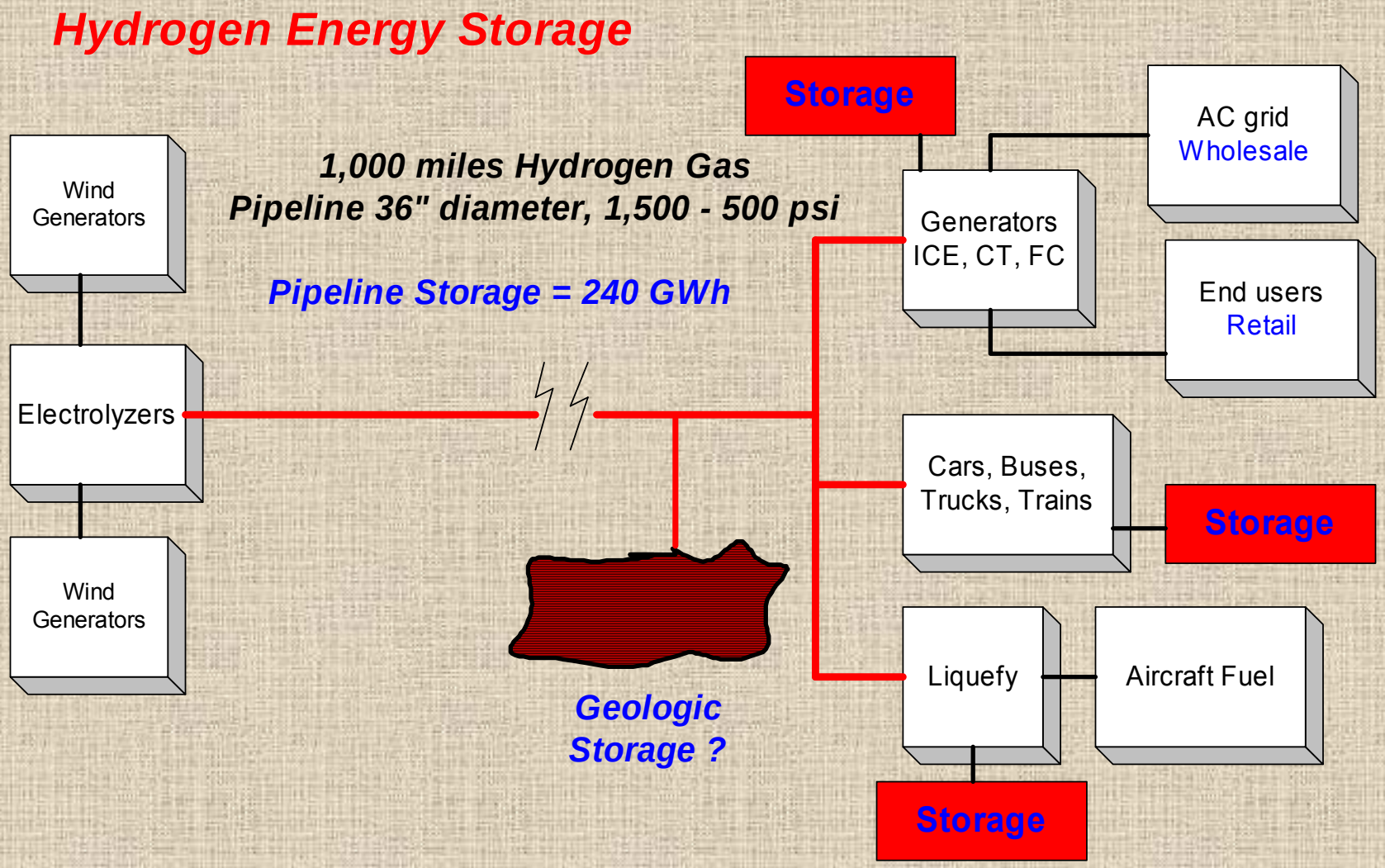
Great Plains Windplant, Pipeline Hourly Output for Typical Week



Great Plains Windplant: Actual Hourly Output

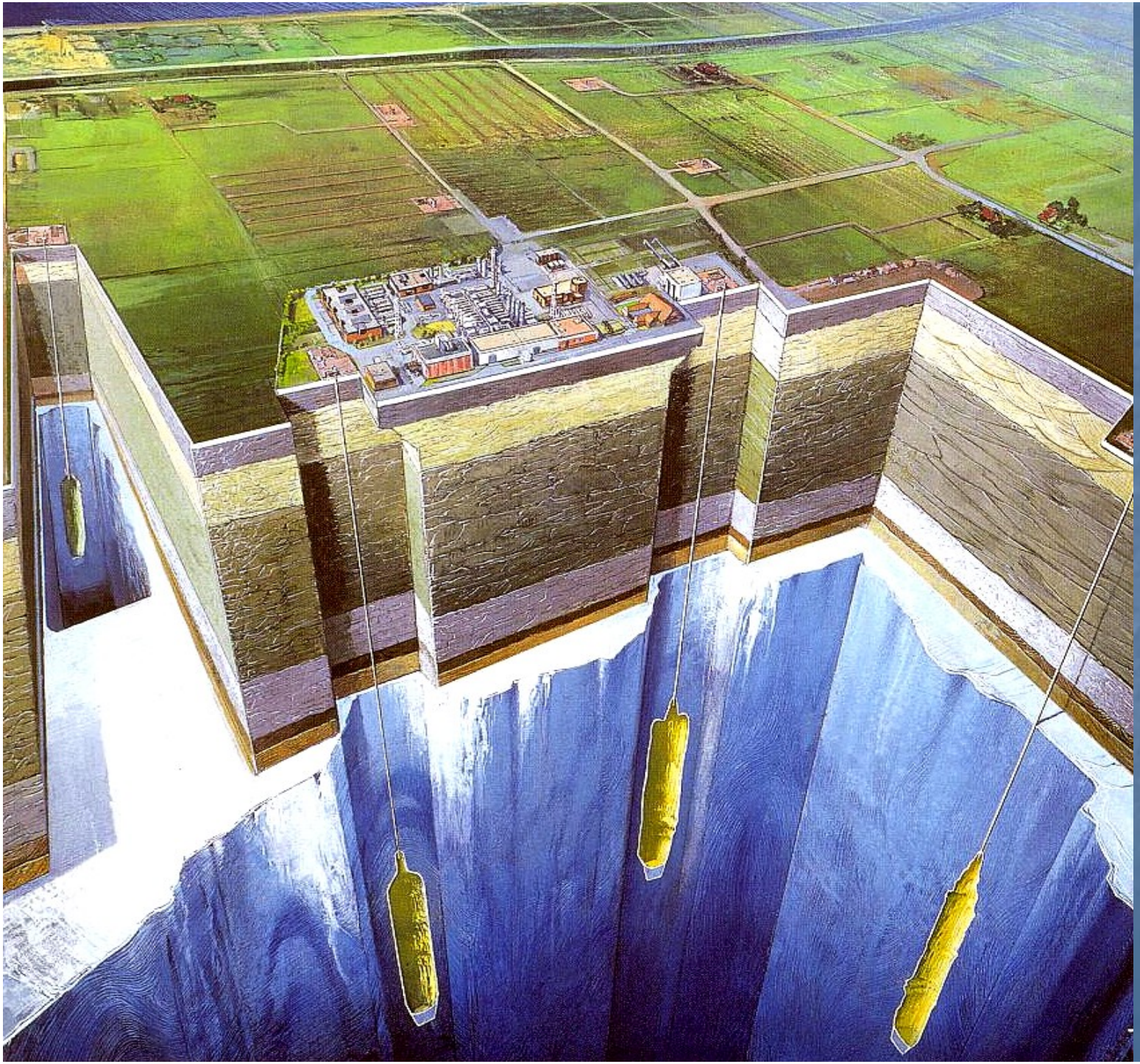


"Firming" Cavern Storage



Annual – scale "Firming"
Great Plains Wind

- **Potential, 12 states, ~50% land area:**
  - **10,000 TWh = 100 quads = entire USA energy**
  - **2,800,000 MW nameplate**
- **Seasonality:**
  - **Summer minimum**
  - **Spring – Summer maximum storage**
  - **"Firming" energy storage, per 1,000 MW wind:**
    - **as electricity = 450 GWh**
    - **as GH2 = 15,712 tons, metric @ 2,500 tons / cavern = 6 caverns**
  - **"Firming" energy storage, all great Plains wind:**
    - **as GH2 = 17,000 caverns @ $15M each = $264 billion**

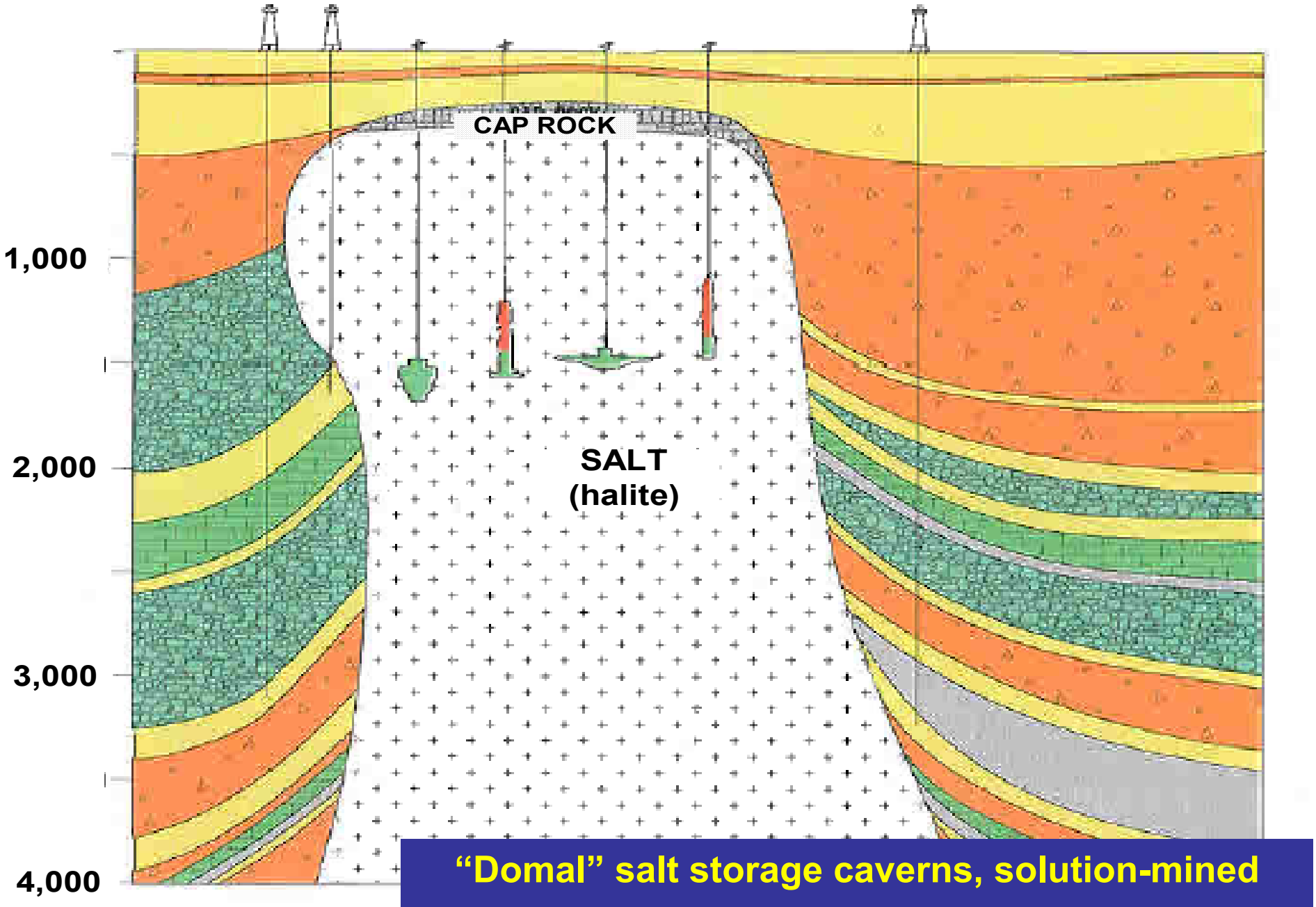


Domal Salt Storage Caverns

PB ESS

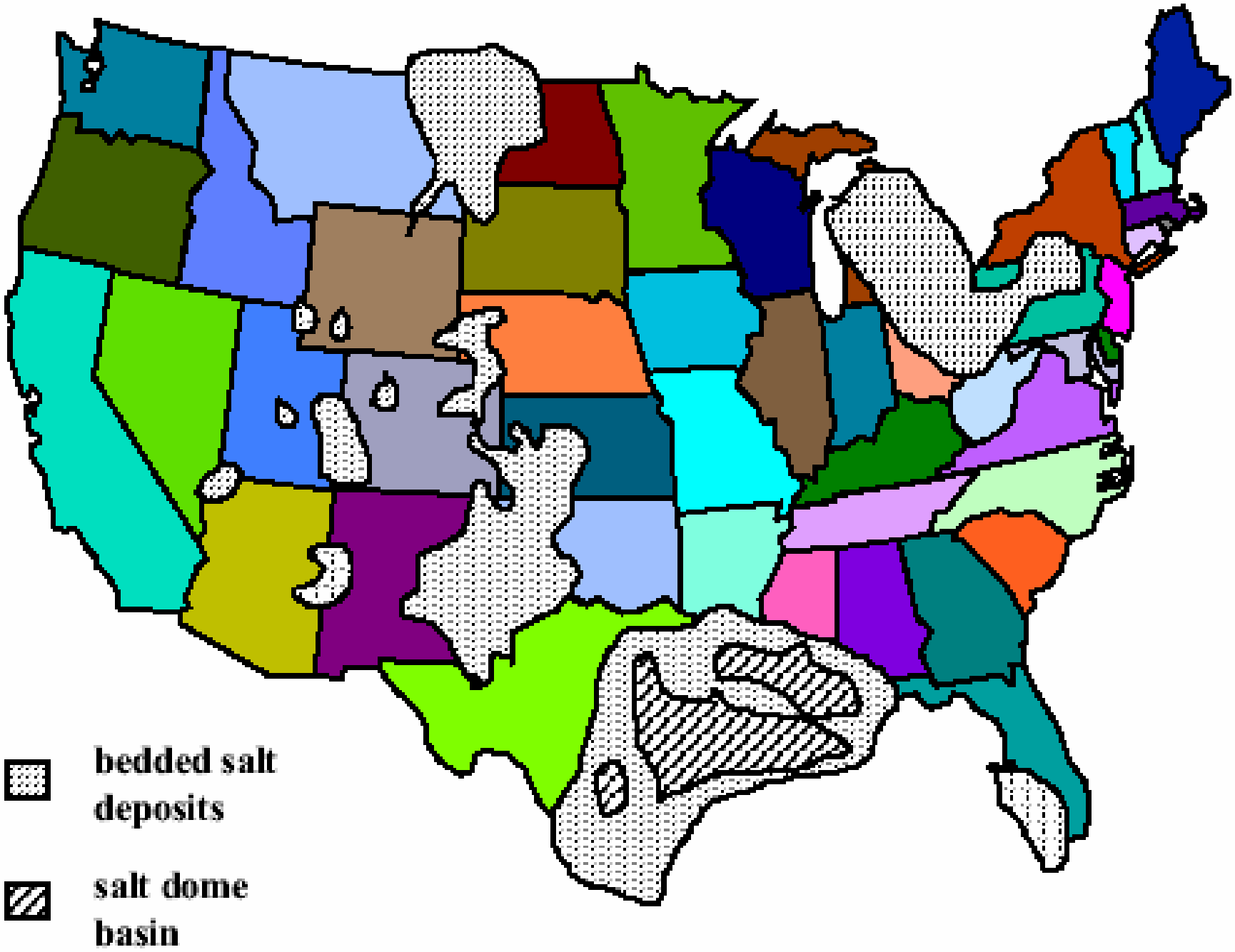
Wellhead, new Gaseous Hydrogen Storage Cavern

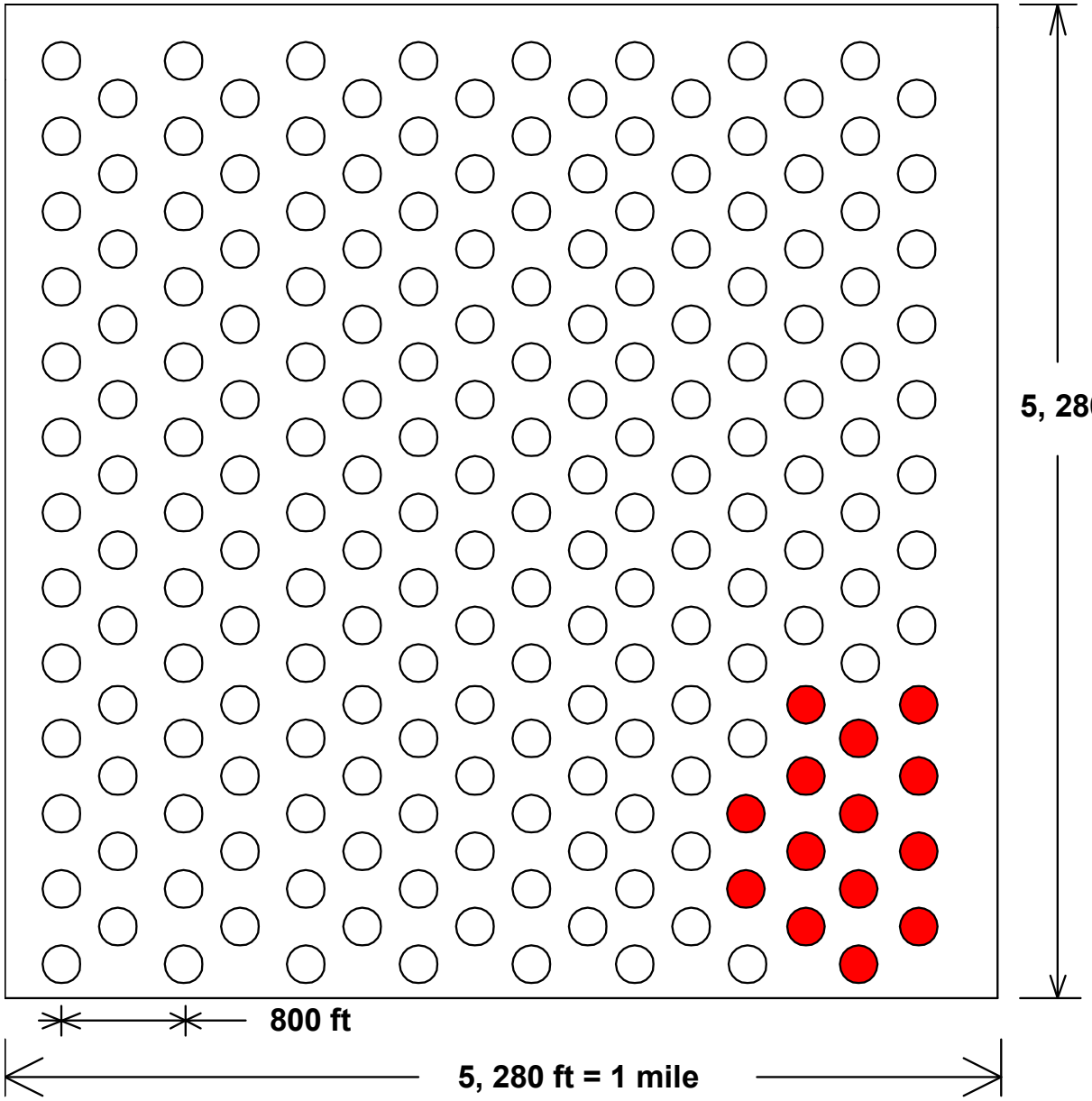
- PRAXAIR
- Commissioned 2007
- In domal salt, in Texas



"Domal" salt storage caverns, solution-mined

Meters below ground level


bedded salt deposits
salt dome basin

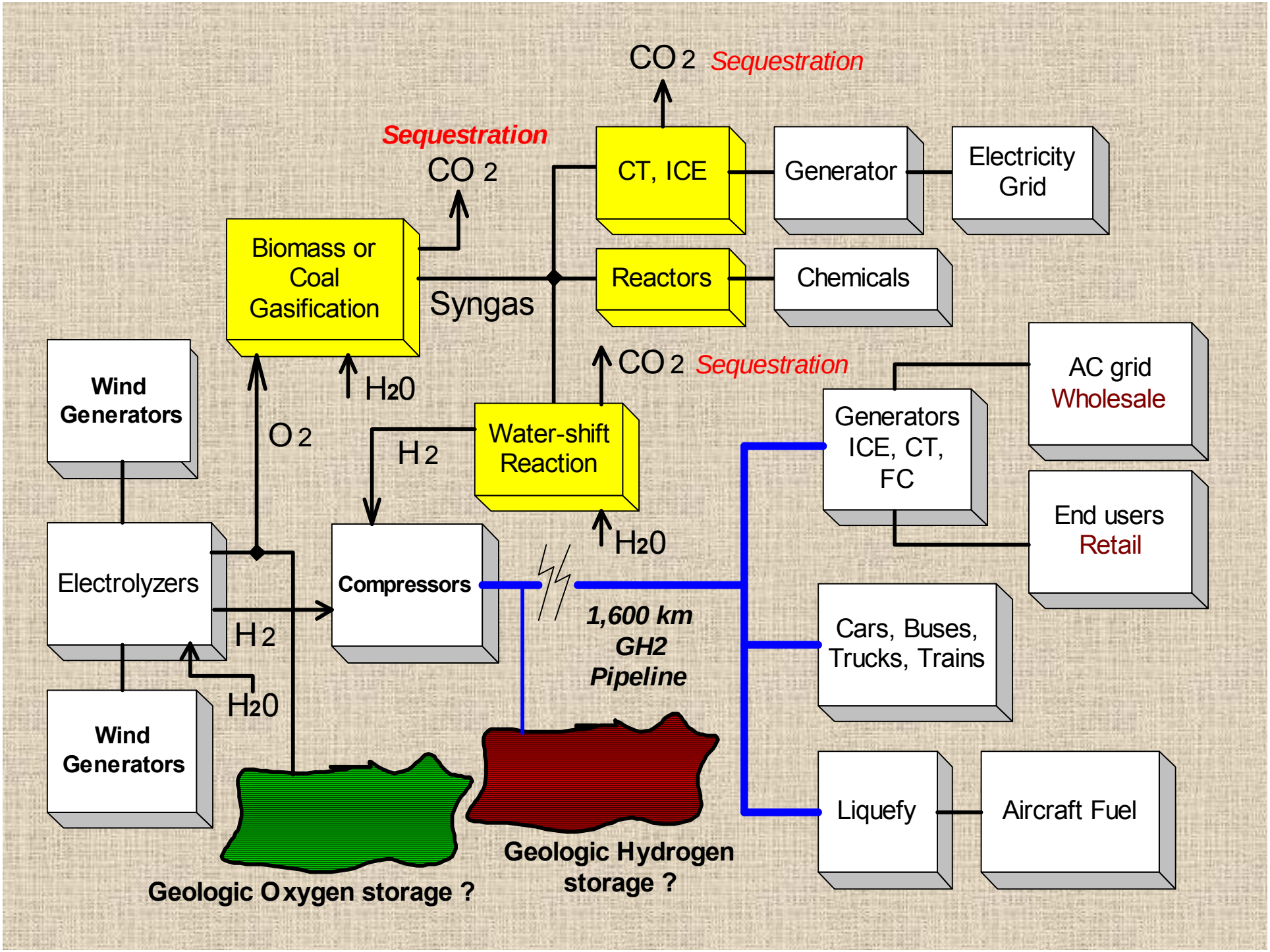


“Firm” 4,000 MW Great Plains wind

14 caverns

Maximum Cavern Packing Density

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

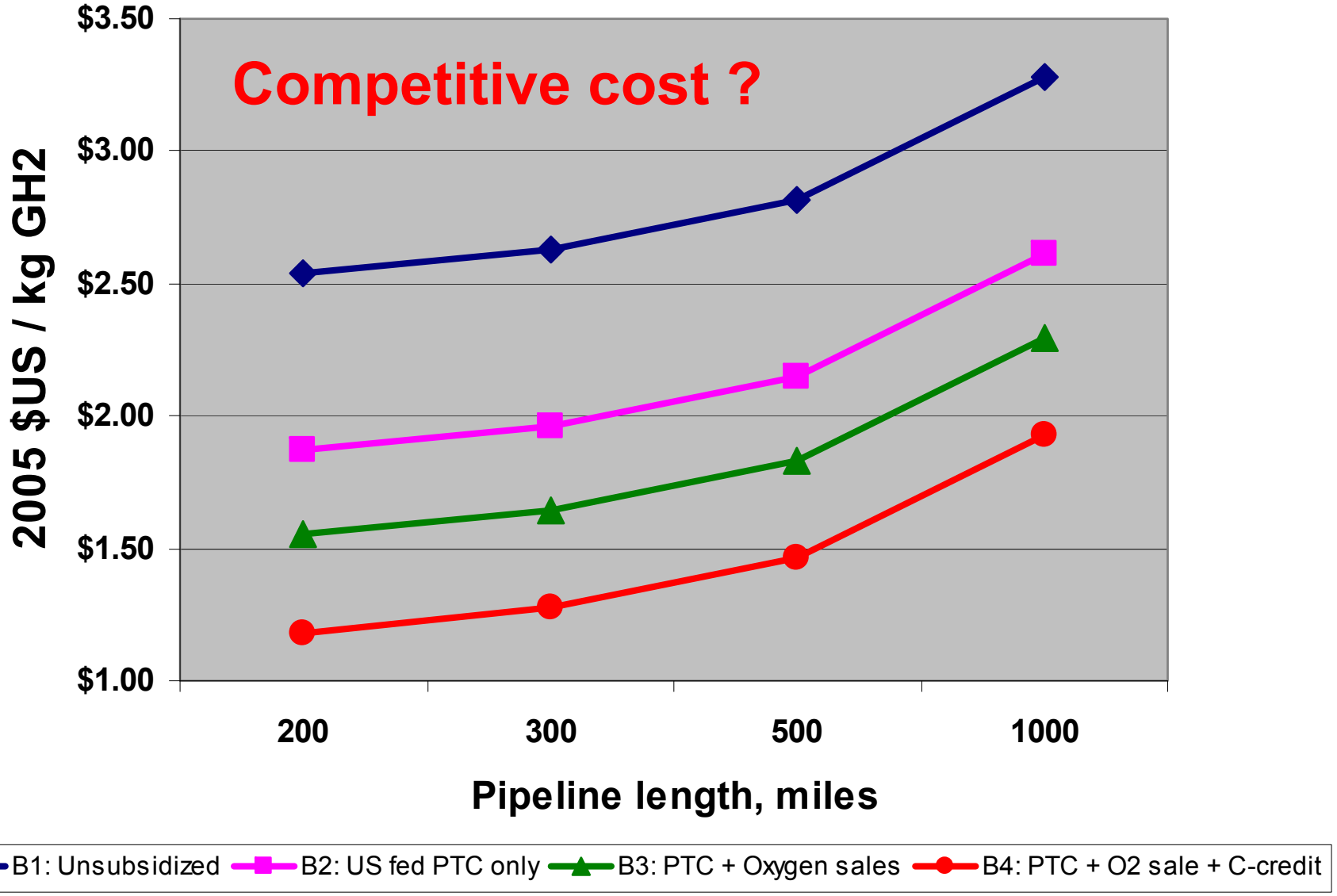

CO 2 Sequestration
Sequestration
CO 2
CT, ICE
Generator
Electricity Grid
Biomass or Coal Gasification
Syngas
Reactors
Chemicals
CO 2 Sequestration
H20
Wind Generators
O 2
H 2
Water-shift Reaction
AC grid Wholesale
Generators ICE, CT, FC
End users Retail
Electrolyzers
Compressors
H20
1,600 km GH2 Pipeline
H 2
Cars, Buses, Trucks, Trains
H20
Wind Generators
Liquefy
Aircraft Fuel
Geologic Hydrogen storage ?
Geologic Oxygen storage ?

Total Installed Capital Cost
1,000 mile pipeline, $US million

Windplant size	**1,000 MW**	**2,000 MW**
Wind generators	$ 1,000	$ 2,000
Electrolyzers	500	1,000
Pipeline, 20” *	1,100	1,100
TOTAL	$ 2,600	$ 4,100

* $ 1.1 M / mile

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



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

Windplant size	**1,000 MW** [million]	**2,000 MW** [million]
Wind generators	$ 1,000	$ 2,000
Electrolyzers	500	1,000
Pipeline, 20"	1,100	1,100
# storage caverns	[4]	[8]
Caverns @ $10M ea	40	80
Cushion gas @ $5M ea	20	40
TOTAL	$ 2,660	$ 4,220

Cavern storage: ~ 3 % of total capital cost

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

Windplant size	**1,000 MW** [million]	**2,000 MW** [million]
Wind generators	$ 1,000	$ 2,000
Electrolyzers	500	1,000
Pipeline, 20"	1,100	1,100
# storage caverns	[4]	[8]
Caverns @ $50M ea	200	400
Cushion gas @ $5M ea	30	60
TOTAL	$ 2,830	$ 4,560

Cavern storage: ~ 10 % of total capital cost

Optimistic: "Firming" Storage Capital Cost for ALL Great Plains Wind

Adds VALUE: strategic, market

- Salt caverns: ~ 17,000
  - Excavate: $10 M each $ 170 B
  - Cushion gas: $5 M each $ 85 B
  - Total **$ 255 B**
- NH3 tanks: ~ 5,000
  - Capital $25 M each **$125 B**

3: Shortest path to benign, secure, abundant energy

- Anhydrous Ammonia (NH3) pipelines, tanks
  - Conversion, gathering
  - Transmission
  - Storage: tanks
  - Distribution
- ’08 Farm Bill Sec 9003:

  “Renewable Fertilizer Research”
- “Winds of Change”: IA, $100K USDA, wind → NH3
- Iowa Power Fund: 2 R+D applications

Anhydrous Ammonia, NH_3 Fertilizer → Fuel

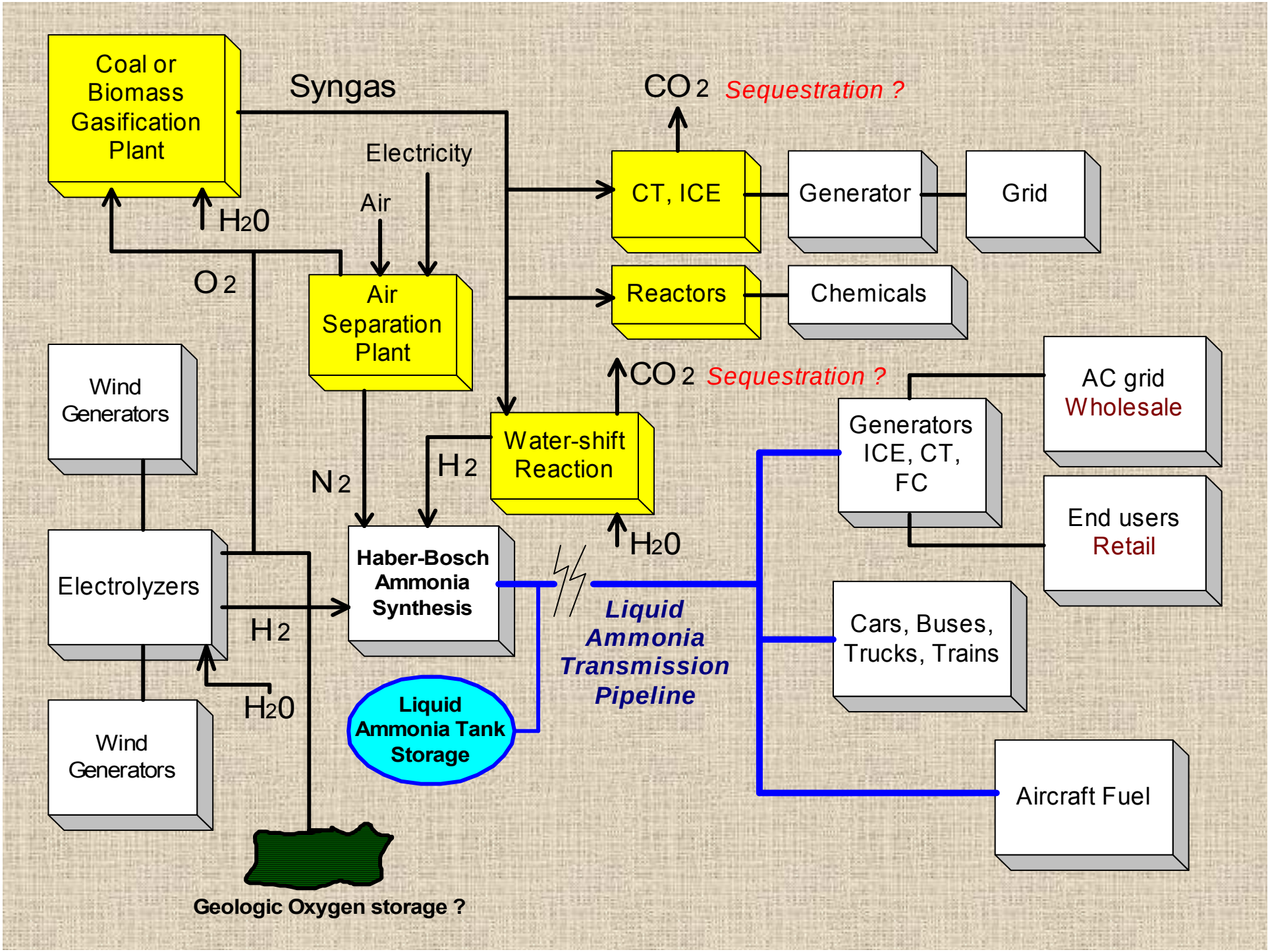
Business case:

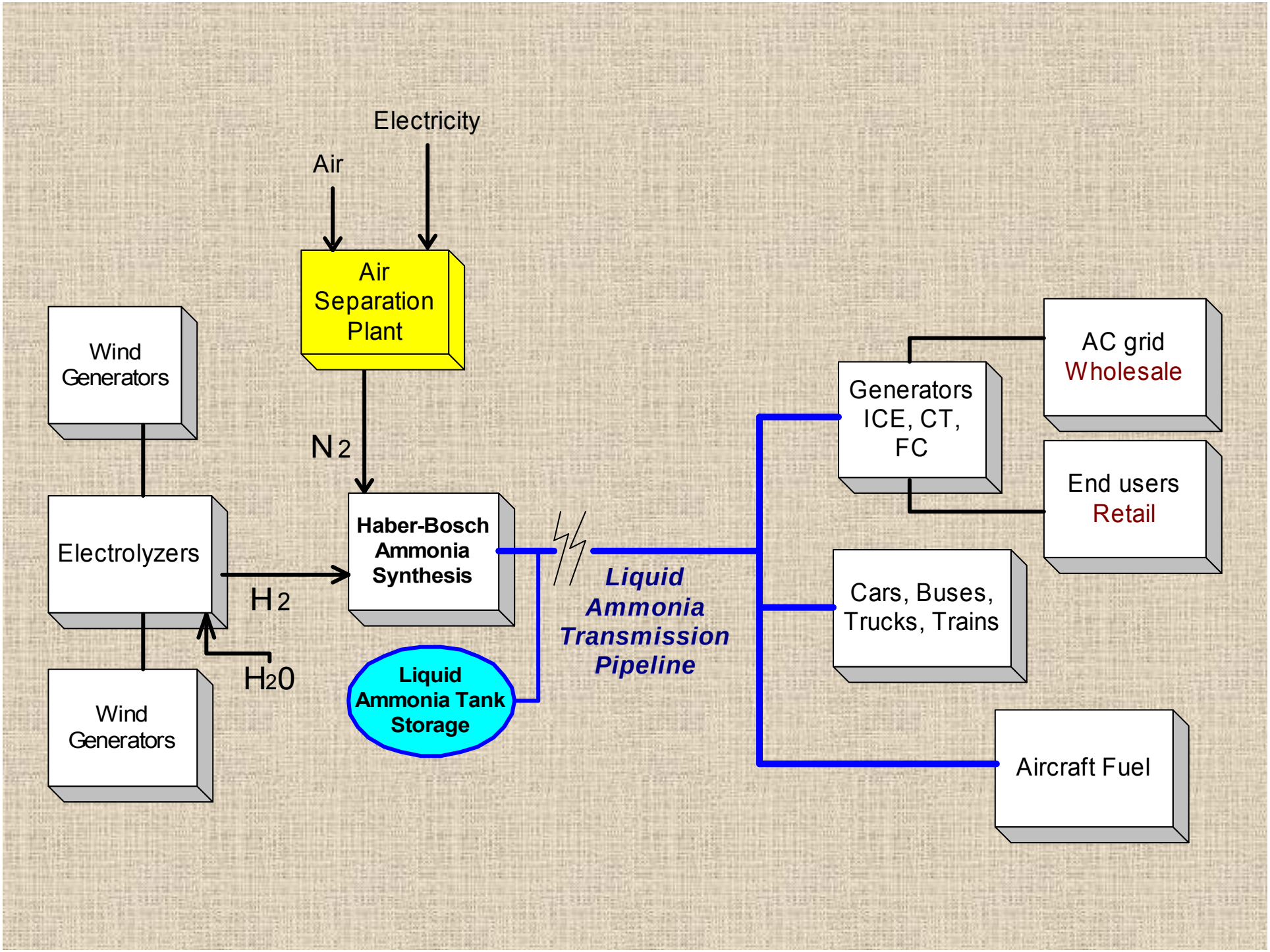
- Market size, share:
  - 15 mt / yr ag fertilizer
  - 5 mt / yr other
  - ? mtT / yr NH3 fuel
  - ICE, CT, fuel cell
- RE - NH3 competes with coal, imports

"Ammonia Nation ?"

Anhydrous ammonia (NH3)

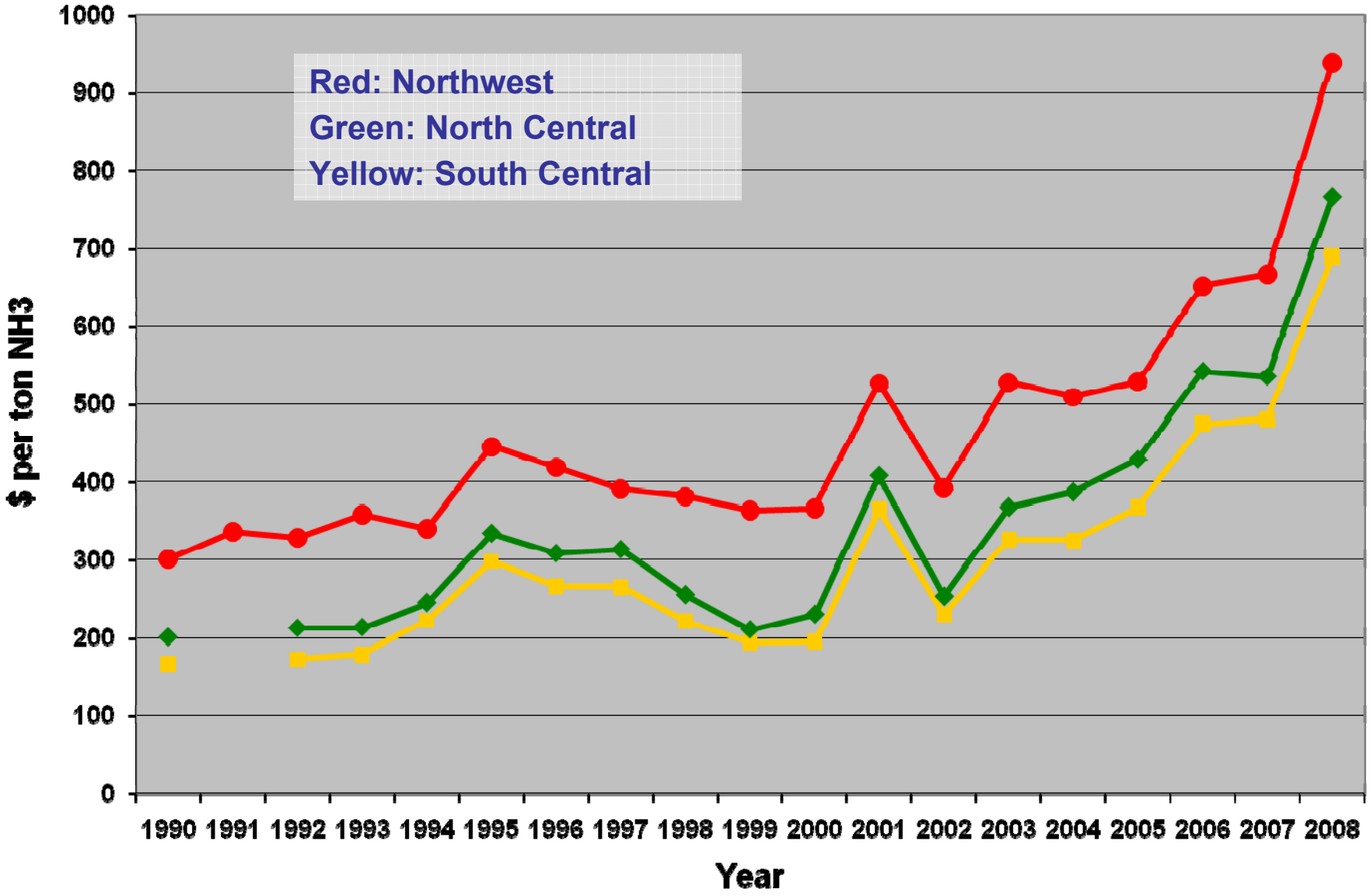
- Low-cost transmission, storage: liquid
- Transportation fuel
- Stationary generation, CHP
- Total USA annual energy '02 - 06
  - 100 quads
  - 10,000 TWh
- More renewables than coal
- Coal limits:
  - Only 200 year supply ?
  - CCS limits: where to put the CO2 ?


Coal or Biomass Gasification Plant
Syngas
CO2 Sequestration ?
Electricity
Air
H20
CT, ICE
Generator
Grid
O2
Air Separation Plant
Reactors
Chemicals
Wind Generators
CO2 Sequestration ?
AC grid Wholesale
Generators ICE, CT, FC
Water-shift Reaction
N2
H2
End users Retail
H20
Electrolyzers
Haber-Bosch Ammonia Synthesis
Liquid Ammonia Transmission Pipeline
Cars, Buses, Trucks, Trains
H2
H20
Wind Generators
Liquid Ammonia Tank Storage
Aircraft Fuel
Geologic Oxygen storage ?


Electricity
Air
Air Separation Plant
Wind Generators
N2
Electrolyzers
Haber-Bosch Ammonia Synthesis
H2
H20
Wind Generators
Liquid Ammonia Tank Storage
Liquid Ammonia Transmission Pipeline
Generators ICE, CT, FC
AC grid Wholesale
End users Retail
Cars, Buses, Trucks, Trains
Aircraft Fuel

NH_3 Ag Fertilizer Tanks, Wind Generators, NW Iowa

Regional ammonia prices paid by U.S. farmers in April



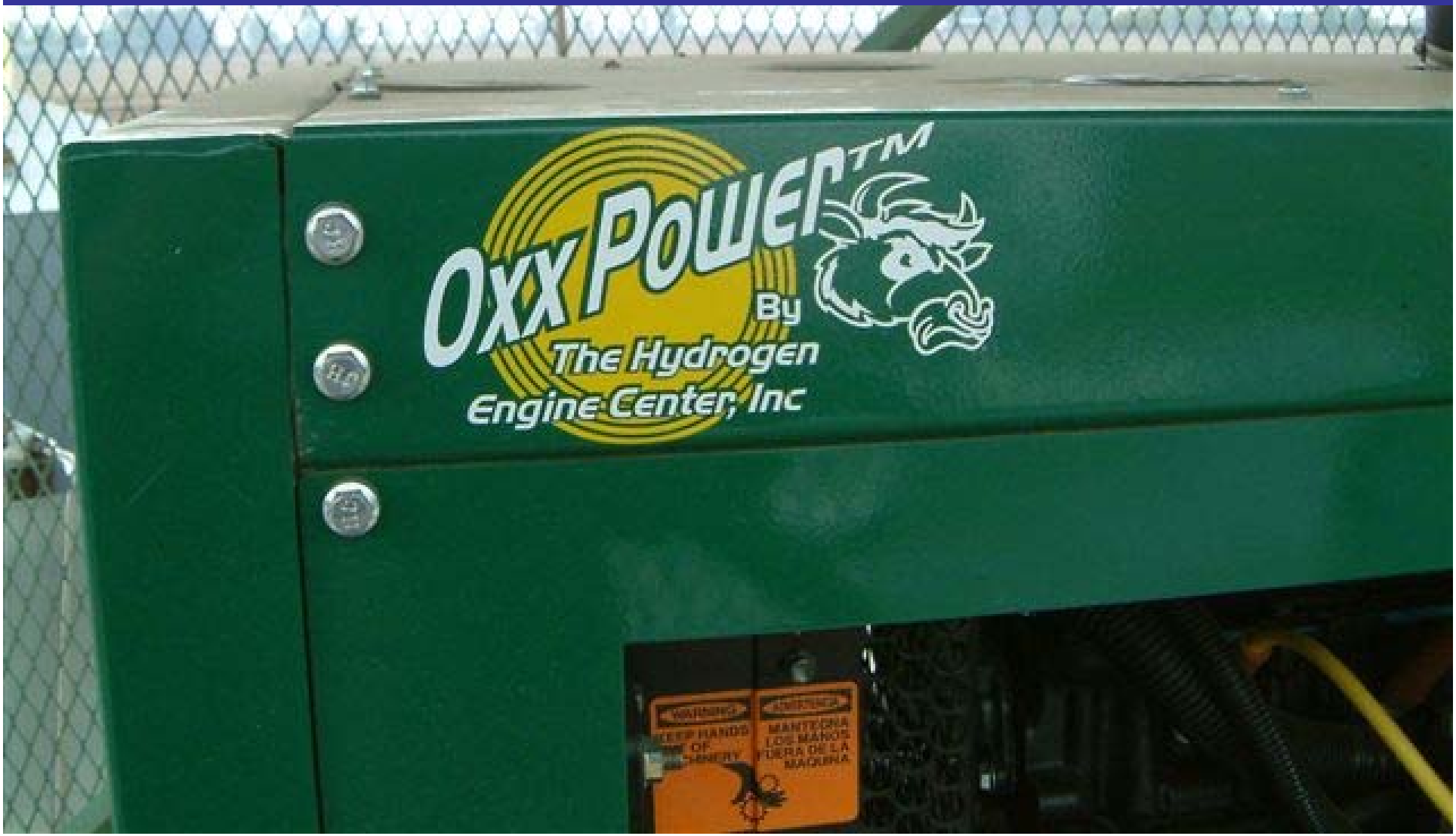
Ammonia-fueled ICE, irrigation pump, Visalia, CA
Installed Nov 06

1,000 hours, ICE, 6 cyl, 100 hp
75% ammonia, 25% propane

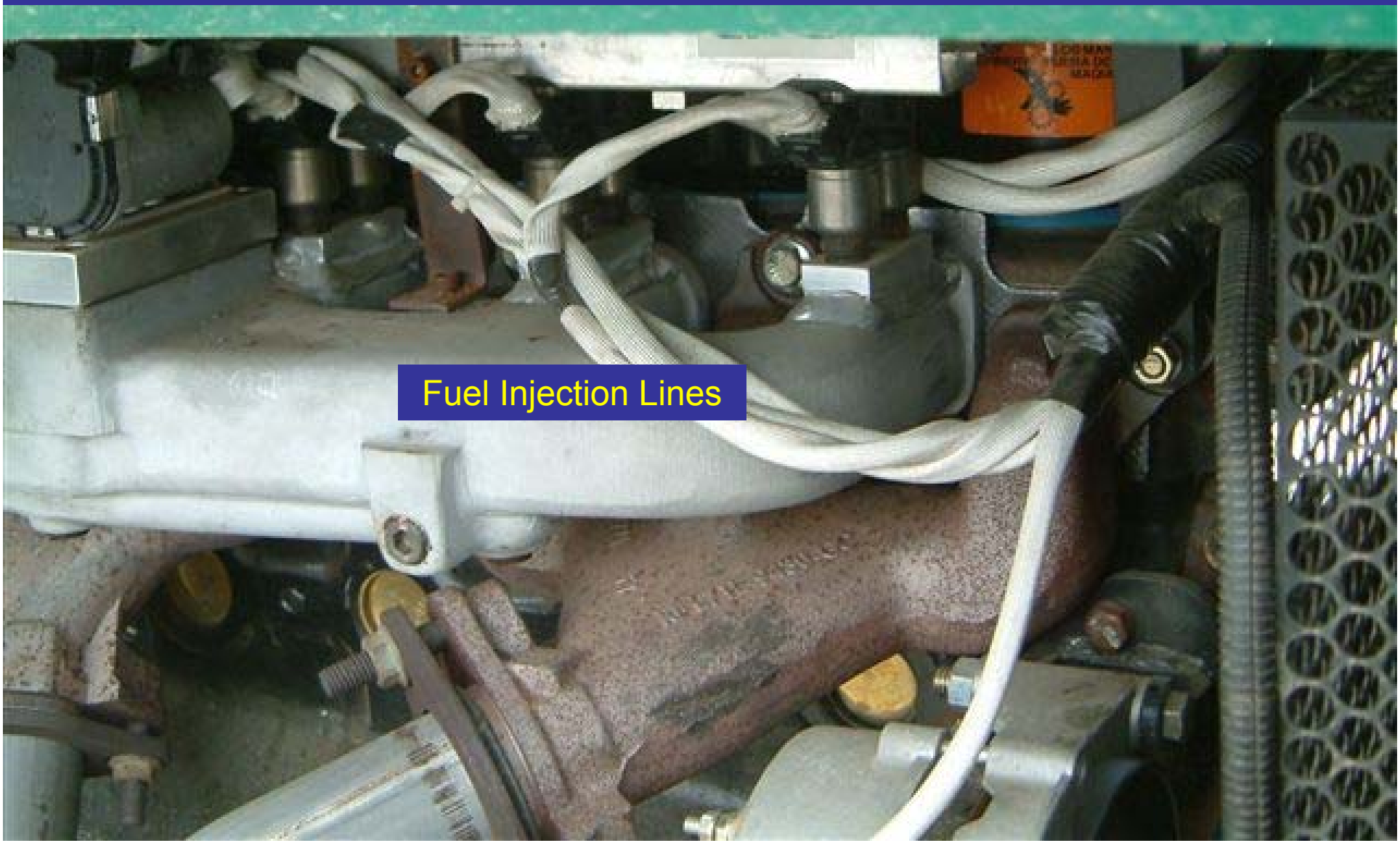
Hydrogen Engine Center, Algona, IA

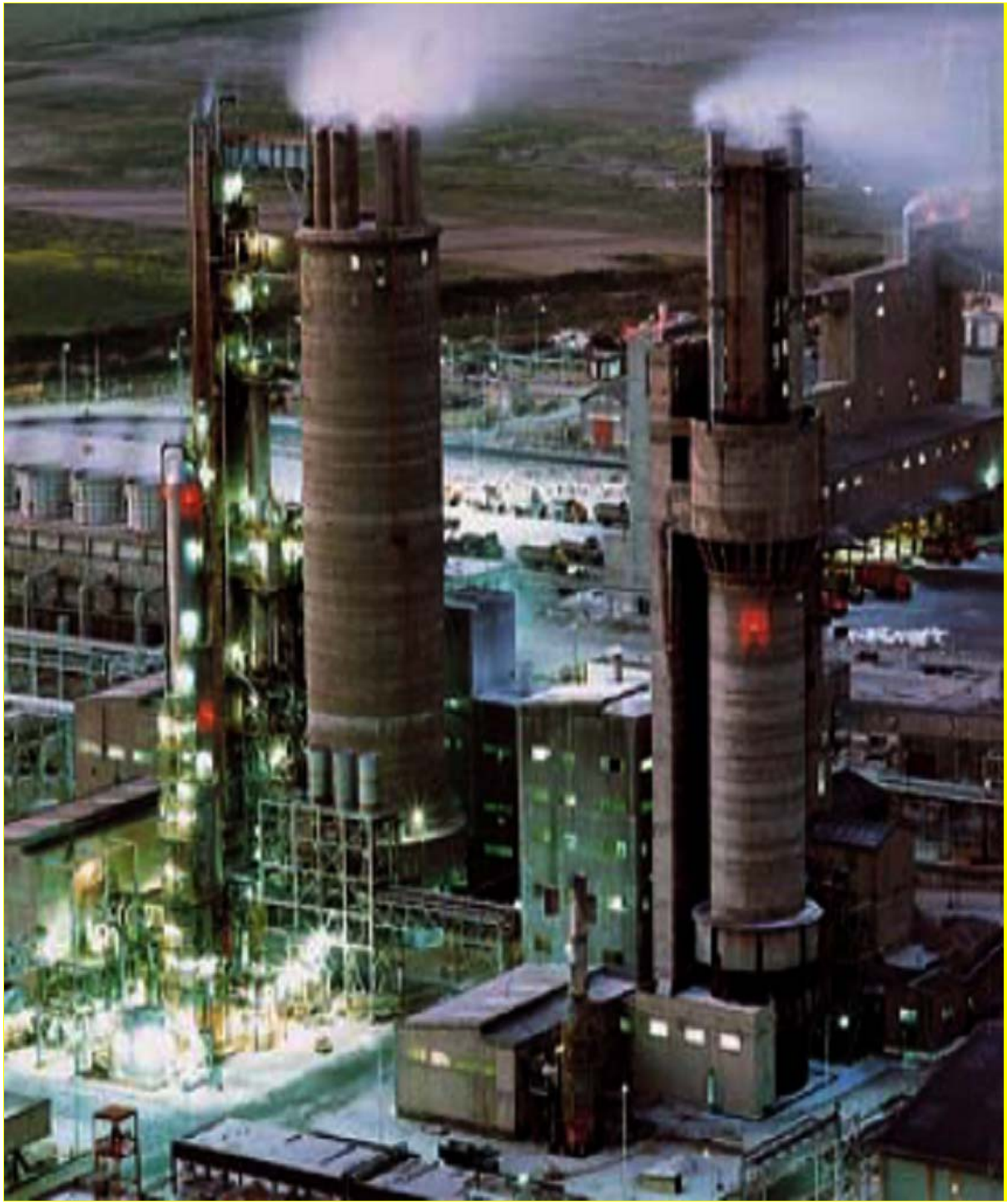
1,000 hours, ICE, 6 cyl, 100 hp

75% ammonia, 25% propane



Hydrogen Engine Center, Algona, IA
Fuel Injected ICE, 6 cyl, 100 hp
75% ammonia, 25% propane





Ammonia
(NH_3)
Synthesis
Plant

Natural Gas

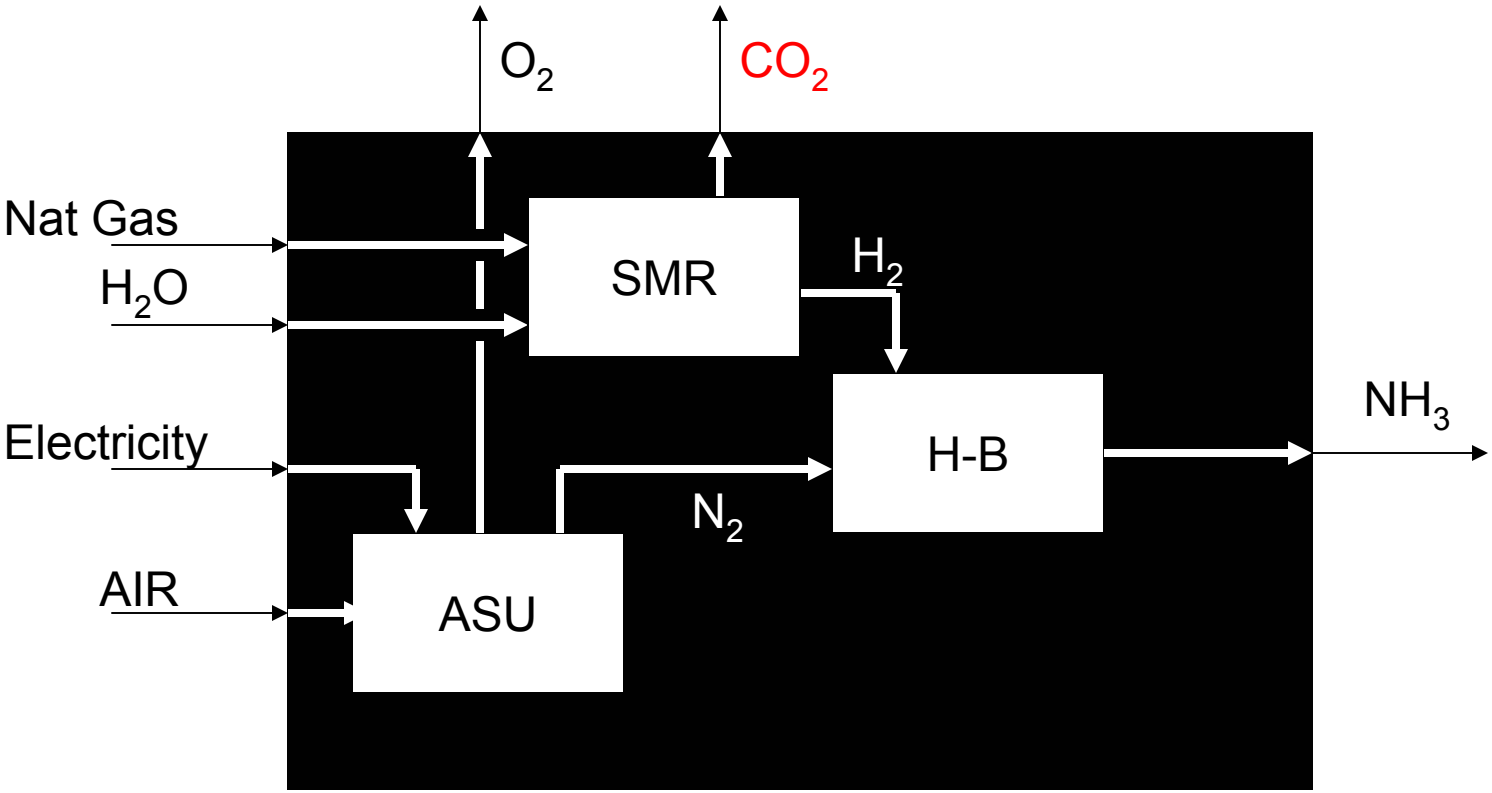
Feed

1 – 3,000 tpd

Haber-Bosch
“Synloop”

Inside the Black Box: Steam Reforming + Haber-Bosch

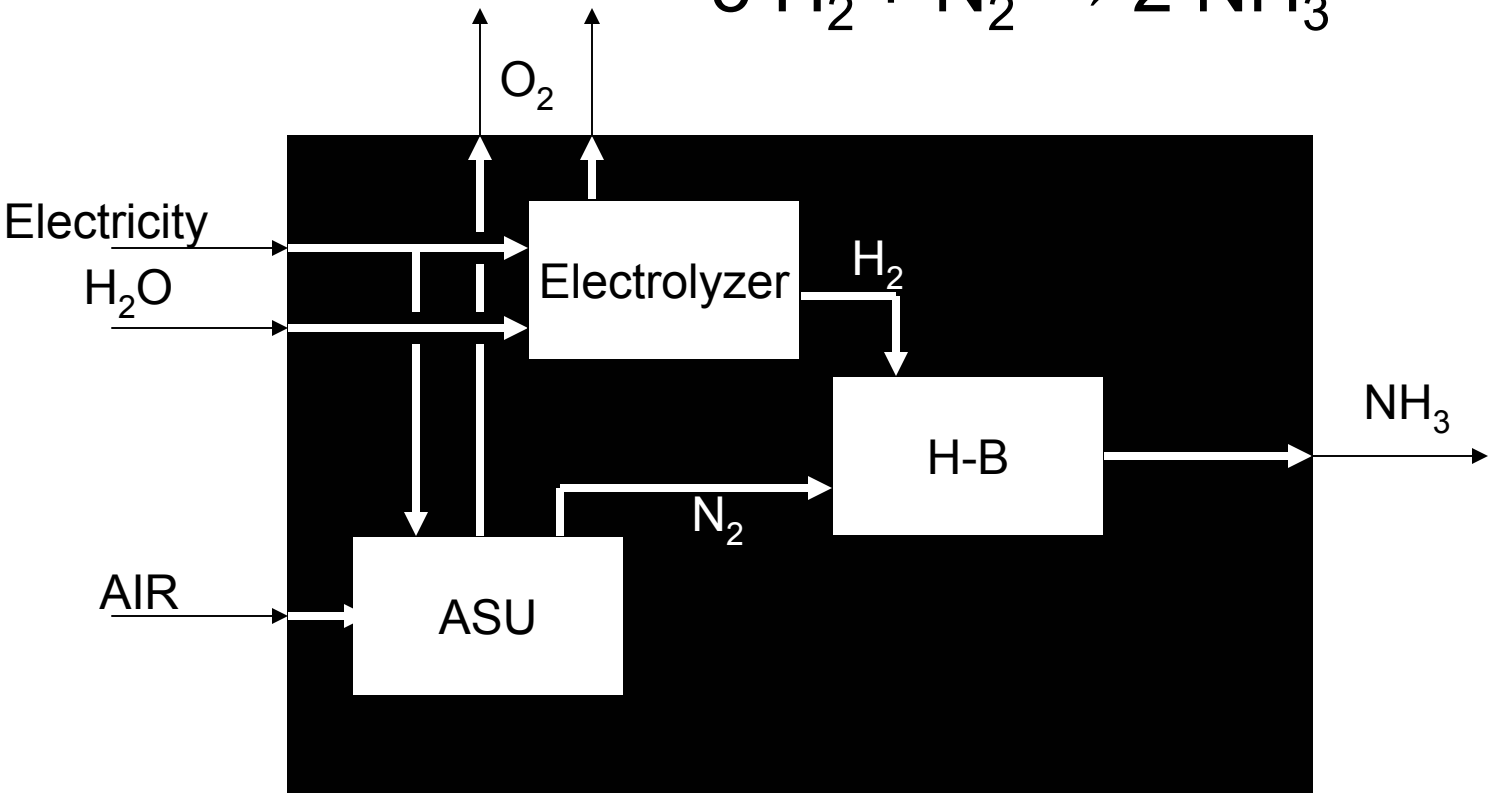
$$3\ CH_4 + 6\ H_2O + 4\ N_2 \rightarrow 3\ CO_2 + 8\ NH_3$$



Energy consumption ~33 MBtu (9500 kWh) per ton NH_3

Inside the Black Box: HB Plus Electrolysis

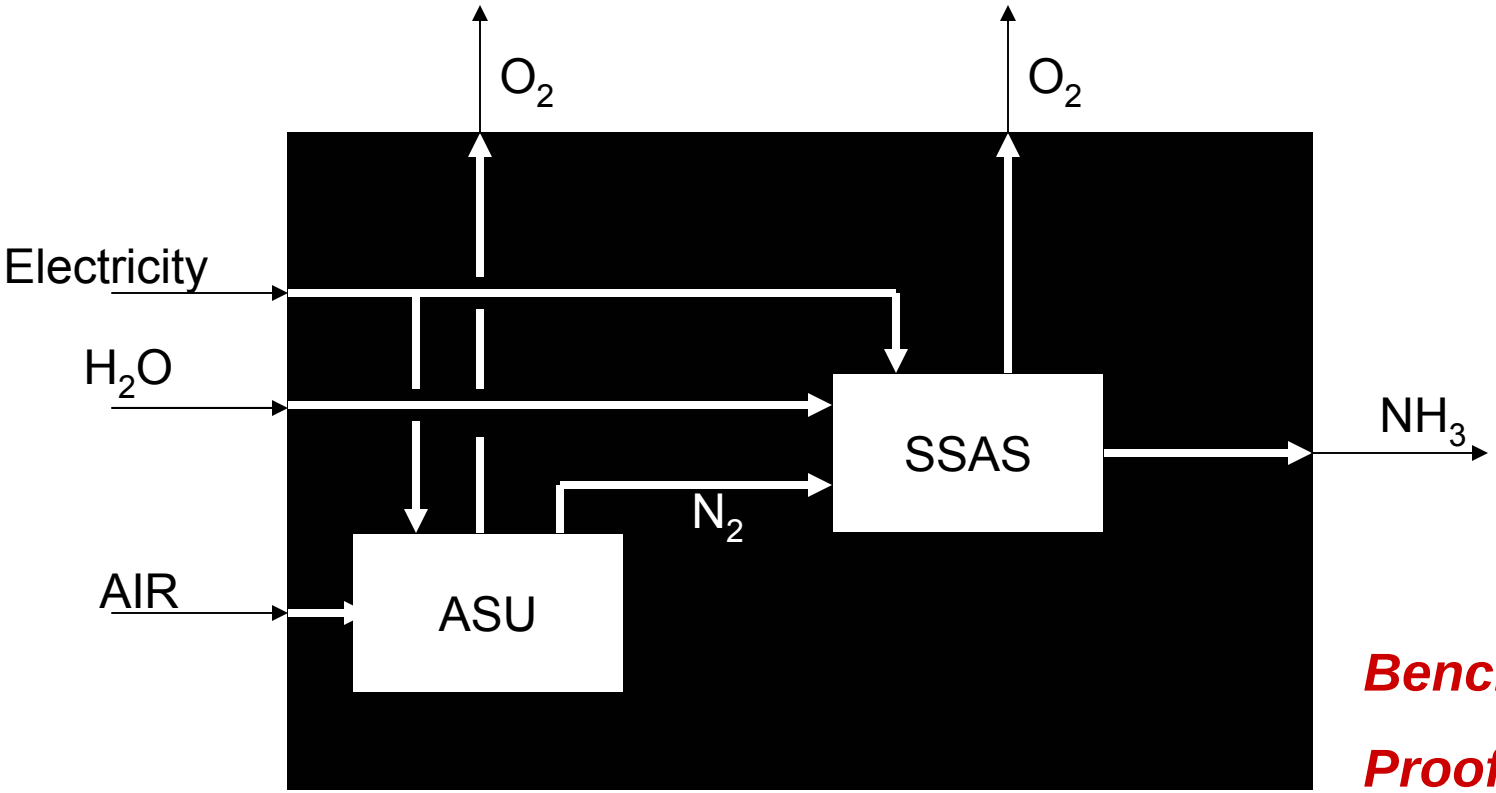
$$3\ H_2O \rightarrow 3\ H_2 + 3/2\ O_2$$
$$3\ H_2 + N_2 \rightarrow 2\ NH_3$$



Energy consumption ~12,000 kWh per ton NH_3

Inside the Black Box: Solid State Ammonia Synthesis

$$6\ H_2O + 2\ N_2 \rightarrow 3\ O_2 + 4\ NH_3$$

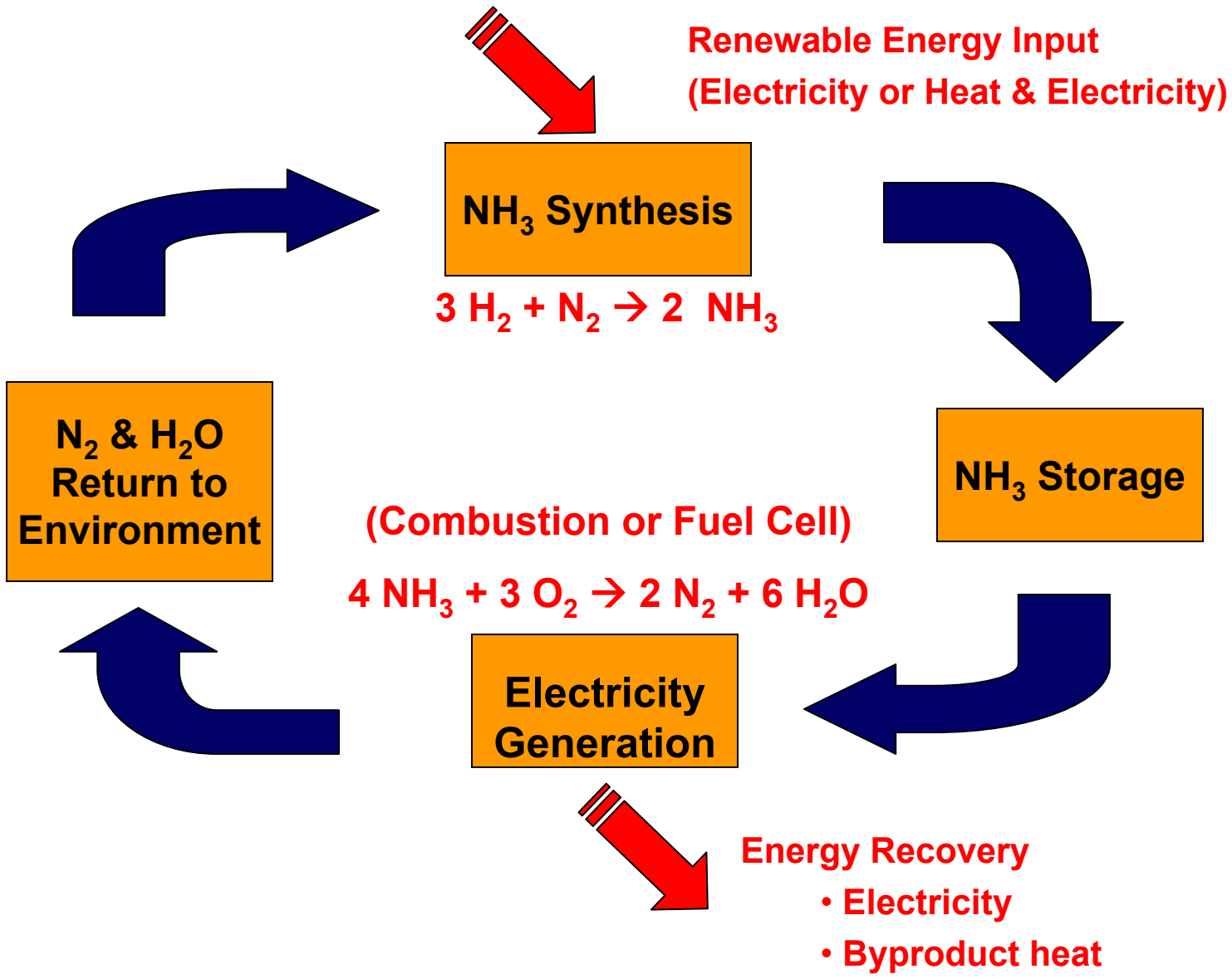


Benchtop

Proof-of-concept

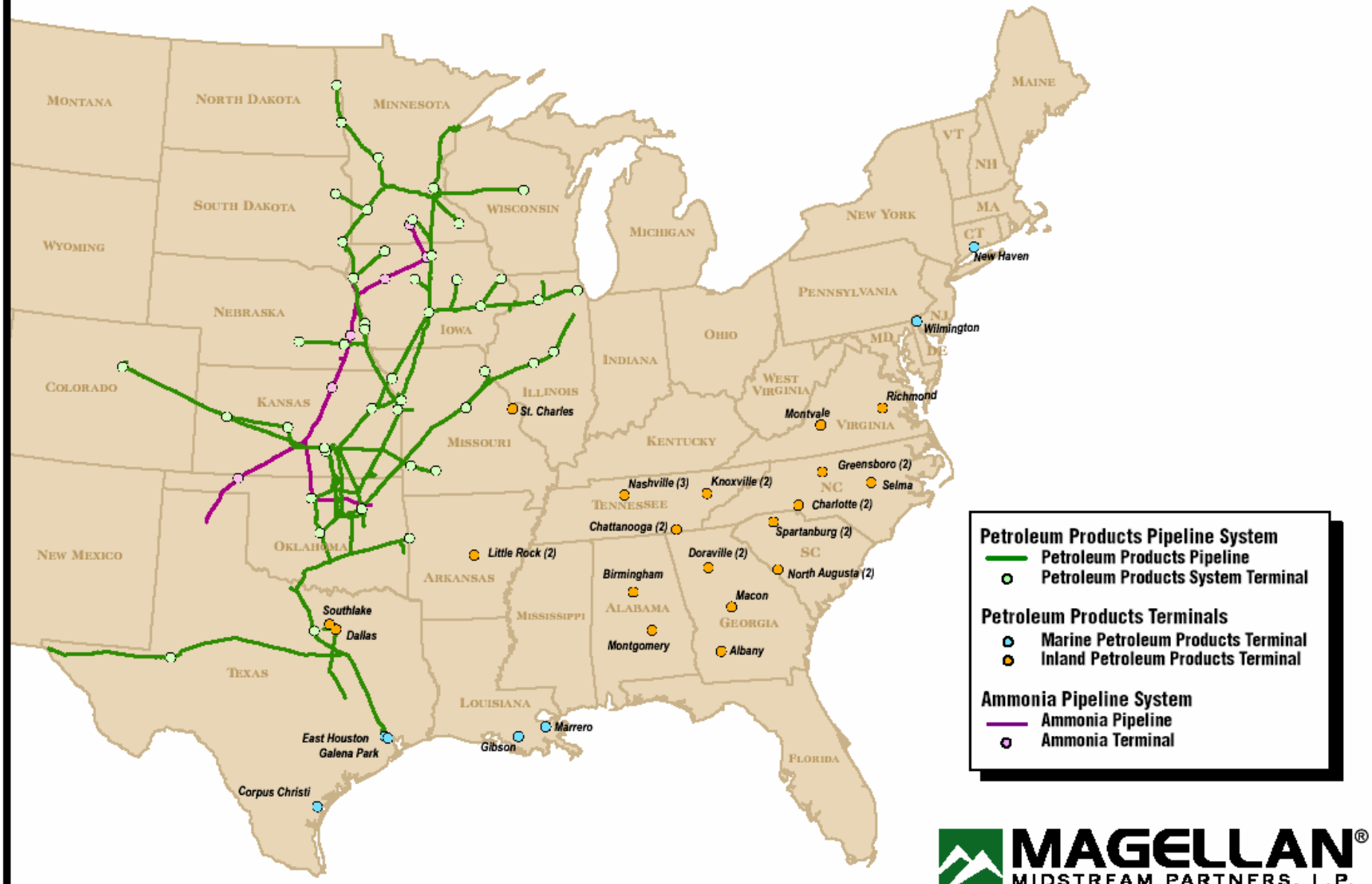
Energy consumption 7000 - 8000 kWh per ton NH_3

Green Ammonia Cycle
Renewable-source, C-free

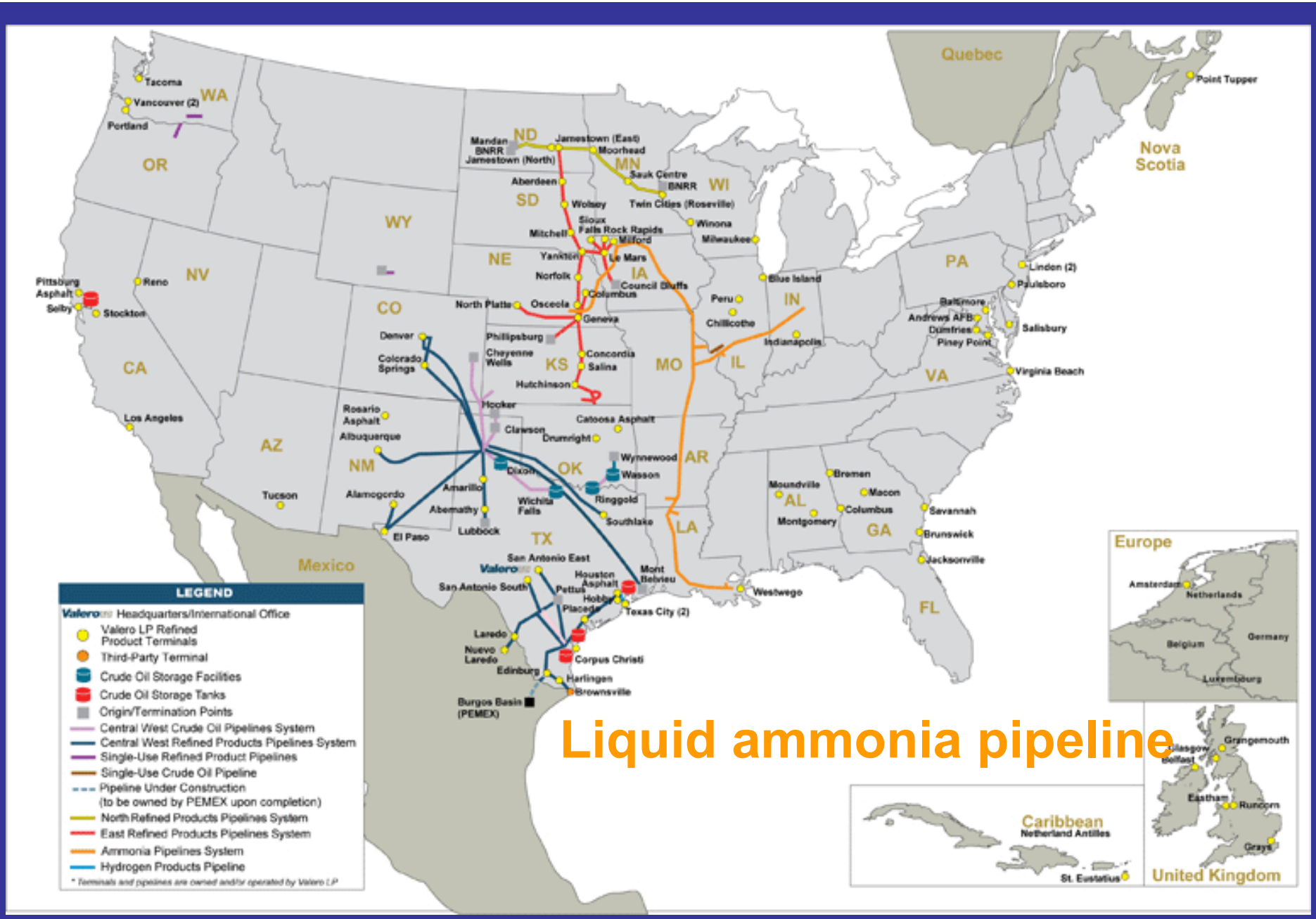


Asset Portfolio

Liquid ammonia pipeline



MAGELLAN®
MIDSTREAM PARTNERS, L.P.



Valero LP Operations

“Atmospheric”

Liquid Ammonia Storage Tank

30,000 Tons

~$15M turnkey

-33 C

Ammonia
534 kg H2

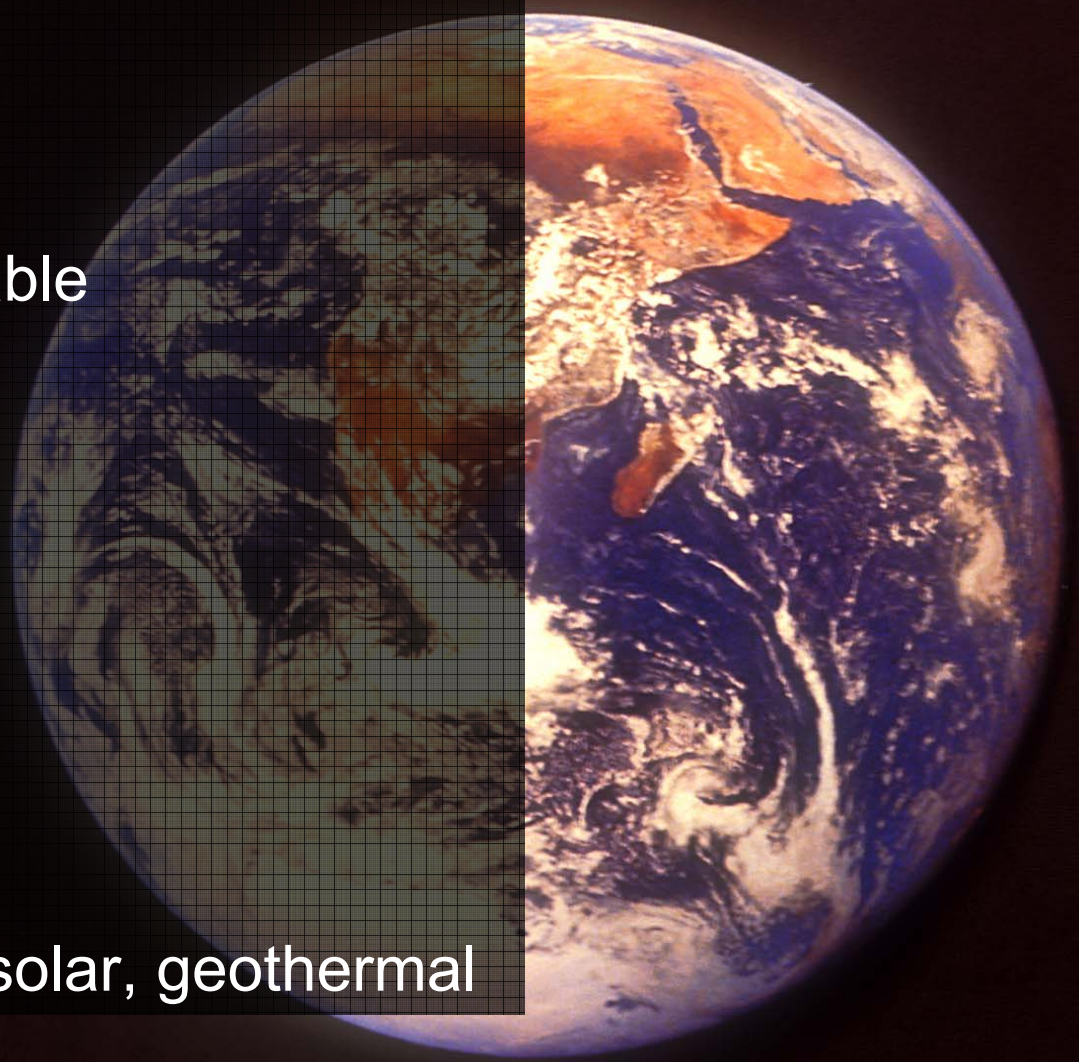
Hydrogen gas
350 kg H2

Annual – scale "Firming"
Great Plains Wind

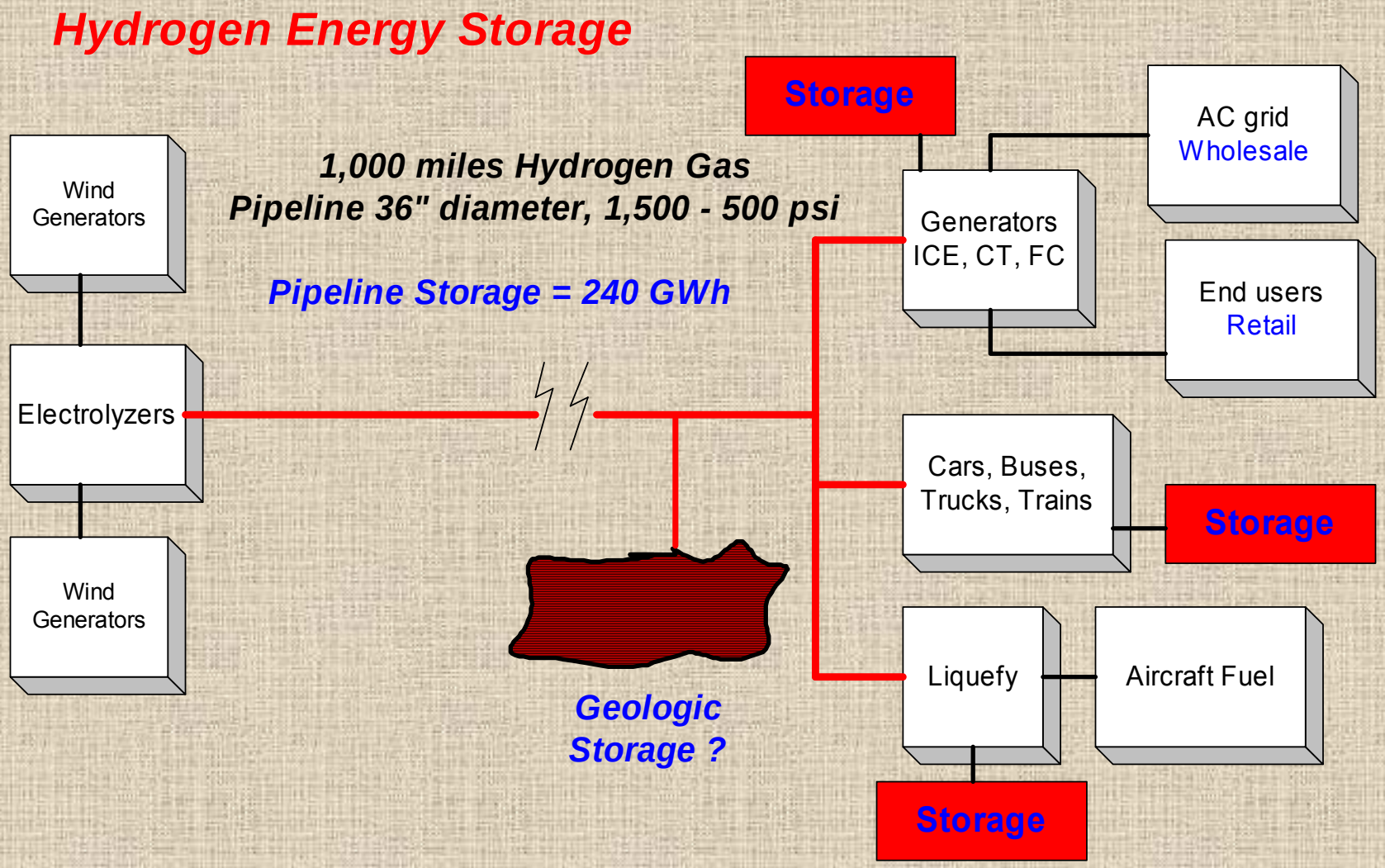
- **Potential, 12 states, ~50% land area:**
  - **10,000 TWh = 100 quads = entire USA energy**
  - **2,800,000 MW nameplate**
- **Seasonality:**
  - **Summer minimum**
  - **Spring – Summer maximum storage**
  - **"Firming" energy storage, per 1,000 MW wind:**
    - **As electricity = 450 GWh**
    - **As GH2 = 15,712 tons, metric @ 2,500 tons / cavern = 6 caverns**
    - **As NH3 = 87,291 tons, metric @ 60,000 tons / tank = 1.4 tanks**
  - **"Firming" energy storage, all great Plains wind:**
    - **As GH2 = 17,000 caverns @ $15M each = $264 billion**
    - **As NH3 = 5,000 tanks @ $25M each = $127 billion**

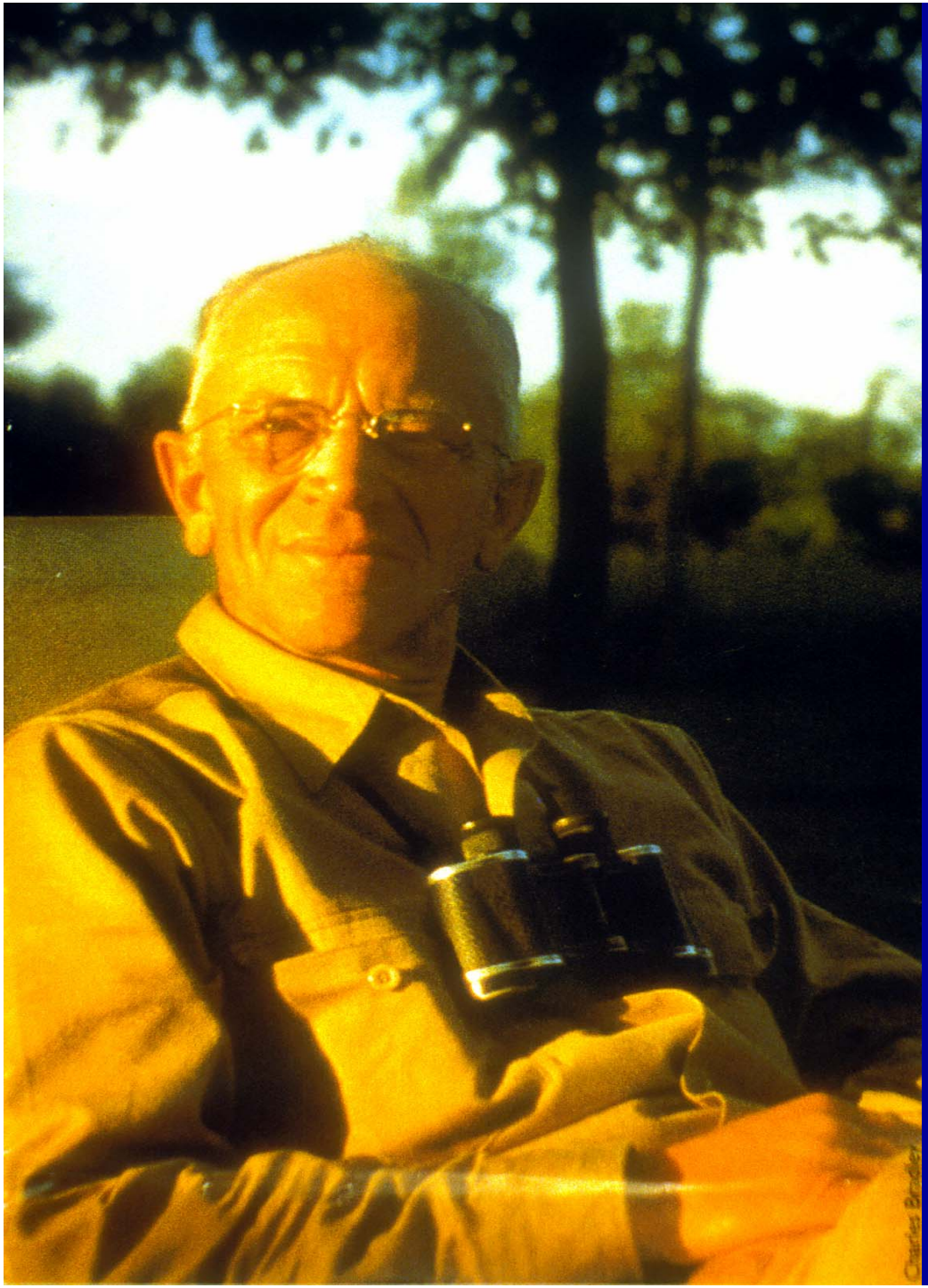
MUST Run the World on Renewables – plus Nuclear ?

- Global
- Indigenous
- Firm: available
- C-free
- Benign
- Abundant
- Affordable
- Equitable
- Perpetual: solar, geothermal



"Firming" Cavern Storage





Aldo Leopold

1887 - 1948

There are two spiritual dangers in not owning a farm:

One is supposing that breakfast comes from the grocery;

The other is supposing that heat comes from the furnace.

Aldo Leopold, "A Sand County Almanac"

Pogo

"We have met the enemy..."

You cannot have peace without justice

Running the World on Renewables

DVD's available

Energy Expo, IRENEW
UNI, CEEE, Cedar Falls, IA
13 Sept 08

Bill Leighty, Director
The Leighty Foundation
Juneau, AK
wleighty@earthlink.net
907-586-1426 206-719-5554 cell

Ammonia as Hydrogen Carrier, Fuel

- Anhydrous, NH3
- C – free; H source ?
- ~ 18% H, weight
- ~ 100 liters = 500 mile range, car
- ~ 15 M tons / year USA, 5 M as NH3
- Good safety record: ag, industry
- Infrastructure in place
- Liquid storage: -10 C, 1 atm
- 60,000 ton tanks common
- Self-odorized
- ICE operates at 50% efficiency, low emissions
- Toxic

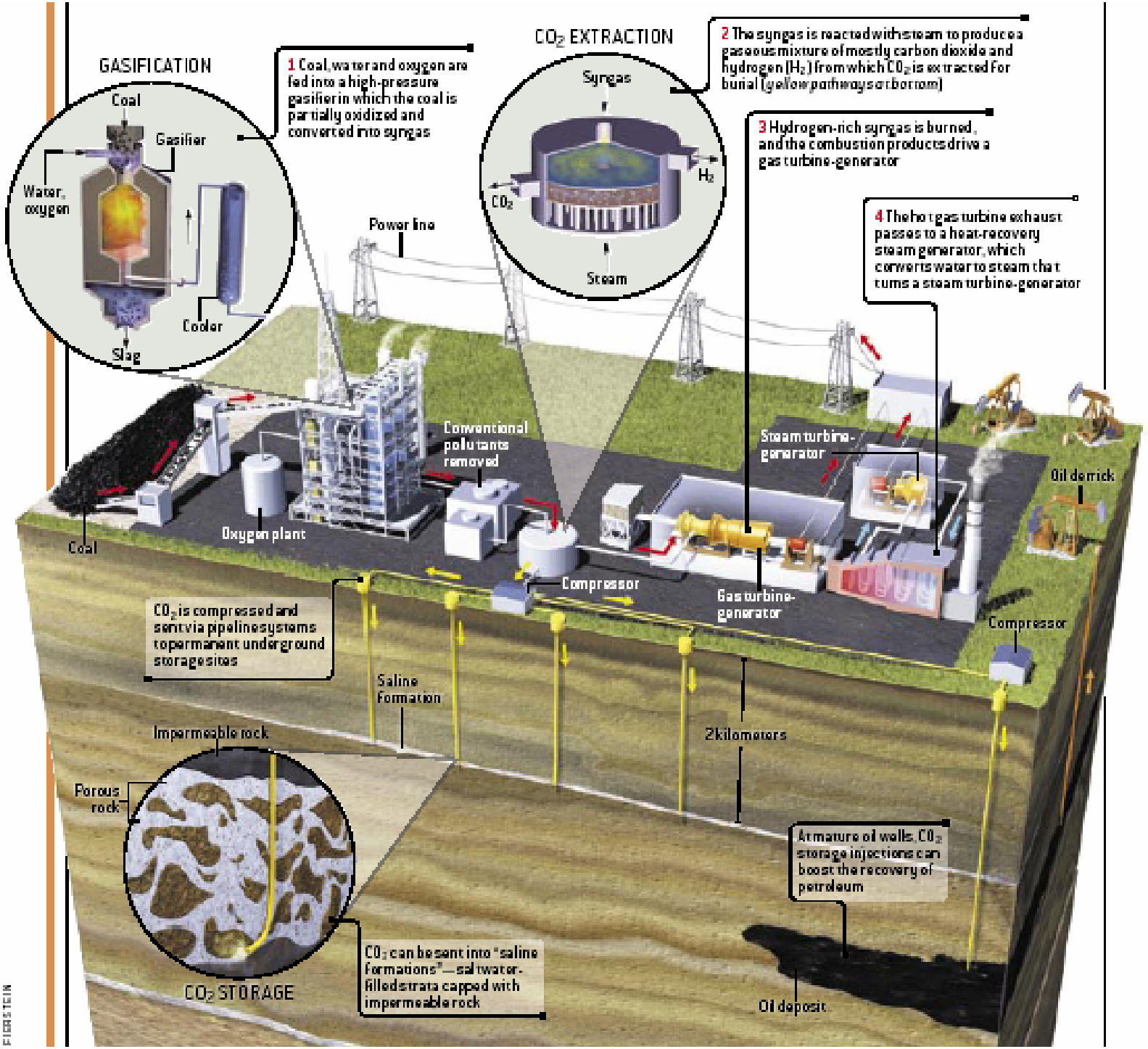
Ammonia Conferences: Anhydrous Ammonia (NH_3) as an energy and hydrogen carrier and energy storage medium

- First two annual conferences archives at: http://www.energy.iastate.edu/renewable/
- 28 Oct 04 Proceedings: http://www.energy.iastate.edu/renewable/biomass/AmmoniaMtg.html
- 13-14 Oct 05 Proceedings: http://www.energy.iastate.edu/renewable/biomass/AmmoniaMtg05.html
- **9-10 Oct 06 -- Denver, Denver West Marriott, Golden, CO:** http://www.energy.iastate.edu/renewable/biomass/ammonia2006/Ammonia2006.html

  " Ammonia, the Key to U.S. Energy Independence "

GW-scale Transmission + Storage Options

- **Electricity: HVAC, HVDC**
  - **CAES compressed air energy storage**
  - **Vanadium Redox battery (VRB Power Systems)**
  - **Sodium-sulfur battery**
  - **PHEV (distributed)**
- **Liquid Hydrogen (LH2)**
  - **Pipeline, truck, rail car, ship**
  - **1/3 energy to liquefy**
- **Gaseous Hydrogen (GH2)**
  - **Pipeline**
  - **Geologic: salt caverns (man-made)**
  - **Geologic: natural formations**
- **Ammonia (NH3) liquid**
  - **Tank, refrigerated, 10K – 60K ton**
  - **Truck, rail car, ship**
- **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**
  - **Al – Ga** Alumina



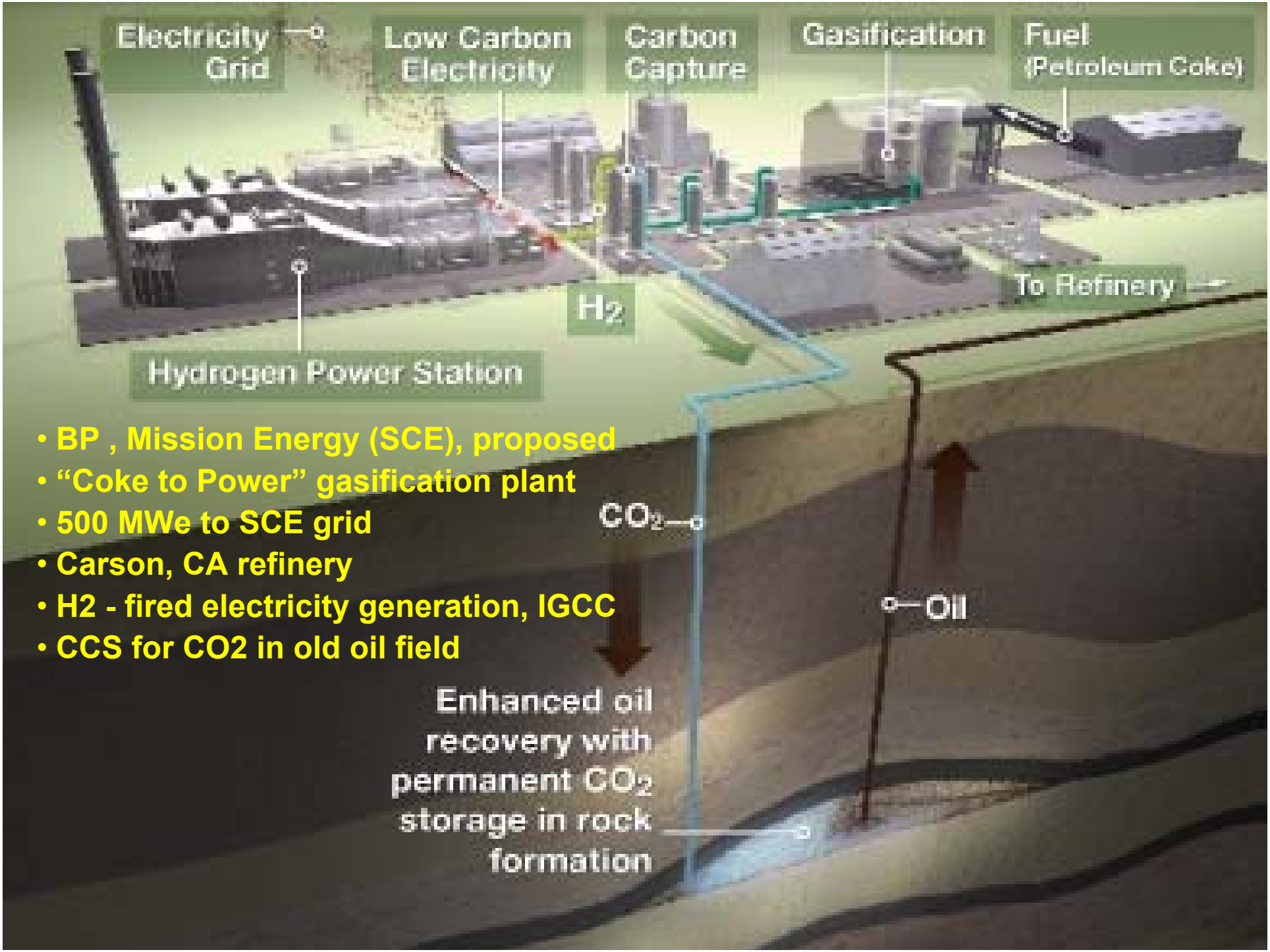
FIGES TEIN

IGCC

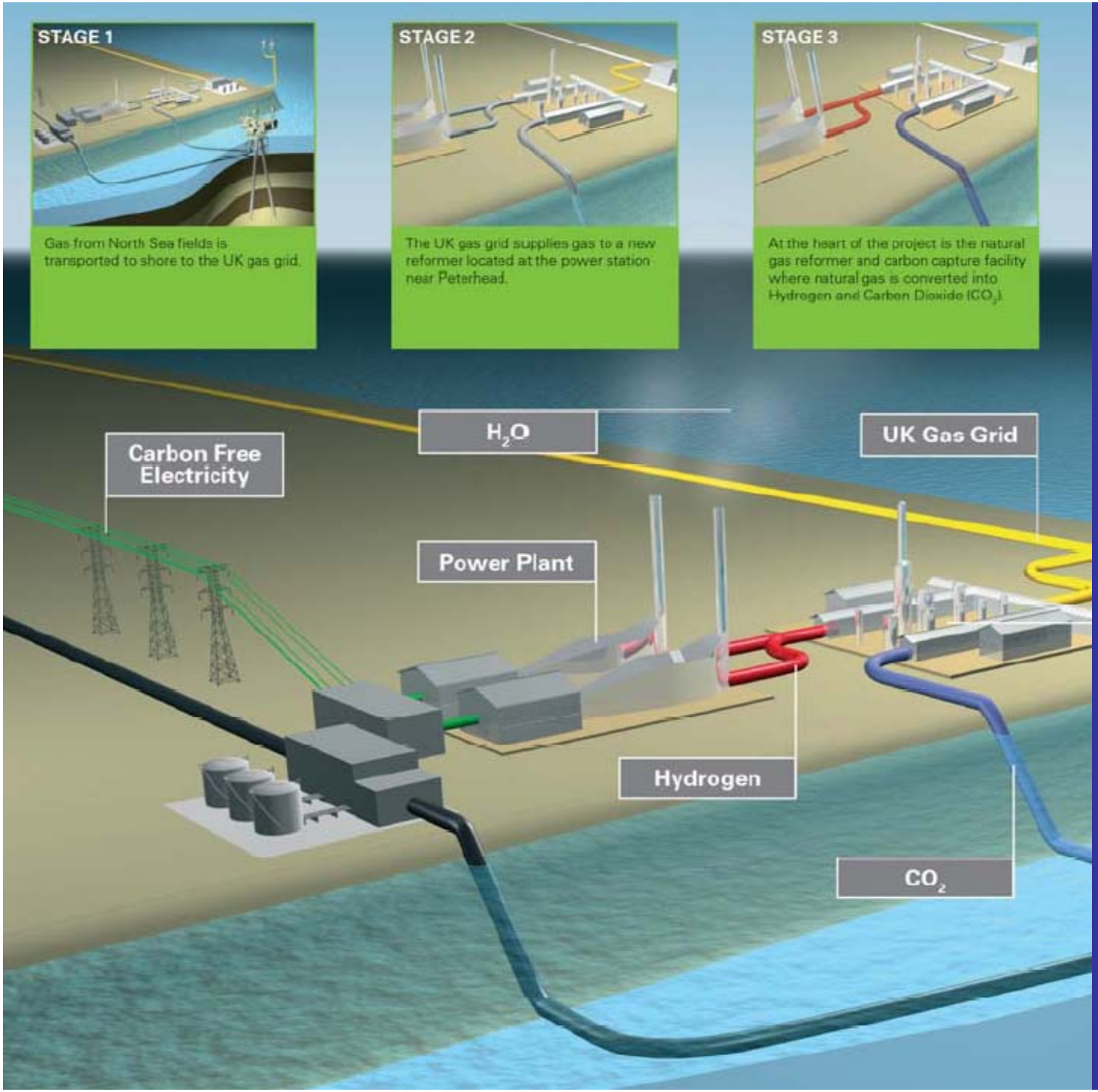
coal power plant

with CCS*

*** Carbon Capture and Sequestration***



- BP , Mission Energy (SCE), proposed
- "Coke to Power" gasification plant
- 500 MWe to SCE grid
- Carson, CA refinery
- H2 - fired electricity generation, IGCC
- CCS for CO2 in old oil field



BP Miller Field, North Sea

NG→H2 + CO2→ electricity + CO2

with CCS* and enhanced oil recovery

*** carbon capture and sequestration**

Alaska Applied Sciences, Inc.

560 kW windplant

Palm Springs, CA

Humanity's Goal ?

A sustainable,

benign-source, equitable,

global energy economy

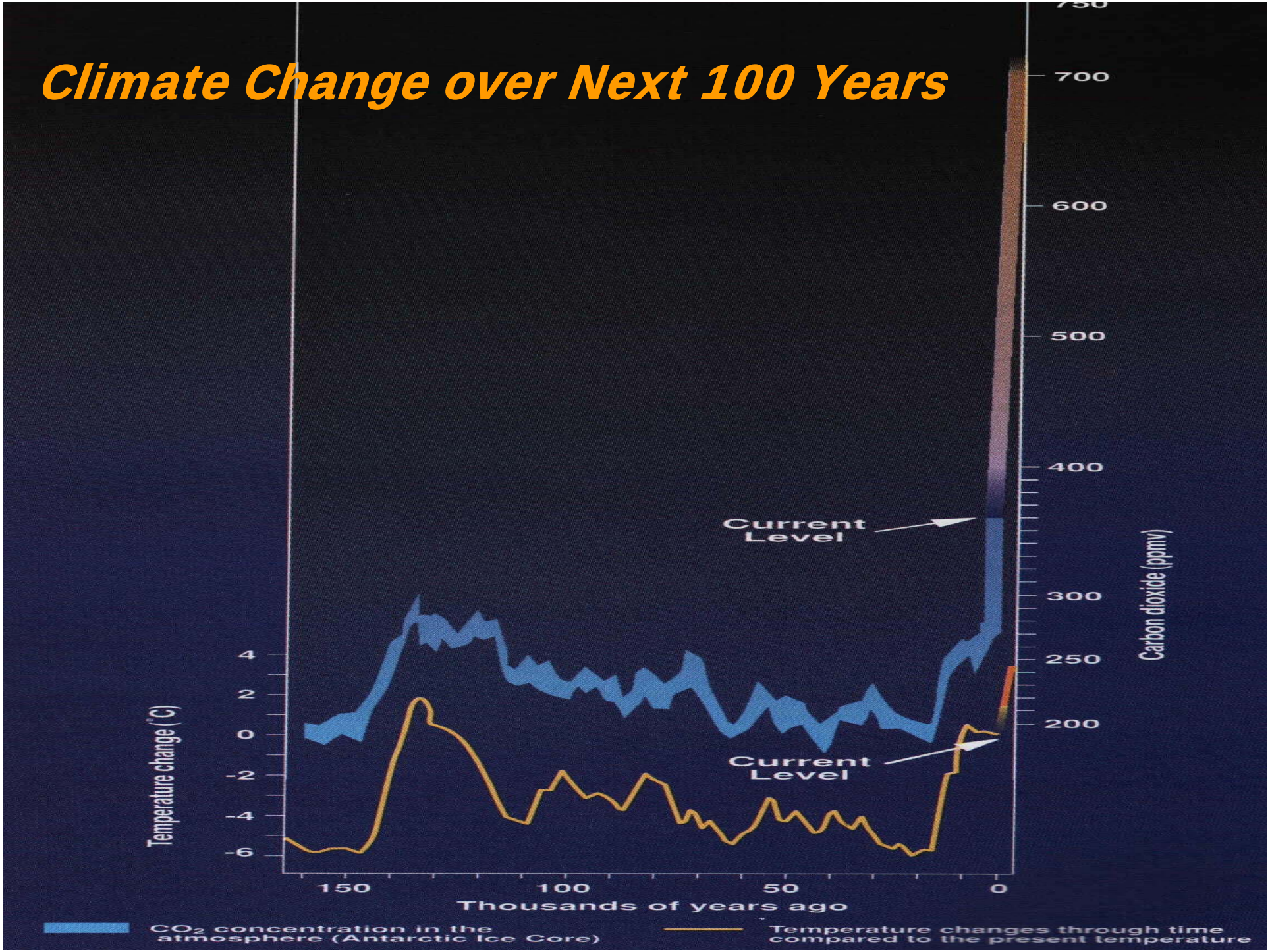
Rapid Climate Change (GCC)
Global Warming (GW)

Sustainable

" Meeting our needs without compromising the ability of future generations to meet their own needs "

United Nations Commission on
Environment and Development (UNCED)
"Our Common Future", 1987

Climate Change over Next 100 Years



beyond
petroleum