Alternatives to Electricity for Transmission, Firming Storage, and Integration of GW-scale Wind and Solar via Hydrogen and Ammonia Pipelines

Windpower 2015
Orlando, FL   May 18 – 21

Session 8B: The "Mostly Wind" Grid – Implications for Reliability, Markets and Storage
1515 – 1630 20 May

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Mendenhall Glacier, Juneau, AK

June ‘71

Mendenhall Glacier, Juneau, AK
10 October 10

Mendenhall Glacier, Juneau, AK
10 October 10

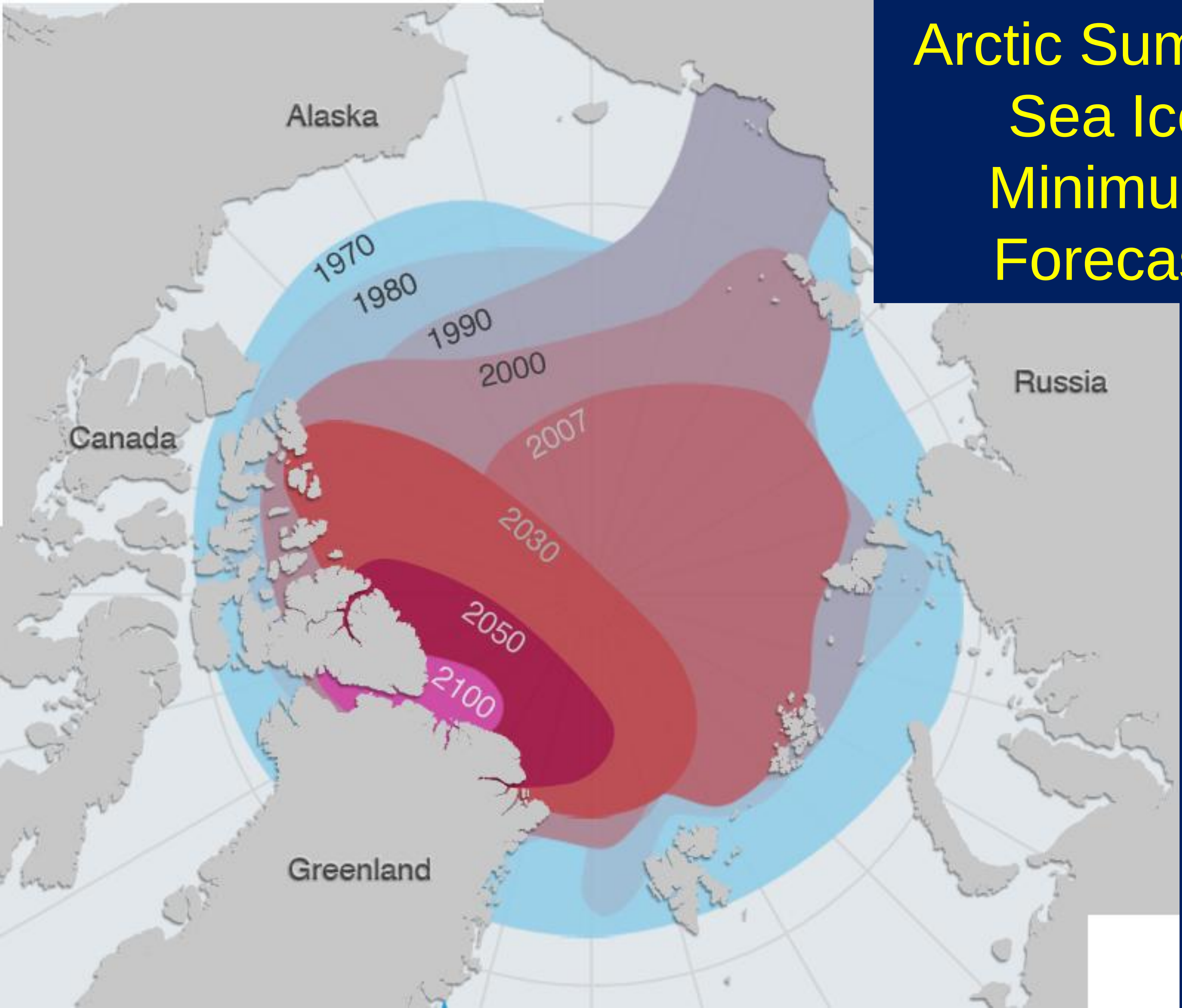
Muir Glacier, Alaska, 1895

Glacier face is 100 m high; east side Muir Inlet, Glacier Bay

Muir Inlet, Alaska, 2005

Approximate same location, east side, Muir Inlet, Glacier Bay

Arctic Summer Sea Ice Minimum Forecast



Shishmaref, Alaska

Winter storms coastal erosion

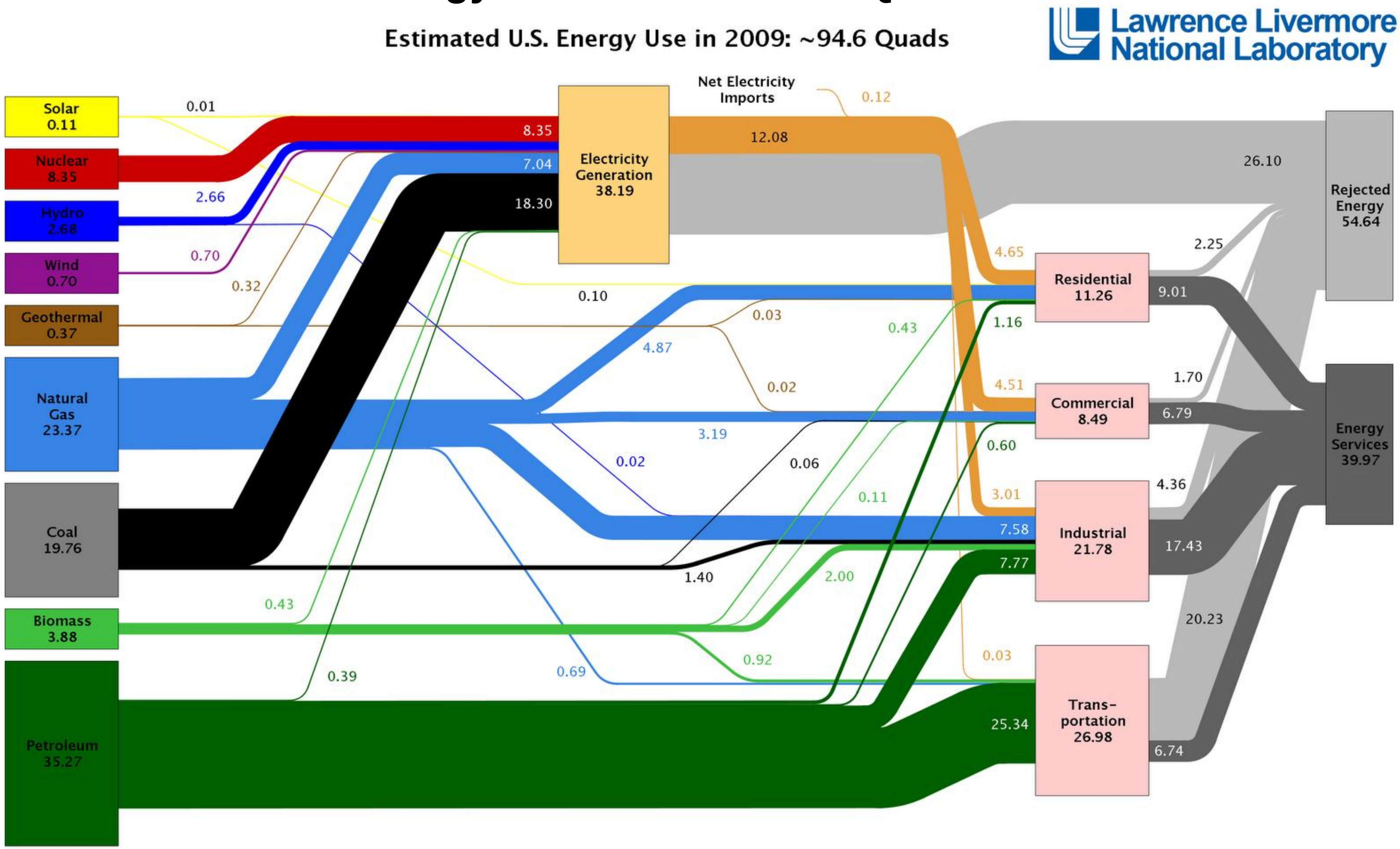
MUST Run the World on Renewables – plus Nuclear ?

- Rapid climate change
- Ocean acidification
- Sea level rise
- Species extinctions
- Violent human conflict

MUST Run the World on Renewables – plus Nuclear ?

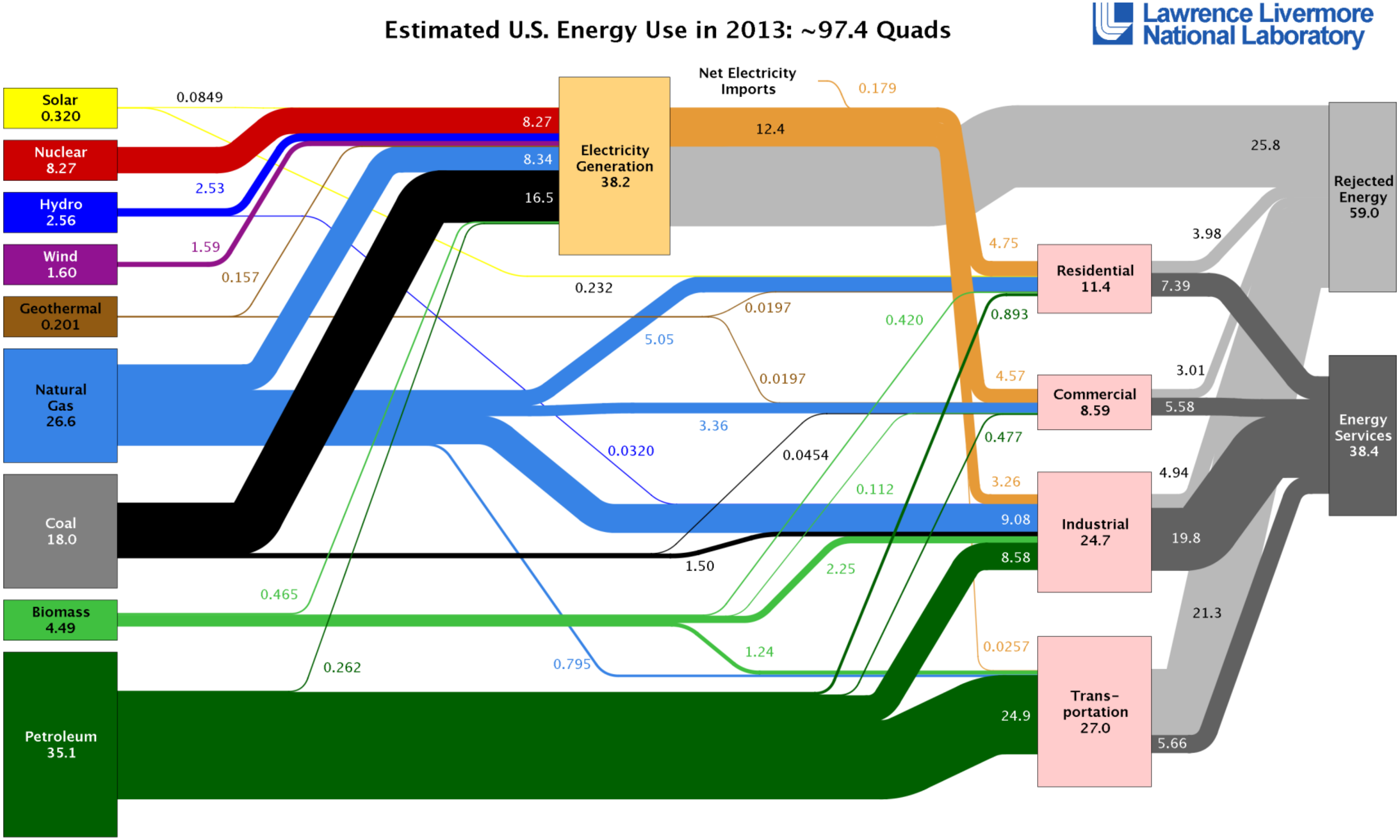
- Demand growth
- Water for energy
- War
- Depletion of Oil and Gas
- Only 200 years of Coal left
- Only Source of Income:
  - Sunshine
  - Tides
  - Spending our capital

Estimated U.S. Energy Use in 2009: ~ 95 Quads



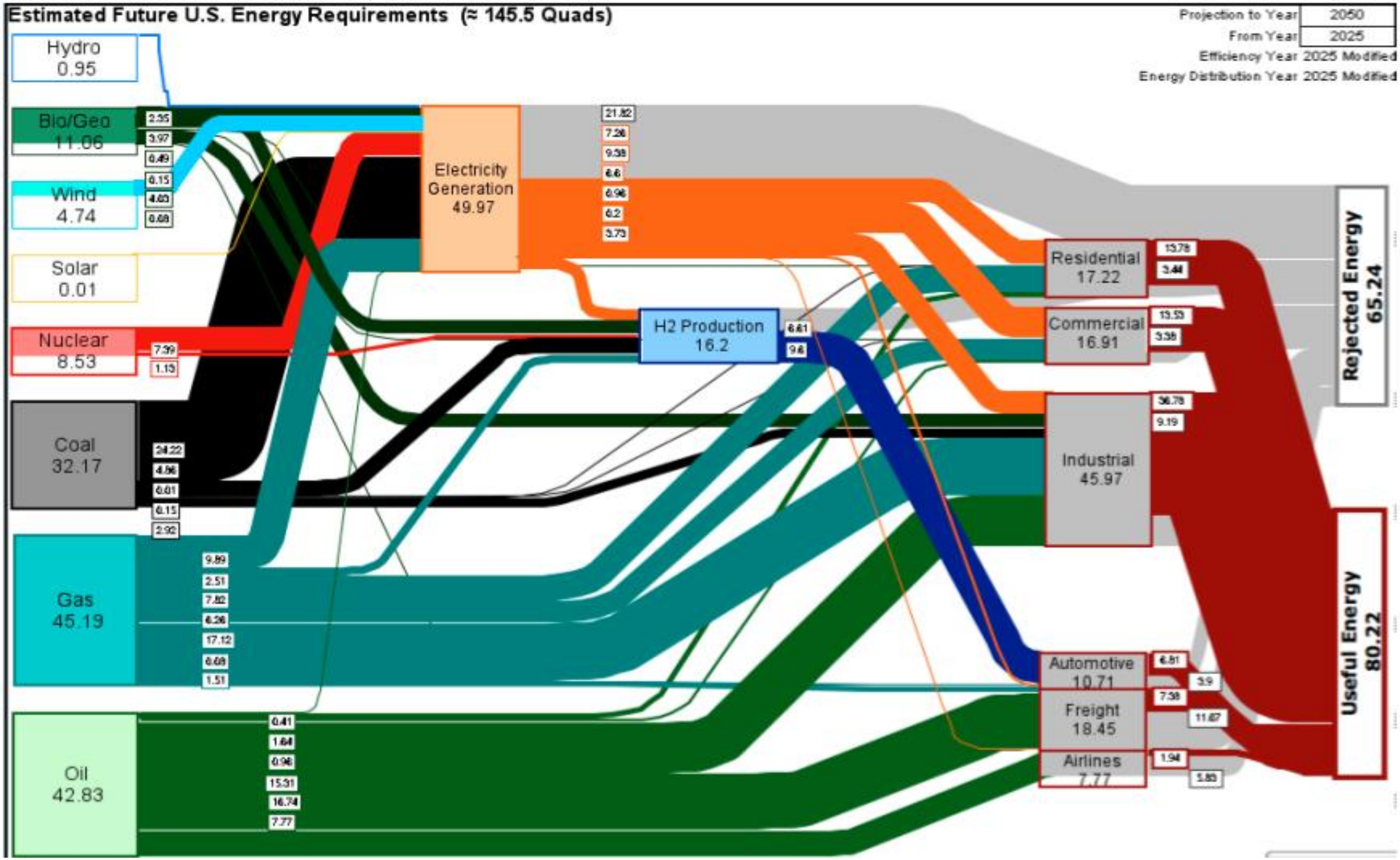
Source: LLNL 2010. Data is based on DOE/EIA-0384(2009), August 2010. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Estimated U.S. Energy Use in 2013: ~ 97 Quads



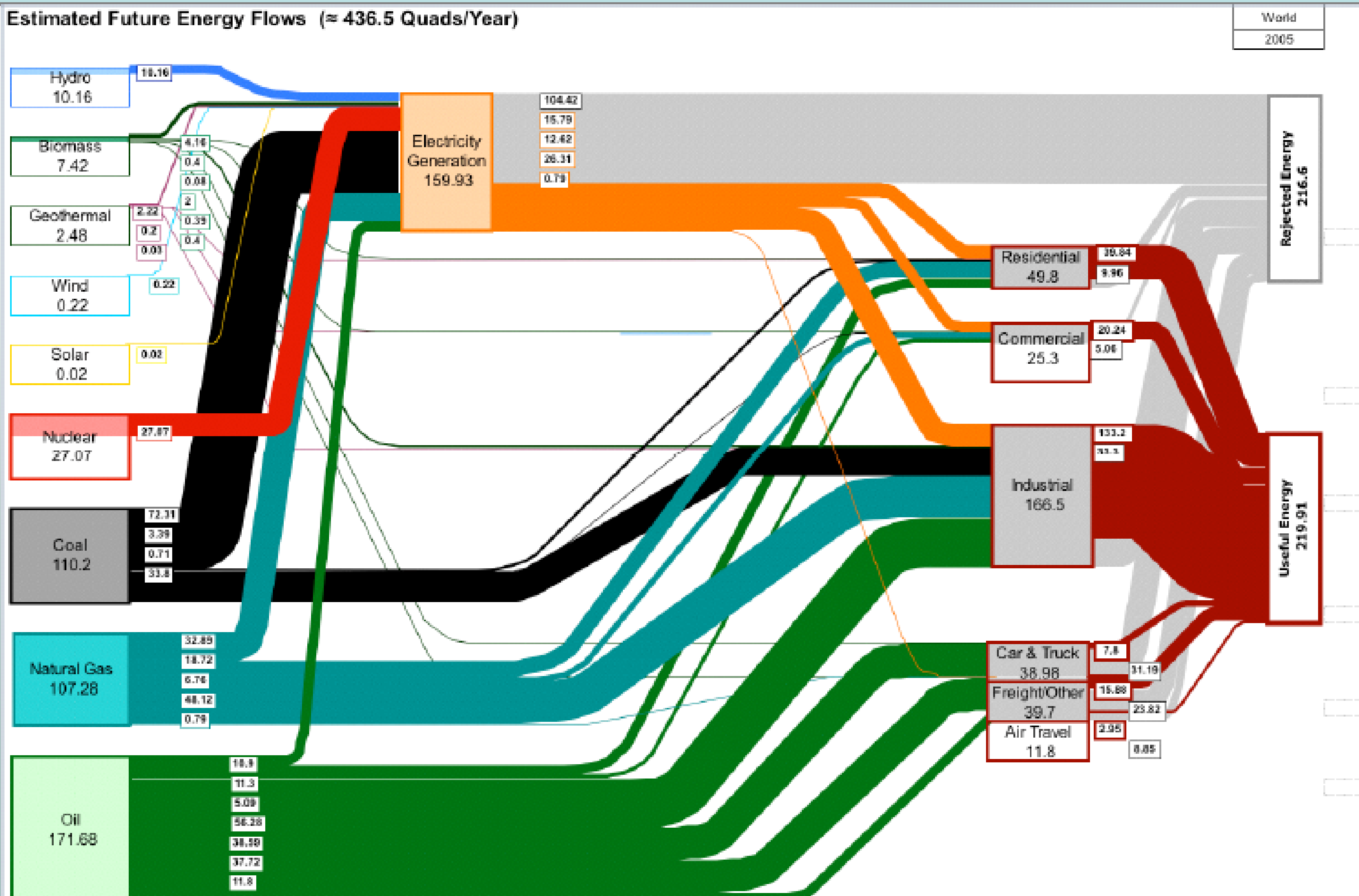
Source: LLNL 2014. Data is based on DOE/EIA-0035(2014-03), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Estimated U.S. Energy Use in 2050: 145 Quads



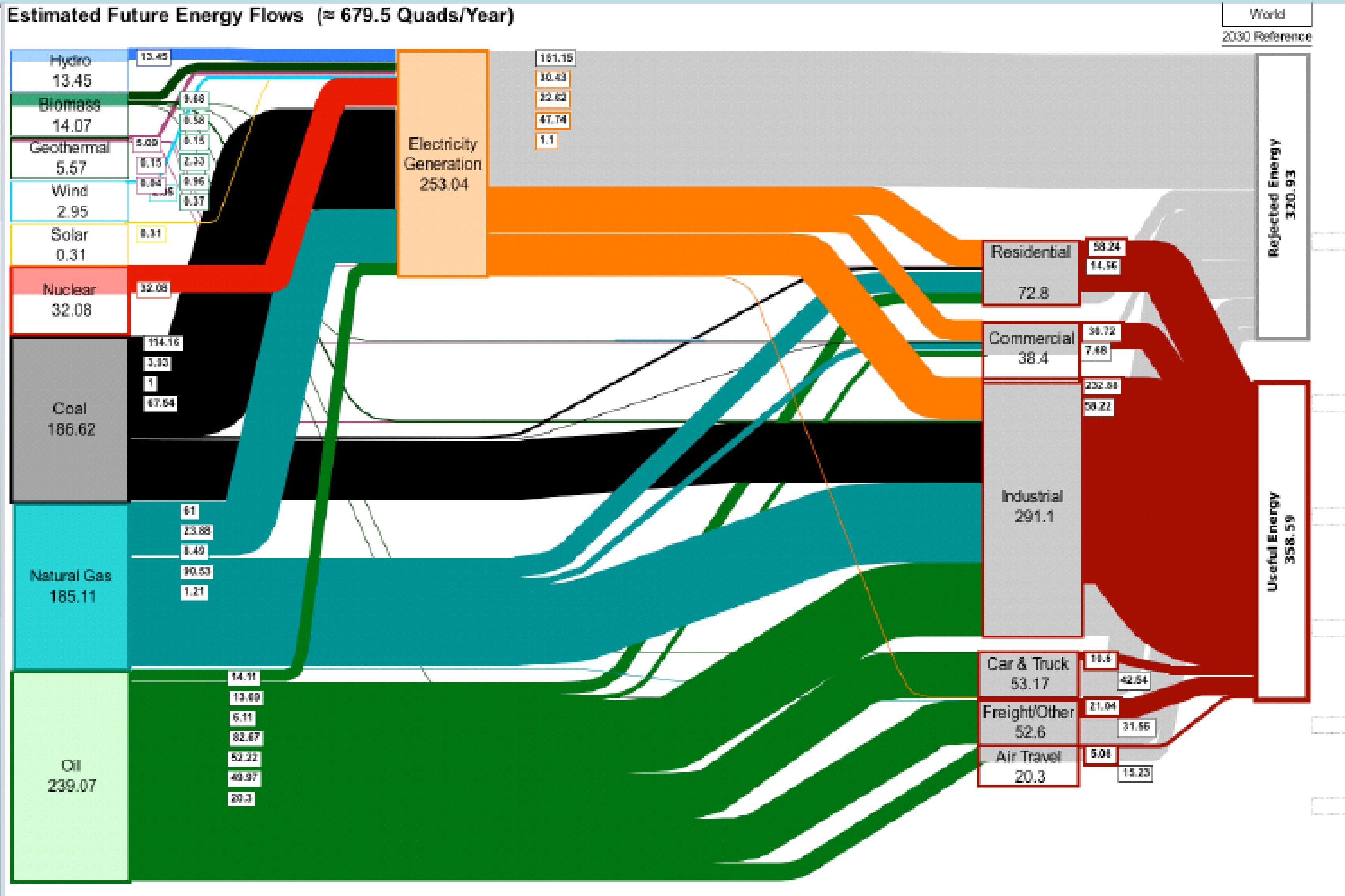
2005 World Energy ~ 436 Quads/yr

(International Energy Outlook 2006)

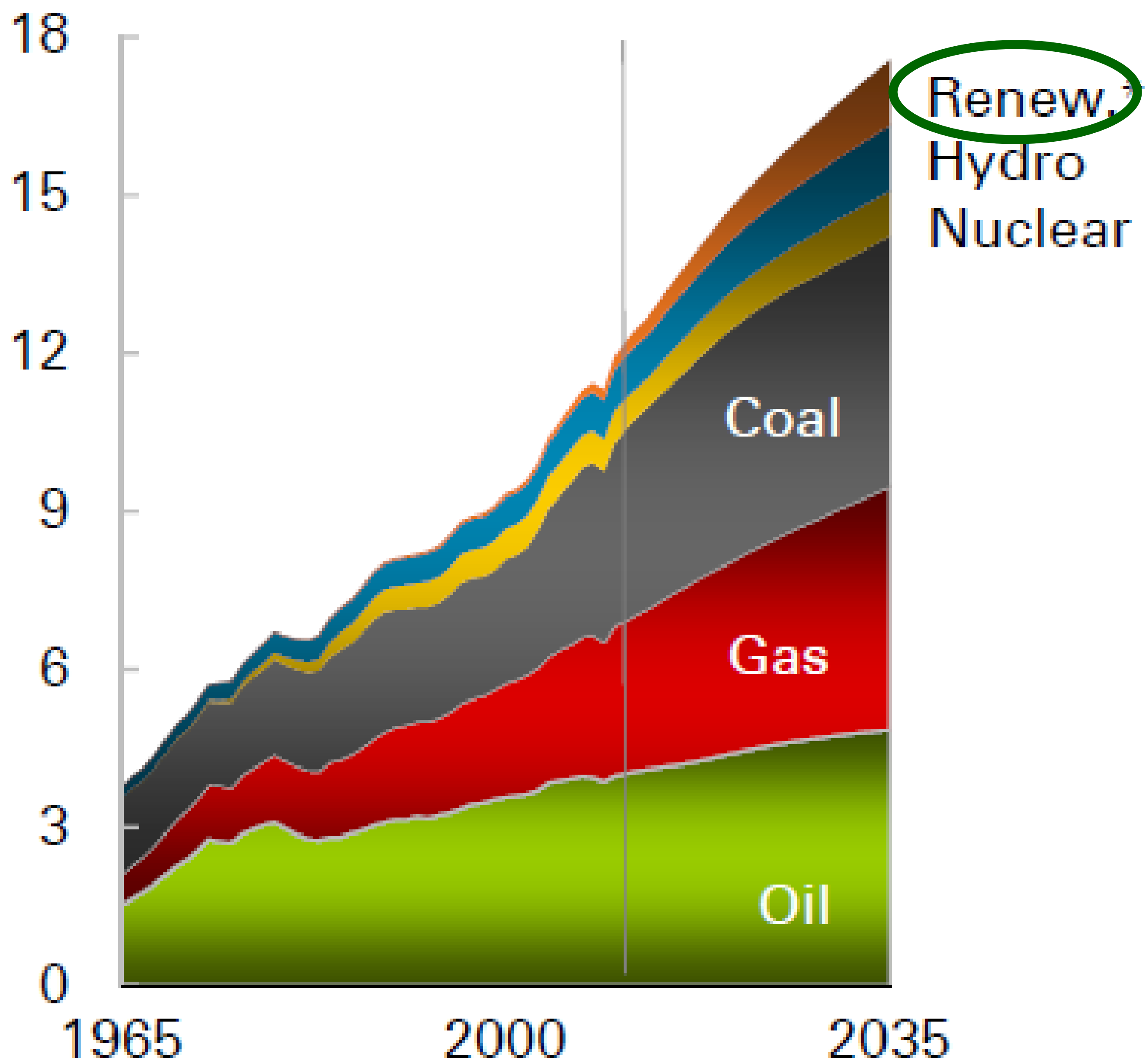


Projected World Energy ~ 680 Quads/yr

***2030 Reference Case** (IEO 2006)*

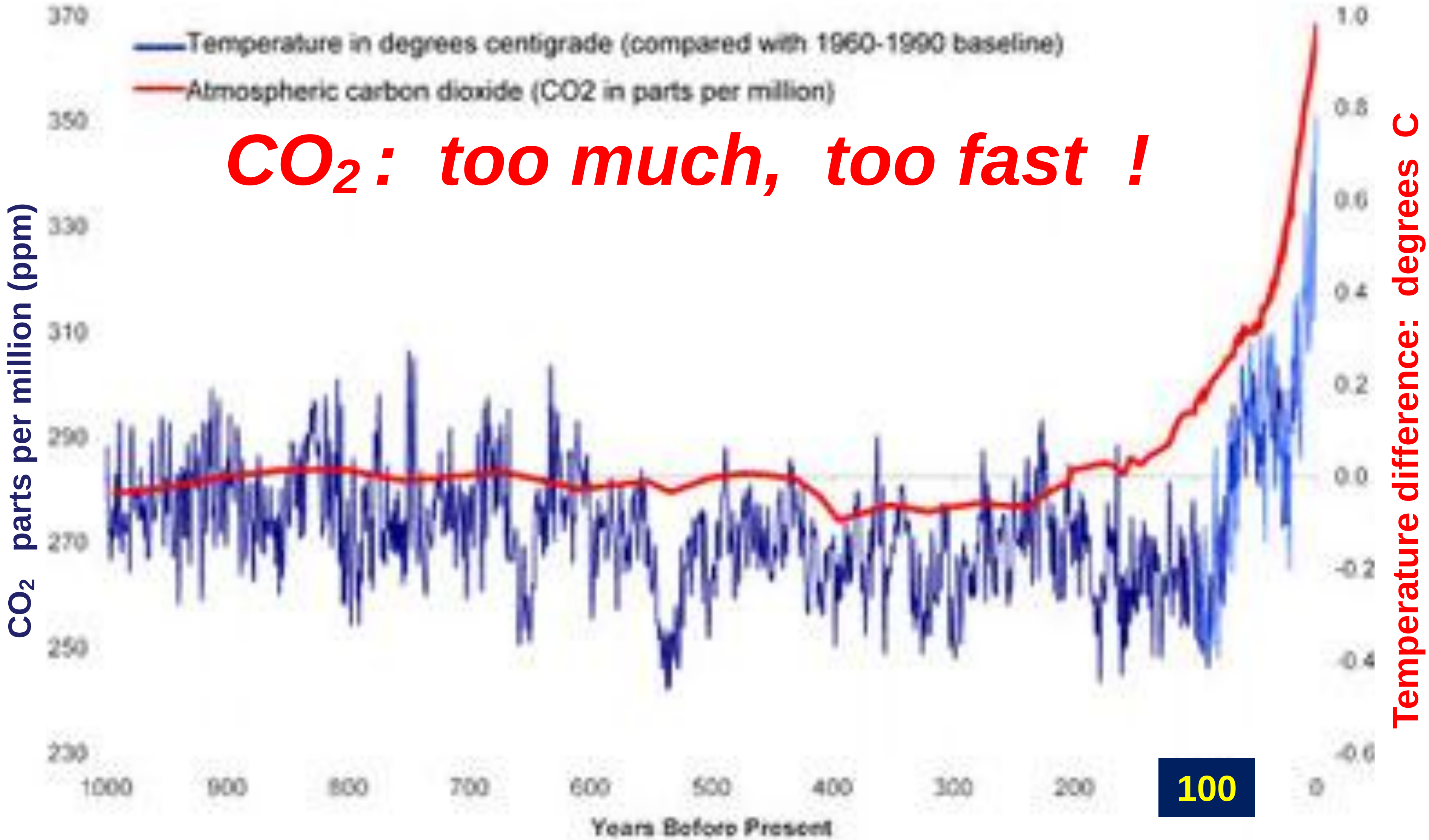


Billion tons of oil equivalent (toe)

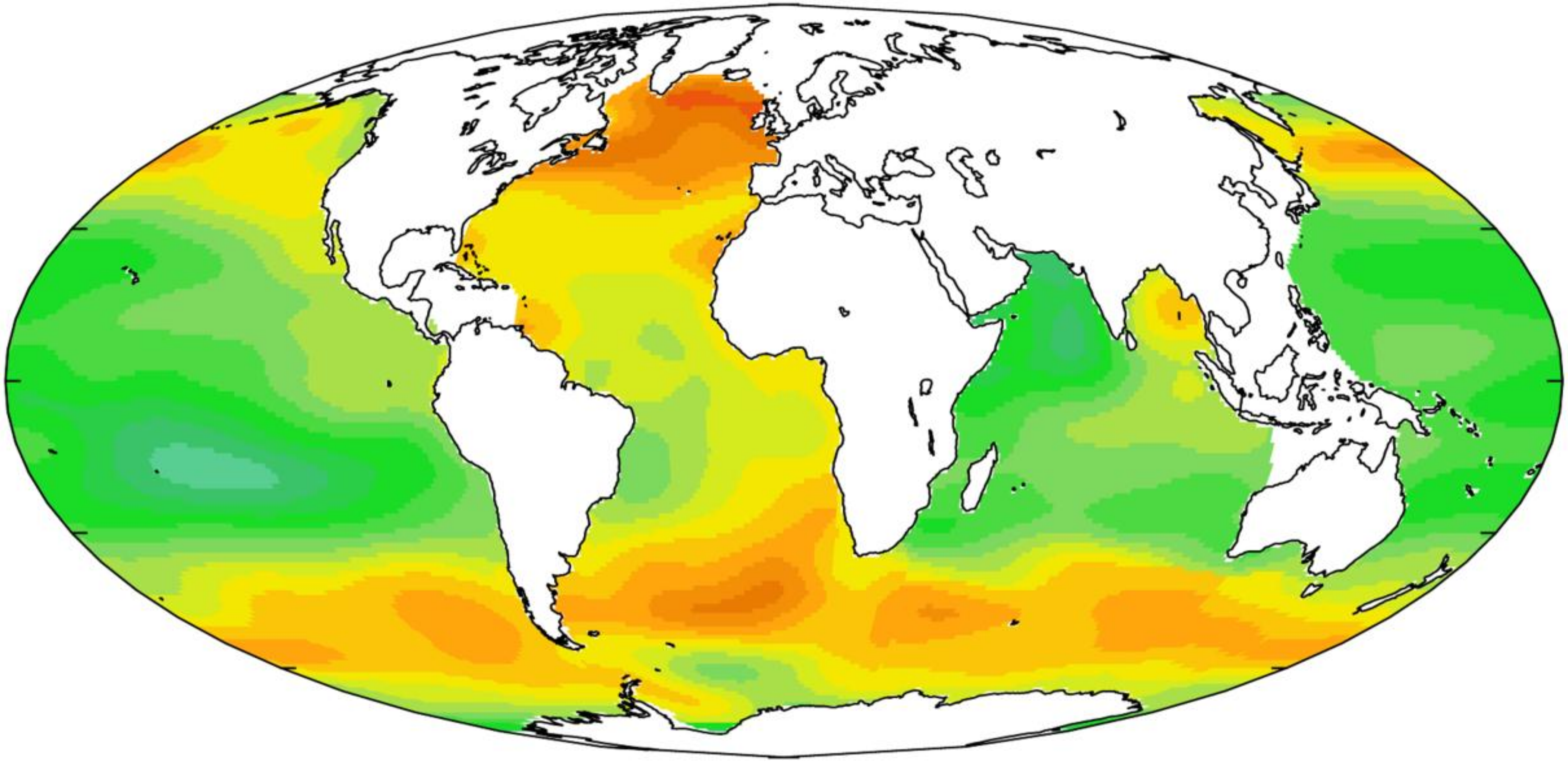


World Primary Energy Consumption

BP Energy Outlook 2035



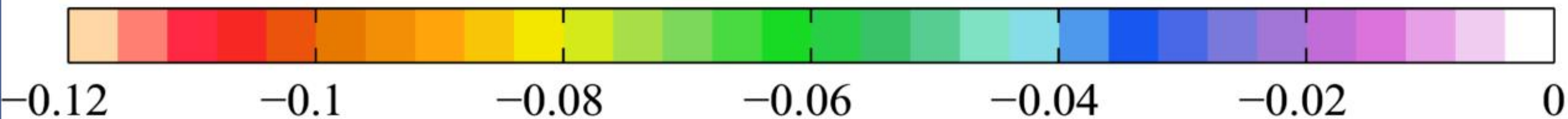
1,000 years history



“Evil Twin of Global Warming”

“The Other CO2 Problem”

Δ sea−surface pH [−]

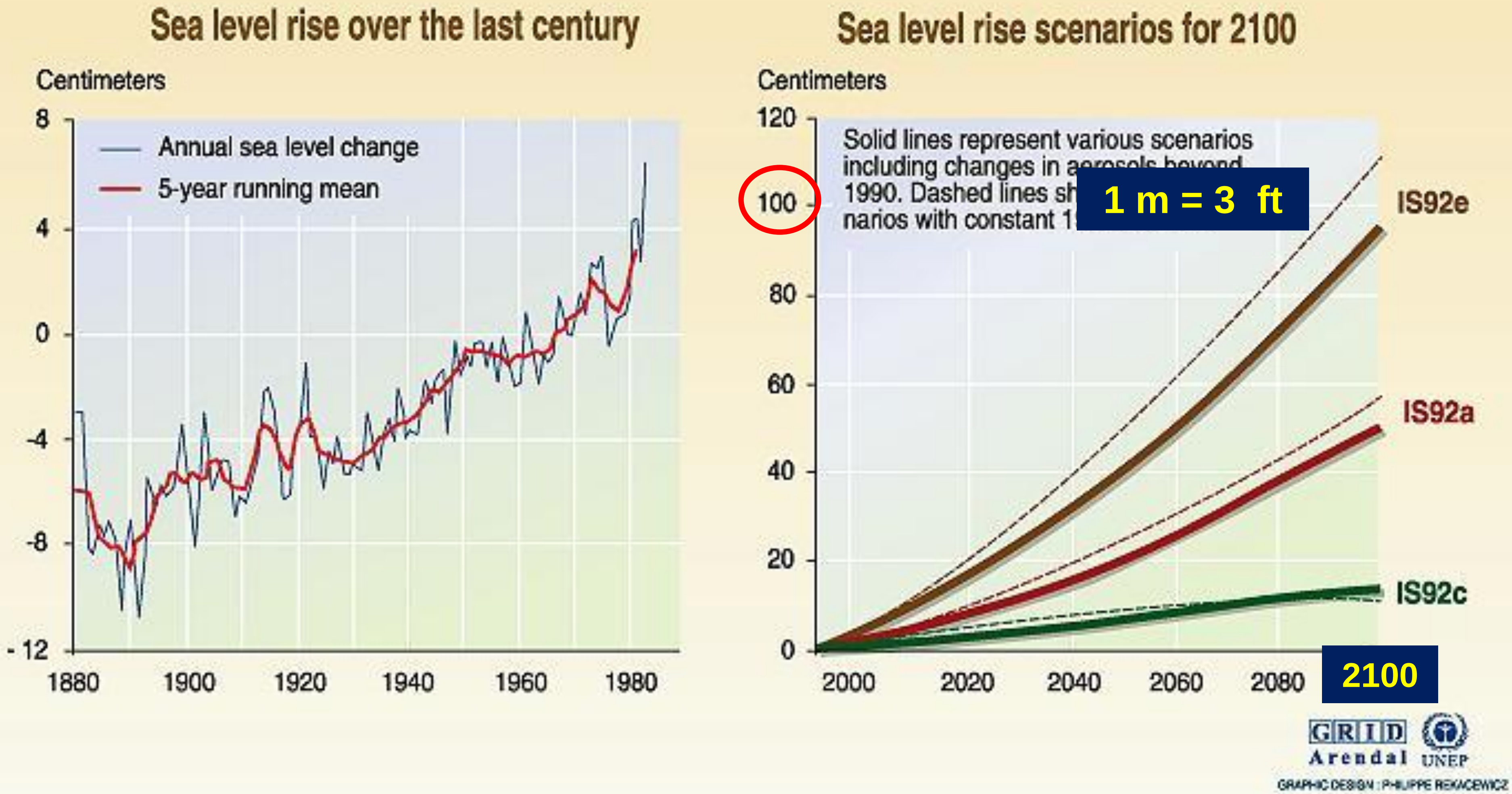


NOAA – NMFS:

- **Juneau**
- **Sitka**

Ocean Acidification: lowering pH
Neutral = 7.0

Sea level rise due to global warming

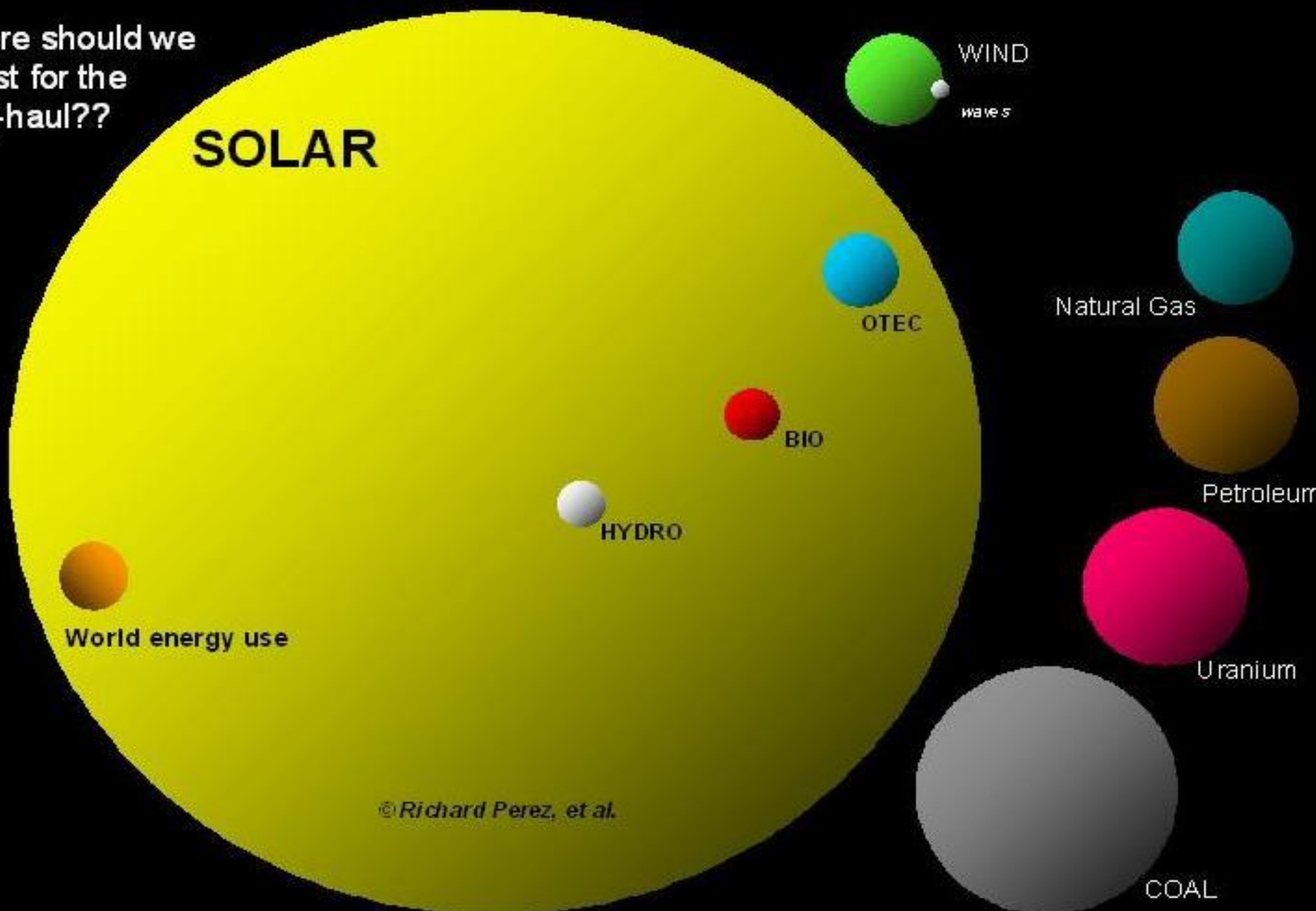


Source: Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge university press, 1996; Sea level rise over the last century, adapted from Gornitz and Lebedeff, 1987.

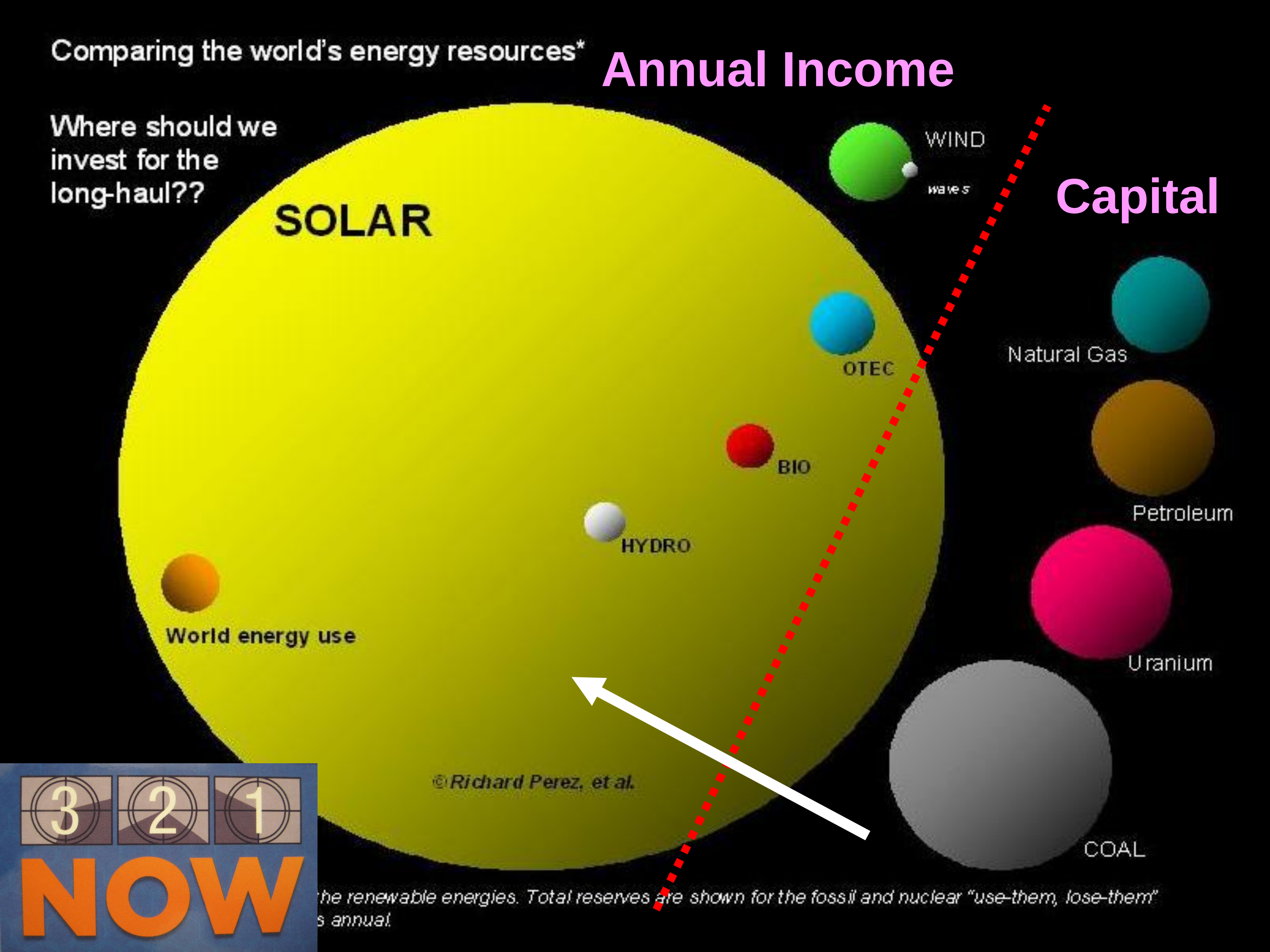
Sea level is rising at an increasing rate: NOAA
Now ~ 3 mm / year = 1/8 inch / year

Comparing the world's energy resources*

Where should we invest for the long-haul??



*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.



Comparing the world's energy resources*
Annual Income
Capital
Where should we invest for the long-haul??
SOLAR
WIND
waves
OTEC
Natural Gas
BIO
Petroleum
HYDRO
World energy use
Uranium
© Richard Perez, et al.
COAL
3 2 1
NOW
the renewable energies. Total reserves are shown for the fossil and nuclear "use-them, lose-them"
s annual.

Transform World's Largest Industry

- **85% fossil**
- **100% renewables**
- **Quickly**
- **Prudently**
- **Profitably**
- **Nuclear ?**
- **Beyond electricity**

January Week: Electricity

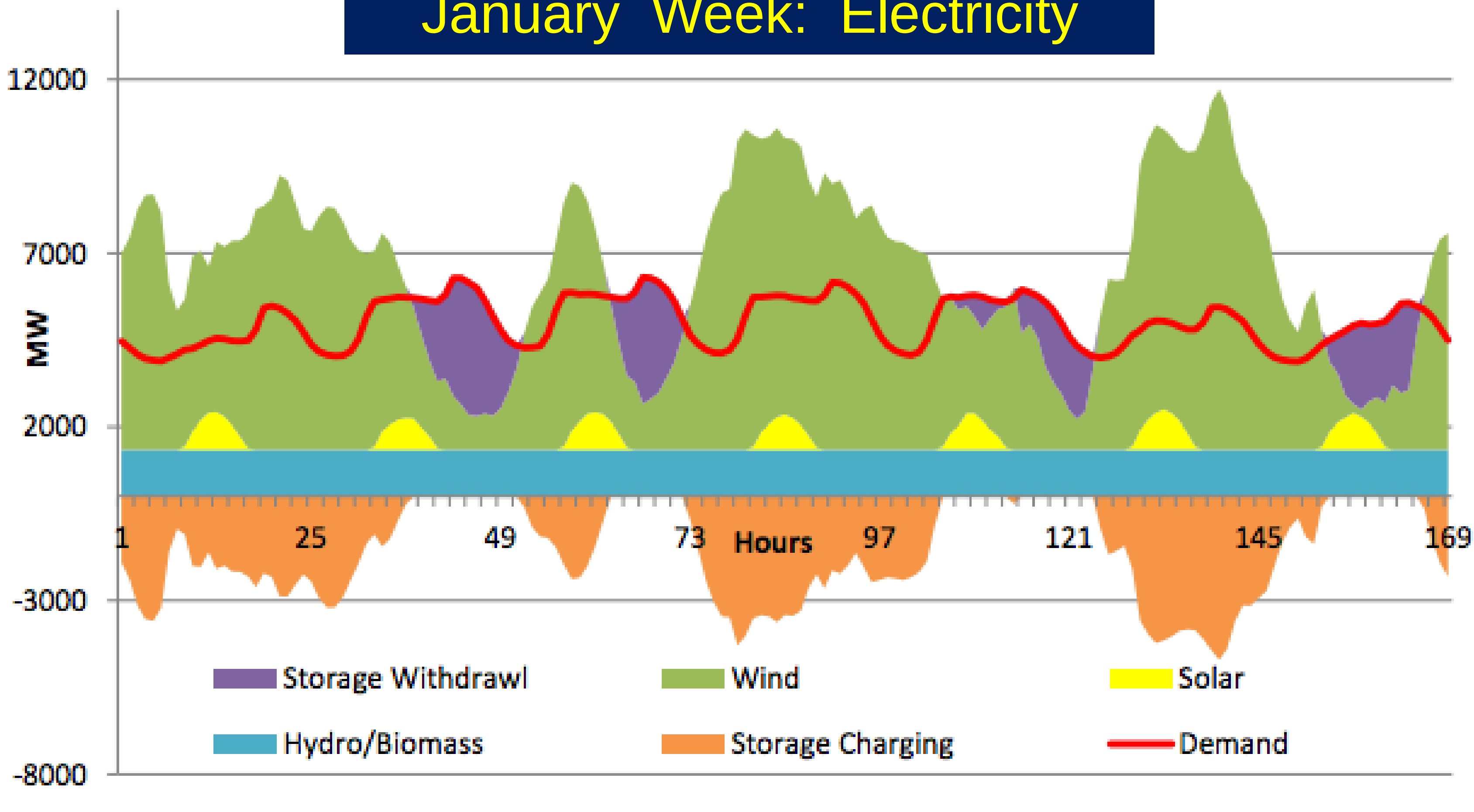


Figure III-6: Hourly supply and demand with storage, January 1-7, 2007. *Source: IEER.*

Hypothetical:
100 % Renewable Electricity System in Minnesota

Run the World on Renewables

“ Providing all global energy with wind, water, and solar power (WWS) ”

Jacobson & Delucchi

Energy Policy 39 (2011)

“ Wind Vision ” 2015

- Goal: 404 GW by 2050 @ 40% CF =

  404 x 8,760 x 0.4 =

  1,415,616 GWh / year =

  1,415 TWh / year =

  4.8 Quads =

  < 5% Total US energy by 2050
- 12 windy Great Plains states: 34,000 TWh =

  115 Quads

“ Wind Vision ” -- 2015

- Goals:
  1. Reduce Wind Costs
  2. Expand Developable Areas
  3. Increase Economic Value for US
- Understand potential: affordable, reliable, low-carbon US energy portfolio and economy
- US only
- Electricity market only … “across all U.S. market sectors and regions.”
- Model transmission expansion:

  10 million MW-miles by 2030

  29 million MW-miles by 2050

Need a new “Central Study Scenario”:

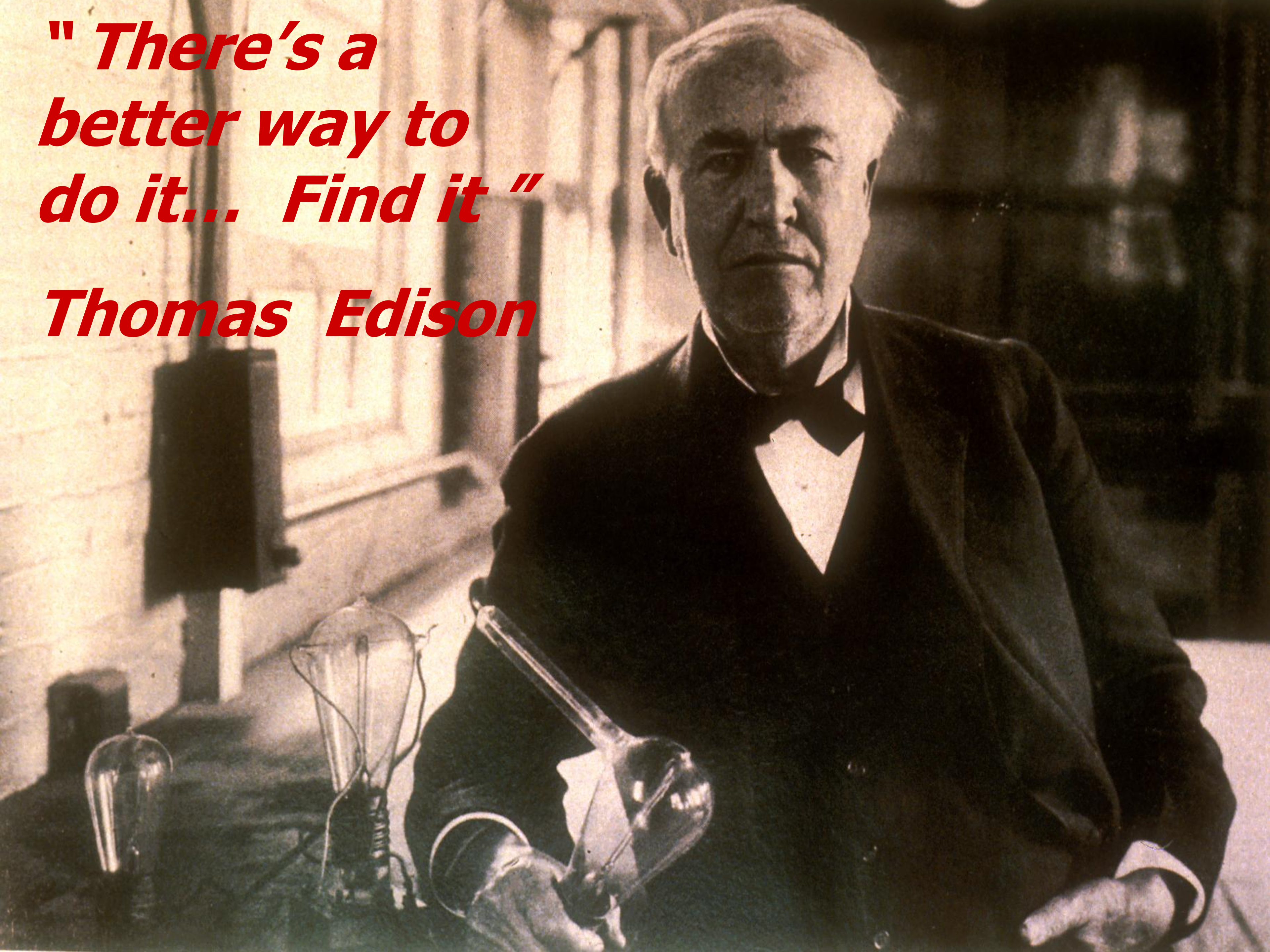
Alternatives to Electricity Systems

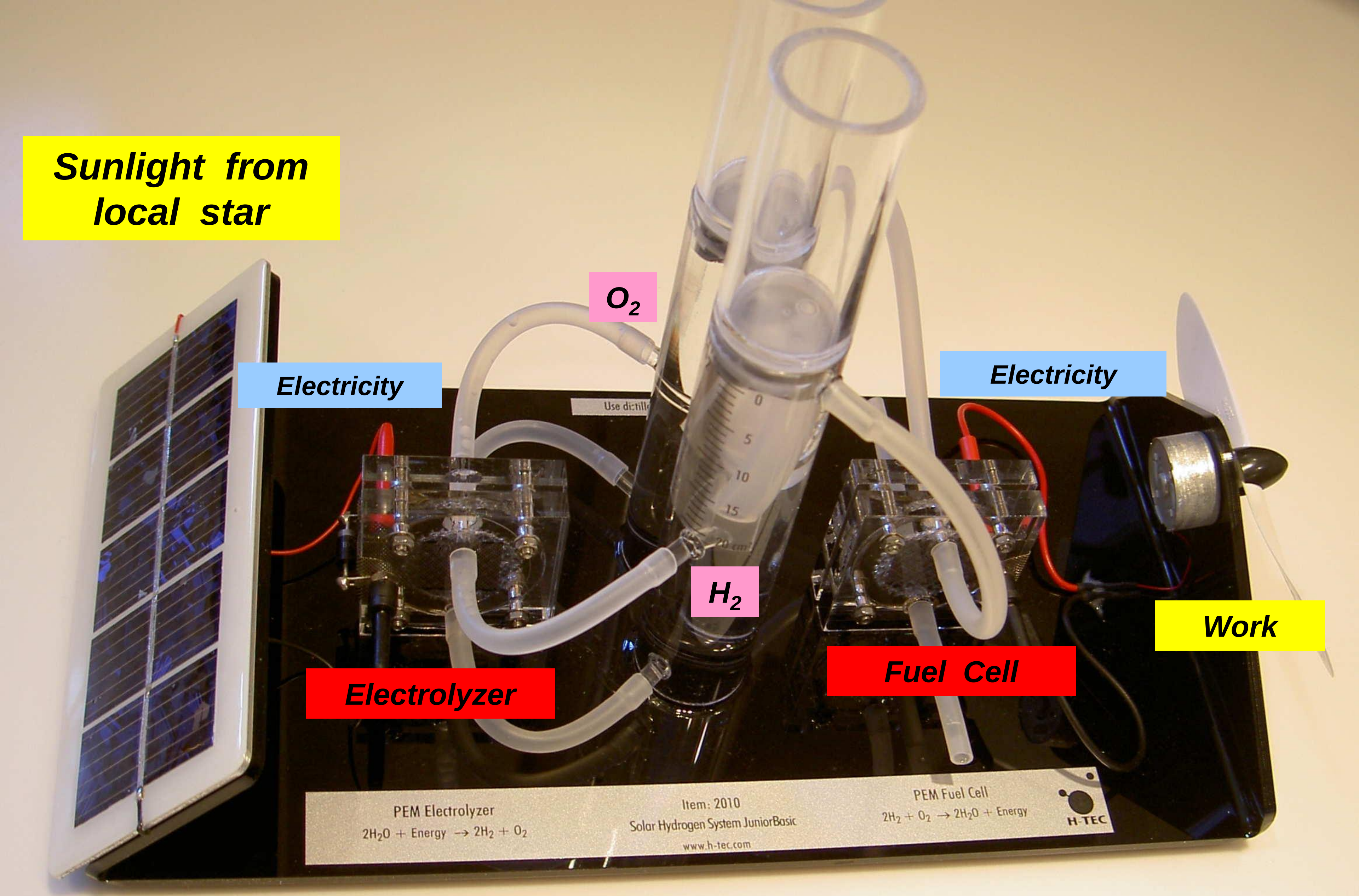
Need a new "Central Study Scenario": Alternatives to Electricity Systems

- Beyond Electricity:

  complete renewables systems

- New markets: wind-source fuels
  - Transportation
  - Distributed
    - CHP – Combined Heat and Power
    - DHS – District Heating and Cooling

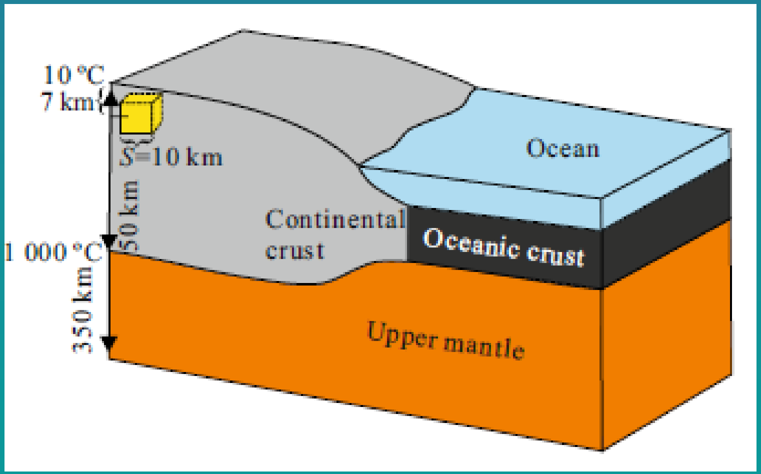

" There's a better way to do it… Find it "
Thomas Edison

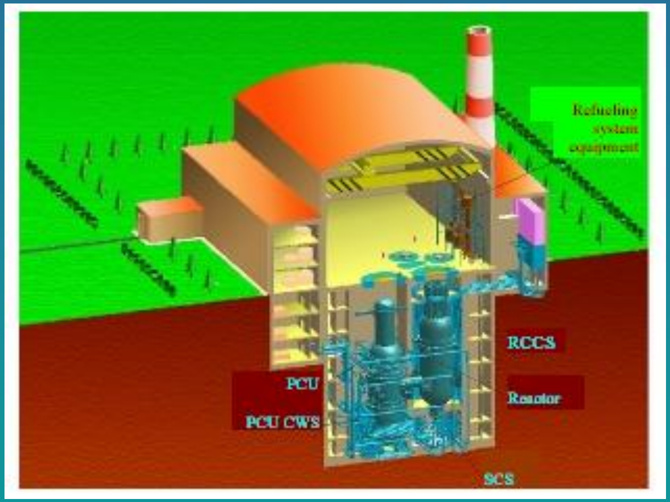


Solar Hydrogen Energy System

Competition: Need a new "Central Study Scenario" Alternatives to Electricity Systems

- Solar
  - PV, CSP
  - Centralized, distributed
- Nuclear: SMR's
- Geothermal

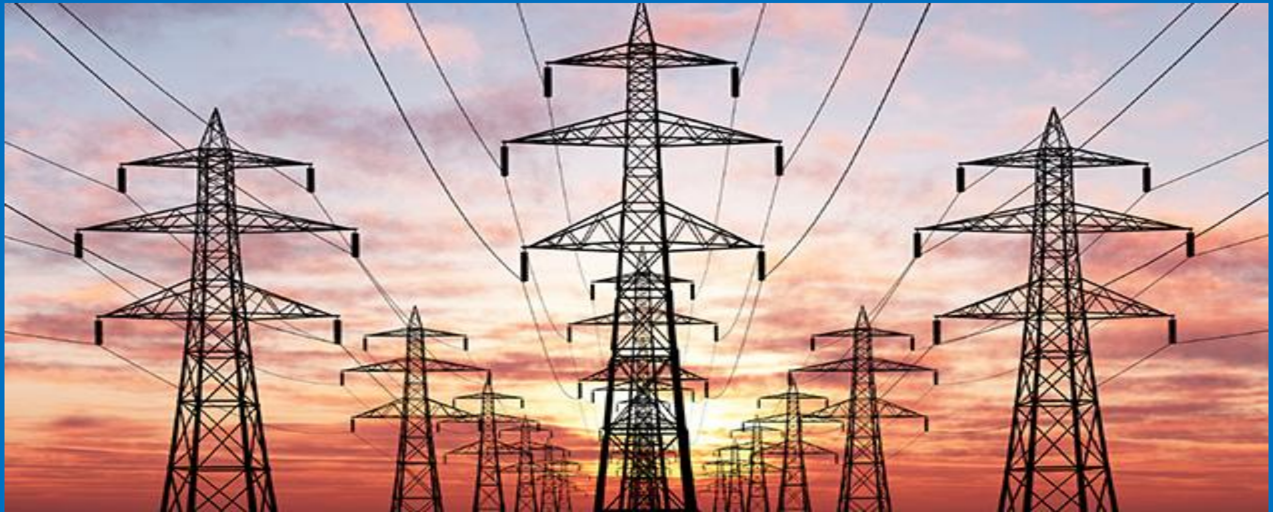




- Collaborative: NREL, GE, AWEA, EPRI, UCS, NRDC, Universities ….
- All USA's 100 Quads → "Run World on RE"
- With electricity alone ?
- Alternatives to Electricity systems for:
    1. Gathering and transmission
    2. Annual-scale firming storage
    3. Integration
- New markets
- New "Wind Vision" chapter

If your only tool is a hammer …

If your only product is electricity …



Jim Rogers,
former CEO,
Duke Energy

" If everyone has rooftop PV and a battery, utilities are just supplying backup power "

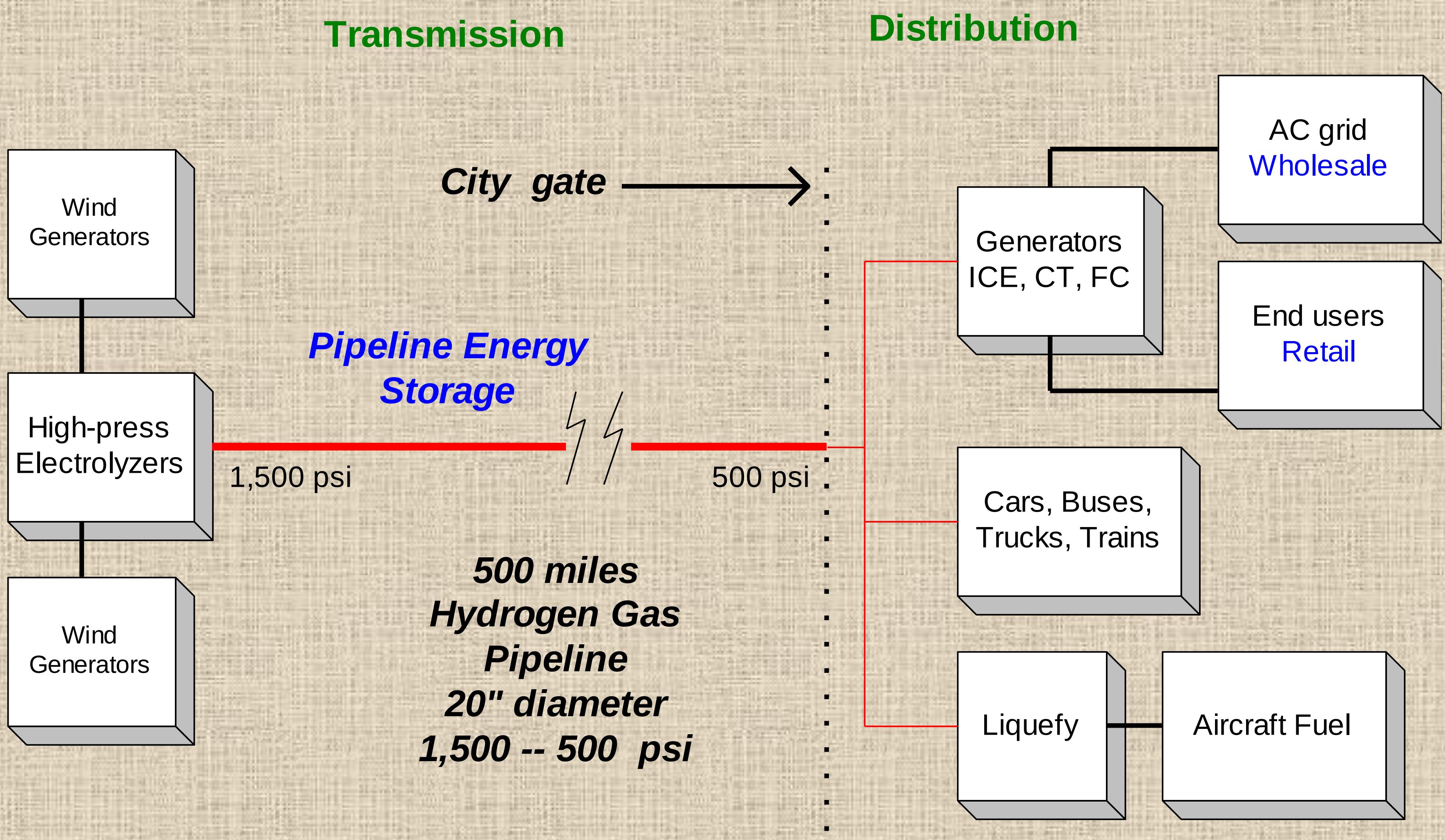
What Grid ?

- “Smart Grid” $ Billions
  - Mostly DSM
  - Vulnerable to Cyberattack ?
  - “Smart” ≠ more capacity:
    transmission + storage
- 3,000 new 3 GW elec lines ?
- “ Run the World on Renewables ” ?
- Evolve, atrophy ?

Suboptimal ?
Opportunity cost

US $ 45 trillion
New infrastructure invest
By 2030

Compressorless system: No geologic storage



The New Benchmark in Electrolysis

MW PEM Stack

Electrical Power Input	1.5 MW (overdrive)
Hydrogen Output	285 Nm3/h
Max. Operating Pressure	40 bar (g)
Certifications	PED (97/23/EC)

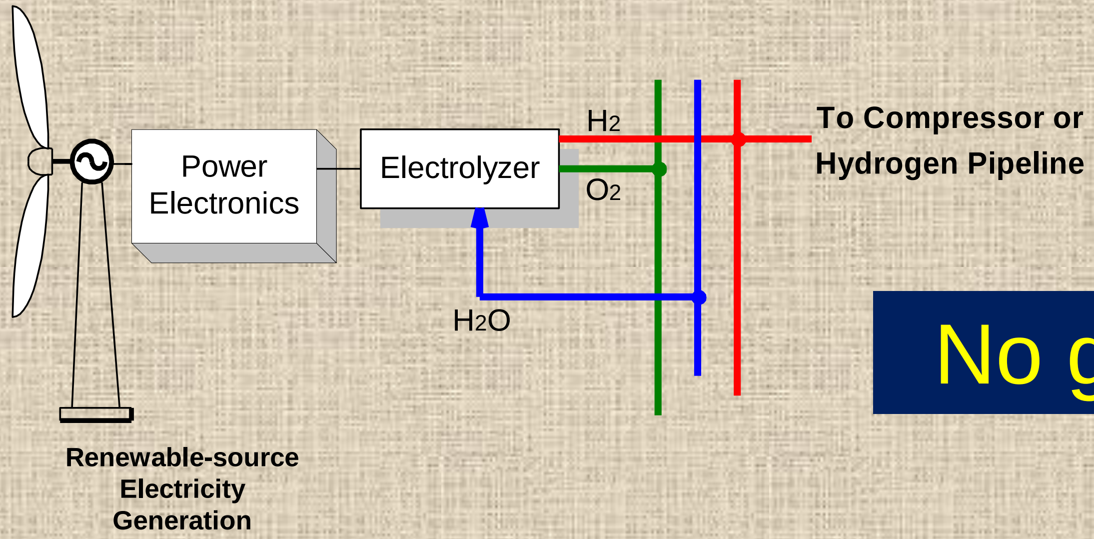
Electrolyzers:

Siemens
Hydrogenics
ProtonOnsite
ITM Power
GE

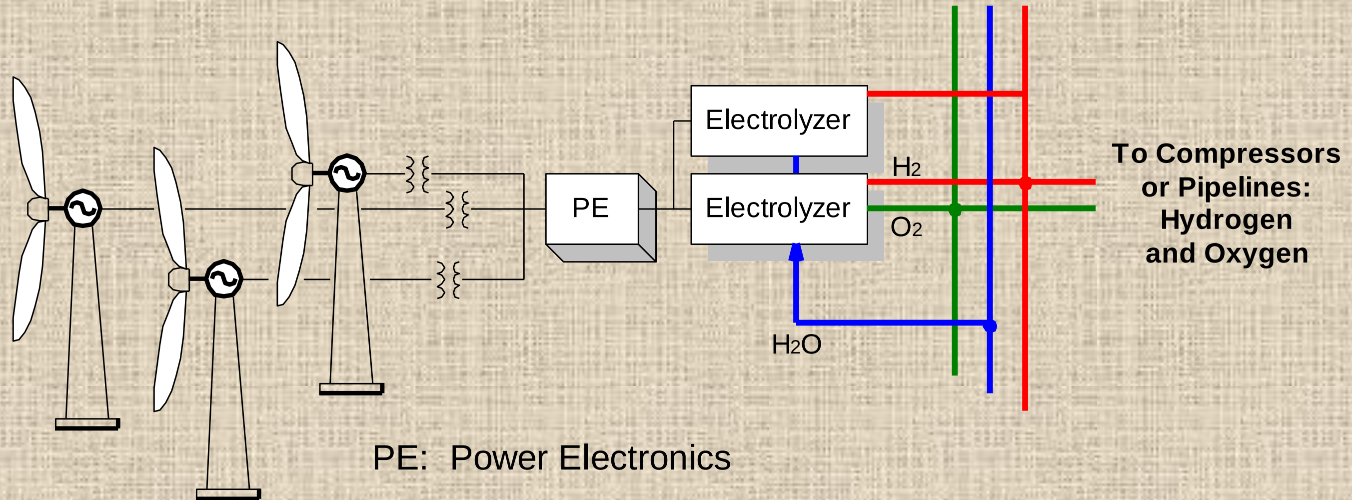
Wind to Hydrogen   Power to Gas

" Energiepark Mainz "

Siemens, Linde, Stadtwerke Mainz, RheinMain University



No grid connection



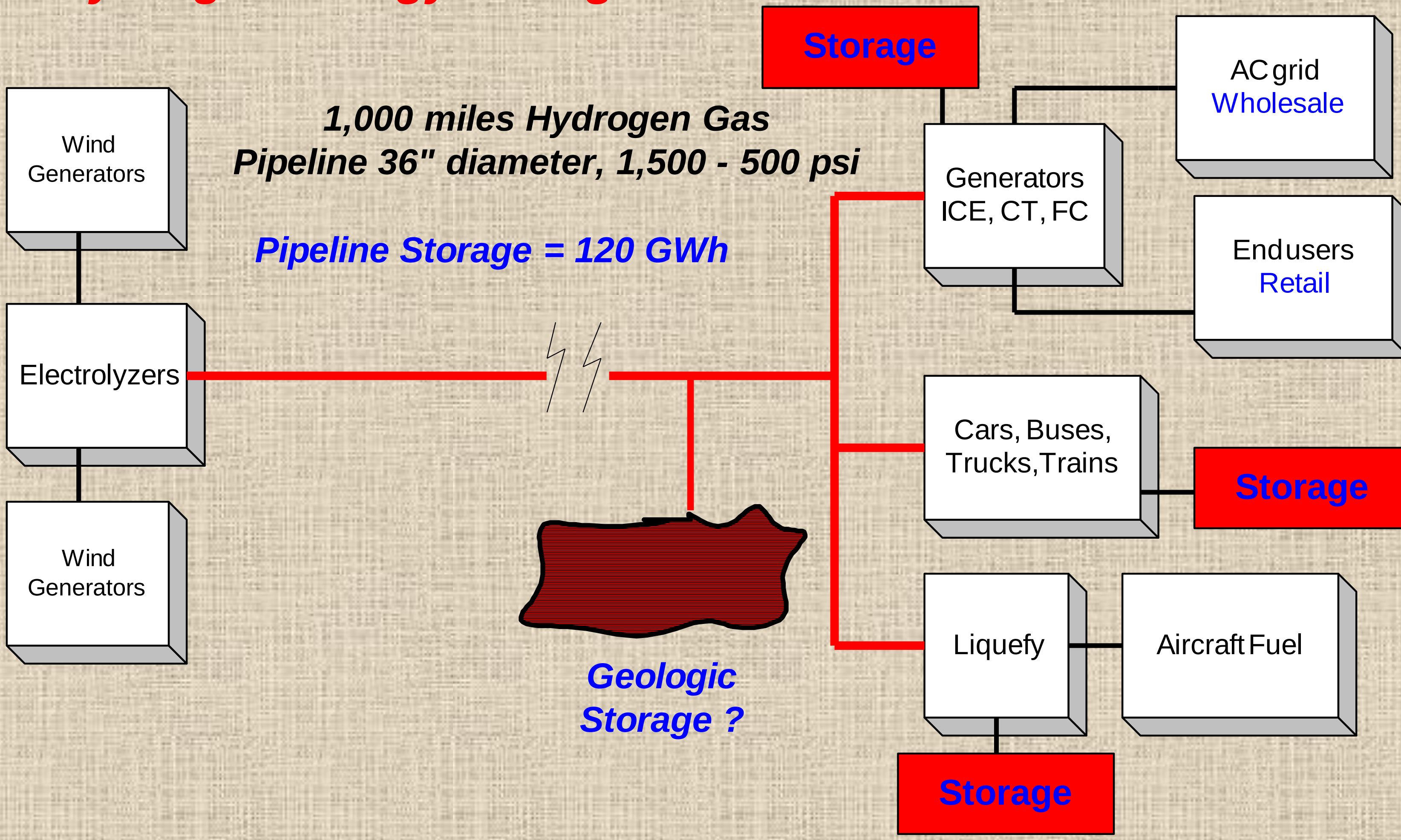
Topology Options: H_2 and O_2 Production and Gathering from Renewable Energy Generation

ABB ACS800 low voltage wind turbine converter


Amrumbank West
8 km
HelWin beta
85 km
Helgoland
Büsum
45 km
UW Büttel
Cuxhaven

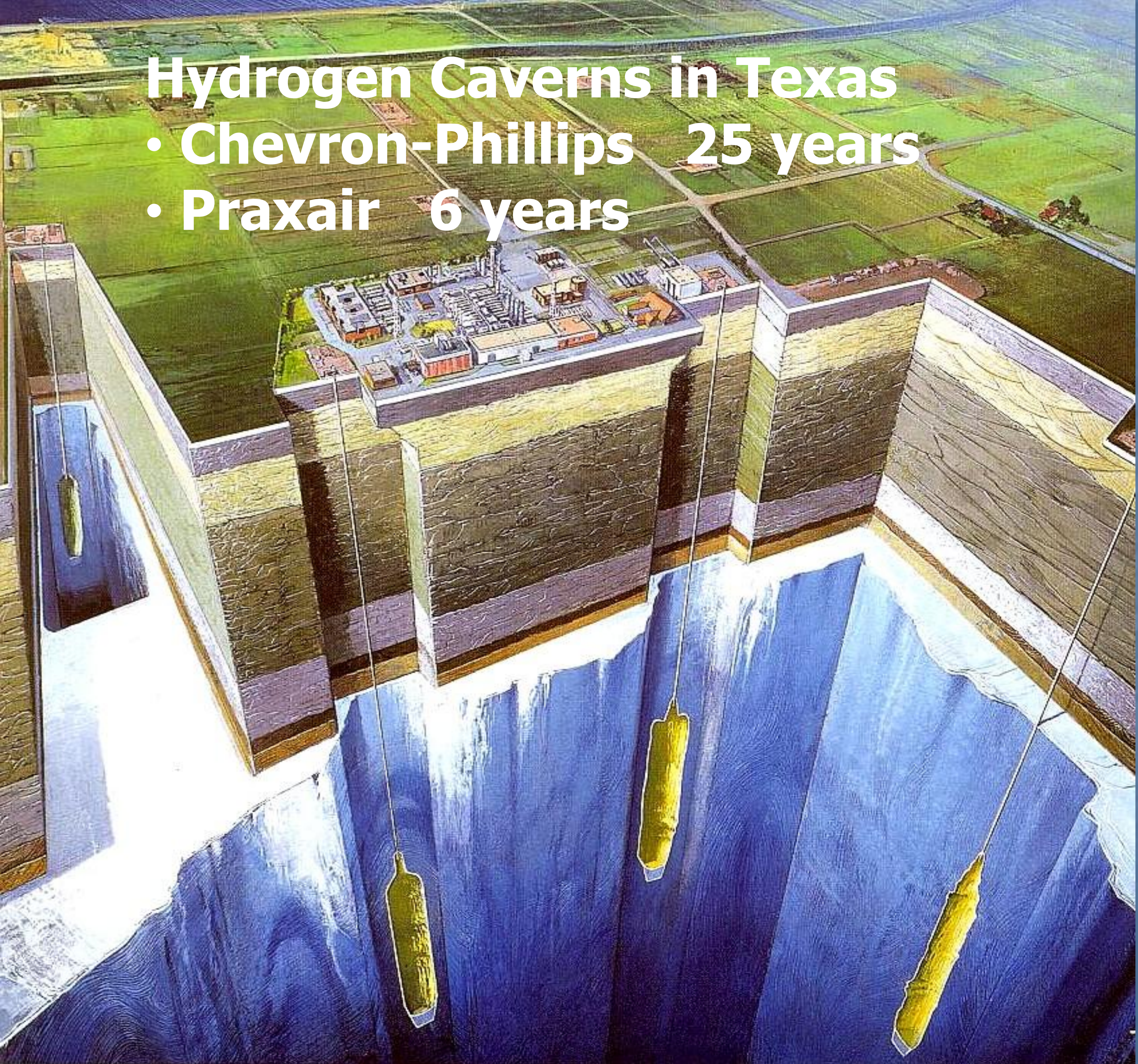

TAKLIFT 4

Hydrogen Energy Storage



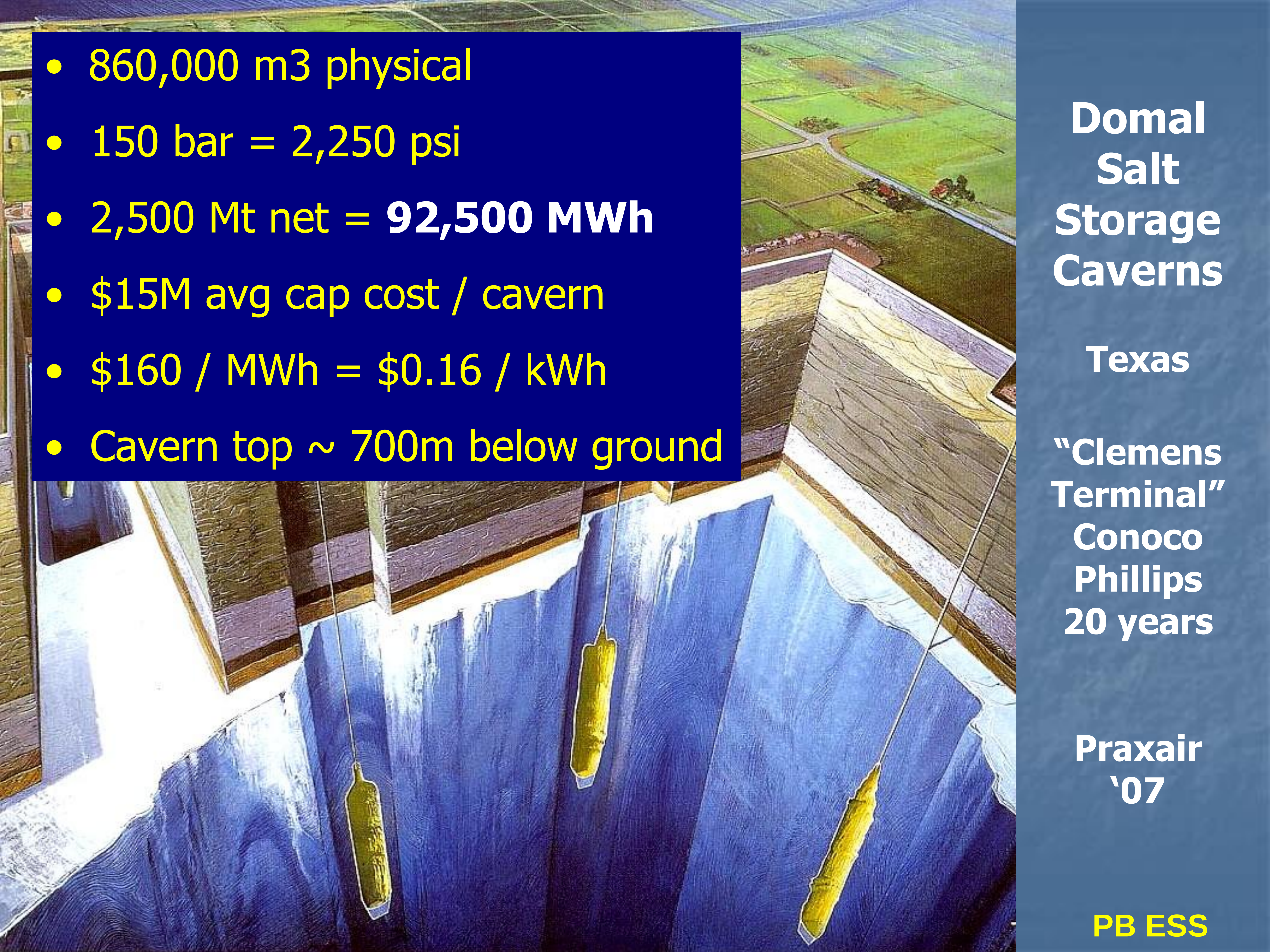
Hydrogen Caverns in Texas

- Chevron-Phillips   25 years
- Praxair   6 years



Domal Salt Storage Caverns

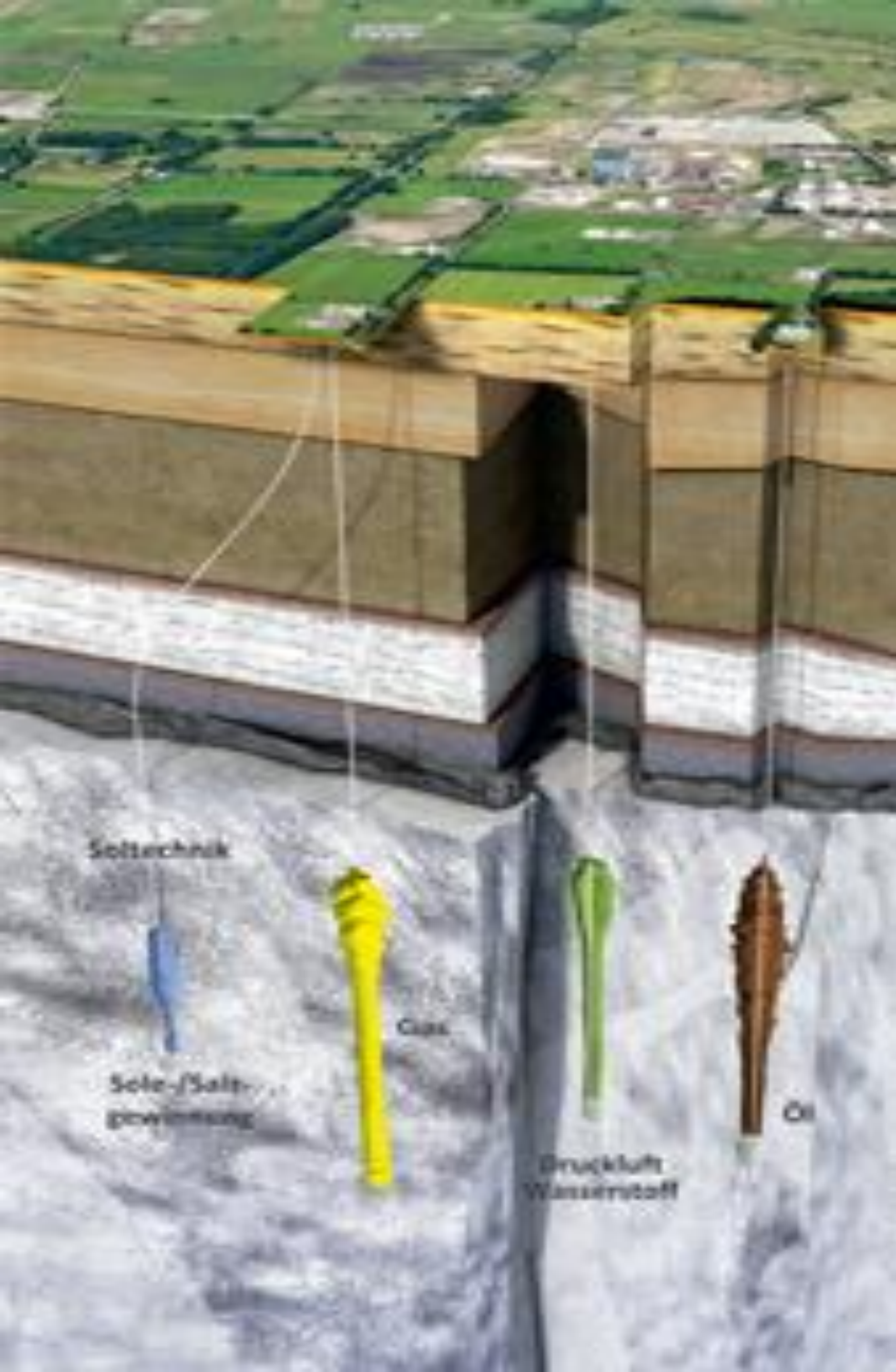
PB ESS



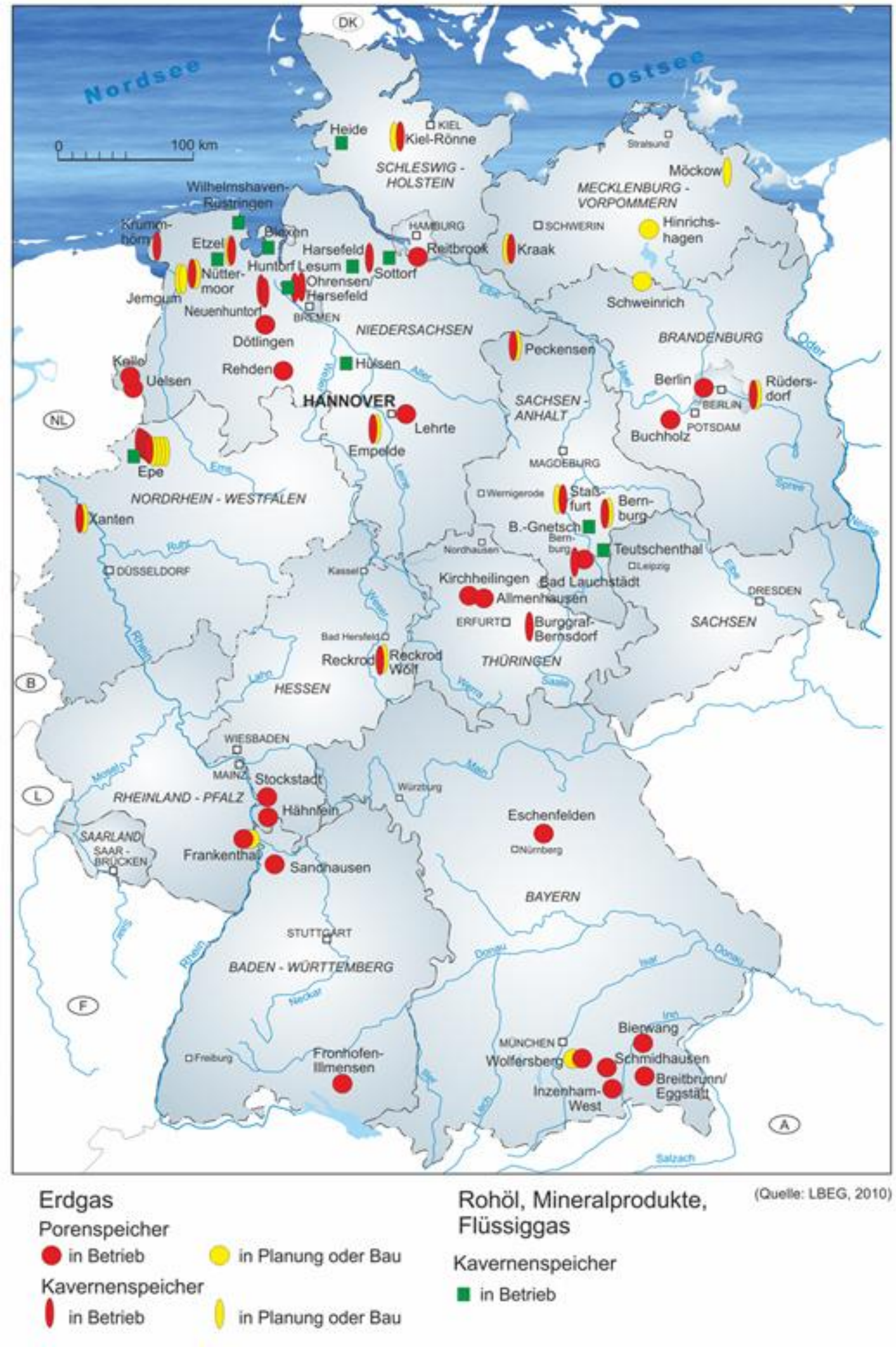
860,000 m3 physical
150 bar = 2,250 psi
2,500 Mt net = 92,500 MWh
$15M avg cap cost / cavern
$160 / MWh = $0.16 / kWh
Cavern top ~ 700m below ground
Domal Salt Storage Caverns
Texas
“Clemens Terminal” Conoco Phillips 20 years
Praxair ‘07
PB ESS

Renewable-source GH2 geologic storage potential

Candidate formations for manmade, solution-mined, salt caverns

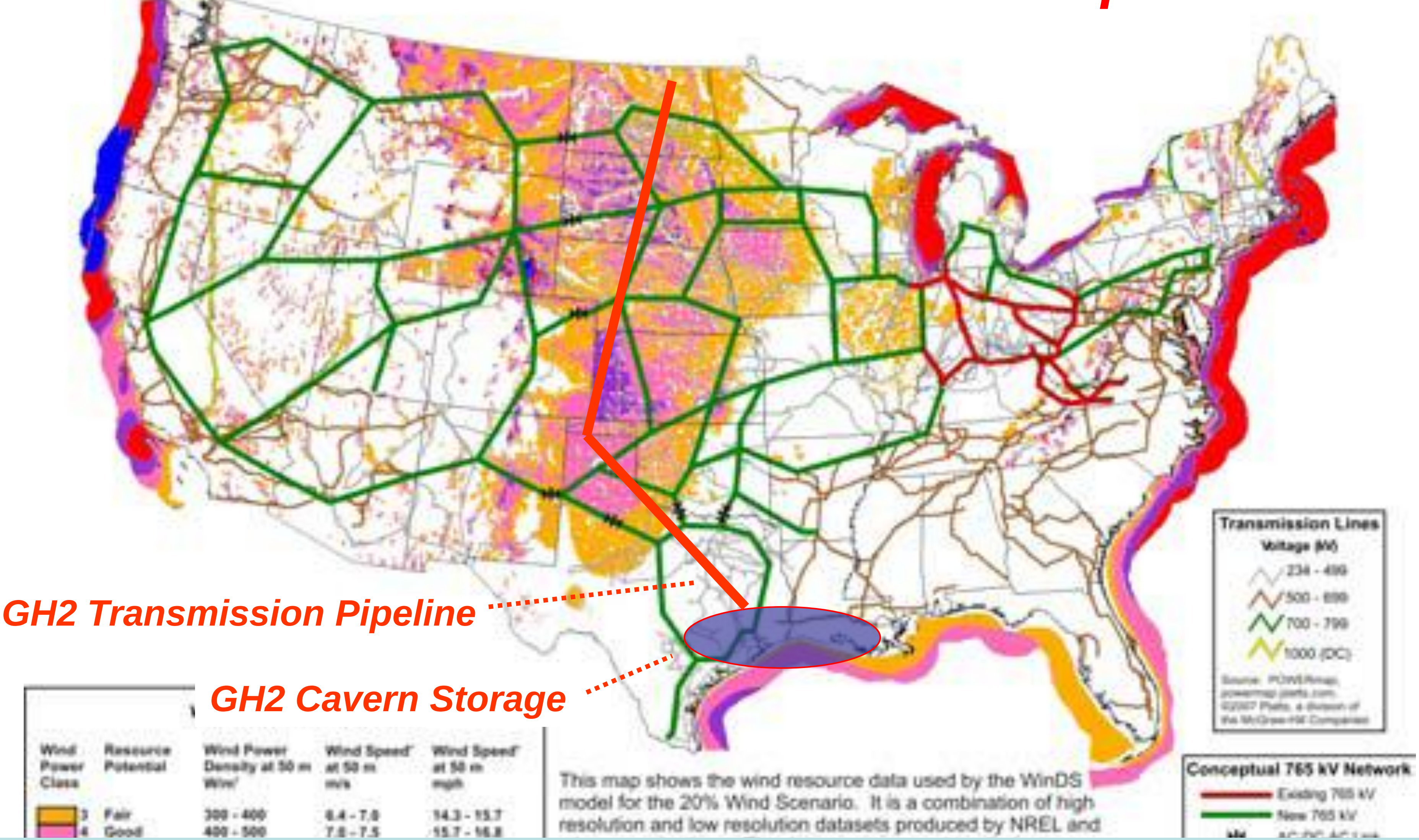


Soltechnik
Sole-/Salzgewinnung
Gas
Druckluft
Wasserstoff
Öl



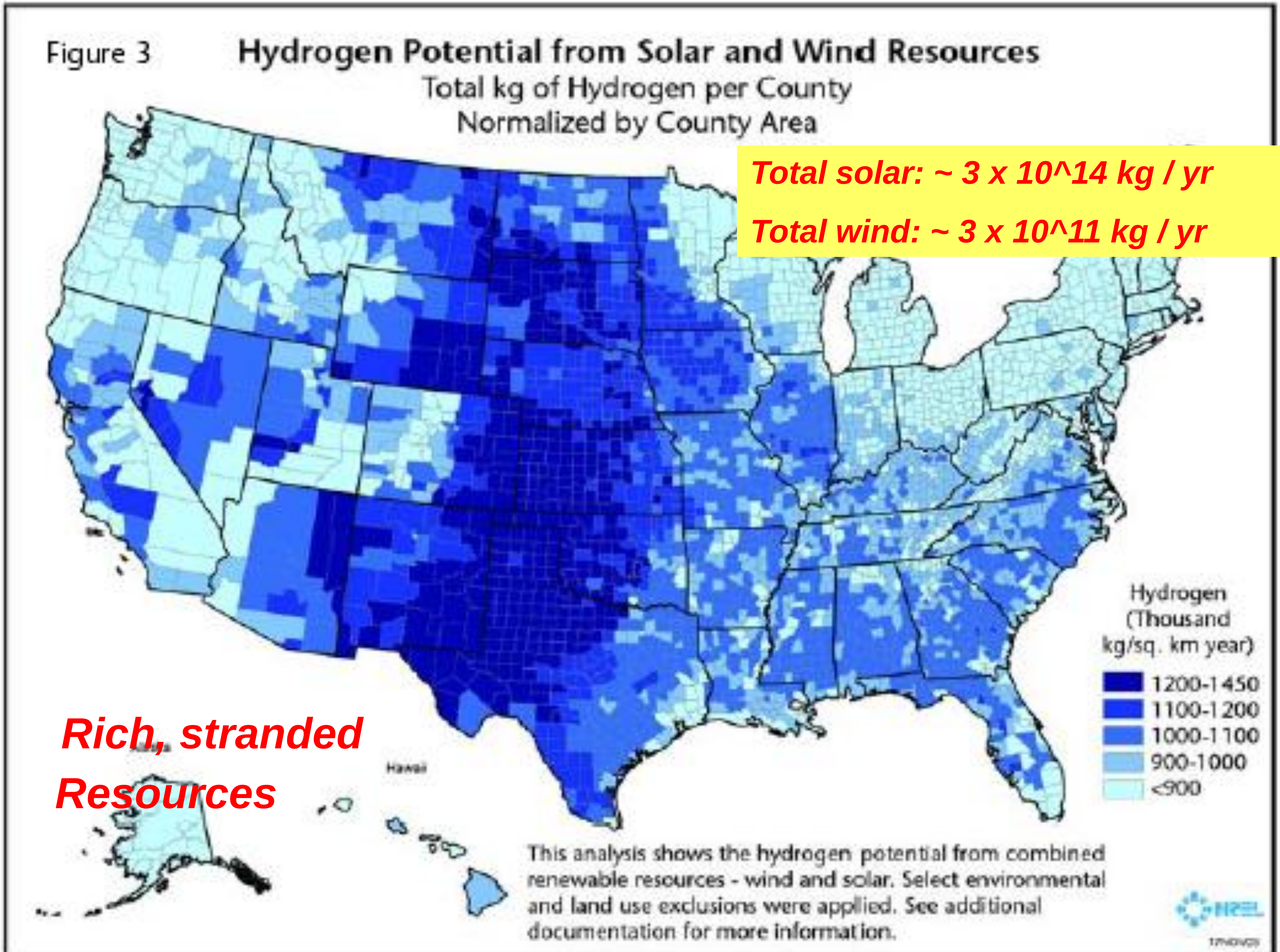
DK
Nordsee
Ostsee
0
100 km
Heide
KIEL
Kiel-Rönne
SCHLESWIG - HOLSTEIN
Stralsund
Möckow
MECKLENBURG - VORPOMMERN
Wilhelmshaven-Rüstringen
Krummhörn
Etzel
Blexen
HAMBURG
SCHWERIN
Hinrichshagen
Harsefeld
Reitbrook
Kraak
Nüttermoor
Huntorf
Lesum
Sottorf
Jemgum
Ohrensen/Harsefeld
Schweinrich
Neuenhuntorf
BREMEN
NIEDERSACHSEN
Elbe
Dötlingen
BRANDENBURG
Peckensen
Oder
Kalle
Rehden
Hülsen
Uelsen
Aller
Berlin
Rüdersdorf
HANNOVER
SACHSEN - ANHALT
BERLIN
NL
Lehrte
Buchholz
POTSDAM
Empelde
Epe
MAGDEBURG
Ems
Wernigerode
Staßfurt
Bernburg
NORDRHEIN - WESTFALEN
Xanten
B.-Gnetsch
Teutschenthal
Nordhausen
Ruhr
Leipzig
Kassel
Kirchheilingen
Bad Lauchstädt
DÜSSELDORF
Allmenhausen
DRESDEN
ERFURT
Burggraf-Bernsdorf
SACHSEN
Bad Hersfeld
Reckrod
Reckrod Wölf
THÜRINGEN
B
HESSEN
Rhein
Lahn
Saale
WIESBADEN
MAINZ
Stockstadt
Würzburg
Main
L
RHEINLAND - PFALZ
Hähnlein
Eschenfelden
SAARLAND
SAARBRÜCKEN
Frankenthal
Nürnberg
Sandhausen
BAYERN
STUTTGART
BADEN - WÜRTTEMBERG
Donau
Neckar
F
Inn
Isar
Bierwang
MÜNCHEN
Wolfersberg
Schmidhausen
Freiburg
Fronhofen-Illmensen
Breitbrunn/Eggstätt
Inzenham-West
A
Salzach
Erdgas
Porenspeicher
in Betrieb
in Planung oder Bau
Kavernenspeicher
in Betrieb
in Planung oder Bau
Rohöl, Mineralprodukte, Flüssiggas
Kavernenspeicher
in Betrieb
(Quelle: LBEG, 2010)

GH2 Transmission Pipeline



Wind Potential ~ 10,000 GW

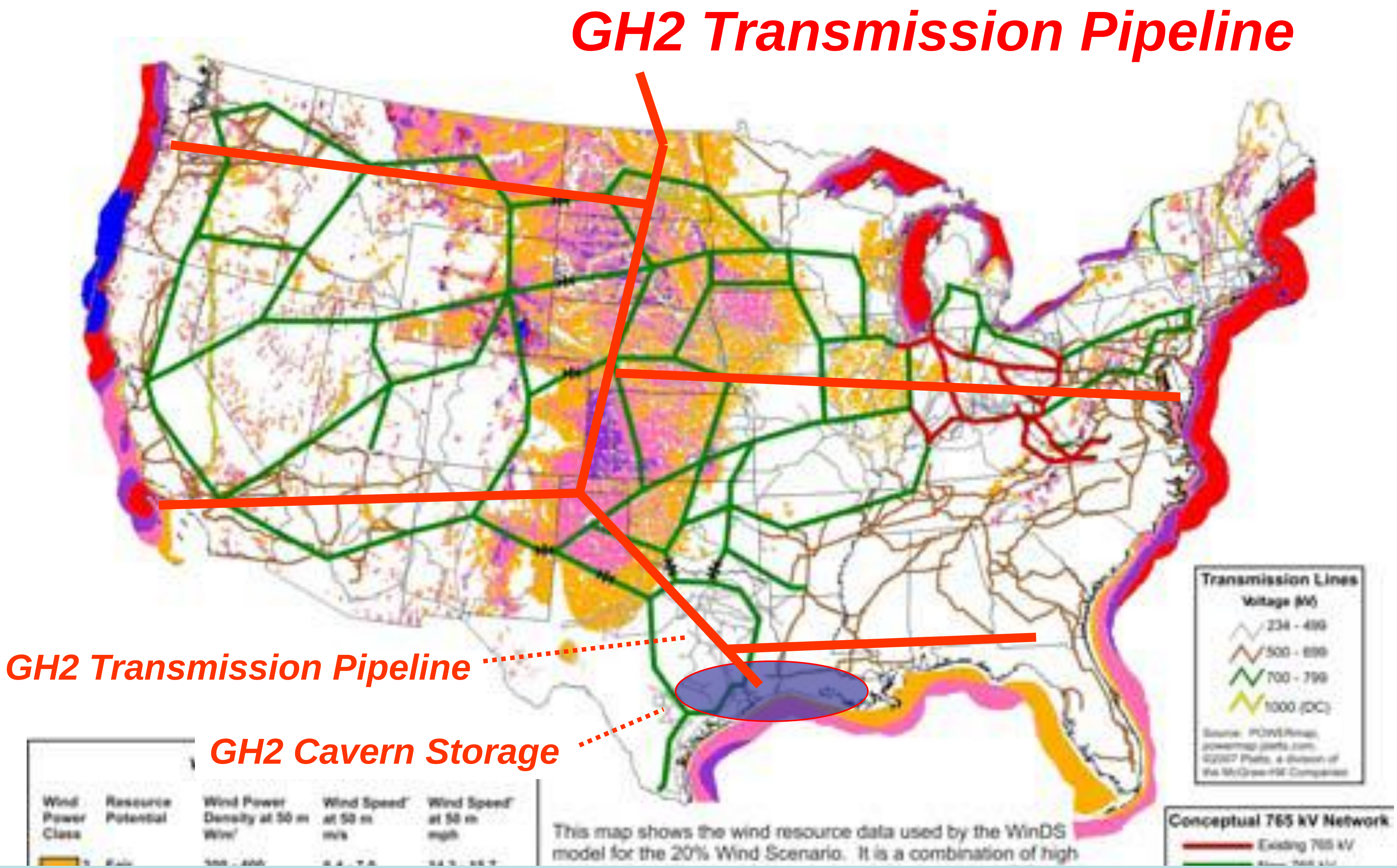
12 Great Plains states



Total solar: ~ 3 x 10^14 kg / yr

Total wind: ~ 3 x 10^11 kg / yr

Rich, stranded Resources

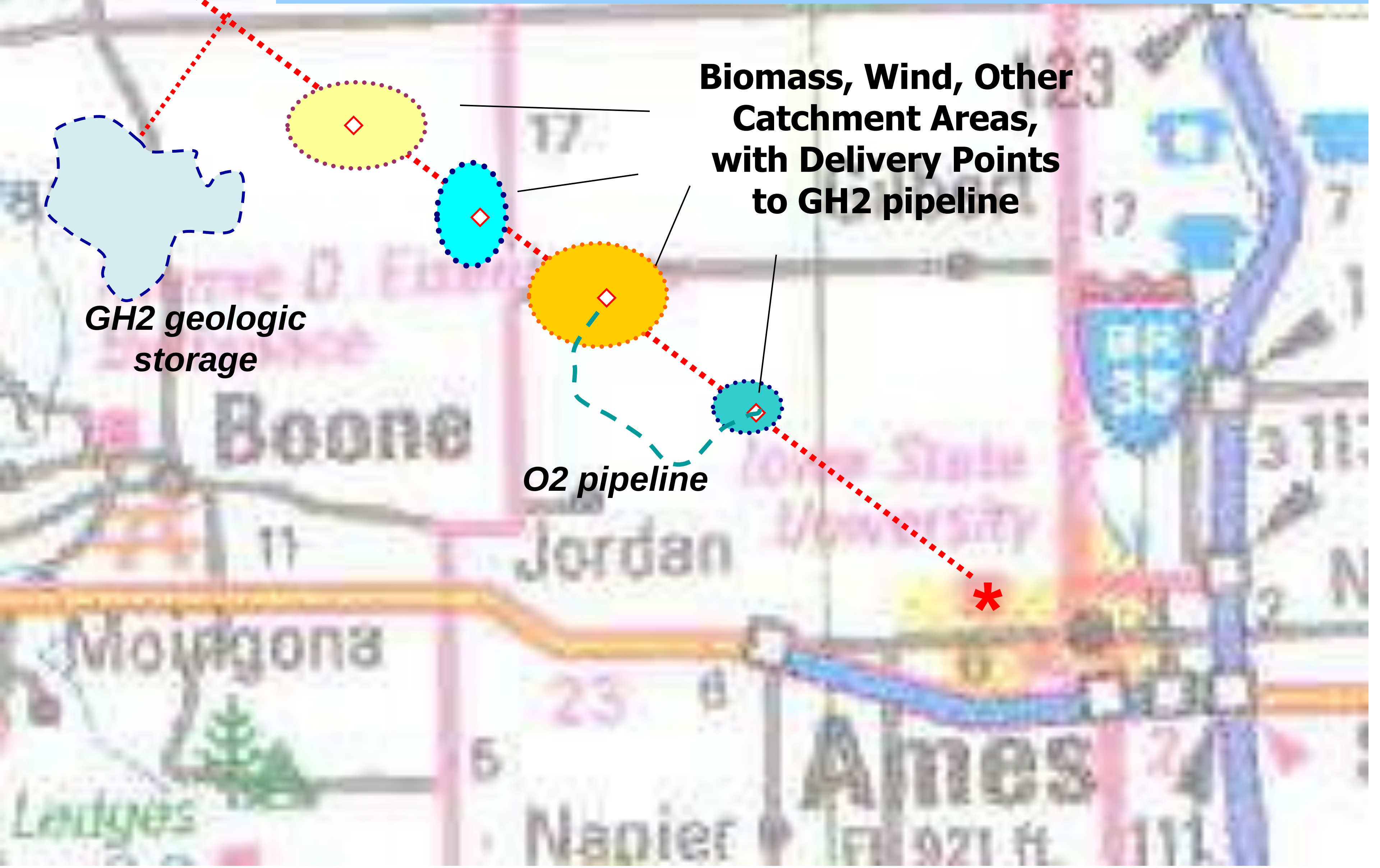


Wind Potential ~ 10,000 GW

12 Great Plains states

- **Collaborative: NREL, GE, AWEA, EPRI, UCS, NRDC, Universities ….**
- **New "Wind Vision" chapter**

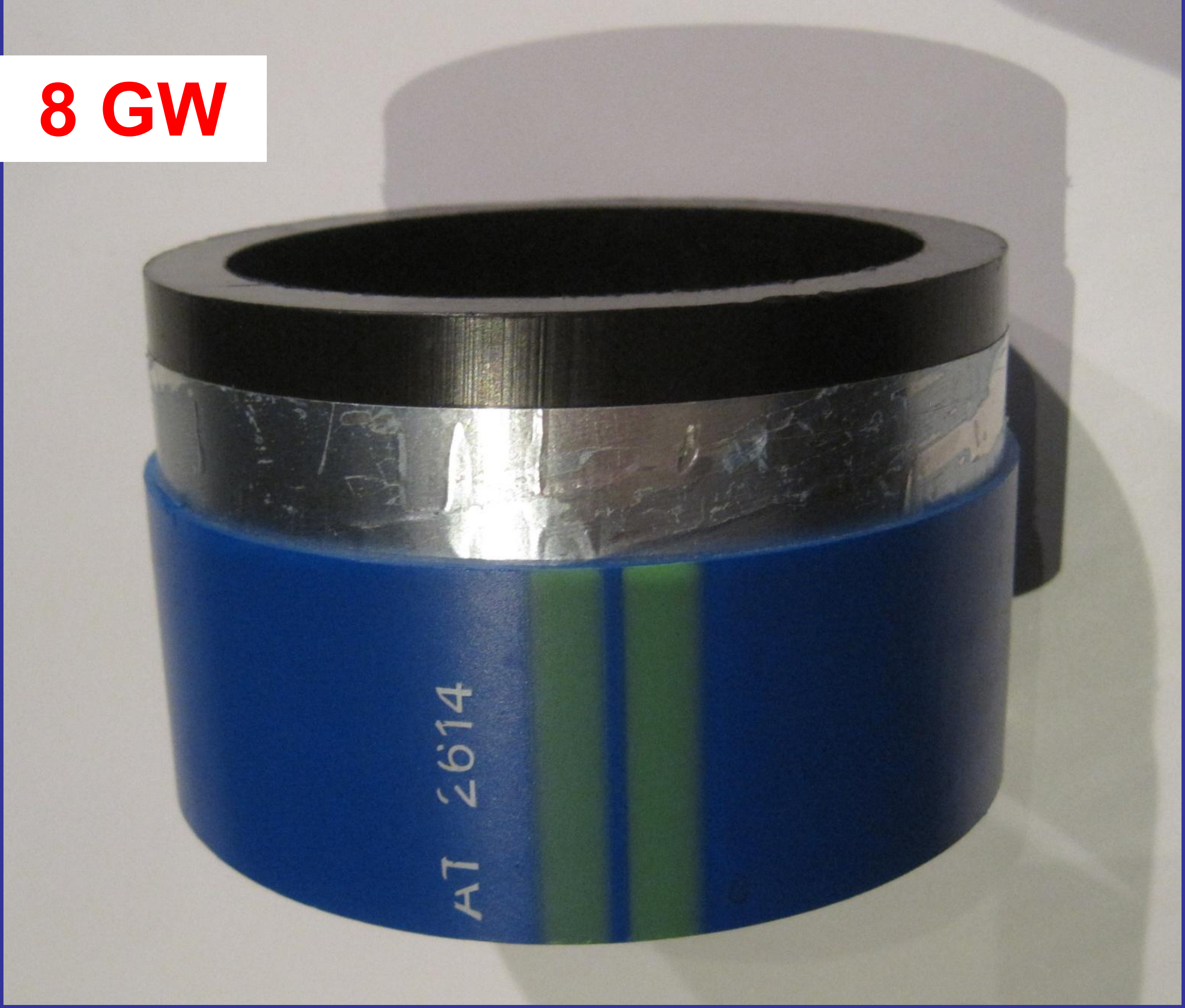
Pilot plant: ***generation, conversion, collection, storage CORRIDOR, SYSTEM***



Renewables, Electrochemical

Airbus Industrie concept: liquid hydrogen fueled

36” = 8 GW



Smart Pipe, Houston

Polymer-metal linepipe avoids hydrogen embrittlement

Hydrogen Fuel Cell Bus

Toyota:

- **Battery-electric vehicles (BEV's) only "... in short range vehicles ..."**
- **Will not make BEV's**
- **5,680 patents royalty-free**

Toyota Mirai Fuel Cell car: Hydrogen fuel only

Mercedes-Benz - Ford

“ No one will make money on electric cars In ‘reasonable time’ ”

Dieter Zetsche, Mercedes CEO

Mercedes-Benz B-class Fuel Cell car

Honda - GM

Honda Fuel Cell car
2016 production ?

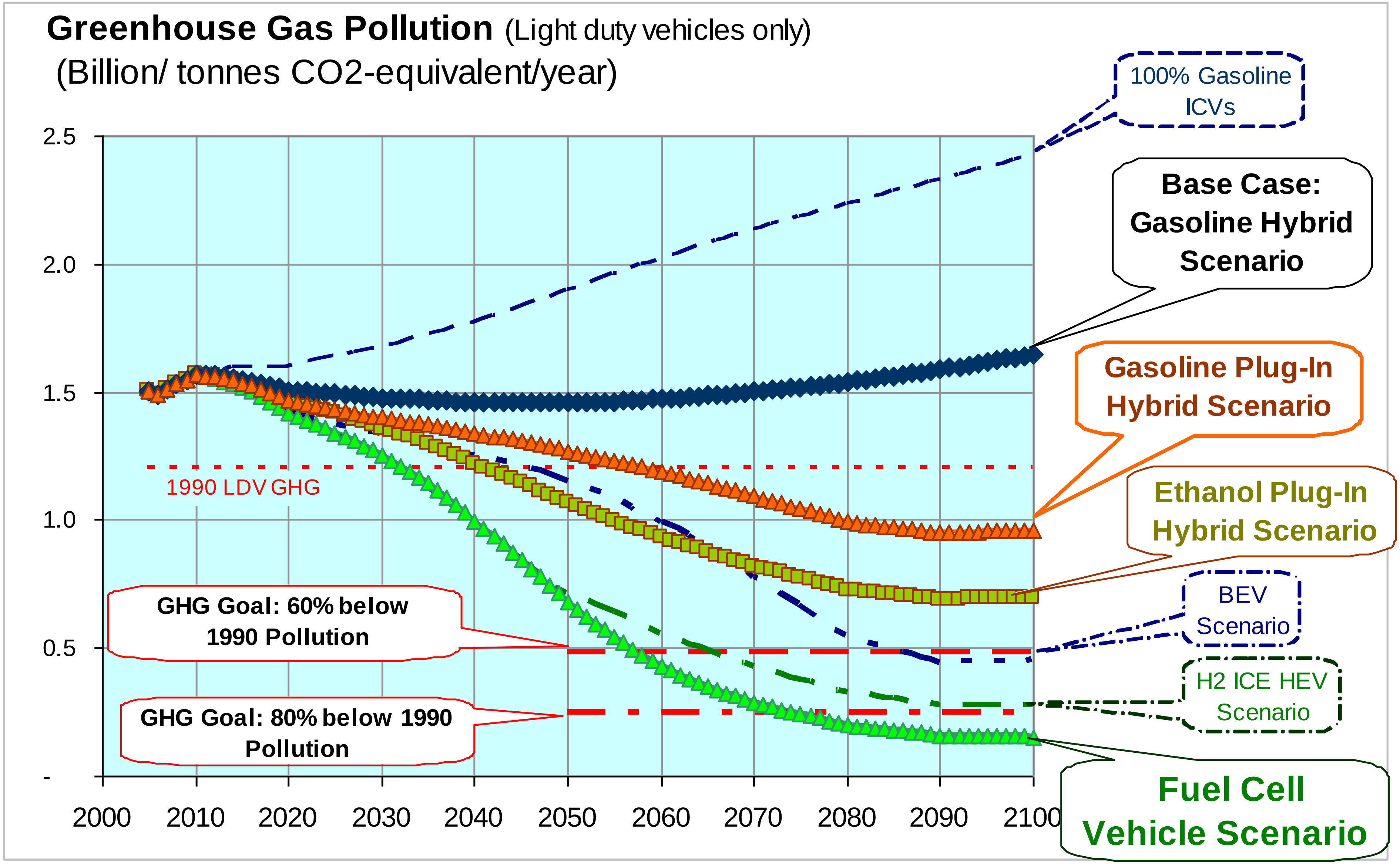

Fuel Cell

Fueling the Hyundai Tucson Fuel Cell car
3 minutes

Elon Musk, Tesla Co-Founder, CEO, and Product Architect

“Hydrogen is an incredibly dumb … fuel”
Fuel cell cars “are extremely silly”
“… fuel cell is so bullshit …”

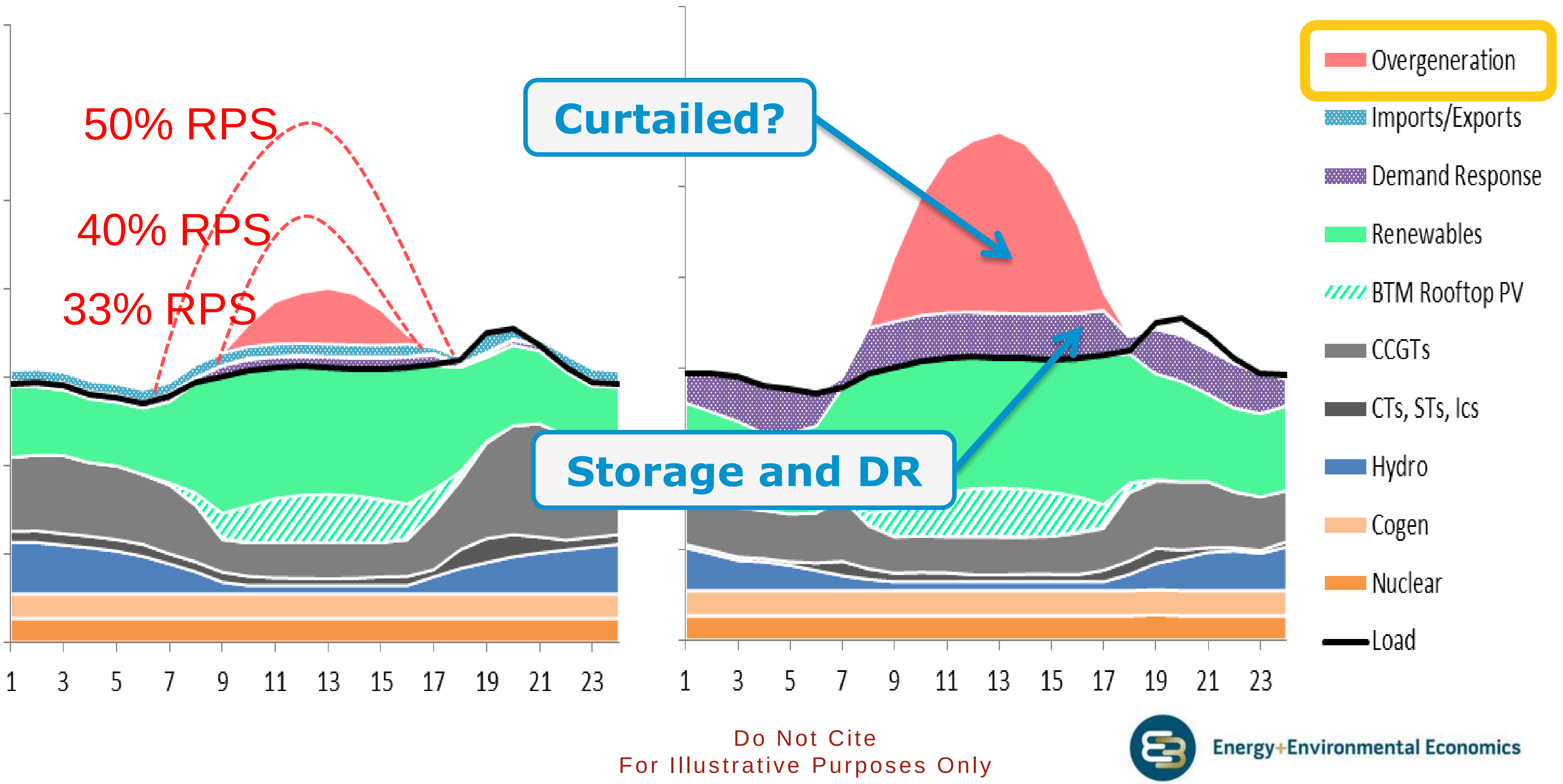
80% below 1990 by 2050, CO2 from "cars"



CA: 20% of Light Duty Vehicles (LDV) hydrogen fueled, by 2030

- **20% of 45 M vehicles = 9 M**
- **@ 78 mpg = 78 miles / kg H2**
- **12,000 miles / year = 150 kg H2 / year**
- **1,800 M kg H2 / year = 1.7 MMt H2 fuel / year**
- **@ 50 kWh / kg 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**

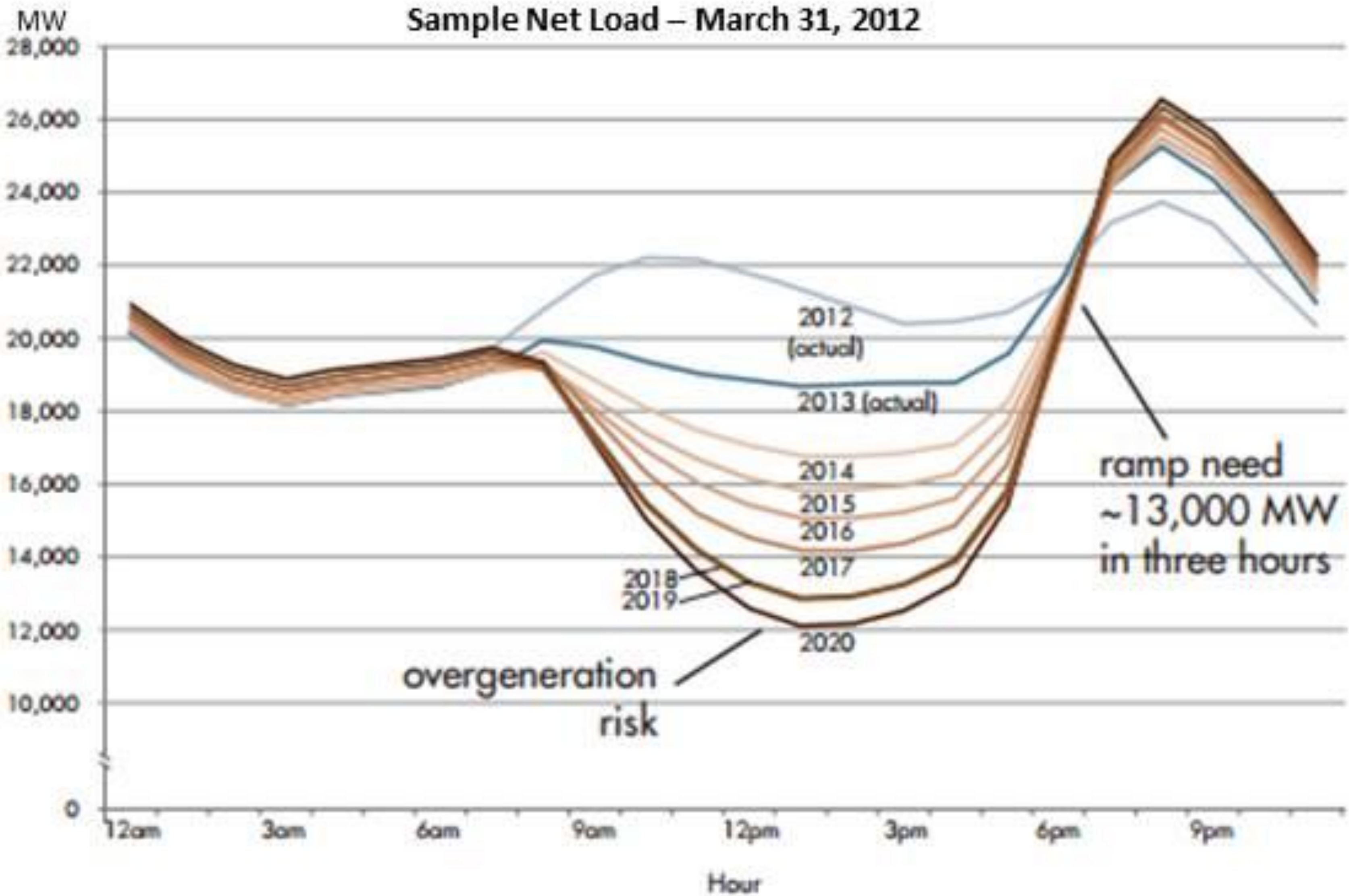
California's surplus renewable generation



Source: Adapted from + *Valuing Storage,* Eric Cutter, Energy + Environmental Economics – October 2013

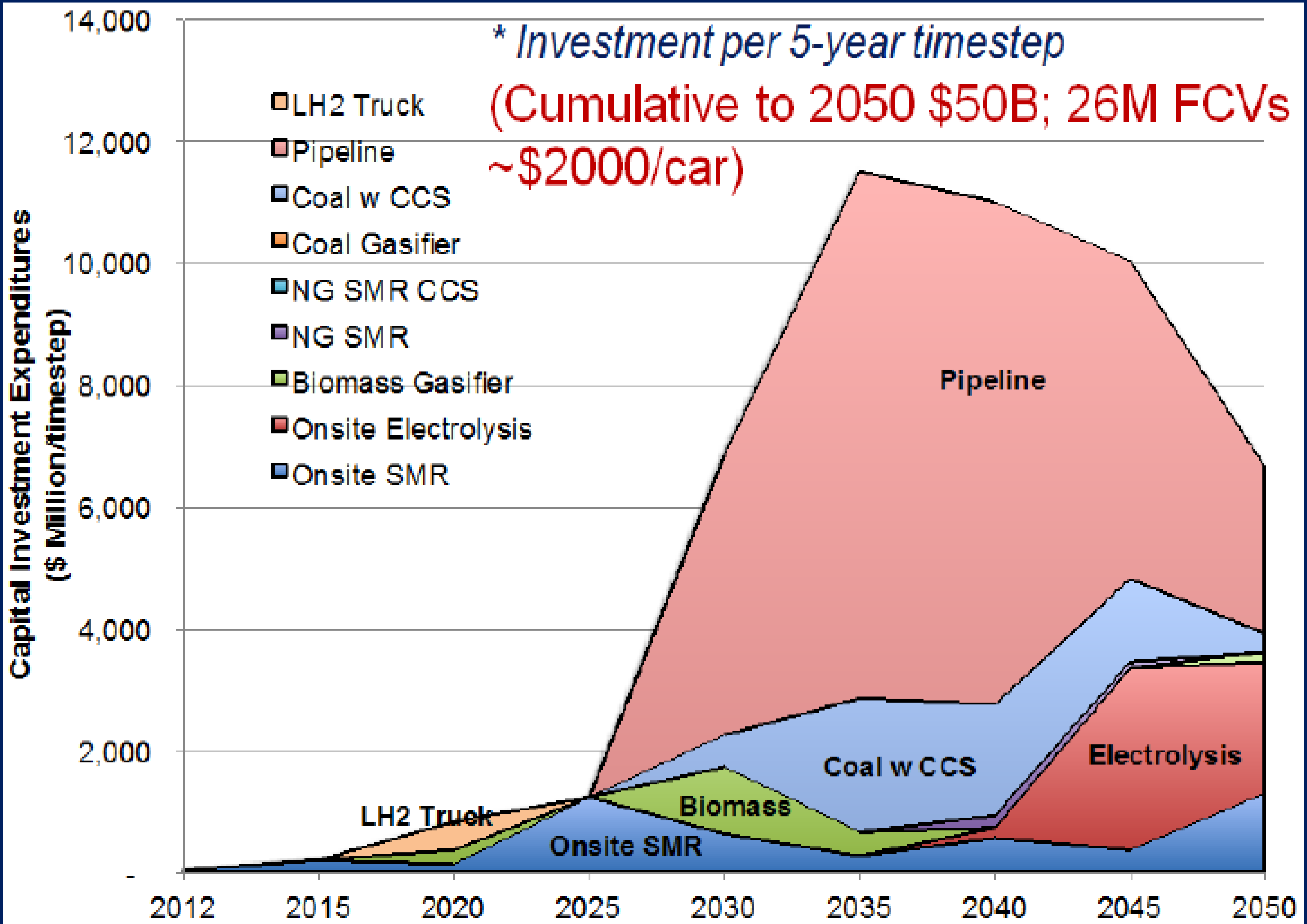
CA “Duck Curve”: solar overgeneration, steep ramp

Electric utilities NET load



CA Independent System Operator - CAISO

“Hydrogen Transition” UC Davis, ITS “NEXTSteps”



January 2015

Northern CA Hydrogen Stations

Open

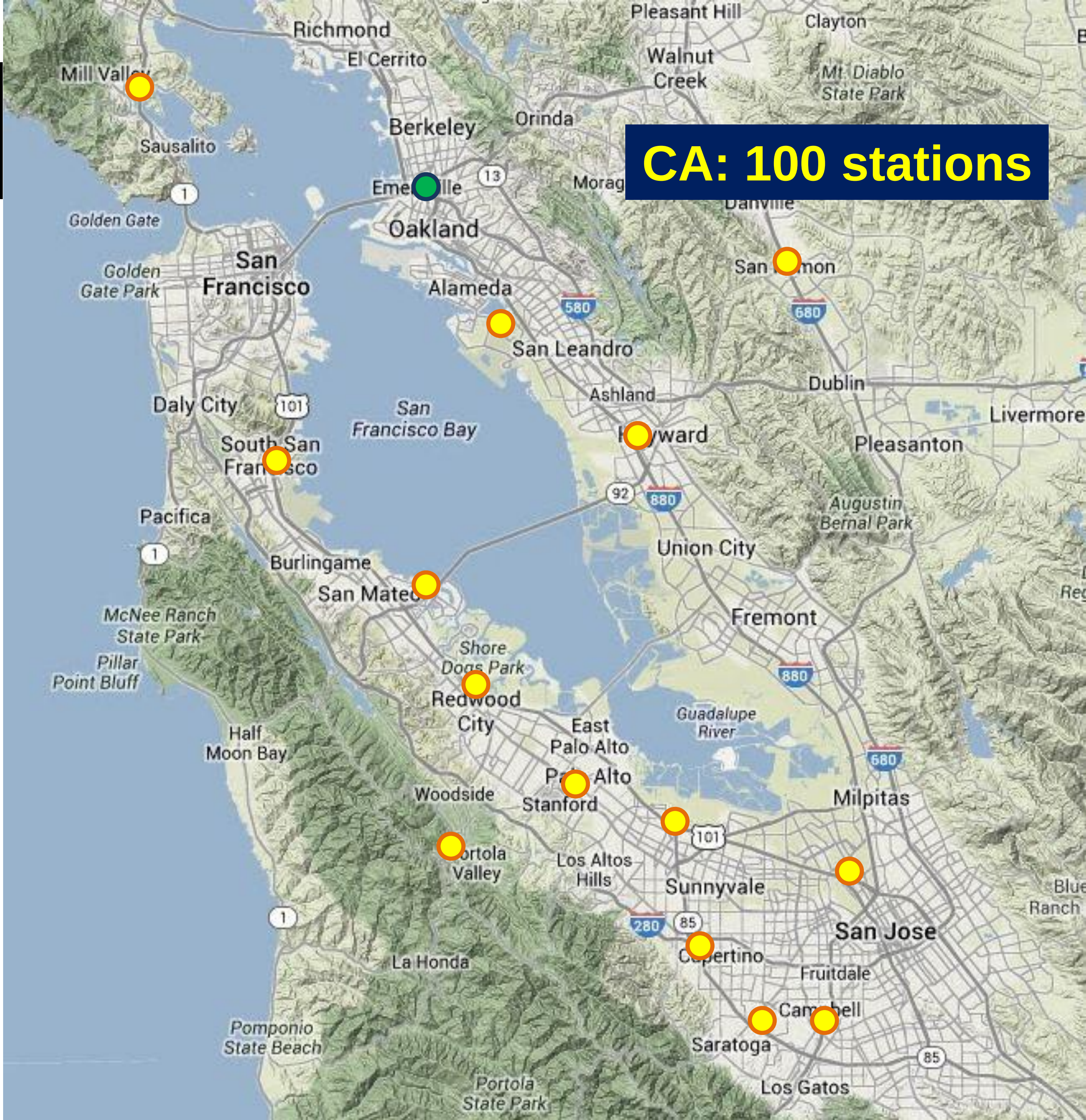
Emeryville – AC Transit

In Development

Cupertino
Foster City
Mountain View
*West Sacramento

Campbell
Hayward
Mill Valley
Oakland
Palo Alto
Redwood City
*Rohnert Park
San Jose
San Ramon
Saratoga
South San Francisco
*Truckee
Woodside

Not shown on map



California Fuel Cell Partnership
DRIVING FOR THE FUTURE
Managed by BKi

Southern CA Hydrogen Stations

Open

Burbank
Fountain Valley – OCSD
Irvine – UC Irvine
Los Angeles - Harbor City
Newport Beach
*Thousand Palms – SunLine Transit
Torrance

In Development

Anaheim
Chino (upgrade)
Diamond Bar (upgrade)
Irvine - UC Irvine (upgrade)
Irvine - Walnut Ave.
Lawndale
Los Angeles – Cal State LA
Los Angeles - West LA 2
Los Angeles - Woodland Hills
Los Angeles - Beverly Blvd.
Mission Viejo
Redondo Beach
San Juan Capistrano
Santa Monica

*Coalinga
Costa Mesa
La Canada Flintridge
Laguna Niguel
Lake Forest
Long Beach
Los Angeles – LAX (upgrade)
Los Angeles - Lincoln Blvd.
Los Angeles - Hollywood Blvd.
Ontario
Orange
Pacific Palisades
*Riverside
*San Diego
*Santa Barbara
South Pasadena

Not shown on map

Germany Hydrogen Fuel Stations 2023

H2 Mobility

DAIMLER · TOTAL · AIR LIQUIDE · OMV · Linde

Partners:

Air Liquide	Shell
Daimler	Total
Linde	OMV

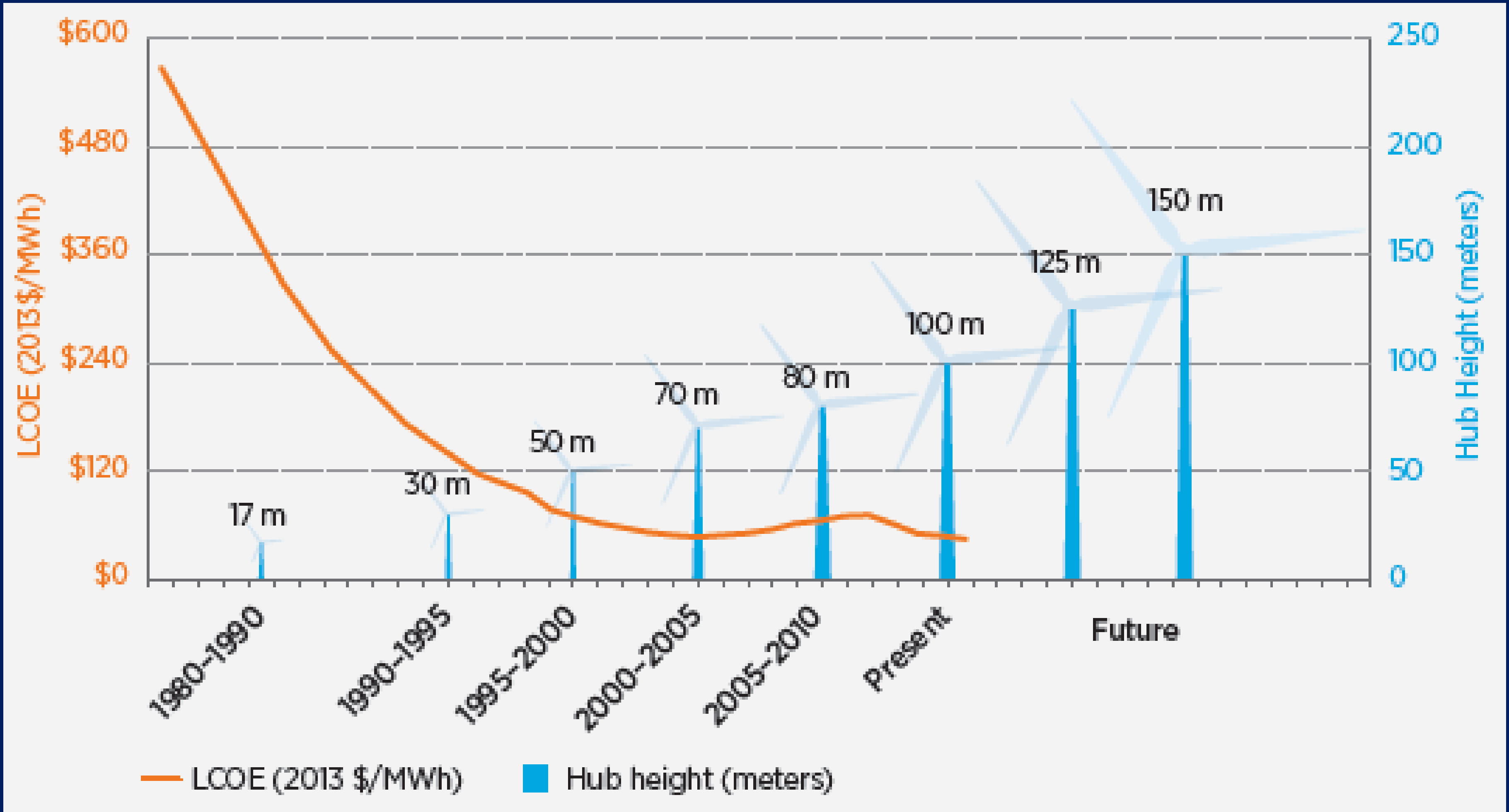
Targets:

- 100 by 2017
- 400 by 2023
- € 350 million invest
- 90 km max spacing on freeways

H2 Mobility

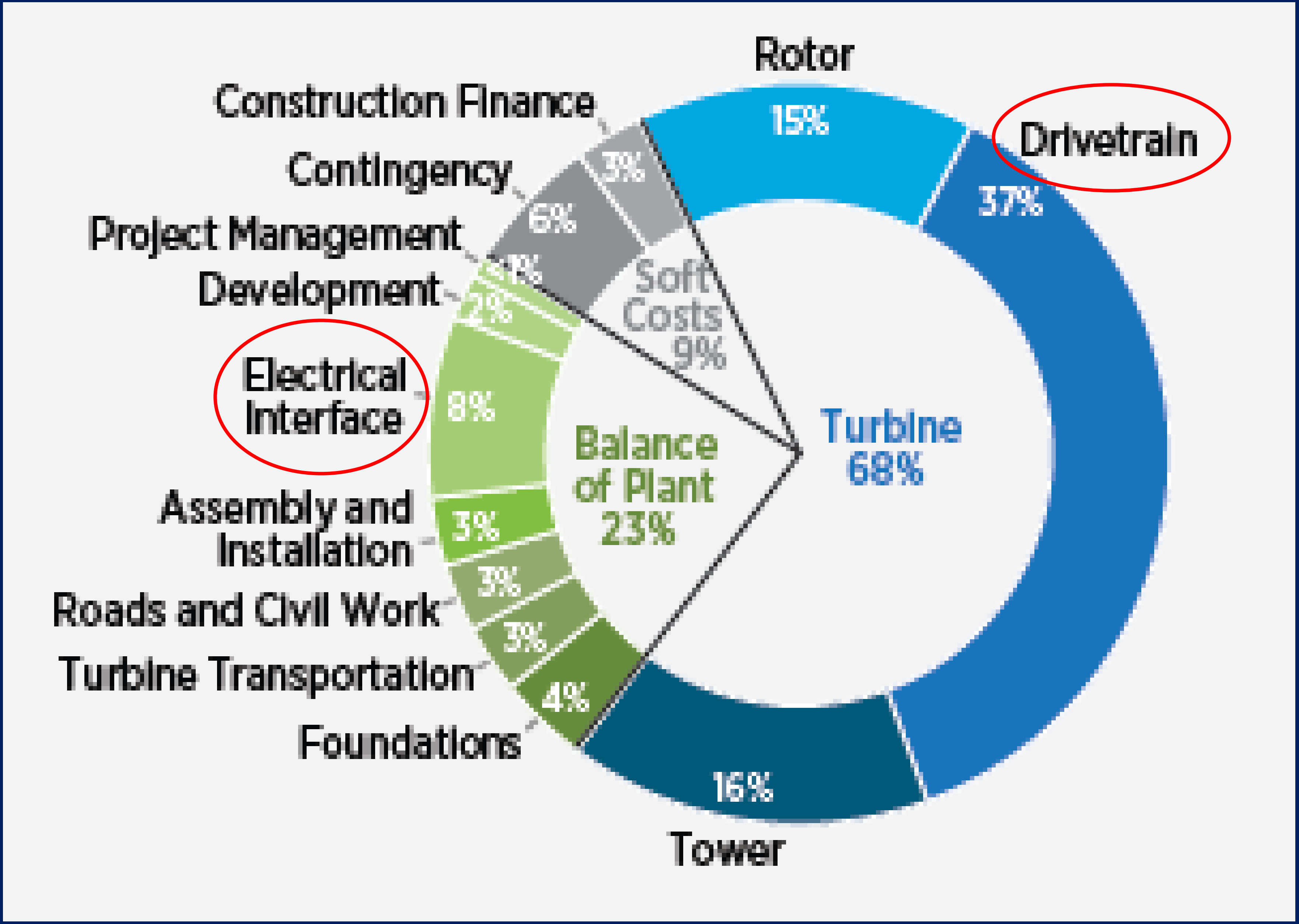
Japan: Hydrogen Society has begun!
100 Fueling Stations 2015

Iwatani

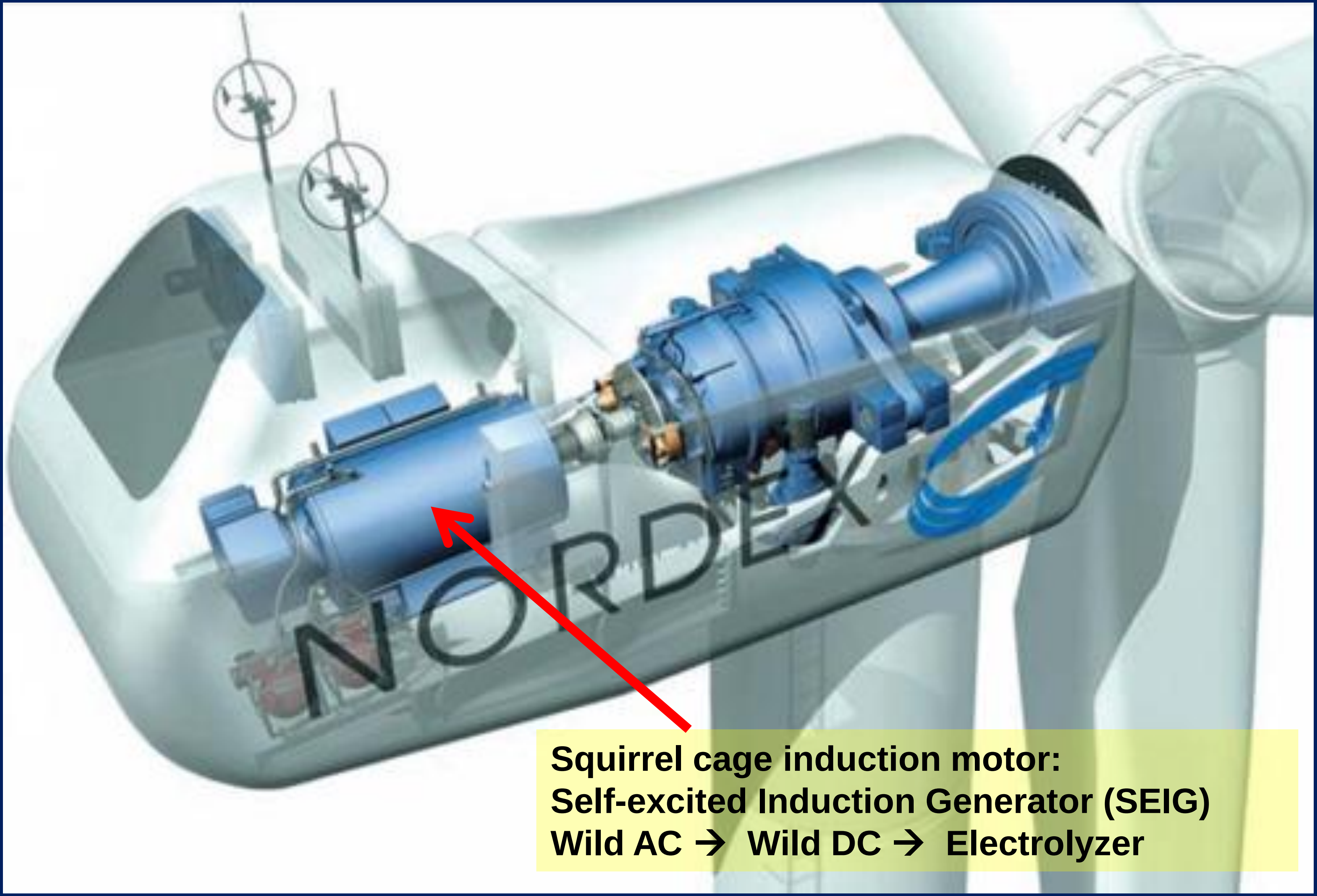


Wind LCOE reduction

“ Wind Vision ” Executive Summary



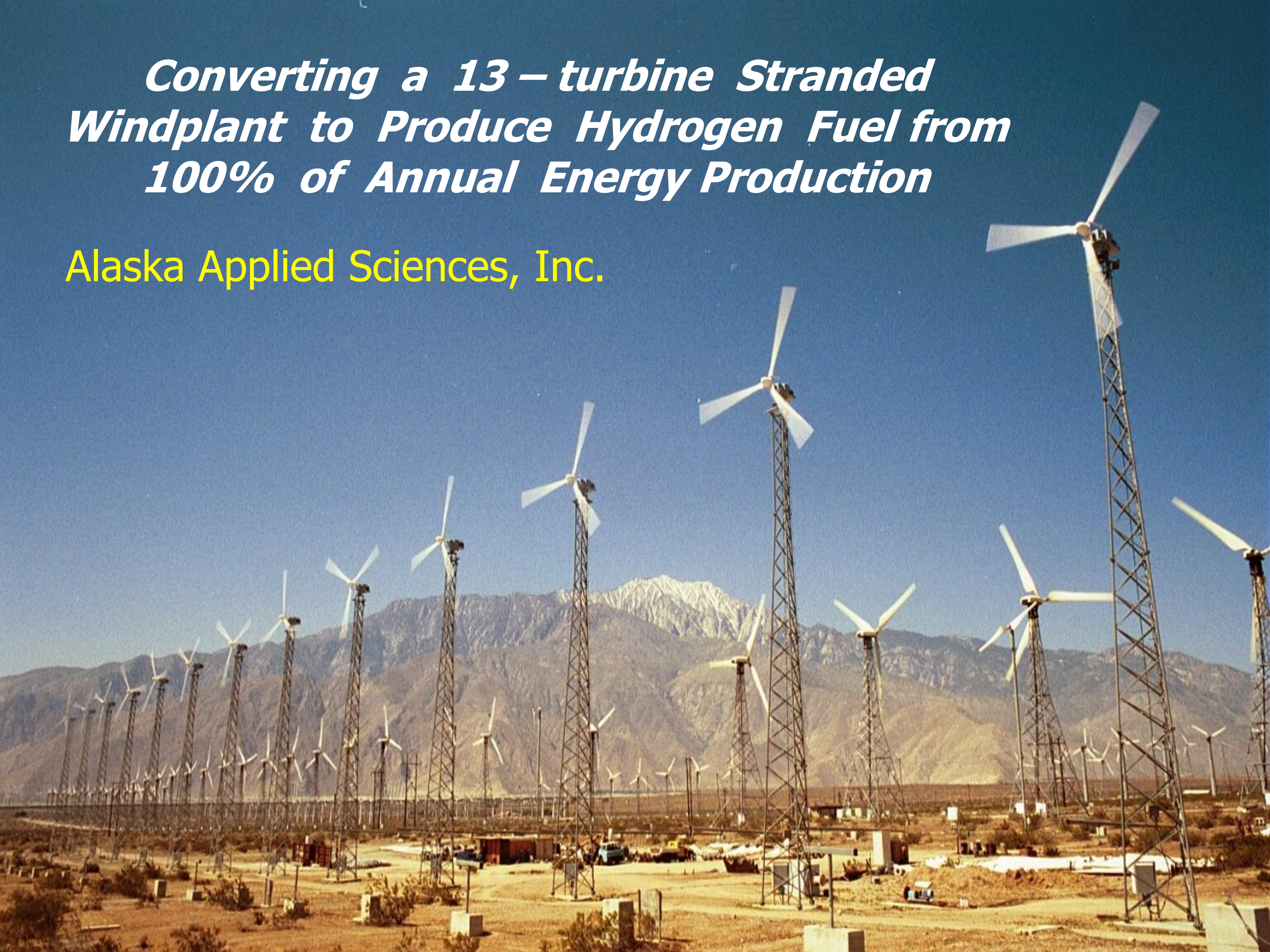
Installed CAPEX: land-based, utility-scale

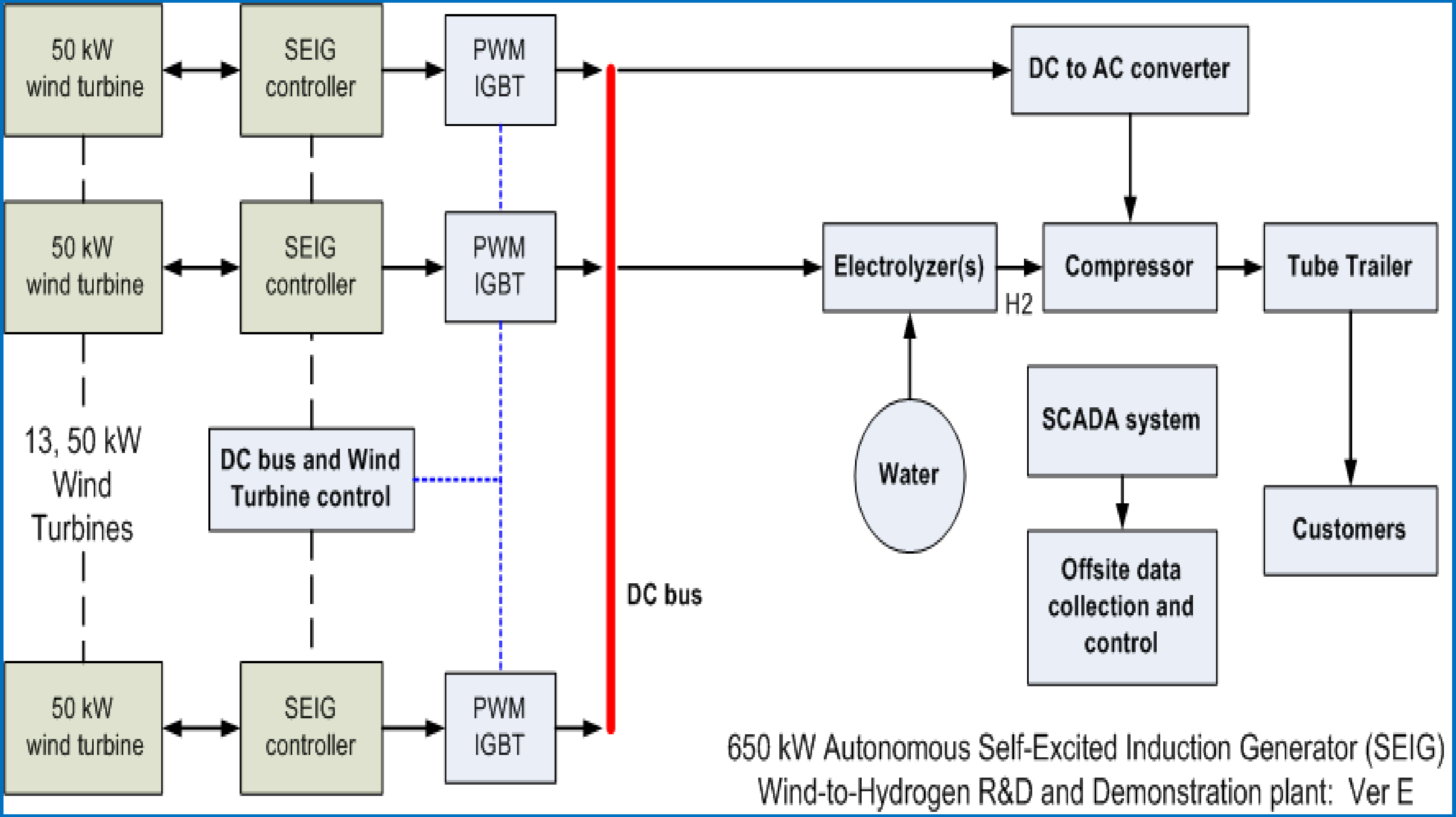


Dedicated Hydrogen Production: No Grid Connection

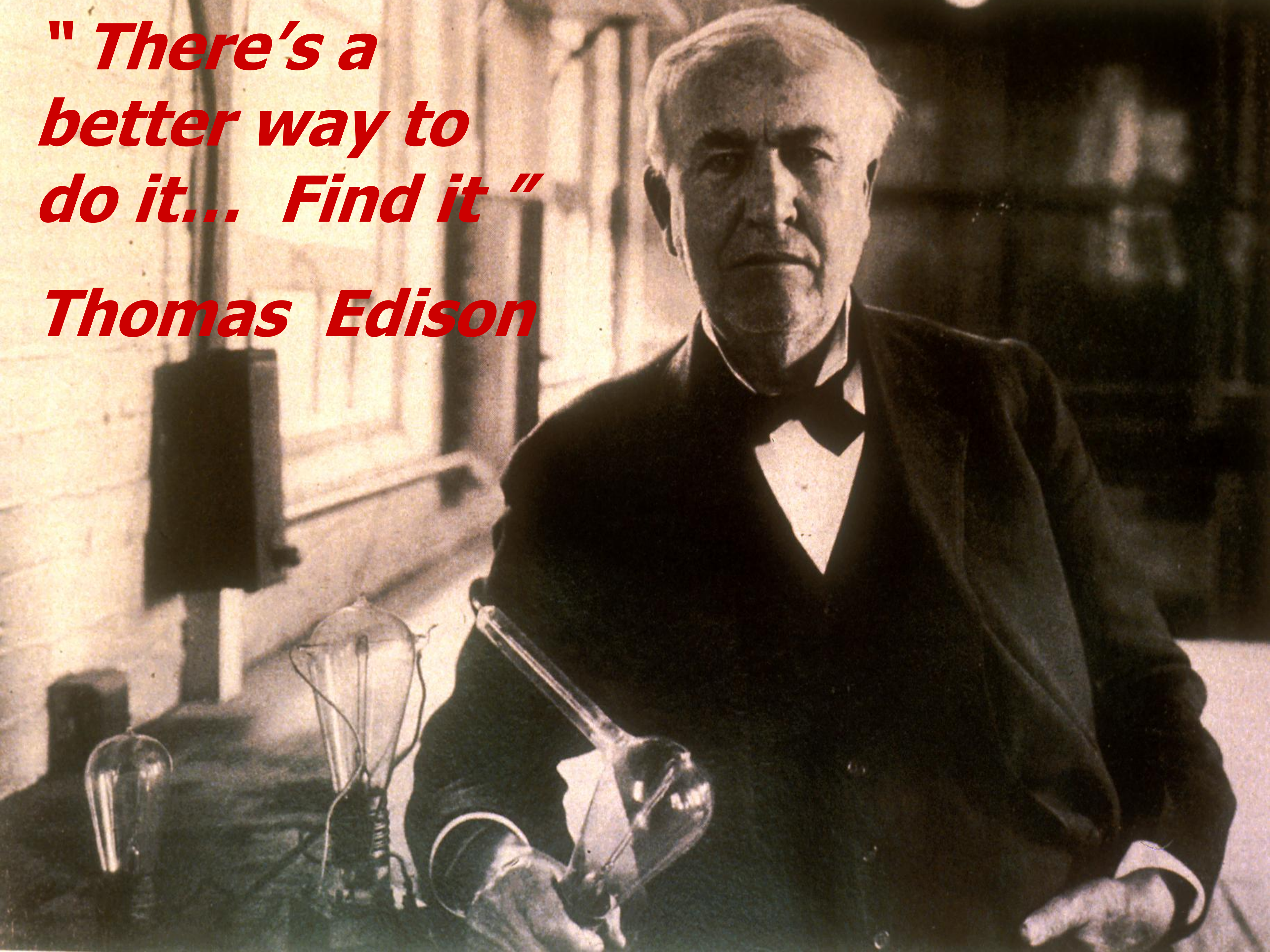
Converting a 13 – turbine Stranded Windplant to Produce Hydrogen Fuel from 100% of Annual Energy Production

Alaska Applied Sciences, Inc.



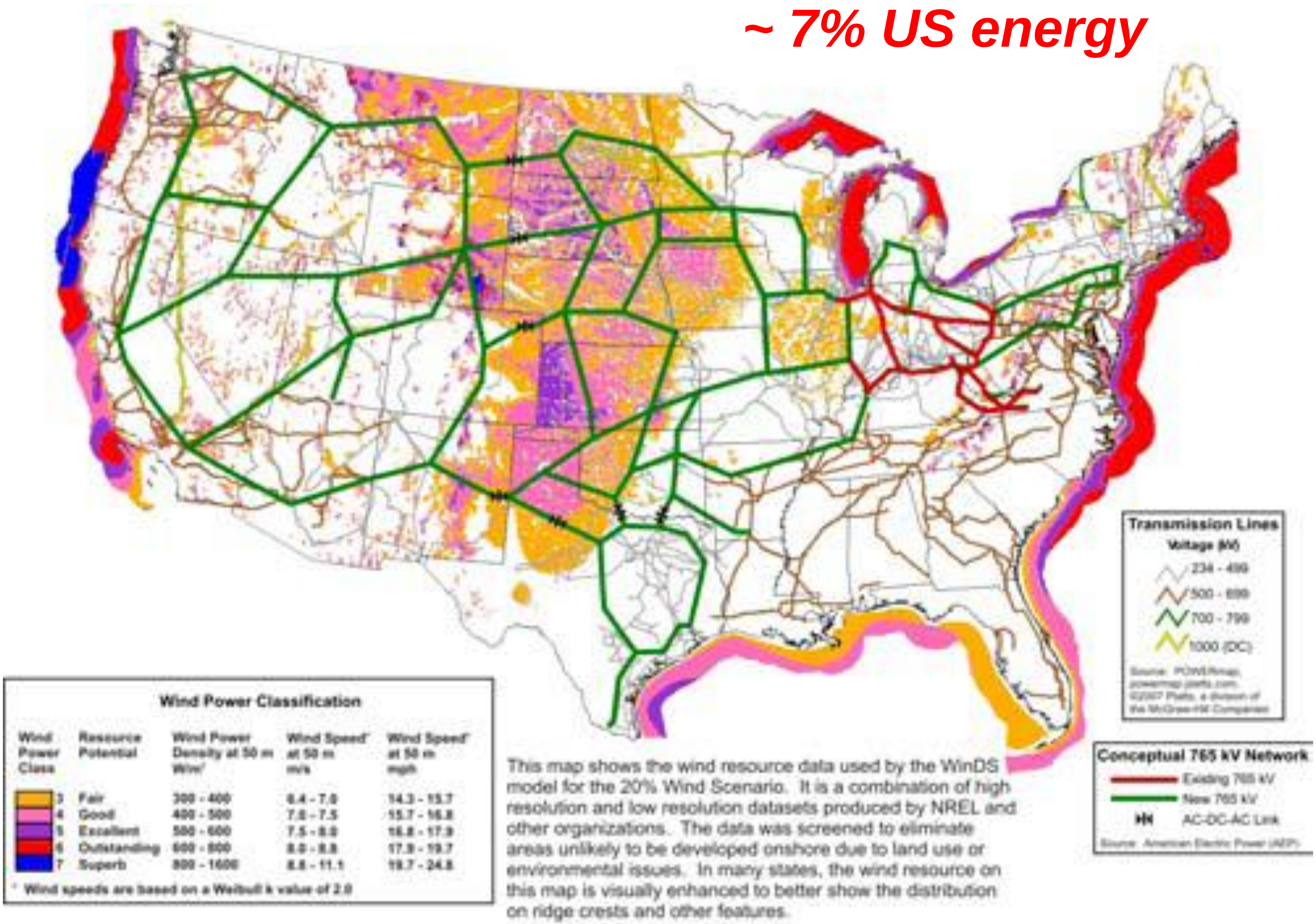


Self-Excited Induction Generator (SEIG)
Reduce Hydrogen cost
ARPA-E app: NREL, et al, 2015


" There's a
better way to
do it… Find it "
Thomas Edison

AWEA: 20% Electricity from Wind by 2030

~ 7% US energy



The Great Plains Wind Resource

Exporting From 12 Windiest Great Plains States

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

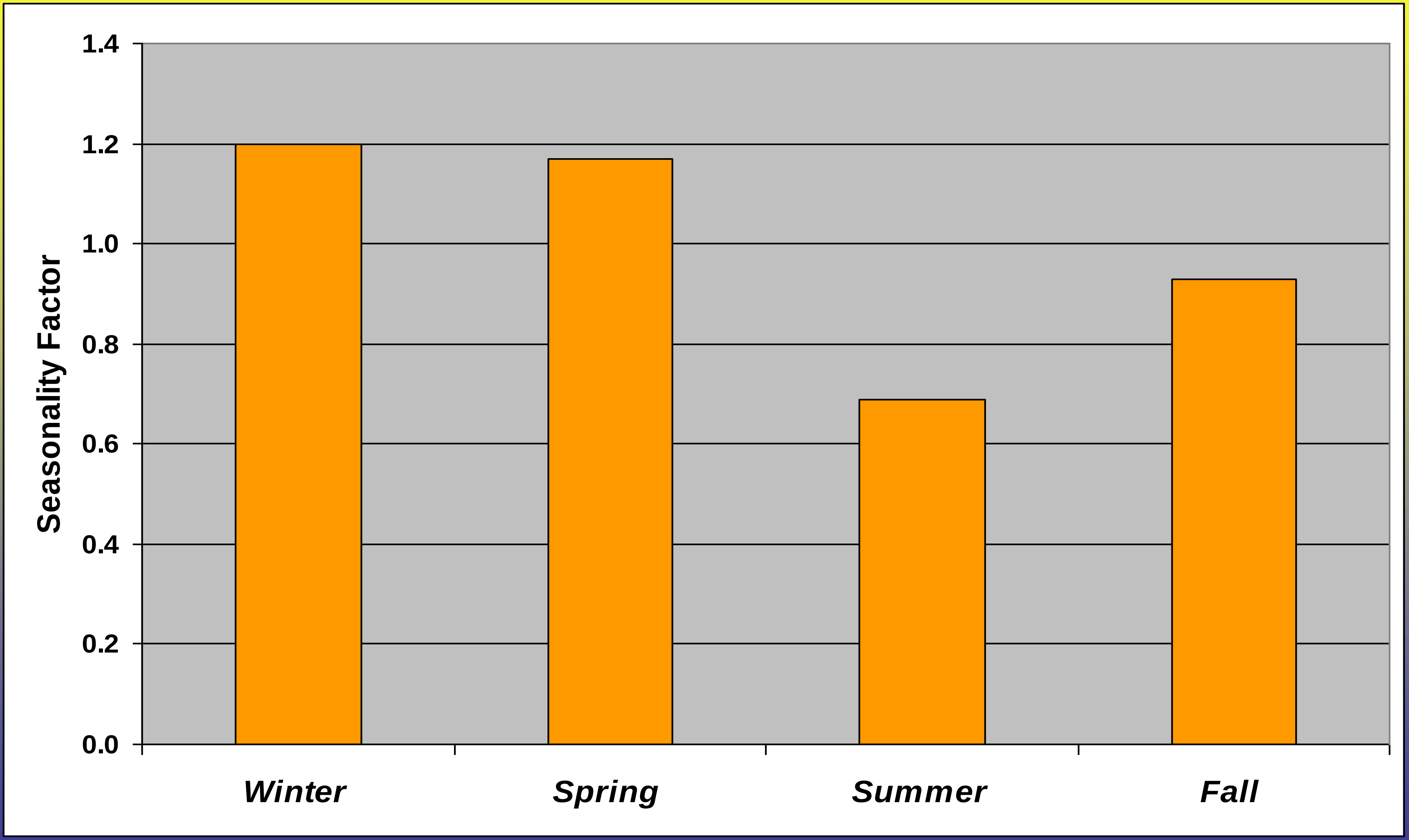
Capacity at 500 miles length **Capacity Factor (CF) = 30%**

State	Annual Energy Production (TWh)	Nameplate Installed Capacity (MW)	Nameplate Installed Capacity (GW)	6 GW 36" GH2 Hydrogen Pipelines	$ Billion Total Capital Cost	3 GW 500 KV HVDC Electric Lines	$ Billion Total Capital Cost
Texas	6,528	1,901,530	1,902	317		634	
Kansas	3,647	952,371	952	159		317	
Nebraska	3,540	917,999	918	153		306	
South Dakota	3,412	882,412	882	147		294	
Montana	3,229	944,004	944	157		315	
North Dakota	2,984	770,196	770	128		257	
Iowa	2,026	570,714	571	95		190	
Wyoming	1,944	552,073	552	92		184	
Oklahoma	1,789	516,822	517	86		172	
Minnesota	1,679	489,271	489	82		163	
New Mexico	1,645	492,083	492	82		164	
Colorado	1,288	387,220	387	65		129	
TOTALS	33,711	9,376,694	9,377	1,563	$1,500	3,126	$2,000

Wind energy source: Archer, Jacobson 2003

Wind Seasonality, Northern Great Plains

Normalized to 1.0 per season



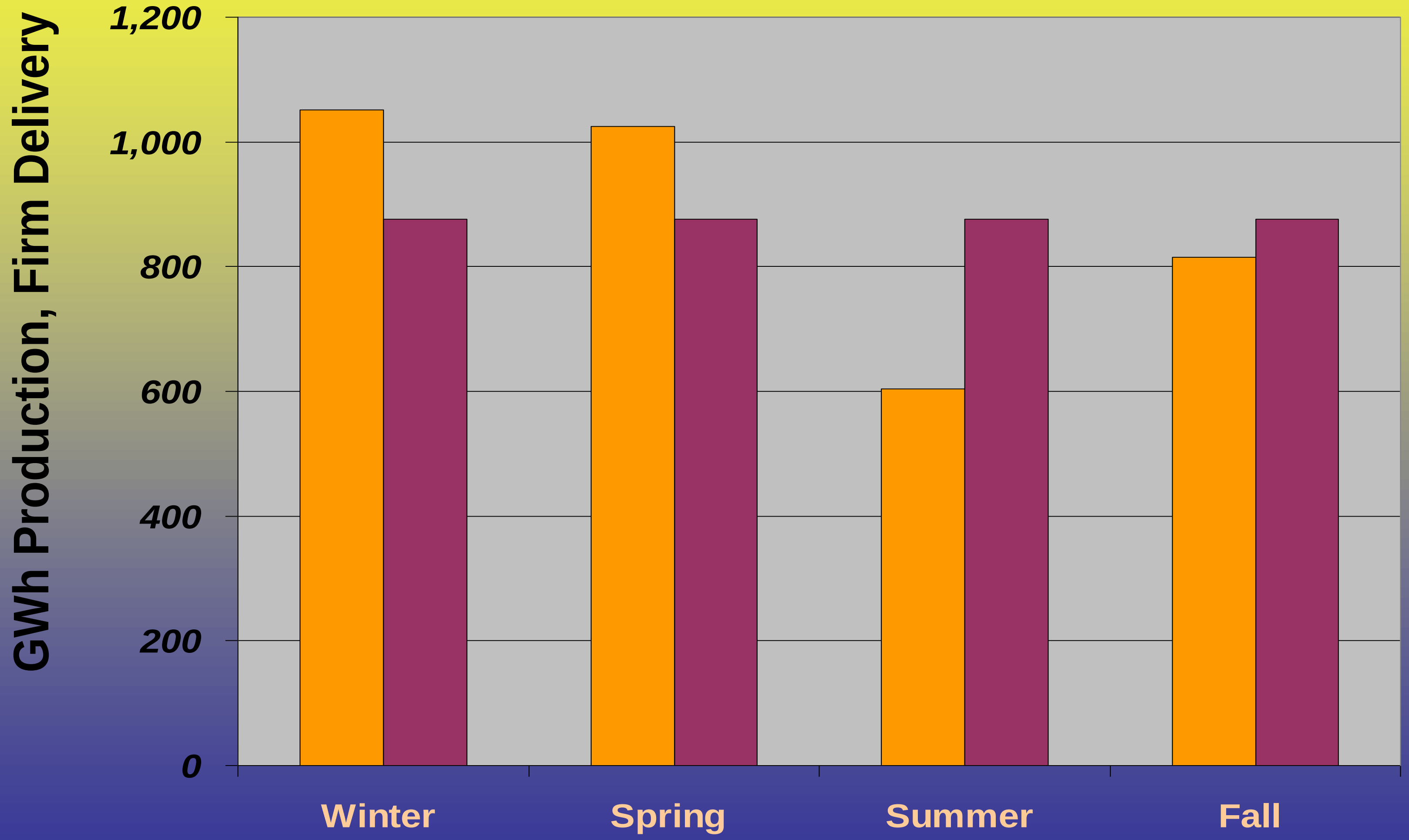
Wind Seasonality, Northern Great Plains

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



320 GWh

Annual firming, 1,000 MW wind

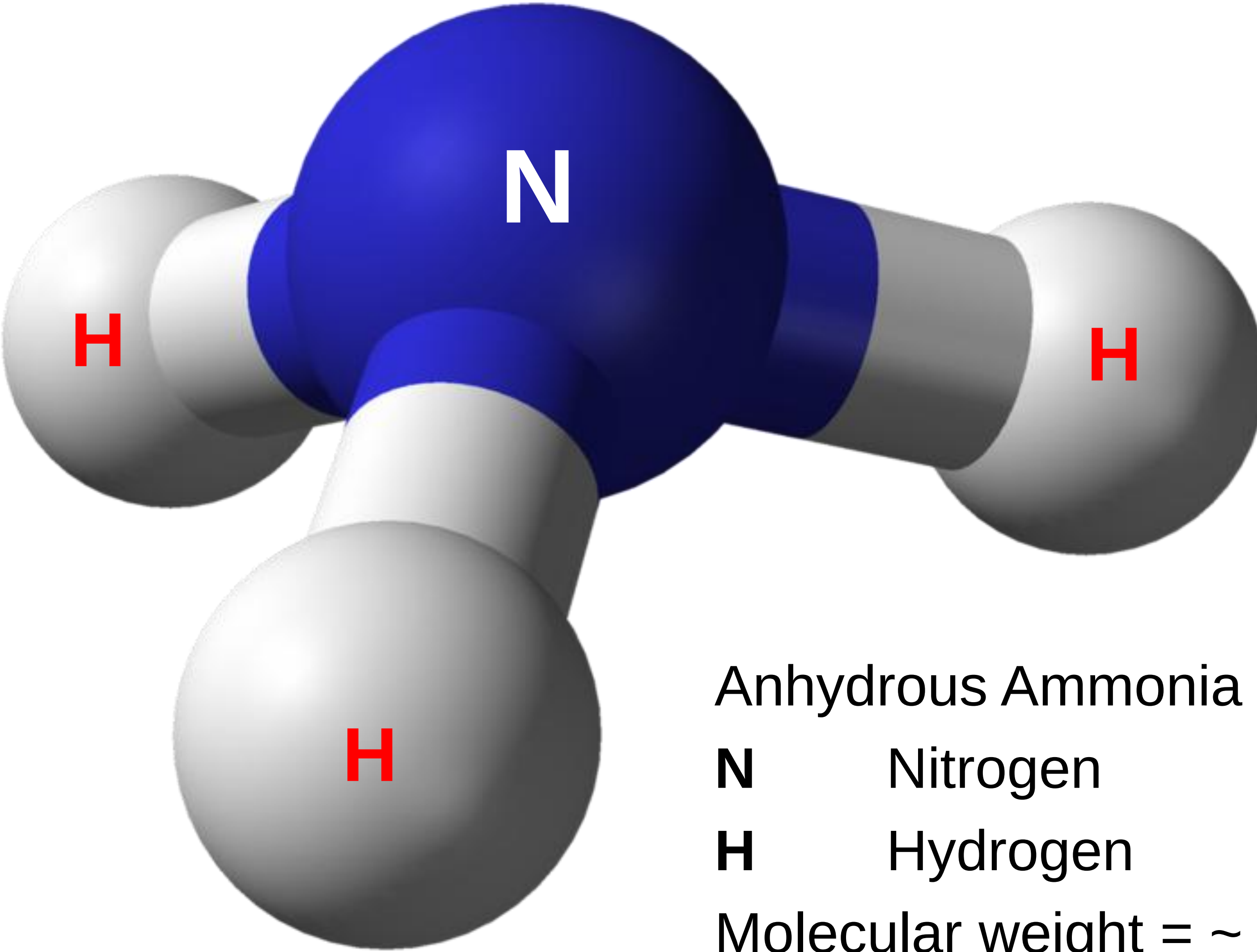
- **CAES (compressed air energy storage)**
  - **O&M: $46 / MWh typical**
  - **Iowa: Power = 268 MW**

    Energy capacity = 5,360 MWh

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

    Storage @ $40 / kWh = $ 13 Billion

    Storage @ $1 / kWh = $ 325 Million
- **Battery**
  - **O&M: 90% efficiency round-trip**
  - **Capital: $500 / kWh = $ 160 Billion**
  - **Capital: $300 / kWh = $ 96 Billion**



Anhydrous Ammonia **NH_3**

N Nitrogen

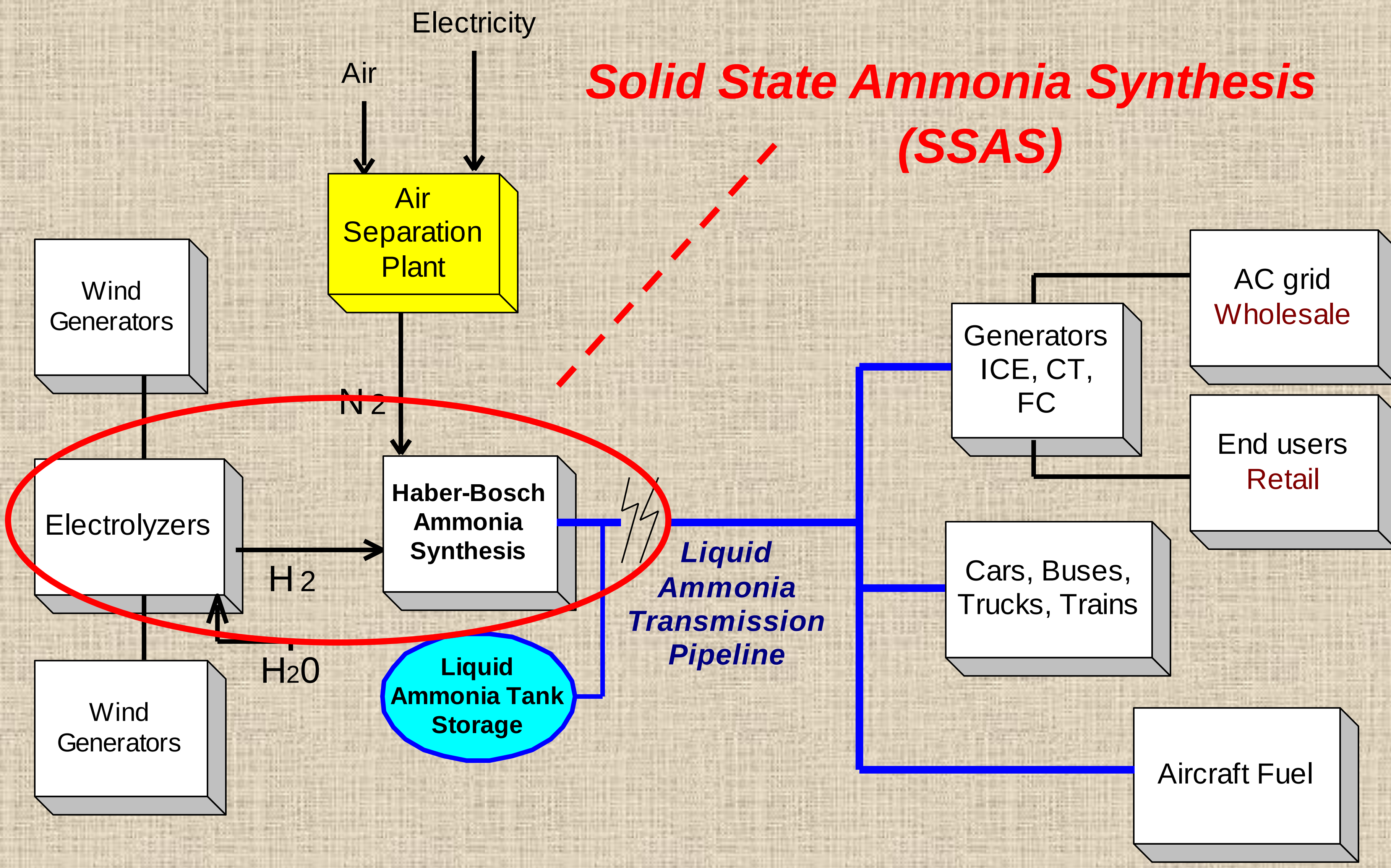
H Hydrogen

Molecular weight = ~ 17

18% **H** by weight: “other hydrogen”

$NH_3 + O_2 = N_2 + H_2O$

RE Ammonia Transmission + Storage Scenario



’09 ARPA-E “Grids” Goal: $100 / kWh

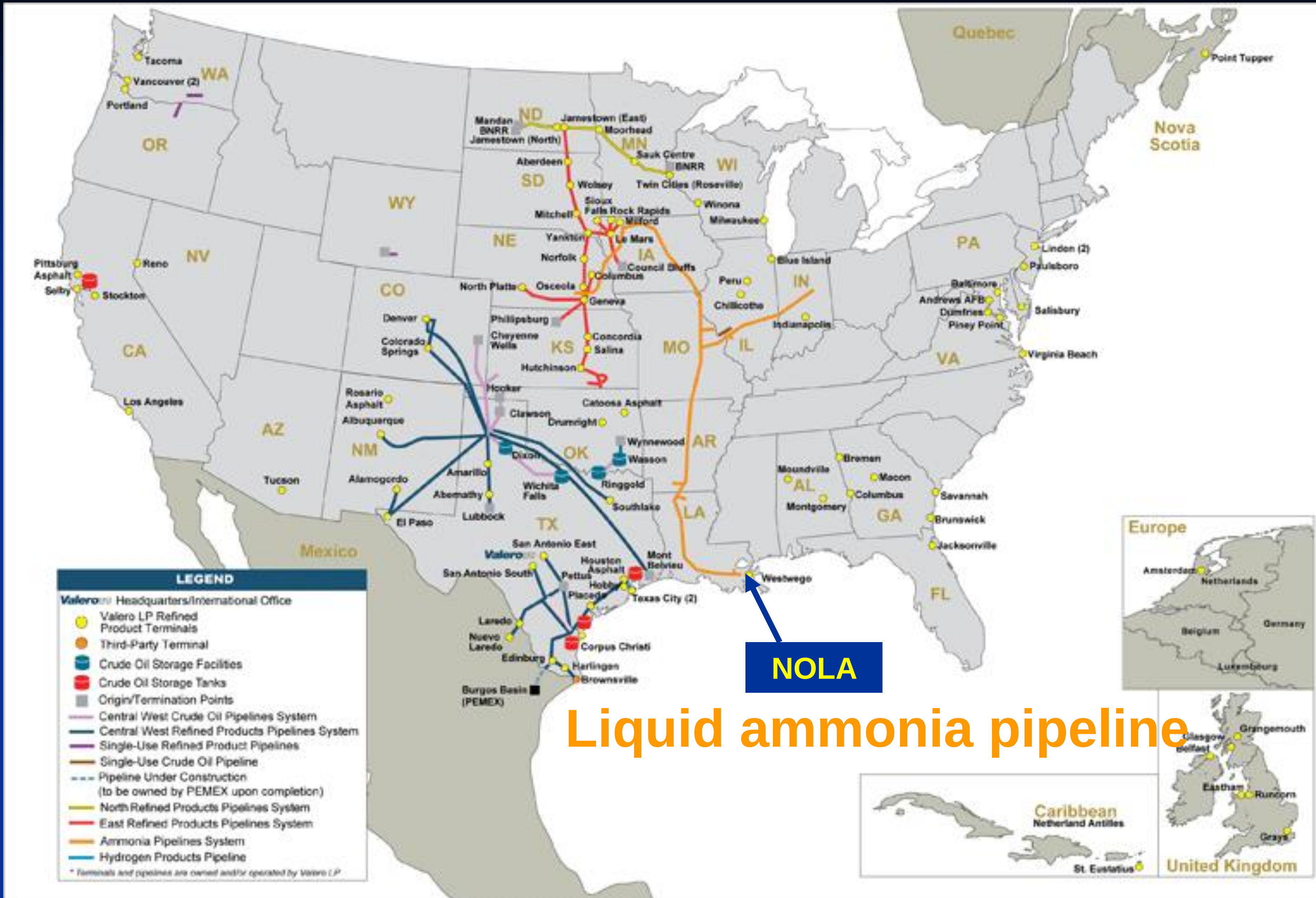
Total storage = 380 GWh

“Atmospheric” Liquid Ammonia Storage Tank (corn belt)

-33 C   1 Atm

Each: 30,000 Tons, 190 GWh $ 15M turnkey

$ 80 / MWh = $ 0.08 / kWh   capital cost



Valero LP Operations

Capital Cost per GW-mile

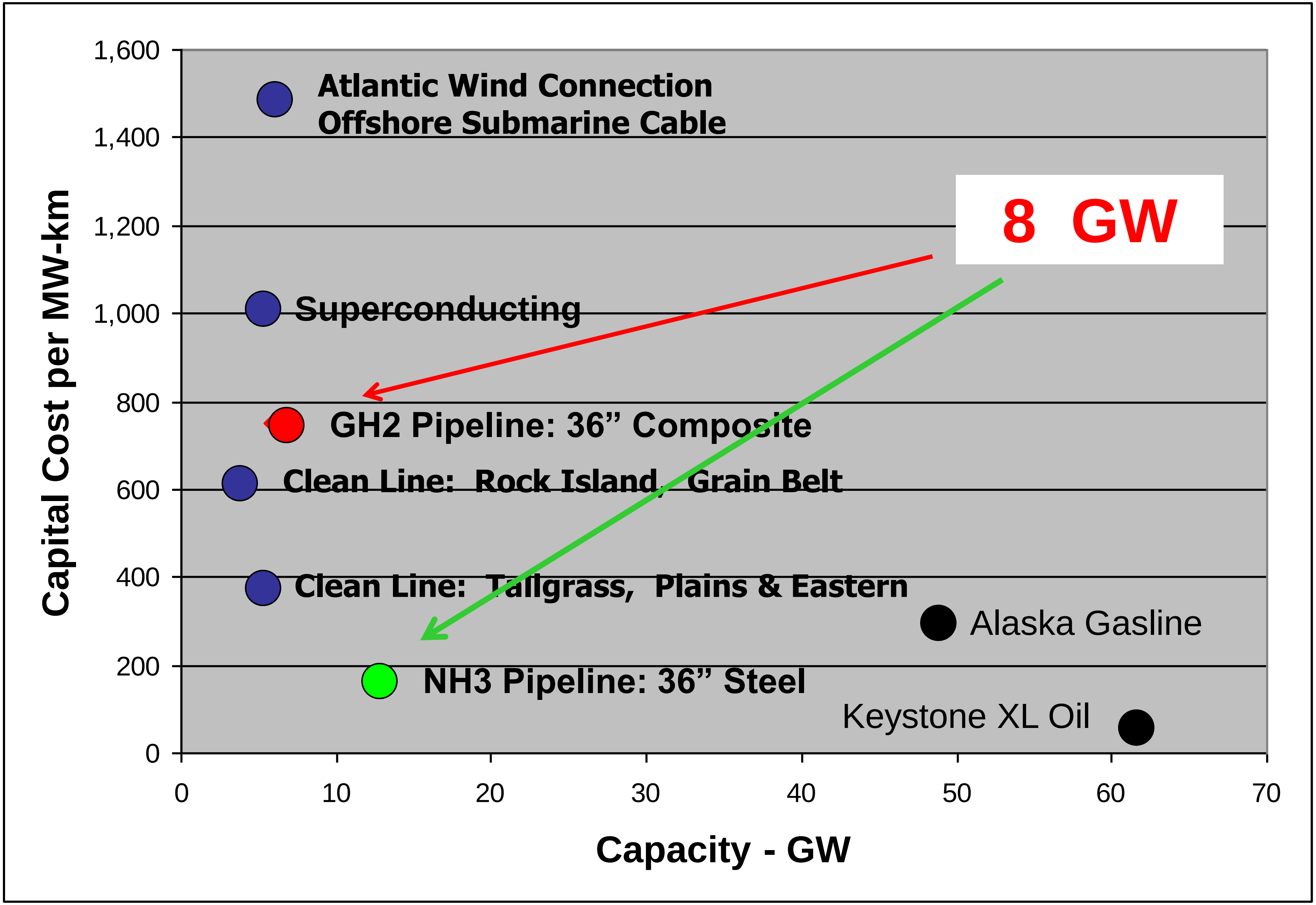
Electricity :	KV	Capacity MW	$M / GW-mile
• SEIA:	765	5,000	1.3
	345	1,000	2.6
• AEP-AWEA	765	5,000	3.2
Consensus ?			2.5

Hydrogen pipeline:

36”, 100 bar, 500 miles, no compress 0.3

Ammonia pipeline:

10” , liquid, 500 miles, with pumping 0.2



Transmission capital costs compared

320 GWh
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
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    Storage @ $40 / kWh = $ 13 Billion
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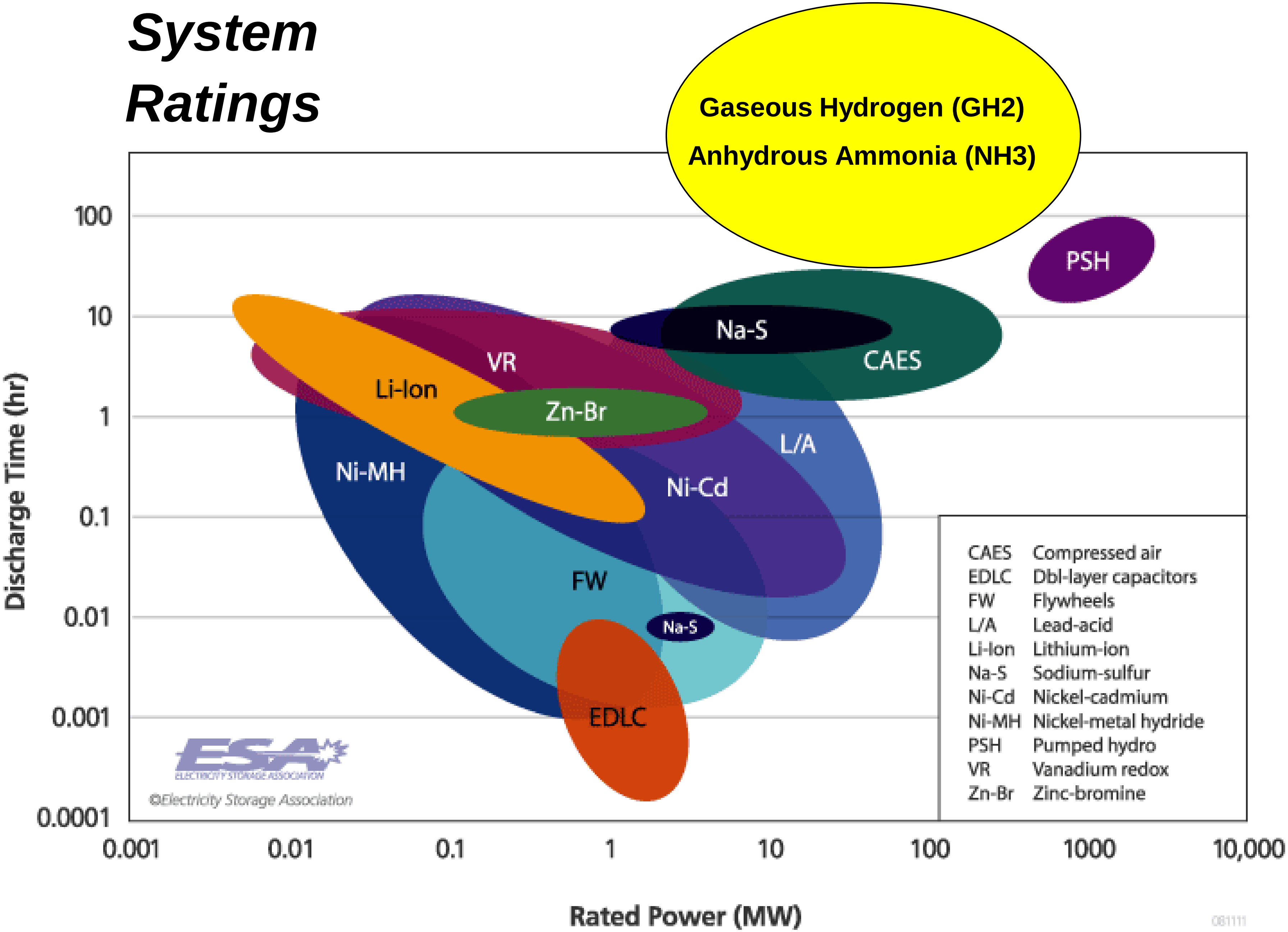
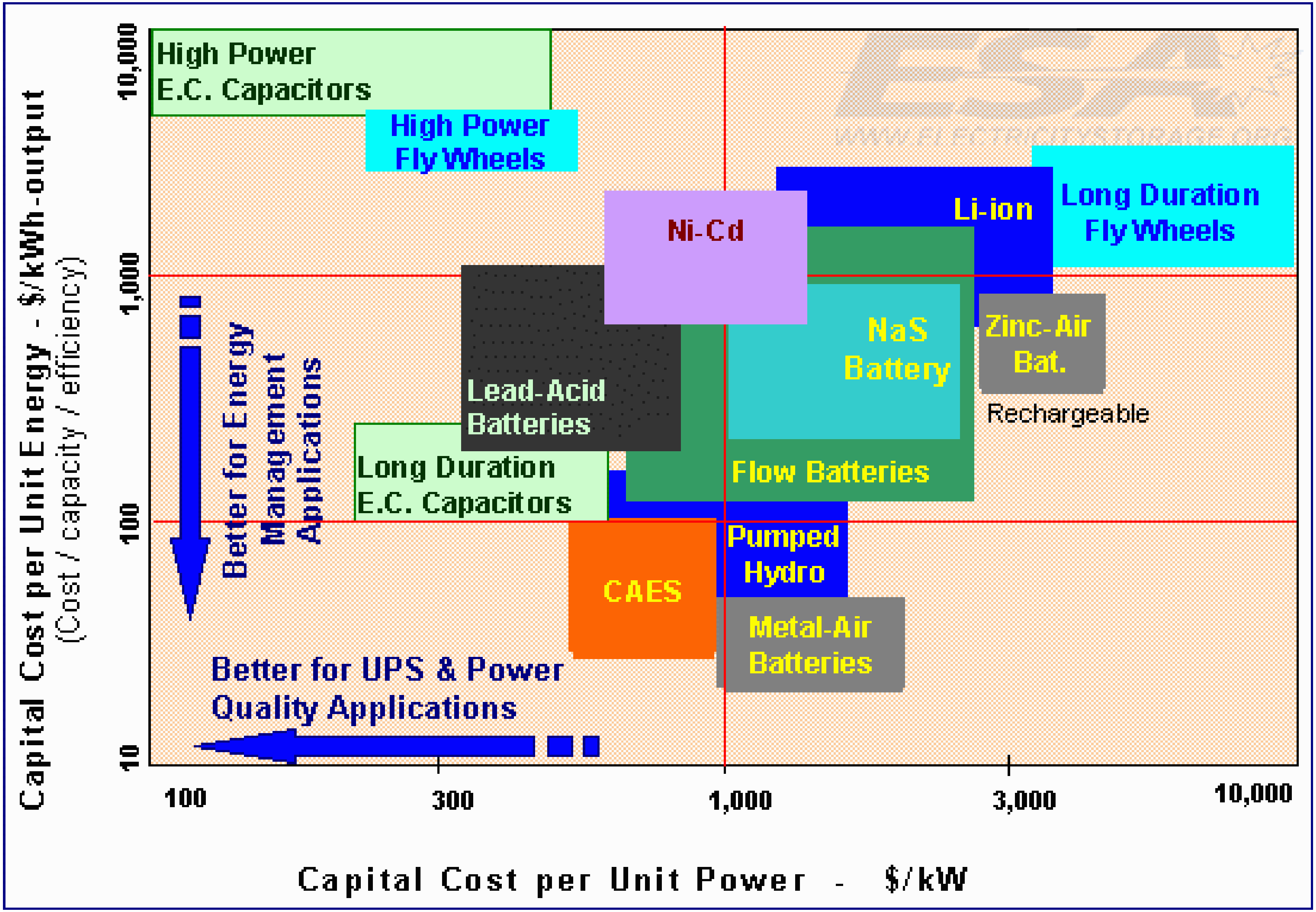
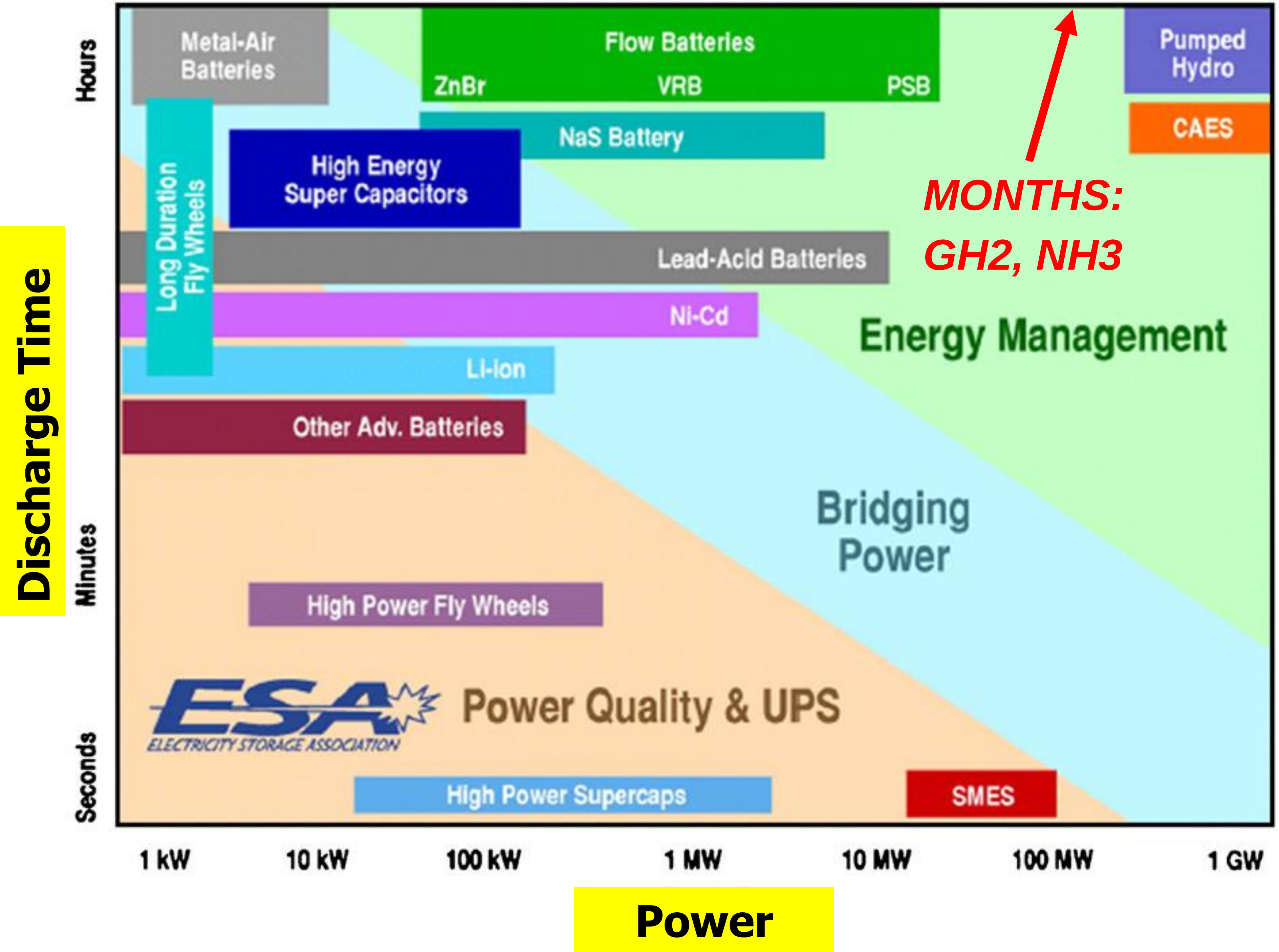
- Battery
  - O&M: 90% efficiency round-trip
  - Capital: $500 / kWh = $ 160 Billion
  - Capital: $300 / kWh = $ 96 Billion
- GH2 (3 hydrogen caverns) Capital $70 Million
- NH3 (2 ammonia tanks) Capital $30 Million

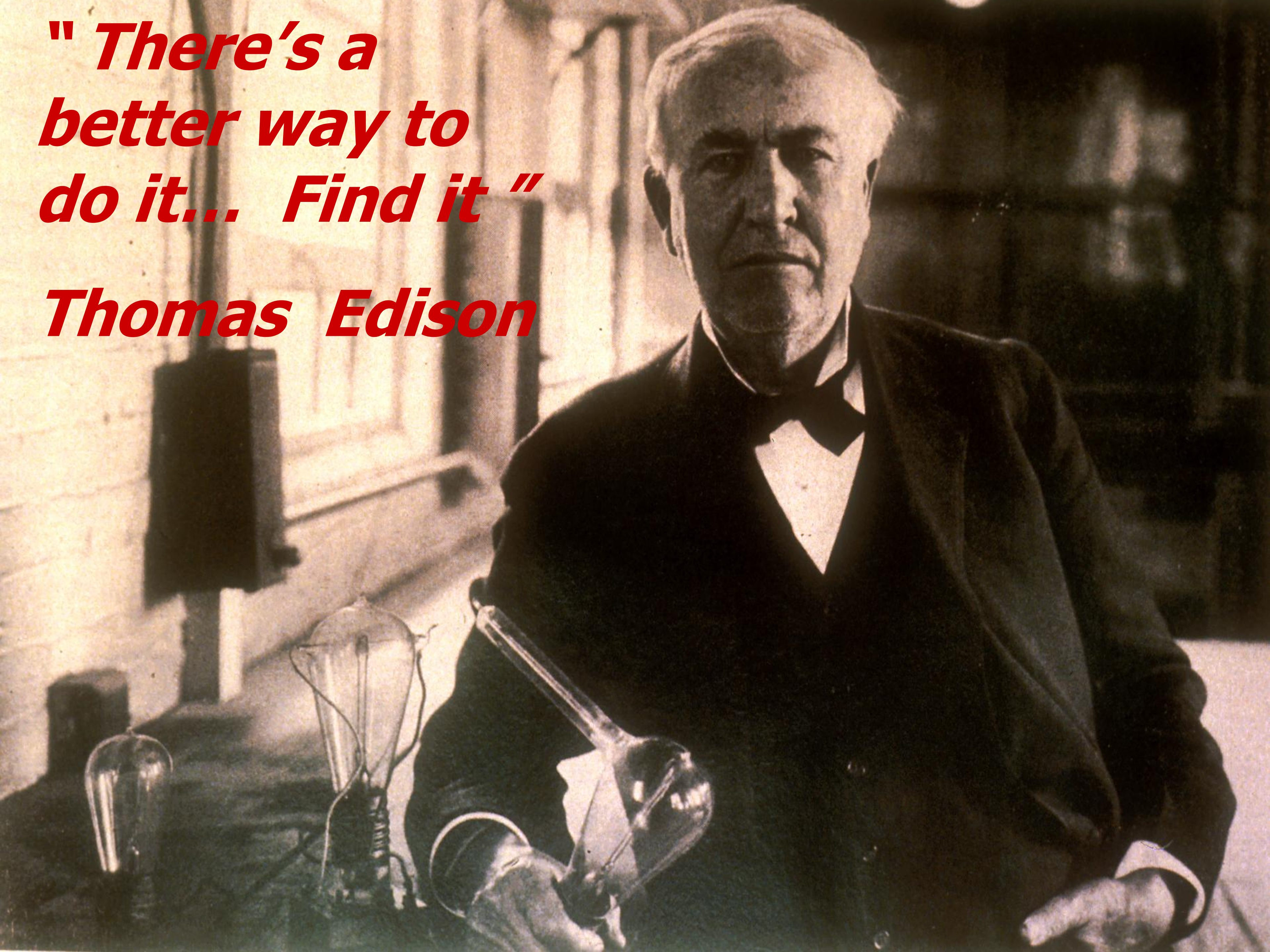
System Ratings



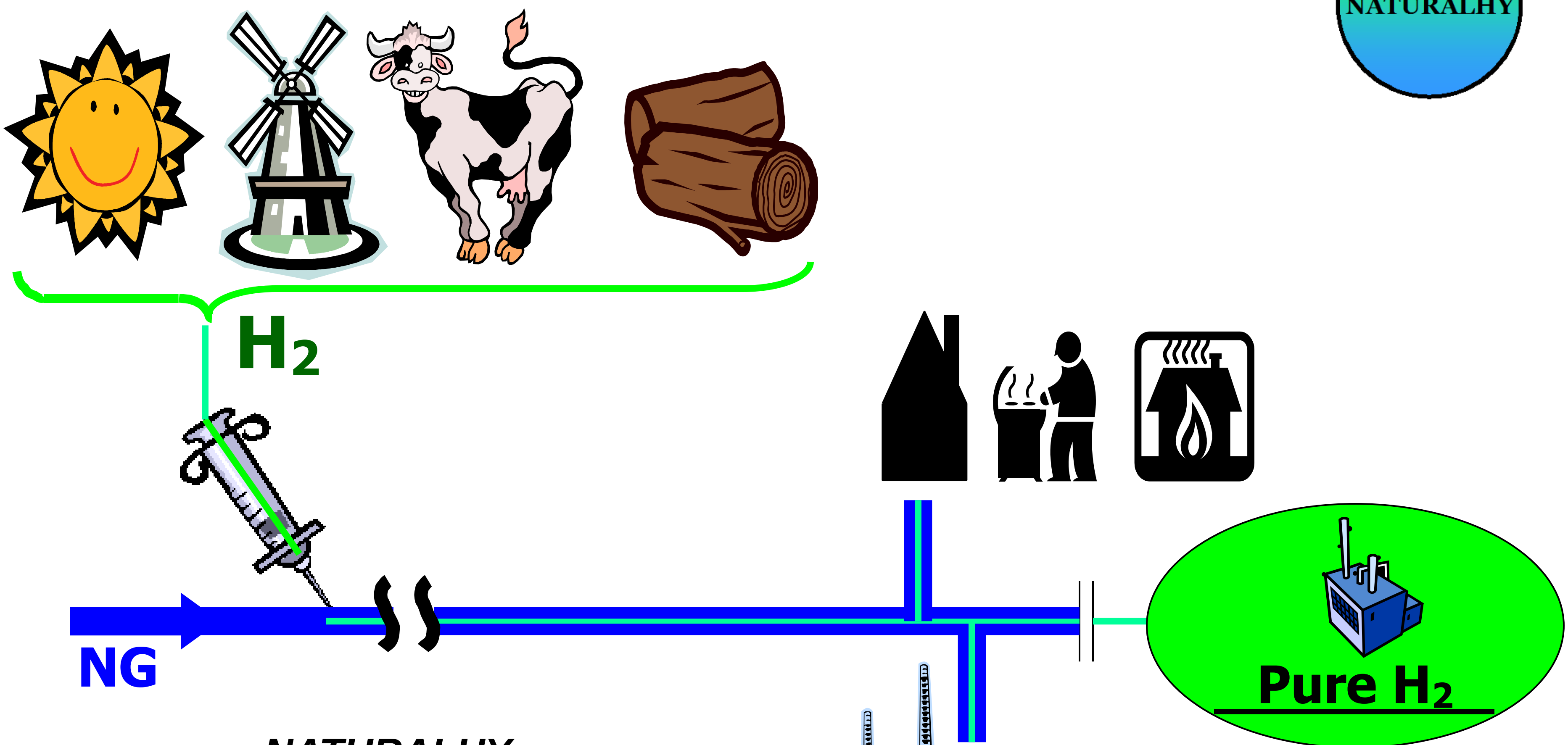

High Power
E.C. Capacitors
High Power
Fly Wheels
Ni-Cd
Li-ion
Long Duration
Fly Wheels
Lead-Acid
Batteries
NaS
Battery
Zinc-Air
Bat.
Rechargeable
Flow Batteries
Long Duration
E.C. Capacitors
Pumped
Hydro
CAES
Metal-Air
Batteries
Better for Energy Management Applications
Better for UPS & Power Quality Applications
Capital Cost per Unit Energy - $/kWh-output
(Cost / capacity / efficiency)
10,000
1,000
100
10
100
300
1,000
3,000
10,000
Capital Cost per Unit Power - $/kW

GH2 and NH3


Discharge Time
Hours
Minutes
Seconds
Metal-Air Batteries
Flow Batteries
ZnBr
VRB
PSB
Pumped Hydro
CAES
NaS Battery
High Energy Super Capacitors
Long Duration Fly Wheels
Lead-Acid Batteries
MONTHS: GH2, NH3
Ni-Cd
Energy Management
Li-Ion
Other Adv. Batteries
Bridging Power
High Power Fly Wheels
ESA
ELECTRICITY STORAGE ASSOCIATION
Power Quality & UPS
High Power Supercaps
SMES
1 kW
10 kW
100 kW
1 MW
10 MW
100 MW
1 GW
Power

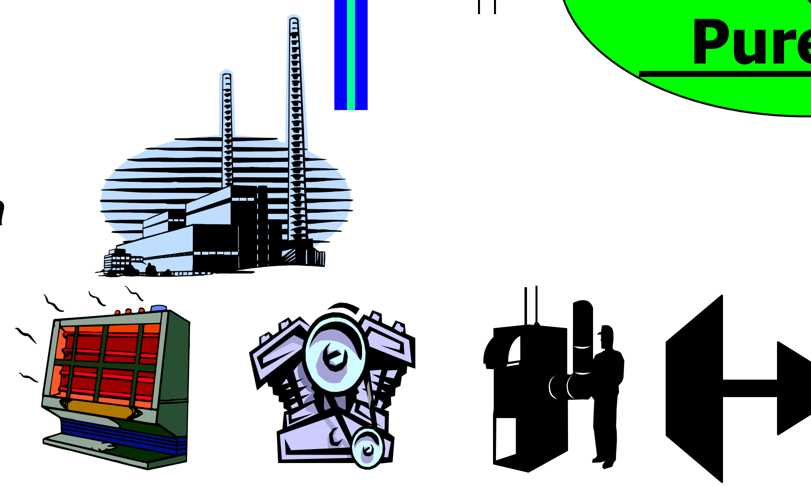

" There's a better way to do it... Find it "
Thomas Edison

The NATURALHY approach: EC, R+D



NATURALHY:

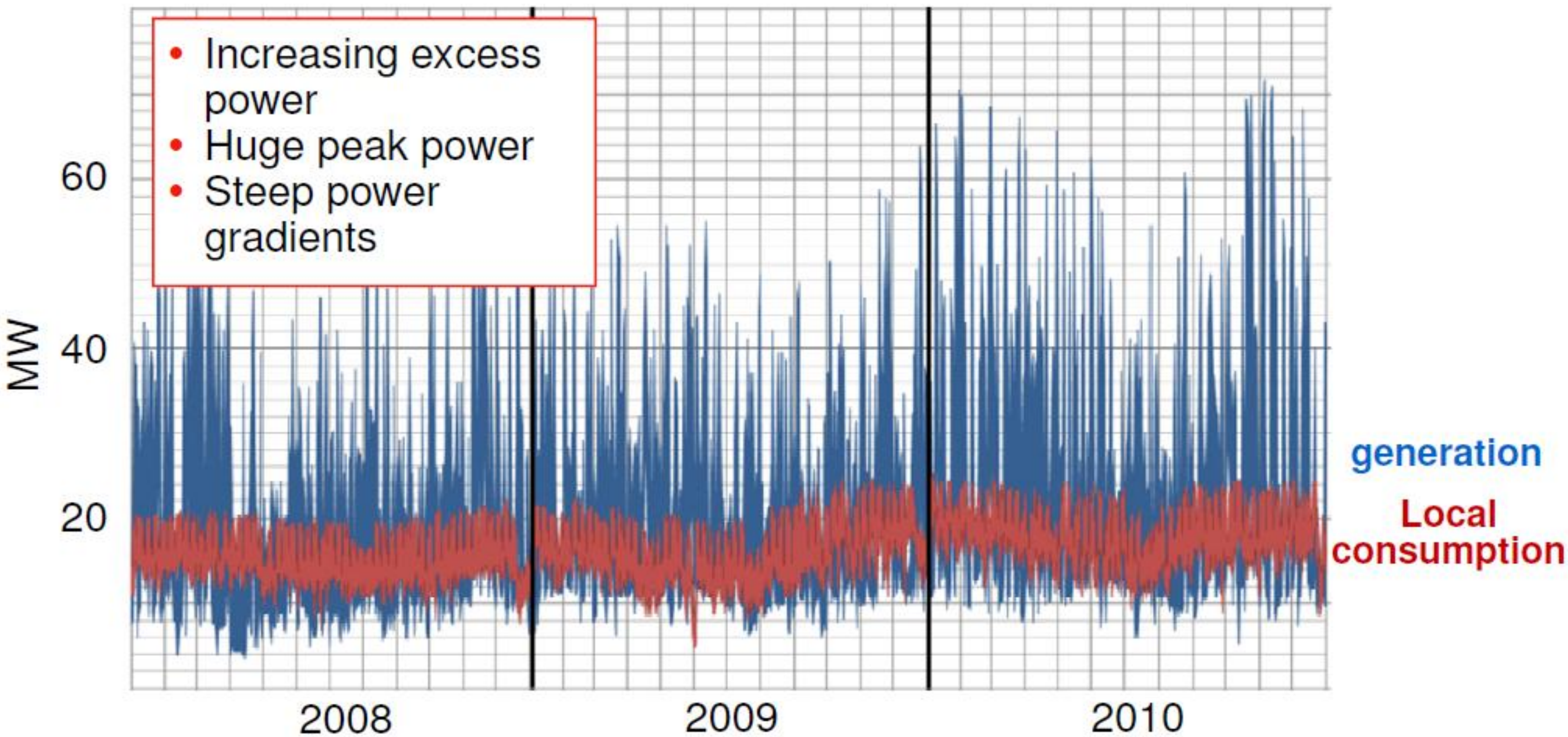
- ***Breaks "chicken-egg" dilemma***
- ***Bridge to sustainable future***



Prepared by
O. Florisson
Gasunie

Free Storage + Free Transmission in E.on Natural Gas Pipeline System

Falkenhagen Region in Northern Germany



Solution: Storage of excess wind power instead of curtailment.

Source: Presentation by Dr. Alexander Vogel, Head of Alternative Energy Systems, E.ON Ruhrgas at Gas to Power Conference, Cologne, Germany – November 2012

E.ON first Power-to-Gas plant
Injecting hydrogen into natural gas grid

2MW Power-to-Gas Demonstration Plant in Falkenhagen, Germany

Alternatives to Electricity:
Japan to import Hydrogen-rich liquid fuels

1. Liquid Hydrogen (LH2)

   Kawasaki

2. Liquid anhydrous ammonia (NH3)

   Sumitomo

3. Cycle: Toluene (C7H8) ← → Methylcyclohexane (C7H14) (MCH)

   Chiyoda

Aleutians wind to Japan via liquid fuel(s) tankers

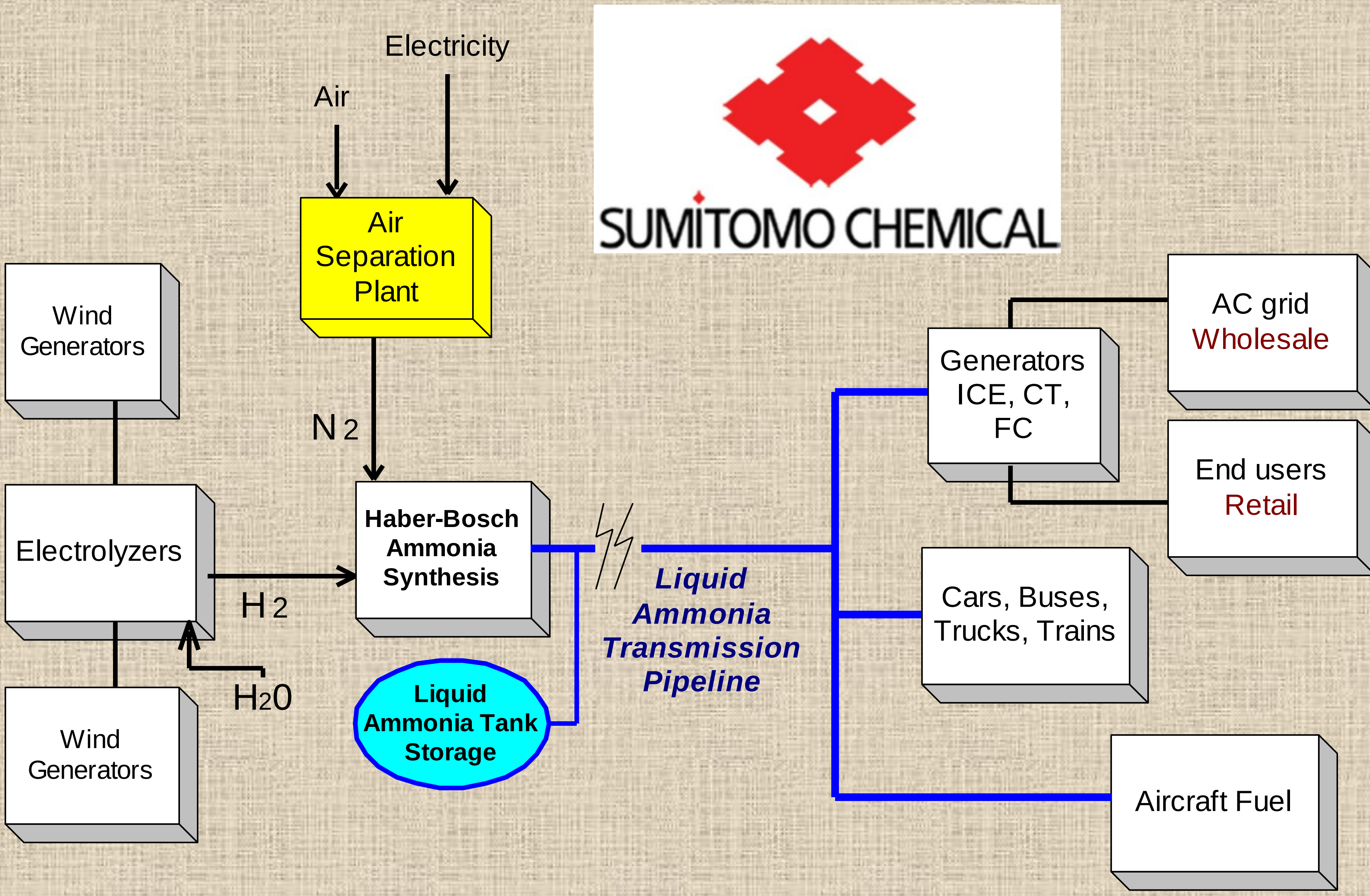
Japan: Import Carbon-emissions-free liquid Hydrogen fuel

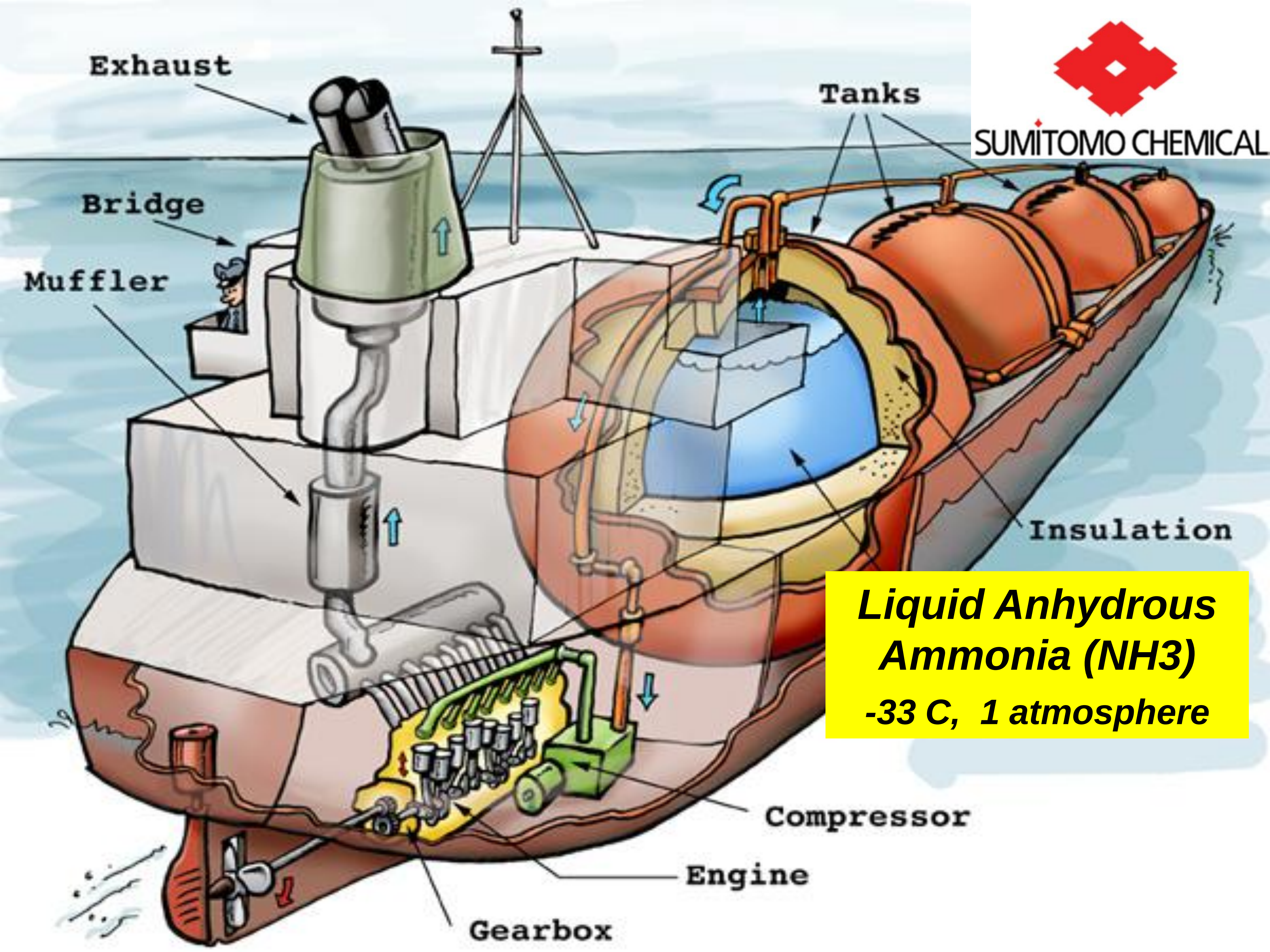
Kawasaki LH2 ocean tanker, truck

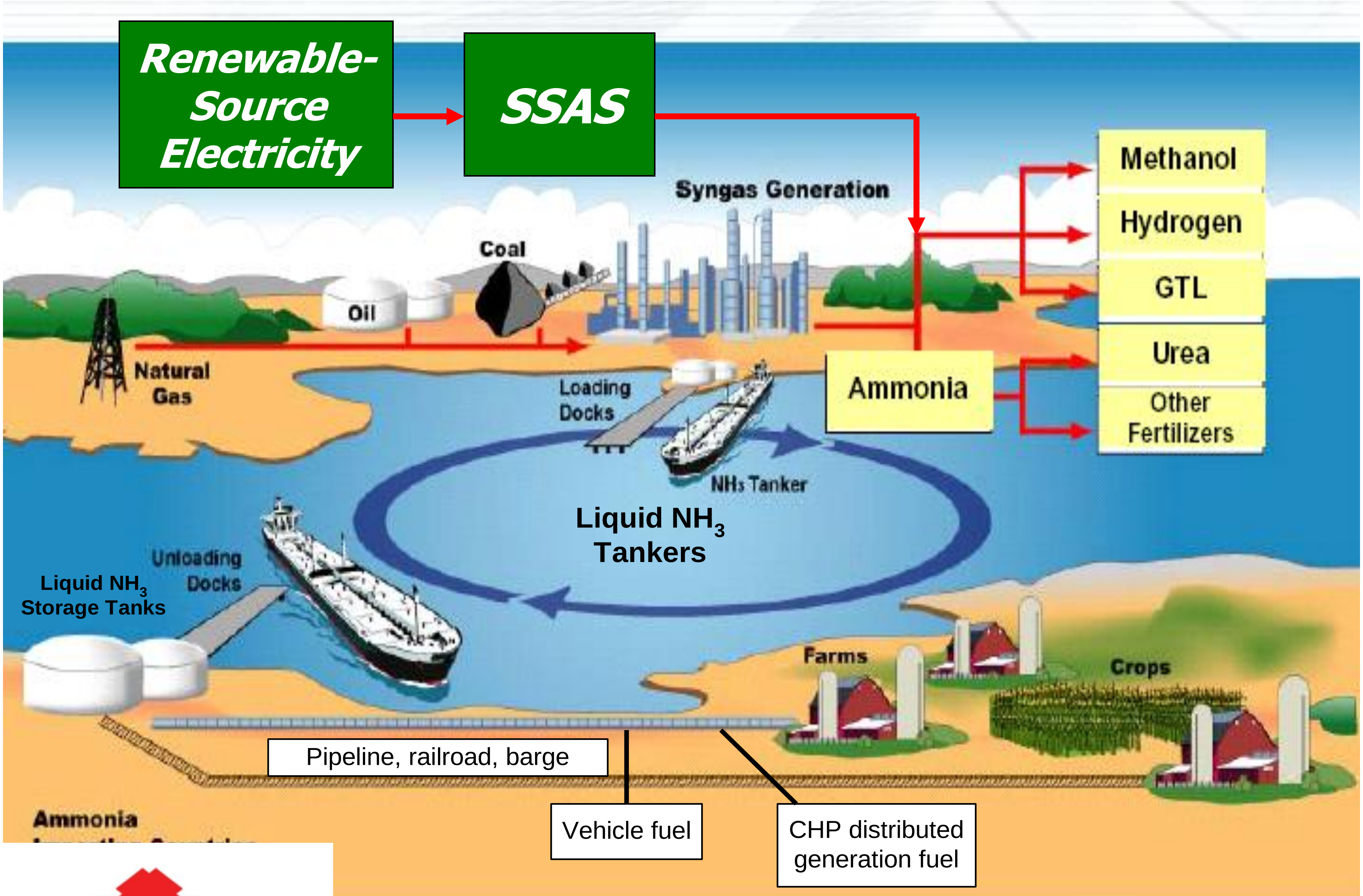
World Smart Energy Week

Tokyo, 26 Feb 14

RE Ammonia Transmission + Storage Scenario

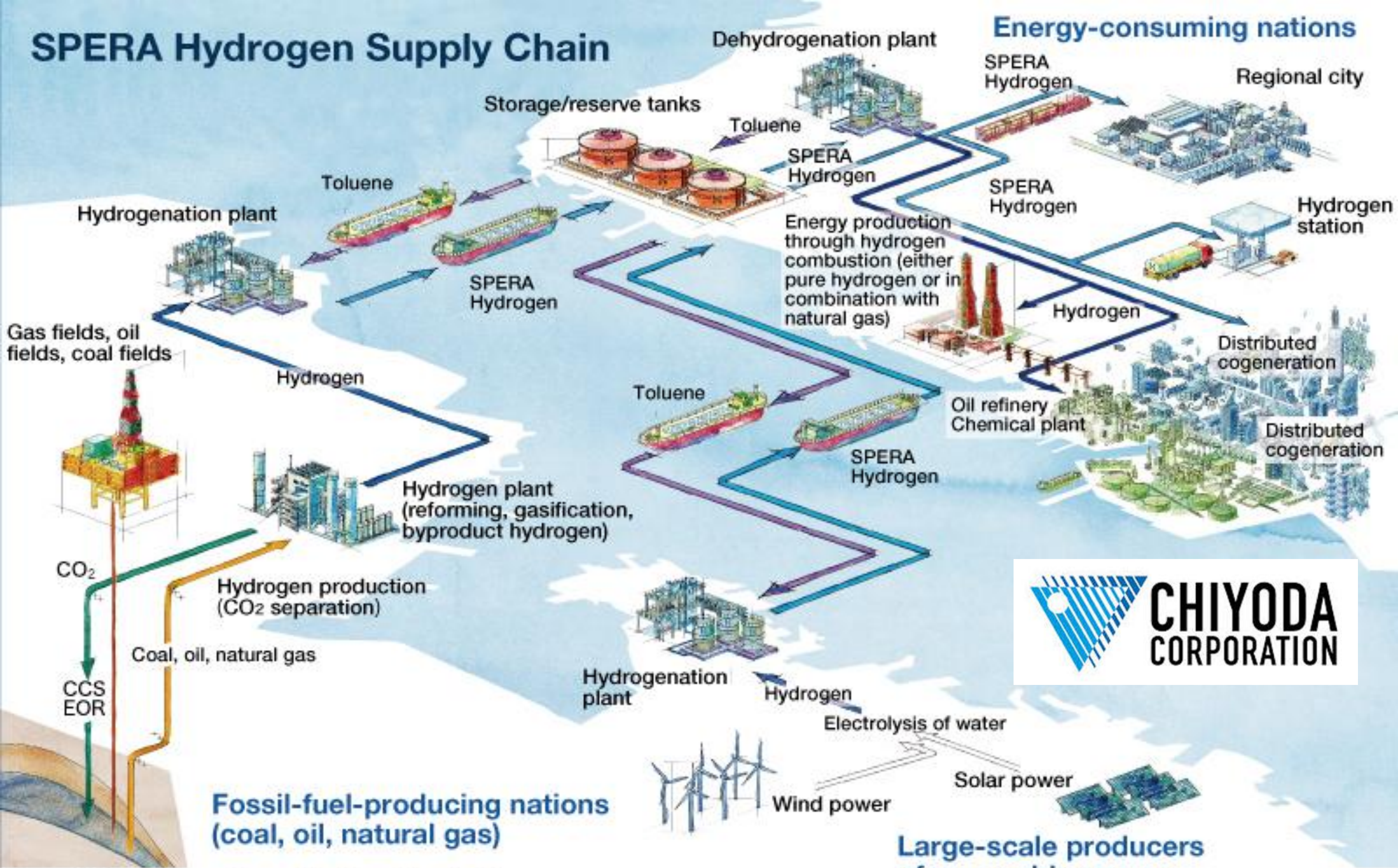



Exhaust
Bridge
Muffler
Tanks
SUMITOMO CHEMICAL
Insulation
Liquid Anhydrous
Ammonia (NH3)
-33 C, 1 atmosphere
Compressor
Engine
Gearbox



SUMITOMO CHEMICAL

KBR
Energy and Chemicals



Source: Chiyoda Corporation ; editorial revisions by *Nippon.com*.

Chiyoda Chemical and Heavy Industry

Organic hydride import cycle:

Toluene (C_7H_8) ←→ Methylcyclohexane (C_7H_{14})

Japan
Chiyoda Chemical

CHIYODA CORPORATION

Hydrogen transportation and storage as Methylcyclohexane (MCH) (C_7H_{14})

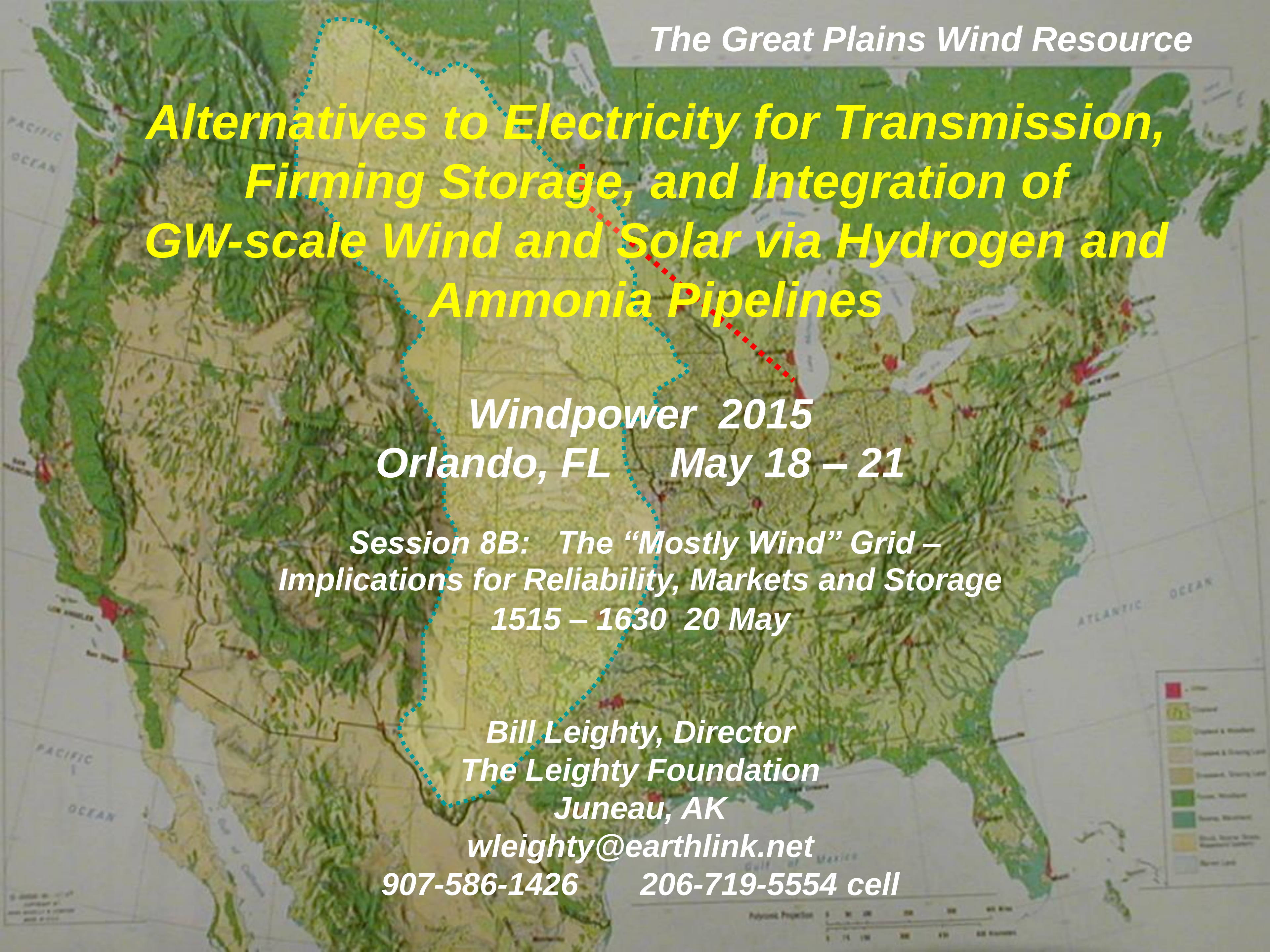
"Spera": Latin for "hope"

“ Infectious ”

- **Bigger “Wind Vision”**
  - **“Run World on Renewables”**
  - **Quickly ramp 2 – 10 x**
- **Complete RE systems**
- **New markets: C-free fuels**
- **Alternatives to Electricity systems for:**
  1. **Gathering and transmission**
  2. **Annual-scale firming storage**
  3. **Integration**
- **Collaborative: NREL, GE, AWEA, EPRI, UCS, NRDC, Universities ….**

The Great Plains Wind Resource

Alternatives to Electricity for Transmission, Firming Storage, and Integration of GW-scale Wind and Solar via Hydrogen and Ammonia Pipelines



Windpower 2015
Orlando, FL May 18 – 21

Session 8B: The "Mostly Wind" Grid – Implications for Reliability, Markets and Storage
1515 – 1630 20 May

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

End 20 May 15 presentation.
Following slides are supplemental

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

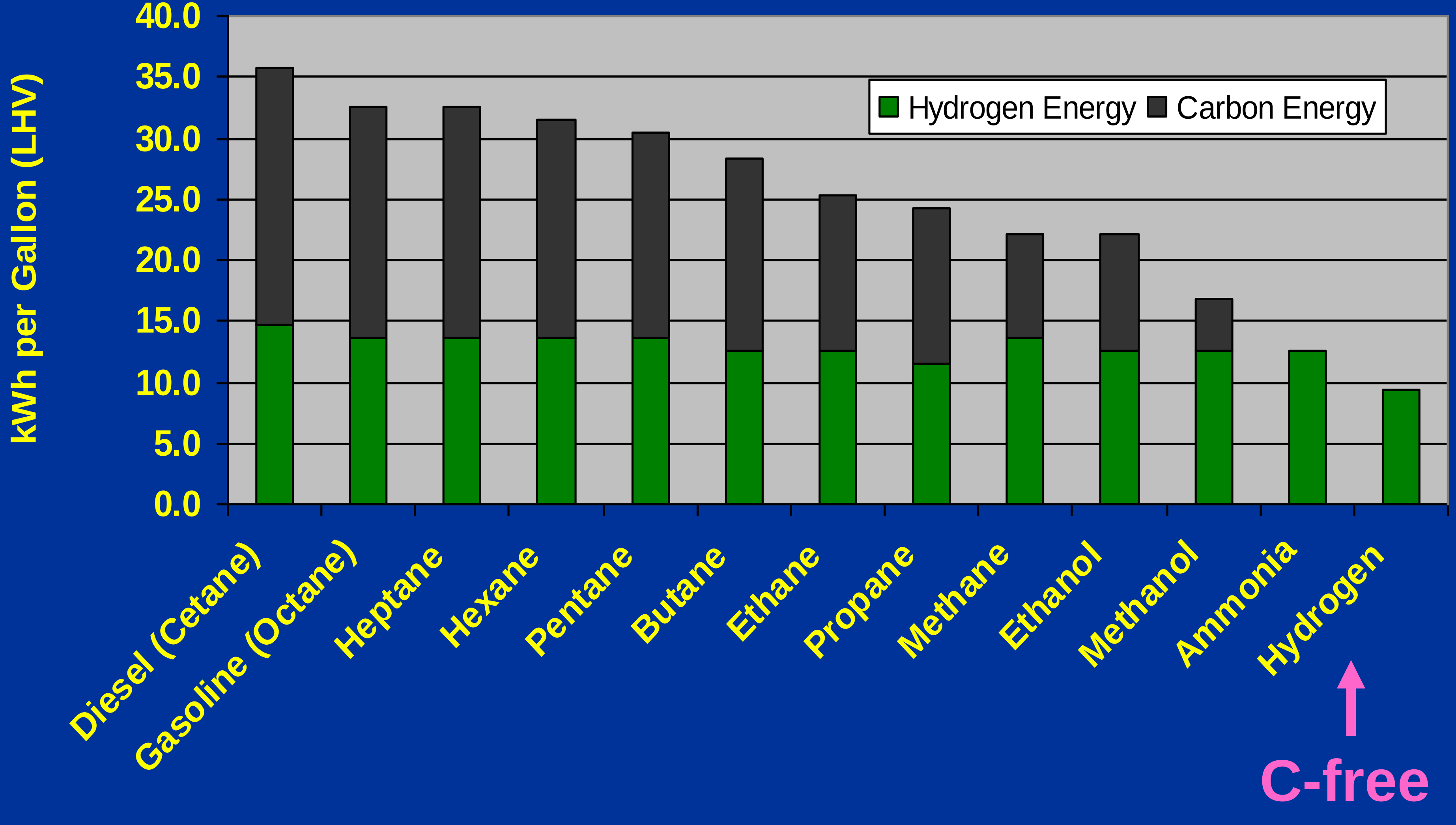
but only after they have tried everything else ”

Winston Churchill

The dog caught the car.

Dan Reicher

Volumetric Energy Density of Fuels (Fuels in their Liquid State)



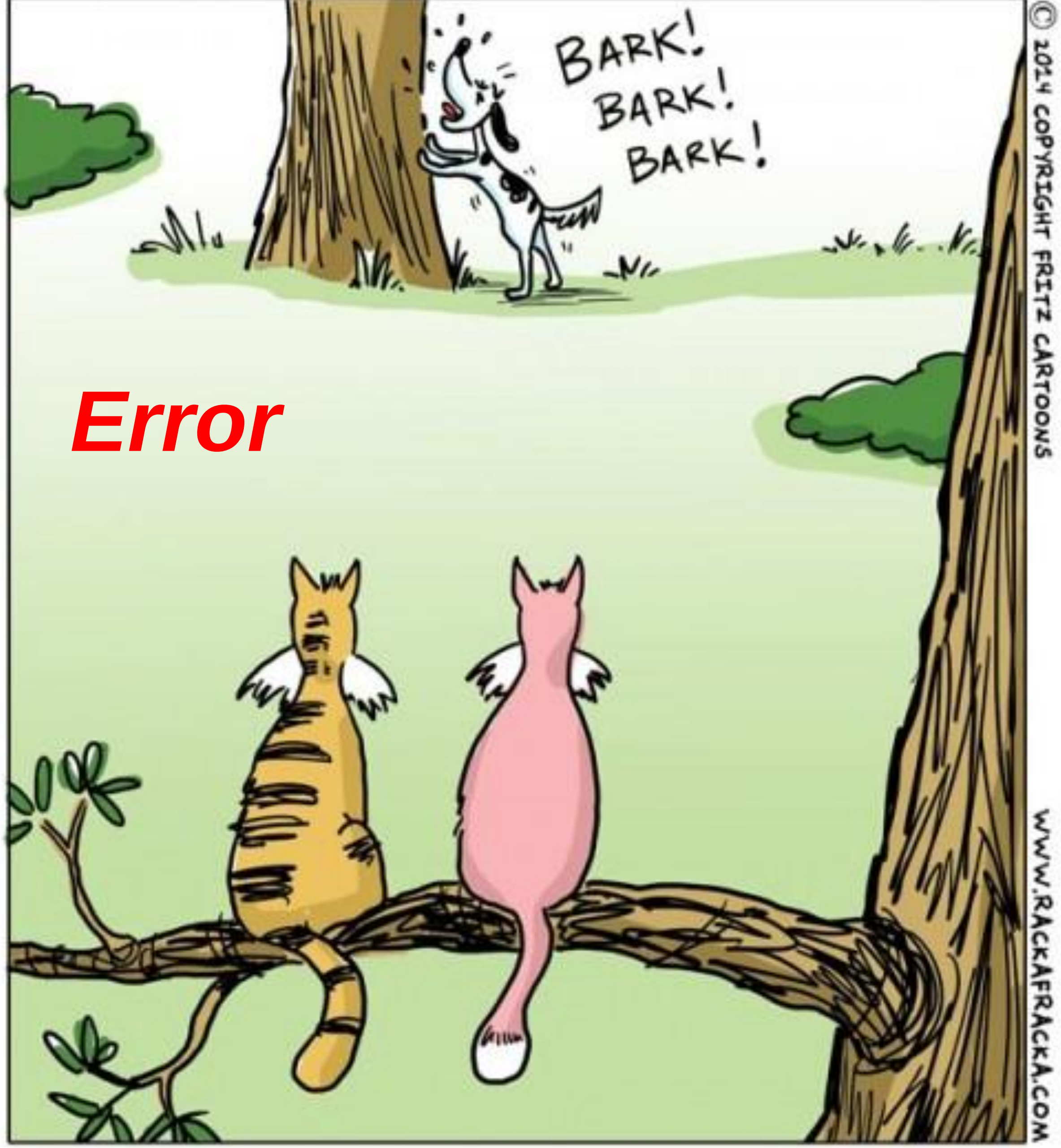
350 miles

5 GW

$ 5B

1,750 GW-miles @ $5,000M = $2.8M / GW-mile

Error



BUSTER WAS CAUGHT BARKING UP THE WRONG TREE AGAIN.

Danger