Running the World on Renewables: Energy Sustainability with God on our side?

Wartburg College

6 October 09

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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
Humanity’s Goal?

A sustainable, benign-source, equitable, global energy economy
Joseph Campbell 1904 - 87

“ The Power of Myth ”, Bill Moyers

“What Myth are we living?”
GOTT MIT UNS  "God with Us"
Only the Abrahamic Religions ?
MUST Run the World on Renewables – plus Nuclear?
Earth’s only source of income: Solar radiation, lunar tides
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:
  - Sunshine
  - Tides
  - Meteors and dust
- Spend our capital?
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
- Hydrogen, ammonia, ?
MUST Run the World on Renewables – plus Nuclear?

- Global
- Indigenous
- Firm: available
- C-free
- Benign
- Abundant
- Affordable
- Equitable
- Perpetual:
  - solar
  - geothermal
  - tidal
CO$_2$ in the Atmosphere

WE'RE HERE: 385.92 ppm

WE NEED TO GET BELOW: 350 ppm

www.350.org
Solar Hydrogen Energy System

Sunlight from local star

Electrolyzer

Electricity

H₂

O₂

Fuel Cell

Electricity

Work

2H₂O = Energy → 2H₂ + O₂
Hydrogen Fuel Cell
Proton Exchange Membrane (PEM) type

Hydrogen (H2) combines with Oxygen (O2) to make electricity + heat + water (H2O)
Watch our language!

“Run”

6. Move freely and without restraint
8. Take part in a race or contest
12. Ply between places
19. Operate or function
35. Perform or accomplish
46. Operate or drive
50. Manage or conduct
...
67.
Watch our language!

• Nuclear weapons
• Sustainable
  – Sustainability
  – Sustainable development
• Environment
  – Environmental
  – Environmentalist
  – Earth protection
• Natural
• Global warming
• Global climate change, rapid climate change
• kW, kWh
• Stewardship
Rad’i cal  adj.

1. a) of or from the root or roots; going to the foundation or source of something fundamental; basic
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
**Sustain what?**

1. Keep in existence; maintain
2. Supply with necessities or nourishment; provide for
3. Support from below; keep from falling or sinking; prop
4. Support the spirits, vitality, or resolution of; encourage
5. Bear up under; withstand
   - Economy back on track?
   - Get my job back?
   - More of the same?
   - Lower price of gasoline?
   - My grandkids? Seventh generation?
   - New Vision, Paradigm, Myth?
Sustain what?

• New Vision, Paradigm, Myth?

• “Where there is no vision the people perish“

Proverbs 29
“In every deliberation, we must consider the impact on the seventh generation... even if it requires having skin as thick as the bark of a pine.”

— Great Law of the Iroquois
“Poetry's really about what can't be said... when you can't find words for something.”

“Nobody finds words for grief... for love... for lust.”

W.S. Merwin
poet
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”
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

NW Iowa 190 MW windplant

Diverse!
Geothermal: hot water, surface recharge
“Enhanced”, “Engineered” Geothermal  Mt. Spurr, Alaska
Hot dry rock: flash injected water to steam
Photobiological

*Rhodobacter sphaeroides*
Algae:
Chlamydomonas reinhardtii

Photo: Tasios Melis, PhD,
UC Berkeley, USA
Dry Biomass
Concentrating Solar Power (CSP)
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 $\frac{1}{3}$ of China’s energy demand in 2030
Currents: Tidal, River, Ocean
Wave Generation
500 kW

"LIMPET", Island of I slay, off Scotland coast

Reinforced concrete Capture Chamber set into the excavated rock face.

The Wells Turbines rotate in the same direction regardless of the direction of the air flow. Thus generating irrespective of upward or downward movement of the water column.

Air is compressed and decompressed by the Oscillating Water Column (OWC). This causes air to be forced through the Wells Turbine and is then drawn back through the Wells Turbine.

"Limpet": Land Installed Marine Powered Energy Transformer

UK

Wavegen
Wave Generation

Oregon State University Conceptual Wave Park

Magnetic Shaft anchored to sea floor

Electric Coil secured to heaving buoy

Permanent Magnet Linear Generator Buoy

Source: Nicolle Rager Fuller, NSF
Big Island, Hawaii: OTEC: Ocean Thermal Energy Conversion
Comparing the world’s energy resources*

Where should we invest for the long-haul??

SOLAR

*yearly potential is shown for the renewable energies. Total reserves are shown for the fossil and nuclear “use-them, lose-them” resources. World energy use is annual.
12% world coal
Figure 3: Hydrogen Potential from Solar and Wind Resources

Total kg of Hydrogen per County
Normalized by County Area

Total solar: $\sim 3 \times 10^{14}$ kg/yr
Total wind: $\sim 3 \times 10^{11}$ kg/yr

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.
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:
  - CO₂ – emissions – free; benign
  - 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,
  - Distribution
  - “Firming” storage: salt caverns, tanks
- Pilot plants needed:
  - every major new industrial process
  - IRHTDF
3: **Shortest path to benign, secure, abundant energy**

- Anhydrous Ammonia (NH₃) fuel pipelines
  - Conversion, gathering
  - Transmission
  - Storage: tanks
  - Distribution
- Pilot plants needed:
  - Every major new industrial process
  - ’08 Farm Bill Title IX:
    “Renewable Fertilizer Research”
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
“America is addicted to oil.”

Jan 31, 2006, State of the Union,
President G. W. Bush

Humanity is addicted to energy
Slavery in America
Lance Armstrong
2002

Peak  500 Watts
Average  250 Watts

3 kWh per day
( 12 hour day )
746 Watts = 1 hp
Kilowatt-hour (kWh):

- Energy = power (Watts) × time (hours)
- 1,000 Watt-hours
- 2.6 million foot-pounds
- 1 Sherpa-week (100 pounds from 3,000 ft to 29,000 ft)
- 3,410 Btu = 640 lbs water heated 5 °F
Energy Slaves

USA:

35 Lance Armstrongs per person

working 24 / 7
DOE-EIA: Estimated 2005 US energy use

Estimated Future U.S. Energy Requirements - 96.8 Quads

- Hydro: 0.94
- Bio/Geo: 3.81
- Wind: 0.06
- Solar: 0
- Nuclear: 7.48
- Coal: 20.83
- Gas: 24.73
- Oil: 38.96

Electricity Generation: 33.91
H2 Production: 0

Residential: 11.89
Commercial: 8.96
Industrial: 26.36
Automotive: 16.18
Freight: 9.19
Airlines: 2.8

Useful Energy: 44.76
Rejected Energy: 52.06

Projection Year 2005
From Year 2005
Efficiency Year 2005
Energy Distribution Year 2005
EIA estimated 2025 energy use

Estimated Future U.S. Energy Requirements - 133.1 Quads

- Hydro: 0.96
- Bio/Geo: 5.94
- Wind: 0.11
- Solar: 0.01
- Nuclear: 7.64
- Coal: 26.89
- Gas: 34.88
- Oil: 56.7

Electricity Generation: 45.74

Useful Energy: 59.64

Rejected Energy: 73.47

Residential: 14.09
Commercial: 12.31
Industrial: 34.81
Automotive: 25.83
Freight: 13.18
Airlines: 5.06

H2 Production: 0

From Year 2025 Efficiency Year 2025 Energy Distribution Year 2025
THE END OF CHEAP OIL

SPECIAL REPORT:

WORLD
WORLD OUTSIDE PERSIAN GULF
PERSIAN GULF
U.S. AND CANADA
FORMER SOVIET UNION
U.K. AND NORWAY

ANNUAL OIL PRODUCTION (BILLIONS OF BARRELS)

USA total crude oil production

- Lower 48 = 189 BBbls
- North Slope = 16 BBbls
- ANWR = 6, 10, 16 BBbls
Proposed ANS* Gas Pipeline

“ALCAN” Alaska Highway Route

TransCanada Pipelines

* Alaska North Slope
Arctic National Wildlife Refuge (ANWR)

* 1002 Area
Methane Hydrate (clathrate)

Methane: $\text{CH}_4$

Water ice: $\text{H}_2\text{O}$

- More hydrocarbon than all oil + gas
- Deep seabed
- Inaccessible?
- Methane release?
The Fossil Fuel Age: a “Blink of an Eye” between the First and Second Solar Civilizations

Coal, Oil, Gas

First Solar Civilization  Second Solar Civilization

10000  5000  BC  AD  5000  10000
Titusville, PA
1859
First oil well
in USA
The First Solar Civilization

One-fourth of farm’s solar energy harvest to draft animals
The Second Solar Civilization

- Diverse
- Benign
- Renewable
  - Electricity
  - Hydrogen
  - Ammonia
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”, ammonia, ?
CO₂ in the Atmosphere

WE’RE HERE: 385.92 ppm

WE NEED TO GET BELOW: 350 ppm
“The unleashed power of the atom has changed everything save our modes of thinking and we thus drift toward unparalleled catastrophe.”

New York Times 25 May 1946
Svante Arrhenius

Sweden

1905
Nobel Prize
Chemistry

Proved CO$_2$ is heat-trapping gas in 1896
The Greenhouse Effect

Some solar radiation is reflected by the Earth and the atmosphere.

Some of the infrared radiation passes through the atmosphere, and some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the Earth's surface and the lower atmosphere.

Solar radiation passes through the clear atmosphere.

Most radiation is absorbed by the Earth's surface and warms it.

Infrared radiation is emitted from the Earth's surface.
Five Principal Greenhouse Gases (GHG’s)
1 gallon = 7 lbs

- Gasoline
- Diesel
- Jet

Burned = 20 lbs CO$_2$

(carbon dioxide)
Carbon Dioxide Concentrations

Ice Core Data

Mauna Loa (Hawaii)

Source: Office of Science and Technology Policy, Oct 97
CO$_2$ concentration (parts per million)

Thousands of years before 2006
Variations of the Earth’s surface temperature for...

Departures in temperature in °C (from the 1961-1990 average)

the past 140 years (global)

140 years: global

Departures in temperature in °C (from the 1961-1990 average)

the past 1000 years (Northern Hemisphere)

1,000 years: northern hemisphere

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
World Carbon Dioxide Emissions by Country
1990 - 2030

Source data: EIA 2007
CO₂ emission

Million tons
Per year
Earth Surface Temperature °C
Relative to 1980
Sea Level Rise: mm per year (estimate)

1870 – 1993
~ 1.7 mm / year

1993 – 2009
~ 3.3 mm / year
~ 1 ft / century
Climate Change over Next 100 Years

- CO₂ concentration in the atmosphere (Antarctic Ice Core)
- Temperature changes over time compared to the present temperature
Around the Americas       “Ocean Watch”
Dave Thoreson, Arnolds Park, IA
Around the Americas  June ‘09 ➔ Aug ‘10
Bellot Strait  27 Aug 09
Greenhouse gas emission scenarios

Pre-industrial age: 280 ppm  Today: 385 ppm

Stabilization Targets

www.350.org  24 Oct 09
CO2 in the Atmosphere

WE’RE HERE: 385.92 ppm

WE NEED TO GET BELOW: 350 ppm

www.350.org
How much will the Kyoto Protocol reduce emissions?

• 15th Conference of the Parties (COP15)

• United Nations Framework Convention on Climate Change (UNFCCC)

  Opened for signature on May 9, 1992, at Rio Earth Summit

  In force March 21, 1994 “... to achieve stabilization of greenhouse gas concentrations in the atmosphere at a low enough level to prevent dangerous anthropogenic interference with the climate system “

• Intergovernmental Panel on Climate Change (IPCC)

• Successor to Kyoto Protocol

• Ban Ki-moon: “We sink or swim together”
“... the [Waxman-Markey] bill is inadequate in a very simple way... you've got to cut off the coal source “
“... for avoiding catastrophic climate disruption ...”
Wedges

Efficiency & Conservation
• Increased transport efficiency
• Reducing miles traveled
• Increased heating efficiency
• Increased efficiency of electricity production

Fossil-Fuel-Based Strategies
• Fuel switching (coal to gas)
• Fossil-based electricity with carbon capture & storage (CCS)
• Coal synfuels with CCS
• Fossil-based hydrogen fuel with CCS

Nuclear Energy
• Nuclear electricity

Renewables and Biostorage
• Wind-generated electricity
• Solar electricity
• Wind-generated hydrogen fuel
• Biofuels
• Forest storage
• Soil storage
5 meter sea level rise by 2100: high CO2 emissions
18 ft sea level rise
CO₂ in the Atmosphere

WE’RE HERE: 385.92 ppm

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www.350.org
YO! AMIGO!!
WE NEED THAT TREE TO PROTECT US FROM THE GREENHOUSE EFFECT!
Doomsday Scenario

• “Hot, Flat, and Crowded” -- T. Friedman
• “Catastrophic climate disruption”
• Ocean acidification
• Rising sea level
• Storms, flood, drought
• Tropical pests and diseases move north
• Peak oil, gas, coal
• Environmental refugees: humans, other
• Species extinction
Doomsday Scenario

- Cannot accept, indulge, yield
- Unfair: species, future generations
- Profane, insult creation-evolution
- Rapture: “Gott mit Uns”
- WWII: amazing
  - Mobilization
  - Sacrifice
Pogo

“We have met the enemy...”
Joseph Campbell 1904 - 87

“The Power of Myth”, Bill Moyers

“Follow your bliss”

“What Myth are we living?”
New Myth

• Beyond “Gott mit Uns”
• Bigger loyalty, allegiance, patriotism
• Run world on renewables
• Responsibility: united by threat
Humanity’s Goal?

A sustainable, benign-source, equitable, global energy economy

- Rapid Climate Change (GCC)
- Peak oil, gas, coal
- Energy security
Joel Barker:
• The Business of Paradigms
• Paradigm Paralysis
“The Structure of Scientific Revolutions” -- 1973

- Paradigm
- Paradigm paralysis
- Paradigm shift
Ilya Prigogine

1977 Nobel Prize, Chemistry

• Surprisingly alive
• Twitchy, searching, self aware
• Self-destruct ?
• Self-shaking to higher ground
George Land

- Purpose of all life
- Growth
- Higher, more complex
  - organization
  - individual
“There’s a way to do it better ... Find it”
“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
Business Case for Sustainability

- Dow Jones Sustainability Index outperforms DJIA
- Goldman Sachs July ‘09: ESG companies lead by average 25%
- 72% outperformed industry peers
- Regional environmental protection outperforms
- Triple bottom line: people, planet, profit
- Attract, retain talent
- Reduce risk, distrust cost
- Labor productivity
• Cut GHG 65% 1990–2010: - 80 %
• Rev up 6%/y 2000–10, no increased energy
  Energy - 9 % since ‘90
  Production + 30 %
• 2010: from renewables
  10% of energy
  25% of feed stock
• Saved $3 B, 2000 - 05
Eco-Efficiency savings = $2.2 B

Average Net Income (2003-2007) = $2.2 B

- Waste reduction
- Energy use flat

Annual Savings

$1.8 B

$0.4 B
Wal-Mart hired CDP to assess suppliers in China:

- Carbon footprint
- Supplier standards

- 100% renewable energy
- Zero waste
- Carbon neutral
- Saved $11B / yr packaging
Clorox & Sierra Club

- Clorox Greenworks #2 USA Green Brand ‘09
- First year sales $40M
- $470,000 to Sierra Club ‘08 sales.
Renewable Energy Sources in Germany, 1975 – 2007

2009:
10 % total energy
15 % electricity
The Land Institute
Salina, KS

- Perennial, herbaceous, seedbearing polyculture
- Nature as measure
- Mimic pre-Columbus prairie
- Save topsoil
- Reduce inputs: energy, fertilizer, chemicals

Wes Jackson, co-founder
Green Jobs in Renewable Energy

- Invent, design, engineer, test
- Component mfg: blade, tower, gearbox, panel, geothermal block, tank, pipe
- Project planning, finance
- Project installation: transport, road, underground wire + pipe, substation, erection crane, electricians, mechs
- Project maintenance: elec, mech tech, supervisor
High Temperature Gas Reactor (HTGR)

Same Problems:
- High plant cost
- Waste disposal
- Accidents
- Insurance
- Proliferation
- Limited fuel
Nuclear Fusion

ITER

International Thermonuclear Energy Reactor

France

2018

first plasma
Running the World on Renewables: Energy Sustainability with God on our side?
WE'RE HERE: 385.92 ppm

WE NEED TO GET BELOW: 350 ppm

CO₂ in the Atmosphere

www.350.org
## Exporting From 12 Windiest Great Plains States

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

Wind energy source: PNL-7789, 1991

*at 500 miles average length*

<table>
<thead>
<tr>
<th>State</th>
<th>AEP, TWh</th>
<th>Wind Gen MW (nameplate) (40% CF)</th>
<th>6 GW 36” GH2 export pipelines</th>
<th>$ Billion Total Capital Cost *</th>
<th>3 GW export HVDC lines</th>
<th>$ Billion Total Capital Cost *</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Dakota</td>
<td>1,210</td>
<td>345,320</td>
<td>50</td>
<td>50</td>
<td>100</td>
<td>60</td>
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<tr>
<td>Texas</td>
<td>1,190</td>
<td>339,612</td>
<td>48</td>
<td>48</td>
<td>100</td>
<td>60</td>
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<tr>
<td>Kansas</td>
<td>1,070</td>
<td>305,365</td>
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<td>43</td>
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<td>60</td>
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<td>South Dakota</td>
<td>1,030</td>
<td>293,950</td>
<td>41</td>
<td>41</td>
<td>100</td>
<td>60</td>
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<td>Montana</td>
<td>1,020</td>
<td>291,096</td>
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<td>Nebraska</td>
<td>868</td>
<td>247,717</td>
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<td>80</td>
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<td>Wyoming</td>
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<td>Oklahoma</td>
<td>725</td>
<td>206,906</td>
<td>29</td>
<td>29</td>
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<td>Minnesota</td>
<td>657</td>
<td>187,500</td>
<td>26</td>
<td>26</td>
<td>60</td>
<td>36</td>
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<tr>
<td>Iowa</td>
<td>551</td>
<td>157,249</td>
<td>22</td>
<td>22</td>
<td>50</td>
<td>30</td>
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<tr>
<td>Colorado</td>
<td>481</td>
<td>137,272</td>
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<tr>
<td>New Mexico</td>
<td>435</td>
<td>124,144</td>
<td>17</td>
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<td>40</td>
<td>24</td>
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<tr>
<td><strong>TOTALS</strong></td>
<td><strong>9,984</strong></td>
<td><strong>2,849,316</strong></td>
<td><strong>401</strong></td>
<td><strong>$ 401</strong></td>
<td><strong>890</strong></td>
<td><strong>$ 534</strong></td>
</tr>
</tbody>
</table>
High Voltage Direct Current Transmission

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

Six Plains states wind needs 560 lines at 3,000 MW each

SIEMENS HVDC line +/- 500 kv
# Iowa Wind Potential

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual energy production, TWh</td>
<td>550</td>
</tr>
<tr>
<td>Installed wind generation, MW</td>
<td>157,249</td>
</tr>
<tr>
<td>Export electric lines</td>
<td>50</td>
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<tr>
<td>Export electric lines cost</td>
<td>$30 billion</td>
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<tr>
<td>Export hydrogen pipelines</td>
<td>20</td>
</tr>
<tr>
<td>Export hydrogen pipelines cost</td>
<td>$20 billion</td>
</tr>
</tbody>
</table>
Used Only 20% of North Dakota’s Wind Potential!

All of Iowa’s Electricity
Natural Gas
Petroleum

New + / - 500 kv HVDC electric lines
AWEA 20% Wind by 2030

Frontier Line + Transwest Express $\sim= 115$ GW
Wind Potential $\sim= 3,000$ GW
Figure 3

Hydrogen Potential from Solar and Wind Resources
Total kg of Hydrogen per County
Normalized by County Area

Total solar: $\sim 3 \times 10^{14} \text{ kg / yr}$
Total wind: $\sim 3 \times 10^{11} \text{ kg / yr}$

Rich, stranded
Resources

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.
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
Pickens Plan

- Bold, large-scale, motivates thinking
- Rally public: “Army”
- Disappoint? Disillusion?
- 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?
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
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
Annual – scale “Firming”
Great Plains Wind

• Potential, 12 states, ~50% land area:
  – 10,000 TWh = 100 quads = entire USA
  – 2,800,000 MW nameplate

• Seasonality:
  – “Firming” energy storage,
    per 1,000 MW wind = 320 GWh
“Firm” energy worth more

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

Sunlight from local star

Electricity → Hydrogen (H₂) → Electrolyzer → Oxygen (O₂)

Fuel Cell

Work
Hydrogen Transmission Scenario

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

Storage: 120 GWh

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

Wind Generators
Electrolyzers
Compressors

AC grid Wholesale
Generators ICE, CT, FC
End users Retail

Cars, Buses, Trucks, Trains
Liquefy
Aircraft Fuel
Norsk Hydro electrolyzer, KOH type
560 kW input, 130 Nm3 / hour at 450 psi (30 bar)
Compressorless system: No firming storage

Transmission

- Wind Generators
- High-press Electrolyzers

City gate

Pipeline Energy

- Storage
  - Wind Generators

1,500 psi

500 miles

Hydrogen Gas Pipeline
20" diameter
1,500 -- 500 psi

Distribution

- AC grid
  - Wholesale
- End users
  - Retail
- Generators
  - ICE, CT, FC
- Cars, Buses, Trucks, Trains
- Liquefy
- Aircraft Fuel

500 psi

Transmission Distribution

Compressorless system: No firming storage
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.
City-gate GH2 cost @ 15% CRF, 20” pipeline, from 2,000 MW Great Plains windplant

Competitive cost?
"Firming" Cavern Storage

Hydrogen Energy Storage

Wind Generators

Electrolyzers

Wind Generators

1,000 miles Hydrogen Gas Pipeline 36" diameter, 1,500 - 500 psi

Pipeline Storage = 240 GWh

Storage

Generators ICE, CT, FC

End users Retail

Storage

Cars, Buses, Trucks, Trains

Storage

Liquefy

Aircraft Fuel

Storage

Geologic Storage?
Domal Salt Storage Caverns
(8 \times 13) = 104 + (8 \times 12) = 96 \quad \text{Total} = 200 \text{ caverns per square mile}

Each cavern is 200 ft diam, with minimum 200 ft web separation.

“Firm” 4,000 MW Great Plains wind

14 caverns

Maximum Cavern Packing Density
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:
  – “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
AWEA 20% Wind by 2030

Wind Potential $\approx 3,000$ GW

Frontier Line + Transwest Express $\approx 115$ GW
AWEA 20% Wind by 2030

Wind Potential $\sim 3,000$ GW

Frontier Line + Transwest Express $\sim 115$ GW
AWEA 20% Wind by 2030

Frontier Line + Transwest Express $\approx 115$ GW

Wind Potential $\approx 3,000$ GW
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?
Estimated 2050 energy use
(H₂ fleet using wind electrolysis)
EC: The NATURALHY concept

NATURALHY:

- Breaks “chicken-egg” dilemma
- Bridge to sustainable future
Hydrogen, Fuel Cell       Running on water ?
Hydrogen - fueled
2005 Prius
ICE Hybrid

www.qtww.com
Energy System of the Future

Frank Novachek, Director Corporate Planning
Utsira Island, Norway
Utsira Island
Norway

Wind – Hydrogen Autonomous System

Replaces aging electricity cable from mainland
The wind – hydrogen plant at Utsira

A vision becoming reality
Continental Supergrid – EPRI concept “Energy Pipeline”

Thermal Insulation

Vacuum

Electrical Insulation

SC*: MgB$_2$ magnesium diboride superconductor

LH2**: liquid hydrogen coolant, energy transmit

~ 100 GW elec LVDC +

~ 100 GW LH2

* SC: MgB$_2$ magnesium diboride superconductor

** LH2: liquid hydrogen coolant, energy transmit

Continental Supergrid – EPRI concept “Energy Pipeline”
Airbus Industrie concept: liquid hydrogen fueled
Proposed Northeast Asia Natural Gas Pipeline
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 plant needed*

- Every major new industrial process
- Diverse, large-scale, stranded
- Renewables-source systems
- IRHTDF
- Posters: Japan, Canada, IPHE
The Second Solar Civilization

Alaska should begin to build it
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

* Ames
* Des Moines

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.

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Biomass, Wind, Other Catchment Areas, with Delivery Points to GH2 pipeline

IRHTDF: generation, conversion, collection, storage corridor

GH2 geologic storage

O2 pipeline
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
Ammonia (N\textsubscript{H\textsubscript{3}}) Synthesis Plant
Natural Gas Feed
1 – 3,000 tpd

Haber-Bosch “Synloop”
Inside the Black Box:
Steam Reforming + Haber-Bosch

$$3 \text{CH}_4 + 6 \text{H}_2\text{O} + 4 \text{N}_2 \rightarrow 3 \text{CO}_2 + 8 \text{NH}_3$$

Energy consumption ~33 MBtu (9500 kWh) per ton $\text{NH}_3$
NH₃ Ag Fertilizer Tanks, Wind Generators, NW Iowa
Inside the Black Box: HB Plus Electrolysis

3 H₂O → 3 H₂ + 3/2 O₂
3 H₂ + N₂ → 2 NH₃

Energy consumption ~12,000 kWh per ton NH₃
Inside the Black Box: Solid State Ammonia Synthesis

\[ 6 \text{H}_2\text{O} + 2 \text{N}_2 \rightarrow 3 \text{O}_2 + 4 \text{NH}_3 \]

Energy consumption 7000 - 8000 kWh per ton \( \text{NH}_3 \)

Benchtop
Proof-of-concept
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
Valero LP  Operations
MONTHS:
GH2, NH3
“Atmospheric”

Liquid Ammonia Storage Tank

30,000 Tons
190 GWh
$15M turnkey
$77 / MWh

-33 C
1 Atm
Ammonia
534 kg  H2
$10,000

Hydrogen gas
350 kg  H2
$400,000
“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?
320,000 MWh storage
Annual firming, 1,000 MW wind

• VRB
  – O&M: 80% efficiency round-trip
  – Capital: $500 / kWh = $160 Billion

• CAES
  – 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

• GH2  Capital  $70 Million
• NH3  Capital  $30 Million
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
Annual – scale “Firming”
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Running the World on Renewables: Energy Sustainability with God on our side?
DOE-EIA: Estimated **2005** US energy use

Estimated Future U.S. Energy Requirements - 96.8 Quads

- **Hydro** 0.94
- **Bio/Geo** 3.81
- **Wind** 0.06
- **Solar** 0
- **Nuclear** 7.48
- **Coal** 20.83
- **Gas** 24.73
- **Oil** 38.96

Electricity Generation 33.91

- **Residential** 11.89
- **Commercial** 8.96
- **Industrial** 26.36

H2 Production 0

- **Automotive** 16.18
- **Freight** 9.19
- **Airlines** 2.9

Useful Energy 44.76

Rejected Energy 52.06

Projection Year 2005
From Year 2005
Efficiency Year 2005
Energy Distribution Year 2005
What can I do?

- 350.org 24 Oct 09
- Learn, understand: invest in confidence
  - Energy: world, USA, local, self
  - GW / GCC: emergency?
  - DECIDE
- Invest in efficiency, conservation, lifestyle
- Drive a small car; buy a hybrid
- Drive NO car; public transit
- Join: IRENEW, UCS, NRDC, ED,
- Many others – connect
- No new coal plants; retire old ones
- Congress: strong climate protection law by Copenhagen
- Ag: Land Institute
• 15th Conference of the Parties (COP15)
• United Nations Framework Convention on Climate Change (UNFCCC)
  
  Opened for signature on May 9, 1992, at Rio Earth Summit
  
  In force March 21, 1994 “... to achieve stabilization of greenhouse gas concentrations in the atmosphere at a low enough level to prevent dangerous anthropogenic interference with the climate system “
  
• Intergovernmental Panel on Climate Change (IPCC)
• Successor to Kyoto Protocol
• Ban Ki-moon: “We sink or swim together”
WE’RE HERE: 385.92 ppm

WE NEED TO GET BELOW: 350 ppm

CO₂ in the Atmosphere

www.350.org
“Toughness is seeing what you don’t want to see, hearing what you don’t want to hear, and doing what you don’t want to do… with enthusiasm.”
“In every deliberation, we must consider the impact on the seventh generation... even if it requires having skin as thick as the bark of a pine.”

— Great Law of the Iroquois
GAIA theory: Earth is a single living organism

James Lovelock
Garrett Hardin
1915 – 2003

1968, Science

“The Tragedy of the Commons”
Plan B 4.0: Mobilizing To Save Civilization

Lester Brown
Earth Policy Institute
Comparing the world’s energy resources*

Where should we invest for the long-haul??

SOLAR

World energy use

*yearly potential is shown for the renewable energies. Total reserves are shown for the fossil and nuclear “use-them, lose-them” resources. World energy use is annual.
What can I do?

- “Toughness” Planet Manager, Earth Protector
- Tough, not enviro wimp
- Oct 24 action: 350.org
- Decide about climate change danger
- Help each other; get help: Your church, club, “circle”, college
- Imagine + build a New Myth
- Attitude and action
- Take responsibility
- Become Earth Protector and Planet Manager
- “Be the change you want to see in the world.” -- Gandhi
- Beyond blame, fear, hate
- NO bottled water
- NO new coal plants
- Green your investment portfolio
- Stop Iowa sprawl: KFOI
- Join renewables + conservation: IRENEW, other non-profit
- Imagine a world Beyond War
- Imagine a bigger patriotism – wear an Earth pin
- Market for green jobs
New Vision, Strategy, Action

• YOU, WE must decide:  *L. de – cisio*  *To cut away*
• Mobilizing to save civilization
• 60 days to Copenhagen COP15:
  • Need strong Senate “climate defense” bill
  • Empower Congress - be “tough”
• Run the world, and USA, on renewables
• Green jobs
• Agronomy: The Land Institute – perennial, herbaceous, seedbearing polyculture
• Conservation & efficiency best investments
• WWII response, sacrifice, investment
New Myth

• Beyond “Gott mit Uns”
• What “sustain”?
• Responsibility: seventh generation
• Toughness: “… bark of a pine”
• GAIA
• Our Common Future. We are One. Global Commons
• Earth Protector and Planet Manager
• Unite to face common threat
• “Be the change you want to see in the world.” -- Gandhi
• Bigger loyalty, allegiance, patriotism – Earth pin, poster
• Astronauts speak
• “… Not man apart …”
Integrity is wholeness, the greatest beauty is Organic wholeness, the wholeness of life and things, the divine beauty of the universe.

Love that, not man
Apart from that, or else you will share man's pitiful confusions, or drown in despair when his days darken.
Running the World on Renewables:
Energy Sustainability with
God on our side?

DVD’s, handouts

Wartburg College

6 October 09

Bill Leighty
The Leighty Foundation
wleighty@earthlink.net