

WindFuels Competitors and their Challenges

*WindFuels – Economically Producing Fuels
from Point-source CO₂ and Off-peak Wind*

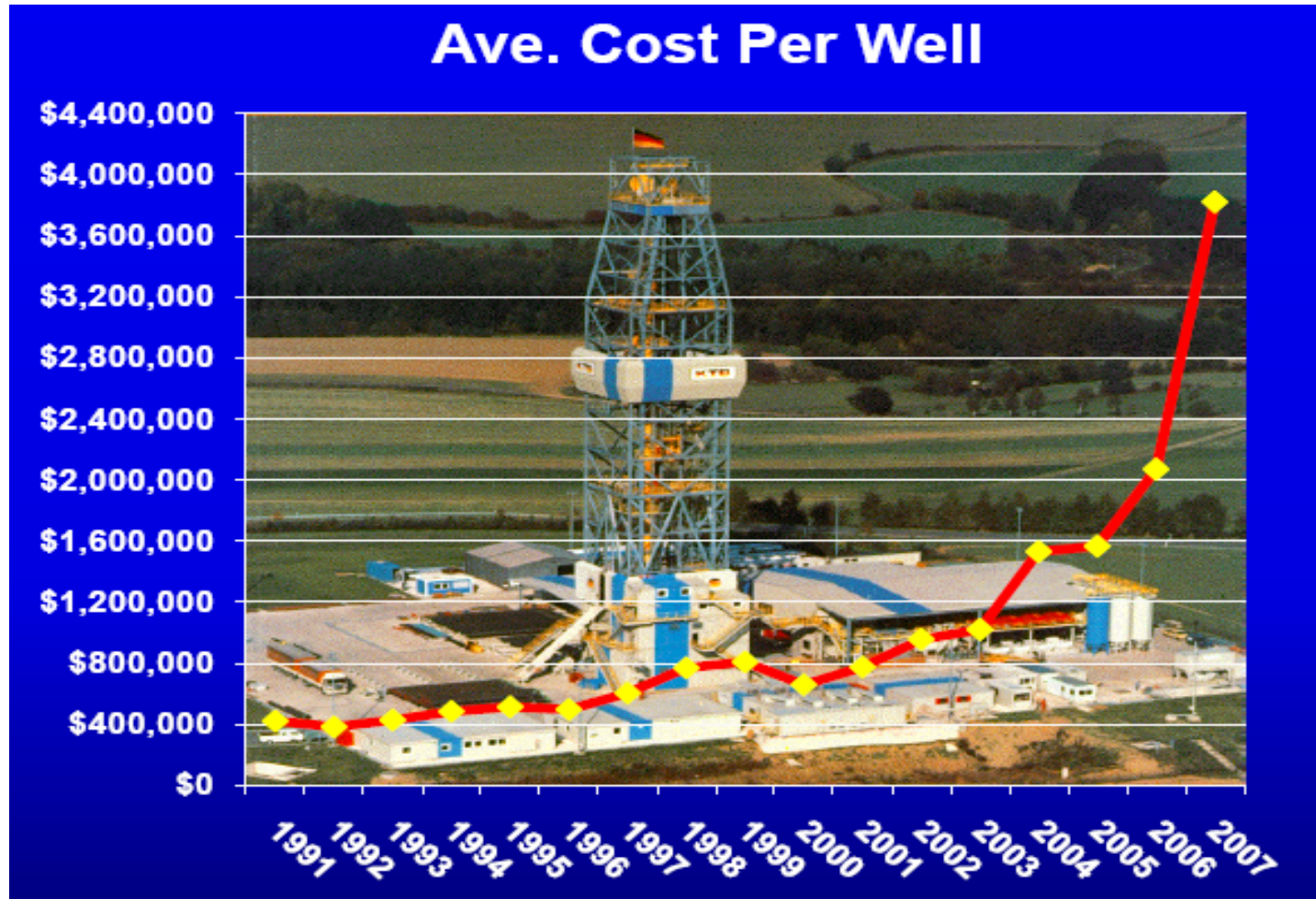


A scalable, competitive energy and climate solution.

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Few Renewables Advocates Really Understand the Magnitude of the Looming Oil Challenge



Average cost per oil well, from EIA data.

***Peak Oil, Peak Coal, Peak Gas,
and Peak Uranium are coming.***

In June 2008, when petroleum demand briefly came within 1.5% of supply, we had a foretaste of what can be expected after 2014.

Likely Estimates:

A Severe Oil Crunch - 2014

Less recognized:

Peak Coal - 2030

Biofuels – not scalable, and a “Crime Against Humanity” (UN)

The *net* contribution in 2010 - about 1% of oil.

Corn & grain prices increased by ~60% annually
for 3 years !

Newly tilled soil creates a **“carbon debt”**
for 30 to 250 years.

Recent EPA study finds most biofuels are only
7% carbon neutral.

Oceanic Dead Zones are rapidly expanding from
fertilizer run-off and top-soil erosion.

Most aquifers are being **rapidly pumped dry**.

Land is needed to feed a billion hungry people.

*Biofuels are making billions of dollars for ADM, POET,
Monsanto, Bunge, Cargill, and other corporations, but
making life worse for billions of people on the planet.*

Cellulosic ethanol will not compete

- Cellulosic feedstocks were **\$25/ton** in 2001.
- Wood pellets
2011: **\$150-240/ton** in the U.S.
Have sold for **\$350/ton** in Europe
Expect **\$300/ton** in 6 years in the U.S.
- Ethanol from feedstocks at \$300/ton – will cost over **\$4.50/gal.**

wood pellet plant



Under 29% of the carbon in the feedstocks going into cellulosic ethanol refineries ends up in the ethanol. Most of the rest is emitted as CO₂.

The Micro-algae Mirage

The cheapest, commercially available microalgae today (food industry) costs **\$5000/ton**.

Several methods proposed for high-oil micro-algae:

(1) large plastic tanks, (2) racetrack ponds...

- Solazyme has sold non-photosynthetic algal oil (from sugar-fed algae) to the Navy for **\$425/gal**.
- Their CEO says photosynthetic algae is 1000X more expensive (we think its only 30X more expensive).
- **Fuels** from green algae won't be under **\$70/gal** by 2020.



Thermonuclear-Fusion, an Impractical Dream

The latest official projections are like those of 40 years ago: “We’ll see commercial, profitable, limitless electricity from fusion in 40-50 years.”

The cost of the potential ITER electrical output would be ~10,000 times that of wind energy.

- **The first fusion power plant, DEMO, is projected to begin producing 500 MW net electrical output in 2035 at 50% duty cycle. (Lifetime unknown – maybe a few years.)**
- **Probable initial cost (in 2010\$) of over \$70/W_{PE}.**
- ***If DEMO works as expected, its energy cost would be over 300 times that of wind energy.***

The Hydrogen Economy...

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- Storage and distribution costs are 30 times greater than for liquid fuels.
 - Osaka recently introduced a methane-fed hydrogen fuel cell (35% efficiency) for **\$36,000/kW**.
 - Automotive fuel cells 20 years from now will still be 10 times more expensive than advanced internal-combustion engines.
 - A pipeline network to distribute hydrogen to homes would probably cost 3 times as much as that for natural gas.

**Hydrogen has a place –
but not for cars or home heating.**

De-hyping Solar PV



- **Solar PV** currently contributes about **0.1%** of the US electrical energy.
- The installed price for roof-top solar is about \$7 per watt of peak electrical power (W_p).
- One of the larger PV plants in North America has a contract to sell its power at \$0.44/kWhr – 4 times the average price for electrical power in the U.S.

Why does this matter?

Solar will be providing under 0.5% of global electrical energy by 2015.

Concentrated Solar Power (CSP) Facts



- **Nevada Solar One, 70 MW_{PE}, completed in 2007, was the tenth CSP plant built in the U.S. It cost \$3.5/W_{PE}, and it has:**
 - Peak solar collection efficiency of 66%,**
 - Peak thermal conversion efficiency (at 660 K) of 35%,**
 - Capacity factor of 22%,**
 - Mean overall solar efficiency (annual basis) under 12%.**
- **A PowerTower with thermal storage costs about \$6.2/W_{PE}.**
 - Peak thermal conversion efficiency (at 840 K) of 38%,**
 - Capacity factor of 35%,**
 - Mean overall solar efficiency (annual basis) of 24%.**
- **New CSP construction has been nearly frozen since early 2008.**
- **CSP (in all its variations) is in its death throws.**

Renewable Energy Costs

The Levelized Costs of Energy (LCOE) depend as much on discount rate and lifetimes as they do on initial *total system cost per peak watt* (C_{PE}), capacity factor (F , ratio of mean to peak power), and Operating & Maintenance (O&M) costs.

Best available current data on renewable energy costs, 3/2010						
Resource	C_{PE} (\$/W _{PE})	Capacity Factor F	Fuel+ O&M \$/MWhr	Lifetime years	LCOE 5% \$/MWhr	LCOE 10% \$/MWhr
Wind (prime)	1.5	0.35	1	40	29	51
Hydro (prime)	5.5	0.5	1	50	69	127
New Nuclear	8.3	0.85	26	40	90	139
Clean Coal +CCS	5	0.8	45	35	92	123
CSP, 80 MW	3.9	0.23	45	30	170	250
large PV, AZ	6.7	0.19	10	30	309	500
EGS	35	0.85	60	30	409	630
Fusion	70	0.5	50	2	8600	9300

Methanol Synthesis

Thermo-chemical process has been demonstrated for synthesis of methanol from CO₂ and H₂. **Byproduct is mostly just water.**

Hence, some researchers have advocated a “Methanol Economy.”

Problems with Fossil Methanol

- Methanol has 5X the toxicity and vapor pressure of modern gasoline,
 - a lower flash point (11°C)
 - less than half the energy density of gasoline
 - higher corrosiveness
- Without CO₂ sequestration, methanol from coal produces 70% more **GHGs** than oil.
- Fossil feedstocks are limited and will soon be expensive.

Fossil-based Fischer Tropsch Synthesis

Fischer-Tropsch Synthesis (FTS), like methanol synthesis, converts a syngas ($\text{CO} + \text{H}_2 + \text{some CO}_2$) into synfuels (diesel or gasoline) and waste heat in a catalytic reactor.

FTS reactions are not narrowly selected – i.e., they produce a wide range of products and thus require fairly complex separations.

**CO_2 from Fossil-Based Synfuels
is Not Sustainable**

**FTS of diesel from 1 kg coal
yields 2 kg of CO_2 and 0.3 kg of fuel.**



Heavy Oil is Expensive – and Dirty

- The total CO₂ release associated with products from tar sands is 60% more than that of conventional oil.



- Extra heavy oil (tar or oil sands) is very high in nitrogen compounds, sulfur, metals, tars, aromatics, resins, and dirt.

- It requires extensive clean-up, cracking, hydrogenation, hydro-isomerization, alkylation, and other chemical processing.

- The cost of the hydrogen required (from natural gas) to make usable fuels from heavy oil could add \$30/bbl by 2020.

- The cost of removal of other impurities (nitrogen compounds, metals, dirt...) from heavy oil is similar to the cost of the hydrogen.

- Much of the clean-up and chemical processing must be done at the resource site – where labor is extremely expensive.

- Heavy oil contributed 1% as much as conventional oil in 1995. It accounts for 5% of all oil today, and it may account for 10% of all oil by 2020.

- **The IEA recommended a tax on tar-sands products of \$50-60/bbl.**

Shale Oil is Even More Expensive

- The US oil shale resource is enormous, but that which can be economically recovered at under \$115/bbl is not.
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- Balancing costs and environmental concerns, the most promising process appears to be the Shell In-situ Conversion Process (ICP).
 - The veins need to be over 30 m thick, contain over 20 gal/ton, and extend for tens of acres.
 - The total CO₂ released from products from the first Shell ICP demonstration will be nearly twice that for conventional oil.
 - A recent estimate is that oil needs to be over \$130/bbl for ICP with on-site CO₂ sequestration to compete, except perhaps from a few choice sites.
 - **Shale oil is not expected to amount to even 1% of all oil by 2020.**
 - No low-carbon shale-oil projects (i.e., with 90% upstream CO₂ sequestration) are currently in progress.

Nuclear is not Competitive in the US

- 1 GW_E nuclear power plants today are being quoted at \$6B-\$12B.

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- There is no way to drive the costs down because the nuclear power-plant-construction industry in the US is effectively controlled by monopolies.
 - The next new nuke in the US won't be generating power before 2016.
 - Construction requires 20,000,000 on-site hours of skilled labor.
 - The upfront costs *alone* for nuclear energy today are *2 to 4 times those of wind energy after correcting for capacity factors*.
 - Fuel costs *alone* for nuclear energy could exceed the cost of wind energy 10 years from now.
 - The recent decision on Yucca mountain assures there will be no acceptable solution to the nuclear waste storage problem.
 - Breeder reactors might partially solve the waste disposal problem – but they will be **2 to 5 times** as expensive, have greatly increased risks, and they will not be available for at least 20 years.



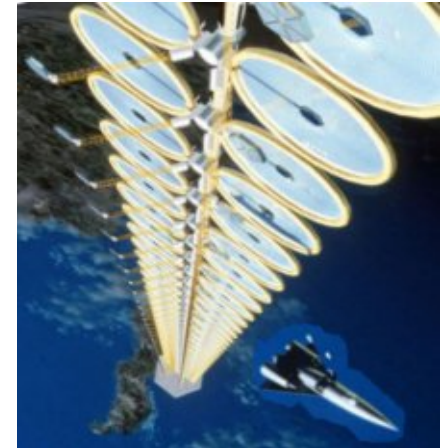
Liquefied Natural Gas (LNG) Will be as Expensive as Oil

- LNG demand will grow strongly because it has lower carbon and much lower processing costs compared to oil.
- **Global supply of LNG is about 250 MMT, or 12% of NG.**
- The spot price of LNG is likely to stay near the mean of propane and heating oil (~\$23/GJ in 5/2011) – not the costs of producing and transporting LNG.
- **LNG demand will grow faster than supply after 2013, and then the price of LNG will be similar to that for propane, which could make LNG over \$30/GJ by 2016.**
- The high value of LNG along with the high costs of GTL plants will slow the building of new methane-GTL plants (both for methanol and diesel production) within a few years.



The Space-Based Solar-Power Dream

- The last substantive studies, from the mid-1970's, concluded the in-space mass would be about 30 kg/kW of net power produced on earth. (The SBSP paper of 10/2007 contained no new substantive analysis.)
- **Progress in PV cells and other advances might allow an order of magnitude reduction in mass compared to estimates from the 1970's.**
- It is unlikely that launch costs for Geosynchronous Orbit (GEO) could be reduced below the average of the past two decades (\$30,000/kg), as fuel and materials prices will be 10 times higher.
- **Balance of system costs would likely exceed twice the launch costs.**
- It is highly unlikely the paper-thin (essentially unprotected) PV cells could have a lifetime in space of more than 10 years.
- **With the above assumptions, after correcting for capacity factor differences, SBSP energy would cost 200 times more than wind energy.**
- **If the system fails after one year, the energy would cost 2000 times that of wind.**



Electric Cars Have Major Limitations



Doty Windfuels

- Gasoline-electric hybrids are great, but pure electric vehicles (EVs) will not be accepted by many consumers in North America and most other markets.
- **The recent NAS/NAE/NRC study shows under 15% reduction in GHGs/mile from the use of electric vehicles compared to conventional cars by 2030.**
- The NAS/NAE/NRC study shows full life-cycle hidden and environmental costs for EVs are *worse* than for conventional gasoline vehicles.
- **Some Li-ion batteries for EVs in 2010 may have dropped to \$400/kWh, but all the companies have been losing an enormous amount of money.**
- **It took 15 years for the sales of hybrids in America to reach their current level of about 3% of all new car sales.**
- Electric cars accounted for 0.04% of car sales in the U.S. in the first quarter of 2011, and are unlikely to account for 2% of global new car sales by 2020.
- **The “Smart Grid” will have little impact until real-time electricity rates are available to most consumers – and that is probably still 10 years away.**

After a century of R&D, the chances of even a 40% improvement in cost-effectiveness of batteries over the next three decades are extremely low.

Reality on the Competition – in 2015

1. The price of LNG will be close to that for oil per energy content, which could make LNG over \$30/GJ – 10 times the cost of natural gas in 1998.
2. **Most high-grade cellulosic feedstocks will be \$300/ton – and they will be consumed by co-firing (wood pellets), domestic heating (logs), CHP, and cows (hays and other grasses).**
3. Carbon taxes on fuels from tar sands and coal could be \$60/bbl.
4. **Gasoline and diesel from many tar-sands projects will cost \$4 to \$7/gal.**
5. Nuclear power plants will be ~\$12B/GW – not even close to competitive.
6. **Solar will be contributing under 0.5% of the global electrical energy.**
7. Fuels from photosynthetic algae will cost \$60 to \$200/gal.
8. **The costs of hydrogen distribution, storage, and usage will still be 20-30 times those for liquid fuels.**
9. Low-carbon (fully sequestered) coal-to-liquids and shale oil will not compete if oil is under \$170/bbl.
10. **There are a few places around the world where a few GW of tidal power may be harvested – usually at a cost above that of nuclear power.**
11. Objective analyses will still conclude that conventional fusion and Space-Based-Solar-Power would cost over 150 times that of wind energy.
12. **Fewer than 0.5% of the cars being sold in America will be pure electric.**

Why Related Carbon-neutral Concepts are Failing

- The DOE's "Hydrogen Economy"
 - extremely expensive storage, distribution, and fuel cells
- Olah's "Methanol Economy"
 - toxic, not competitive, limited engine compatibility
- Pyrolysis-based bio-ethanol
 - expensive syngas feedstock and cleanup; poor plant designs
- Martin's "Green Freedom" (Nuclear Methanol)
 - or "how to make methanol more toxic and less competitive"
- Severinsky's Nuclear Diesel
 - nuclear; and inefficient RWGS reactor and separations
- Behren's Sea Fuels
 - extremely expensive, no climate benefit,...
- Electrolytic CO (Stoots, Newman,...)
 - extremely expensive electrolytes, inefficient, ...

Many details are available from WindFuels.com in separate publications.

A Better Idea



Synthesizing standard liquid fuels
(gasoline, jet fuel, diesel, ...)
from CO₂ and water
using off-peak wind energy

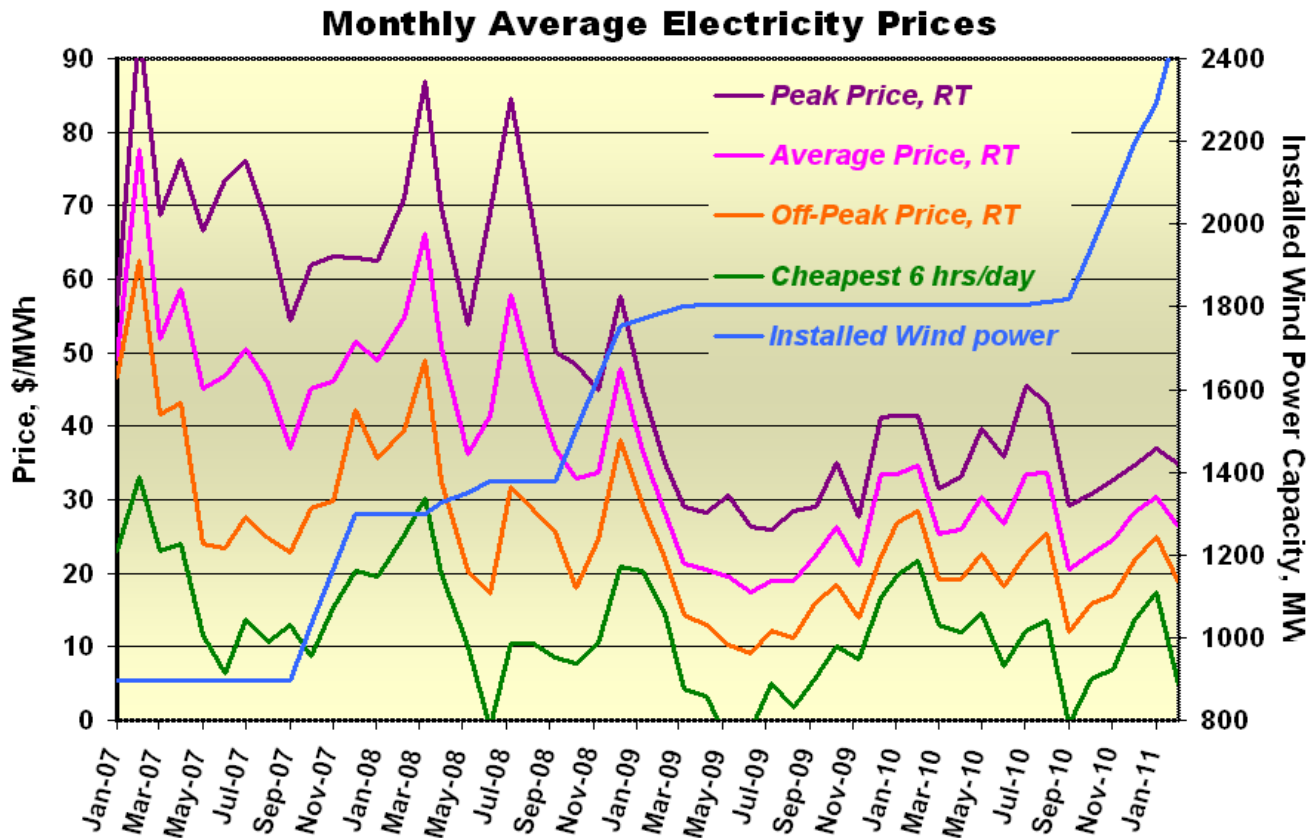
Build on Proven Chemistry

and improve the processes.

**Start with renewable H₂ and CO (from CO₂)
instead of from coal or methane.**

**A truly sustainable solution to the energy
storage, transportation fuels, and climate
challenges.**

The WindFuels Opportunity



4 to 20 times more fuel per acre than biofuels.

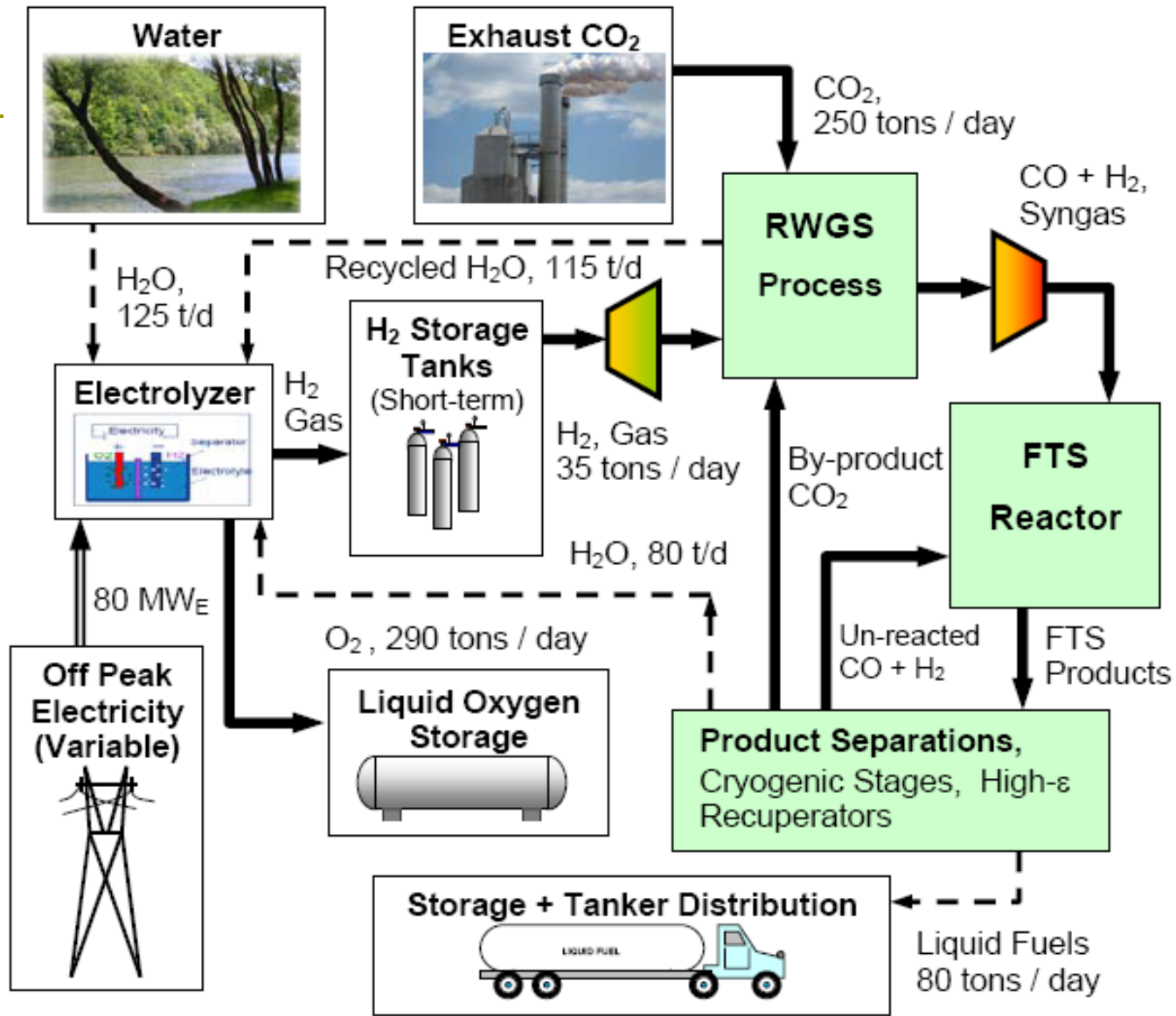
(PV: \$200/MW hr.)

Off-peak wind: \$15/MW hr.)

As more wind is added to the grid, off-peak energy is rapidly becoming very cheap. It is already sometimes free!

WindFuels will be cheaper than tar sands, coal to liquids, or cellulosic ethanol – and **much** cheaper than algae-oil.

WindFuels – Concept Overview



WindFuels ... Hydrogen's daughter



The path we have outlined builds on the best concepts and developments of the “hydrogen economy” visions.

- It starts with sustainable, clean, efficient production of hydrogen from cheap, off-peak wind energy.
- The solution is to put the hydrogen into synthetic fuels that merge seamlessly into our existing energy infrastructure, but this must be done efficiently enough that it can immediately compete with fossil fuels.
- The other big difference from the hydrogen-economy vision is the realization that the most cost-effective source of clean hydrogen is not nuclear breeder reactors, but off-peak wind energy – at least for now, and probably for at least 35 years.

The Major Technical Advances

- Nearly a **factor of two increase in the efficiency of production of syngas** from water and CO₂.
- An **order of magnitude reduction in the losses seen in recycling** of the unreacted Fischer-Tropsch (FT) reactants (H₂, CO₂, CO).
- An order of magnitude **advance in cost-effectiveness of gas-to-gas recuperators** with high thermal effectiveness (up to 97%).
- **Advances in the catalysts.**
- **Optimized plant integration.**
- A **50% improvement in efficiency of conversion of waste heat** from the FT reactor and electrolyzer to electricity.

WindFuels Economics – The Basics

Even without cap-and-trade or the Investment Tax Credit, WindFuels can compete when oil is as little as \$60/bbl.

- At \$10/MW hr, the wind energy cost in jet fuel or gasoline will be under \$0.75/gal – and for ethanol (91 MJ), about \$0.50/gal.
- The CO₂ (\$75/ton) might initially cost ~\$0.70 per gallon of product, but eventually it will be nearly free.
- The co-produced (nearly free) liquid oxygen (LOX) may be worth up to \$1 per gallon of liquid fuels produced.
- **Pay-back on the RFTS plants could be under 2 years.**
- Mid-term assumptions: mean wind energy cost of \$2.8/GJ (\$10/MW hr); electrolysis efficiency of 72%; RFTS plant efficiency of 70% HHV; conversion of electrolysis and FTS waste heats at 58% of Carnot limits; 50% net system HHV efficiency.

A Realistic Energy/Climate Plan

The Sustainable-Grid Energy Mix in the U.S. in 2040

- **Natural Gas (currently 21%), drops to 20%, mostly peaking.**
- **Nuclear (currently 20%), drops to 17%, mostly base-load.**
- **Coal (currently 46%), drops to 16%, mostly for peaking.**
- **Hydro (currently 6%), grows to 8%, used mostly for peak.**
- **Diesel (currently 2%), grows to 4%, all for peaking.**
- **Biomass (currently 1.4%), grows to 2%, mostly for peak.**
- **Geothermal (currently 0.4%), grows to 1%, mostly peaking.**
- **Solar (currently ~0.1%), grows to 2%, all for peaking.**
- **Wind (currently 2.0%), grows to 30% of the grid (mostly off-peak), plus 40% of our transportation fuels.**

The market generated by *WindFuels* for off-peak grid power allows wind to maintain its rapid growth and to reduce our dependence on foreign oil.

The Primary WindFuels Challenges

- The Agrofuels industry and lobby
- Lack of appreciation for the looming oil crisis
- Disinformation on promises of current “alternatives”
- Extreme risk aversion by investors and the DOE
- Turf protection by established researchers
- Very little process design is currently supported
- Closed-mindedness amongst many energy experts
- The needed developments are not “sexy” sounding
- NIH (Not Invented Here) attitude

*None of the WindFuels **technical** challenges compares to the above non-technical challenges.*

Summary



Emphasis on biofuels will impoverish our nation and the world.

“Advanced biofuels” will not be much more practical.

- When the last coal power plants are shut down in 2090, some of the CO₂ needed for *WindFuels* may have to be extracted from the atmosphere. Our children will be able to do this separation economically. At that point we'll see our net fossil CO₂ release go essentially to zero.
- The sooner we begin directing resources toward *WindFuels*, the sooner we can rest assured that our transportation fuel, agriculture, civilization, and climate are secure for future generations.

Thank you for your attention.