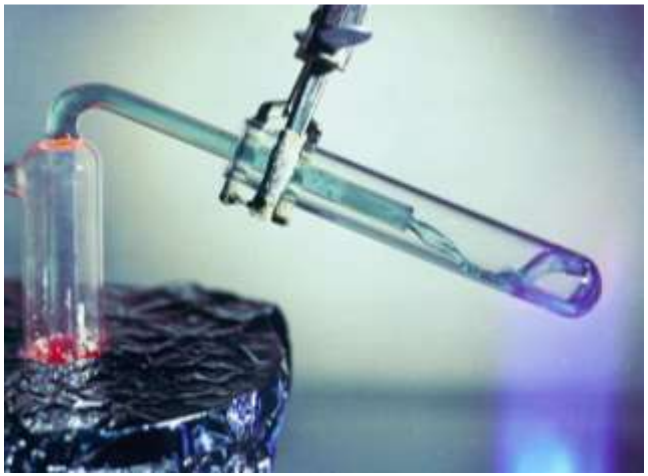
Nuclear Ammonia - A Sustainable Nuclear Renaissance's 'Killer App'



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8TH Annual NH3 Fuel Conference 19-21Sep11, Portland OR

We need non-fossil energy sources ASAP.

The immediate US problem is oil – mostly used for transportation.

Ammonia can fuel vehicles requiring range and power that cannot be provided by batteries.

Ammonia fuel produced from sustainable nuclear energy would be cheap and “green” forever.

“Kicking the can down the road” will kill our grandkids

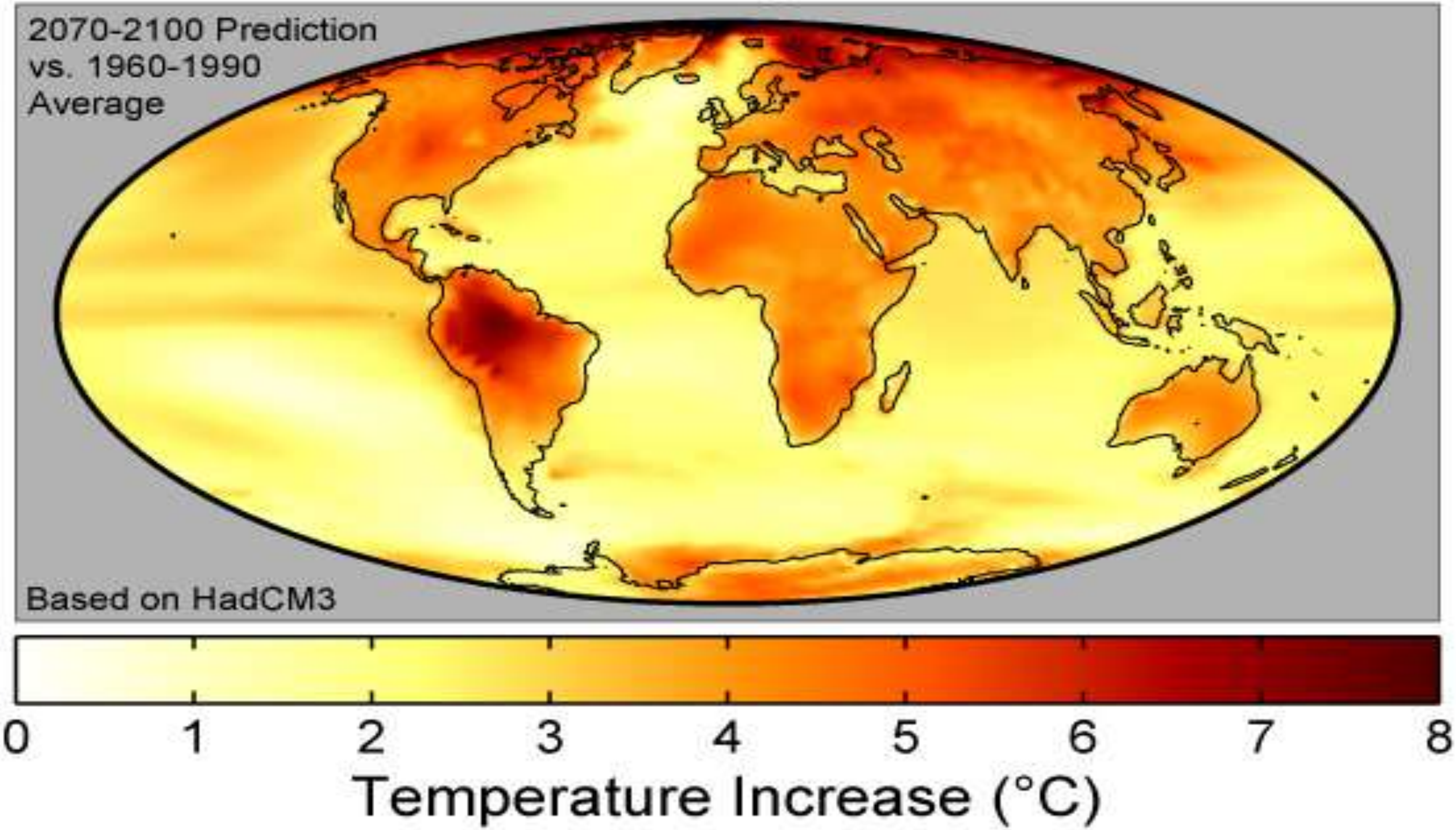
- If we wish to preserve a planet similar to that on which civilization developed and to which life is adapted, paleoclimate evidence and ongoing climate change suggest that CO_2 needs to be reduced from its current 385 ppm to at most 350 ppm
- Phase out of emissions from coal/oil is itself an enormous challenge. However, if the tar sands are thrown into the mix ***it is essentially game over***
- Our government’s target to limit global warming to 2°C, is a recipe for global climate disasters, not a “guardrail"

James Hanson, June 2011
http://www.columbia.edu/~jeh1/mailings/2011/20110603_SilenceIsDeadly.pdf

We could have an "Arab Spring"

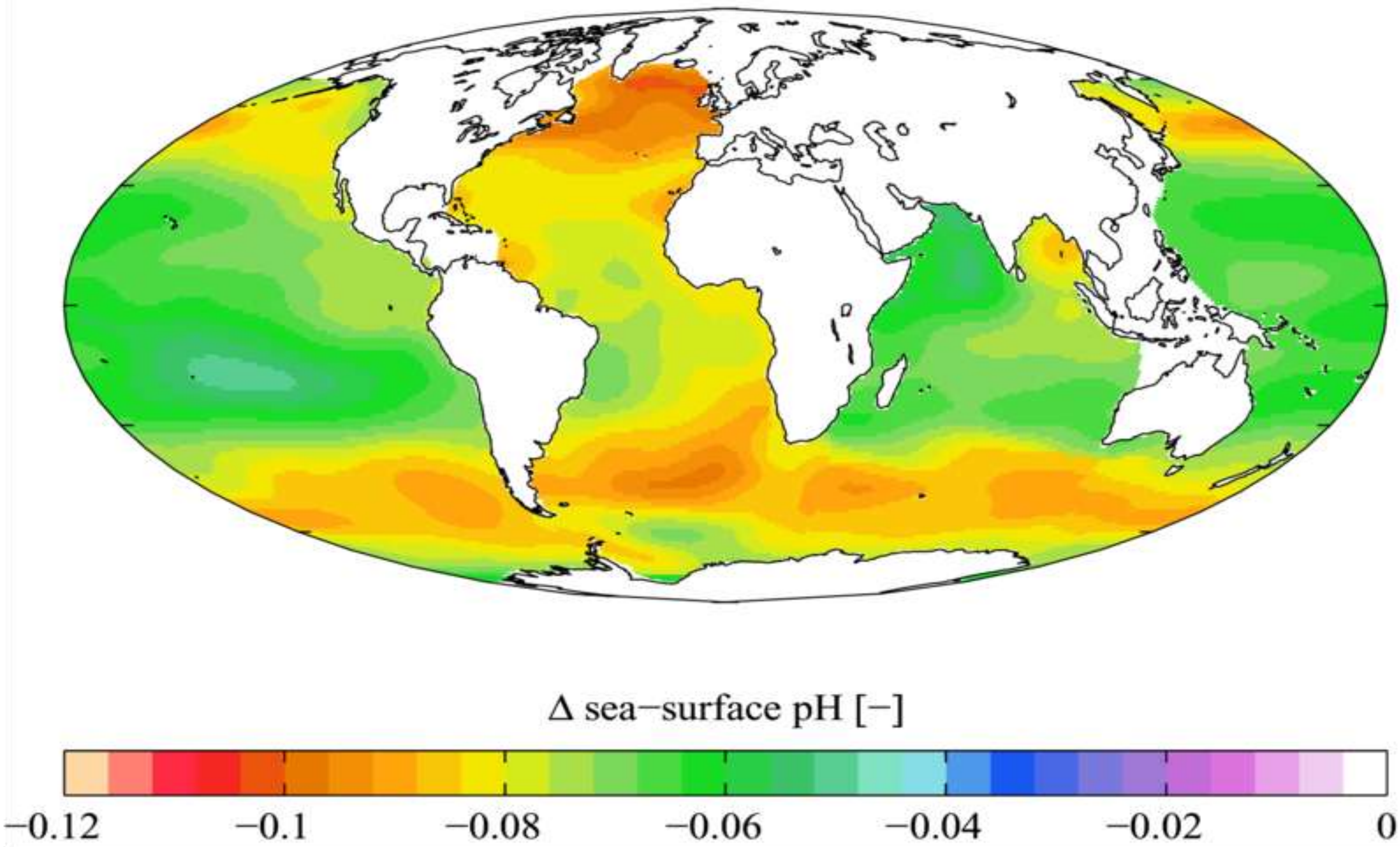
- America's "new poor" is yesterday's "middle class"
- 40% of this country's black children now live in poverty
- 33% of this country's "hispanic" children now live in poverty
- Millions of college graduates can't find jobs
- Increasingly "unusual" weather is costing US citizens hundreds of $billions/a
- Well-heeled established/special interest groups (e.g., "big" oil, gas, coal, etc.) set government policy to protect their fiefdoms/technologies

Global Warming Predictions



“Point of No Return” is <u>under</u> 2ºC

Anthropogenic Change in Ocean pH 1700s-1990s



"Business as usual" will kill off much of the ocean's life by 2100

Technology policy lies at the core of the climate change challenge.

Prof. Jeffrey Sachs
Economist, Columbia University
Director of The Earth Institute

http://www.sciam.com/article.cfm?id=technological-keys-to-climate-protection-extended

"If we try to restrain emissions without a fundamentally new set of technologies, we will end up stifling economic growth, including the development prospects for billions of people.

"We will need much more than a price on carbon.

"…technologies developed in the rich world will need to be adopted rapidly in poorer countries.

90% of the stuff we use is fuel

material	***Mtonnes/a (% Imported)***
aluminum	3.25 (45%)
ammonia	22 (45%)
plastics	28 (?)
steel	93 (25%)
cement	100 (20%)
nat gas	**403 (19%)**
coal	**858 (2%)**
oil	**984 (71%)**
∑fuels/total	**90.12%**

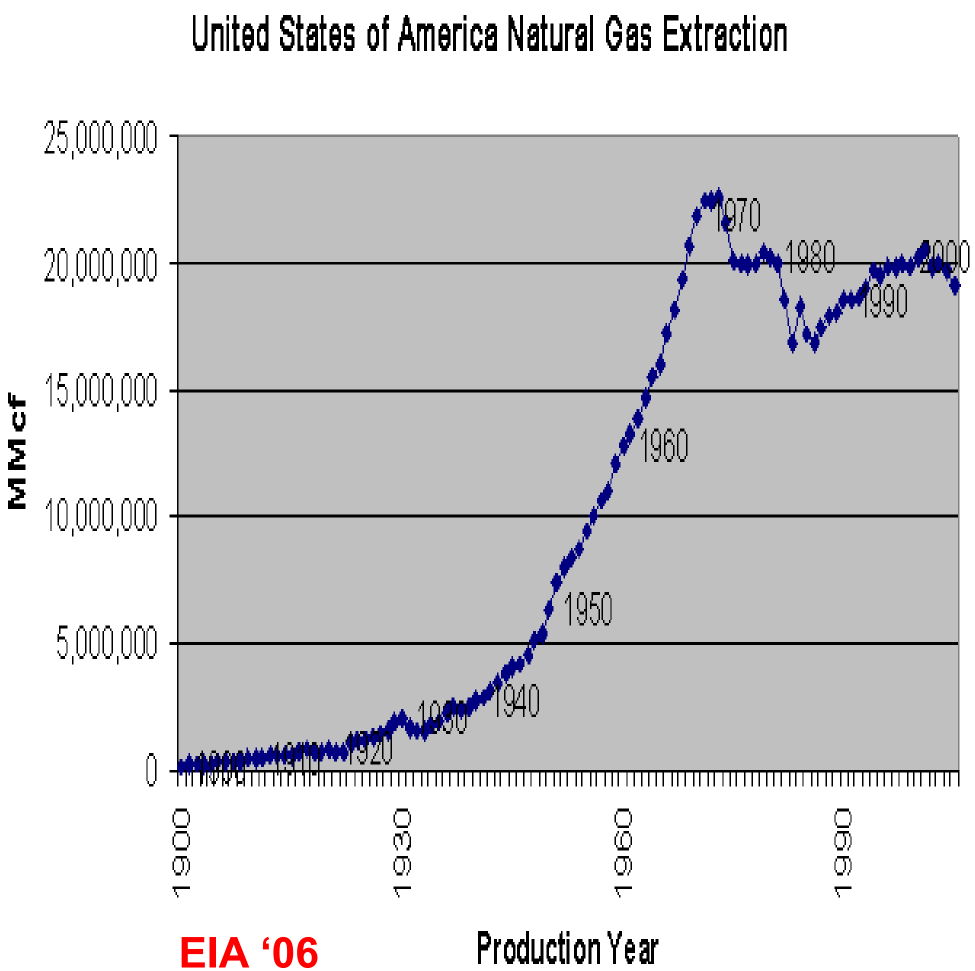
coal will soon run out.

- Proven world coal reserves = 843 gigatonnes [EIA 2006]
- At current consumption rate, would last 132 years
- At 2.5% increase/year, it'll last until 2065

shale "oil" will soon run out.

Total world kerogen reserve ~500 gigatonnes
(~3/5ths that of coal) DOE 2006

GAS WILL SOON RUN OUT



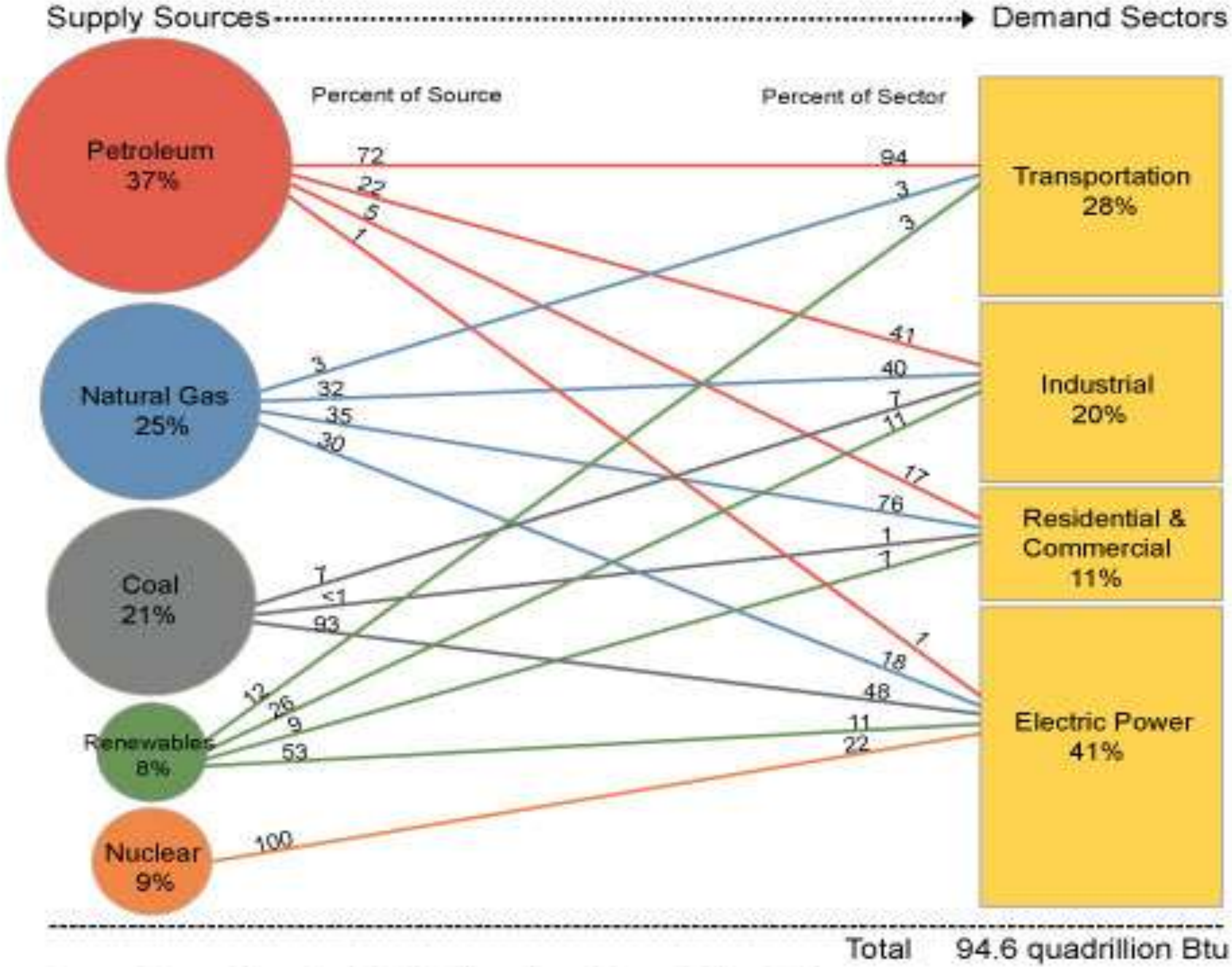
EIA '06

- Not enough (~350* quads)
- The "vast deposits of clean American gas" require hydofracking, which…
- requires the injection of vast amounts of water and "chemicals"
- 30-70% of which plus any leached salts eventually ends up back on the surface and/or in the water supply

Oil will run out first

- Proven world oil reserves = 243 gigatonnes [EIA 2010]
- At current consumption rate(89 million bbls/d), would last 53 years
- At 2.5% increase/year, it'll last until 2045

USA ENERGY



Source: Energy Information Administration, *Annual Energy Review 2009*

The Costs of Addiction

The US produces only ~91 of the ~260 billion gallons of petroleum used/a

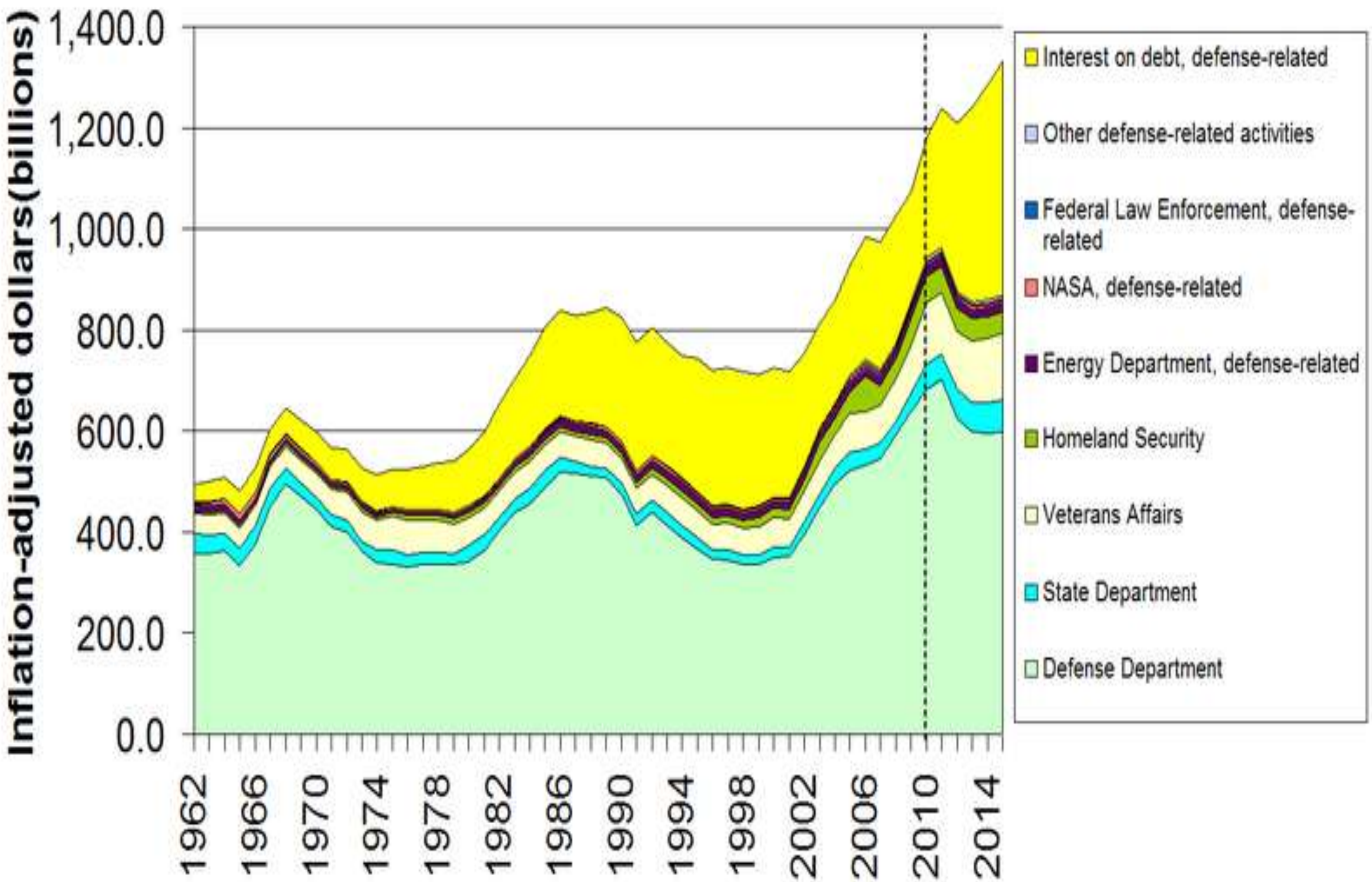
We pay ~$400 billion/a for imported oil

From 1976 to 2007 we spent $7.3 trillion to “maintain a US presence” in the Persian Gulf

http://www.foreignpolicy.com/articles/2010/08/05/the_ministry_of_oil_defense

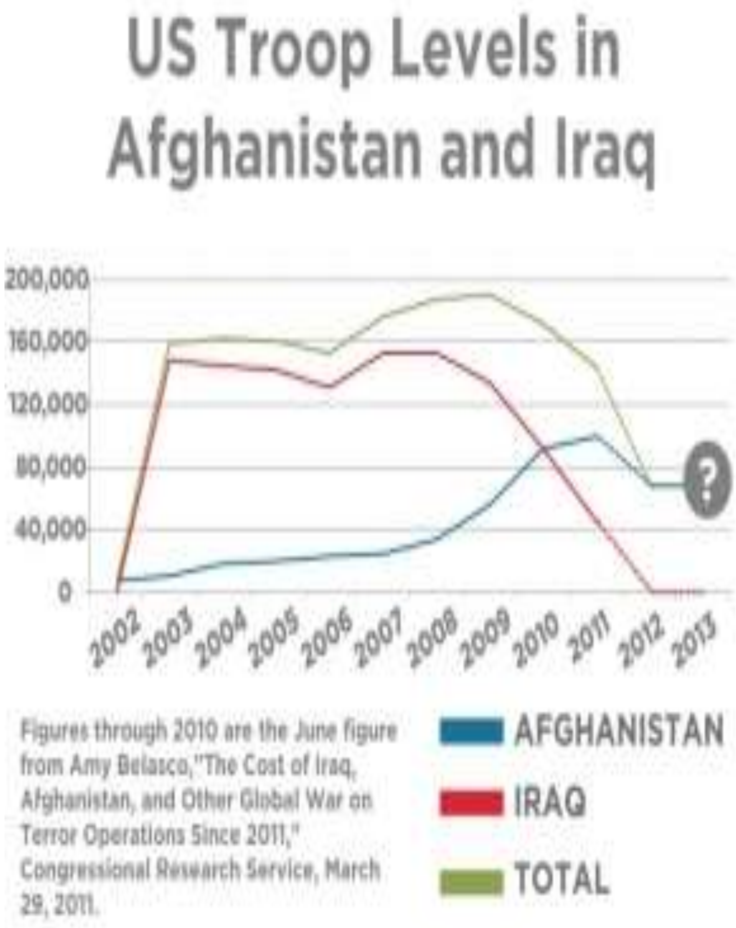
And…

Costs continued



And…

Post-9/11 COST OF "MAINTAINING PRESENCE"*



- **225,000 killed including >6000 US troops & ~24,000 of their allies"**
- **$3.2- 4 trillion (US only)**
- **550,000 VA disability claims**
- **Empowerment of the "military industrial complex" & creation of a huge "Homeland Security" bureaucracy - Loss of civil liberties etc.**
- **Devastated economies – Iraq, Afghanistan, <u>and now ours</u>**

*http://costsofwar.org/

RESOURCE WARS?

In 2003 and again in 2010, Pentagon studies concluded that the greatest danger posed by global climate change is not the degradation of ecosystems per se, but rather the disintegration of entire human societies, producing wholesale starvation, mass migrations and recurring conflict over resources

We must ***implement*** the production of "green" synfuels ASAP

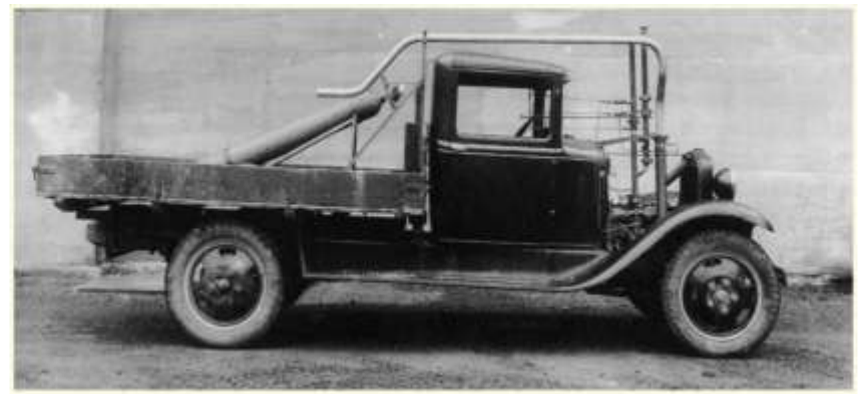
Is DOE on the right track?

“At this point, virtually everything associated with the production, distribution, and onboard storage of hydrogen for personal transportation use faces significant barriers“

Review of the Research Program of the FreedomCAR and Fuel Partnership: First Report (NRC/NAE 2005)

Most of the synfuel should be "Nuclear Ammonia"

- **Absolutely "Green"**
- **Energy dense – liquid at ambient temperature and moderate pressure**
- **Possesses about one-half of the energy density of gasoline (same as methanol) and has 50% more energy volume-wise than liquid hydrogen**
- **Can be used directly in fuel cells, internal combustion engines (ICEs), and combustion turbines - conversion is straightforward**
- **Easy to store, deliver, and dispense - extensive infrastructure already exists**
- **No "great leaps of faith" required**



The rest is “NUCLEAR HYDROCARBON”

Special/small engine apps & aviation will still require CH_x-based fuels

It’s possible to synthesize CH_x (methanol, DME, diesel, etc.) from “nuclear” hydrogen & any carbon source

•There wouldn’t be enough cheap biomass to implement it with “renewable” carbohydrate/fat C (food vs fuel conundrum)

•Collecting sufficient CO_2 from the air going through nuclear reactor cooling towers (e.g., LANL’s “Green Freedom”) is apt to be difficult

Close-coupling nuclear reactors with cement/lime kilns would be far more practical & equally GHG-neutral

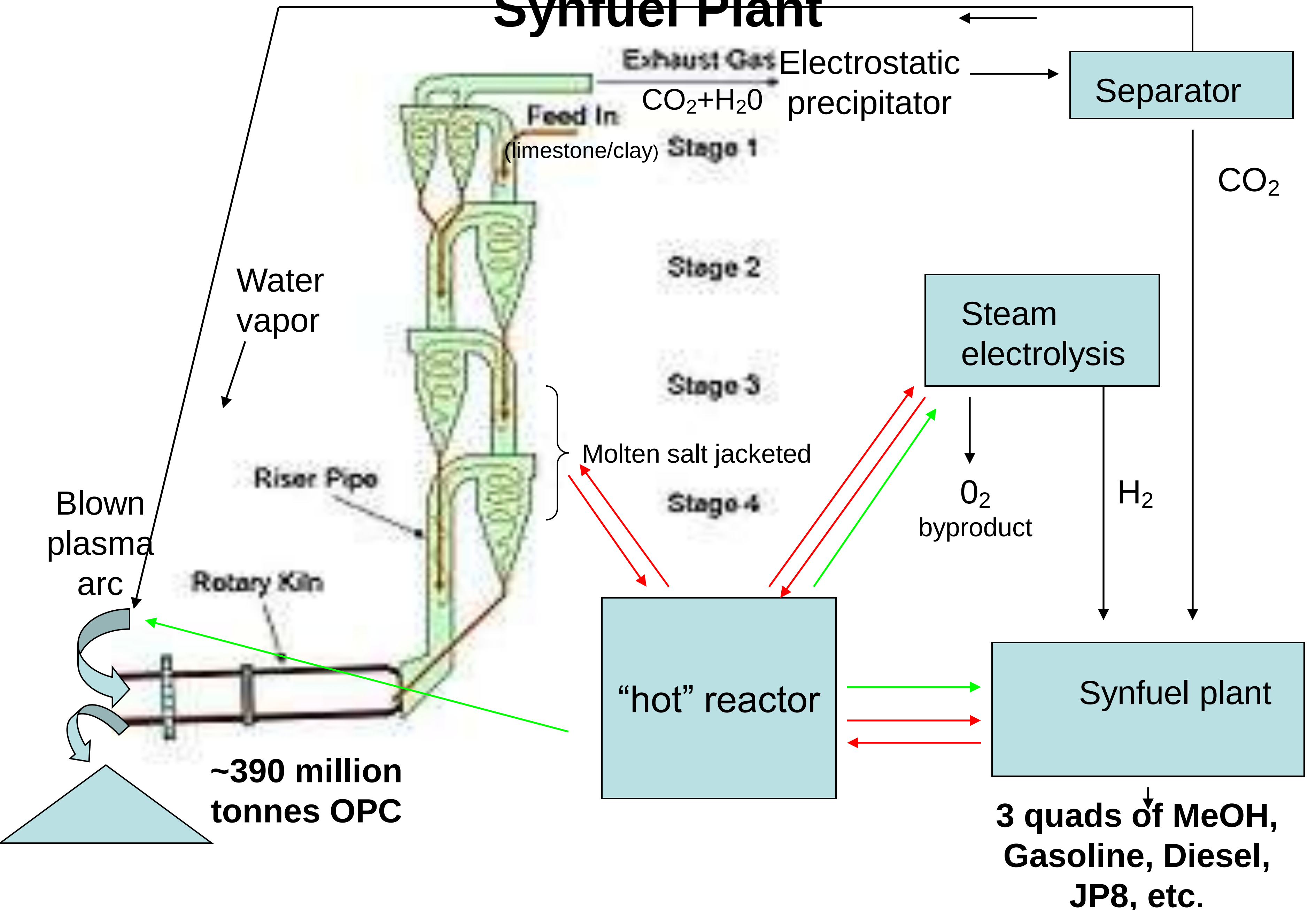
however

The US wouldn’t need enough cement/lime to provide the carbon required to make <u>all</u> of the synfuel it’s apt to need

HOW MUCH?

	quads 2011	% total oil	quads 2050	synfuel
cars	16.7	42.3%	16.7/2	NH_3
freight	7.14	18.1%	7.14/2	NH_3
aviation	3.39	8.6%	3.39/2	CH_x
industrial	9.66	24.5%	2	NH_3
agriculture	0.7	1.8%	0.7	NH_3
military	0.62	1.6%	0.62	CH_x
other	1.30	3.3%	1.3	CH_x/NH_3
	total quads NH_3 =		**15.27**	
	total quads CH_x =		**2.96**	

Nuke-Powered Cement Kiln/Carbonaceous Synfuel Plant



Why “GHG neutral”?

- **Lime/OPC based concretes inevitably absorb CO_2 from the atmosphere**
- **That process increases their strength but lowers their pH**
- **pH lowering is “bad” only if/when embedded rebar corrodes (a fundamental weakness of today’s concrete structures)**

Solution?

Use a more durable (& cheaper) rebar material

Basalt Fiber Concrete Rebar

1. Higher specific strength - one ton of basalt rebar replaces 9.6 tons of steel
2. Far more resistant to corrosion/deterioration
3. Same coefficient of thermal expansion as concrete
4. No permanent deformation when bent
5. Chemically inert, compatible with concretes having different pH

http://pulwell.en.alibaba.com/product/211051519-200709139/Basalt_fiber_rebar_BFRP_rebar_composite_rebar.html

It'd be very cheap to make with Nuke power

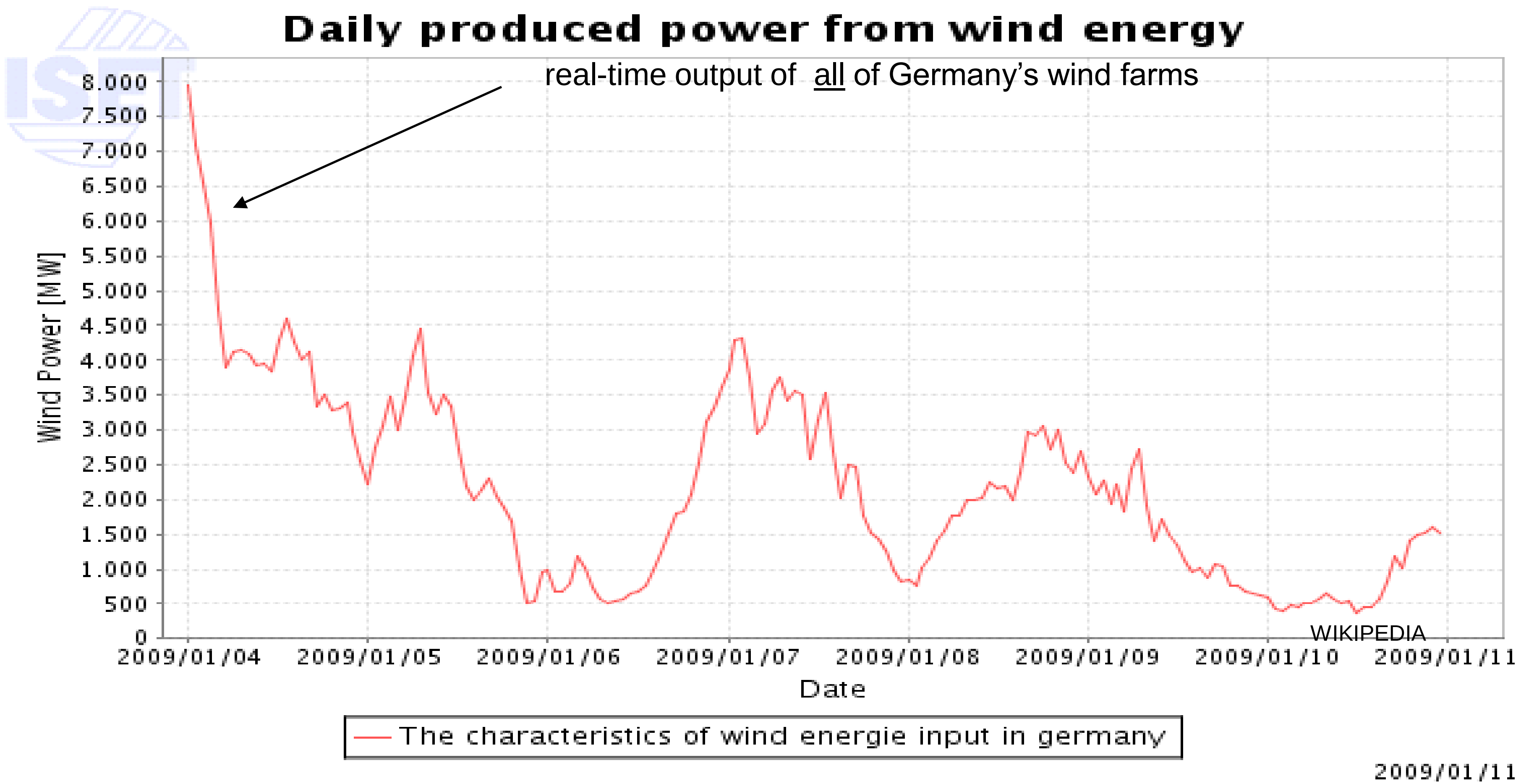
“renewable” energy sources couldn’t produce enough synfuel

	US quads ('09)	*comment*
solar	0.11	unreliable
wind	0.7	unreliable
geothermal	0.37	not renewable
biomass	3.88	maxed out
hydro	2.68	maxed out

Estimated requirement = 18.3 quads

That’s why we need a “nuclear renaissance”!

ONE REASON WHY YOU CAN'T RUN A FACTORY WITH WIND POWER



Average power ≈ 20% of nameplate capacity (22.8 GW)

HOW MUCH SYNFUEL cont.

- **At 22.5 kJ/g, 15.27 quads/a worth of ammonia corresponds to 715 million tonnes - about 35 times the USA's current consumption & 60 times its current production**
- **At 145k BTU/gal, 2.965 quads/a of CH_x synfuel* corresponds to ~20.4 billion bbl/a (vs today's ~260 billion/a)**

***The CO_2 going into CHx will be scrubbed from the off gas of close-coupled nuke-powered cement plants (~390 million tonnes OPC/a)**

How much nuke power would be needed?

Ammonia: John’s (Holbrook’s) ~6800 KWhr/ton processheat-assisted SSAS energy requirement fig. corresponds to 0.833 Joule’s worth of NH_3 fuel heat per joule electrical input, so…

- **15.27 quads/a of fuel ammonia would require 15.27/0.833 quads = 1.93E^{19} J/a of electricity…**
- **which corresponds to 6.13E^{11} J/s …**
- **which corresponds to ~613 full-size (~1 GWe) reactors**

How much nuke…cont.?

CH_x: LANL's "*Green Freedom*" analysis suggests that 1 joule's worth of a reactor's <u>thermal</u> power could produce ~0.4 joule's worth of "gasoline", so…

- **2.965/0.4 quads/a corresponds to 2.48E^{11} J/s (watts)…**
- **which would require another ~100 full-size reactors**

How much nuke…cont.

I'm not through yet because our descendants must also reindustrialize their country (reverse our generation's "outsourcing") and repair/replace a good deal of its crumbling infrastructure

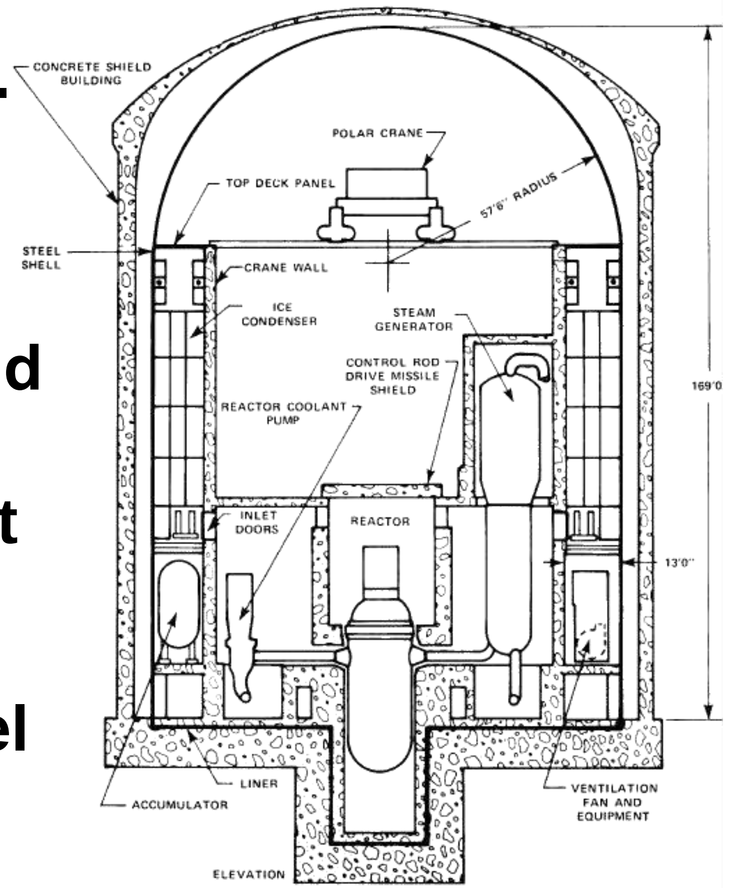
today's US non-transport energy use = 57.4 quads/a ≈ 820 full-size reactors

Consequently

They will need at least 1500 big reactors

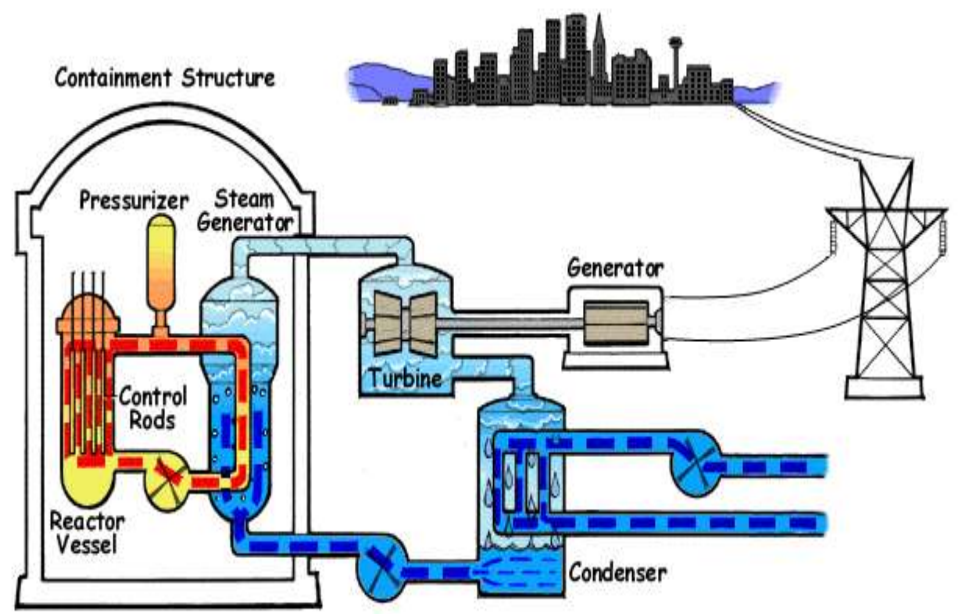
The Nuclear Path Taken…

- **the civilian nuclear industry developed as it did because Adm. Rickover chose Light Water Reactors (LWRs) to power his submarines**
- **LWRs burn ^{235}U not "uranium" and are therefore not sustainable**
- **DOE is <u>not</u> investing a significant fraction of its resources to developing either of two possible genuinely sustainable nuclear fuel cycles**

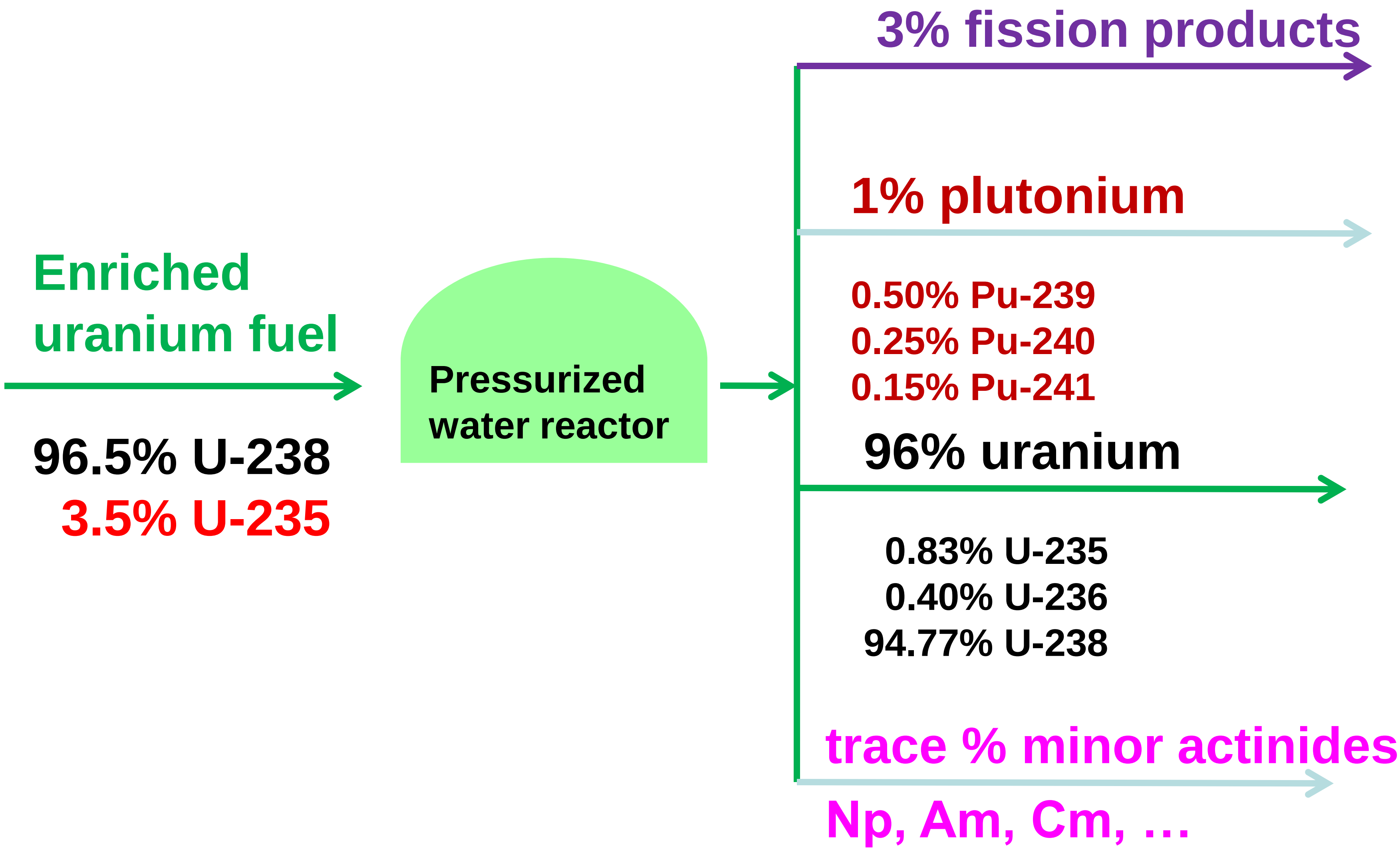


What's wrong with the nuclear industry's "light water" reactors?

- **Too expensive to build (extreme operating pressures require massive containment vessels)**
- **Too expensive to fuel due to poor thermal efficiencies, limited fuel assembly lifetimes, & intrinsically expensive/politically problematic fissile (requires "enrichment")**
- **Too "dirty" - spent LWR fuel contains enough plutonium and other TRU to render waste management problematic but not enough to make reprocessing ("recycling") worthwhile**
- **Unsustainable - fissile material is ^{235}U (not "uranium") & they don't breed enough plutonium to refuel themselves**



Today's reactors use only 3% of their fuel's potential energy

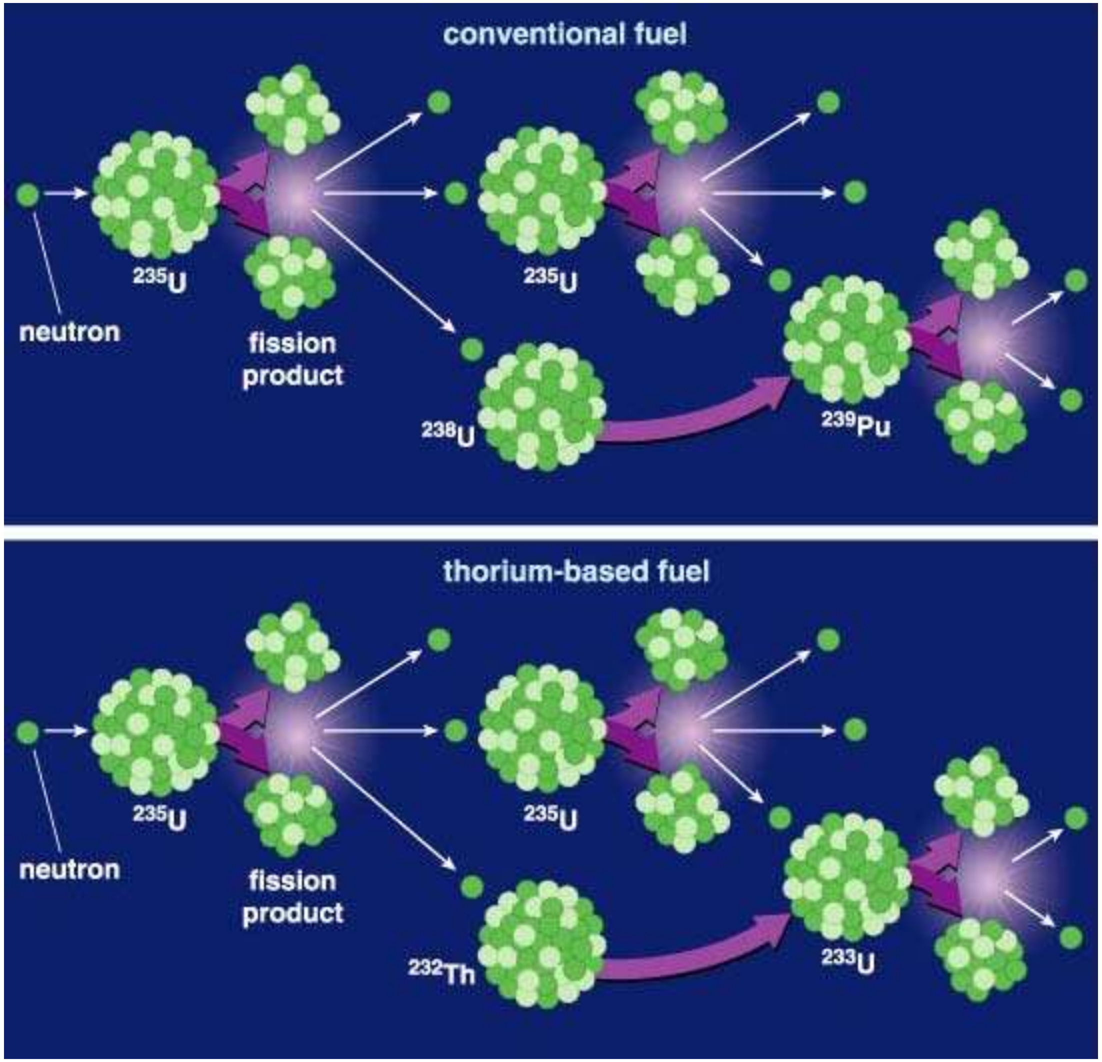


Is there "Plenty of Uranium"?

According to the NEA/IAEA "Red Book" there is about 16 million tonnes of natural uranium available at a "reasonable" price*. Since Mankind would need about 10,000 GWe's worth of nuclear generating capacity to become totally "green" and once-through reactors consume ~200 tonnes of raw uranium/GW_e-yr, 16 million tonnes corresponds to an <u>8-year</u> fuel supply.

*http://www.ne.doe.gov/neac/Meetings/June92009/ANTT_Final_report_209_meeting.pdf

Breeder reactors are also “renewable”



Relative Amounts of Nuclear Fuel in the World

LFTR

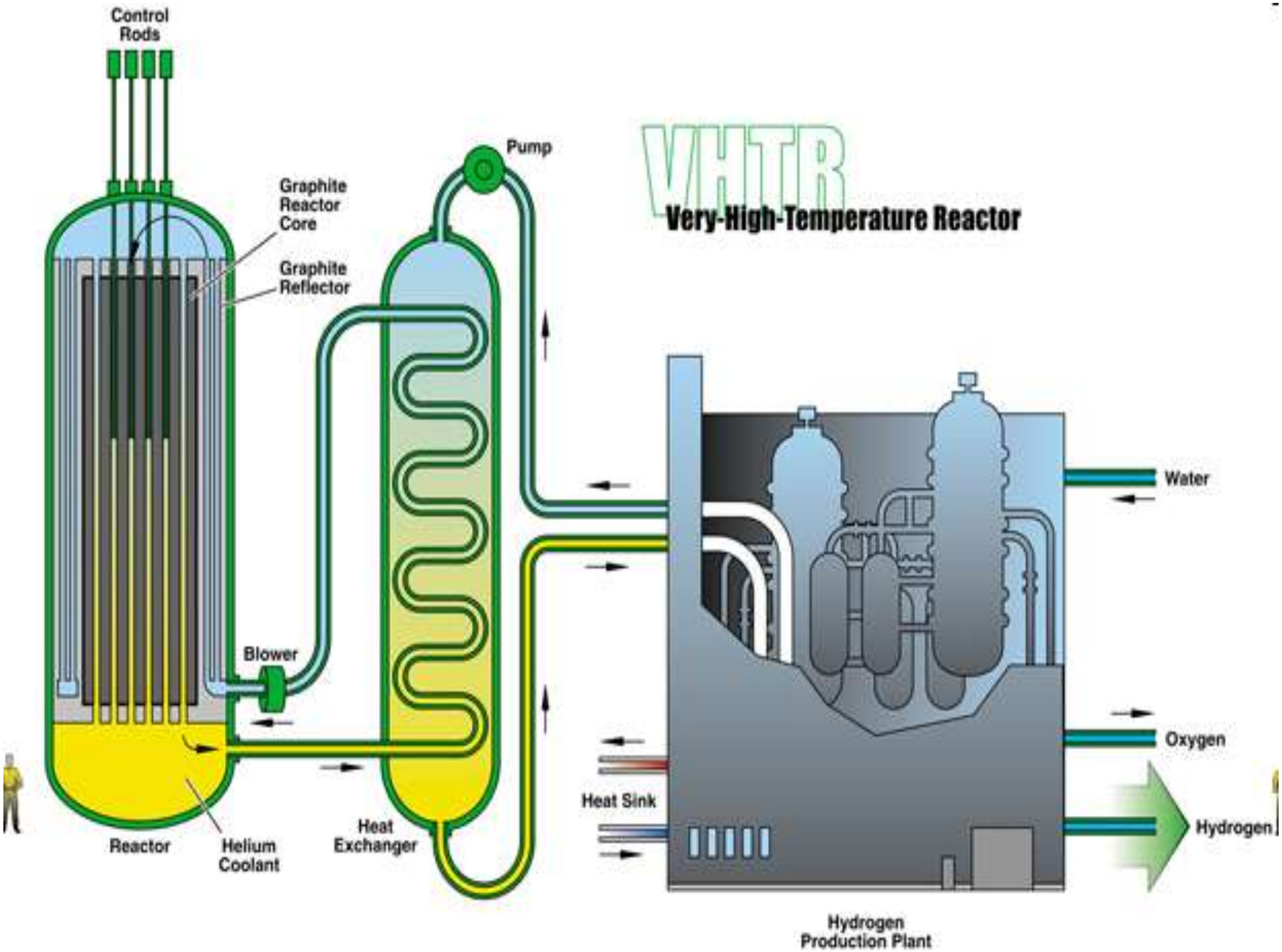
Today's & most of DOE's "GEN IV" reactors

LMFBR (IFR)

Is DOE on the right track?

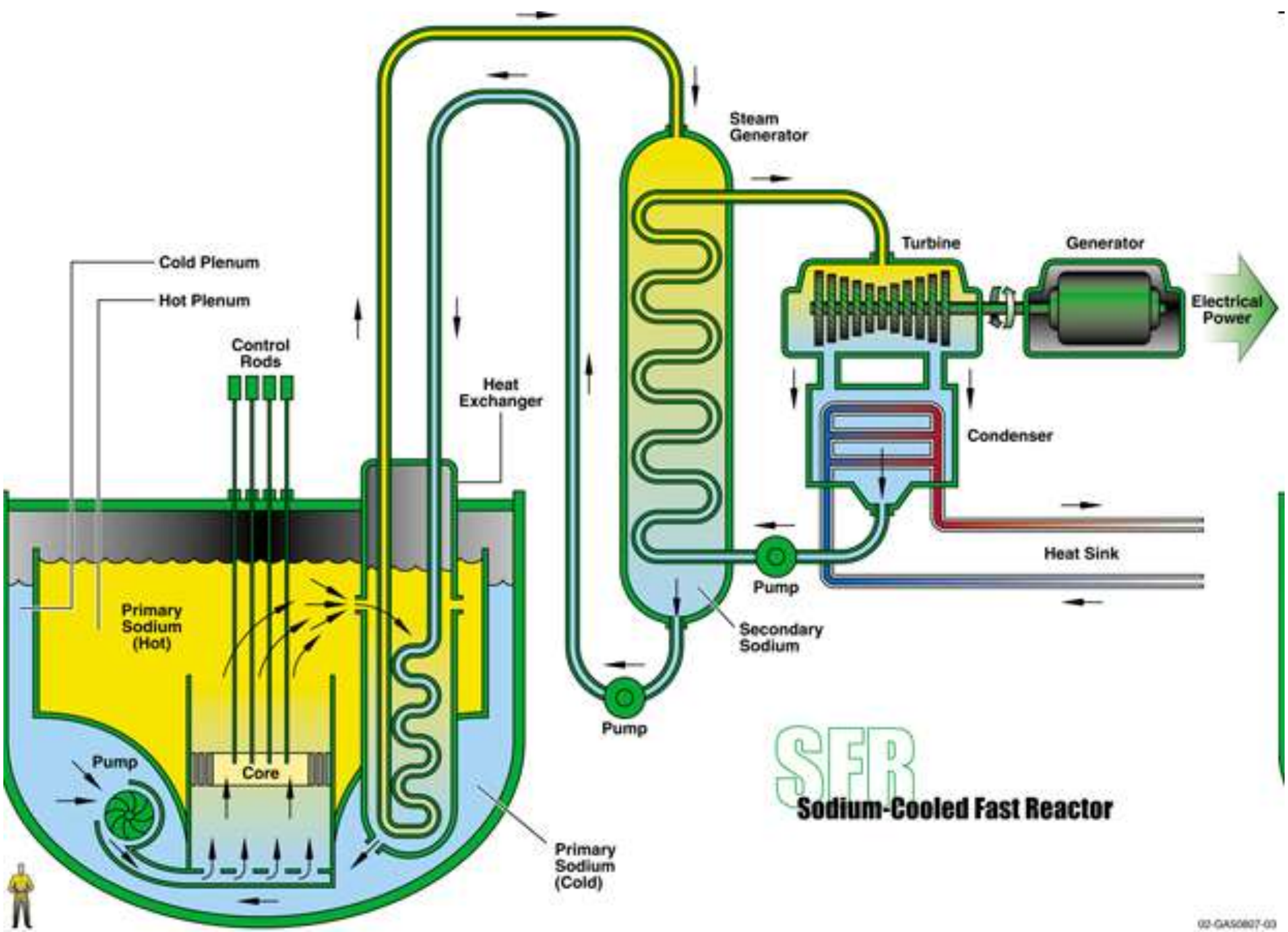
NO!

- **Wrong reactors**
- **Wrong fuel cycles**
- **Too little**
- **Too late**



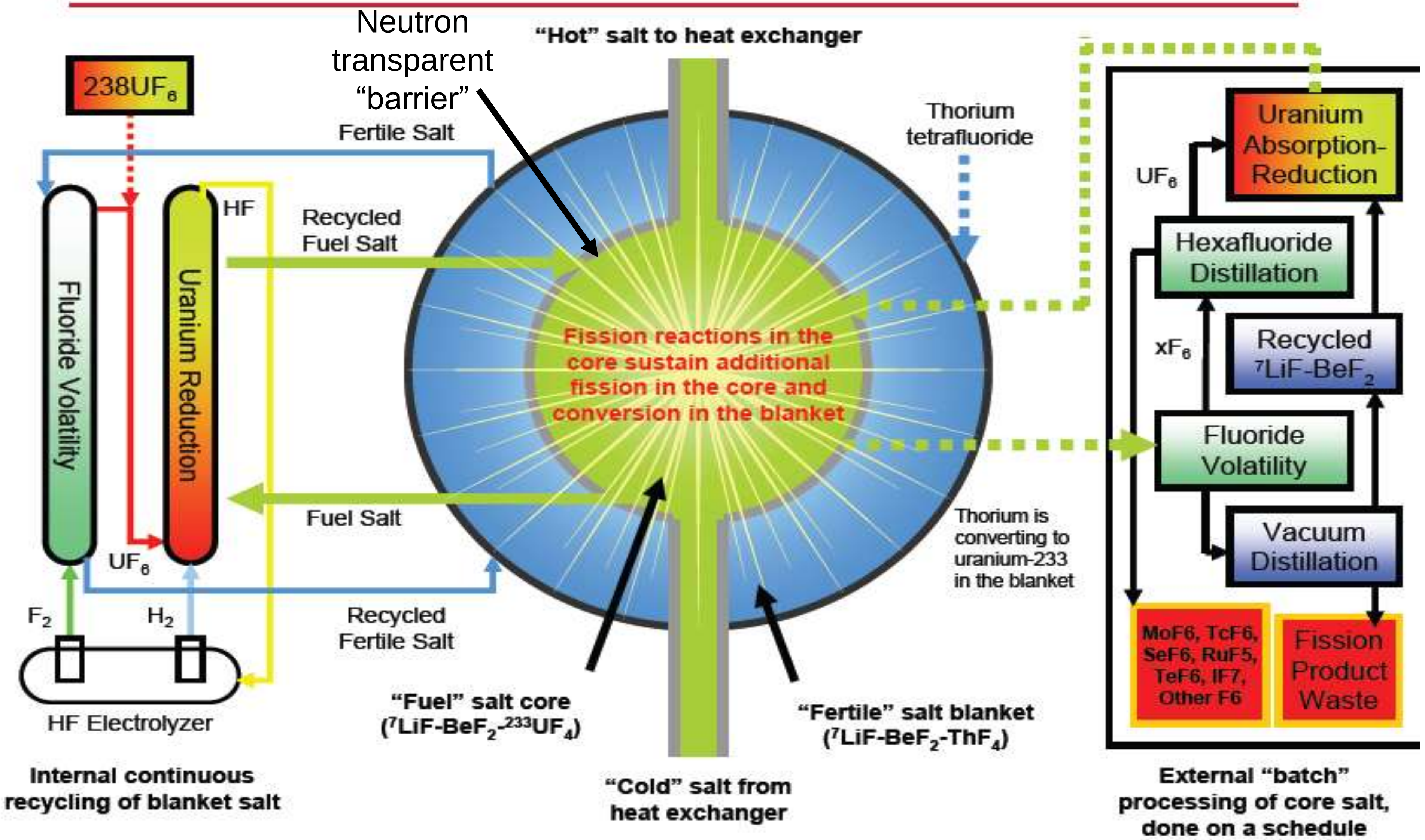
DOE/INL's front-running Gen IV option (aka NGNP)

Another ^{235}U burner - non sustainable

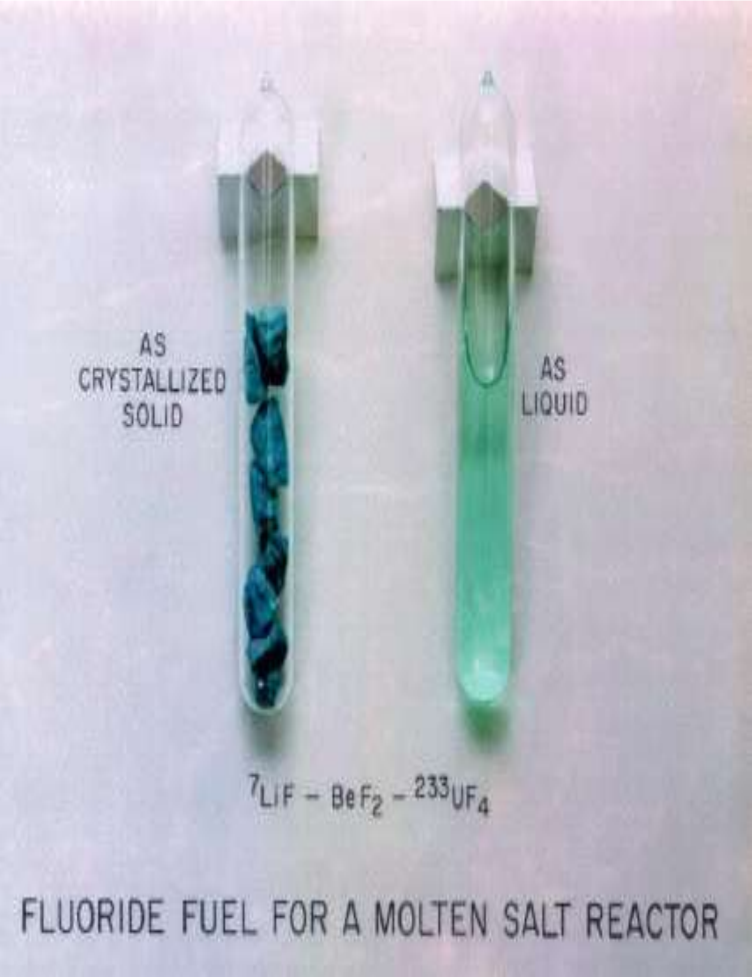


DOE/INL's runner-up GEN IV candidate - a "burner" not a breeder - **if reconfigured, it could become a <u>L</u>iquid <u>M</u>etal <u>F</u>ast <u>B</u>reeder (of plutonium from ^{238}U) <u>R</u>eactor (aka IFR)**

A better breeder – the Liquid Fluoride Thorium Reactor (LFTR)



What makes LFTR different?



1. **Liquid fuel**

   Both fission and "breeding" take place in stable, low viscosity, low vapor pressure liquids which are **CONTINUOUSLY** circulated through heat exchange & purification modules

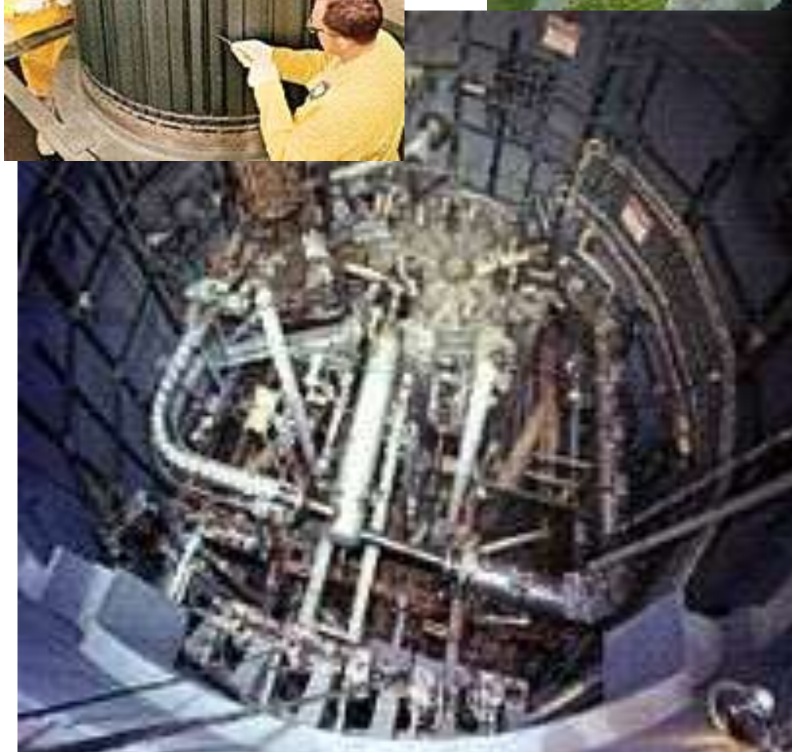
2. **Thorium-based**

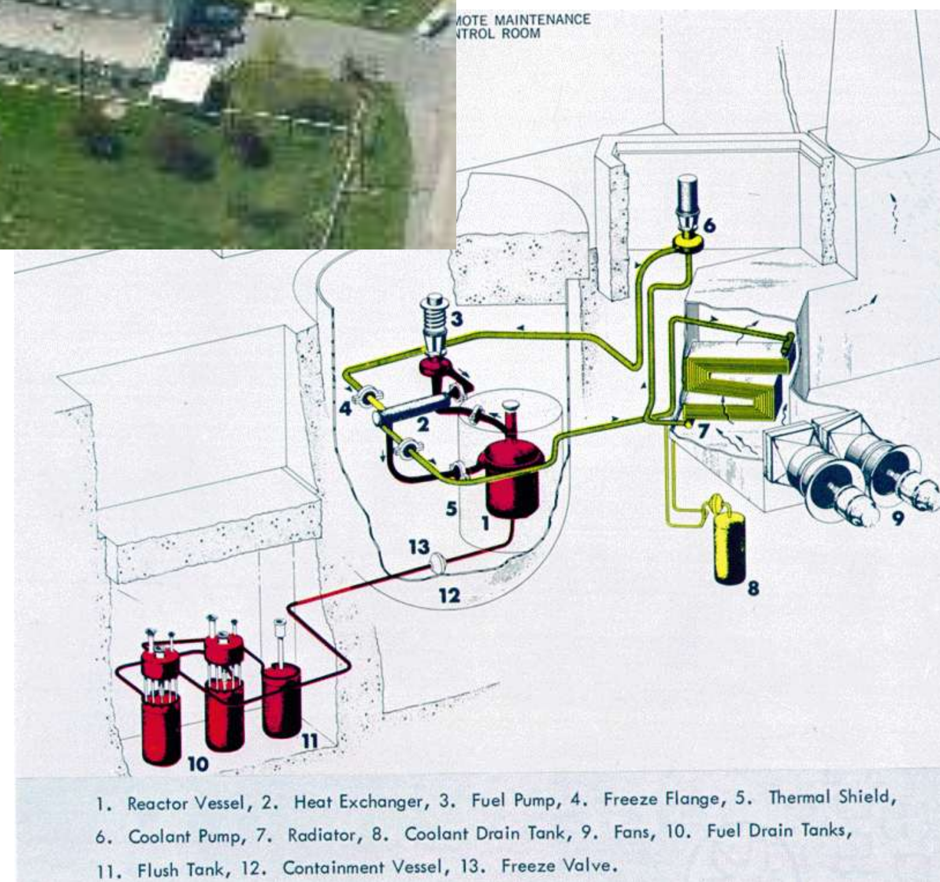
   The material "burned" is ^{233}U obtained by continuously breeding ^{232}Th. Since it is not a practical material for nuclear weapons, the AEC devoted much less attention to it than the $^{235}U/^{238}U \rightarrow ^{239}Pu$ breeder cycle

3. **"Chemist's Reactor"**

   CONTINUOUS chemical processing permits steady-state operation and a much smaller total fissile inventory/kW_e than any other sort of nuclear reactor

ORNL's Molten Salt Reactor Experiment (1965-1969)





Compared to a LMFBR (aka IFR), a LFTR has…

- ...less chance of a “core disruptive incident” (FLiBe’s vapor pressure is much lower than is sodium’s)
- …smaller pumps & piping (FLiBe possesses higher heat capacity)
- …simpler/safer fuel “recycling” system
- …much less chance of a chemical explosion (FLiBe doesn’t react with water or air)
- ….less chance of thermal shock to system components (FLiBe possesses lower heat conductivity and the reactor core naturally tends to stay at a fixed temperature)
- …much lower (5-10 x) fissile inventory in both the reactor and ancillary fuel recycling system
- …more easily managed radwaste (much less TRU)

And should therefore be much cheaper

LFTR would be walk-away safe

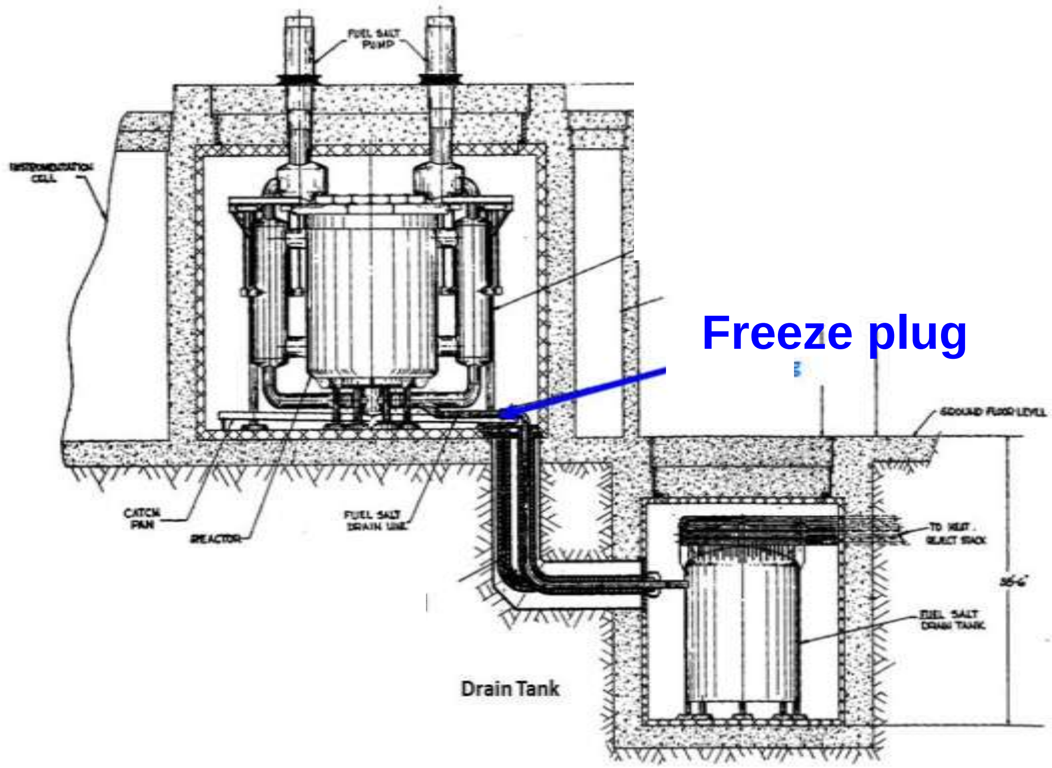
Stable reactivity

Fuel already melted

No internal pressure
(makes it cheaper too)

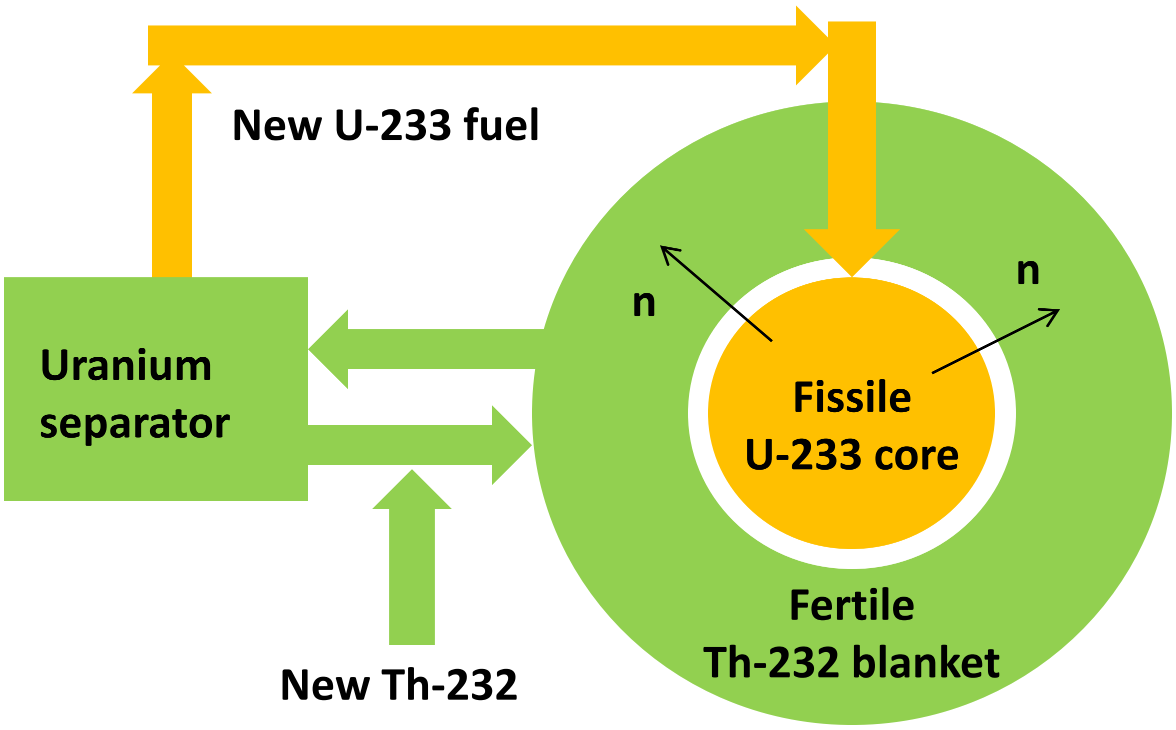
Melting freeze plug
dumps salt to tank

Salt from rupture or leak
will solidify



Passive cooling
dump tank

Uranium from a commercial LFTR will not be used for weapons.



Breeds only as much U-233 as it consumes.

Removing any will stop the LFTR.

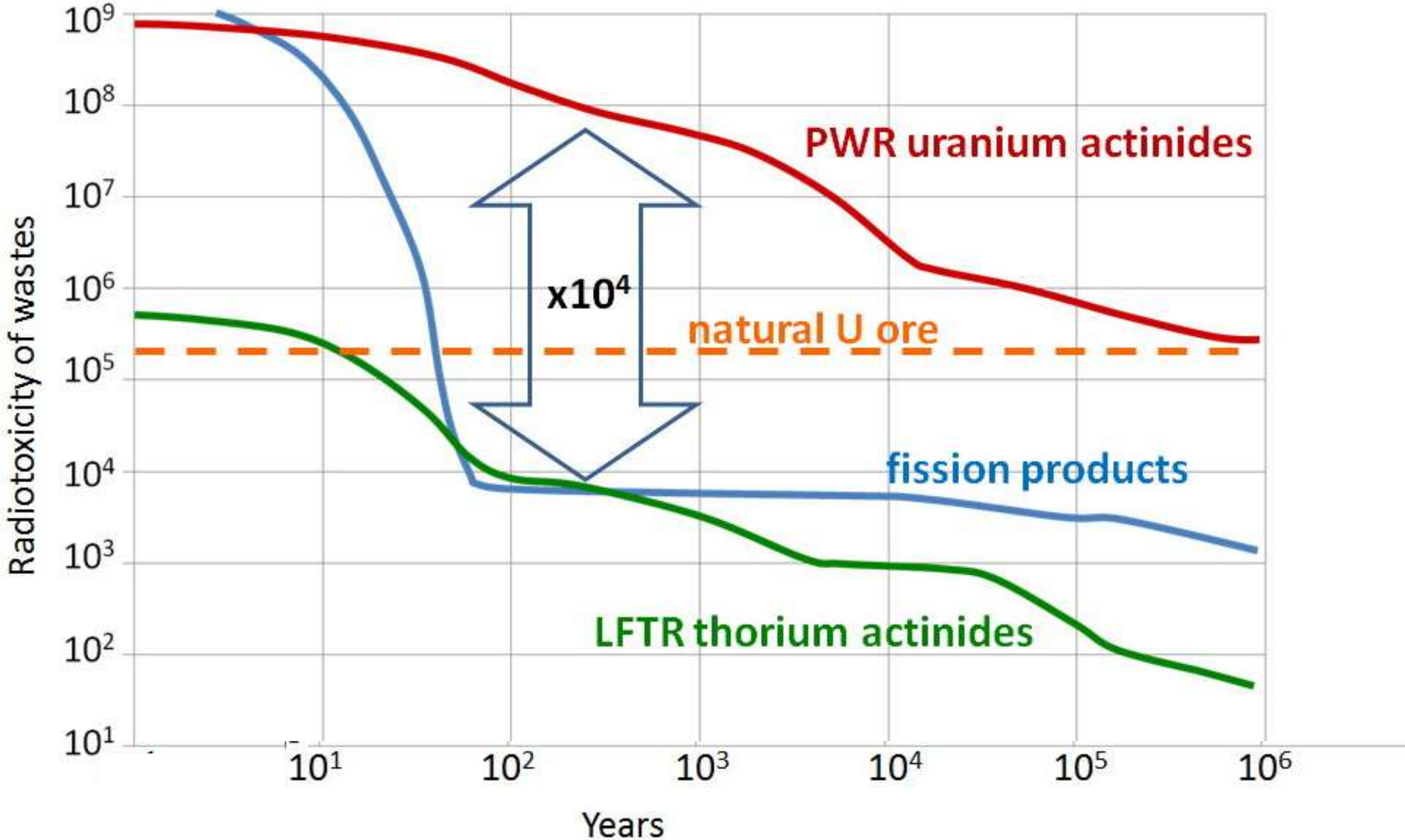
U-232 contamination will be 0.13%.

A 5 kg sphere of it radiates 4,200 mrem/hr at 1 meter.

After 72 hours of exposure a weapons worker will likely die.

India, Pakistan, and North Korea demonstrated far less technically challenging and costly paths.

LFTR produces < 1% of the long-lived radiotoxic waste of today’s reactors.



LFTR fuel would never run out

- **@ ~2.7 g/cc, the mass of the Earth's crustal landmass to 1 km depth (the "accessible" part) ≈ $4.2E^{17}$ tonnes**
- **Total CH_x (coal + shale kerogen + petroleum + natural gas) reserves* = 843+500+170+125 = 1513 gigatonnes**
- **Wt fraction CH_x = $1513E^9/4.2E^{17}$ = 0.0000039 (3.9 ppm)**
- **@ 12 ppm, Th in the same rock ≈ 4655 gigatonnes**
- **@ 200 Mev/atom, the fission of one gram of thorium via LFTR produces $8.3E^{10}$ Joules of energy <u>and no GHG</u>**
- **Combustion of one gram of CH_x produces about 37,000 Joules of energy <u>plus ~3.1 g of GHG</u>**

∴LFTR:∑fossil energy = (4655/1513)(8.3E10/$3.7E^4$) = 6,800,000:1

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*Recent EIA estimates

More Killer Apps

- Desalination: the Mid East's/No Africa's chronic drought/famine/economic problems could be solved with ~100 reactors
- Cheap, safe, fast, & consumer-friendly US mass transit: more trains & more tracks - remember your Eurail pass?
- Meaningful work/employment for everyone (not just "service" jobs): the USA's industrial & public infrastructure could be totally rebuilt
- No more resource limitations: cheap electricity means that we could wouldn't need "ores"

SUMMARY

- **Mankind must switch to non-fossil energy sources ASAP**
- **The most immediate problem (esp. for the USA) is oil – most of which is utilized as a transportation fuel**
- **Ammonia is an attractive synfuel fuel for vehicles which require more range/power than can be provided by reasonable-size batteries**
- **If that ammonia is produced with energy generated by a "renewable" nuclear fuel cycle it will become extremely cheap, absolutely "green", and available forever**
- **Politically correct "renewable" energy cannot do this**

Primary Sources

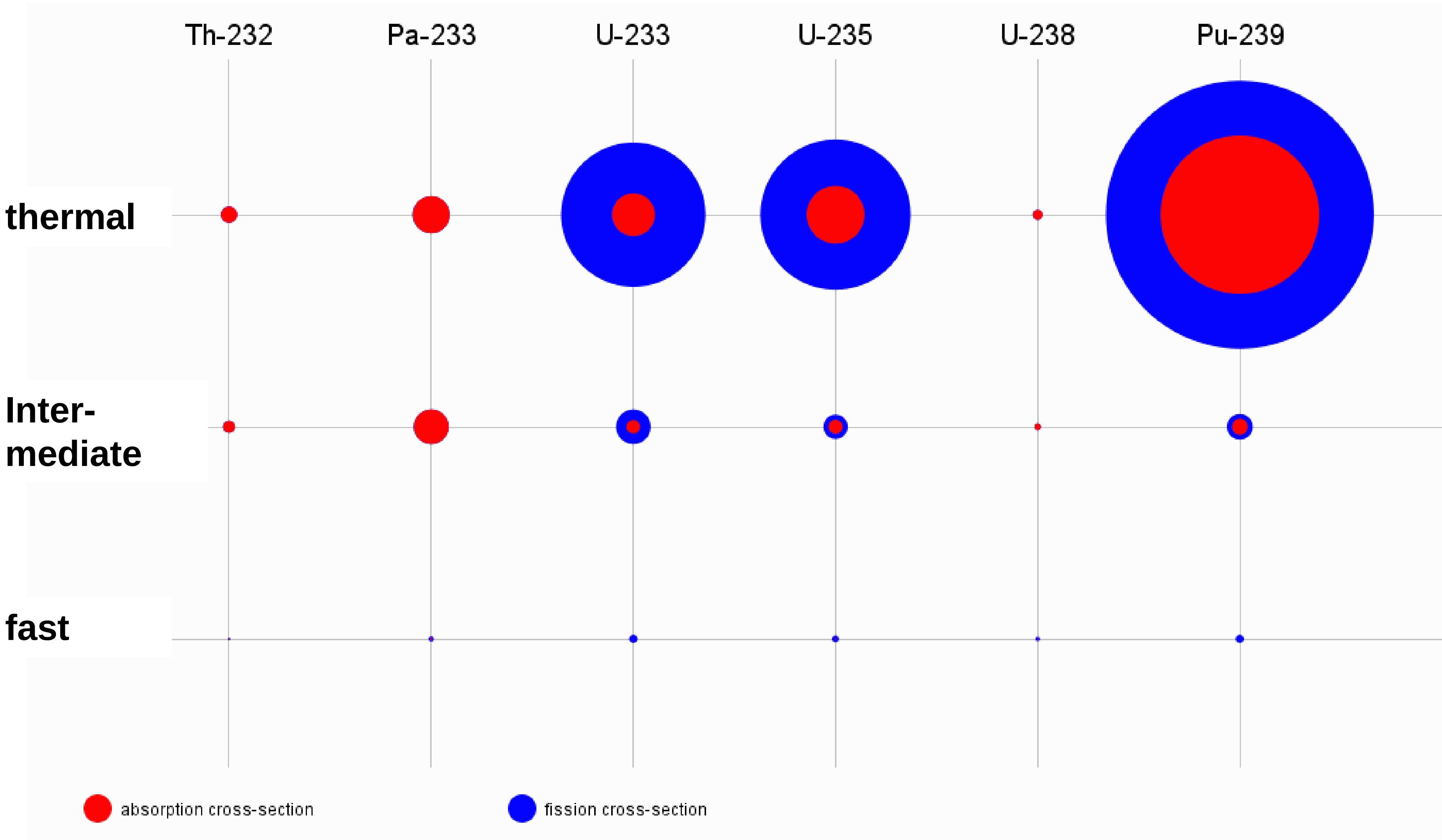
GOOGLE/WIKIPEDIA/internet for just about everything

special mention to…

- ammoniafuelnetwork.org: website devoted to promoting ammonia as a fuel – links to research reports, slide shows, etc
- Kirk Sorensen's "Energyfromthorium" web/blog site – free pdfs of ORNL's MSBR research reports, a great discussion forum, & links to modern papers/lectures/slide shows
- Alvin Weinberg and H. E Goeller's seminal 1974 essay ("The Age of Substitutability" – OSTI 5045860) refuting the "Club of Rome's" dire predictions (e.g., *Limits to Growth* and *Mankind at the Turning Point)* about the inevitability of "Malthusian Catastrophe" when the oil runs out

EXTRA SLIDES

High ***thermal*** absorption, fission cross sections lead to low fissile mass & cost



The Age of Substitutability*

- **With breeder reactors future society could subsist with relatively little loss of living standard on infinite or near-infinite minerals**
- **Such a civilization would be based largely on glass, plastic, wood, cement, iron, aluminum, and magnesium**

*Goeller, H. E. and Weinberg, A. M., "The Age of Substitutability", *Science* 20, February 1976 (also OSTI 5045860)

Fuel is Mankind's only <u>limited</u> resource*

STUFF	RESOURCE	% in resource	TONS
CHx_{rec}**	Coal + oil + gas	>75	1.0E+13
C_{ox}	limestone	12	2.0E+15
Si	sand, sandstone	45	1.2E+16
Ca	limestone	40	5.0E+15
H_{ox}	water	11	1.7E+17
Fe	basalt	10	1.8E+15
Al	clay	21	1.1E+15
Mg	seawater	0.012	1.0E+15
N	air	80	4.5E+15
O	air	20	1.1E+15
S	gypsum	23	1.1E+15

****"rec"= recoverable with positive_energy balance**

*Goeller, H. E. and Weinberg, A. M., "The Age of Substitutability", *Science* 20, February 1976 (also OSTI 5045860)

How could our grandkids make 3 quads worth of “green” CH_x synfuel?

Why our grandkids will want more cement than we do

- They must repair/replace the USA's crumbling infrastructure - roads, bridges, etc
- Asphalt will be rare/expensive
- It's made of abundant/cheap raw materials
- Its manufacture could provide them with enough CH_x synfuel for aviation, etc.
- Manufacture/use via LFTR would render it GHG-neutral via "carbonation"

Aim High! Use air cooling.

A typical 1 GW_e LWR's cooling tower evaporates 20,000 gal of water/min.

LFTRs could achieve good efficiencies with "dry" cooling

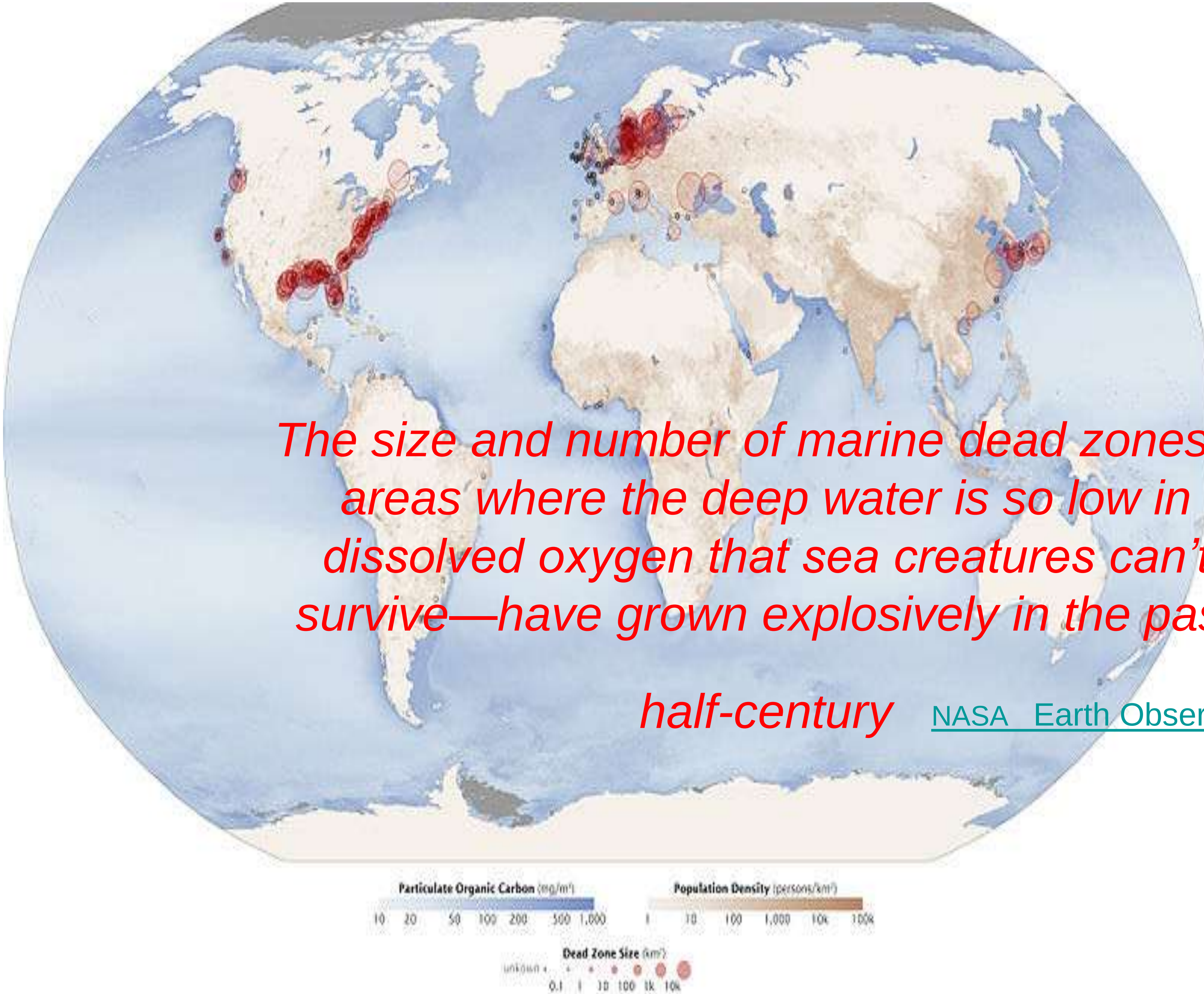
Nuclear power was kindest to the human environment in 1969-1996.

Energy Chain	Accidents with > 4 fatalities	Fatalities	Fatalities per GW-year
Coal	185	8,100	0.35
Oil	330	14,000	0.38
Natural Gas	85	1,500	0.08
LPG	75	2,500	2.9
Hydro	10	5,100	0.9
Nuclear	1	28	0.0085

htpp://gabe.web.psi.ch/pdfs/PSI_**Report**/ENSAD98.pdf

Paul Scherrer Institut, November 1998, Severe Accidents in the Energy Sector

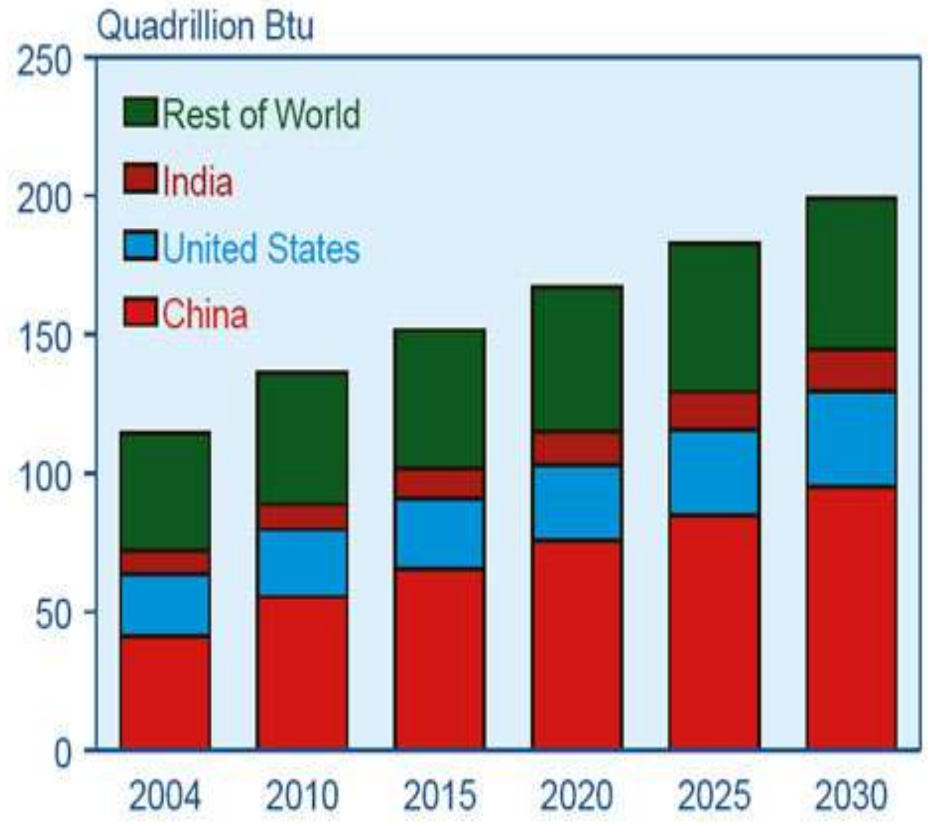
Global environmental problems mount.



The size and number of marine dead zones—areas where the deep water is so low in dissolved oxygen that sea creatures can't survive—have grown explosively in the past half-century NASA Earth Observatory

Energy and coal use is growing rapidly in developing nations.

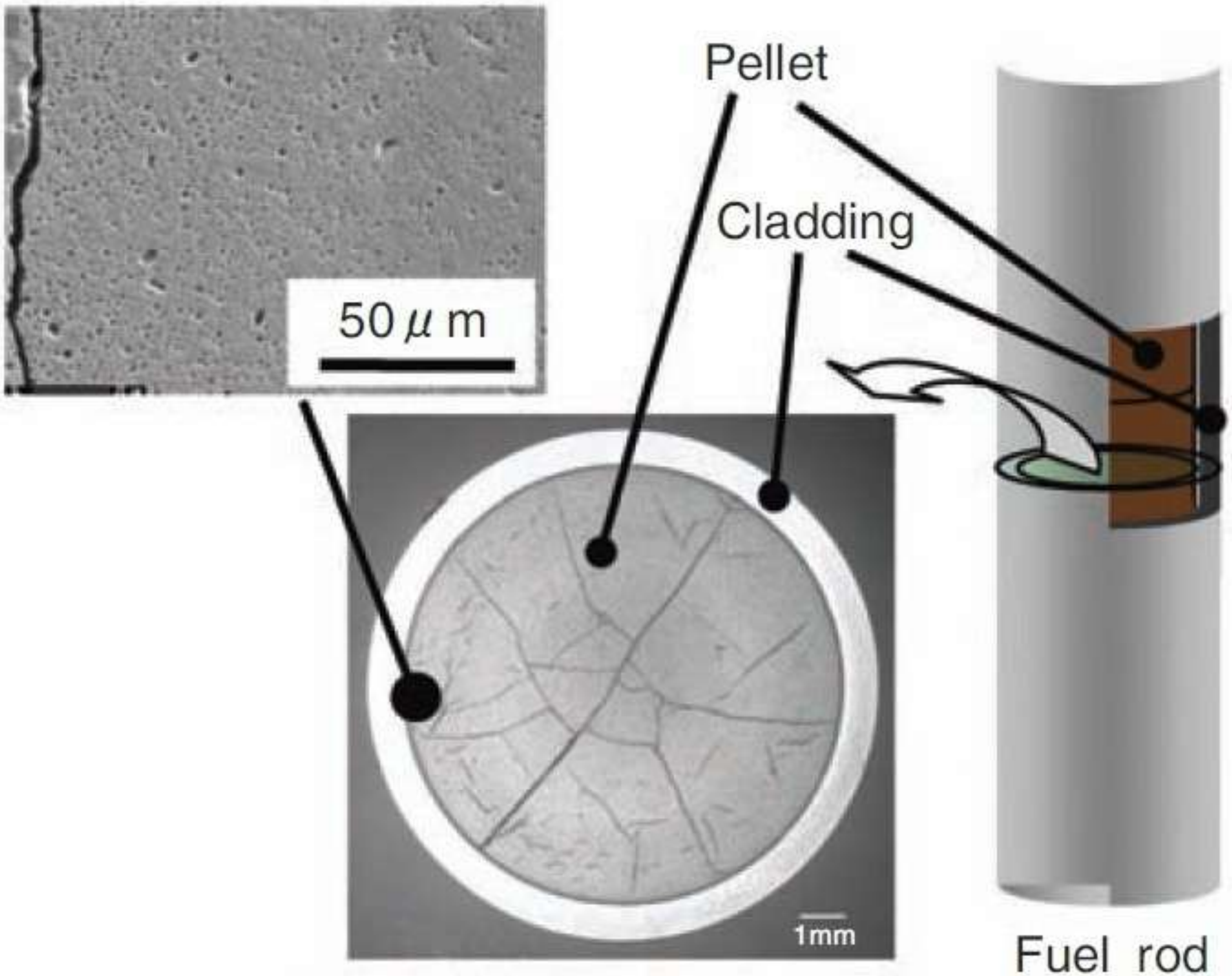
Non-OECD energy use



World coal use

http://www.eia.doe.gov/oiaf/ieo/world.html

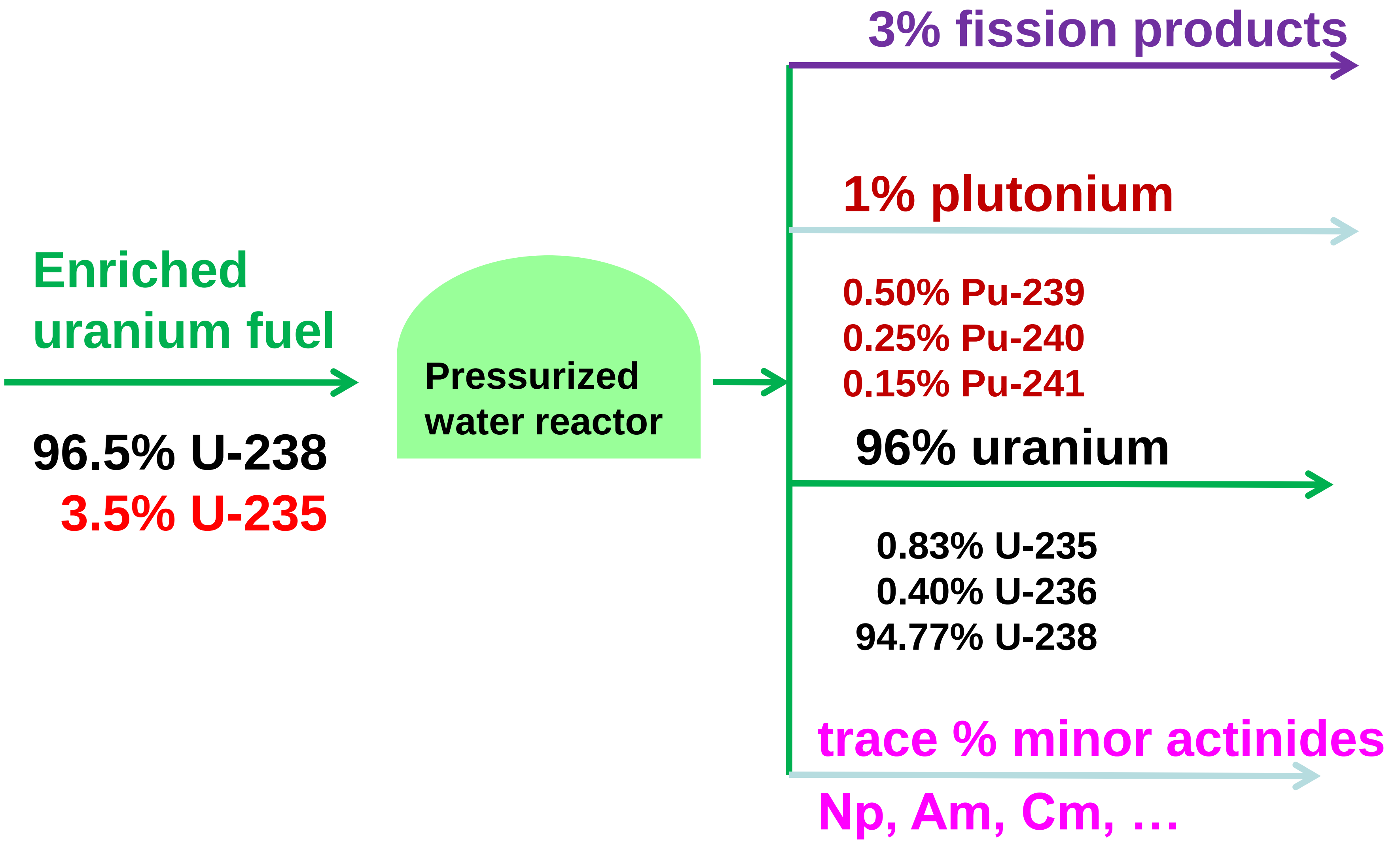
Radiation, fission products, and heat damage solid fuel.



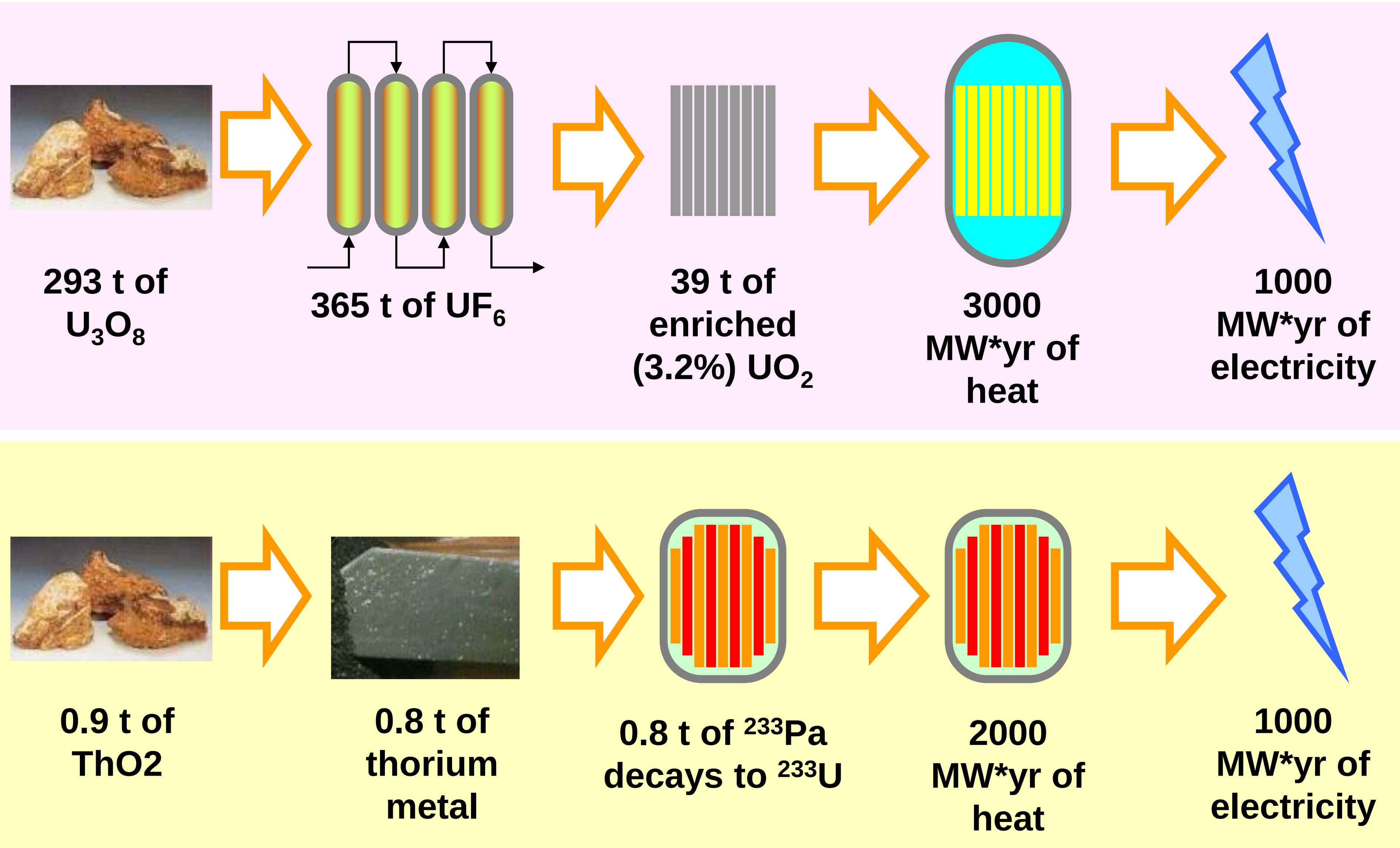
A cross section of fuel rod

Zirconium cladding must contain fuel and fission products for centuries.

Solid fuel reactors use only 3% of the potential energy.

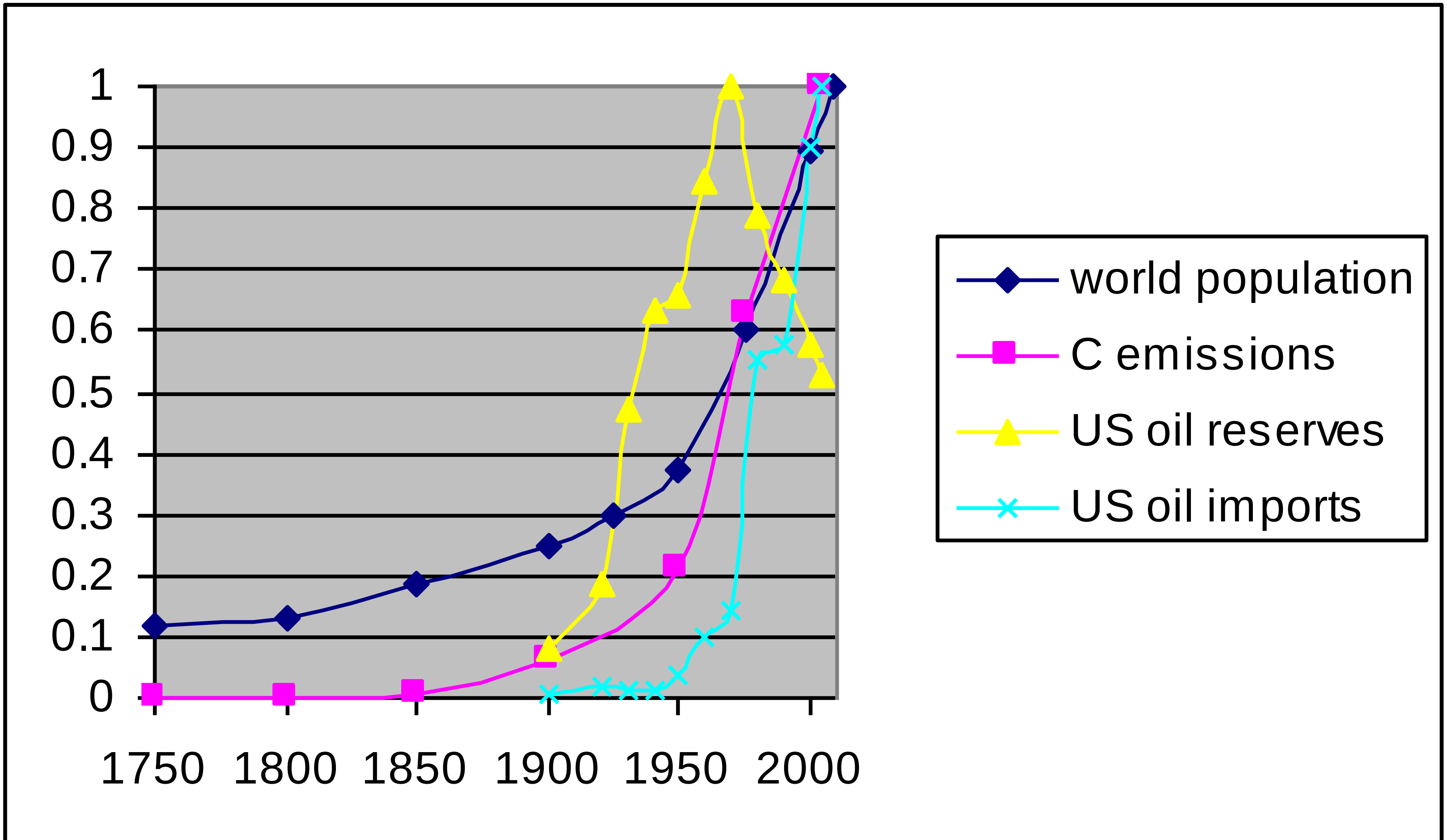


All thorium can be burned, but only 0.7% of uranium is fissile U-235.

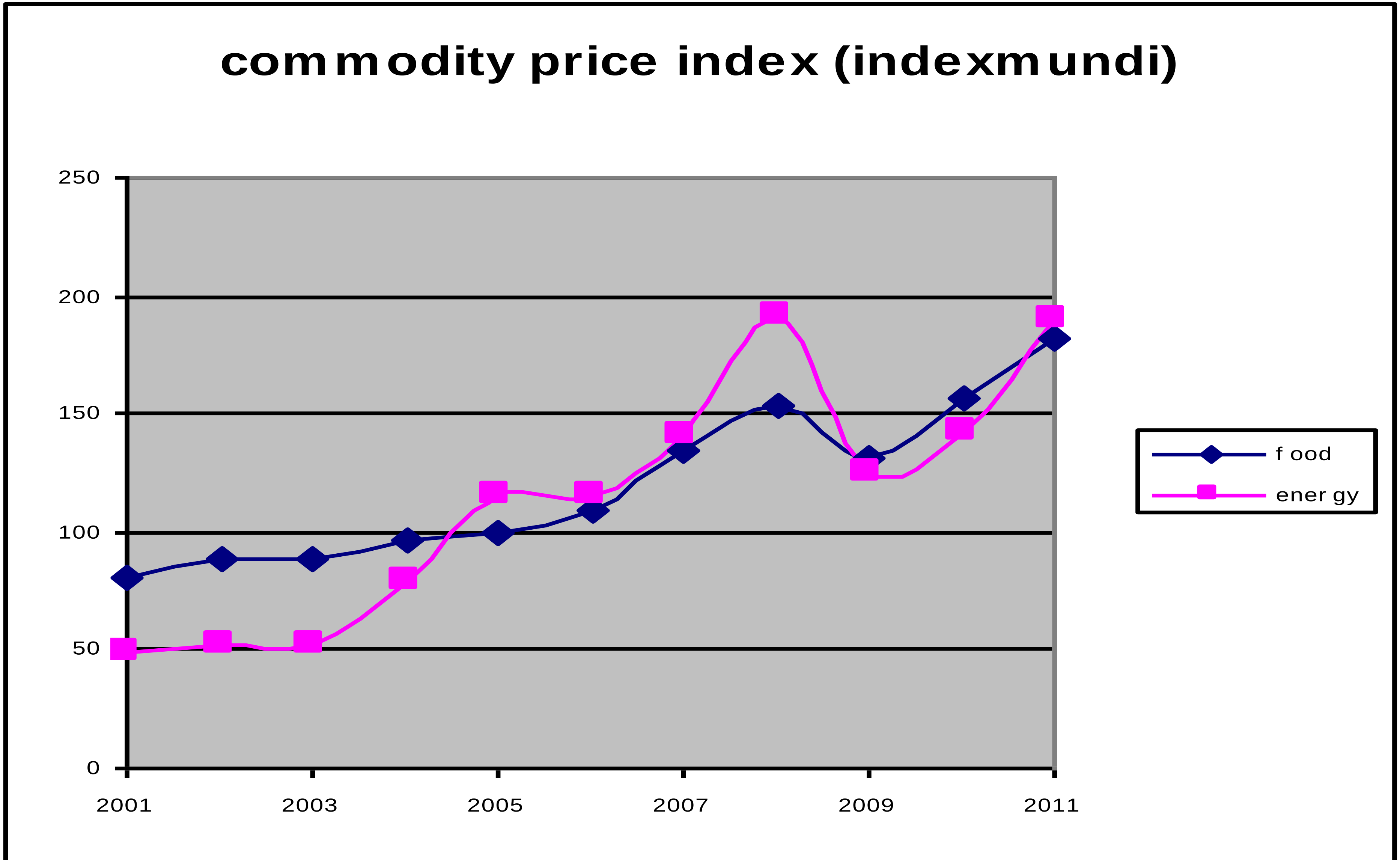


WISE nuclear fuel material calculator: http://www.wise-uranium.org/nfcm.html

We've been marching off a cliff



BIOMASS ISN'T "FREE"



*CHEMISTRY**

The "formula" of what we use

$(CH_X)_{.802}$ $(SiO_2)_{.122}$ $(CaCO_3)_{.045}$ $Fe_{.011}$all $other_{.035}$

The "formula" of the Earth's surface

$O_{.5884}$ $Si_{.1931}$ $H(ox)_{.0658}$ $Al_{.0507}$ $Fe_{.0132}$ … $CHx_{.00004}$

---

* Weinberg & Goeller, "The Age of Substitutability", 1975

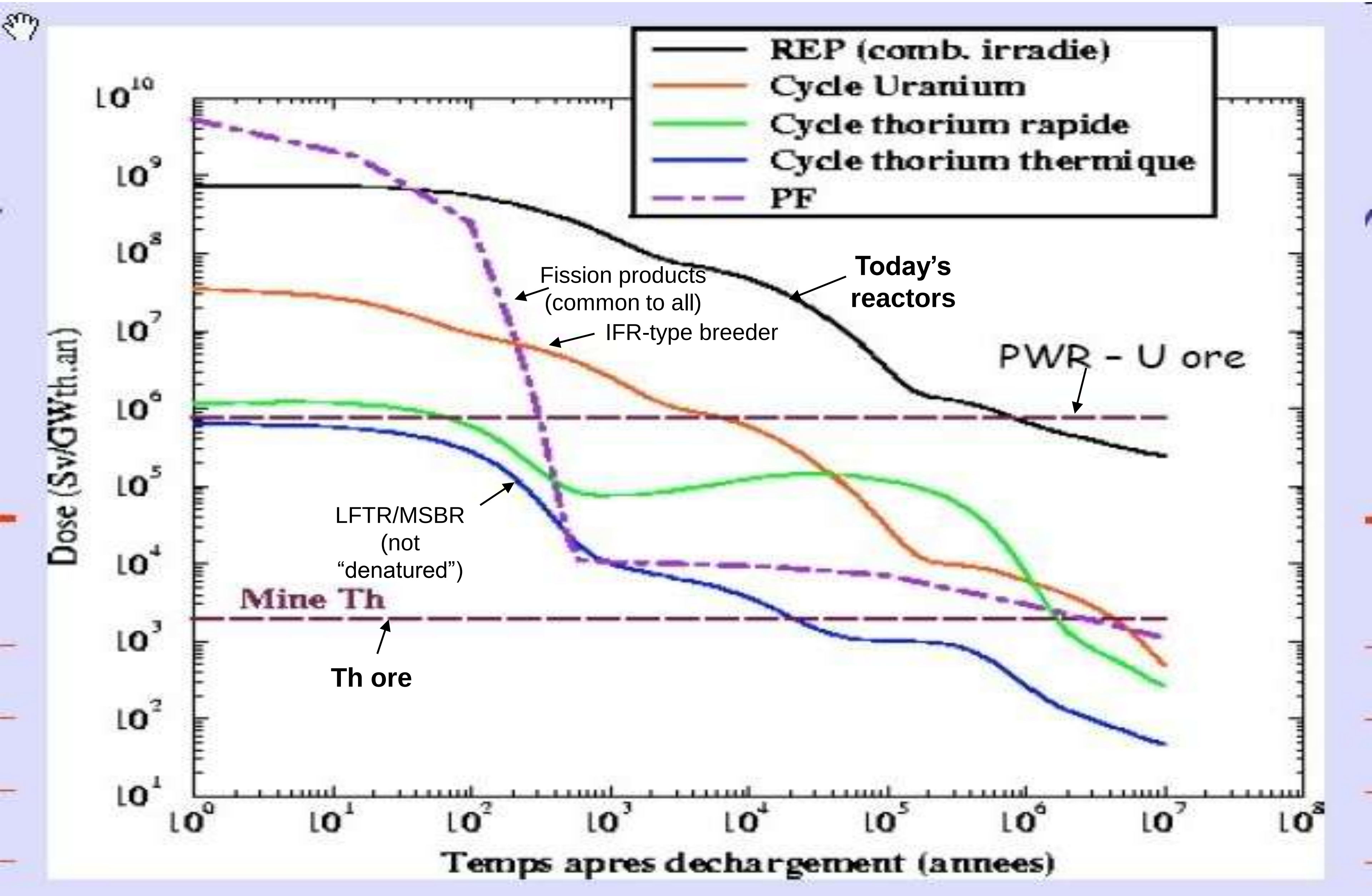
We Must Avoid Exaggerated Claims!

"…are promoting an idea for a container-size (ammonia-generating) unit to be installed at gas stations." … can produce LNH3 for about 80 cents/gal…etc..." ***New Scientist***, 1 sep11*

- Do gas stations have air separators?
- Are gas stations wired for multimegawatt electrical inputs?
- Do they/we expect subsidies far greater than that which generated 2007's massive run-up in food prices?

Inconvenient truth: at today's electricity prices, the cost of producing just the H in a gallon of LNH3 (via HTE @850C) would be about $2.25.

*http://www.newscientist.com/article/mg21128285.100-ammonia-cleans-up.html



Sylvain David (France)

RADWASTE TOXICITY wrt Time

The USA's Oil Addiction

- US consumption ~290 billion gallons/year (2/3rds for transportation)
- US production ~91 billion gallons/year
- Gasoline ~140 billion gallons/year
- Diesel ~30 billion gallons/year
- Asphalt ~30 million tonnes/yr (2.1% of total)

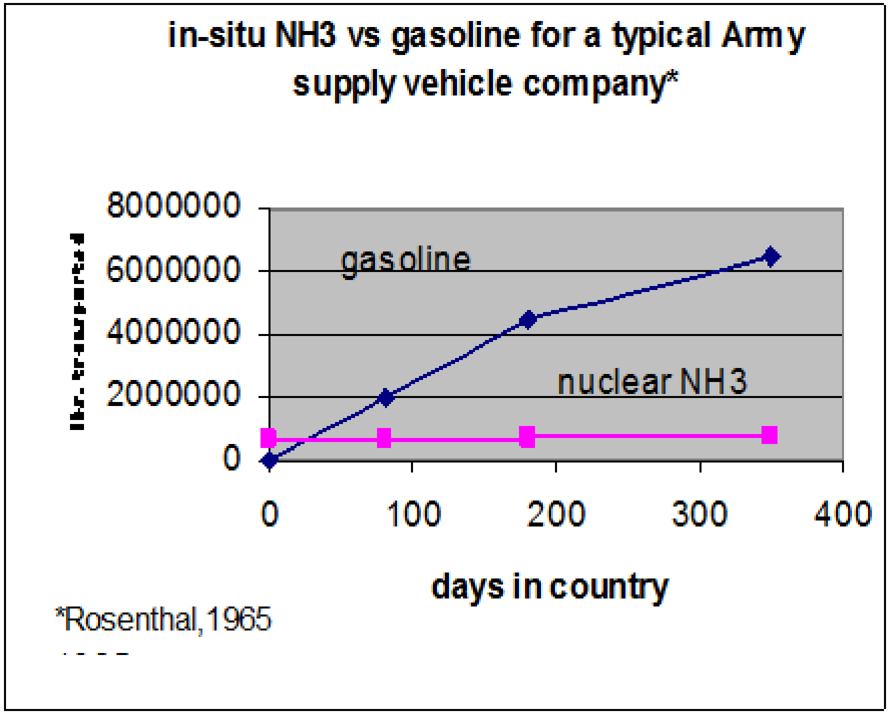
COSTS

- More Climate "Change" (tornados, floods, droughts, etc)
- Economic & social stagnation
- Oil imports currently cost us ~400 $billion/year
- From 1976 to 2007, we spent 7.3 $trillion tax dollars to "maintain a US presence" in the Persian Gulf
- During that same period we've fought several wars to maintain/sustain our dependency on foreign oil - current cost ~0.7 $trillion/a

Will the Military be "Nuclear Ammonia's" First Customer?

The US Army's "energy depot" program established need & technical basis during the 1960's

- **GM/Allison/Allis Chalmers established NH_3's utility in ICE's, gas turbines, and fuel cells**
- **Portable nuclear powered Haber Bosch-based NH_3 plants were designed**
- **Program petered out because the Army's tiny reactors couldn't produce enough (80 gal/hr)**



We're still fighting foreign wars, contractors now charge taxpayers $400/gal for the Army's "front line" fuel, and we now know how to make and use ammonia more efficiently – which brings us to a discussion of more appropriate nuclear reactors

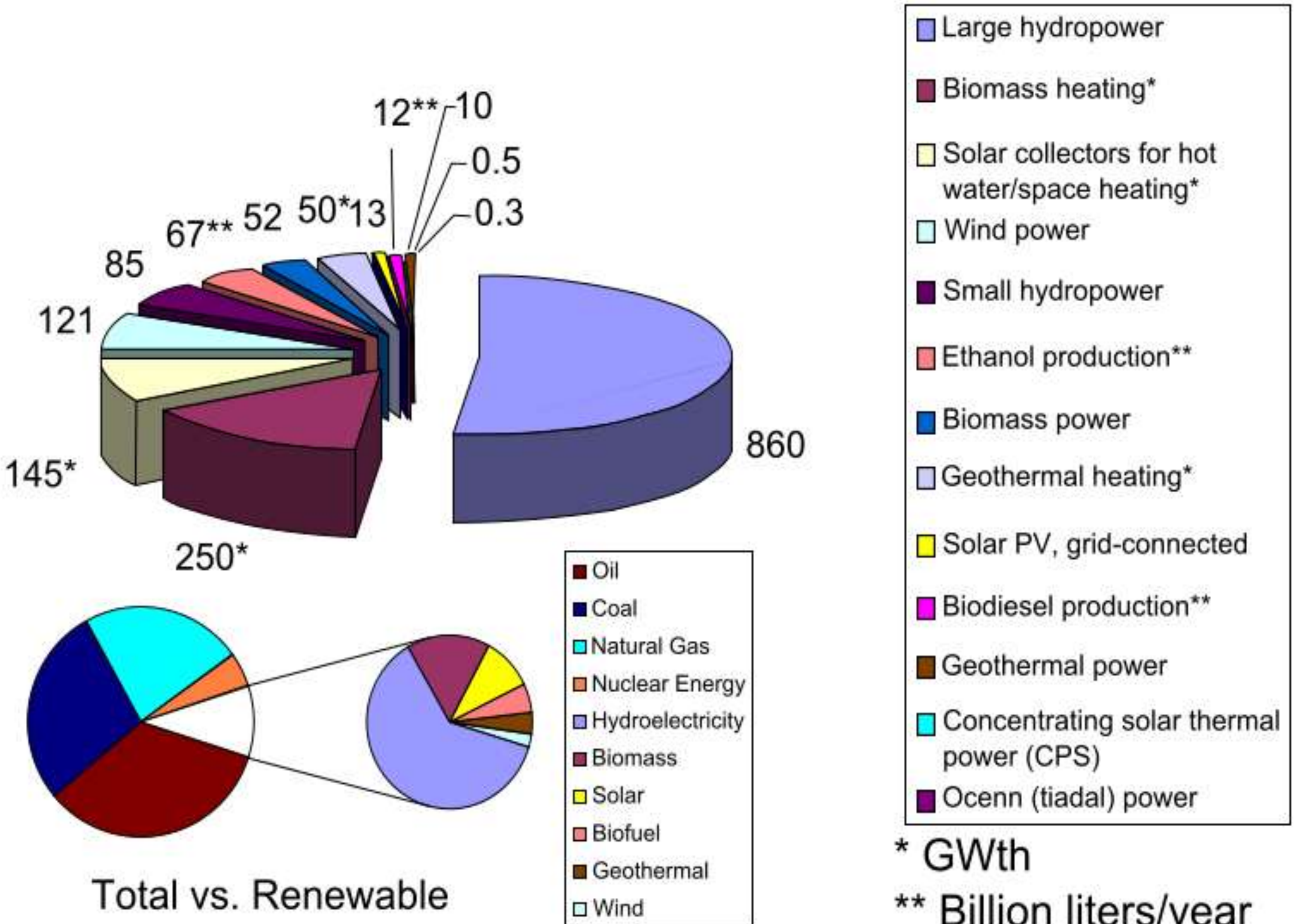
How Much Stuff Do We Use?

material	***Mtonnes/a (f Imported)***
aluminum	3.25 (45%)
ammonia	22 (45%)
plastics	28 (?)
steel	93 (25%)
cement	100 (20%)
nat gas	403 (19%)
coal	858 (2%)
oil	984 (71%)
∑fuels/total	90.12%

The “Sweet Spot” for Ammonia Production

- Cheap electricity – stranded power sources (e.g., windmills situated where there’s lots of wind but few people) and off-peak nuclear/coal-generated power
- Inexpensive process heat – concentrated solar & (more practical) the “waste heat” generated by high temperature nuclear reactors (conventional light water reactors (LWRs) aren’t hot enough)

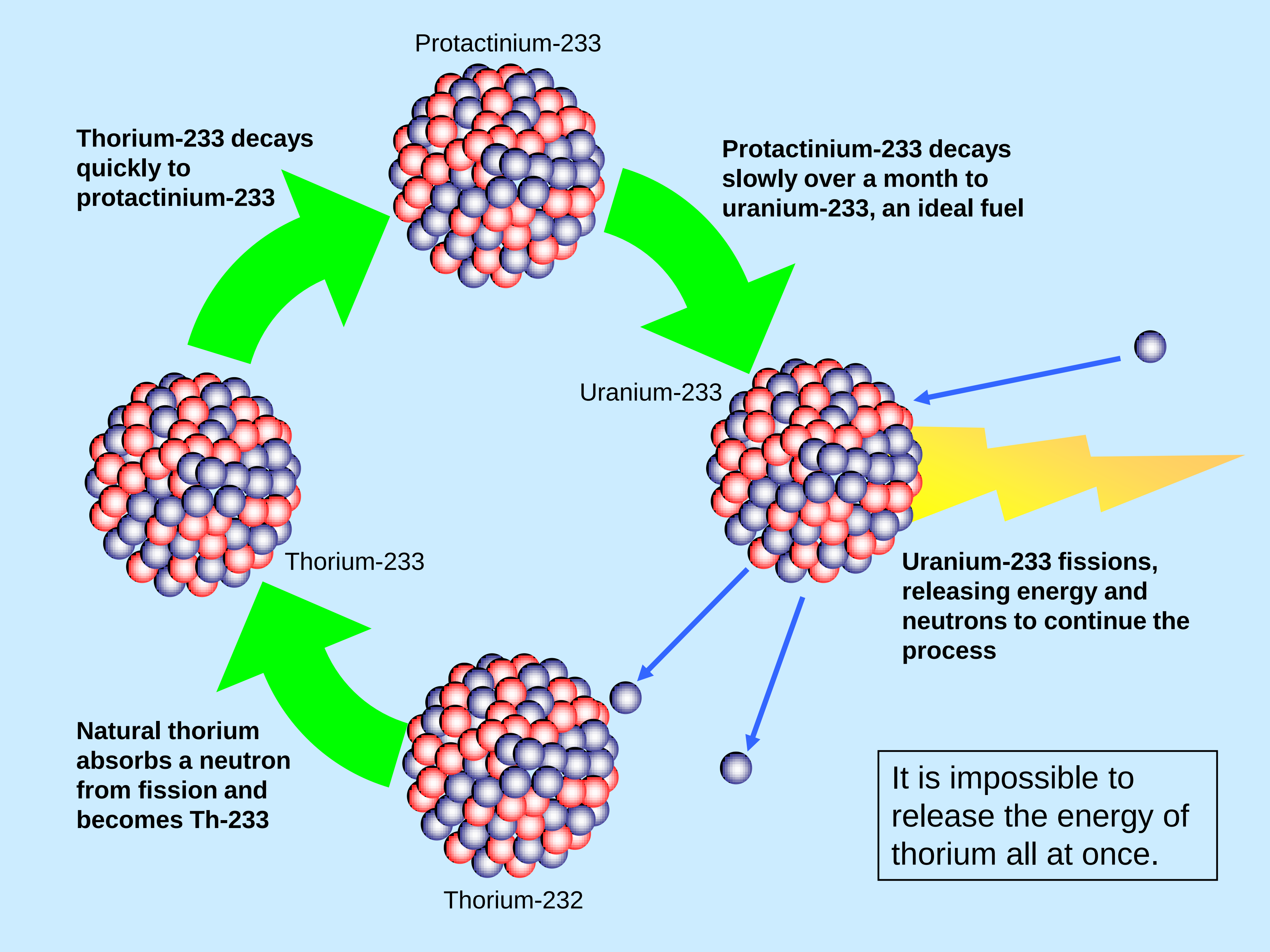
Renewable energy, end of 2008 (GW)



* GWth

** Billion liters/year

http://en.wikipedia.org/wiki/Renewable_energy


Protactinium-233
Thorium-233 decays quickly to protactinium-233
Protactinium-233 decays slowly over a month to uranium-233, an ideal fuel
Uranium-233
Thorium-233
Uranium-233 fissions, releasing energy and neutrons to continue the process
Natural thorium absorbs a neutron from fission and becomes Th-233
Thorium-232
It is impossible to release the energy of thorium all at once.

Renewable energy would wreck the environment

Jesse E. Ausubel
• Director, Program for the Human Environment, Rockefeller University.
• Program Director, Alfred P Sloan Foundation.
• Former Director of Studies, Carnegie Commission on Science, Technology, and Government.

http://phe.rockefeller.edu/jesse/index.html

Flooding the entire province of Ontario behind a 60 m dam would provide 80% of the power of Canada’s existing nuclear electric plants.

Displacing a single nuclear power plant with biomass would require 1,000 square miles of prime Iowa farm land.

Wind farms on 300 square miles of land could displace a 1 GW nuclear plant.

60 square miles of photovoltaic cells could generate 1 GW.

Powering New York City would require a wind farm the size of Connecticut.

Relative Comparison:
Uranium vs Thorium Based Nuclear Power

	Uranium LWR (light water reactor, high pressure low temp)	*Thorium LFTR (liquid fluoride thorium reactor, low pressure high temp)*
Plant Safety	Good (but very high pressure)	Better (low pressure, passive containment)
Burn Existing Nuclear Waste	Limited	Yes
Radioactive Waste Volume (relative)	1	1/30th
Waste Storage Requirements	10,000+ yrs.	~300 yrs.
Produce Weapon Suitable Fuel	Yes	No
High Value By-Products	Limited	Extensive
Fuel Burning Efficiency	<1%	>95%
Fuel Mining Waste Vol. (relative)	1000	1
World fuel Reserves (relative)	1	>1000
Fuel Type - Fuel Fabrication/Qualification	Solid Expensive/Long	Liquid Cheap/Short
Plant Cost (relative)	1 (high pressure)	<1 (low pressure)
Plant Thermal Efficiency	~35% (low temp)	~50% (high temp)
Cooling Requirements	Water	Water or Air
Development Status	Commercial Now	Demonstrated 1950-1970

Source: http://www.energyfromthorium.com/ppt/thoriumEnergyGeneration.ppt

More info.

- **Spark-Ignited Ammonia Engines and Gensets** thollinger@hydrogenenginecenter.com
- **Ammonia-Powered Diesel Engines,** nolson@iastate.edu & **vagosta@optonline.net)**
- **Ammonia-Gasoline and Ammonia-Ethanol Engines** sbohac@umich.edu)
- **Ammonia-Gasoline Engine Conversions** casey@lasercompliance.com)
- **Solid-State Ammonia Synthesis (SSAS)** jganley@howard.edu)
- **Cracked ammonia (alkaline) fuel cells** (Apollo Energy Systems) http://www.electricauto.com
- **Molten salt/thorium-fueled reactors** http://home.earthlink.net/~bhoglund/

Perspectives on the US Energy Future

2008 → **2050**

~14 Quads*
(2.41 Bbbl crude oil)

~24 Quads*
(4.11 Bbbl crude oil)
(assumes ave. 2% growth in demand year to year)

Current US Electric Power Production Units
- Biomass – 270
- Coal Fired Boiler – 1,4600
- Petroleum Coke – 31
- Combine Cycle NG – 1,686
- Comb. Turbine – 2,882
- Diesel – 4,514
- Fuel Oil – 13
- Geothermal – 215
- Hydro – 4,138
- Incinerators – 96
- NG Boiler – 776
- Nuclear – 104
- Oil Fired Boiler – 327
- Solar – 31
- Wind - 341

(US Chemical Plants ~15,000)

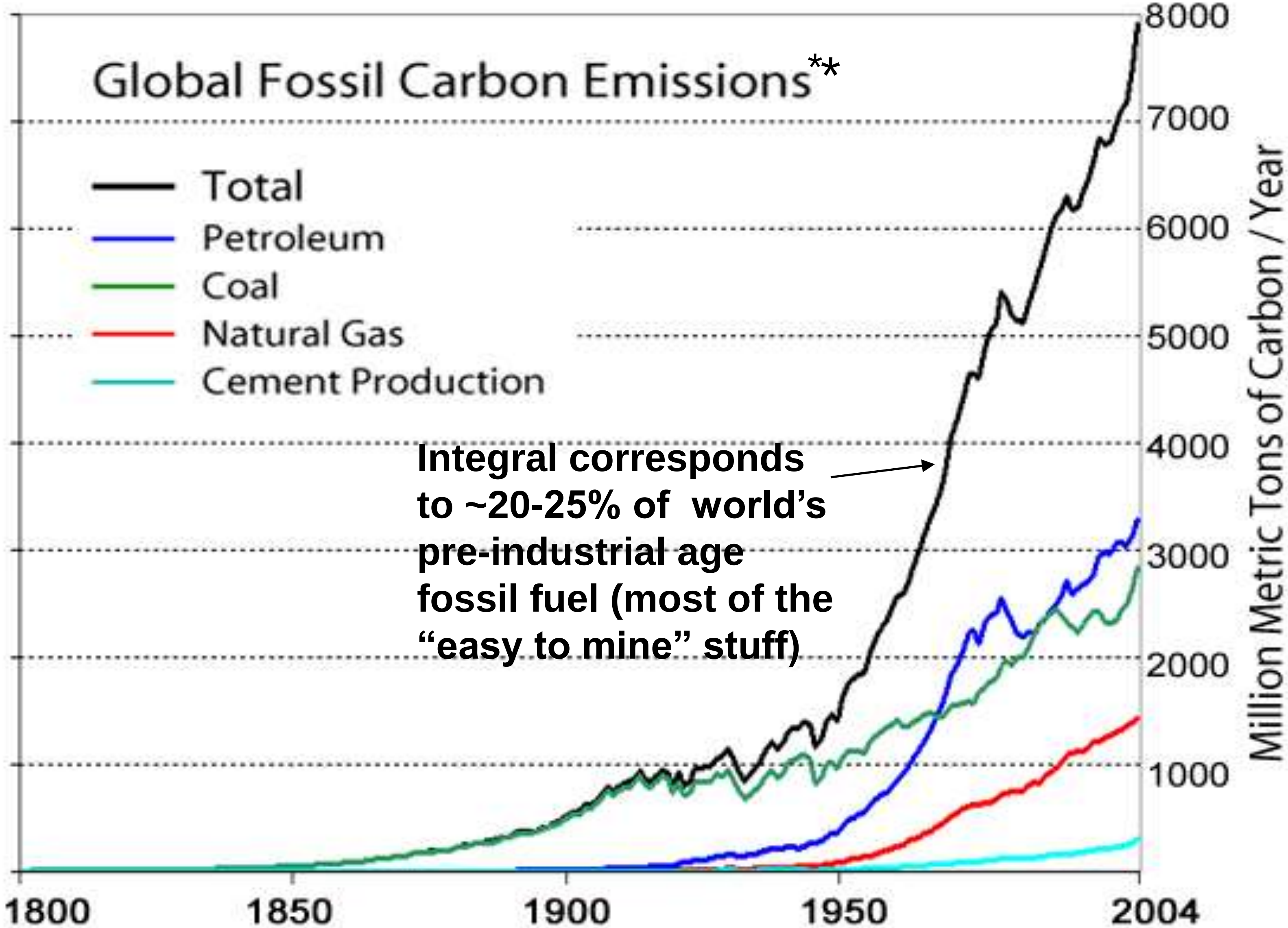
Thorium Based Nuclear
- **~ 2000 LFTRs**
- **< 10% Coal**
- **< 10% Petroleum (electric cars)**
- **Yucca Mountain not needed for long term waste storage**
- **Electricity and other products**

Current Trend
- **~ 150 LWRs**
- **> 70% Coal**
- **> 95% Petroleum (transportation)**
- **2+ Yucca Mtns. for long term waste storage (~$180B)**

Ambitious Conventional Nuclear
- **~ 2000 LWRs**
  - **Not enough uranium supply for this**
- **< 10% Coal**
- **< 10% Petroleum (transportation)**
- **10+ Yucca Mtns. for long term waste storage (~$900B)**

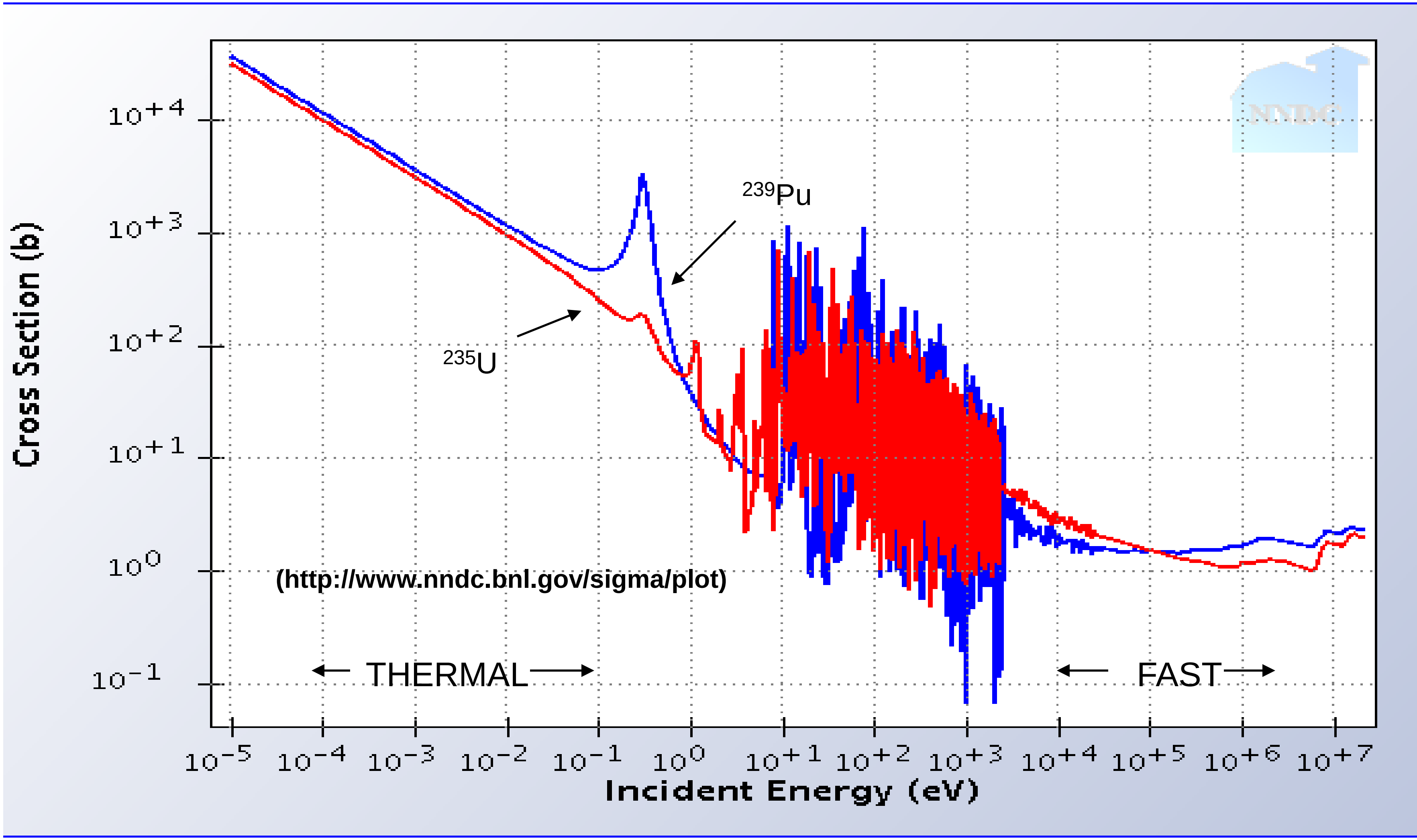
N.B.: High risk due to the safety, proliferation and waste issues and associated political and public opinion issues

*Source: DOE Historical Net Electricity Generation by State by Type of Producer by Energy Source, 1990-2006

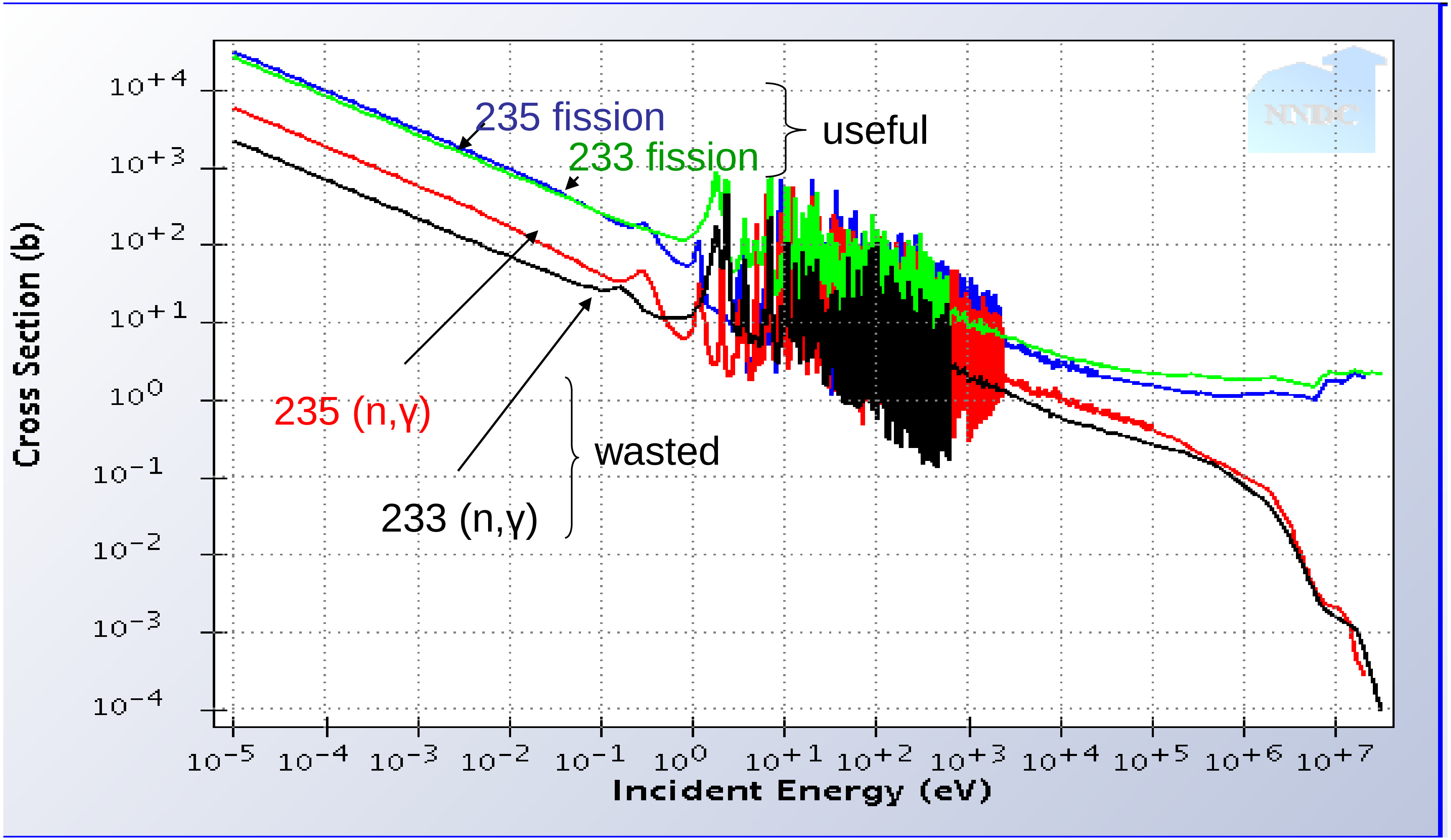


*http://en.wikipedia.org/wiki/Fossil Fuel

Why FAST reactors require big fissile inventories



Why ^{233}U is a better fuel than ^{235}U



http://www.nndc.bnl.gov

SSAS in a nutshell

- Solid state electrochemical process - works like a fuel cell in reverse
- 550ºC steam adsorbs and decomposes on a electrocatalyst at the anodic side of a proton conducting ceramic (PCC) membrane
- Hydrogen atoms from the decomposed steam are stripped of their electrons by an external voltage and become protons. Remaining oxygen atoms recombine and volatilize and are separated from the steam loop as a separate by-product.
- The resulting protons conduct through the PCC "electrolyte" via defect hopping and then…
- Chemically combine with adsorbed nitrogen on the other (cathode) side to form ammonia

Mankind Must Switch to Nuclear Power

- We're rapidly using up the World's fossil fuel reserves, the first to go will be petroleum
- In doing so we're rapidly destroying the World's climate
- In an increasingly hungry world "biofuels" is a cruel hoax & wind/solar are too unreliable, too expensive, & and too dilute* to power modern industrial societies
- If it were to be implemented properly, nuclear power could satisfy 100% of mankind's energy and raw material needs with no GHG emissions

unfortunately

Today's approach to implementing nuclear power is unsustainable, too "dirty", too controversial, and too expensive

---

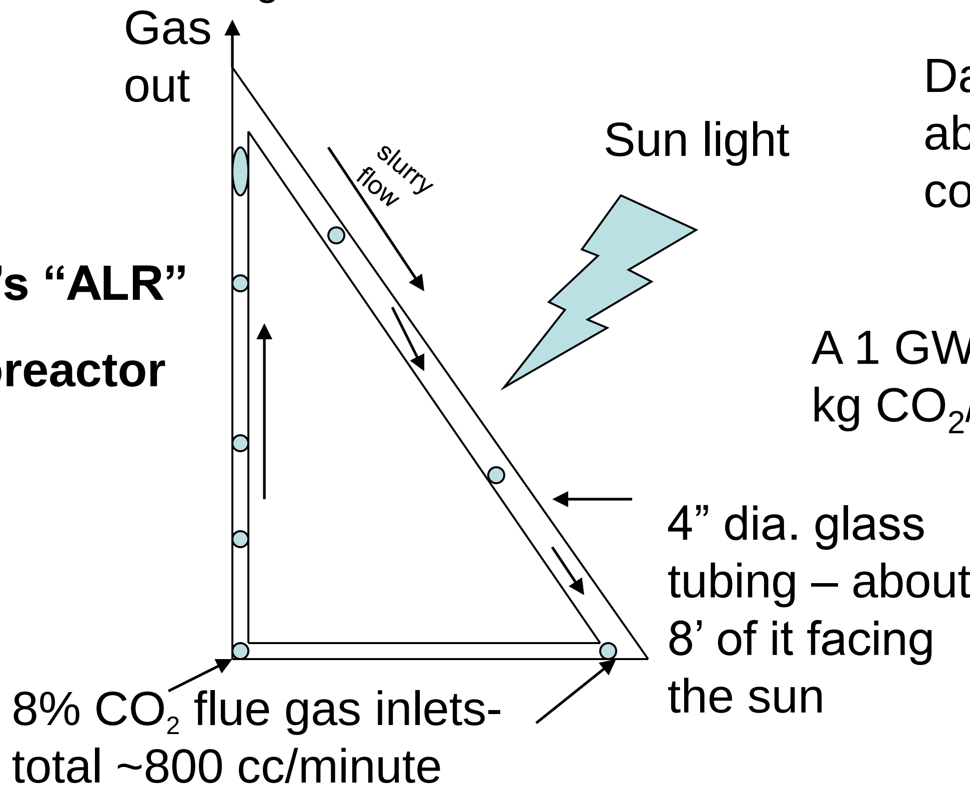
*Renewable power densities: wind 1.2 W/m^2, photovoltaic 6-7 W/m^2

ALGAL BIOFUELS?

Typical Claim: Since algae contain up to 50% “oil” & rapidly grow in bioreactors fed with flue gas from coal fired power plants, etc., we could grow our own “biodiesel” in a way that simultaneously purifies industrial waste gases & doesn’t compete with food production

BASIS document: *"Airlift Bioreactors for Algal Growth on Flue Gas….,* Ind. Eng. Chem. Rev., Vol 44, No 16, 1654-1663, 2005. (MIT)

MIT’s “ALR” bioreactor



Data: in bright sunlight, the algae slurry absorbed/utilized ~ 80% of the CO_2 … corresponds to ~0.0017 CO_2/s

A 1 GWe coal-fired power plant emits ~250 kg CO_2/s (that’s ~150 million “ALRs”)

WHY "2 Fluid" ?

DOE's 1 fluid "straw man" MSR mixes thorium with fissile in a single solvent salt – a "simple" design but complex/expensive to operate as a breeder (unresolved chemistry issues)

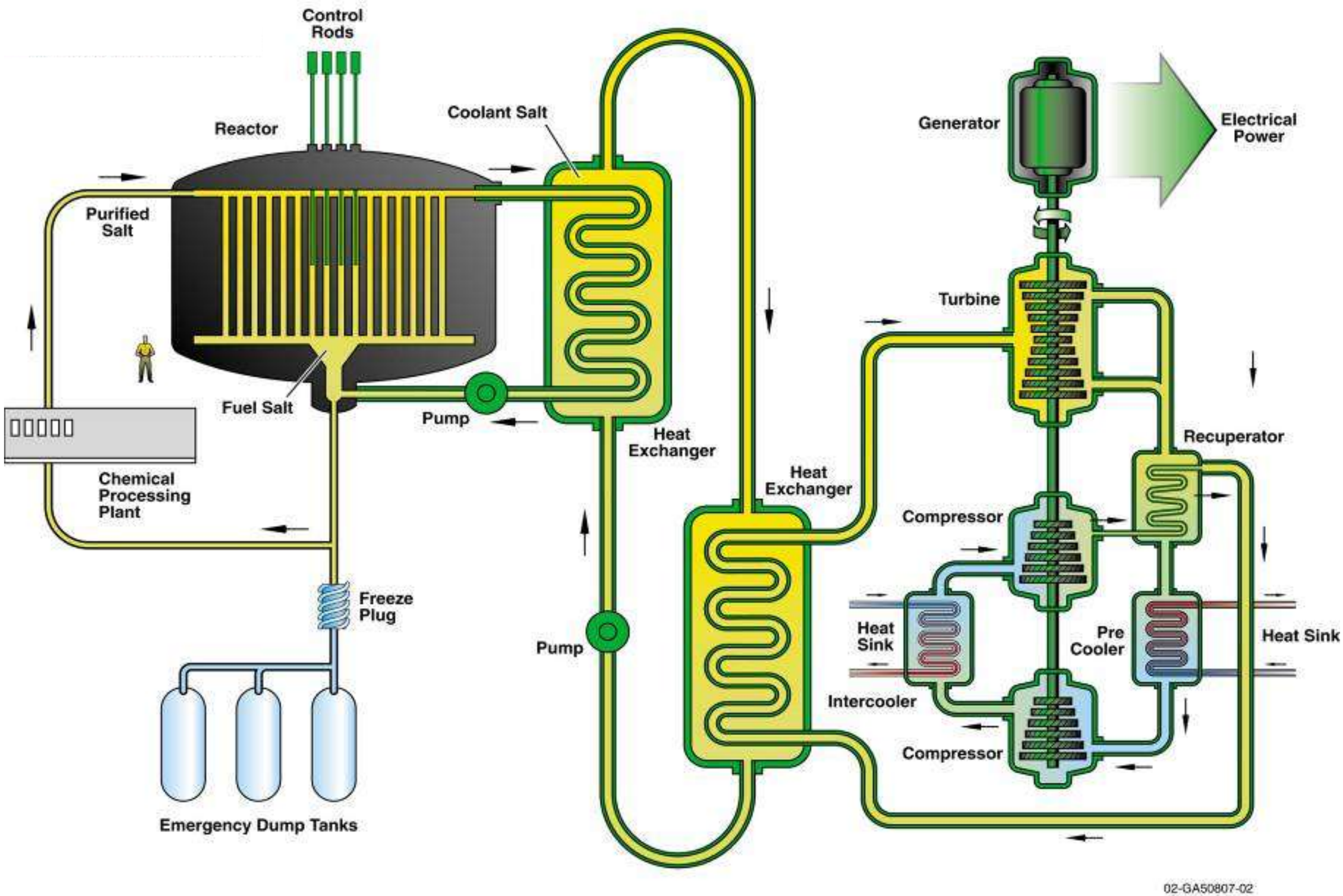
A 2 fluid breeder's fissile containing salt (core) is physically separated from the surrounding blanket salt, which…

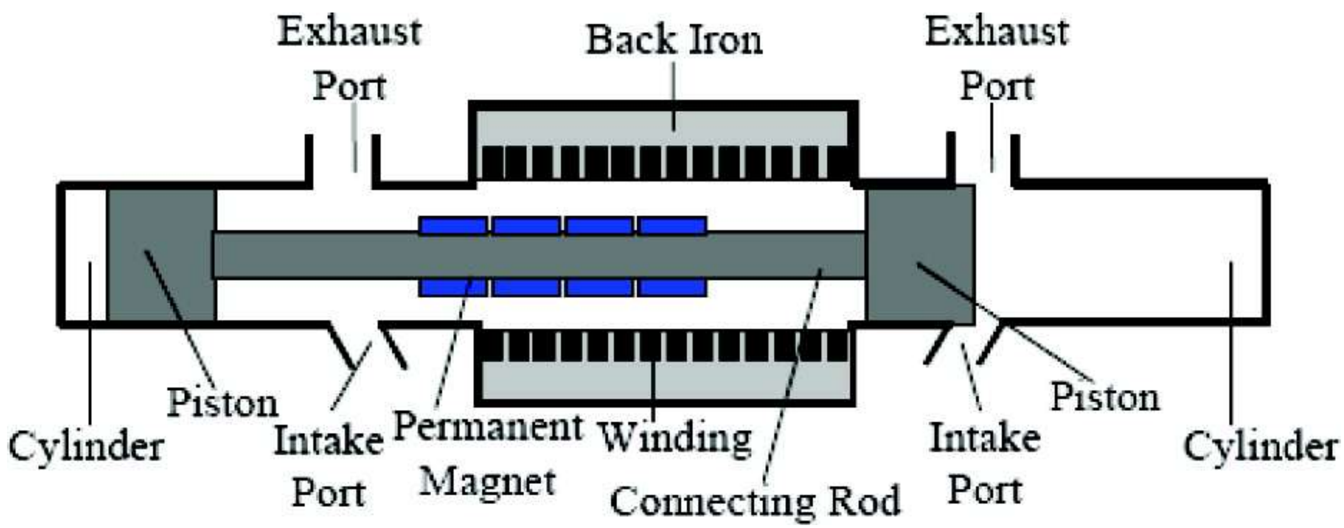
- renders salt clean-up chemistry (FP removal) easier/cheaper
- reduces fissile inventory
- renders ^{233}Pa removal unnecessary*, and…
- enhances negative temperature/void coefficients (safety)

---

*The Pa isolation step required by a 1 fluid breeder is not only difficult/expensive but creates a proliferation issue because it would allow "terrorists" to produce pure ^{233}U – no ^{232}U

INL's MSR Gen IV Straw Man (zero R&D)

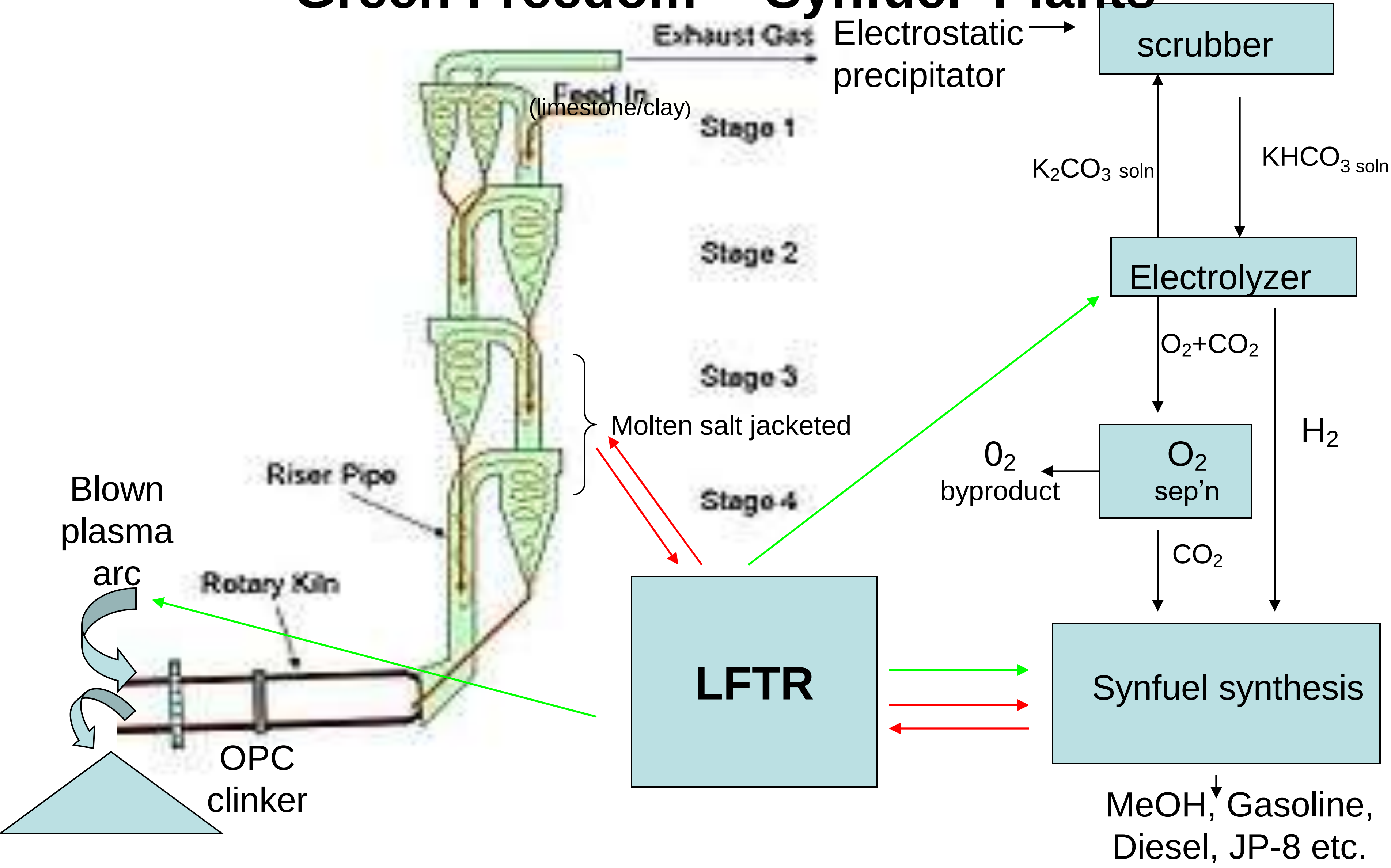


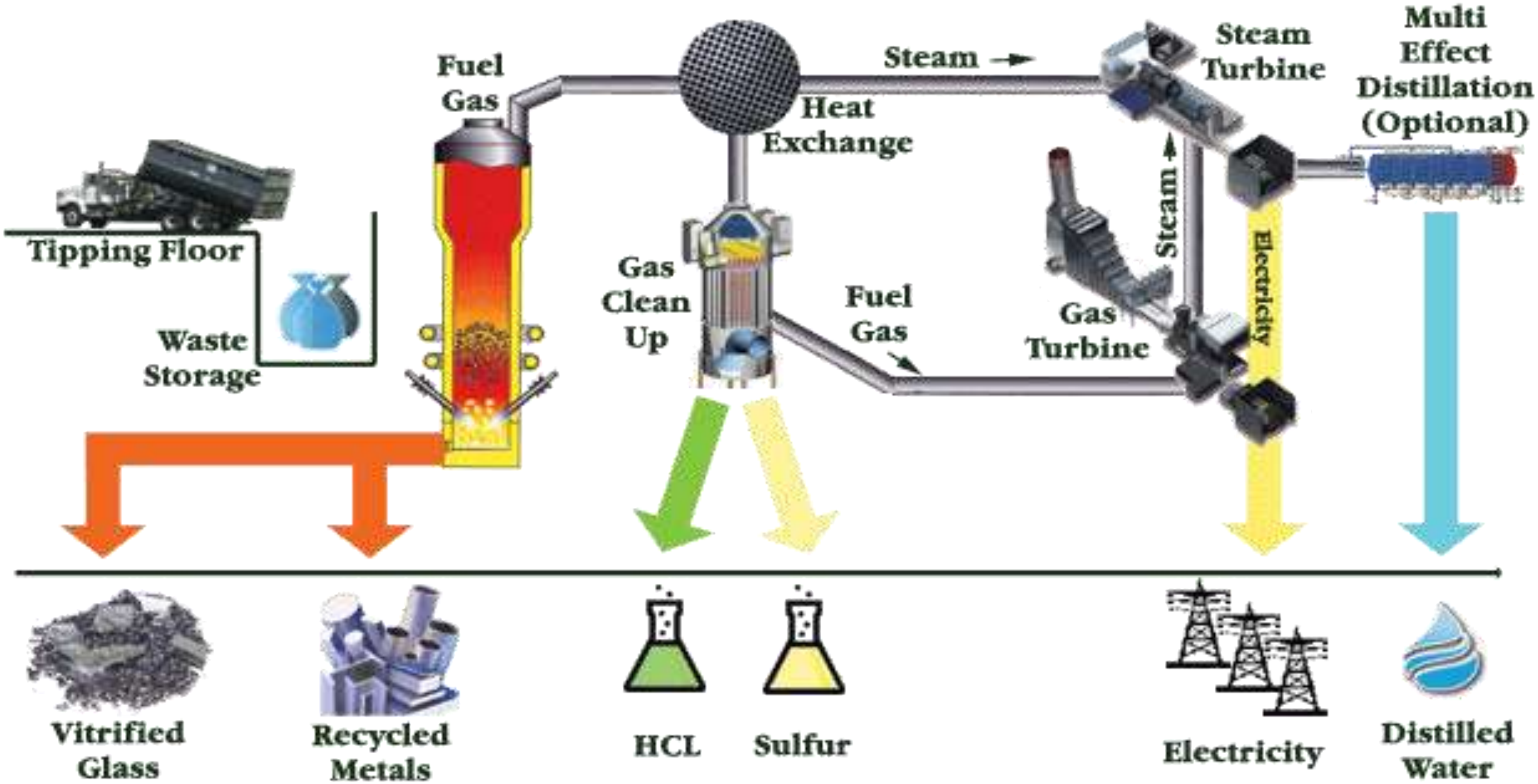


Free Piston Linear Alternator - 50% eff. on lean NH_3/air mix @48:1 CR

Published in: Qingfeng Li; Jin Xiao; Zhen Huang; *Energy Fuels* **2008,** 22, 3443-3449.
DOI: 10.1021/ef800217k

LFTR-Powered, Close-Coupled Cement & Green Freedom™ Synfuel Plants





Universal waste treatment/recycle system: One of "Prescription for the Planet"'s three revolutionary technologies (the others are the IFR and boron synfuel)

2007: MARTIN / KUBIC, LANL: Air capture with K_2CO_3

Green Freedom™ concept making gasoline with CO_2 from air with **nuclear** energy

Uses the reactor's cooling tower

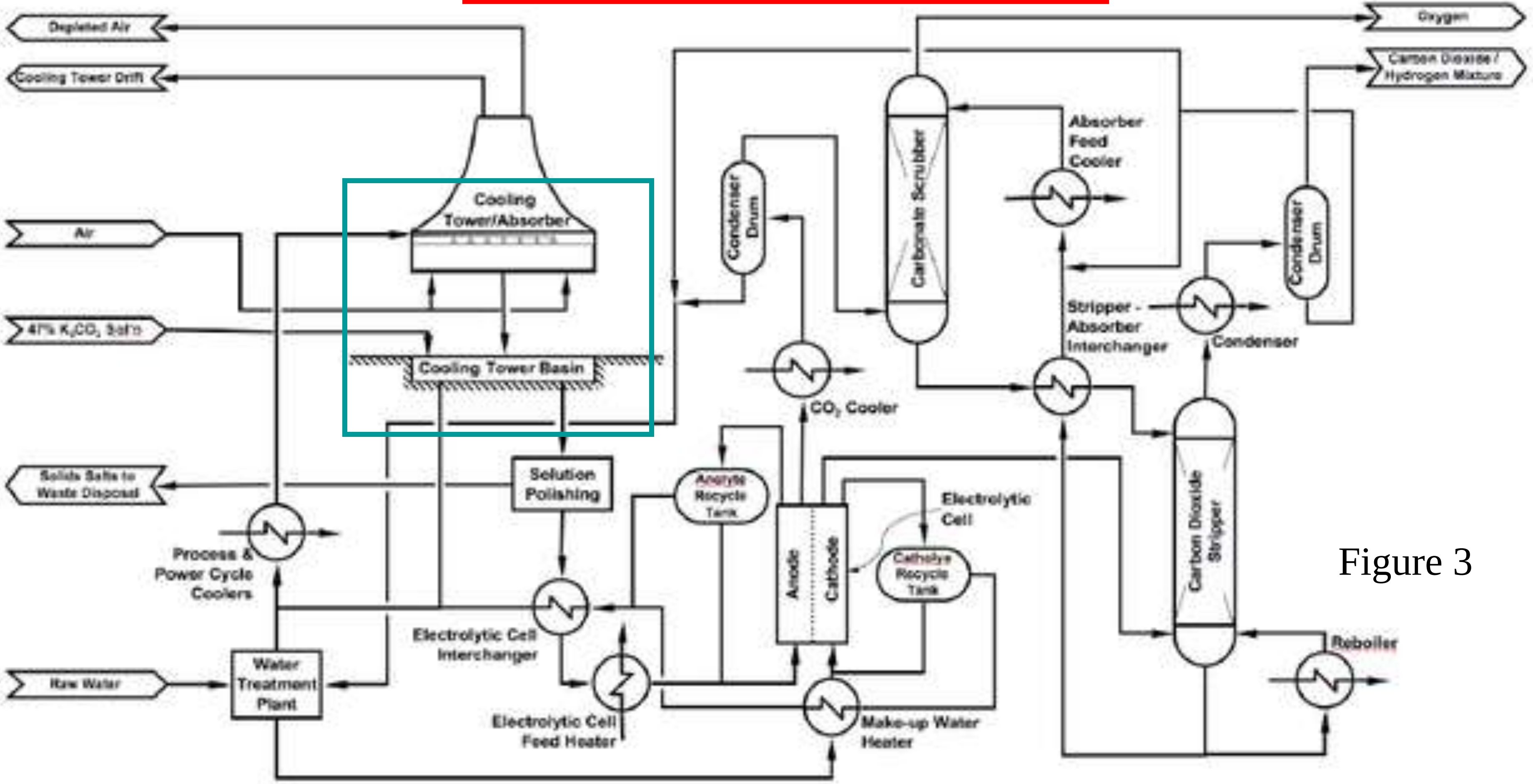


Figure 3

Green Freedom's key assumption is suspect

- The air passing through a typical GEN III nuke's cooling tower would only contain 10-15% of the carbon (CO_2) required by that concept's close-coupled synfuel plant
- This problem is further exacerbated by the fact that even sophisticated air scrubbing systems* usually don't recover more than about 60% of the CO_2

*http://people.ucalgary.ca/~keith/Misc/AC%20talk%20MIT%20Sept%20 2008.pdf

Using (cooling) towers 2

2005 KEITH

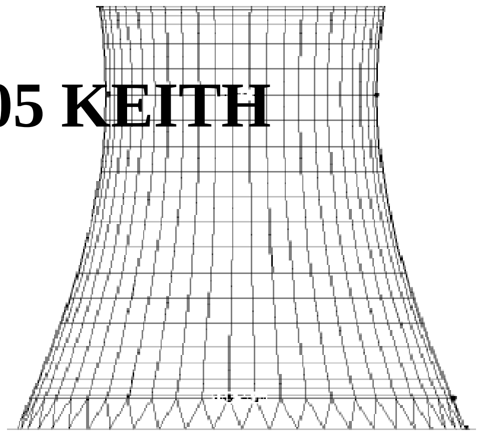


Figure 7

TABLE B.2
NaOH spray tower air capture unit: key parameters

Parameter	Value	Motivation
Tower diameter	110 m	Equal to cooling tower
Tower height	120 m	Equal to cooling tower
Air velocity	2 m/s	Reasonable value[a]
CO_2 capture efficiency from air	50%	Reasonable value[b]
Mean drop diameter	0.7 mm	Spray distribution from a hollow-cone spray nozzle
NaOH concentration in solution	3–6 mol/l	Adjusted to minimize evaporative loss based on local climate.
Carbonate captured per pass[b]	0.2 mol/l	Based on numerical model of falling drops
Solution flow rate	1 m^3/s	Fixed by above parameters
Pressure drop accross tower[b]	22 Pa	Based on numerical model of falling drops; excludes wall friction.
Electricity use	1.4 MW	Based on 75% fan and 85% pump efficiency
Carbon capture rate	76000 tC/yr	Fixed by above parameters
Capital cost[c]	$12 million	(Cooling tower cost)×1.5[c]
Operation and maintenence cost	400,000 $/yr	Conservative guess

[a]The air velocity trades off higher CO_2 throughput, i.e. lower capital cost, with increased fan energy (since fan energy goes as the square of velocity). While this value is not optimized, it falls in the likely range of the optimal value since capital costs baloon for air speeds much below this, and fan electricity costs dominate for values much above this.
[b]The capture efficiency trades off higher CO_2 throughput, i.e. lower capital cost, with increased solution pumping. Because higher efficiencies require exponentially more energy to achieve, but low efficiencies drive up capital costs, 50% is in the likely optimal range.
[c]The contactor has additional cost over a cooling tower of fans and some liquid-handling components.

In the contactor, CO_2 is absorbed into NaOH solution forming sodium carbonate (Na_2CO_3), which is then sent to the "causticizer", where the NaOH is regenerated by addition of lime (CaO) in a batch process.

The resulting $CaCO_3$ solid is sent to the calciner where it is heated in a kiln to regenerate the CaO, driving off the CO_2 in the process known as calcination.

The CO_2 is then captured from the flue gas by conventional means (such as an amine system), compressed, and sequestered for long term storage.

The net result is that CO_2 is concentrated from atmospheric levels to those required for compression and storage.

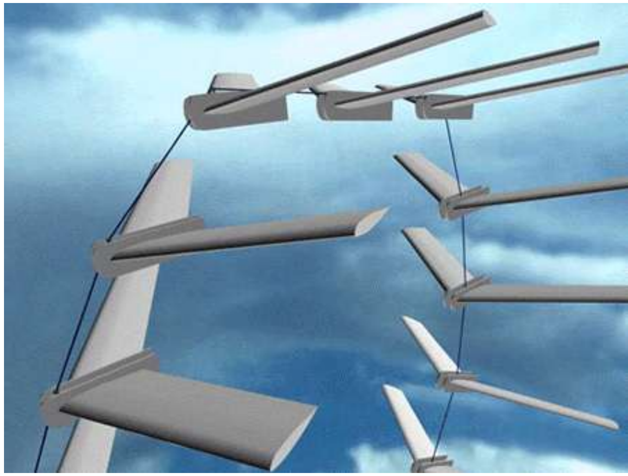
***The primary inputs are energy, water**, and small amounts of Na_2CO_3 and $CaCO_3$ to make up for losses in the regeneration process*

Carbon capture rate: 76,000 tC/yr

If CO_2 capture efficiency 50%
as stated by the authors

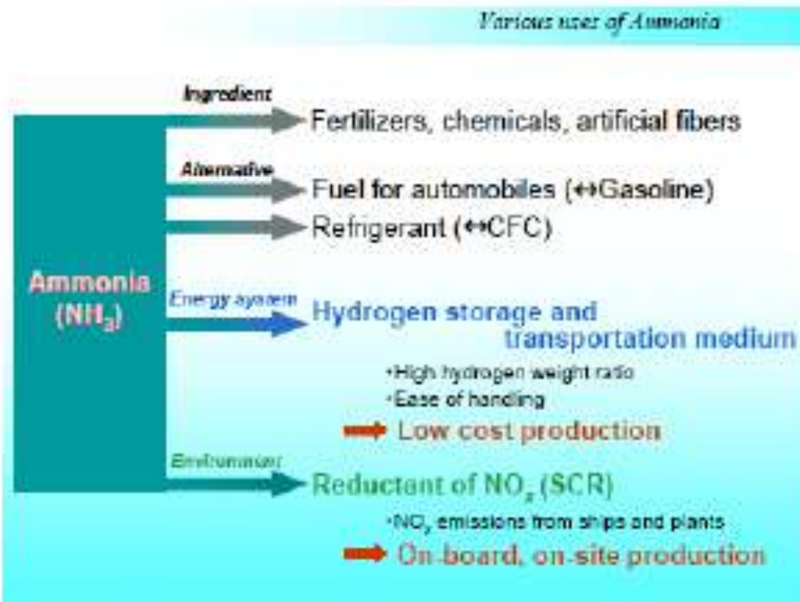
2007 HOLBROOK *Why Ammonia?*

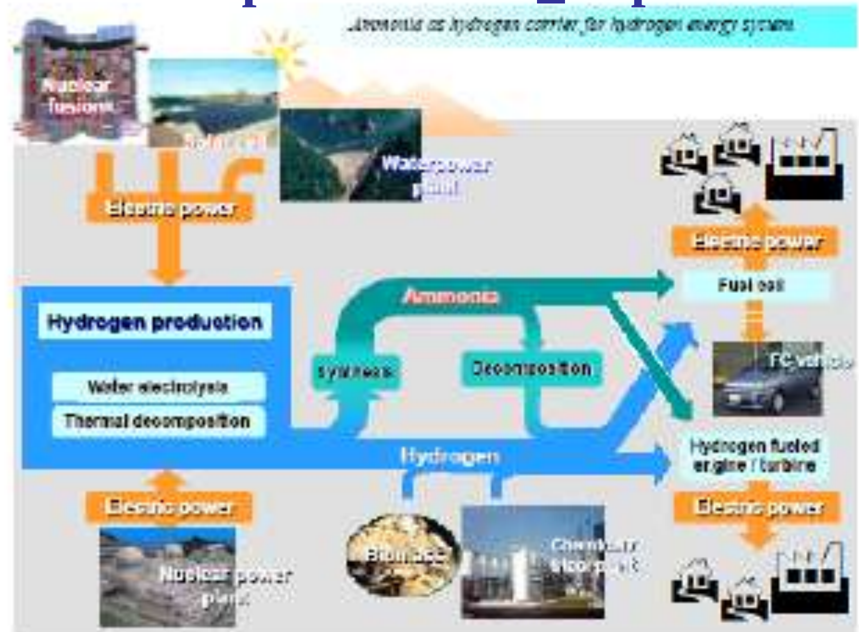
- *Ammonia is the only practical (viable?) liquid fuel that can be made from water, air, and renewable energy*
- *Energy dense*
- *Clean burning direct fuel: no carbon*
- *Excellent hydrogen carrier*
- *Widespread use/experience (#2 chemical)*
  - *US consumes 20 million tons per year*
  - *130 million tons produced annually worldwide*
- *Exists as liquid at moderate pressure/temperature Transmission and firming storage for renewables*
- *Large existing market and delivery infrastructure*
- *Ammonia pipelines ~3000 miles currently used*
- *No corrosion or embitterment problems*
- *Approximately 4.5 million tons of large-tank ammonia storage*



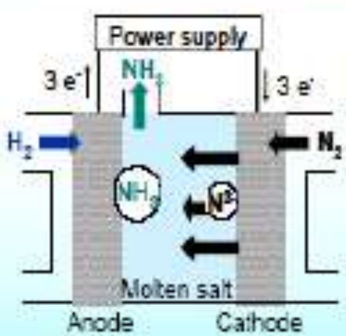
Hydrogen Energy System Coupled with Ammonia Economy

www1.doshisha.ac.jp/~ene-cent/research/example/ammonia_en.pdf





Electrolytic synthesis of ammonia under atmospheric pressure



Anodic: $N^{3-} \rightarrow N + 3e^-$

$3/2\ H_2 \rightarrow 3H$

$N + 3H \rightarrow NH_3$

Cathodic: $1/2\ N_2 + 3e^- \rightarrow N^{3-}$

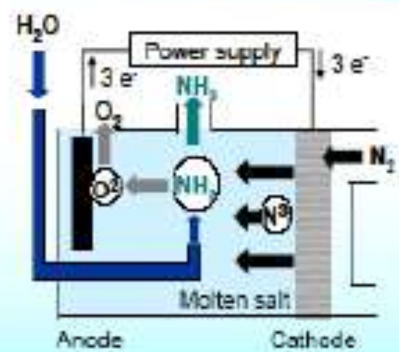
Total: $1/2\ N_2 + 3/2\ H_2 \rightarrow NH_3$

Principle of electrolytic synthesis of NH_3 from H_2 and N_2 under atmospheric pressure

Theoretical electrolysis voltage

0.054 V at 800 K

Electrolytic synthesis of ammonia from H_2O and N_2



Anodic: $O^{2-} \rightarrow 1/2\ O_2 + 2e^-$

Bulk: $N^{3-} + 3/2\ H_2O \rightarrow NH_3 + 3/2\ O^{2-}$

Cathodic: $1/2\ N_2 + 3e^- \rightarrow N^{3-}$

Total: $1/2\ N_2 + 3/2\ H_2O \rightarrow NH_3 + 3/4\ O_2$

Principle of electrolytic synthesis of NH_3 from H_2O and N_2

Theoretical electrolysis voltage

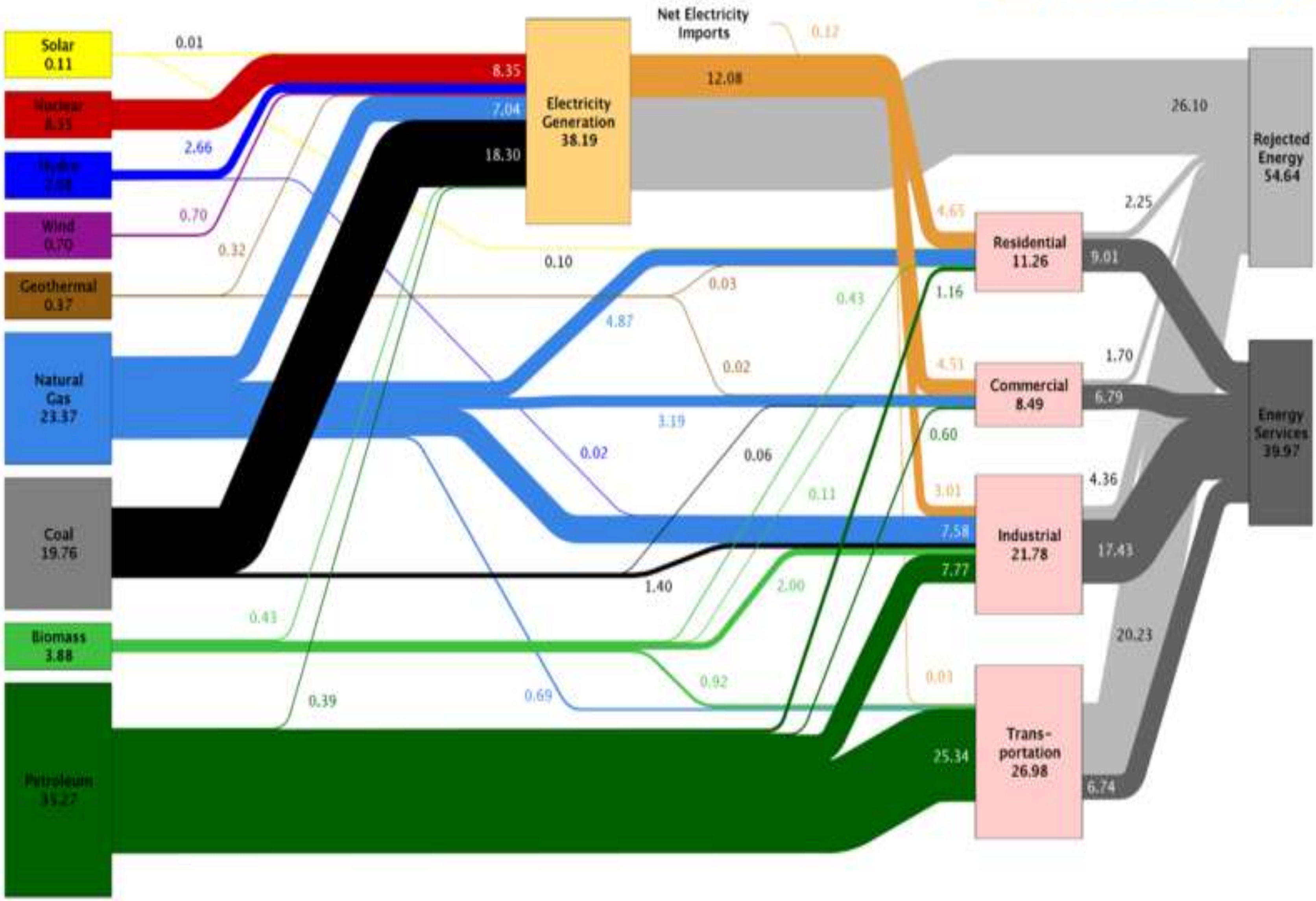
1.17 V at 800 K

LFTR-Powered Cement Kiln/Carbonaceous Synfuel Plant cont.

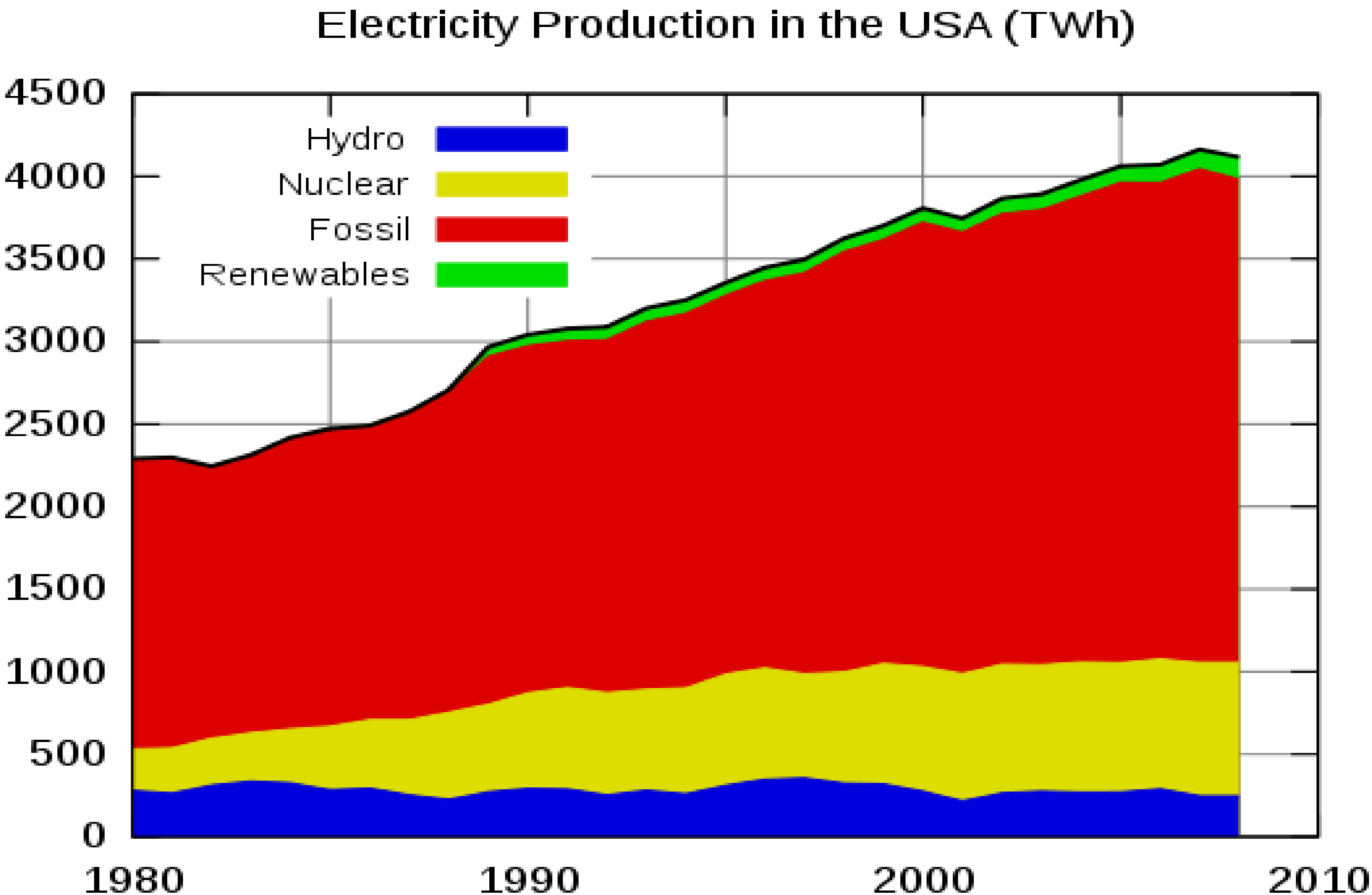
- The production of 3 quads worth of synfuel would co-generate about 390 million tonnes of OPC
- Today we only use about 100 million tonnes of OPC per year

???

Estimated U.S. Energy Use in 2009: ~94.6 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


Electricity Production in the USA (TWh)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1980
1990
2000
2010
Hydro
Nuclear
Fossil
Renewables

Putting out the FIRE

- **The USA's economic system has become largely based upon the speculations of an unregulated financial sector (<u>F</u>inance, <u>I</u>nsurance and <u>R</u>eal <u>E</u>state –"FIRE") which has grown exponentially while much of the rest of the economy has withered**
- **It is primarily due to the fact that our government protects the fiefdoms of the "establishment" (e.g., its own people/programs, the health professions & the insurance, financial, & pharmaceutical industries) while subjecting both us and <u>new ideas</u> to the tender mercies of untrammeled capitalism**
- **Our government's policies have encouraged the deindustrialization which has left us with crumbling infrastructure and insufficient good jobs to provide a decent standard of living for many**
- **This combined with the consequences of Peak Oil and Global Warming constitute facts which must be addressed**
- **A properly implemented *Nuclear Renaissance could* provide a technological fix**

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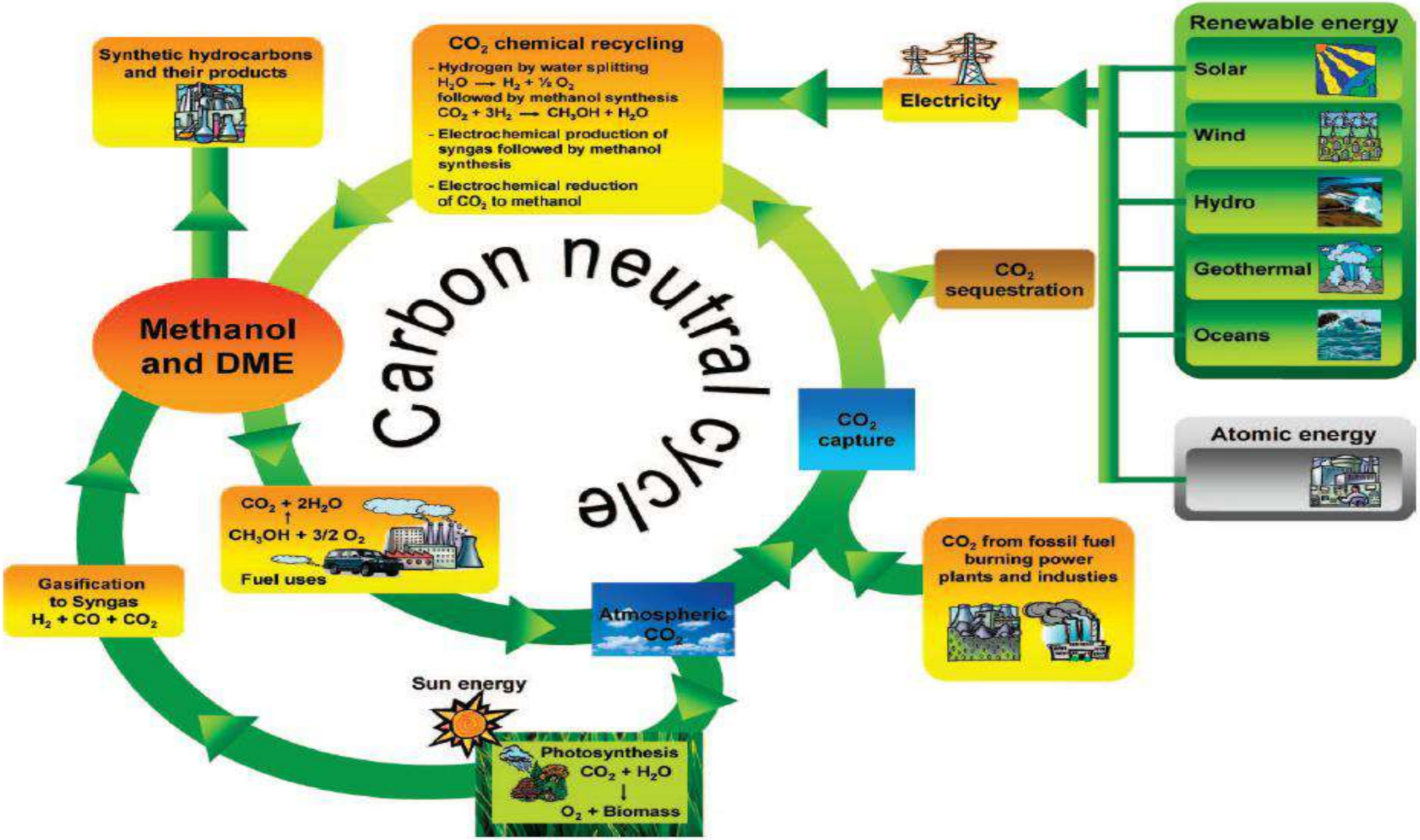
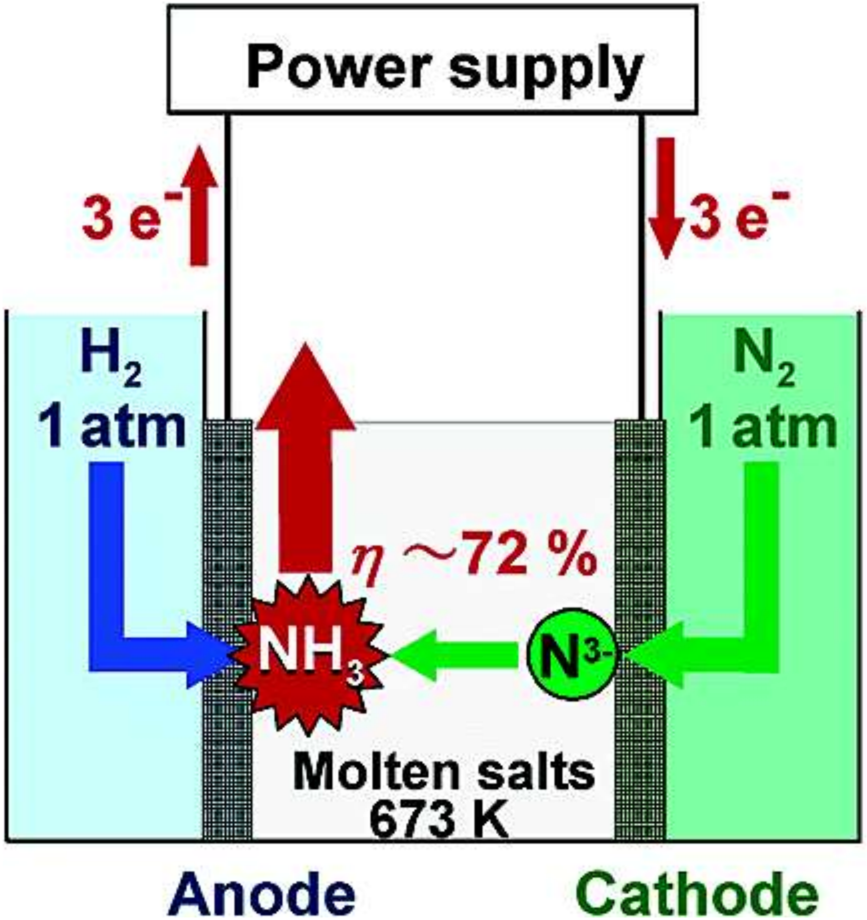
*__total special interest lobbying expenditures in 2008 = $3.3 billion__

http://www.opensecrets.org/lobby/index.php



George A. Olah, Alain Goeppert, and G.K. Surya Prakash, *"Chemical recycling of CO2 to…",* J. Org. Chem. Vol. 74, No. 2, **2009**



Anode

$$3/2\ H_2 + N^{3-} \rightarrow NH_3 + 3\ e^-$$

Cathode

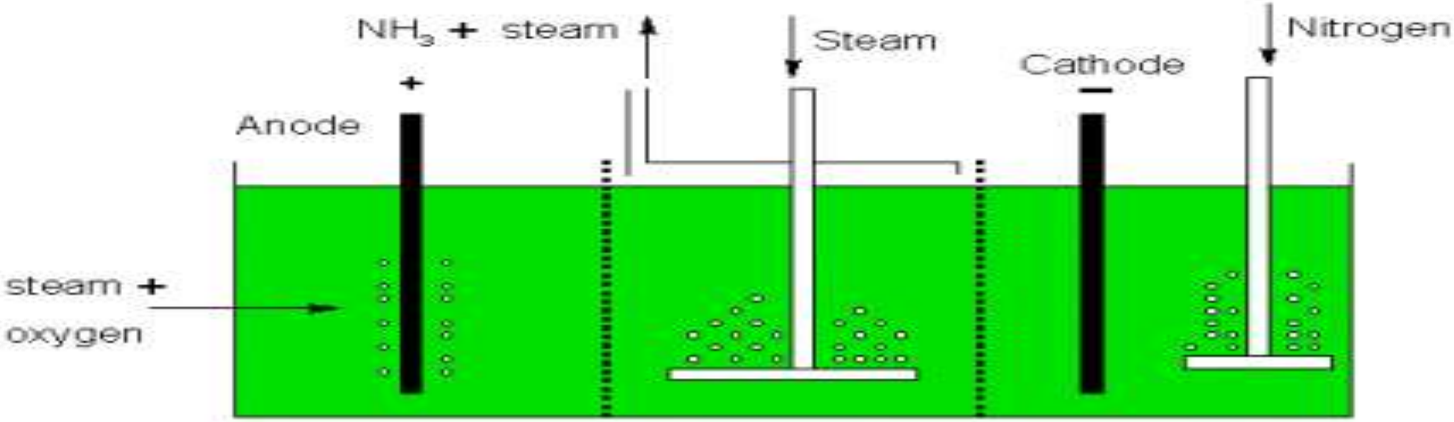
$$1/2\ N_2 + 3\ e^- \rightarrow N^{3-}$$

Total

$$3/2\ H_2 + 1/2\ N_2 \rightarrow NH_3$$

Murikami et al, J. Am. Chem. Soc., 2003, 125 (2), pp 334–335

Ammonia Electrosynthesis in Molten Lithium Hydroxide



Molten anhydrous LiOH (m.p. 450 C) electrolyte at ca 500 C

Cathode : 6 Li^{1+} + electricity -----------> 6 Li^{o} ;

then 6 Li^{o} + N_2 (g) -------> 2 Li_3N

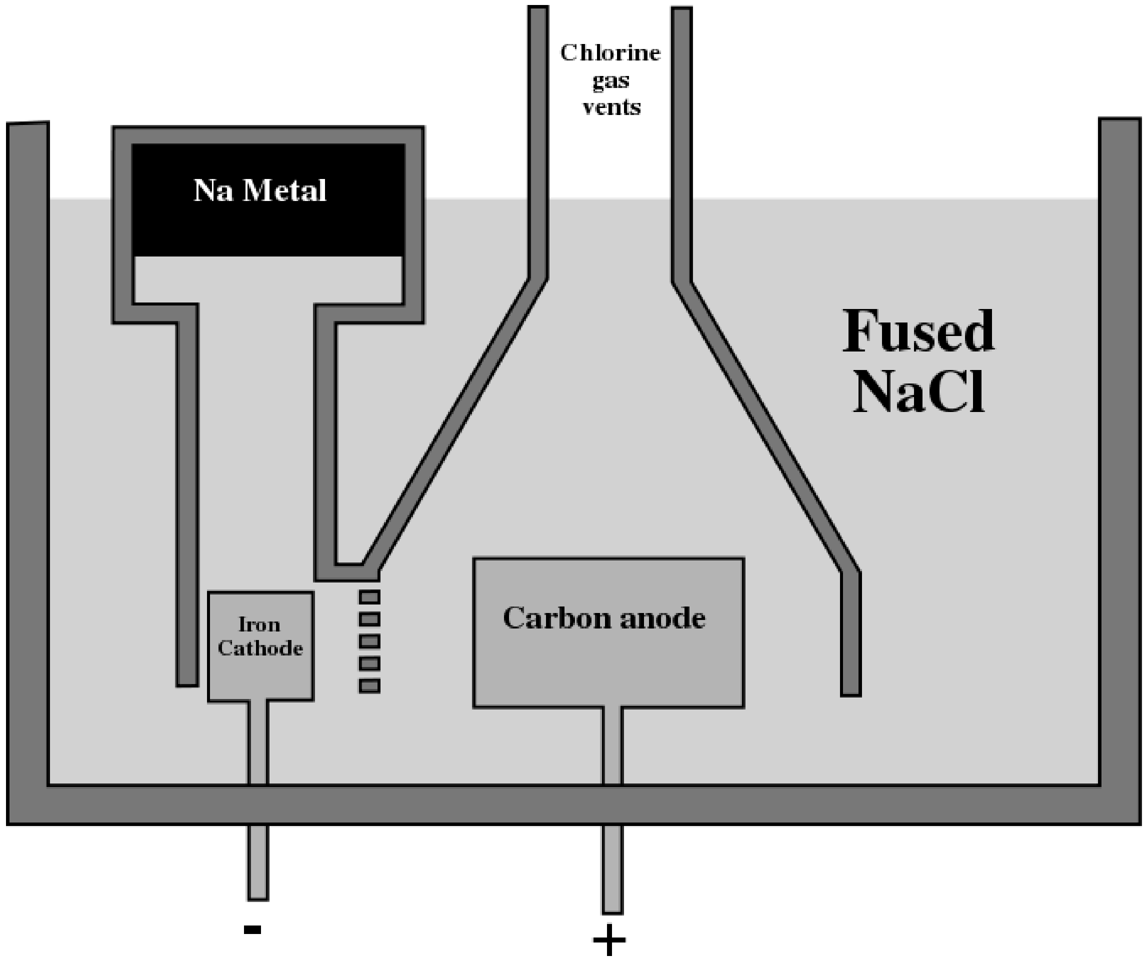
Middle chamber : 2 Li_3N + 6 H_2O (g) ---------> 6 LiOH + 2 NH_3 (g)

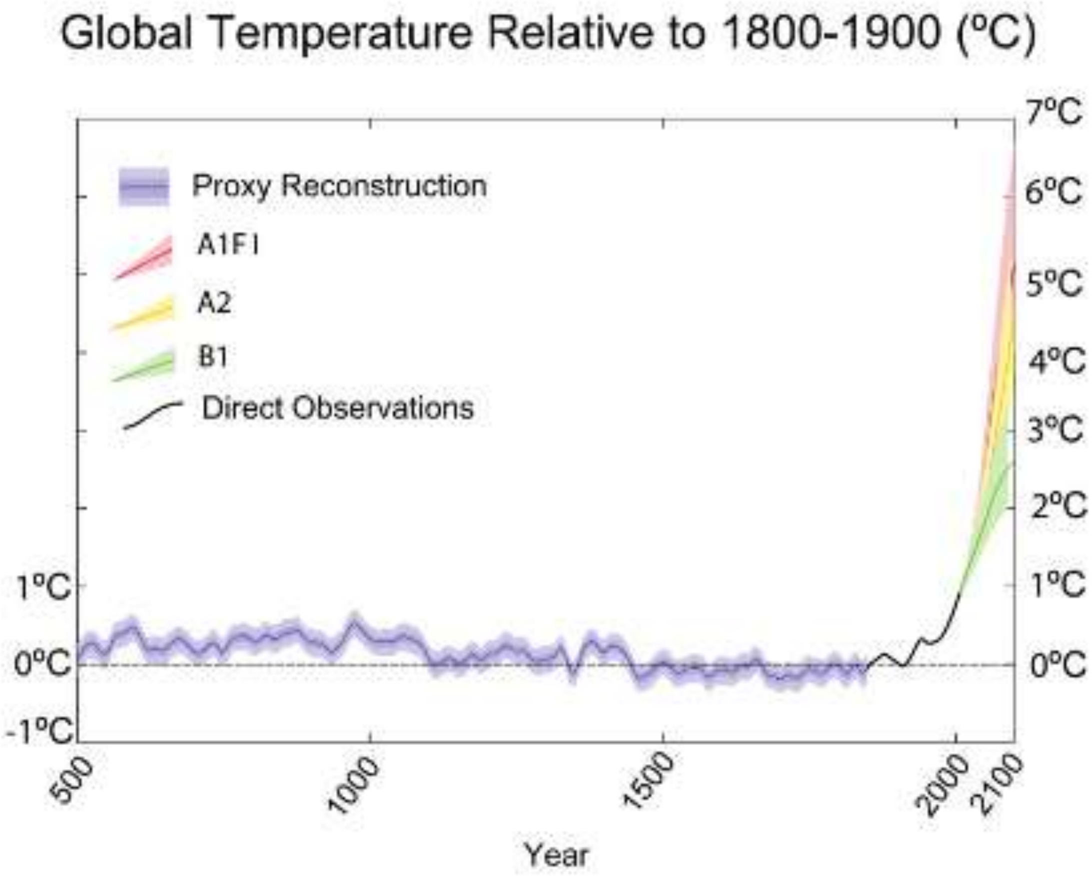
Anode : 6 LiOH ---------> 6 Li^{1+} + 1.5 O_2 (g) + 3 H_2O (g)

Net reaction : N_2 (g) + 3 H_2O + electricity ---------> 2 NH_3 (g) + 1.5 O_2 (g)

http://www.chemexplore.net/lithium.htm

Downs Cell for alkali metal prdn.





http://inside.mines.edu/~jbeach/ammonia-fuel.v02.pdf

Our best hope?

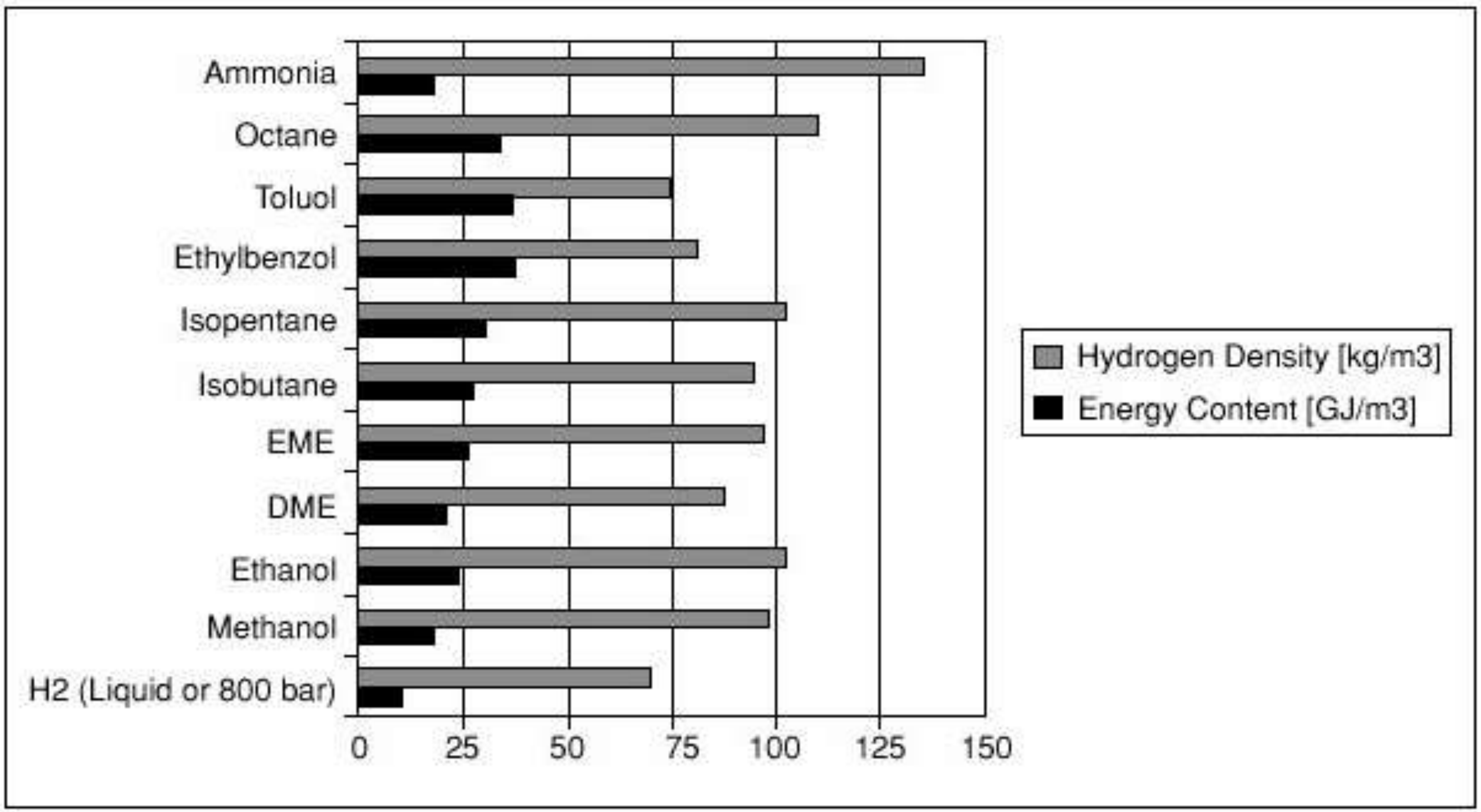
“The US military - the world's single biggest user of petrol - is intent on reducing its costly oil consumption without having to suffer major cuts to its force. How? The Department of Defense is committed to going "green", making energy a strategic issue for the first time.”

Unfortunately

"The US military is doing the right thing but not doing it right…pays too much attention to the energy consumed by buildings and platforms rather than that used by tactical vehicles, especially aircraft and ground vehicles…virtually 100% oil”.

http://www.geopoliticalmonitor.com/us-military-to-cut-oil-consumption-4292/

Hydrogen density and heating value of ammonia and other liquid fuels.



Ammonia used in a conventional fuel cell must first be "cracked" to a mix of elemental N_2 & H_2

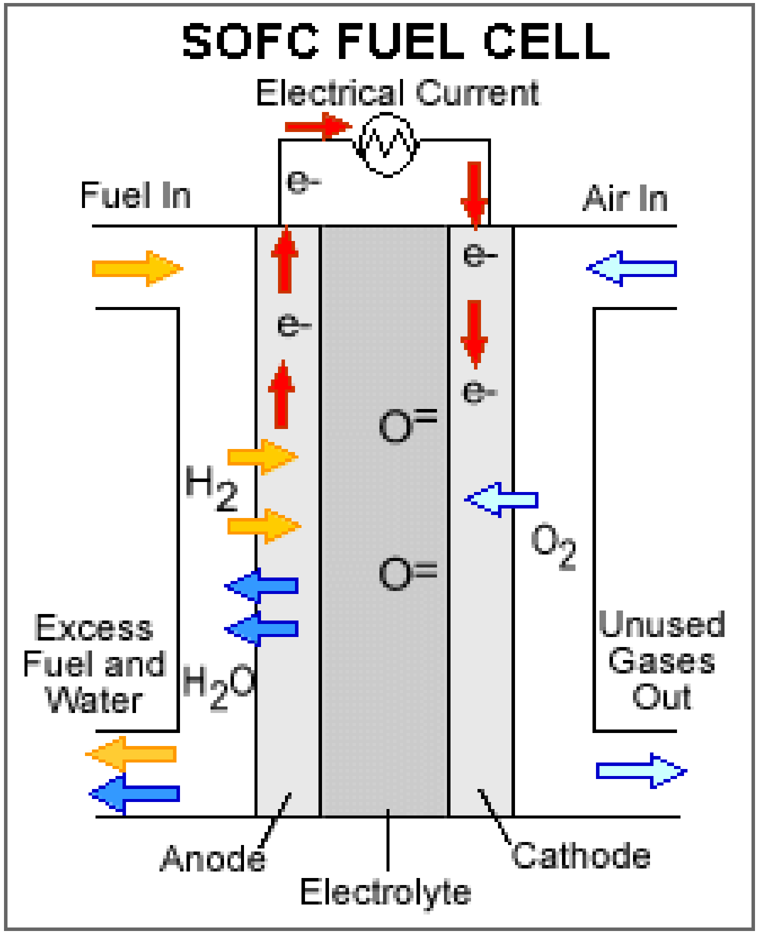
- A fuel cell exhaust flame-heated stainless steel "cracker" works fine [Kordesch et al]
- Alkaline fuel cells are more practical than the usually envisioned acidic PEM types because, a) they're much cheaper (works fine with a silver rather than Pt catalyst) and b) aren't "poisoned" by traces of residual ammonia.

Ref.

http://www.electricauto.com/_pdfs/Ammonia_HydrogenSource.pdf

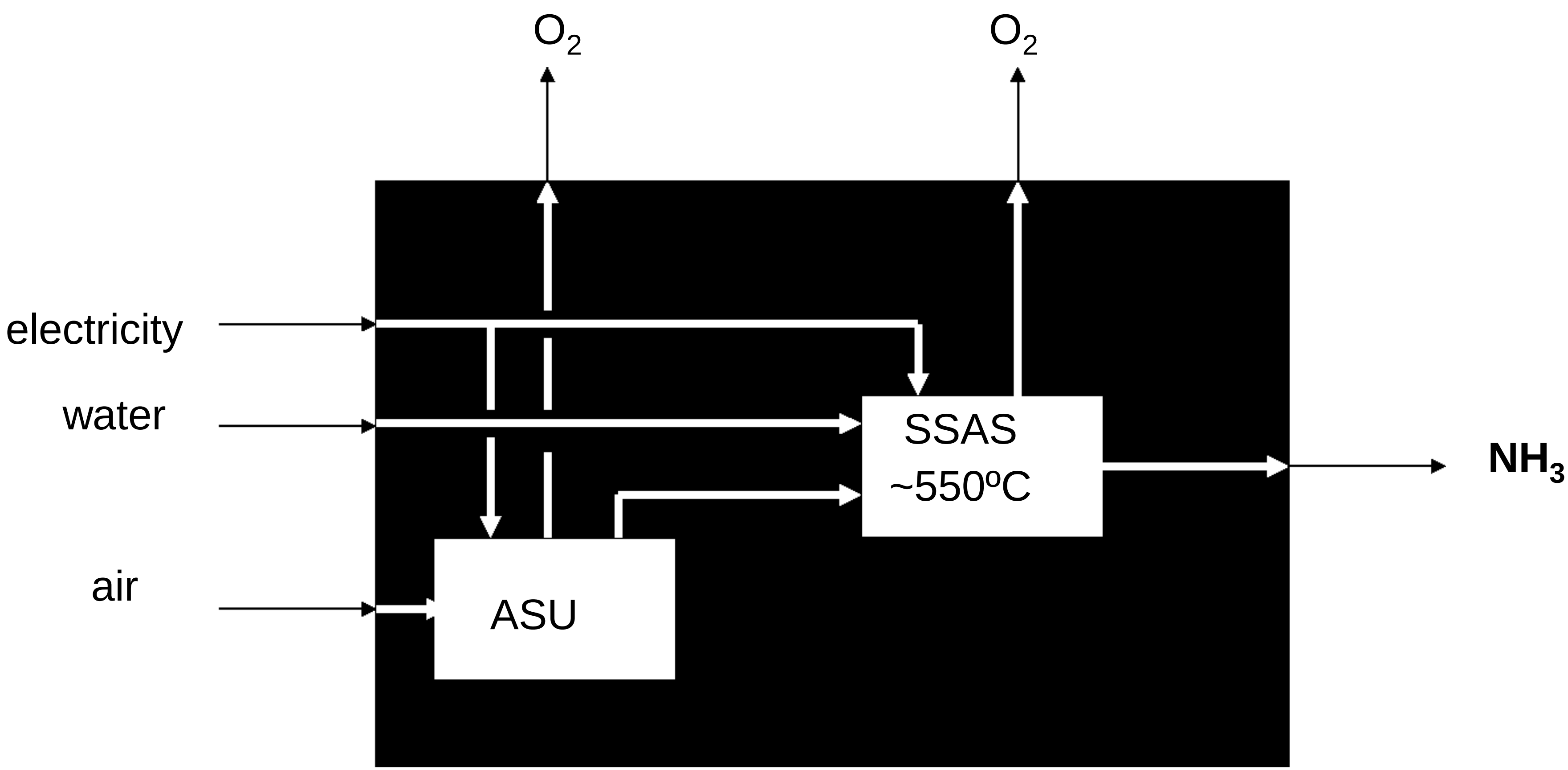
A Better Way - Direct Ammonia Fuel Cells (DAFC)

- **Several sorts of fuel cells can operate directly with ammonia (and air) without first "cracking" it to elemental hydrogen**
- **Solid oxide fuel cells work with direct ammonia feed-recently cells based on proton-conducting ceramic electrolytes and molten salt electrolytes have been developed**
- **They all enable high efficiency conversion of ammonia to electric power and therefore take advantage of the superior energy density storage of ammonia compared to hydrogen.**



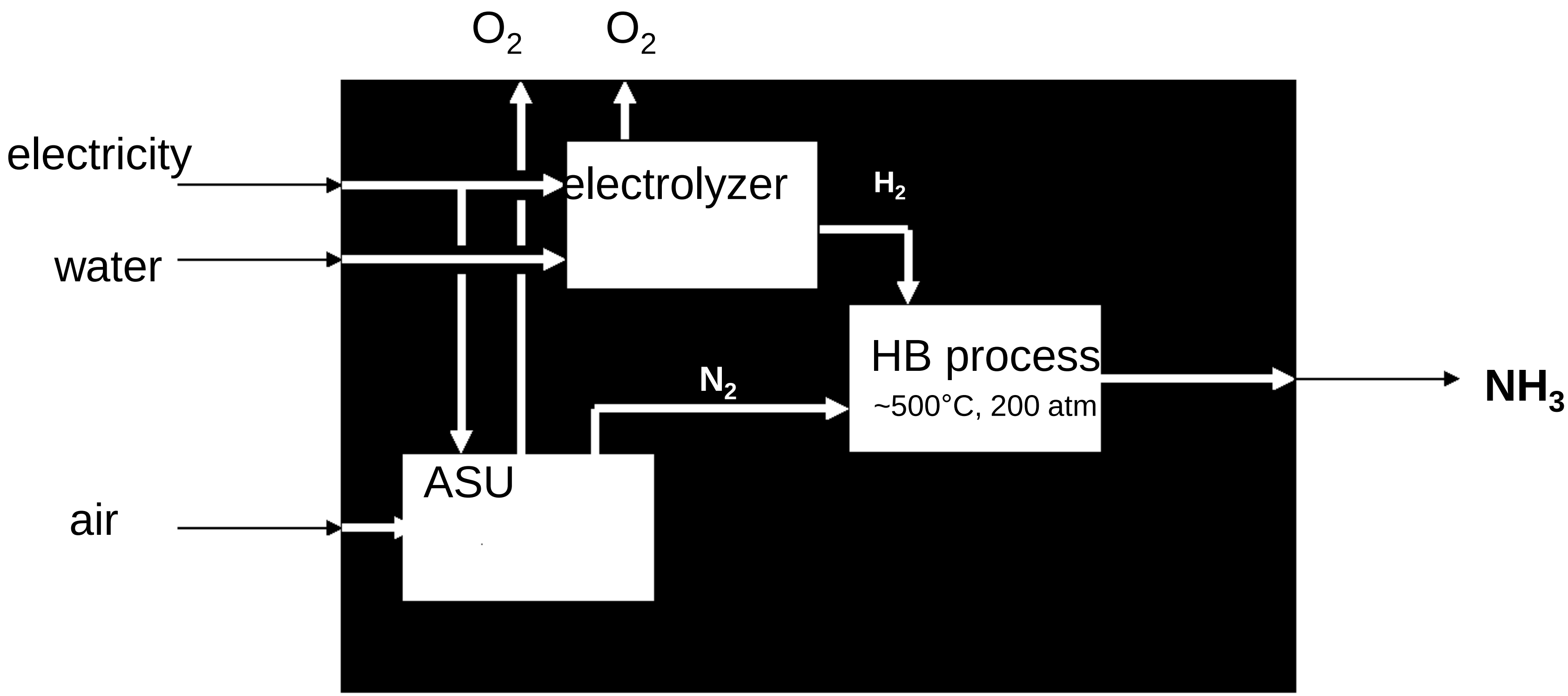
(Contact: Jason Ganley, NHThree LLC, 202-806-4796, jganley@howard.edu or Andy McFarlan, KANNET Natural Resources Canada, 613-995-2376, anmcfarl@nrcan.gc.ca)

“Green” Ammonia - SSAS



Energy input ~7500 kWhr/ton of ammonia

"Green" Ammonia – electrolysis + Haber-Bosch



Energy input ~12,000 kWhr/ton of ammonia

SSAS Features/Advantages

- Simple/cheap - doesn't require a separate water electrolyzer (but nevertheless still produces the valuable pure O_2 by-product)
- The enormous pressure required for the Haber-Bosch process isn't required
- Easy scale-up – just add more synthesis tube bundles
- Superior overall efficiency

A key point is that H_2 gas is never formed as an intermediate product & therefore doesn't have to be stored/handled

Eisenhower’s Farewell Address

“As one who has witnessed the horror and lingering sadness of war – as one who knows that another war could utterly destroy this civilization which has been so slowly and painfully built over thousands of years – I wish that I could say tonight that a lasting peace is in sight.

As we peer into society’s future, we--you and I and our government– must avoid the impulse to live only for today, plundering for our own ease & convenience, the precious resources of tomorrow. We cannot mortgage the material assets of our grandchildren, without risking the loss also of their spiritual and political heritage. We want democracy to survive for all generations to come, not to become the insolvent phantom of tomorrow.”

Why don't we act?

- Cognitive dissonance/bias/distortion/ inertia
- Wishful thinking
- True believer syndrome (irrational faith in "principles")
- Conflict avoidance
- Sunk cost bias

Abetted by

- Deliberate misinformation via a for-hire news media
- Information overload
- Economic fears/uncertainties
- Special interests dominated government