A Conservative Approach to the Development of Hybrid Fusion

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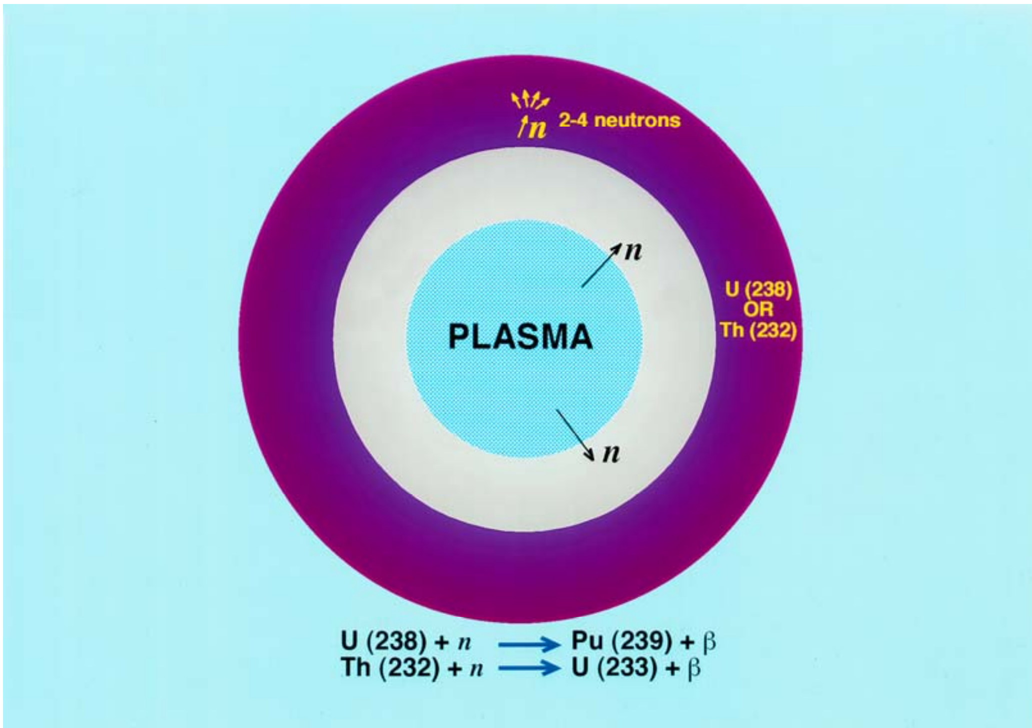
Points I hope to make:

- Energy, not waste cleanup is the crucial issue.
- Some of the MFE schemes for waste disposal are **VERY** aggressive as regards the plasma science.
- Other waste options besides burial are available and are further along in development than fusion.
- Fusion has real advantages over these other approaches as regards fuel production.
- More conservative approaches for large scale energy and waste treatment for midcentury appear to exist for both MFE and IFE and have a better chance of success.
- Time horizon appears long, but in reality is **VERY** short.

The fusion hybrid:
From Hans Bethe, Phys. Today, May 1979



Wall must contain Neutron multiplier so To breed both T and ^{233}U

But each 233U releases ~200 MeV when burned. Q is effectively raised by at least an order of magnitude

Fission is energy rich and neutron poor, while fusion is energy poor and neutron rich. A perfect match!

This is a very old idea

- Andrei Sakharov, Memoirs, p142: “An important proposal of mine (in 1951 or late 1950) was that neutrons from thermonuclear reactions be used for breeding purposes”.

- Hans Bethe, Physics Today, May, 1979: “It seems important to me to have an achievable goal in the not too distant future in order to encourage continued work, and continued progress toward the larger goal, in this case pure fusion”

- Others: L. Lidsky, R. Moir, W. Stacy, D. Jassby, etc

Energy cost of a neutron

- Fission reactors (thermal or fast neutron): E~200MeV, ~2.3 neutrons (thermal a little less, fast neutron a little more), 1 to continue reaction, so 1.3 neutrons for other purposes, or ~150Mev/n
- Accelerators: Electricity (η~33%) →Accelerator (η~50%) →1Gev proton →~30 spallation neutrons, or 200 MeV/n
- Fusion: E~20MeV →2-4 neutrons (Bethe), one to produce T, so 1-3 for other purposes, or 6-20MeV/n
- FUSION HAS A LOWER ENERGY COST/N BY MORE THAN AN ORDER OF MAGNITUDE

NAS Review ~ 1984

- Recommended against separate program for hybrid fusion:
- Envisioned rapid development of pure fusion. Report was at a time of large and increasing fusion budgets.
- Saw conventional and hybrid fusion as following the same path so hybrid could ride coattails. One could always switch to hybrid fusion at an appropriate time.

What has changed?

- Fusion’s disappearing coattails
- Much faster world development, especially in China and India than NAS envisioned
- China now world’s largest carbon emitter
- Africa, Latin America and rest of Asia will most likely follow
- Energy supplies are extremely stressed
- Possibility that tokamaks, magnetic fusion’s best hope may stop short of reaching pure fusion (9)
- Possible End of Yucca Mountain, Waste disposal????
- From 1992-2008 I seemed to be about the only one, at least in USA, advocating hybrid fusion (1-10)
- Interest and recent meetings devoted to the hybrid.

What role should fusion play now?

- One might think that we go to hybrid fusion instead of pure fusion, great new vistas open up.
- But if pure fusion is next to impossible, then hybrid fusion is very difficult.
- In my opinion this means the best pure fusion device will be the best hybrid fusion device
- This leaves only tokamaks and laser fusion left standing. Only these have the worldwide infrastructure and sufficient head start to continue the race.
- USA has already abandoned partially constructed mirrors and stellarators.

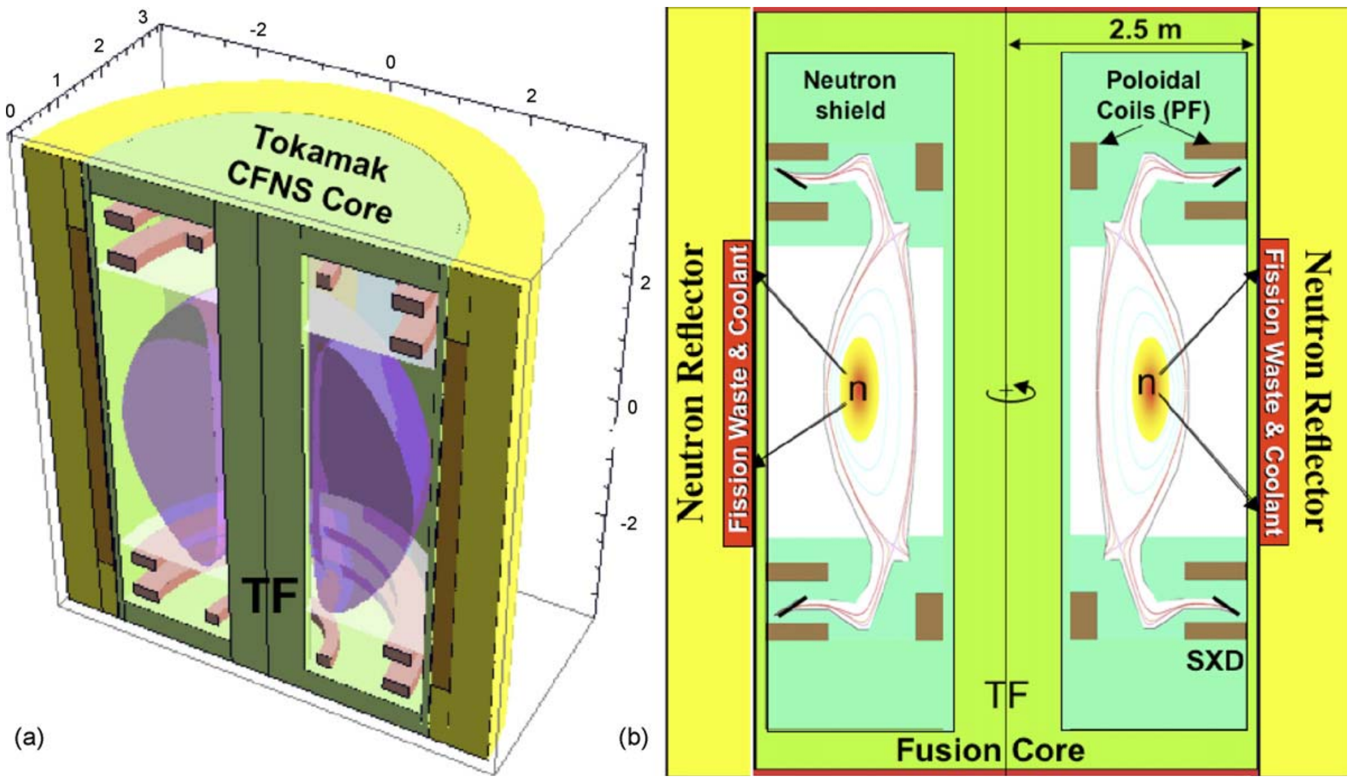
What to do with these neutrons?

- Boil water i.e pure fusion, (Maybe in 22nd century)*
- Burn actinide Waste (No, certainly not first application)*
- Fast Fission, i.e. combine fission and fusion in a single power plant (No, certainly not first application)*
- Fission Suppressed, i.e. use fusion to produce nuclear fuel for use in conventional nuclear plants (yes)*
- Transmute long lived radio isotopes, i.e ^{99}Tc (maybe)* [see ref 6]

* Author's opinion

Conference seems to be focusing on waste treatment, portraying glass as half full, I'd like to give the half empty perspective

From Kotschenreuther et al, Fusion Engineering and Design, 84, p83, 2009



Fusion reactor surrounded by subcritical fission reactor

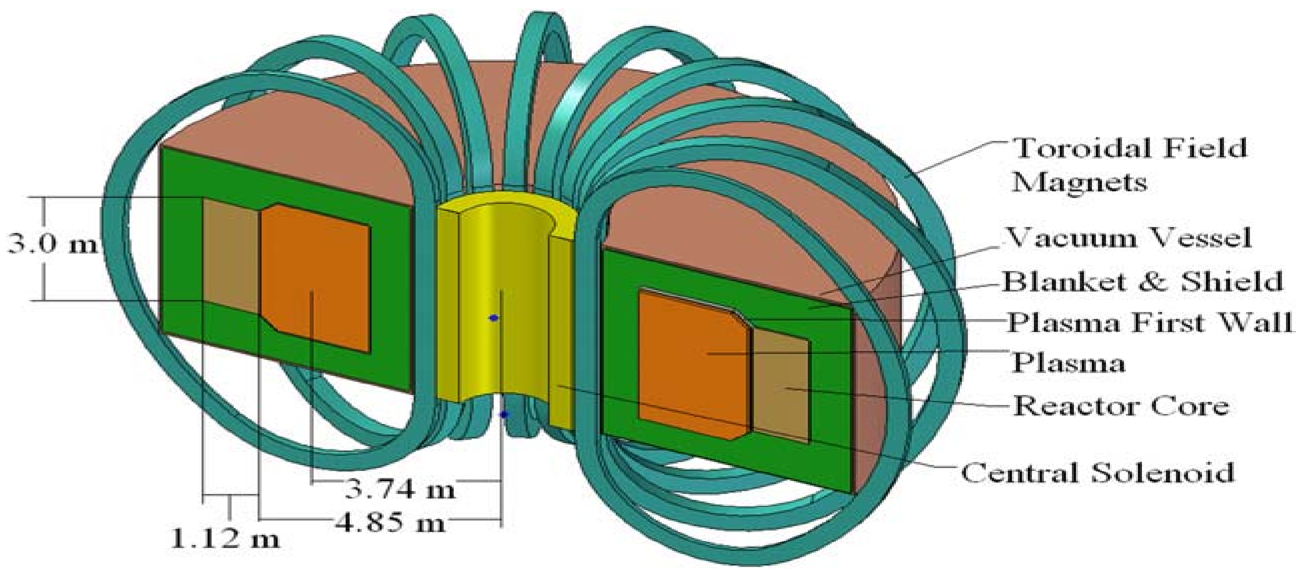
- Neither a subcritical fission reactor nor fusion reactor has ever been built, but they have to work together seamlessly.
- Google search on subcritical reactors emphasize accelerators to provide neutrons, accelerators at least have standoff; 100 MW fusion reactor sits right in the middle of a 3 GW nuclear reactor, k apparently~0.5- 0.7, so most neutrons from fission anyway.
- Plasma which we do not understand very well, and which might disrupt, is just a thin wall away from a ton or so of plutonium.   Significant safety issue.

Subcritical reactor con’t

- Uses copper magnets. Power drain not given, but in GA FDF proposal seemed to require 500 MW, but for a larger system
- Beams, rf, lots of wires, etc, must pass through a 3GW nuclear reactor to reach the plasma deep inside. Can this really be done? Has anything like this ever been done?
- Can the thin center post really absorb the neutron flux and the current from all the toroidal field coils and remain viable? How would one cool it?
- In places walls seem thinner than conventional designs. Neutron leakage?

A Conventional tokamak approach

- From Stacy et al, nuclear Technology, 162, 53, 2008. More nuclear science than I'll ever understand, but plasma requirements seem to push the envelope.



Let's look at confined energy

- Energy:

$$E_{tor}(MJ) = 2\pi^2 R(m)a(m)b(m)\frac{2B_{tor}(T)^2}{5}$$

$$E_{pol} \approx 2\pi^2 Rab\frac{2B_{pol}{}^2(r=\sqrt{ab})}{5}$$

$$E_{plas} \approx \beta\left(E_{tor} + E_{pol}\right) \equiv 10^{-2}\frac{\beta_N I}{aB}\left(E_{tor} + E_{pol}\right)$$

What are these energies, and energy densities for JT-60, ITER, Scientific prototype, Texas and GA Tech waste burners, and NSTX?

Remember 2 MJ ~ 1 pound of TNT, and plasma, poloidal, and maybe even toroidal energy can be released suddenly.

The energy content and energy densities in UTX and GATECH proposed devices (which might disrupt) are orders of magnitude greater than any other existing or proposed device.

	JT-60	Sci. Pro	ITER	NSTX	UTX	GA Tech
R(m)	3.4	4	6.2	0.8	1.35	3.9
a(M)	1.1	1	1.7	0.4	0.75	1
b(M)	1.5	1	3	0.8	2.25	2
Vol(M3)	110	80	630	5	45	150
I(MA)	3.4	2.3	15	1.5	15	10
B(T)	4.2	5.5	5.3	0.55	30	
Epol+Epl (MJ)	3	1.7	75	0.25	300*	300@
E/V (MJ/M3)	0.027	0.021	0.12	0.05	7	2

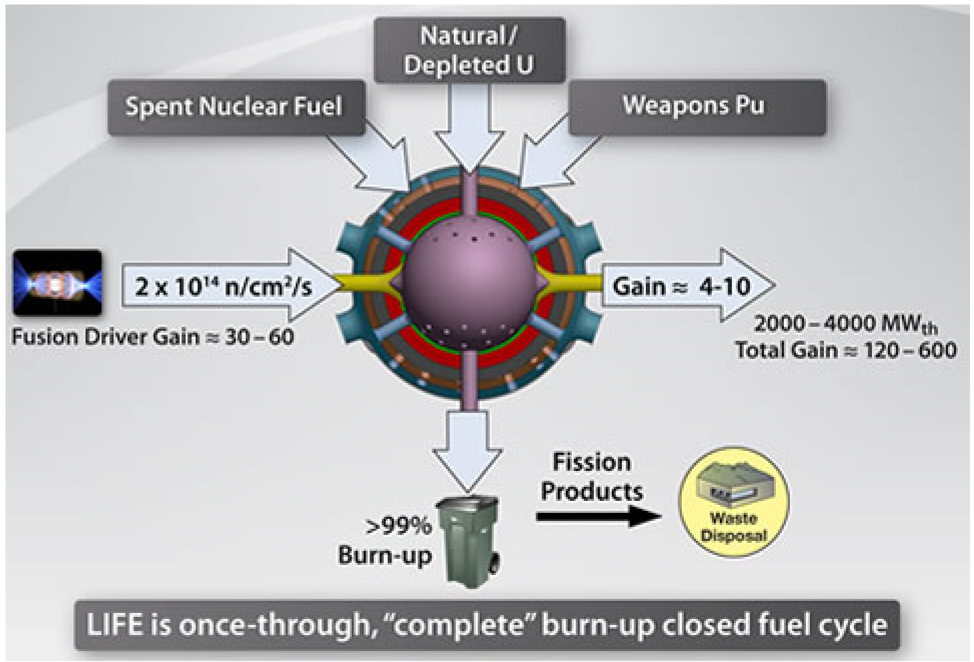
- *Including toroidal field energy since a disruption will most likely release it also
- @Assuming Epl~Epol

There are also neutron predictions

	JET/JT-60 Transient	JET/JT-60 Steady	ITER	UTX	GA Tech
R(m)	3.4	3.4	6.2	1.35	3.9
V(M^3)	110	110	630	45	150
P(n,MW)	20	<10	400	100	500

- Question: Why do the UTX and GA Tech machines do so much better than ITER which was designed by the best in the world over a period of decades?
- We want the answer to this not from GA Tech or UTX, but from the ITER designers. If ITER approves, why did they design such a large, expensive machine?

What about Livermore's LIFE?

- 

Being sold principally as a way to burn up nuclear wastes. Proposes an indirect drive pellet (gain~30-50) being injected 10-15 times a second.

MORE ON LIFE

- Indirect drive requires the dropped pellet to be properly oriented on three axes, rather than a sphere as in direct drive pellets.
- Indirect drive reduces gain.
- Cost of the hohlraums: Denise Hinkel told me that current hohlraums cost ~$10,000 and have expensive metal, i.e. gold, etc.
- LIFE has neither been documented in the archival literature nor been reviewed by an external committee (as of early June, 2009).
- LLNL portrays LIFE as environmentally benign, but how do they think Greenpeace and NRDC will react when they learn that they plan to blow up the equivalent of 15-25 lbs of TNT, 10 times a second in a chamber surrounded by a ton or so of plutonium?

Regarding accidents

- Despite the late night comic’s take on the continual explosions in an IFE waste disposal scheme, it has no stored energy near the actinides, so less of a chance of a catastrophic single point failure than the MFE version which, may disrupt and release energy of hundreds of pounds of TNT right into the plutonium.
- If waste treatment is the sole option considered for early fusion development, probably IFE is the only way to go.

Why not use fast neutron reactors to treat waste.

- A solution to the waste actinide problem already exists, fast neutron reactors like the IFR and AFR. These have been built, tested and they work.
- One could argue that IFE or MFE is an expensive, and technically risky, and indeed dangerous solution to a problem which has already been solved.

Is fusion better than fast neutron fission (i.e. Integral fast reactor (IFR))?

- Kotschenreuther: “The transuranic ‘sludge’ is extremely unfavorable as a fuel for any critical system”
- But:
- Charles Till (Leader of IFR project) in PBS frontline interview: “.. But {the waste contains} none of the long lived toxic elements like plutonium, americium or curium, the so called man made elements.”
- Wikipedia article on IFR: “The reactor was an unmoderated design running on fast neutrons, designed to allow any transuranic isotope to be consumed.”
- George Stanford (a designer of the IFR): “Transuranic sludge” is a strange term. That “sludge” is ideal for getting IFR’s running…. Wikipedia is correct, any actinide, from uranium on up can be consumed in an IFR.”

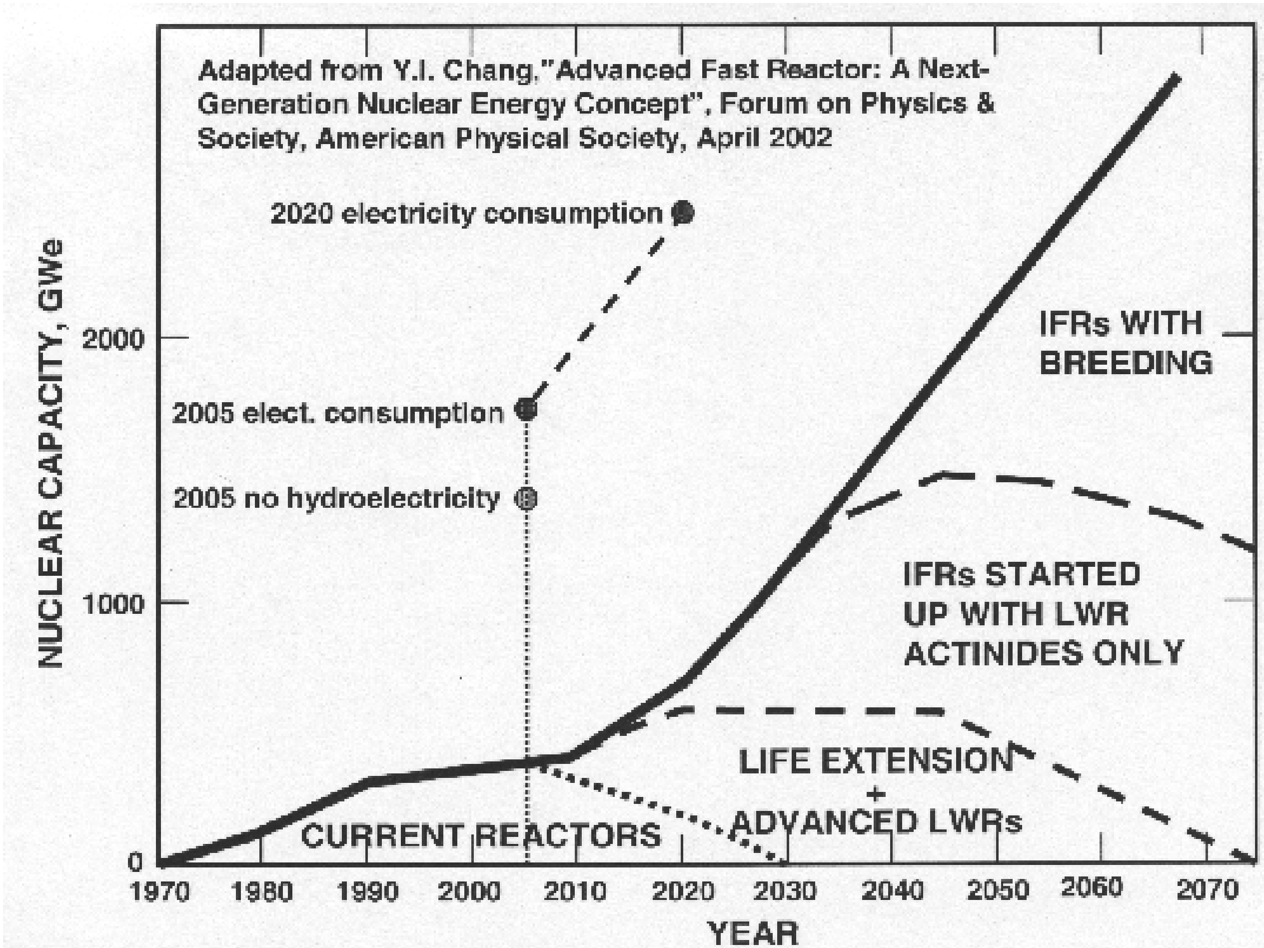
The IFR

- Was built and worked well for several years.
- Claimed it burns all transuranic elements, and does so in reactor mode which is passively safe.
- Can run as a breeder, burner, or in a breakeven mode.
- Molten salt breeder reactors, using the thorium cycle make the same claim.
- Also there are years of experience with superphenix
- Why not use fusion for something breeder reactors admit they cannot do, namely produce large, and necessary amounts of nuclear fuel?

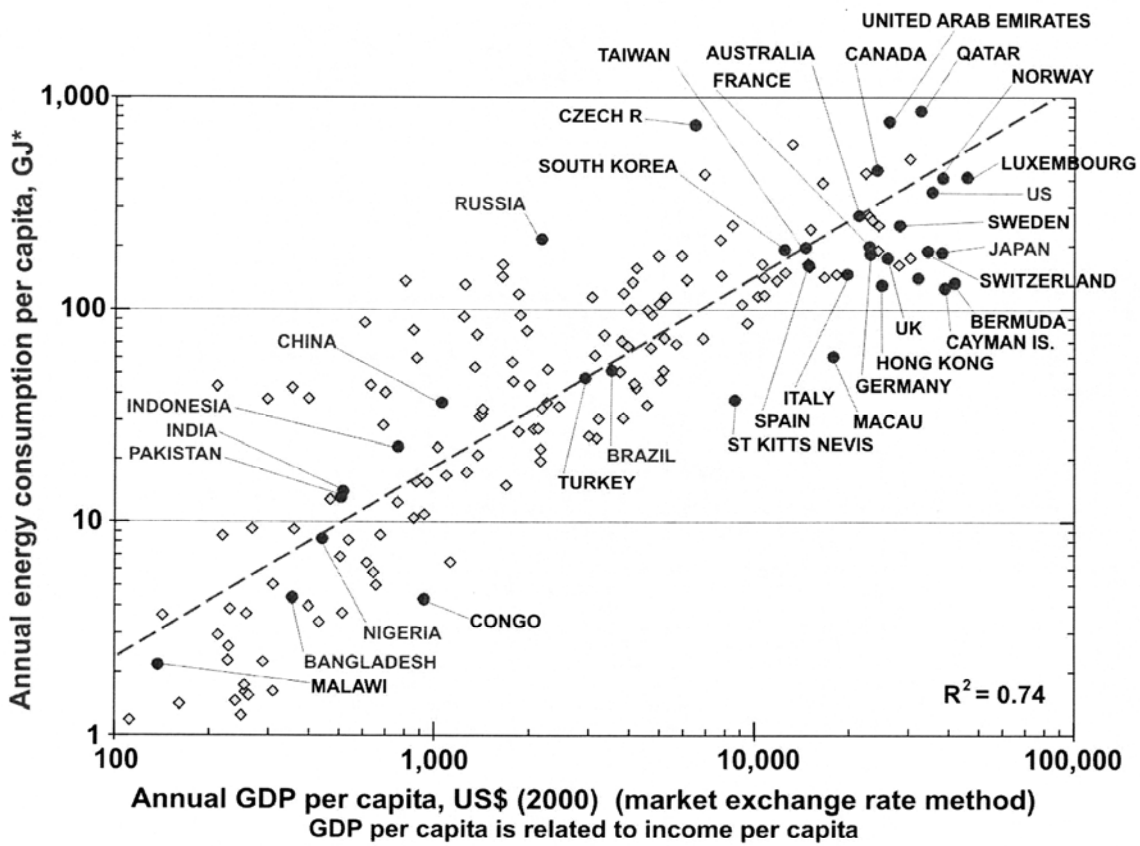
Emails from Dan Meneley (former head of Canadian nuclear society) and George Stanford.

- **I've nearly finished prepping my talk for the CNS on June 13th (2006) -- from what I can see now, we will need A LOT of fissile isotopes if we want to fill in the petroleum-energy deficit that is coming upon us. Breeders cannot do it -- your competition will be enrichment of expensive uranium, electro-breeding. Good luck.**
- **We (I'm on the Executive of the Environmental Sciences Division of ANS) held a "Sustainable Nuclear" double session at the ANS Annual in Reno a couple of weeks ago. I have copies of all the presentations. ………… The result was an interesting mixture of "we have lots", just put the price up and we'll deliver (we've heard the same from Saudi recently) and "better be sure you have a long-term fuel supply contract before you build a new thermal reactor".**
- Fissile material will be at a premium in 4 or 5 decades…..I think the role for fusion is the one you propose, namely as a breeder of fissile material if the time comes when the maximum IFR breeding rate is insufficient to meet demand.

From Yoon Chang, also a strong advocate of breeders, claiming they cannot breed fast enough for what he sees as the growth of demand



Country’s energy use vs per capita GNP



*1,000,000,000 GJ = 1 EJ
1 GJ = 1,000,000,000 J

Source: Energy Information Administration
International Energy Annual 2003
July 8, 2005

What about Kyoto and CO_2

	1990	2005	%increase
Non Warsaw Eur.	2166	2516	16
Warsaw Eur.	2621	2129	-19
USA	4747	5289	11
Japan	935	1075	15
China	1454	2844	96
India	288	862	199
Egypt	42	98	133
Malawi	0.53	0.85	62

The world needs energy, where from?

Oil and Gas? We will run out of economical supply certainly in our children's lifetime.

Coal? Environmental problems, and we will run out in our grandchildren's lifetime anyway.

Nuclear? Once through cycle with high grade ore will not supply us for very long. Expensive low grade ore may be an option, seawater is much too dilute in uranium.

Breeding by fusion or fission seem like about only other choices.

The options are few, time to start is now; it takes decades to make major changes in energy infrastructure.

Solar, wind and biofuel? Bit players at best.

(see supplementary viewgraphs) .

• Fission Suppressed Mode (Ralph Moir and others)

- Use a liquid or flowing blanket and reprocess the ^{233}U or ^{239}P on the fly and burn these in a reactor designed to do this and only this.
- Proliferation considerations, $^{232}Th/^{233}U$ cycle
- One calculation [Moir] shows that in a ‘engineered blanket’, one fusion neutron produces 1.1 triton, 0.73 ^{233}U and 35 MeV.
- But the 0.73 ^{233}U when burned produce ~150MeV!
- A Large ITER sized reactor, 1.5 GW neutron power could produce enough fuel for five 1 GWe LWR’s.
- The fuel could be exported, even to countries we did not fully trust, as long as we got the spent fuel back to reprocess.
- Indeed, why shouldn’t the USA, using its scientific and engineering expertise become the Saudi Arabia of the mid to lat 21st century?

- Question: Doesn’t breeding both T and ^{233}U make the blanket much more complicated that just breeding T as in pure fusion?
- Answer: Absolutely not! If it is too complicated to breed both in a single blanket, and hybrids pervade the economy, some can breed T and others ^{233}U.
- Also an overwhelming advantage of the hybrid, the wall flux is only ~10% of what it would be for pure fusion.

Freidberg and Kadak, Nature Physics, June 2009

- Nuclear energy, and particularly LWR’s are the worlds main hope for greatly expanding energy. (yes*)
- Solar, wind and biofuel cannot be big players. (yes*)
- Critical nuclear reactors work fine and there is no need to develop subcritical reactors. (yes*)
- The hybrid could help waste disposal, but other approaches are way ahead. (yes*)
- “There is not a sufficiently compelling case to demand an urgent Manhattan-like project for its development” (yes*)
- No need in the near term for fuel produced by a hybrid as an MIT study shows we have enough for 50-100 years. (maybe*)
- * author opinion

Freidberg and Kadak, con't

- What if 50-100 years turns out to be 25-50?
- Do we want to tie the fate of civilization to this study?
- Such studies are notoriously unreliable. How often have we read about amazing new oil fields in Brazil, North Dakota, Alaska…, but oil production keeps slowly decreasing.
- Shouldn't we hedge our bets?
- Price signal from uranium indicates scarcity.
- Are we so unconcerned with our descendents, and so well endowed with energy that we can throw away 99% of it?

Freidberg and Kadak con’t

- I have published studies in the archival literature indicating that with an ITER based hybrid approach, one could develop ‘energy parks’ which could supply large scale carbon free energy by midcentury. (See references on last slide and supplementary viewgraphs.)
- If F&P’s 50-100 years turns out to be 50 years or less, the time scales fit, if 25, we could be in big trouble.
- The next 40 years will require changes to energy infrastructure far beyond that of the last 50.
- These changes will take decade to put in place.
- The time to start is **NOW**.

A conservative approach

- Emphasis on the next step.
- Two modest sized development approaches, one for MFE, one for IFE.

Conservative Design Rules

- Even with Q=∞, the tokamak is restricted in the current, pressure and density it can contain.

Conservative design rules (CDR) (9):

1) Current: q(a)>3

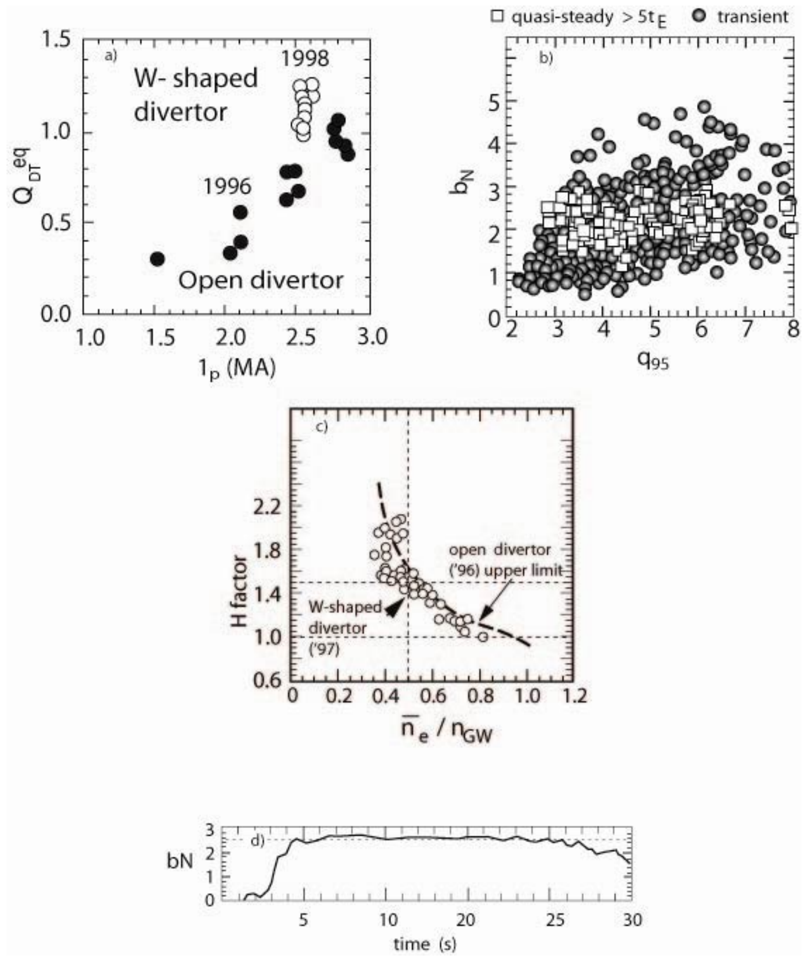
2) Pressure: β_N <2.5

3) Density <3/4 Greenwald Density

4) Blanket at least 1.5 meters thick

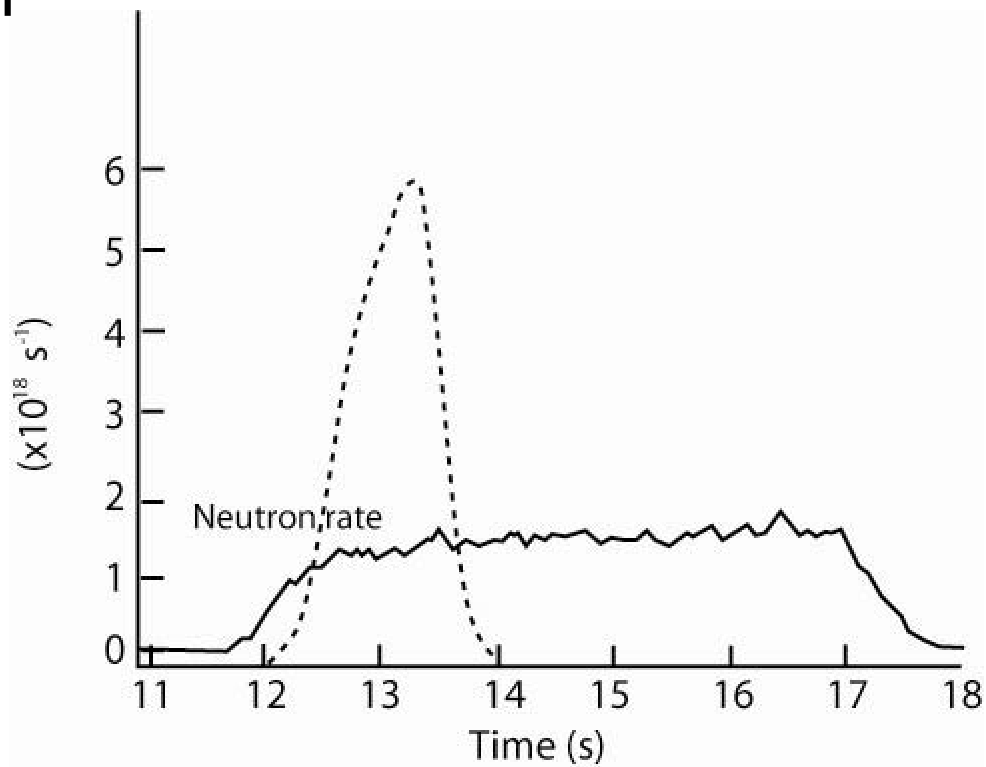
- Best neutron shots on JET and TFTR ~ factor of 2 below CDR, best steady shots factor ~5 below.
- Estimates of ITER also factor of 3 below CDR
- I claim conservative design rules prevent economic power from tokamaks (9).

Are conservative design rules valid? Example from JT-60U



But the best neutron shot were transient

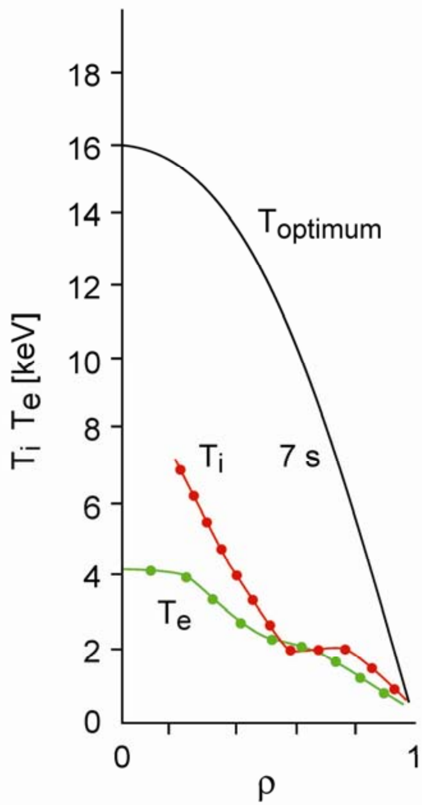
Example from JET



Best long lived shots ~ factor of 5-10 below CDR for JET and JT-60

Why don't steady state shots on JT-60 give CDR results?

Temperature in JT-60U



- For a $ß_n$=2.5, and parabolic profile, optimum maximum temperature for a beta limited plasma is 16keV.
- JT-60 results have half max T_i and probably less than 1/3 average T_i

MFE: The scientific prototype

- The idea is to build a tokamak run steady state in DT, but otherwise as close to the plasma physics regime we are familiar with as possible.
- It would have superconducting field coils like Tore-Supra, EAST, K-Star and India's.
- Take TFTR, but add 1.5 meters to its major radius to fit in a blanket. Parameters become R=4, a=b=1, B=5.5. Once these are specified, CDR's specify neutron power. Good confinement cannot make it any better, bad confinement only makes it worse.
- Energy content and energy density are well within the range of what has been established for tokamaks.

The scientific prototype

- One comment I got was that this is easy and boring. Not so, there are significant plasma physics problems:
- Running the current cw with either neutral beams or rf in a way consistent with a high neutron flux.
- Ten years ago TFTR, JET and JT-60 got Q~1 transient discharges but have still not been able to achieve this in long lived discharges.
- All control mechanisms have to be consistent with operating in a high neutron flux environment.
- **Bottom line: There are still significant plasma physics problems!**

Neutron production (MW)

	Design	Actual	CDR
JET (transient)		16	32
JET (Steady)		4	35
TFTR (transient)		10.7	31
Sci. Prototype		27*	55
ITER	400		1500
Large ITER	1600		4000

- *Assuming Sci. Prototype achieves half the CDR power.

The scientific prototype tasks

- First achieve a steady Q~1 plasma in DT
- Then demonstrate tritium self sufficiency. Without it, no fusion scheme, pure or hybrid makes any sense.
- Then breed significant quantities of ^{233}U and mix it with ^{238}U to make nuclear fuel for LWR's.
- Only after this, after the disruption threshold is known to absolute certainty, transmute some plutonium.

The NRL KrF Laser fusion project

- Hope is:
- With direct drive, enhanced gain (gain >100 for 500kJ laser).
- With shorter wavelength KrF laser can achieve higher pressure and laser irradiance.
- Rayleigh Taylor and Richtmeyer Meshkov instability handled by structured laser pulse.
- Seems not overly sensitive to fast electrons.
- The 2 ω_p instability could limit parameter space.

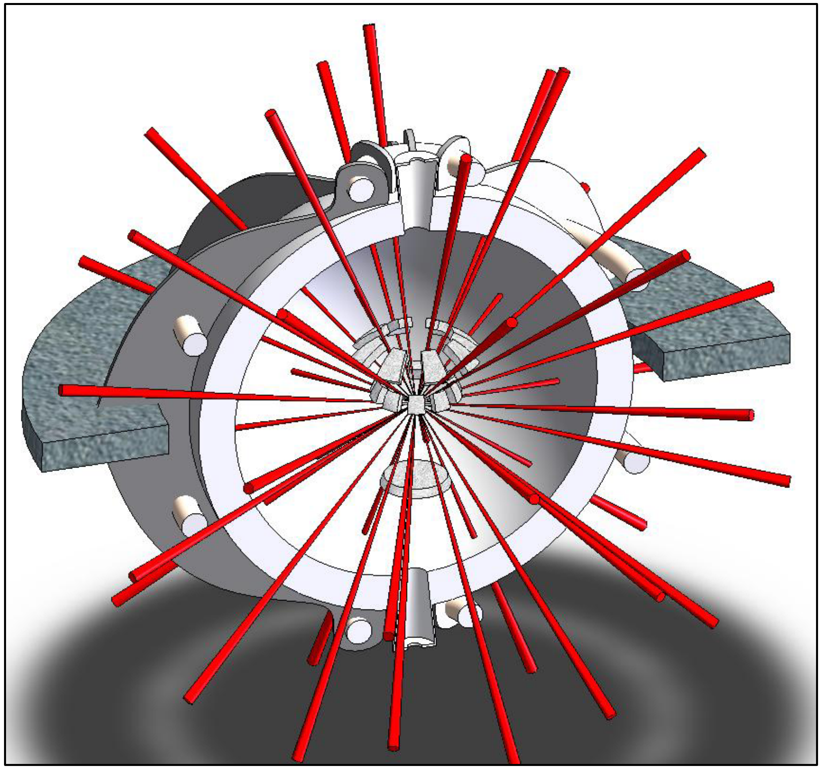
Three linked experimental programs:

- NIKE: 3 kJ single shot KrF laser: planar target studies and laser development (Google NRL NIKE laser)
- ELECTRA: A rep-rated KrF laser, 5Hz, 750 Joules, >100,000 shots so far (Google NRL Electra laser)
- HAPL (NRL Led/Multi institution): Development of the technologies needed for laser fusion. (Google NRL HAPL high average power laser)

- Proposed Fusion Test Facility:
  - High power rep-rated system designed to produce 100-150MW neutron average power – an intense point neutron source.
  - Has been documented in archival literature and reviewed by an external DoE review committee.

Goal: Development & Deployment of Fusion Energy

Using Repetitively Pulsed High-Energy Lasers



Fusion Test Facility
150 MW (thermal)
Operating by 2020
Google NRL FTF Fusion
Test Facility

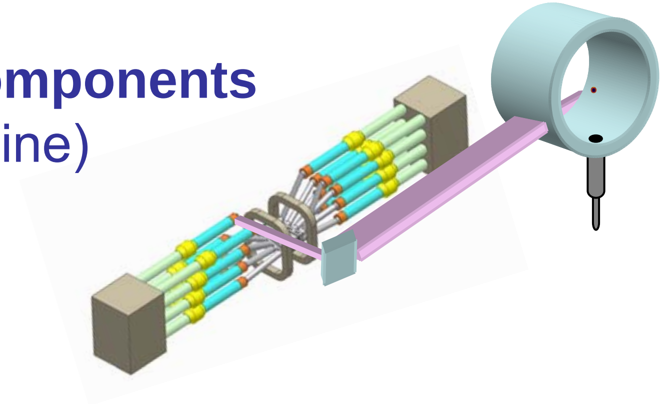
NRL is very serious about this effort, estimated cost << ITER

Our three-stage plan for laser IFE:

Key elements are developed and implemented in progressively more capable IFE oriented facilities

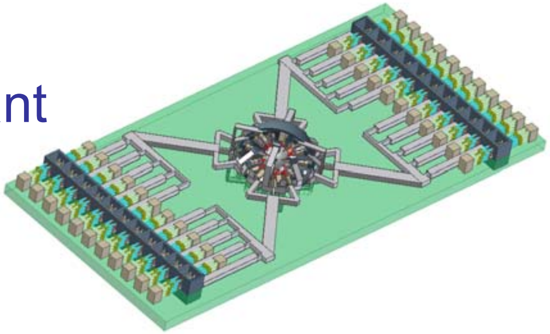
Stage I **(~6 years) : Develop full size components**

- Laser module (25 kJ 5 Hz KrF beam line)
- Target fabrication/injection/tracking
- Chamber
- Verify pellet physics



Stage II **(~2014-2022): Fusion Test Facility (FTF)**

- Demonstrate physics / technologies for a power plant
- Operating: ~2019



Stage III **(~2024 - 2032): Prototype Power plant(s)**

- Electricity to the grid
- Significant participation by private industry

Scientific prototype cost estimates

- Based on ITER – admittedly a moving target, but to the extent possible, starting point is reality:

Large ITER: R = 8, $ ~ 20B

ITER R = 6, $ ~ 10B

So $\$ \sim R^{2.5}$

Scientific prototype: $ ~3-4B

How can we afford this?

- **It’s easy!**
- Assume average lifetime of a large tokomak experiment is 15 years.
- Base program is $0.25B/yr, so in 15 years we have $3.75B, more than enough for the scientific prototype.
- We do not lack the resources, perhaps we lack the will and determination.
- If we offer up part of the base program, congress would probably enhance total budget.

What to propose

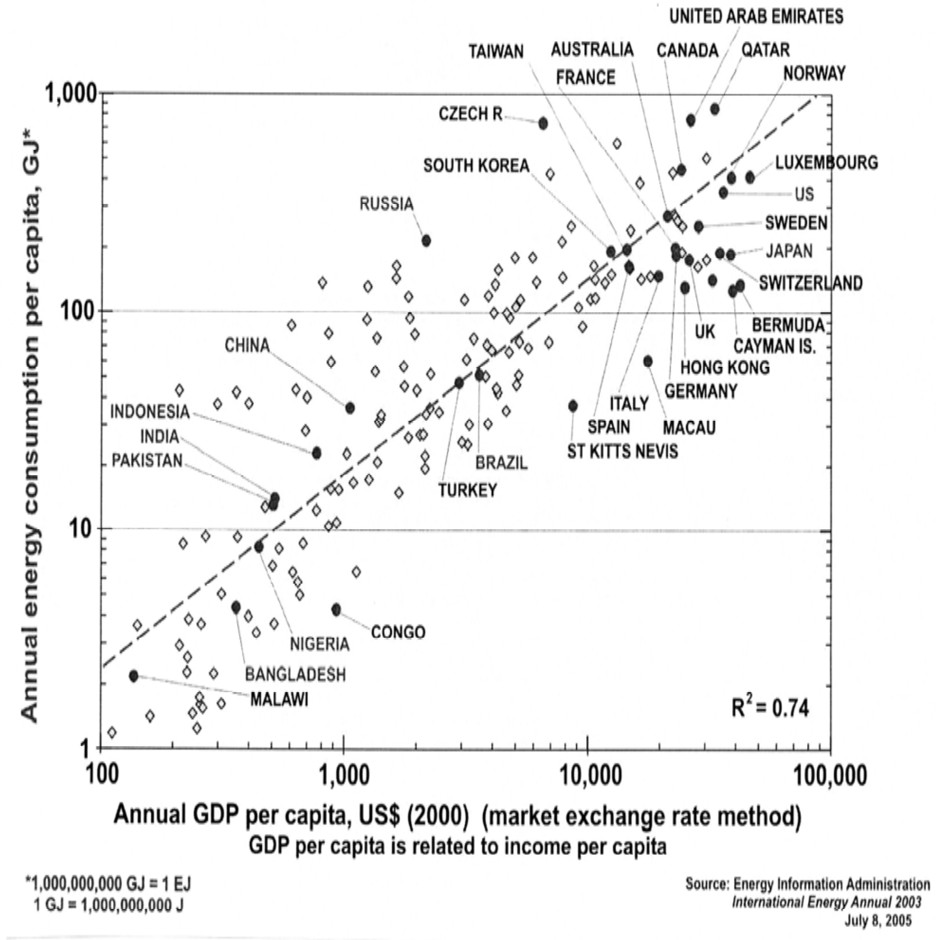
- Estimate IFE FTF cost ~ MFE part
- Propose both: $8-10B over 15 years including a reduced base program
- Strictly USA led project (but of course using foreign expertise), no bottomless pits of international negotiations.
- A conservative approach, likely to succeed. Takes the next giant step toward either pure or hybrid fusion for energy or waste treatment.
- Time horizon appears long, but in reality is short.
- **THE TIME TO START IS NOW!**

Manhattan Project?

- F and K advise against Manhattan project.
- Is scientific prototype **AND** FTF a Manhattan scale project?
- Manhattan Project was $27B (in 2009 $) in 4 years*.
- This is $8-10B project in 15 years.
- **NOT EVEN A STATEN ISLAND PROJECT.**
- *not an easy number to pin down accurately

The upshot:

- Without fission or fusion breeding, not only will we be unable to lift low countries up the curve, the high countries will begin to slide back down.
- **This is the real threat to civilization.**



Published papers, available from author, contact wallymanheimer@yahoo.com,

- 1. W. Manheimer, *The Transition of Plasma and Beam Research at NRL, from Death Rays to Doo dads*, Plenary talk on winning IEEE PSAC Award, IEEE Plasma Science Conference, Boston, June 1996
- 2. W. Manheimer, *Back to the Future, the Historical, Scientific, Naval and Environmental Case for Fission Fusion,* Fusion Tech. 36, 1, (1999);
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- 4. M. Hoffert el al, *Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet*, Science 298, 981, (2002)
- 5. W. Manheimer, *An Alternate Development Path for Magnetic Fusion,* J. Fusion Energy, 20, #4, 131, (2001, cc2003);
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- 9. W. Manheimer, *Hybrid Fusion, the Only Viable Development Path for Tokamaks?*, J. Fusion Energy, vol 28, #1, p. 60, 2009
- 10. W. Manheimer, *Hybrid Fusion and Energy Parks for Sustainable Development*, accepted for Asian Journal of Physics, special issue on renewable and sustainable energy, Vol 18, #1, Jan-March 2009

Supplementary viewgraphs

The dilemma of solar, wind and biofuel.

President Obama’s hopes and plans

- Campaign promise #440 (Politifact.com): “Will cut US consumption of foreign oil by 2.5 million barrels per day.” (No time given, but presumably < 8 years)
- Inauguration speech “We will get energy from the sun, the wind and the soil.”
- 2.5million b/day ~160 GW, or 55GWe
- Stipulate the electric energy storage problem and electric car problem have both been solved.
- What does 55GWe mean for solar, wind and biofuel?

Renewable energy solar

- Mid latitude ~1KW/M^2 PEAK, 200W/m^2 average solar power
- Eff ~10% 20MW/km^2,
- 1998-2007 Total photovoltaic shipments <1GW peak, (i.e ~1km^2) <200 MW average.
- Would need 55GW average, 275 GW peak.
- Would have to scale up production by about a factor of 300.

Solar con't

- Would have to cover nearly 3000 km^2 with solar collectors.
- They would have to be kept clean.
- This would most likely be in a desert environment where there are occasional sand storms and very little water.

Renewable Energy Wind

- A modern windmill generates a peak power of ~ 1MW, and an average power of ~200kW.
- For 55GW → 275,000 windmills.
- Takes about 300 km^2 for an average power of 1 GW. Would need to cover nearly 20,000 km^2 (about the size of Connecticut) with windmills
- Sporadic source can lead to grid instability
- Only viable because of large state subsidies
- State can subsidize 1% of power, but not 100%

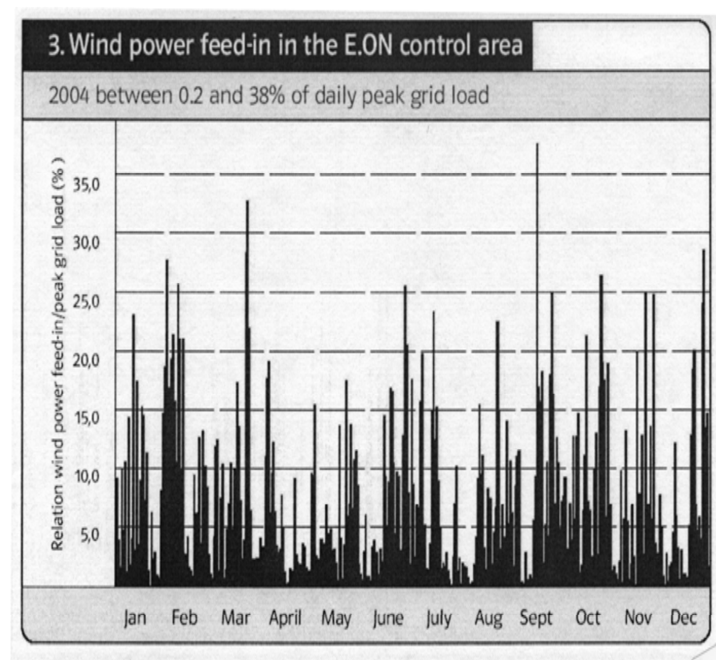
Wind con't

Grid cannot accept more than 10% of capacity from such a sporadic source. More windmills, less fractional utilization. Depends on large state subsidies

Denmark has made largest commitment to wind power (24% of its power, 8% of Nordel grid) but was unable to decommission any thermal power plants and will be unable to meet its Kyoto treaty requirements.

No simple extrapolation of from where wind is now now to providing power on scale required for mid century.

From Eon-Netz, largest wind provider in Germany



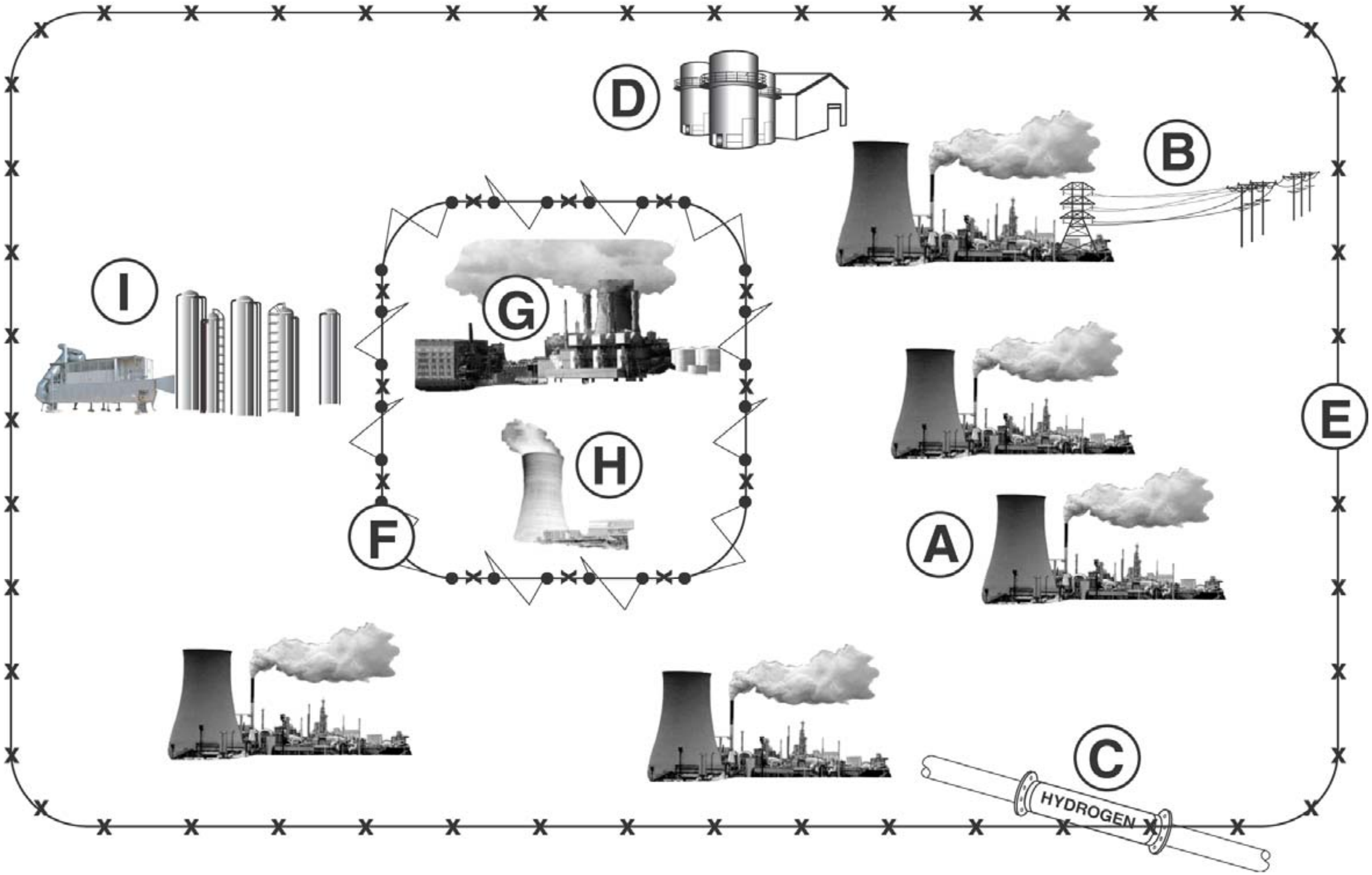
Renewables: Example of Ethanol

- USA produces ~5B gallons of ethanol (energy of ~3.5B gallons oil)/year using 25% of our corn crop. This is ~1% of our petroleum use.
- Petroleum energy to produce ethanol nearly~ ethanol energy. (ANL study shows 1 Joule of oil to produce 1.3 Joules of ethanol)
- 2008 energy Bill mandates 36B gallons of ethanol or methanol by 2020.
- No known economical way of producing methanol from cellulose.
- Photosynthesis is inefficient, and land can be used for other purposes, food, lumber, cotton, conservation, etc.
- Price of corn is already skyrocketing due to American ethanol production, greatly harming poor people in Mexico and elsewhere.
- Bogdan Kippling (IBD) describes it as taking food from the stomachs of the world's poorest to put a speck more gasoline in our cars. He calls this a crime against humanity.
- **And GW is called a moral issue!**

Supplementary viewgraphs

The energy park

This led to the fusion-fission energy park; more than a dream, much less than a careful plan.



Everything shown in the same location, but of course they do not have to be.

The Energy Park (or What Marty Snyder calls 'The Manhattan Project')

More than a dream, certainly less than a careful plan

A. A Nuclear reactor, perhaps of today's design. Each year takes in 1000 kg of ^{233}U (mixed with 24,000 kg of ^{238}U) and discharges, among other things, 200 kg of ^{239}Pu, 750 kg of highly radioactive intermediate Z isotopes, and 50 kg of lower activity isotopes, e.g. ^{99}Tc with 200,000 year half life.

B. Output electricity

C. Output hydrogen

D. Cooling pool where waste is taken and low Z highly radioactive isotopes cool for perhaps 300-500 years. We have already stored in cooling pools for 40 years, or more than one half life if Pu and long lived actinides and radioisotopes are separated out.

E. Low Security fence

F. High security fence

The energy Park, con't

G. Separation plant where actinides (mostly plutonium), highly radioactive elements, and less active elements are separated. Highly radioactive elements go back to cooling pool, plutonium to a plutonium burner, and low active waste perhaps back to fusion reactor for transmutation.

H. Plutonium burner. Separated plutonium from all 5 reactors are burned here. Most likely to be a fast neutron reactor, but might be a thermal neutron reactor if the fertile material is ^{232}Th. (George Stanford thinks 2 IFR's servicing 4 LWR's more accurate estimate; if so fusion requirements reduced by 20%)

I. The fusion reactor. Produces 1.5 GW of neutron power (like the large ITER), 3.5 GW thermal power and 15 GW of ^{233}U, enough to feed the 5 thermal reactors. 5% of wall area might be used to transmute all the low activity elements produced in park if one neutron for 1 transmutation.

The energy Park, conclusion

- Produces 7 GWe
- No long time storage or long distance travel of material with proliferation potential.
- Treats all of its own wastes.
- Waste treated with a combination of fission, fusion and patience.
- Only ^{232}Th comes in, only electricity and hydrogen go out!