Energy for the world, Fusion and Fusion Breeding: The Ugly Duckling becomes the Beautiful Swan

Wallace Manheimer

Retired from NRL

Tom Nelson podcast

- Bringing the whole world's mid century 10B people up to western standards of 4-5 kW per capita, means roughly tripling the world power, from ~ 14TW to ~35-40TW.

- The less developed world takes this very, very seriously.

- Coal use has reached a worldwide maximum in 2022.

- At a DoE meeting in 2009 that I attended, a high-ranking member of the Chinese Academy of Science said that in 2000, the Average Chinese used 10% of the energy of the average American, at the meeting it was 20%, (now it is 30-35%), and they would not rest until it is ~ equal

Sultan Al-Jaber, head of COP 28: Suggested a fossil fuel phase out would not allow sustainable development "unless you want to take the world back into caves."

Indian Prime Minister Narendra Modi in November 2021: "The colonial mindset hasn't gone. We are seeing from developed nations that the path that made them developed is being closed to developing nations".

Former President of Niger, Mohamed Bazoum (June 2022): "Africa is being punished by decisions of western countries to end public financing for foreign fuel projects by the end of 2022. We are going to continue to fight, we have fossil fuel that should be exploited."

- No matter how much Al Gore, John Kerry, and Bill McKibben shake their fingers at them, these countries will continue to develop in the best way they see fit. **There is no stopping it!**

MASS DELUSIONS

The real problem the world faces is not climate change, it is lack of sufficient energy for the developing parts of the world. In this age of instantaneous communication, how much longer will a world with a per capita power use of 5 kW for OECD countries, and 1 kW per capita for the rest of the world be acceptable and sustainable? But to bring the rest of the word up to OECD standards by midcentury would require about tripling the rate of power increase above what BP predicts will happen. Solar and wind cannot do this. At this point, despite inspiring, no pious lectures from the west, large parts of the world are turning to coal. Nothing can stop this. A turn to nuclear power as rapidly as possible, supplemented ultimately by breeding is the best long-term hope. This book has one of the very few descriptions of fusion breeding.

Wallace Manheimer

Wallace Manheimer was born in New York City and was educated in the New York City public schools. His high school sent six graduating students (including him) to MIT.At MIT, he majored in physics and got both an S.B. and a Ph.D. from MIT. Shortly after receiving his Ph.D., he came to The Naval Research Lab (NRL) in Washington DC and began what became a more than 50-year career here, both as a civil servant and as a contractor scientific consultant. He is very proud that he was able to spend that much time with a single employer and believes that NRL has been, and hopefully will remain, a tremendous asset to the Navy, the country, and the world. At NRL he was in the Plasma Physics division and spent about half his time on fusion and the other half on various problems in national defense. He has authored or co-authored about 150 reviewed scientific papers in these areas.

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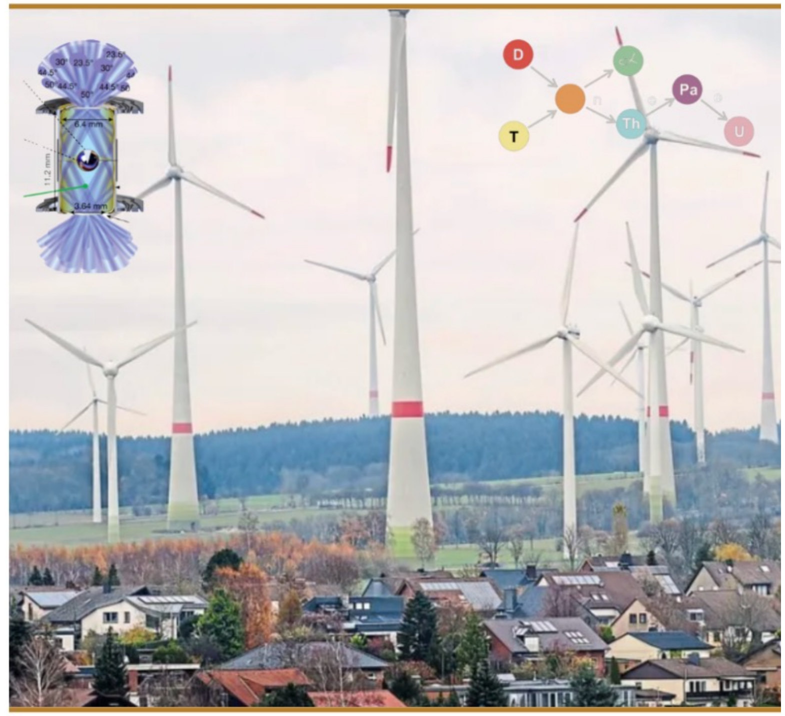
MASS DELUSIONS

How they harm sustainable energy, climate policy, fusion, and fusion breeding

Wallace Manheimer



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- The first 3 sections of the book are about energy needs, show that there is no climate crisis, and solar and windmills cannot even come anywhere close to providing necessary power. (Nelson Podcast 142, Aug 31, 2023)

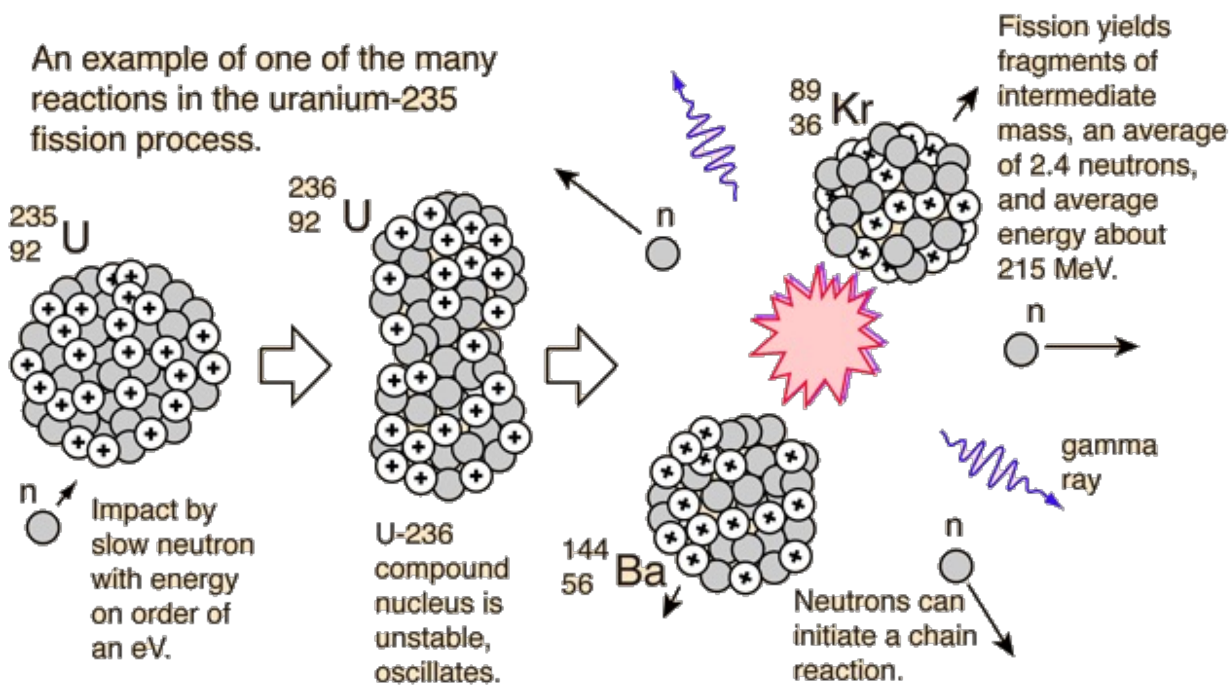
- That is the main image on the cover

- Fossil fuels are a finite resource. If at today's usage, we will run out of them in ~X years, once the world's entire population is brought to western standards, we will run out in ~X/3 years if fossil fuel is the only energy source.

- Let's envision powered by ~20-25TW nuclear, 10TW fossil, 3 TW hydro, and maybe 1-2 TW other, maybe 'trash to power', maybe even a windmill or two in niche markets.

- The two smaller cover images are the fusion configuration of the LLNL experiment, and a fusion breeding reaction. This podcast concentrates on these in sections 4 and 5.

What about Nuclear power?



The light water reactor (LWR) is the most common one today, about 400 are around the world

- Every year it is fueled with ` 1 ton of 235U, the fissile material; mixed in with 24 tons of 238 and generates ~ 1GW.
- The raw fuel is dilute enough in 235U, so it is not a proliferation threat
- The reaction produces 2-3 neutrons, one is needed to continue the chain reaction, the rest, after losses can be used for other purposes including breeding some 239Pu to replace some of the the 235U burned.
- After a year it discharges ~ 24tons of 238U, 0.8 tons of highly radioactive fission fragments with half life of ~ 30 years, and 0.2 tons of Pu and other actinides, or about 20% of the output is future fuel.

How much nuclear fuel is available?

*Hoffert et al estimate 60-300 Terawatt years of mined 235U

- Freidberg and Kadak estimate more, 500-1000 TWyrs
- But at 20 TW's this would last at most 50 years. Each nuclear plant gives about 3 GW thermal, and 1 GW electric.
- Ralph Moir suggested 10,000 1GWe nuclear plants, so fuel would last at most 30 years.
- **Breeding could well be necessary, and maybe much sooner than we think**

Some real honchos of the nuclear world agree that a shortage of nuclear fuel may well be in our future

George Stanford (2006, died in 2013):One of the main designers of the integral fast reactor (IFR)

“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”.

Dan Meneley (2006 died in 2018), former head of the Canadian Nuclear Program and worked also at Argonne on the IFR:

"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 --

And:

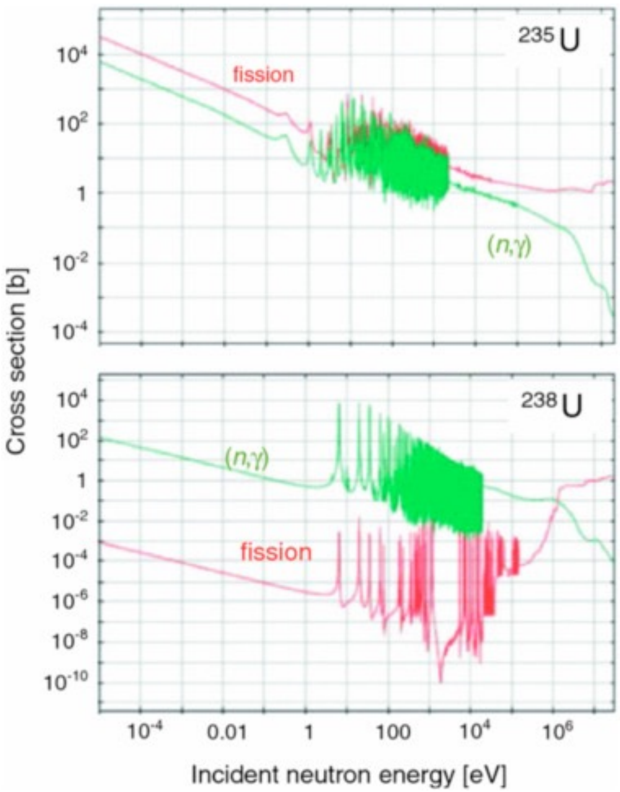
"We (I'm on the Executive of the Environmental Sciences Division of ANS) held a "Sustainable Nuclear" double session at the ANS Annual in Reno a couple of weeks ago. I have copies of all the presentations. .... The result was an interesting mixture of "we have lots", just put the price up and we'll deliver (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"."

Breeding: there are 3, and only 3 options for sustainable power.

1. Fast neutron breeders
2. Thermal thorium breeders
3. Fusion, for direct power; and/or fusion breeding, (making many fewer demands on the plasma) to fuel thermal reactors

Any of these, or a combination of them, can power civilization at 40 TW at least as far into the future as the dawn of civilization was in the past.

Fast neutron reactions are inevitably very complicated and expensive.



Fission neutrons are produced at ~ 2MeV. But the reaction cross section is ~ 2-3 orders of magnitude greater at ~ 0.1 eV, i.e. 1000 degrees C, but only for odd nuclei actinides.

In a 'thermal reactor' the neutrons are slowed down, and then react.

Because of the low cross section, a much longer path length for the neutron is required in a fast neutron reactor, meaning a larger fuel load.

Also, very few coolants are appropriate. Liquid sodium is the typical one.

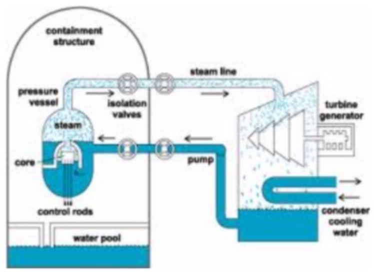
Fast neutrons reactors have been built, Super Phenix in France, Integral Fast Reactor (IFR) in the US, and BN600 and BN800 in Russia (these are hooked up to the Russian grid).

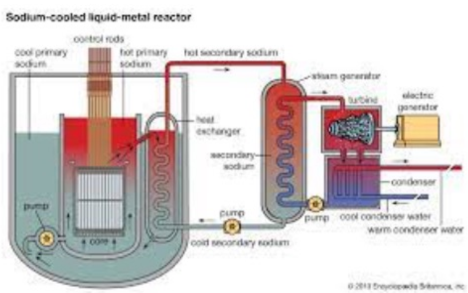
The reaction path is more complicated than in a thermal reactor, since the initial neutrons produced have too low an energy for another fast reaction, so it is a combination of fast neutron reactions, and breeding 239Pu with the slower neutrons and burning them.

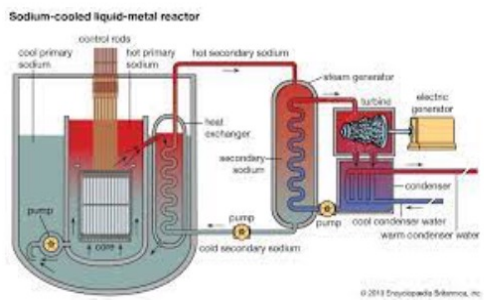
I don't have George Stanford's direct quote anymore, but he did assure me that the IFR could burn any actinide about equally. One IFR can burn the actinide waste of 5 LWR's!

Typically, each nuclear reaction produces 2.7-3 neutrons. One continues the chain reaction; one replaces the burned nucleus, some are lost through other channels, so each reaction produces ~ ½ neutron for other purposes.

Hence at maximum breeding rate, it will take 2 fast neutron reactors to fuel one thermal reactor.







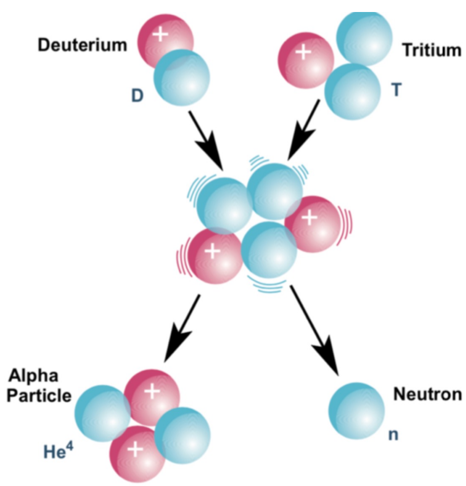
The Key is that each reaction produces ~ 0.5-1 additional fissile nuclei; and all the reactions produce ~ the same energy.

It takes 2 breeders at maximum breeding rate to fuel 1 LWR of = power.

Thorium could also be used in a thermal breeder.

- It is initially fueled with 235U and Thorium. The 235U supplies initial neutrons to convert the thorium into 233U and the reaction continues with the 233U produced.
- It is no longer limited by the amount of mined 235U, there is plenty of thorium.
- This thermal reaction cycle produces more neutrons than the 235U reaction, so the thorium reactor can fuel itself, even if it cannot supply other thermal reactors.
- A thorium reactor has been built in the US and had run for 5 years.
- One drawback is that the fresh fuel is a mixture of thorium and uranium 235 or 233. These can be easily separated chemically; a real proliferation risk!
- Perhaps another Nelson podcast with an expert on fast neutron reactors and thermal thorium breeders would be appropriate and add more insight.

A fusion reactor without breeding is the more studied alternative; but breeding may be the best use for fusion.



The neutron has energy of 14 MeV, much higher energy than fission reaction neutron energy, and the alpha has energy of 3.5 MeV.

The reaction needs a temperature of ~100 million degrees C, or ~ 10 keV .

At this temperature, atoms become ionized, so the material, called a plasma, is composed of free electrons and free ions.

There are two ways to do this, contain it in a strong magnetic field, or heat and compress it by a powerful laser.

Plenty of deuterium exists on earth.

Tritium does not exist on earth, so it must be bred from reaction of a lithium nucleus with the neutron, giving a tritium nucleus and an alpha particle

Fusion could be an ideal breeder!

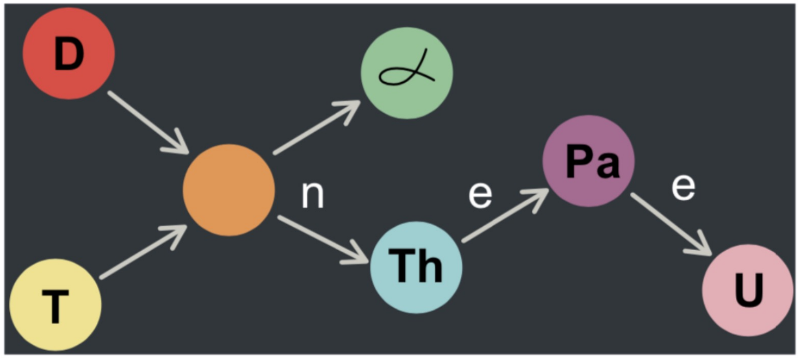
But breeding has always been the ugly duckling of the fusion project, condemned with such ignorant and false statements as:

- Fusion Breeding combines the worst aspects of fusion and fission.
- Fusion breeding might add nuclear fuel, the one problem fission does **NOT** have.

This podcast and other material hope to convert fusion breeding into the beautiful swan.

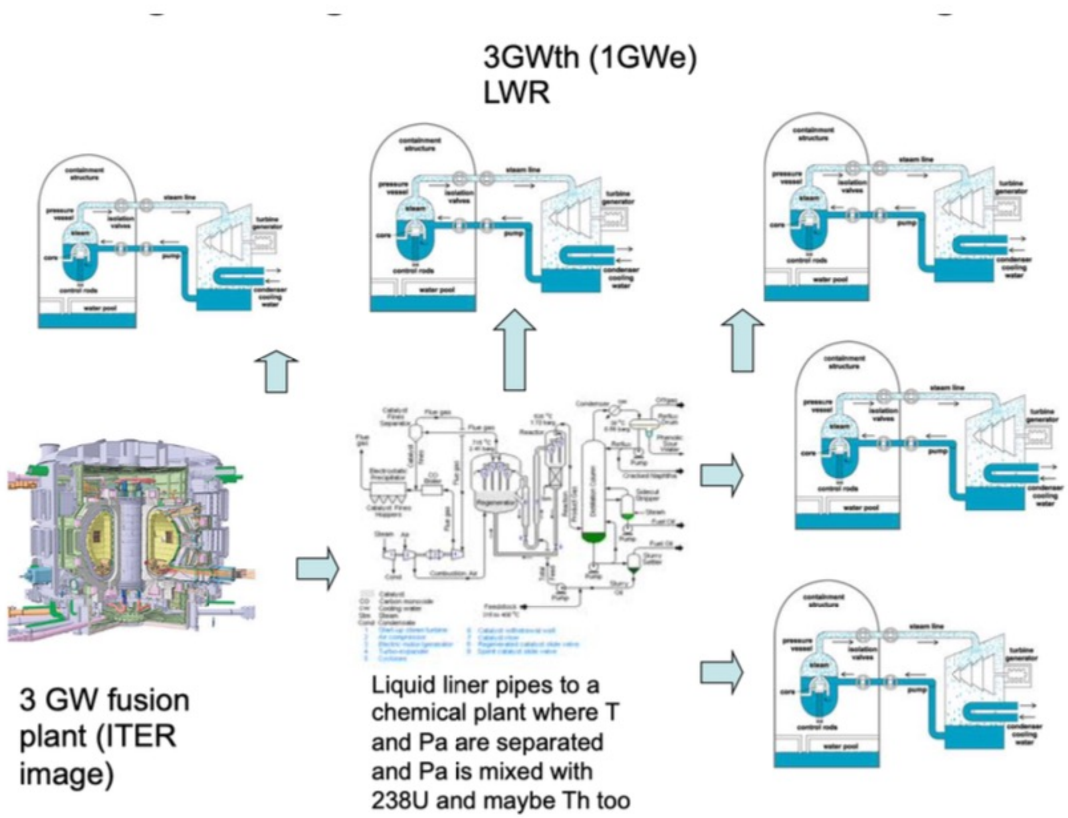
The reaction produces only a single neutron, but because it is so much more energetic than a fission neutron, this neutron can produce ~ 1 or 2 additional neutrons.

One neutron produces the tritium. Probably one is lost in other reaction channels, but there is still one left to breed 233U from thorium, so each fusion reaction produces ½-1 233U.



But the fusion reaction is only 20 MeV whereas the fission reaction is 200 MeV, so the reaction produces fuel for 10 times the energy of the fusion reactor, or one fusion breeder fuels 5-10 thermal reactors.

Hence one fusion breeder can fuel 5-10 conventional nuclear reactors:



The key is that, like fission, each reaction produces 0.5-1 fissile nuclei, but the fusion reaction has only ~ 10% of the energy of the fission reaction, so one fusion breeder fuels 5-10 thermal reactors of = power.

This alone suggests that fusion breeding must be taken very seriously. It may be all that stands between thousands of electric power generators, and an enormous pile of junk in midcenury.

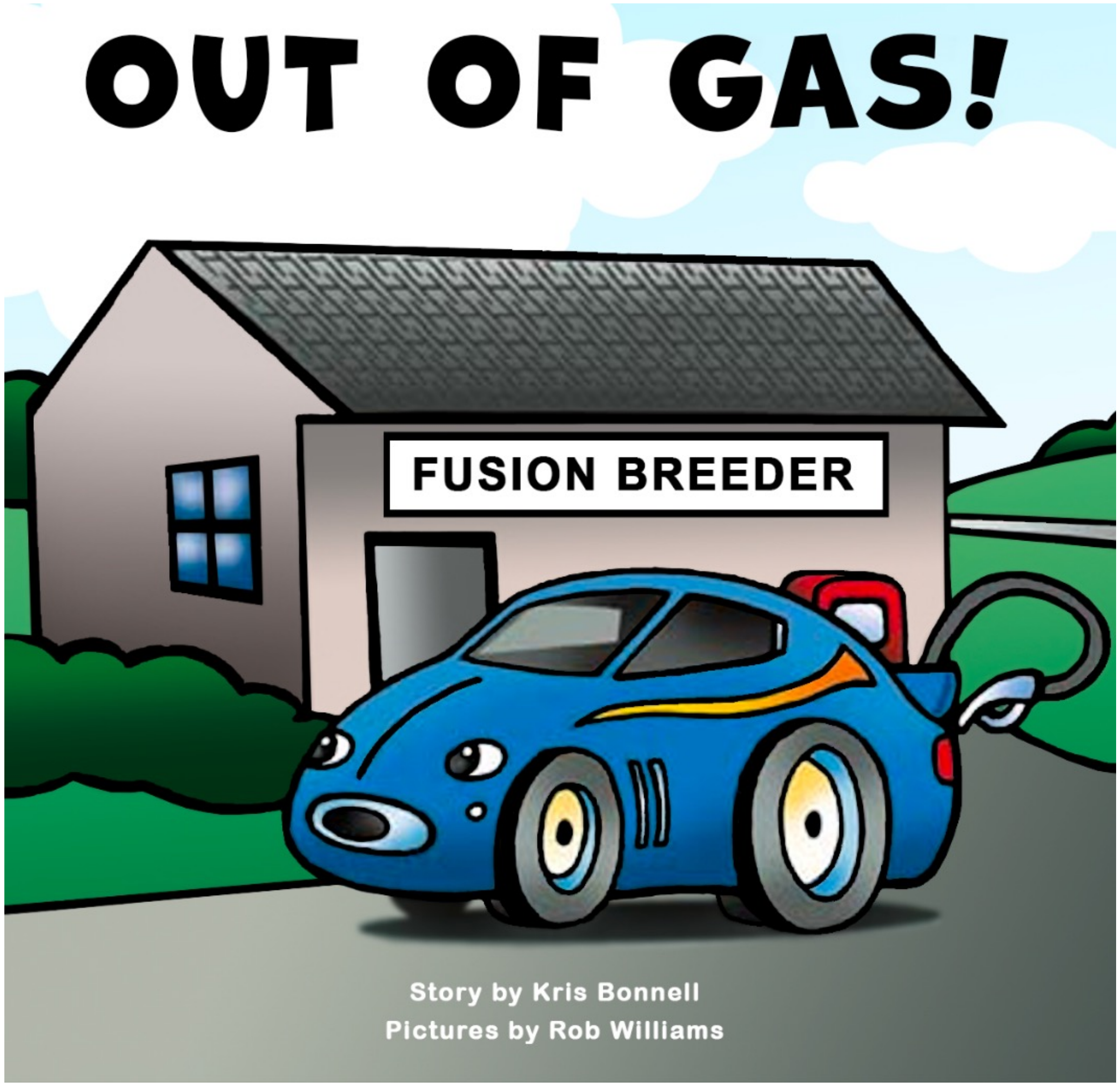
So, what if in its development, which is unavoidable, the rest of the world does build thousands of nuclear power plants.

What if in 30-50 years George Stanford's prophesy proves to be correct and there is no fuel for this enormous investment?

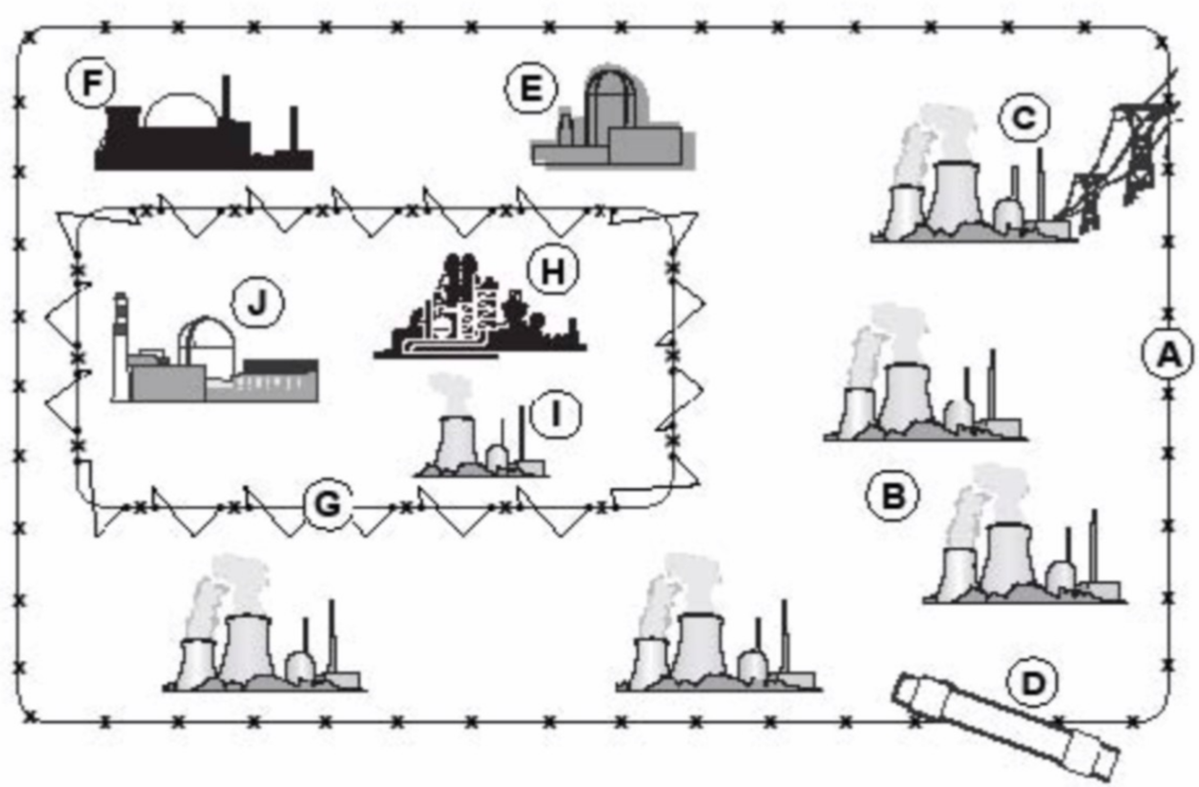
Uranium from the seas won't do it, it is so dilute that it will take more energy to collect and process, than it will give back.

The reactors would be 'stranded' and 'out of gas'. Neither Fast neutron reactors nor thermal thorium breeders could fill their tank.

Only a fusion breeder could!

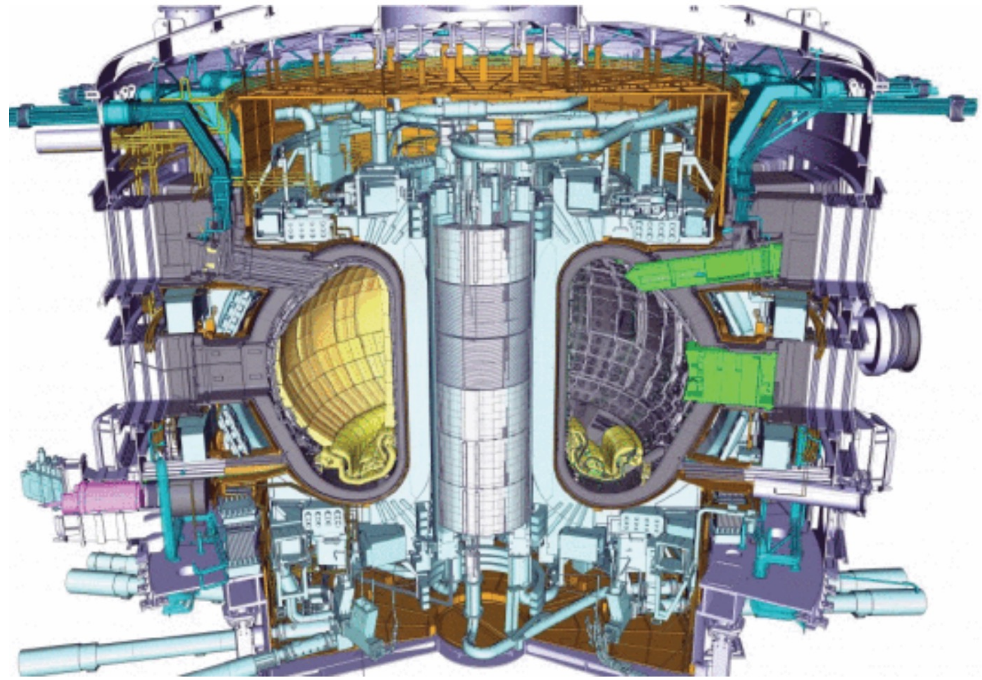

OUT OF GAS!
FUSION BREEDER
Story by Kris Bonnell
Pictures by Rob Williams

This suggests a nuclear architecture where one fusion breeder fuels 5 LWR's or other thermal reactor, and one IFR burns the actinide waste of these 5. This closes the nuclear cycle. This is the Energy Park, more than a dream, much less than a careful plan.



The basic architecture of the energy park could fuel civilization at 40 TW at least as far into the future as the dawn of civilization was in the past. The power would be economically and environmentally sound. There is no long-term storage nor long-distance travel of any fissile material. It is diluted as it is produced, and burned as leaves the thermal reactor. Hence the proliferation risk is minimal to vanishing. It would not produce a ‘plutonium mine’, like say Yucca Mountain, which would plague civilization for half a million years! This is an immoral burden to lay on our descendants.

ITER: Fusion’s Great White Whale!



ITER was originally an 8 meter, 2000 cubic meter 5T field to produce 1.5GW at Q~10, costing ~ $10B. Then the USA pulled out, unwilling to pay the high price.

The partners scaled it down to a 6 Meter, 1000 cubic meter 5 T field, powered in part by a toroidal current, and estimated to cost ~$5B. The USA rejoined and India joined.

Originally agreed upon by 7 major nations in 2005, to be built in France to produce 500 MW of fusion power with 50 MW of beam and microwave power (i.e. Q=10). First plasma in 2016, fusion in 2025.

Cost overruns and delays have been unmerciful! Cost now estimated at ~$25B (at least), first plasma in 2025 and fusion by 2040 assuming no more delays.

Will it ever be finished? Is it really the best approach to fusion? Will we ever harpoon the whale?

Let’s look at some issues with tokamaks

- The current is driven inductively by increasing the magnetic field in the center part. But there is only so much you can increase it before you run out of volt seconds.

- There have been attempts, especially in China and Korea to drive steady state current by inserting microwaves and/or neutral beams. These have in one sense been successful, but mostly have failed because it requires much too much power. Nobody knows how to drive the current in steady state.

- Even if successful, the 500MW of fusion power produces ~150 MW of electric power, as the efficiency of nuclear power plant is typically ~1/3. However, the mechanism to produce the beams and microwaves also have about that efficiency, so the 50 MW of drive power will take ~150MW of wall plug power.

- **Nothing is left for the grid!**

- Tokamak stores a tremendous amount of energy, the magnetic field the energy of a 1-ton bomb, the plasma the energy of a 200 lb. bomb. It is a potential safety concern.

- Tokamaks are constrained by what I have called 'conservative design rules. These are limits to current, pressure and density, above which the tokamak plasma will disrupt. These rules are well established in theory and have been well verified by many experiments on JET and JT-60 . The tokamak community ignores these.

- They mean that to get 3GWth, you would need at least a 10–12-meter radius. At a 5 T field. If the edge of the coil is at the goal line of an American football field, the other end is at ~ 20-yard line.

- Even if ITER succeeds, it is hardly the end of the line. One still must go to the DEMO, a smaller, more powerful, cheaper, steady state machine with higher Q. **Nobody has any idea how to make this.**

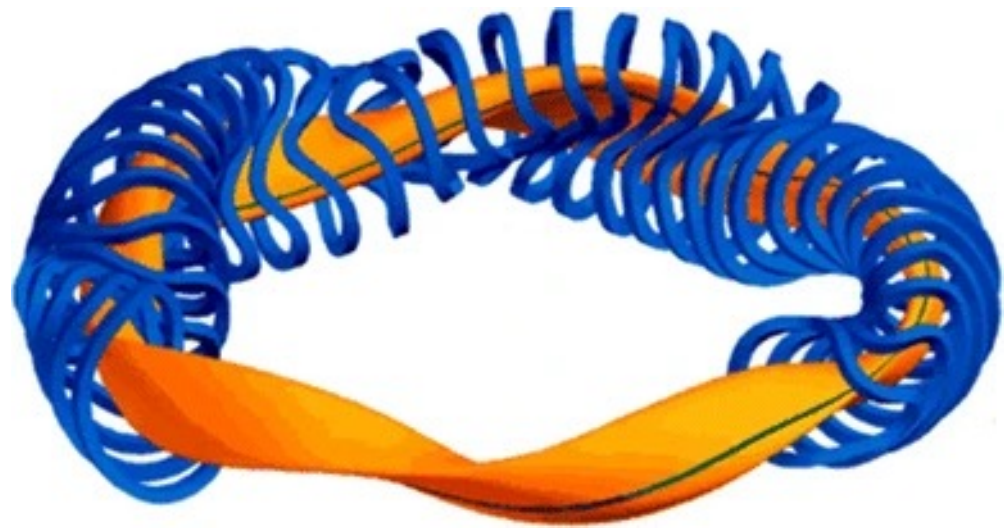
- Experimentally nobody knows what to do with the alpha particles. They are confined, so in a worst-case scenario, they build up in the tokamak until the pressure becomes too great and the plasma disrupts. Nobody has a very good idea what do do with them, although there are lots of paper studies

- Recycling could be a big problem. The walls are hit with 14 MeV neutrons, lots of radiation, fast ions and fast neutrals. Who know what comes back into the plasma and what the effect will be.

- Hence the ITER is only an intermediate step, the next step is called the DEMO, which would have to be smaller, cheaper, more powerful, and have a Q of at least 40 or more. Nobody has any idea of how to achieve this, although there are lots of paper studies.

- **Even if ITER is successful in 2040, it still has a very long way to go before commercial power can be generated by this development path.**

What about stellarators? Germany and Japan have studied this for decades.



They have and advantage of being steady state, but they have not achieved nearly the confinement of tokamaks. (LHD, Wendelstein, a 5.5 meter radius, 30 cubic meters, and 3.5 meter coils)

They have an exceedingly complex magnetic structure.

They are not at all compact, a 3 GW tokamak has a major radius of ~10M,a stellarator probably 25-30 if one does the obvious scaling. If you include the field coils, as tall as a 4 story building, and put one end at the goal line of an American football field, the end point would be at ~ the 20-yard line of the **OPPOSING** team and the coils would reach up to the grandstand's second tier!

It would almost certainly be much more expensive than a tokamak, from the size and complexity alone, even if one could solve the confinement problem.

There are privately funded ‘fusion start ups’ that promise commercial fusion in a decade. It is exceedingly unlikely that any of these ‘start-ups’ will succeed. I’d gladly bet a year’s pension on this. Various statements and predictions:

From Geek Wire, Oct 23, 2023:

“Almost a decade ago, Helion predicted reaching scientific breakeven by 2017.”

“Zap hoped to get there (entific breakeven) this year (2023), though it almost certainly won’t.”

From Jassby, FPS April 2019:

“Tri Alpha says it will produce a working commercial reactor between 2015 and 2020,”

“GF targets prototype by 2015 and a working reactor by 2020”

“Lockheed will have a small fusion reactor prototype (power plant) in five years…and a commercial application within a decade,” Written in 2014.

Possibly the subject of a future Nelson podcast

WHAT TO DO???

Well LLNL just had an enormous triumph with laser fusion!! It made headlines on page 1 of the NYT and WSJ. They achieved a Q of 1.5! It achieved nearly what ITER hopes to achieve 20 years from now at a small fraction of ITER's cost!

The secretary of energy was at the LLNL announcement!! How can DoE energy **possibly ignore this**, especially with problems with every magnetic fusion built so far??

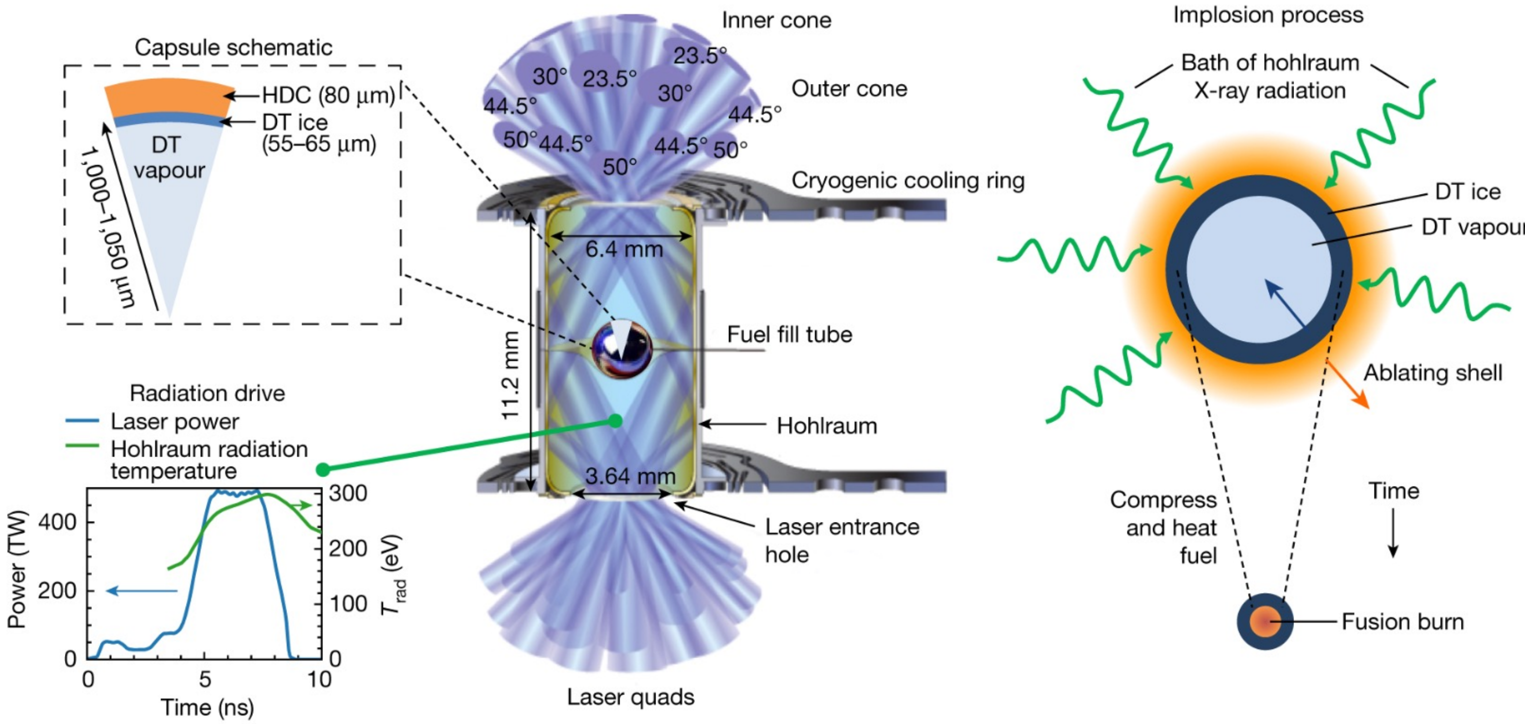
LLNL's scheme is to put the target in a hohlraum, illuminate the walls to produce an intense X-ray burst to implode the target and cause it to fuse.

LLNL is sponsored by nuclear simulation, not energy, and bureaucracy is bureaucracy!!

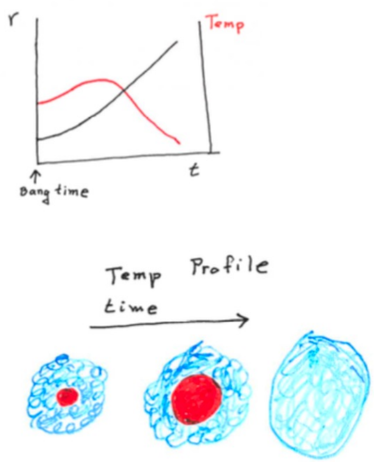
Once the central spot fuses, it produces 14 MeV neutrons which escape, and 3.5 MeV alphas which are absorbed locally and heat the surrounding region so that it fuses. The idea is for these alphas to initiate an alpha generated burn wave. The laser is only the ‘magic match’, it does not sustain the reaction.

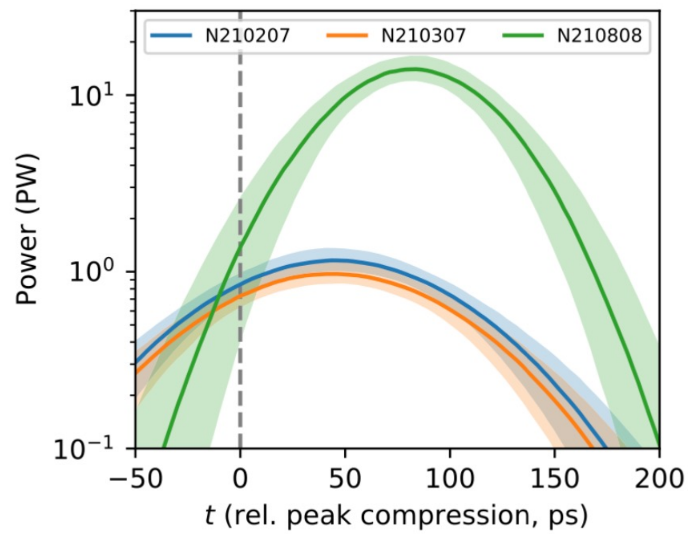
In other words, at the outset, laser fusion solves the problem of what to do with the alphas! It regards them as an essential piece of the puzzle; MFE regards them as a nuisance.

The LLNL/NIF configuration



Their best shot achieved Q=1.5 and produced a burn wave! Everyone knows that as something expands it cools, but this one heated! It can only be an alpha generated burn wave.





My sketches of results presented at 2 LLNL seminars.

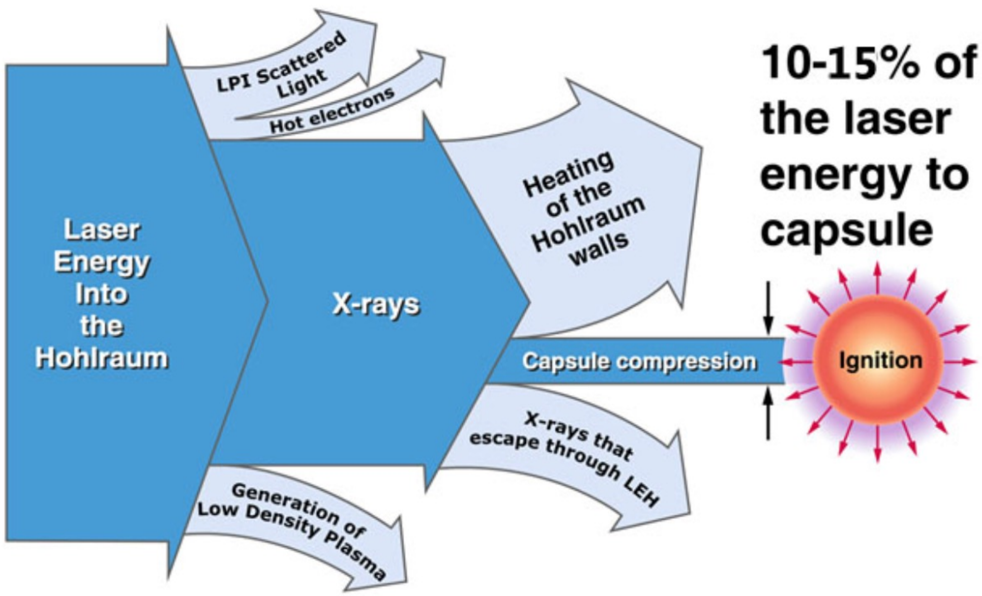
I think 100 years from now, this will be regarded as one of the key 21st century experiments.

The LLNL laser and configuration is appropriate for nuclear simulation, but is not appropriate for energy

Their sponsor is not interested in laser parameters important for energy such as efficiency, rep rate capability, bandwidth, or ability to track a fast-moving wobbling target.

Hohlraums are precisely engineered quantities costing thousands of $$, each containing expensive materials like gold and uranium. Mass production will undoubtedly reduce the cost considerably, but, but say the fusion energy is 100MW, translated to ~ 10kW hours of electricity at 33% efficiency, worth about a dollar. This gives a very, very low upper price limit for the hohlraum cost.

Not only that, only a tiny fraction of the laser light is converted to X-rays which strike the target:



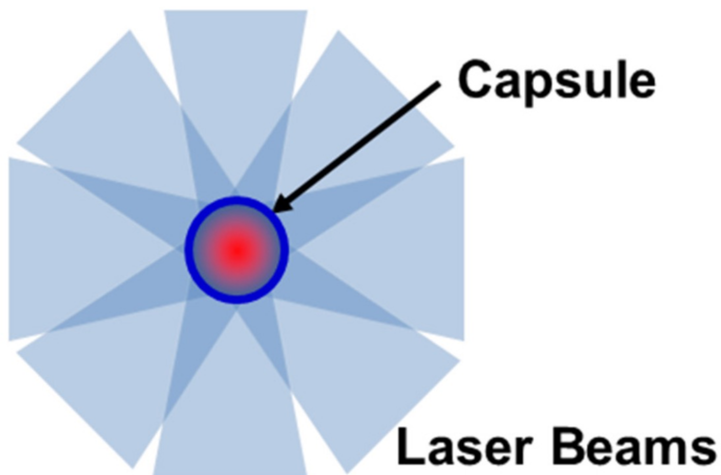
From LLNL

Couldn’t it be better if nearly all the laser beam hit the target?
It is at least worth a **very** big effort to find out.

LLNL demonstrated that it can hit the target if it is in a tent or on a stalk. It is like hitting a golf ball on a tee. However, for energy, the target in the hohlraum must be continually shot in at high speed and their paths are not quite predictable. It is more like hitting a series of fastballs, curveballs, sliders, change ups by someone like Jacob deGrom, on EVERY PITCH! Not only that the target axis would have to be perfectly aligned with the laser axis. This is like the batter hitting the pitch at a particular phase of the ball's spin.

Laser fusion for energy is playing baseball, not golf, which it is playing for nuclear simulation!

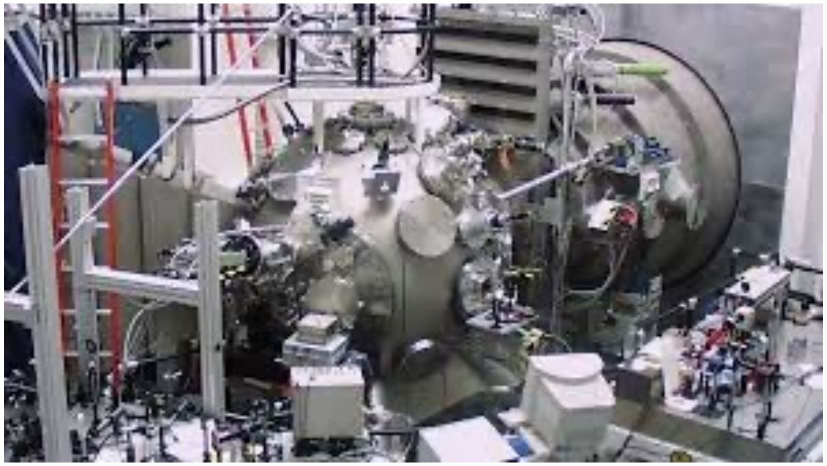
Direct drive uses a spherical target, and most likely an excimer laser, but with no hohlraum, so the target engagement is much simpler, and nearly all the laser light can be focused on the target whatever its orientation.



From NRL

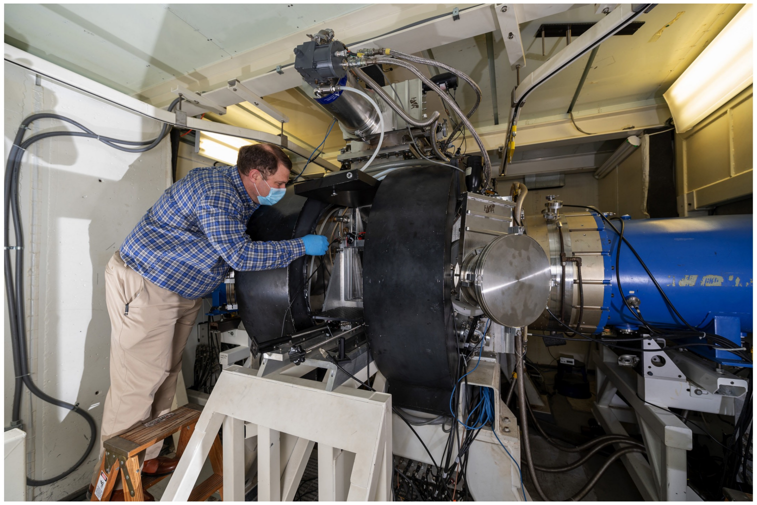
At this point, NRL is the only group looking into laser fusion with excimer lasers.

- NIKE has demonstrated multi kilojoule operation with very smooth beams. It has many of the qualities necessary for fusion as opposed to nuclear simulation.
- It has done many important laser fusion experiments.
- The program has also had a strong theoretical component which I participated in.



The ELECTRA facility is a rep rated laser which so far has the highest average power of any fusion relevant laser. Its mantra was: **Big enough to be convincing, Small enough to be manageable.**

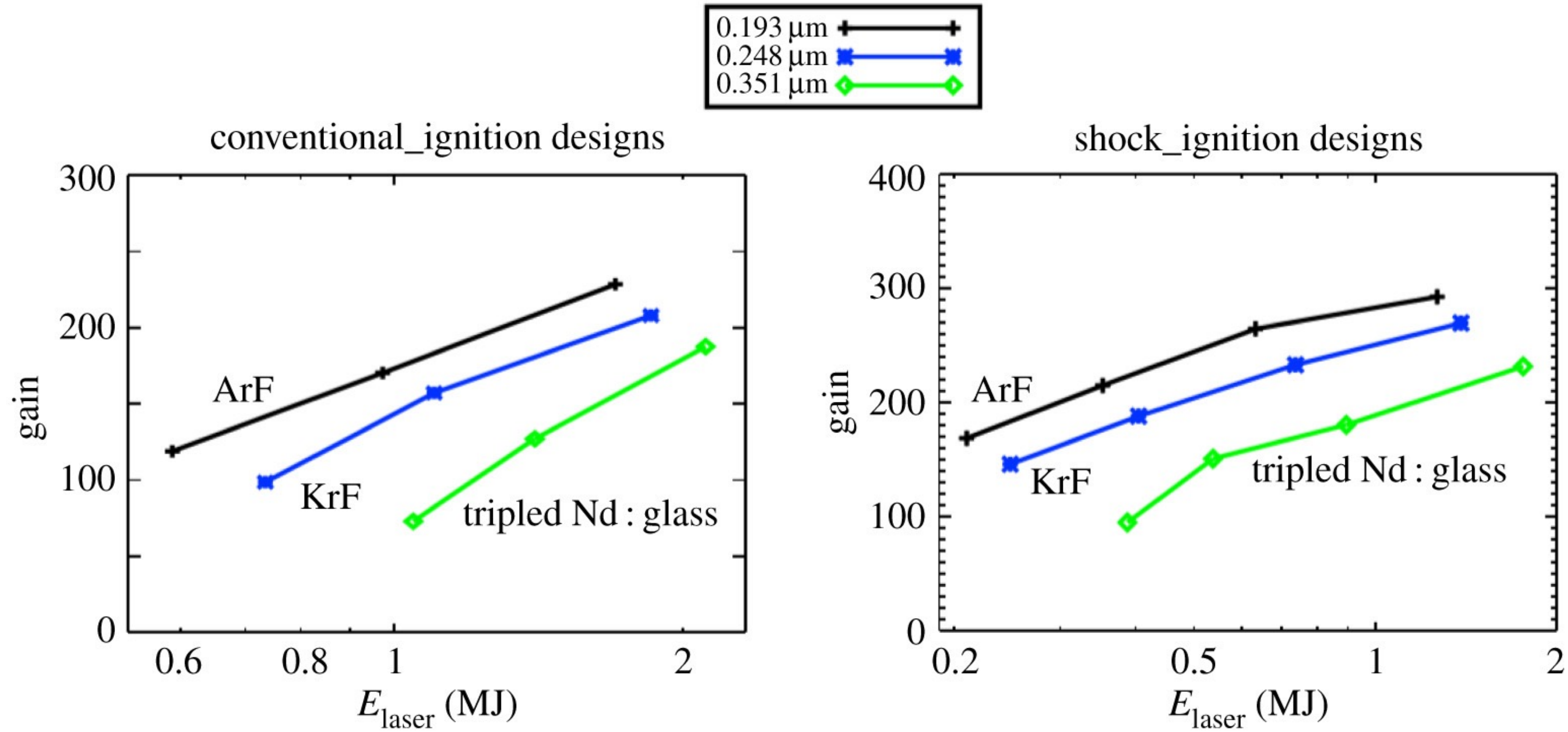
- It has recently been converted from KrF (248 nm) to ArF (193nm).
- It has achieved a world record of laser laser energy of 200 Joules.
- ArF is the shortest wavelength available for laser fusion research.
- This is a uniquely capable facility available for laser fusion research.



Let's look at some advantages of ArF excimer lasers

- NRL calculates a beam to laser efficiency of 16% is possible, and a wall plug efficiency of 10% .
- The laser could have a bandwidth as high as 10 THz, which could have an important effect on stabilizing laser plasma instabilities.
- Where the laser material is a flowing gas rather than a solid, it could have a much higher average power capability.
- Excimer lasers can zoom, that is they can change their focal properties so they can vary their focus to follow a target as it implodes.
- Calculations indicate high Q targets could be achievable depending on the target construction and the laser temporal profile.

Also, NRL (and URLLE) calculations show that in a direct drive configuration, high gain can can likely be achieved



However, at some point, this project must be transferred to a major DoE fusion lab which has the mission and resources for the major commitment this this would entail. NRL has neither the mission nor resources to pull it off, although it can help..

Let's imagine pure fusion. We have a 2 MJ laser producing 500 MJ of fusion energy. This translates into 170 MW or electrical energy.   The 10% efficient laser would need 60 MJ of wall plug energy to power itself at 20MJe. With a targets shot in at 6 times/s, this would about 3 GWth or 1 GWe, with 120MW going to power the laser. Seems reasonable.

A 2 MJ laser seems to be a viable goal, LLNL has built a 1 MJ laser and has increase its energy to 2 MJ. There is no reason to think a 2 MJ ArF laser could not also be built.

But how believable is it that there could be a gain of 250?

Let's look at Livermore's experience.

In 2004, John Lindl and 8 coauthors wrote a very long and detailed article on the physics of direct drive laser fusion. It examined a large region of parameter space and found large volumes of this space where the gain was 10 or more.

As NIF got more and more delayed, in 2010 Steven Haan and 40 coauthors reexamined the issue and found the same large region of parameter space where the gain exceeded 10.

However, when they turned on the laser in 2012, the gain was well under 1%.

They worked very hard over a decade, and their best results now have a Q ~1.5, nearly an order of magnitude below their calculations of 2004 and 2010.

The lesson: There seem to be a variety of unknown or not well-known physics involved in gain calculation. Let's make more conservative estimates to the NRL figures:

Let's assume the laser efficiency is 'only' 7% and the gain 'only' is 50. Then the 2 MJ laser gives is 100 MJ of fusion power, or 30 MJ of electricity. But to produce the 2 MJ of laser light would take 30MJ of wall plug power. Obviously not a viable economic fusion scheme.

But let's examine it for fusion breeding.

First, the breeding reactions are exothermic and roughly double the fusion power, so to produce 3 GWth in a fusion breeder, one would only have to produce 1.5 GWth of neutron power.

So let's imagine producing 100 MJ of Neutron power, from targets shot in 15 times/s.

As a breeder, this would produce 15 GW of 233U, maybe even more with better neutron economy designs.

A single 3GWth (1GWe) laser fusion breeder, with these more conservative parameters, would fuel at least 5 one GWe thermal reactors.

Now let's add up the score, IFE vs MFE:

- MFE must worry about driving steady state currents in tokamaks, IFE does not
- MFE does not know what do do with the alphas, it seems to regard them as a nuisance.   IFE knows what to do with them, they create and alpha burn wave, and LLNL has done this.
- IFE has no conservative design rules to worry about, at least none we know about. It works at both the megajoule and megaton level.
- IFE does not store vast quantities of energy; it is inherently much safer than MFE
- IFE has no problem with recycling. By the time anything bounces off the wall and gets back into the plasma, the reaction is long done with. Steady state MFE probably has a big problem with recycling.
- MFE has no flexibility on where it puts the wall, IFE, which is basically a point source has several options.
- LLNL has also fought delays and cost overruns, but these are nothing compared with ITER's

What to do now?

Take a clue from an earlier action by the PPPL:

In the 1960's they were wedded to stellarators, which at the time got terrible results.

Then the Russians showed that tokamaks had much better confinement.

Almost immediately Princeton switched from stellarators to tokamaks, and had a wonderful 35-year run, until tokamaks ran out of steam.

Now all magnetic fusion has run out of steam, and laser fusion just had an enormous triumph.

I see a path from this triumph to laser fusion power (direct of via breeding) for the world economy.

The US DoE fusion project should learn its lesson from Princeton in the 1960’s

It should mostly abandon MFE and switch to laser fusion by setting up a separate branch of DoE energy to oversee it. The MFE budget now is ~$520M for domestic MFE, and ~$240 for ITER.

It should maintain the $240 for ITER, a large international project.

The $520 should be split between 2 branches, MFE and IFE with IFE getting at least $300M

The $300M should go to a new or existing DoE lab, for laser development and laser light target research, so there will be 2 DoE labs doing serious laser fusion, LLNL and the new lab, LLNL mostly for bombs, the new lab, for energy.

This will cause enormous bureaucratic wars, it will be like slogging through quicksand a mile wide and a mile deep, but it is necessary!

The energy park, more than a dream, but much less

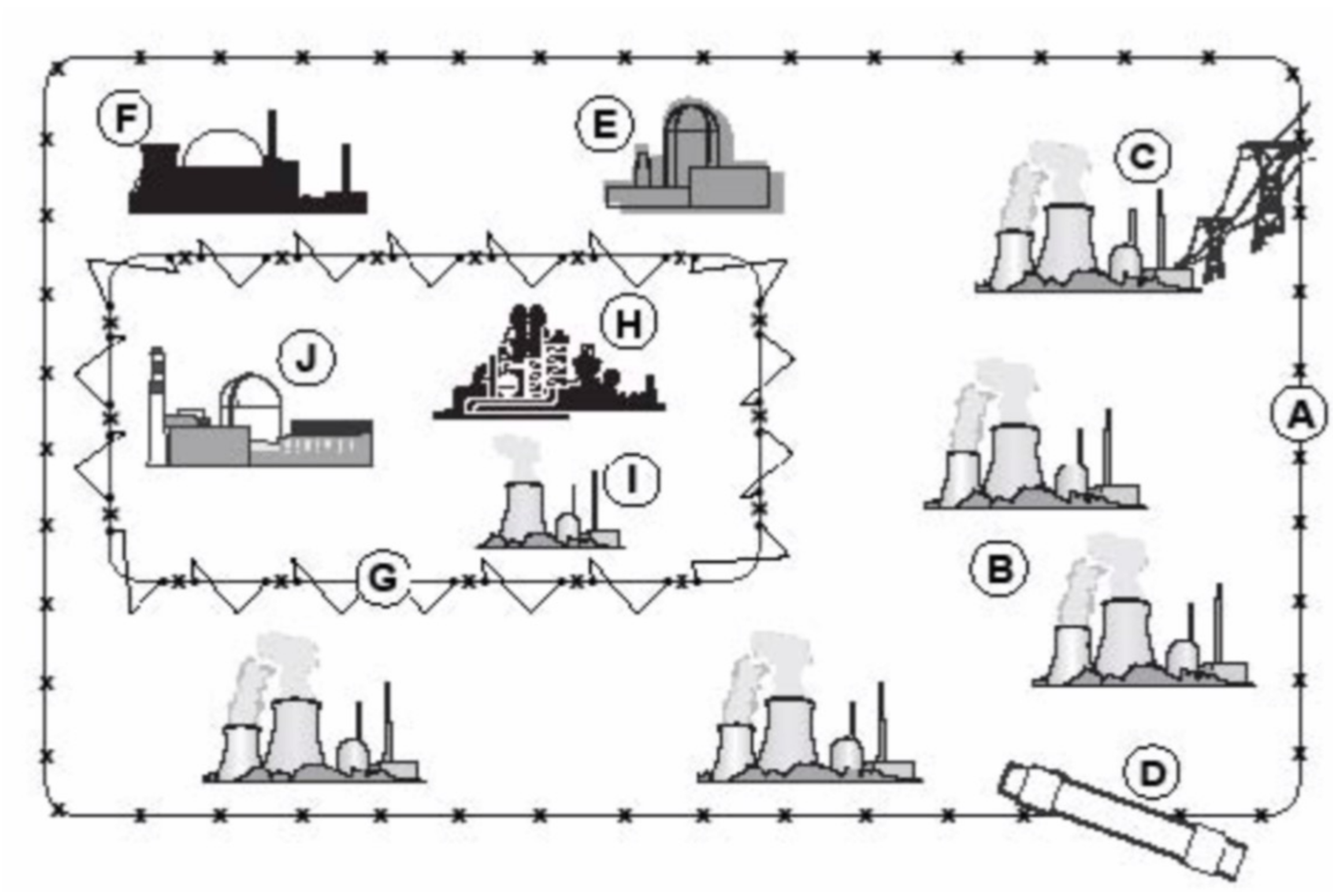


Figure 6: The energy park: A. low security fence; B. 5 thermal 1GWe nuclear reactors, LWRs or more advanced reactors; C. output electricity; D. manufactured fuel pipeline, E. cooling pool for storage of highly radioactive fission products for 300–500 years necessary for them to become inert. This is a time human society can reasonably plan for, unlike the ~ half million years it would take for the plutonium 'waste' to be buried in a repository, essentially creating a plutonium mine; F. liquid or gaseous fuel factory; G. high security fence, everything with proliferation risk, during the short time before it is diluted or burned, is behind this high security fence; H. separation plant. This separates the material discharged from the reactors (B) into fission products and transuranic elements. Fission products which have commercial value would be separated out and sold, the rest go to storage (E), transuranic elements go

A partial 'energy park' on the shore of Lake Huron in Ontario, 8 reactors in Bruce A and B.

Bruce A