Save the Planet: Eliminate CO_2 and Destroy Nuclear Waste

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The Big Problems with Energy

- $CO2$ emissions and other forms of pollution
- Safety
- Cost
- Availability
- Nuclear waste disposal
- Weapons proliferation using nuclear waste

A newer nuclear reactor and fuel cycle, called the Integral Fast Reactor, can address all these problems. No other technology, or combination of technologies, can.

Why Nuclear Power?

Nuclear power is

> *. . . the energy source that can save our planet from another possible disaster: catastrophic climate change. . . .*
>
> *Nuclear energy is the only large-scale, cost-effective energy source that can reduce these emissions [of CO_2] while continuing to satisfy a growing demand for power. . . .*

– Patrick Moore, cofounder of Greenpeace

Problems With Today's U.S. Energy Economy

- 6,697,600,000 tonnes U.S. CO_2 emissions per year.
- 100,000,000 tonnes of toxic solid waste per year from U.S. coal-fired power plants.
- 1,818 tonnes of used light-water nuclear-reactor fuel per year.
- Dependence on foreign energy sources, primarily for transportation fuel.
- Military and foreign policy costs, including wars, to protect access to energy sources.

Modern nuclear power – not 1950's technology – addresses all those problems.

There's One Solution

Essentially everything you've been told about civilian nuclear electric power is wrong. There are solutions to the problems of

- Safety,
- Waste,
- Weapons proliferation,
- Uranium supply,
- Reliability, and
- Cost,

and nuclear power produces almost no CO_2 emissions.

The Solution

The solutions are all embodied in one system, the brainchild of Leonard Koch and his colleagues at Argonne National Laboratory in 1964.

A project, called the Integral Fast Reactor, or IFR, was begun in 1984 to demonstrate the system completely, at commercial scale, leaving absolutely no loose ends.

It was canceled by the Clinton administration in 1994, when it was an inch from completion, at more cost than finishing it. Clinton said “I know; it’s a symbol.”

What Is IFR?

IFR is an advanced liquid metal-cooled breeder reactor, with an integrated fuel reprocessing system.

IFR is inherently safe because of a negative temperature coefficient. The hotter the reactor, the slower the reaction. **It cannot melt down.**

It is **IMPOSSIBLE** for **ANY** nuclear reactor to cause a nuclear explosion. Chernobyl was a steam explosion and a graphite fire in a facility with no containment structure. IFR has neither water nor graphite in the reactor core.

IFR is simpler than current light-water reactors (LWR) because the core operates at atmospheric pressure, making it more reliable, and cheaper to build and operate than LWR.

What Is IFR?

IFR can be fueled from what we currently call LWR waste, a substance we are desperately eager to be rid of, thereby destroying it, **and nothing else can!** **No need for Yucca Mountain.**

IFR produces 5% as much waste as LWR. Almost three quarters of it is stable or has a half-life under one year; 6% more of it can be destroyed. The remaining 20% is less radiotoxic than mined uranium after 200-300 years instead of LWR wastes' 300,000 years. **This is 100,000 times easier to deal with than LWR waste!**

IFR uses 99% of the energy in mined uranium. LWR uses 4-5% of the energy in the enriched uranium put into it, or 0.6% of the energy in mined uranium.

What Is IFR?

IFR does not need uranium isotope enrichment.

IFR creates its own fuel, and about 5% more, from abundant non-fissile natural uranium, or about 1% more from even more abundant thorium.

IFR fuel reprocessing is integrated on-site. No actinides come out except to start a new IFR.

Used IFR fuel is just about the most difficult substance from which to make weapons – more difficult than LWR waste.

No nuclear state makes weapons from used civilian LWR fuel. There are too many simpler and cheaper ways to do it. Jimmy Carter, educated as a nuclear engineer, should have known better when he discontinued U.S. nuclear fuel reprocessing in a naïve attempt to convince other nations not to build nuclear weapons.

Why IFR?

A single complete and permanent solution to all

- Energy supply,
- Energy-related CO_2 emission and pollution,
- Dependence on foreign energy sources, and
- Nuclear safety and waste problems.

Eliminate the "energy resource" excuse for wars.

"[IFR] is the best fast reactor project that has ever been pursued." – Hans Bethe

Replacing Non-Electric Demand with Electricity

Sector	Current Demand as Heat§		If Supplied as Electricity
Commercial / Residential	19%	450 GWth	100 GWe*
Industrial	33%	800 GWth	600 GWe†
Road, Rail, Pipeline	41%	975 GWth	200 GWe¶
Ships, Airplanes	7%	175 GWth	350 GWe‡
Total Non-Electric	100%	2,400 GWth	1,250 GWe
Electric	—	—	464 GWe
Total if all Electric	—	—	$\approx$ 1,700 GWe

§ http://www.eia.doe.gov/energyexplained/index.cfm?page=us_energy_home

* Assumes mostly space and water heating using heat pumps having 460% efficiency (E.g., Mitsubishi EcoDan/BRE).

† Assumes 500 GW as heat provided by electricity + 300/3 GW used directly as electricity. Co-located industries could get process heat directly from a reactor at temperatures up to 1000°F.

¶ Assumes increase in efficiency from 15% to 73%.

‡ Assumes 50% efficient conversion of CO_2 + H_2O + energy to liquid hydrocarbon fuel.

Why Green Won't Work

Corn Ethanol Too much land – 300% of entire country for transportation fuels alone. 1,270% for all energy.

Wind Can't provide more than about 12% of current demand. Up to three times the cost of nuclear. Needs 1/3 of the nation's land.

Solar Photovoltaic Too expensive – 30-50 cents/kWh – up to ten times nuclear. $4\frac{1}{2}$ year energy payback. 69 year financial payback. Needs 295,000 km^2.

Geothermal Causes earthquakes.

Costs

Operating, construction, and delivered electricity costs, taking into account capacity factors and lifetimes†

Fuel	Operating Cost Cents/KWh	Capacity Weighted Construction Cost $/kWe	Capacity Factor	Delivered Cost Cents/kWh
LWR Nuclear	4.9	1,111–2,222	$>$90%	5.15–5.41
Coal	6.0–6.3	1,111–1,667	$>$90%	6.25–6.68
Hydro	4.0–8.0	6,000	$\approx$33%	4.69–8.69
Gas	7.6–9.2	444–888	$>$90%	7.77–9.54
Wind	4.9–10.0	4,762–9,524	$\approx$21%	7.62–15.43
Solar PV	15.0–30.0	40,000–60,000	$\approx$15%	30.21–52.82

Storage costs for solar PV not included
Additional distribution costs for wind and solar PV not included
CO_2, aerosol, and solid waste costs for coal not included
Decommissioning and waste costs for nuclear *are* included

† `http://www.iea.org/Textbase/npsum/ElecCost2010SUM.pdf`

Nuclear Safety

Three Mile Island NOBODY was injured.

Chernobyl UN Chernobyl Forum attributes 56 deaths to the accident, UNSCEAR says 64. WHO found no evidence of ongoing increase in cancer risk.

Fukushima Daiichi One worker got his foot burned by radioactive cooling water.

Nuclear Safety

Nuclear engineers know of two ways to damage a reactor by accident or by operating it incorrectly.

After Three Mile Island, the mechanism of its failure was induced in the Experimental Breeder Reactor II, the prototype for IFR. It shut down gracefully with no actions by the operators or dependence on pumps, computers, control rods, or any moving parts. Neither the reactor nor its operators were harmed. There was no release of radioactive materials.

Shortly thereafter, the second method was induced, with the same results.

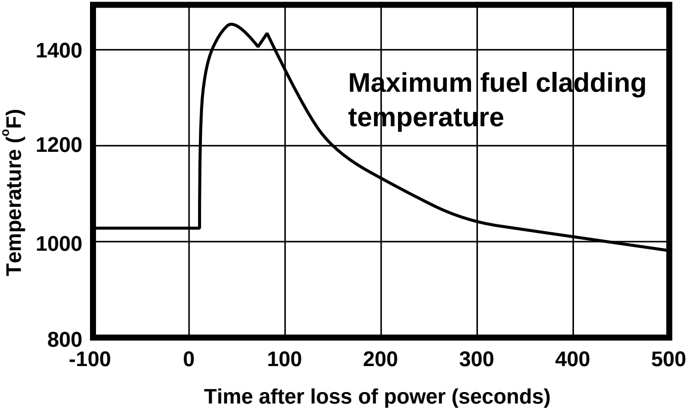
Two months later the second method was tried at Chernobyl, ironically by bypassing safety interlocks in a rush to get a safety check done.

EBR-II Loss-of-Coolant Experiment

"Back in 1986, we actually gave a small prototype advanced fast reactor a couple of chances to melt down. It politely refused both times."

– Pete Planchon, Argonne National Laboratory nuclear engineer

http://www.anl.gov/Media_Center/logos20-1/passive01.htm



Nuclear Power Reactor Waste

Converting 981 kg, or about one tonne, of heavy metal to fission products can produce about one GWe-year of electricity.

Current light-water reactors use less than 5% of the energy in the fuel put into them before the fuel is removed and considered waste, so they produce 20 tonnes of "waste" per GWe-year.

It isn't waste! It's valuable 5%-used fuel.

Since 1957, American civilian LWR's have produced 59,160 tonnes of "waste." If piled on a football field, it would be 7.4 feet deep. The 100,000,000 tonnes of toxic solid waste from one year of operation of the nation's coal-fired power plants would be 74,000 feet deep, or about 740 miles during the time American LWR's have been in operation.

Nuclear Power Reactor Waste

"Waste" from LWR's consists of approximately 93% uranium 238, 0.8% uranium 235, 1.41% plutonium and heavier actinides, and the remaining roughly 5% is fission products.

Uranium 235, plutonium 239, and some heavier actinides are fissile. Uranium 238 is not fissile, but in a reactor it absorbs a neutron, emits two electrons, and becomes fissionable plutonium 239. Breeder reactors do this more efficiently than LWR, making more fuel than they consume, from abundant non-fissile uranium 238 (or thorium 232).

In LWRs, transuranics in used fuel, especially americium, cause control problems and do not fission efficiently. This makes it impossible to cycle all actinides back through LWRs. Even the French system cannot cycle more than three times.

Therefore, used LWR fuel is considered to be waste.

Nuclear Power Reactor Waste

In IFR, transuranics are not troublesome. Rather, they are fuel. If fission products are removed from used fuel, the actinides can be put back into the reactor until they are entirely consumed. Fuel was recycled five times in EBR-II, without causing any problems, before the Clinton administration shut it down.

Since actinides are recycled as fuel until they are completely consumed, IFR produces less than 5% as much waste per GWe-year as LWR – about one tonne per GWe-yr as opposed to 20 tonnes.

Transuranics are dangerously radiotoxic for 300,000 years. The heat waste generates makes it difficult to store. This means that used LWR fuel is a troublesome substance that we are desperately eager to be rid of.

Nuclear Power Reactor Waste

70% of fission products are either stable, or have half lives less than one year. Of these, the radioactive ones are less radiotoxic than natural uranium ore after five to ten years.

6% of fission products (^{99}Tc and ^{129}I) have very long half-lives but can be transmuted to short-lived isotopes (15.46 seconds and 12.36 hours) by neutron absorption within a reactor, effectively destroying them. ^{93}Zr, another 5% of the fission products, can be recycled into fuel pin alloys and cladding.

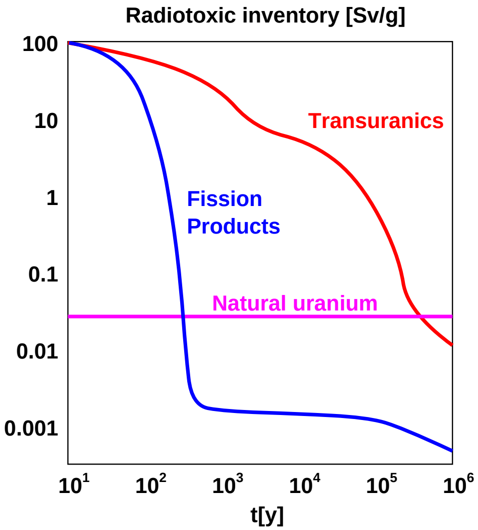
The remaining fission products, about 200 kg per GWe-yr, or about 340 tonnes per year for a 1.7 TWe economy, are less radiotoxic than natural uranium ore after 200-300 years.

At an average density of 8 tonnes per cubic yard, this would occupy about 43 cubic yards, or **fewer than five cement-mixer truck loads for the entire 1,700 GWe national energy economy**.

Nuclear Power Reactor Waste

http://www.stralsakerhetsmyndigheten.se/Global/Publikationer/Tidsskrift/Nucleus/2007/Nucleus-4-2007.pdf

(The Swedish Radiation Safety Authority)



Fission products value

Edwin Sayre† estimated that a tonne of fission products has a commercial value of about $16 million.

† http://brc.gov/e-mails/August10/Commercial Value of 1 Metric ton of used fuel.pdf

Selected fission product values

Element	Mass gr./GWe-yr	Value $/gr.	Value $/GWe-yr
Eu	2,190	60.00	131,400
Nd	69,760	2.20	139,520
Pd	27,420	82.94	2,274,200
Rb	7,300	11.78	86,000
Rh	9,340	500.00	4,670,000
Ru	43,540	45.78	1,993,260
Xe	106,640	1.70	181,000
Y	9,120	10.00	91,200
Total	279,197		$9,566,580

Are fission products waste?

Availability of Nuclear Fuel

Between “depleted” uranium (uranium 238 with very little remaining uranium 235) and LWR “waste” we have about 560,000 tonnes of IFR fuel above ground, already milled and refined. This would power IFR replacements for our LWRs for about 6,200 years, or IFR replacements for our entire electric generating capacity for 1,240 years, or IFR replacements for our entire current energy economy for 330 years.

Is LWR “waste” really waste?

Availability of Nuclear Fuel

Uranium is four times more common than tin and ten times more common than silver. Thorium 232, from which fissile uranium 233 can be produced in reactors by neutron transmutation, is four times more common than uranium.

Known reserves of natural uranium that can be economically recovered at \$130/kg of uranium amount to 4.5 million tonnes.

If the Earth's entire energy economy were powered by IFR's, this would last about 1,200 years.

Availability of Nuclear Fuel

The situation isn't so bleak, however.

Since IFR uses almost 100% of the energy in mined uranium instead of 0.6%, the fuel cost per kWh would be the same as for LWR if uranium cost $22,000/kg. This makes it economically feasible to mine lower quality ores, or to extract uranium from seawater, where there is an estimated 4.5 billion tonnes, or enough for a million years, or five million years if thorium is counted.

Furthermore, uranium and thorium are continuously entering the oceans in inflow from rivers.

Nuclear fission is an inexhaustible energy source.

IFR can produce energy with no downside, and with the advantages that it emits essentially no CO_2, and can destroy LWR waste, a substance we are desperately eager to be rid of – and nothing else can.

Weapons Proliferation

In a bomb, isotopes of plutonium heavier than plutonium 239, together with americium and other transuranics, make for a fizzle rather than a boom.

Separating plutonium 239 and 241 from plutonium 240 is more difficult than separating uranium 235 from uranium 238, because the difference in mass is three times smaller. Plutonium also presents more difficult thermal, chemical, and radiation problems than uranium. Other transuranics, especially americium, make the problem more difficult.

Used LWR fuel is just about the most difficult substance from which to make weapons.

No nation constructs nuclear explosives from used civilian nuclear reactor fuel. Doing so would be a nation-scale project, not the kind of thing a terrorist could do in his basement (or his cave).

Weapons Proliferation

Used IFR fuel is an even more difficult substance from which to make weapons than used LWR fuel.

Adding to that difficulty, used fuel would not leave an IFR for reprocessing. The only time actinides come out of an IFR is to start a new one, and that would be mixed actinides, with all their problems for would-be weaponeers. There are very few opportunities for theft or diversion of actinides.

Unenriched uranium goes into an IFR. The same amount of fission products comes out, or maybe they are stored on-site until the plant is decommissioned.

IFR doesn't need enriched uranium. Once IFR is deployed, any country claiming to need uranium enrichment for civilian electric power is lying: they have a weapons program.

Nuclear Hysteria Regretted

Patrick Moore, a cofounder of Greenpeace, now advocates nuclear power as *the energy source that can save our planet from another possible disaster: catastrophic climate change. . . . Nuclear energy is the only large-scale cost-effective energy source that can reduce these emissions [of CO_2] while continuing to satisfy a growing demand for power. . . .* For his honesty, Greenpeace has kicked him out.

He's not alone. James Lovelock, father of the Gaia theory, Stewart Brand, founder of the Whole Earth Catalog, the late Bishop Hugh Montefiore, founder and director of Friends of the Earth, James Hansen, the outspoken NASA climate scientist, and many other former critics of nuclear power, are now nuclear power advocates.

What Can Be Done

Admirable as they are, conservation, biofuels, wind, solar, geothermal, and hydro either can't power our economy, or cost far more than IFR.

They also can't do anything about LWR "waste."

Using coal, natural gas, and petroleum produces CO_2, other forms of pollution, and other forms of environmental damage.

Hydro is maxed out. No significant useful sites remain untapped.

That leaves nuclear.

To power our economy at today's energy consumption we would need about 1,700 GWe IFR capacity.

What Can Be Done

Starting a 1-GWe IFR requires about 8–10 tonnes of fissile material, which would at first come from used LWR fuel and decommissioned weapons.

The current U.S. inventory of fissile material is 840–885 tonnes in used LWR fuel, plus about 225 tonnes of weapons-grade uranium, or enough to start 80–138 GWe of IFR capacity immediately.

IFR breeds about 5% more fuel than it consumes, so an initial fleet of 80-138 GWe of IFR's, helped along by still-operating LWR's, could reach 1,700 GWe in about 50–60 years, **and destroy all of our LWR and weapons "waste" in another 300 years – instead of 300,000 years – and nothing else can.**

Costs (Big Picture)

A study commissioned by Tony Blair's government and led by Sir Nicholas Stern, former World Bank chief economist and vice president, concluded that developed nations need to spend 1% of GDP to reduce CO_2 emissions by 25–70%, and another 1% coping with climate change.

Spending this amount of today's U.S. GDP during the 50–60 years required to deploy an all-IFR American energy economy would cost $18.8 trillion.

Improvements in the electrical grid necessary to use dispersed and variable energy sources such as wind and solar, over and above those necessary to power the entire economy with electricity, would add another $4.7 trillion.

Deploying 1,700 GWe in IFR's would cost $2.1–$3.7 trillion, depending on whose estimates you accept. Economies of scale and technological maturation will lead to cost reductions.

Conclusion

A single complete and permanent solution to all of our energy, pollution, nuclear waste, foreign energy source dependence, and CO_2 emission problems is within our grasp.

All obstacles to that solution are political, abetted and perpetuated by ignorance, intentional falsehoods, and opportunistic demagoguery, not scientific, technological, or engineering problems.

Competition for energy resources is frequently blamed for wars. IFR would eliminate that excuse.

Breeder reactors with fuel recycling **will be developed.** There is no credible alternative. France, Russia, China, India and Japan are making progress. American experts are dying or retiring faster than youger ones are being prepared. **The United States will soon be a third-world country in energy technology.**

Conclusion

The United States has to choose between two paths:

- Spend \$23 trillion on technologies that don't yet exist, might not work, or can't do the job, to reduce CO_2 emissions by only 25–70%, **and do nothing about LWR waste,**

  or

- Spend \$3.7 trillion (or less), about \$60 billion per year, on proven technology that will **completely eliminate CO_2 emissions AND destroy LWR waste.**

I think the choice is obvious.

There really is no time to waste. We must get started.

Reading

- *Smarter use of nuclear waste*, **Scientific American**, December 2005, by William Hannum, Gerald Marsh and George Stanford.
- **Prescription For The Planet** by Tom Blees.

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