Too much smoke, Too Little Fire

Zubrin opens with "[We have been] doubling our carbon use every thirty years for more than a century. In 1900, humanity burned 0.6 billion tons of carbon per year. This doubled to 1.2 billion in 1930, doubling again to 2.5 billion tons in 1960, then yet again to 5 billion tons in 1990, to 10 billion tons now.1

"Based on history, there is every reason to expect human energy production and use to double again by 2050, and yet again by 2080.

"According to solid measurements, average temperatures have increased by about 1 degree centigrade since 1870. That, admittedly, is not a big deal. It is the equivalent to the warming that a New Yorker would experience if he or she moved to central New Jersey. So, there is no climate catastrophe now. But the climatic effects of continued CO_2 emissions at a level an order of magnitude higher than today would be an entirely different matter."

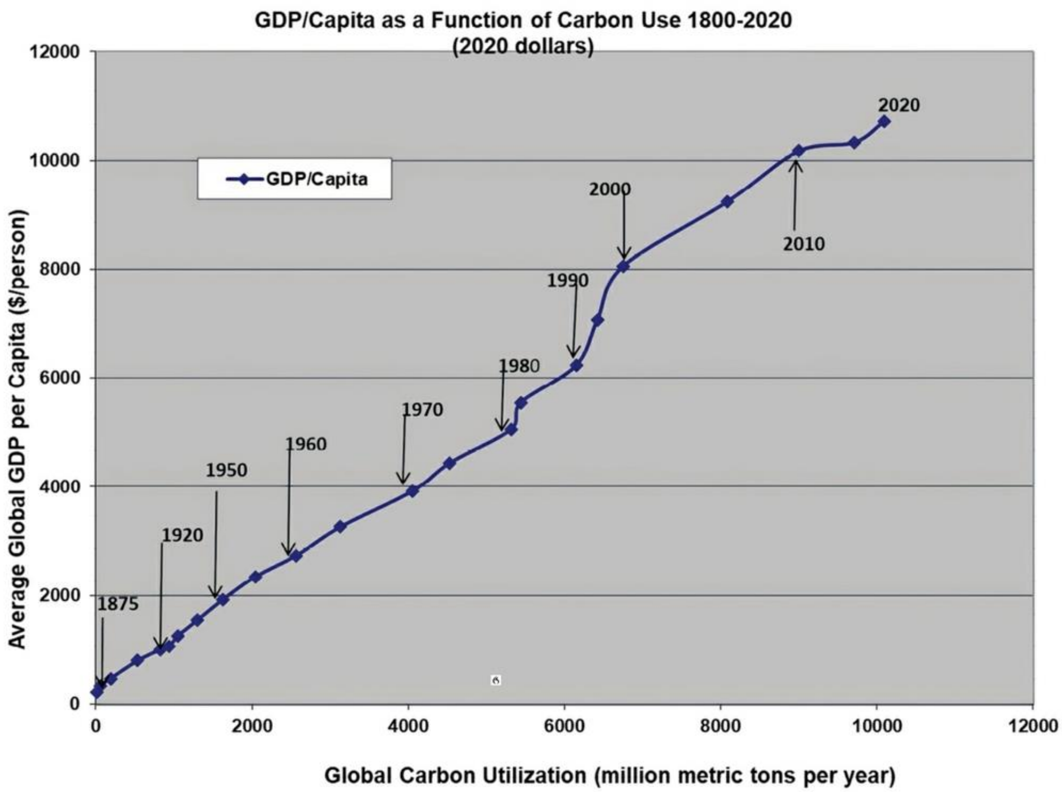
The Case for Nukes Table Of Contents

A Brief History of Power

Mankind has depended on a number of different sources of power, light and transportation energy. Here is a brief list, including the timeframes in which they were adopted.

- Fire – 2 million years ago. Warmth and cooked food.
- Wood fuel – from the beginning
- Charcoal fuel – Neolithic times
- Olive oil
- Wind power for sailing – bronze age
- Waterwheels – classical times
- Windmills for mechanical energy – 12th-century in France
- Coal– 12th-century in England
- Whale blubber for light, heat – 17th century
- Petroleum – 19th century
- Nuclear – 20th century

At this juncture – about 90% of our energy comes from fossil fuels. As the graph shows, increased carbon use has been highly correlated with the increase in the world gross national product.



There are concerns about the continued use of carbon-based fuels:

- Global warming,
- Air pollution,
- Ocean acidification
- The earth's limited endowment

But, all the alternatives going forward have severe limitations – except nuclear

- Solar
- Wind
- Hydro
- Biomass
- Nuclear

Zubrin makes the observation that technology advances are cumulative. The rate of advance depends on how many people are working on improvements and how widely they are shared.

This is Metcalfe's law – the power of a network is equal to the square of its size. Or Isaac Newton: "if I have seen further, it is because I have stood on the shoulders of giants." Zubin credits seafaring, which vastly widened our horizons. He doesn't mention the printing press, which facilitated sharing knowledge over distance and time.

Do We Really Need More Energy

Zubin recounts the way major innovations turn natural resources that had previously been considered useless into something of value. The heavy plow, with coulter and mortarboard, made heavy soils in northern Europe valuable. Horse collars and horseshoes made those animals more valuable. Once discovered, petroleum oil quickly replaced whale oil. A sticky nuisance became a thing of value.

This reviewer's brief take on nuclear fission

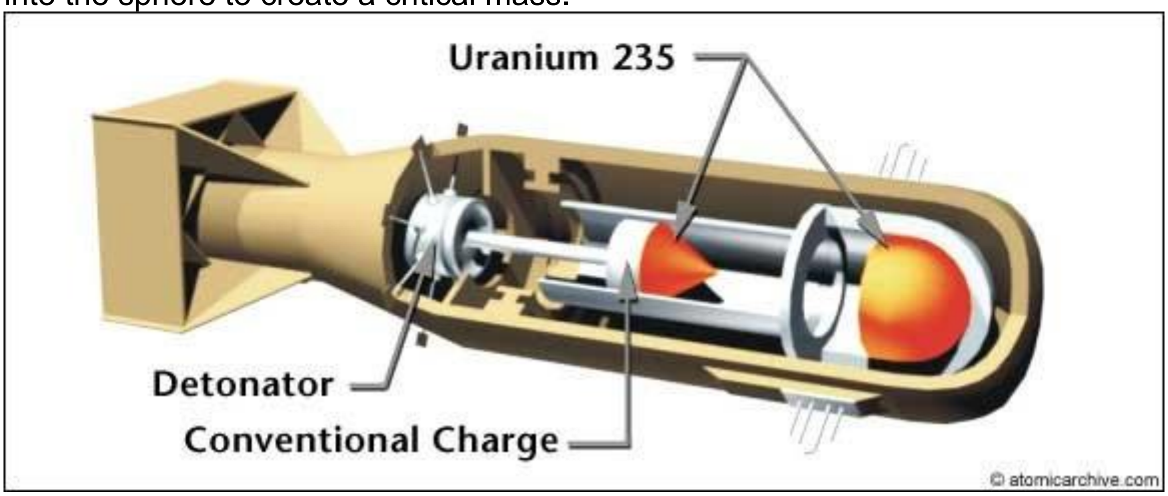
Uranium 235 has a half-life of 703.8 million years. That means if you had a piece of the metal, half of it would have decayed spontaneously in that period of time. Atoms decompose in a long and unpredictable chain of splits, the most persistent products being strontium 90 and cesium 137.

The atoms decay randomly. You can't tell when any single one will go. However, there are so many of them that the rate at which they decay can be predicted very accurately. If you have a quantity of metal, half of it will be decayed by the half-life.

Atoms are small and densely packed. In a one cubic centimeter piece of uranium 235, a million atoms will decay every second. In addition to splitting into smaller elements, a decaying atom also releases various kinds of radiation. In the case of U235 it includes three neutrons.

Those neutrons ordinarily simply escape. If they happen to hit other atoms it doesn't usually do anything. However, if the uranium 235 is densely packed, it raises the chances that a neutron will collide with another U235 atom and cause it to split. When one one decay causes more than one other atom to also split, it's called a chain reaction. It takes 56kg – that's a 7" sphere – of 85% uranium 235 – to make that happen.

That's how you make an atomic bomb. Here's a simplified diagram of Little Boy, the one dropped on Hiroshima. It involved an almost complete sphere of U235 at one end of the bomb and the missing part at the other. A conventional explosion blew the missing chunk into the sphere to create a critical mass.



A nuclear reactor is in a fine balance, such that each atom that decays prompts almost exactly one other atom to decay. It doesn't get out of control – in fact it with good design, it can't get out of control. There are control rods, moderators, and other factors that ensure that the radiation continues at a steady state.

What about Nuclear Energy

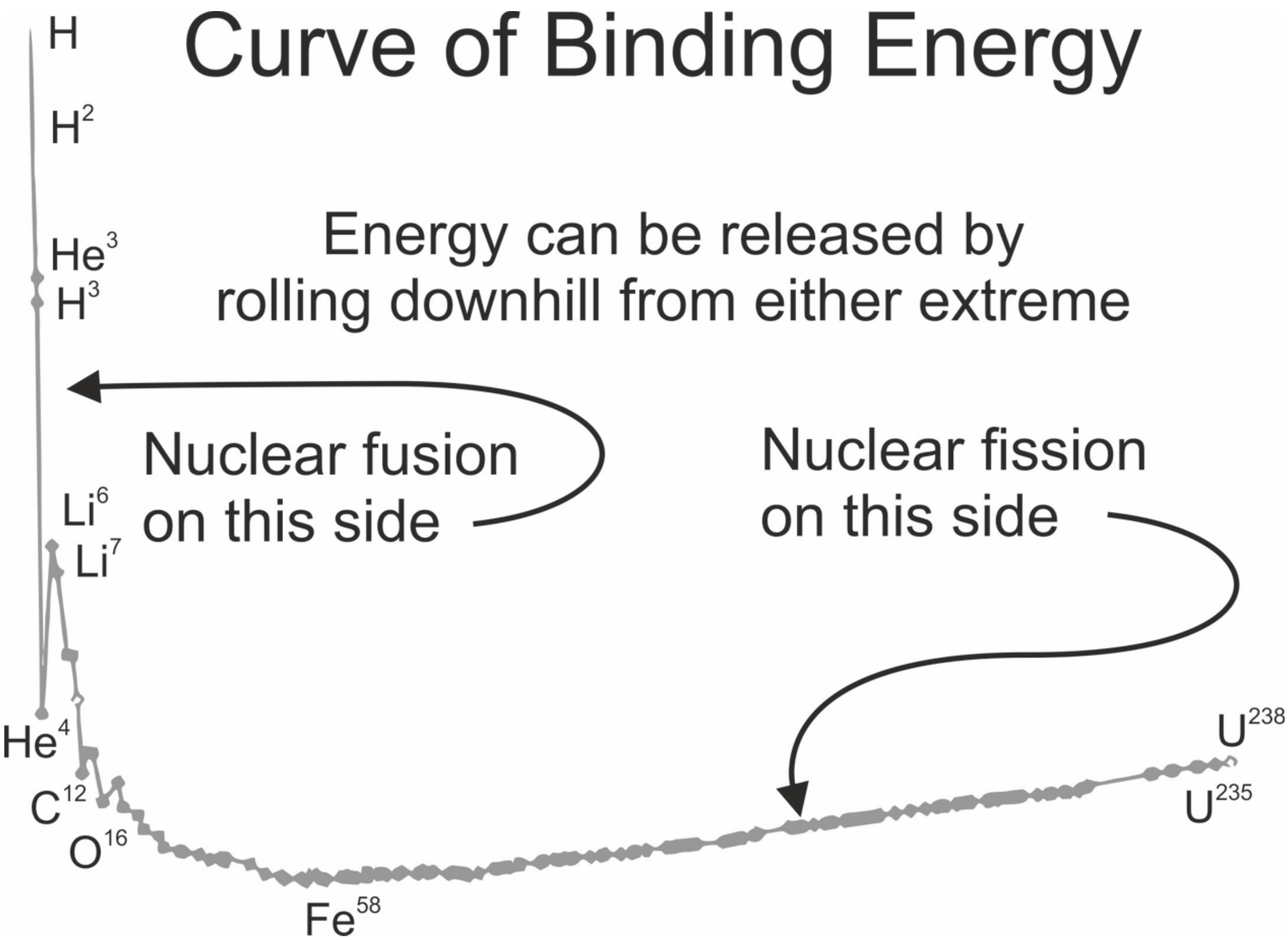
Albert Einstein presented his theory of Special Relativity, one of whose findings is that matter and energy are ultimately two different forms of the same stuff, with the conversion rate between the two given by his famous formula $E=mc^2$, or energy equals mass times the speed of light squared. "The speed of light is 300 million meters per second, so according to Einstein, 1 kilogram of mass — of any kind, gold, dirt, water, or rotten tomatoes — is the energy equivalent of 90 billion Megajoules (MJ), or 25 billion kilowatt hours. That's enough energy to power the entire world for an hour."

Zubrin writes:

> …common hydrogen just has one proton in its nucleus, but there is an oddball minority isotope (it's about 1 out of every 6000 hydrogens on Earth) called deuterium that has both a proton and a neutron. Added together, the combined number of protons and neutrons determine the atomic weight of that isotope. Well almost, but not exactly. The atomic weight of deuterium is not 2.0000, but 2.0141, and the atomic weight of common helium, with 2 protons and 2 neutrons, is not 4.0000 but 4.0026. Two plus two is supposed to equal four, but if you combined two deuteriums to make a helium, instead of getting a nucleus with a weight of 4.0282 the result only weighs 4.0026. You've lost 0.0256 units of mass — 0.64% of the 4-unit total! That's possible, because the four nucleons together pack more efficiently than they do as two pairs. So, the extra packing material, which is manifested in each pair as mass, can be released as energy when they are grouped as a foursome.

	Protons	Neutrons	Electrons	AtWt
Hydrogen	1		1	1
Deuterium	1	1	1	2.0141
Helium	2	2	2	4.0026
2 x Deuterium	2	2	2	4.0282
2 x Deuterium - Helium	0	0	0	0.0256

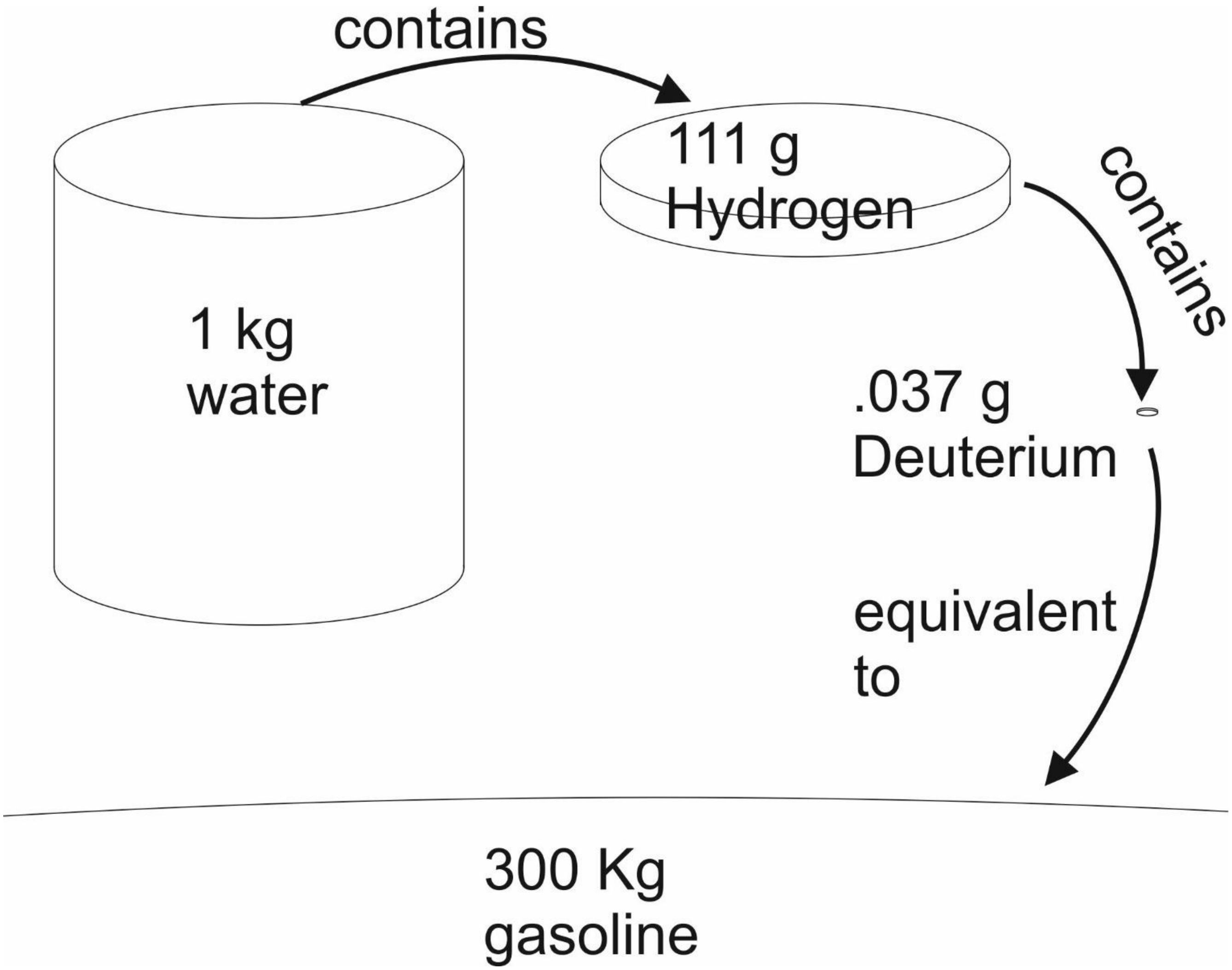
Generalizing to all elements, there is a curve of binding energy. Combining light elements such as hydrogen, helium and lithium into heavier elements releases a great deal of energy. Conversely, at the other end, breaking apart the heaviest elements also releases energy. Per this diagram, energy can be released by "rolling downhill" towards the center (Iron, Fe58). There is no energy to be derived from combining iron with anything – which is probably why it is so abundant. It is an end product of nuclear fusion and fission.



There is four times more energy possible on fusion side than fission, but it is so much either way that it does not matter.

How much energy? Per the next diagram, as Zubrin writes

1. 1 kilogram of water contains
2. 111 grams of hydrogen which contains
3. .037grams of deuterium (1/100 the weight of a US penny) which is equivalent to
4. 300 Kg of gasoline



Fission is easier than fusion. Holding positively charged atomic nuclei close enough together to fuse is very hard. It is much easier to find heavy radioactive elements that were fused long ago in the stars.

There is enough nuclear fuel to last well into the future using only today's proven technologies. The dollar figures in the table below represent the world per capita worth of the electricity that could be generated from each resource, at current prices.

Known Conventional Fossil Fuels	1500	$114,000
Estimated Unknown Conventional Fossil Fuels	3000	$228,000
Nuclear Fission (Uranium ore, without reprocessing)	700	$53,200
Nuclear Fission (Uranium ore, with reprocessing)	100,000	$7,600,000
Nuclear Fission (Thorium ore, with reprocessing)	400,000	$30,400,000

How to Make Nuclear Energy

Nuclear energy involves what are called fast and slow neutrons. Fission creates fast neutrons. They have a small cross-section. They go so fast that they mostly whiz by other atoms of fissile material, whereas they need to collide with them to create a critical chain reaction. That is, a process which is self-sustaining but not out of control.

This works for bombs, which must explode in an instant. The chain reaction takes place instantaneously, before the heat and energy of the explosion has time to disperse the critical mass of fissile material. They make bombs such that fast neutrons are dense enough in the explosive material to cause a chain reaction.

Nuclear reactors require moderation. The neutrons produced by nuclear decay must be slowed down to the point that they collide with other fissile atoms rather than flying by them. Moderation is accomplished by having the neutrons collide with other particles – the smaller the better. The energy loss is inversely proportional to the size difference. Hitting large particles does not slow them down much.

Whatever they hit also has a chance of absorbing them. Properties of the ideal moderator are (1) molecules of small atoms that (2) don't have a high likelihood of absorbing the neutron. In the following table the best atoms for moderation are highlighted in green. Deuterium is both light and non-absorbent. Hydrogen is light, and carbon and oxygen non-absorbent. Therefore, most reactors are moderated by H_2O – water, heavy water, or carbon in the form of graphite.

Fast and slow neutrons are at two ends of a continuum. "By cutting their energy down by a factor of 80 million, from 2 MeV to 0.025 eV (the energy equivalent of room temperature) this “thermalization” process will reduce the neutron’s speed by a factor of 9,000 (because the energy of a particle goes in proportion to its velocity squared)."

Per the following table, the slower, or "thermal" particles, have a bigger cross-section and more likelihood of striking other atoms of fissile material to create a chain reaction. But there is no explosion – it is self-limiting. The chain reaction breaks down when the water boils or things get too hot.

The cross section of a substance is measured in barns. One barn is approximately the cross-sectional area of a uranium nucleus. As this table shows, the cross section varies hugely as a factor of the reactor speed. Caveat: I have written my own interpretations into the table copied from the book.

CROSS SECTIONS OF SELECTED NUCLEAR ENGINEERING MATERIALS (BARNS) A barn is approximately the cross-sectional area of a uranium nucleus.						
	Slow – Reactor speed Thermal Cross Section (barns)			Fast – bomb speed Fast Cross Section (barns)		
Material	Scattering	Absorption	Fission	Scattering	Absorption	Fission
Moderators	These are components of water, heavy water and graphite used to slow neutrons down.					
Hydrogen-1	20	0.3	0	4	0.00004	0
Hydrogen-2	4	0.0004	0	3	0.000007	0
Carbon-12	5	0.002	0	2	0.00001	0
Oxygen-16	4	0.0001	0	3	0.00000003	0
Structure	These are materials used to build a reactor structure and house fuel rods. Zirconium, holding fuel rods, absorbs few neutrons.					
Chromium-52	3	0.5	0	3	0.002	0
Iron-56	10	2	0	20	0.003	0
Nickel-58	20	3	0	3	0.008	0
Zirconium	8	0.18	0	5	0.004	0
Absorbers	These substances "poison" a reaction by absorbing neutrons. If present as products of decay, they have to be removed to sustain a reaction. Cadmium is used to make control rods.					
Boron-10	2	200	0	2	0.04	0
Cadmium-113	100	30,000	0	4	0.05	0
Xenon-135	380,000	2,714,000	0	5	0.0008	0
Fuels	These are fissile materials used in reactors. Those highlighted in red are the good fuels. Only U235 exists in nature.					
Thorium-232	13	7.6	0.0002	5	0.09	0.07
Uranium-233	12	45	531	3	0.01	2
Uranium-235	10	99	583	4	0.09	1.2
Uranium-238	9	2.5	0.00002	5	0.07	0.2

Plutonium-239	8	269	748	5	0.05	2
Plutonium-240	10	286	0.03	5	0.09	1.4

Another discourse on bombs vs. reactors. The issue is holding the material together long enough for the reaction to take place. A bomb involves an instantaneous chain reaction producing immense heat. The reactive materials do not need to be contained. Therefore the reaction can include fusion. A hydrogen bomb is triggered by critical mass of highly enriched U235 or Pu239.

A reactor has to be contained within a physical structure. In order not to melt, it must operate at a much lower temperature. It has to be controlled in order to be sustained. By design, its criticality is usually self-regulating. In a pressurized water reactor, when things get too hot the reaction automatically shuts down.

A reactor was necessary to make plutonium 239 for the "Fat Man" Nagasaki bomb. The U235 "Little Boy" bomb was made using centrifuge separation of the isotopes. No reactor was necessary.

Atoms for Subs, Atoms for Peace

This is the story of the USS Nautilus and Admiral Rickover. Opposition was strong, but he was stronger. The nuclear navy got built.

Eisenhower initiated Atoms for Peace. It got off to a good start. In later chapters we learn how the long knives of the fossil fuel vested interests sabotaged it.

How to Build a Nuclear Reactor

The first nuclear reactors were built in basements, garages and sports stadiums. Zubrin tells how you can do it today, as much to inform readers about their inherent simplicity as to actually encourage doing it.

He describes the simplest, most common design, the Pressurized Water Reactor. It is simple and foolproof. There are more efficient designs, but the major criterion is not operating cost – they are all very economical – but getting approval for the device's safety.

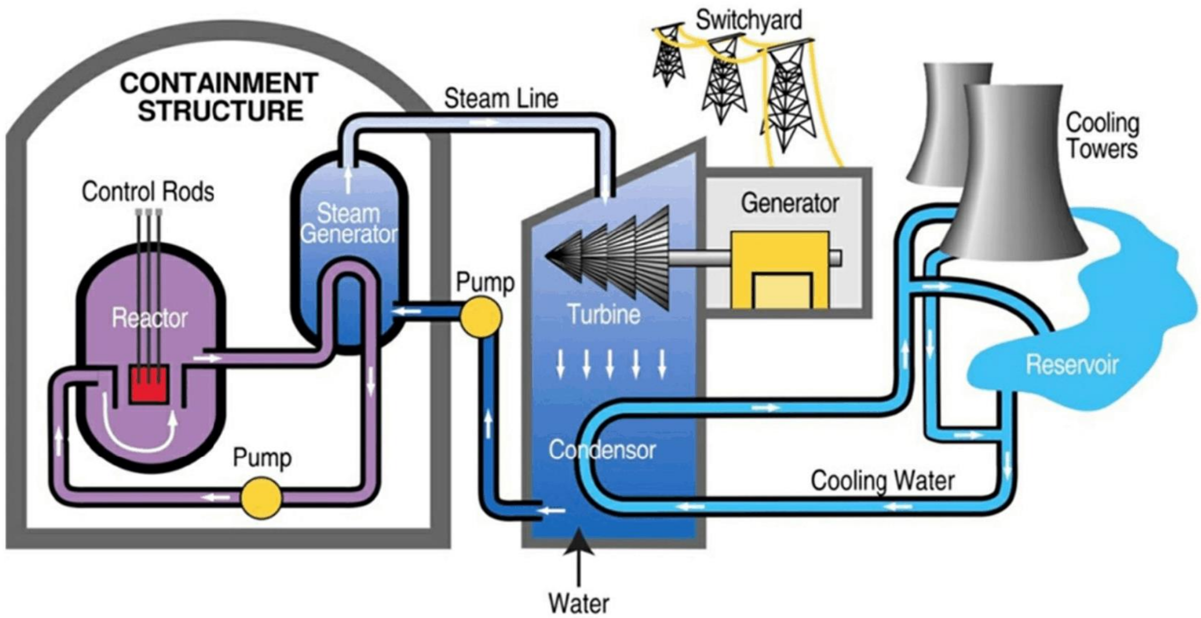


Fig. 7.1 A Pressurized Water Reactor power station. (Credit: US Department of Energy)

Is Nuclear Power Safe?

The average American receives 270 millirems of radiation per year, of which less than 1/22000 comes from nuclear power. Nobody died in two of the three most serious power plant incidents.

In the 1979 Three Mile Island meltdown several safety systems failed. An operator erroneously turned off a safety pump that had automatically turned on. The control rods were dropped into the system, but residual radiation caused the reactor to overheat and burn two centimeters into the ground. A small amount of radiation escaped. Nobody was injured.

The 2011 Fukushima earthquake measured 9.1 on the Richter scale, the 4th most powerful ever recorded. It created a tsunami up to 130 feet high, 40 feet when it hit the reactors. Although the destruction knocked out all of the reactor backup systems, and three of the six units were ruined, the complex shut down without injuring anybody. 28,000 died from the earthquake and tsunami, but nobody from radiation.

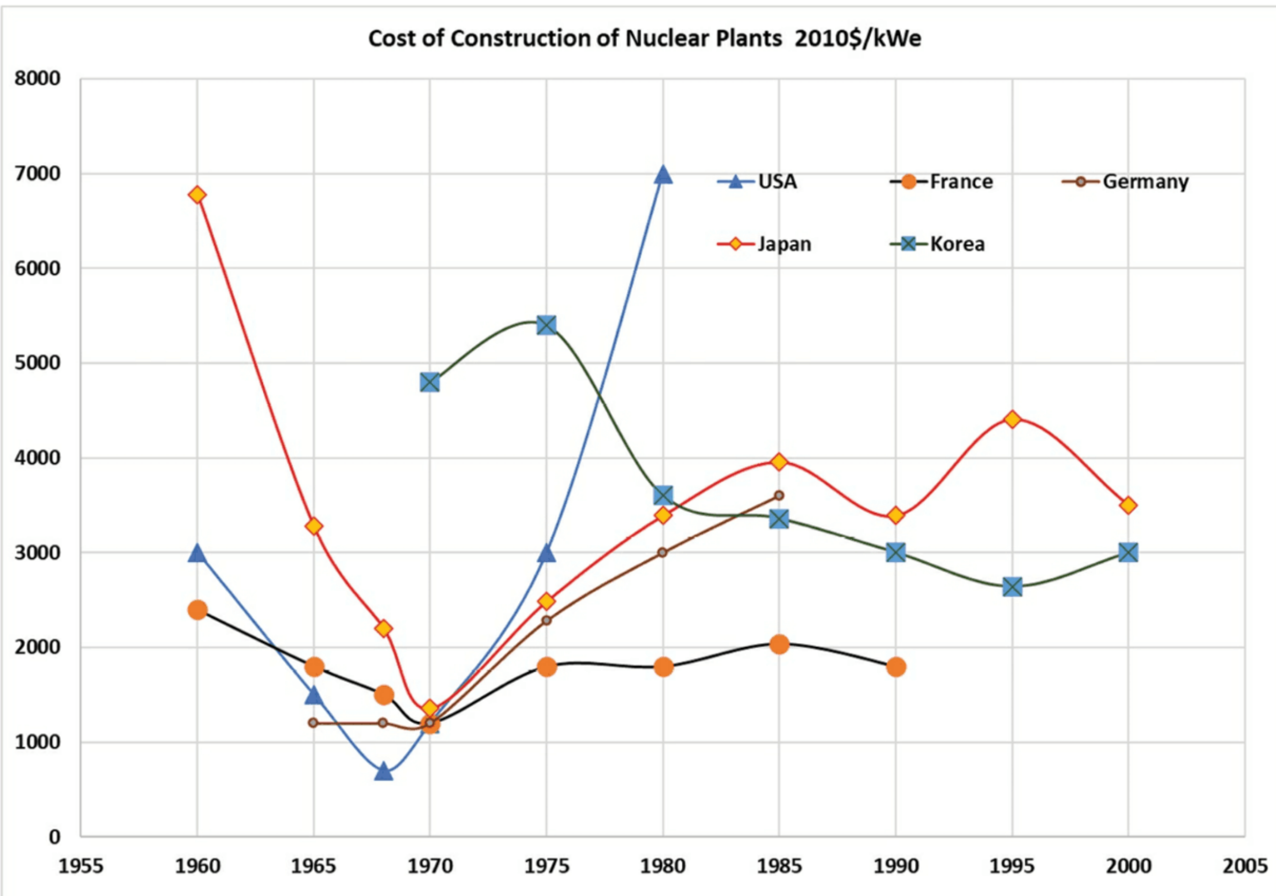
The 1986 Chernobyl meltdown was caused by an irascible martinet named Anatoly Dyatlov, who refused to abort a planned safety exercise after his inexperience subordinated, Leonid Toptunov, made a mistake, told him so, and recommended they stop. Unlike pressurized water systems, a graphite-moderated reactor cannot boil off and automatically stop the chain reaction when it gets out of control. Instead, the graphite caught fire.

The combination of bad design, inexperience and dictatorial management resulted in the meltdown. Fifty people died at the time. The UN believes that at the outside another 5,000 may have eventually died of cancers caused by radiation. By comparison, the BBC estimates that 12,000 coal miners die annually. Many times more die of air pollution from burning coal.,

Thorium reactors would be the answer to concerns about proliferation of nuclear weapons. Thorium 232 works well for generating electricity but the radioactive products it produces – U233 and U232 – are not suitable for making bombs.

How to Cut Costs

The cost of building nuclear generating plants has little to do with the technology. It is all about national regulation – or overregulation. As a result, the cost of building in the USA went up tenfold in constant dollars from 1968 to 1980. Common sense says the cost of technology goes down over time, not up. The cost in France was about a quarter that in the USA.
Per Zubrin, environmentalists oppose and frustrate nuclear because

1. They are dedicated Malthusians and want to stifle progress and shrink the human herd
2. Environmentalists depend on crises to attract members
3. They get paid big time – by gas and oil, coal, solar and wind power interests.
4. 

Breeding More Fuel Than You Burn

Breeder reactors make better use of fuel and can be more efficient. They are a logical step in the evolution of nuclear power. However, the question is political, not technical. Pressurized water systems are proven. They appear to be the simplest and safest for now.

Entrepreneurial Nukes

Governments have ceased innovating in the realm of nuclear reactors, but private industry has not. There are four major types:

- Water Cooled Reactors (light water and heavy water)
- High temperature gas cooled
- Liquid metal cooled
- Molten salt cooled

NuScale corporation makes an SMR – small modular light-water reactor. It is the most conservative design. A look at their investment material indicates that (1) they have a single contract to install their system, in Romania and (2) the value of the stock, traded as NYSE:SMR, has gone nowhere.

This would appear to be the bellwether. When the Romanian venture works, and the full dimension of Germany's disastrous shutdown of nuclear and reliance on wind, solar and Russian natural gas becomes clear, the company could be at the head of a parade back to nuclear.

Ukraine would be a logical customer. Nuclear still provides about half its electricity. The home of Chernobyl fears nuclear less than most. Ukraine is next door to power-hungry customers that have saddled themselves with counterproductive politics that get in the way of building their own plants. It has halted work on two partially completed plants due to the war.

The Power the Lights the Stars

Nuclear fusion was put to use in the H-bomb in the 1950s. It works because the critical mass needs to be held together only for the instant it takes for the fast chain reaction to split the fissile nuclei and combine the fusion nuclei. The intense explosion that results, blowing the nuclear material apart, is the intended result.

Controlled nuclear fusion, without the explosion, has been the objective since the start of the nuclear age. The problem is heat. Fusion reactors must operate at temperatures vastly higher than the melting point of every possible structural material. The fusion must be suspended within an intense magnetic field.

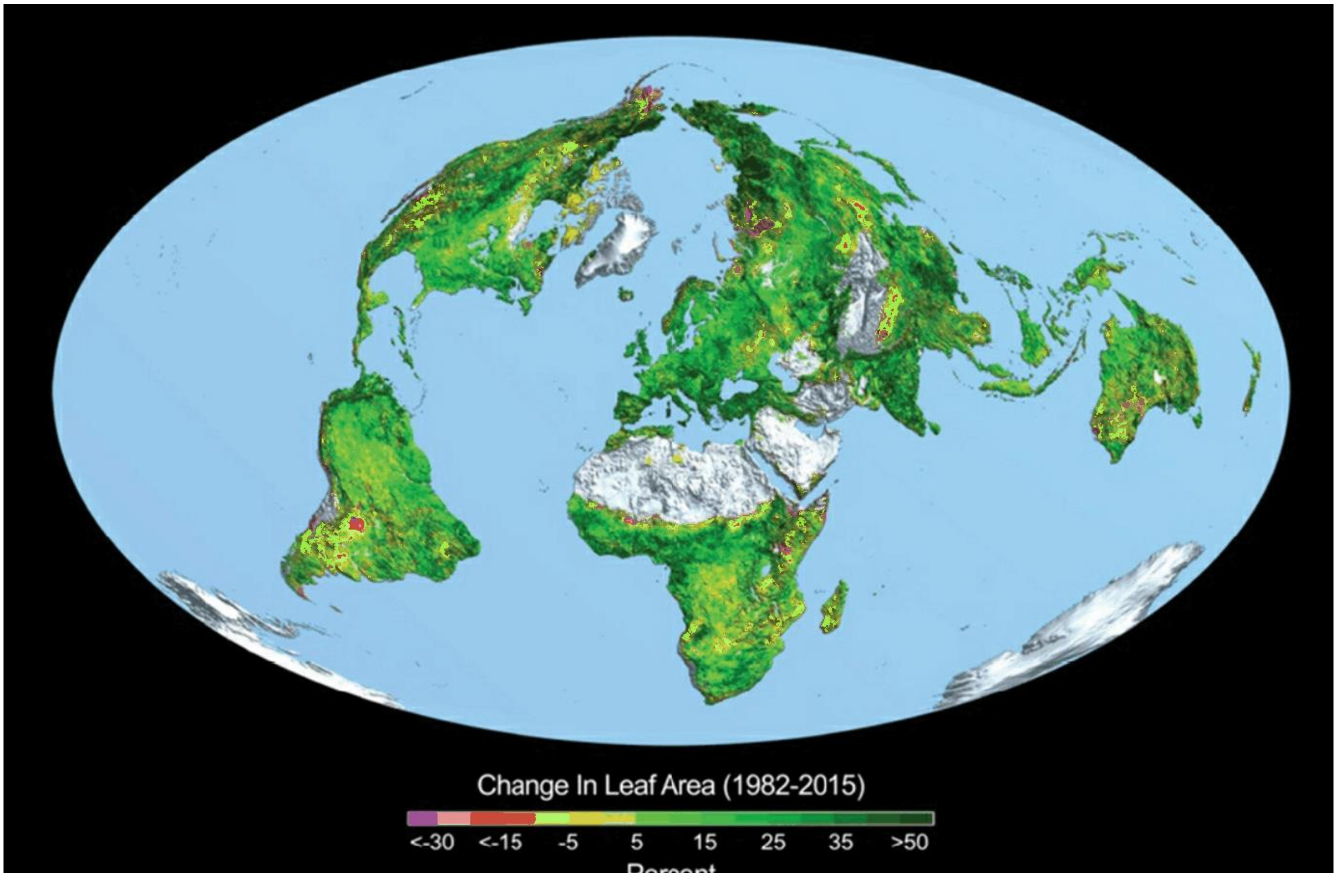
This is hard to do. Once that problem is solved, the dream of limitless energy can be realized. However, in the near term the issue is the more mundane one of getting political support for commonplace nuclear fission solutions that have been proven for half a century.

Opening the Space Frontier

Nuclear must be the source of power for long-distance space travel and distant space colonies. First of all, they have no air to support normal combustion. More importantly, it is the only solution with enough energy density to make it feasible to send by rocket ship. Zubrin has given a lot of thought to how to use nuclear to power rocket ships. Fanciful ideas, but we will be long gone before anybody is in a position to implement them.

Upgrading the Earth

Returning to the realm of near-term practical problems, Zubrin observes that increased CO_2 in the atmosphere has so far been a net benefit, lengthening growing seasons worldwide by about ten days and the total area covered by green leaves by 20%. However, continuing indefinitely is very likely to be counterproductive. The earth needs an alternative, and that alternative is nuclear.



Electric power can be used to create chemical energy in the form of hydrogen for transportation, fertilizers and just about anything else. Put another way, all of our resource problems boil down to limitations imposed by a shortage of energy.

The Way Forward

Politics, driven by fear, which is in turn driven by vested financial interests is the chief obstacle to nuclear energy. The public needs to be informed. More than that, we need a broader realization that our other options are running out. Fossil fuels are somewhat limited. The atmosphere's ability to absorb CO2 is finite, and our tolerance of the pollution and environmental damage they cause even more limited.

Their Program and Ours

Zubrin writes: "[The world] saw tens of millions of people slaughtered [in the 20^{th} century] in the name of struggle for existence that was entirely fictitious. The results of similar thinking in the twenty-first could be far worse. The logic of the limited resource concept leads down an ever more infernal path to the worst evils imaginable. Basically it goes as follows:
Resources are limited.
Therefore: Human aspirations must be crushed.
So, some authority must be empowered to do the crushing.
Since some people must be crushed, we should join with that authority to make sure that it is those we despise who are the ones crushed, rather than us.
By getting rid of such inferior people, we can preserve scarce resources and advance human social evolution, thereby helping to make the world a better place."

This blog includes Zubrin's long passage on Vladimir Putin and his pet philosopher Alexandr Dugin, and how the war in Ukraine is an expression of this mindset.

Zubrin sees growing availability of energy as an essential part of any plan for world peace. Hydroelectric has long been fully exploited, fossil fuels are limited, and solar, wind and biomass have never made any sense. Nuclear is the only option. Let's take off our blinders and use it.