

Thank you for joining us today for this class on Thorium and its use in generating electrical power.

This material is derived from many sources by people who are more informed and experienced than we. If you see a nice graphic, that probably came from them. Almost all the verbiage is ours.

Our contribution has been to organize the info and develop a narrative on the features and benefits of Thorium in a molten salt reactor, to point out some of the implications, and to communicate it to others.

In general, we will try to keep the talk technical-lite. If you find that we are getting too techie, wait a slide or two and it will get better.

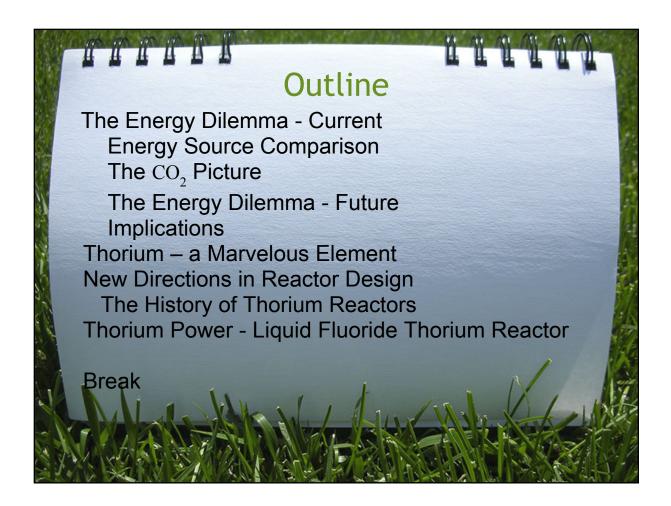
Please bear with us as this presentation has to accomodate multiple audiences, from general public to engineers and scientists



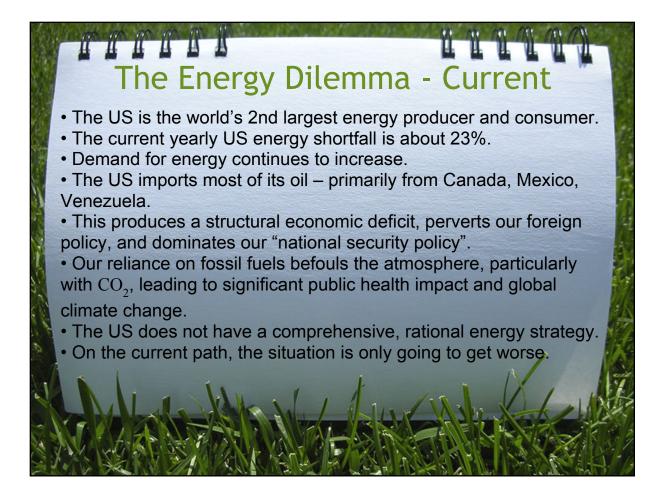
This is the team as it stands today, 10/4/2011.

This effort sprang out of Green Sanctuary activities at the Unitarian Universalist Church of Palo Alto, California.

The evolution happened as a chain reaction in reverse alphabetical order. Hershey got David interested, David got Bob interested, and Bob got Kay and Byron interested. But Kay came forward and said that this is the sort of effort that screams for a grassroots movement of dedicated people to make it happen. So, here we are, starting down the path to a Thorium future.







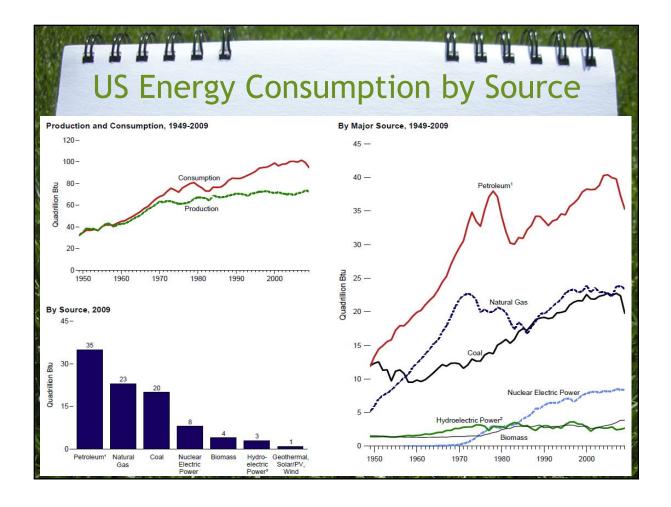
The US produces 15% of the world's energy. It consumes 21%. The US has 4.6% of the world's population.

US oil imports: See slide first. After Venezuela comes Saudi Arabia. Nigeria, Russia, Iraq, and the UK. So the statement that our oil purchases are financing terrorist operations is grossly overblown. It is true that our demand for oil raises global prices which in turn means more revenue for unfriendly oil producing countries.

US oil imports are generally crude oil. The US is number one in oil refining capacity.

In 2007, the US spent \$1.23T on energy (8.8% of GDP), or about \$4100 per person. The total US trade deficit was \$712B. Energy imports netted to about \$283B, i.e. the energy portion or our global trade deficit, or 39.8% of the total trade deficit.

The US imported about 77.5% of its oil at a cost of approximately \$357B.

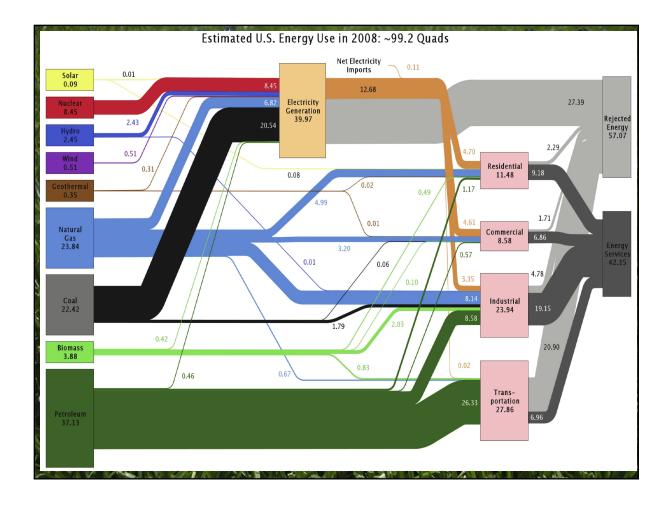


The upper left graph shows the history of our energy trade imbalance which is the bulk of our entire trade imbalance.

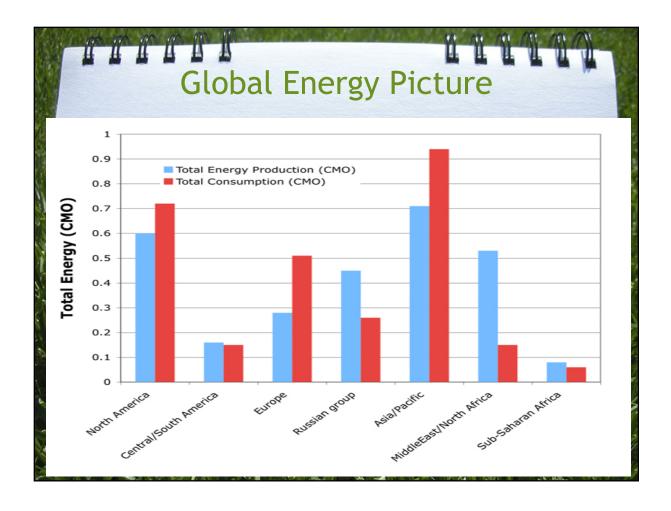
The bottom left graph is in Quad units (=  $10^{15}$  Btu). Since the total is 99, you can think of each number virtually as a percentage value, e.g. petroleum at 35 Quads = approximately 35% the US energy input for the year.

The slight downturns at the end of the graphs in recent years probably reflect the economic slowdown caused by the recession.

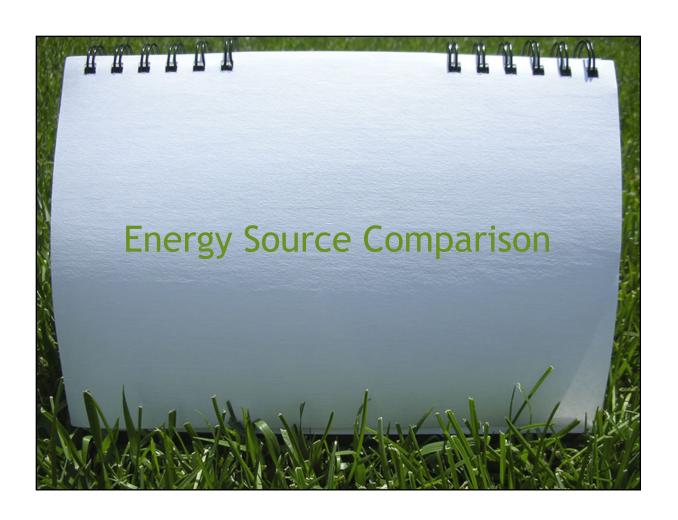
The right chart shows our consumption of each energy source over time. Natural gas and renewables (wind & solar - not shown) will show the largest increases in the short run going forward.

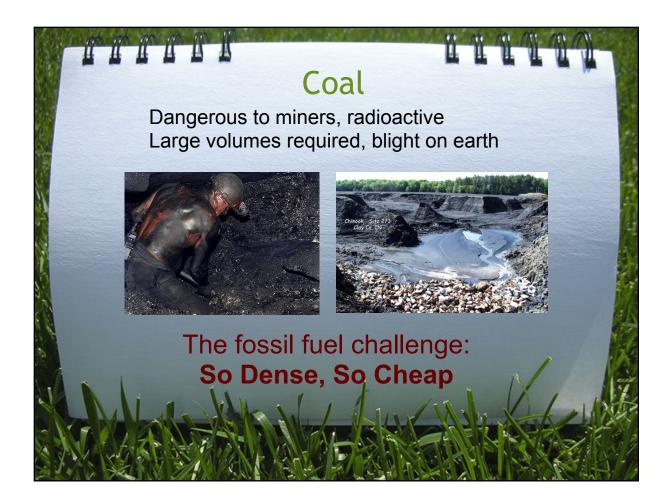


- Developed world similar to US
- · Little petroleum used for electricity
- Except for hydroelectricity & growing biomass, the contribution from renewables is relatively small.
- Electric cars will increase use of electricity. New coal, natural gas plants and maybe nuclear will be brought online to power them.
- 68.5% of energy for electricity generation is wasted.
- 75% transportation energy is lost (mostly cars).
- 57.5% of the total US energy supply is wasted.
- Total energy expenditure = \$1.23T
- Wasted energy cost \$708B
- Oil (transportation only) wasted energy cost \$259B
- The grey portions on the chart represent wasted energy. It is fossil fuel based and the principle source of greenhouse gases. Elimination of these areas is a huge opportunity for fixing the environment.
- This data comes from The Annual Energy Review 2009. It is published yearly by the U.S. Energy Information Administration. If you love real data, this report is for you.

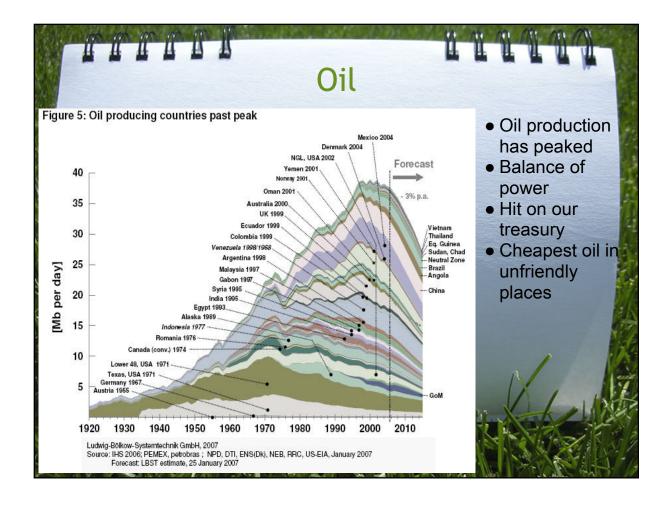


The longer red bars indicate net oil consuming regions vs the blue for net suppliers. Therefore Europe and most of Asia share our dilemma. For the North American bars, if we subtracted Canada's contribution to production, the difference with consumption would be much starker.





- Coal provides about 29.6% of the US energy production today (2009). That equals. 1.1B short tons. The US has 333 underground mines and 155 surface mines.
- China is now the number producer of coal.
- The need for cheap electricity is driving a growth of coal-fired power plants.
- The US has particulate collectors, cooling towers and/or flue/gas desulfurators (or scrubbers) post processing 329,746 megawatts of output.
- •The consumer cost per million BTUs is \$1.88.



- Domestic oil provides about 15.4% of the US energy production today (2009).
- The consumer cost per million BTUs of gasoline is \$21.97. of diesel is \$19.82, of residential fuel oil is \$8.56
- In 2009 the US drilled 13,175 new oil wells.and had 512,000 producing wells averaging 10.1 barrels/day/well.
- US oil production occurs 12.2% in Alaska, and 35.2% offshore. 82.8% of our refining is done domestically at 150 refineries.
- The Strategic Petroleum Reserve is currently at 75 days.
- "How many years of oil reserves do we have left?"

From the start of oil production until today, the traditional answer has always been 40. But this ignores how difficult it is to find and how much that oil will cost to produce. It also doesn't reflect the big blips in demand represented by China and India. It is extremely difficult to think we can reproduce the past. Oil will get more scarce and its ability to hold its consumption levels will become more difficult. What will happen if production levels drop? How will we replace this depleted source?

• 1 barrel of crude oil = 12 men working all year = 25,000 man hours and it can be pulled out of the ground in Iraq it will cost only \$1\$ (though it may sell for  $\sim$100$ )

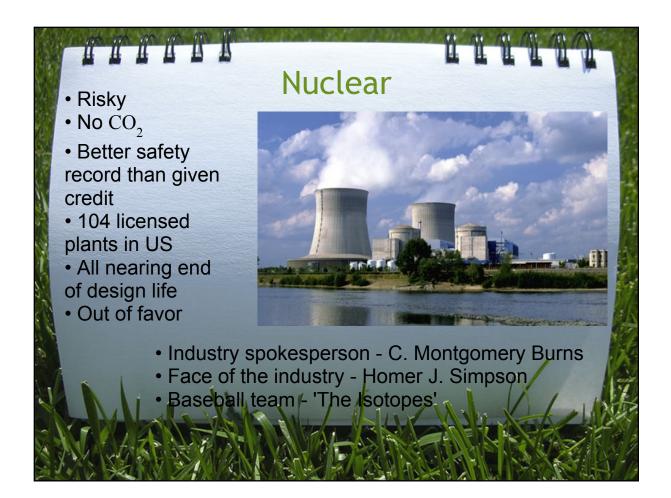


- Natural gas provides about 33.0% of the US energy production today (2009).
- •The consumer cost per million BTUs is \$9.30.
- In 2009, 19,153 natural gas wells were drilled, 496,000 wells were producing  $104,000~{\rm ft}^3$  per day per well.
- The US imports some natural gas from Canada and Trinidad.

Hydrofracting is a process to extract natural gas from shale. Typically, a well is drilled down about a mile and then drilling goes horizontally for some distance, sometimes for miles.

The companies involved in this practice cite how non-porous pipe and cement is included along the drill path and therefore the practice is safe for ground water. The practice includes installing porous pipe toward the end of the drill line. Charges are set off to fracture the shale and free the natural gas. The gas returns to the surface through the well. Sounds good.

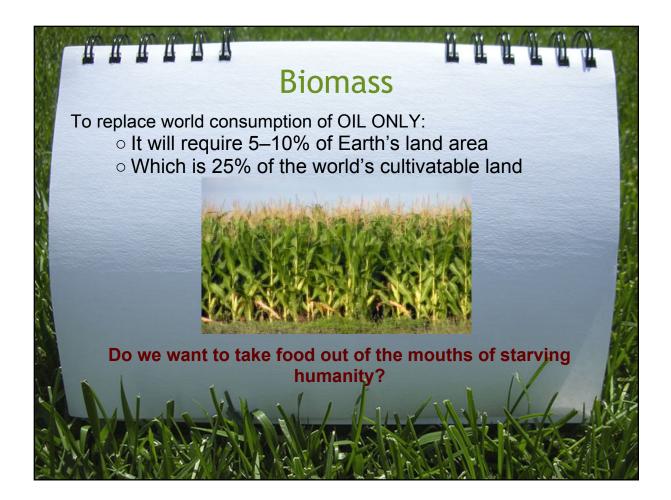
Buy reality is different. The industry was given a waiver in the 2005 energy bill to ignore the Clean Water Act and the Clean Air Act. The drilling companies have been dumping large quantities of chemicals in the wells to assist drilling and gas extraction. The companies are not required to name the chemicals used. Independent investigators have listed over 500 different chemicals being used by the industry. Many of these are known toxins and carcinogens. Though required to clean up chemicals from the drill sites, many of these chemicals have found their way into the drinking water for adjacent communities. For more info, see the documentary "Gasland"



Nuclear provides about 11.4% of the US energy production today (2009). The plants operate at capacities of 91% and 101% in the summer

The consumer cost per million BTUs is \$0.46.

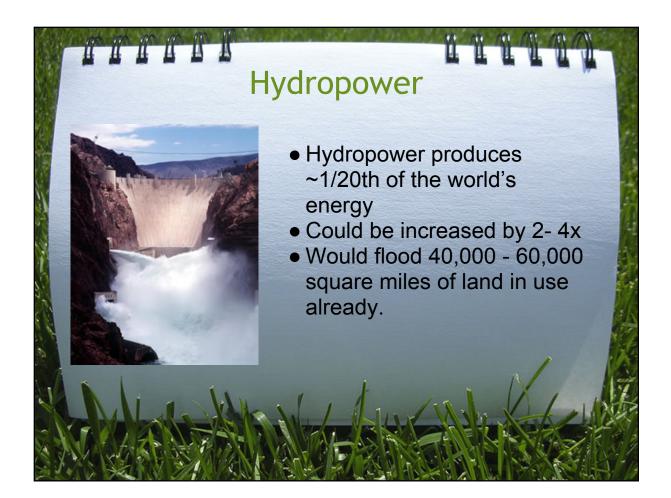
Uranium production has been down for the better part of two decades because the US purchased the material inside Russian nuclear weapons that were being dismantled after the end of the Cold War. In 2009, the US imported 57 million pounds of uranium fuel. The US currently hold stockpiles of 108 million pounds.



Biomass provides about 5.3% of the US energy production today (2009).

Ethanol and biodiesel are the principal products here. This segment also continues to grow due to congressional programs and support.

The consumer cost per million BTUs is \$3.35.

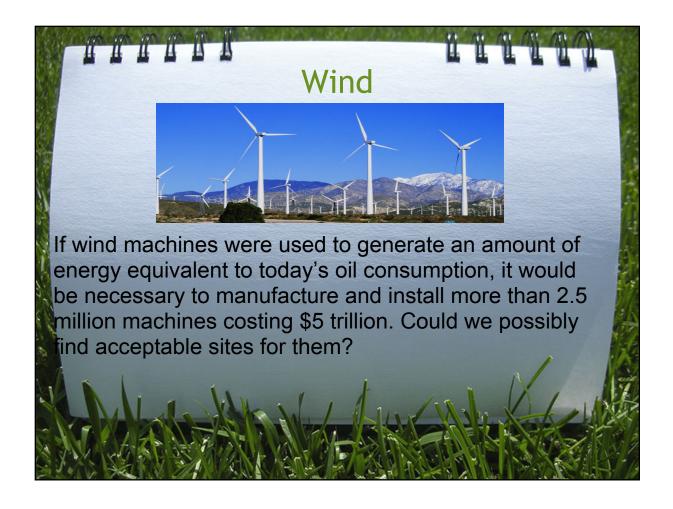


Water power provides about 3.7% of the US energy production today (2009).

Less than 3% of US dams generate power. 59 are hydroelectric out of 8100 major dams. There are 79,000 total US dams. Fresh water advocates argue that dams are a bad water utilization strategy.

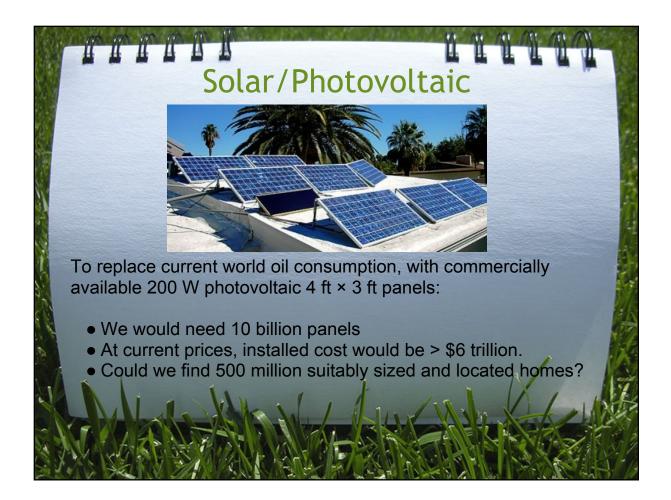
In fact, US policy allows the removal of hydroelectric dams in favor of fish populations. The Condit Dam on the White Salmon River in Washington state was intentionally breached on 10/26/11.

Except for China and parts of the third world and possible Canada, here seems to be almost no interest in putting in new dams. The likelihood of hydroelectric power adding to our future energy equation is practically nil.



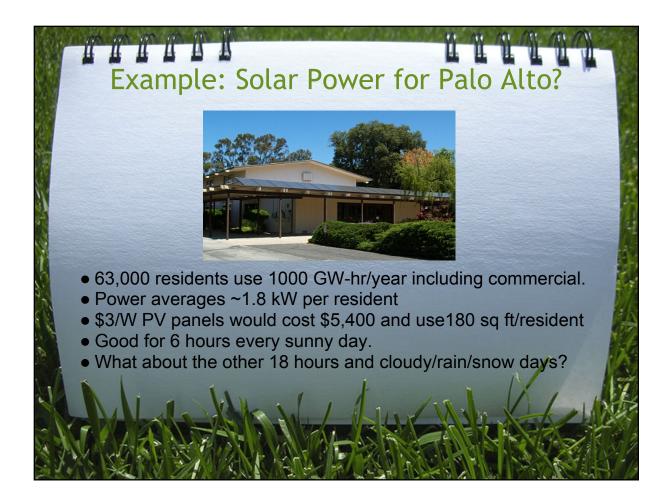
Wind power provides about 1.0% of the US energy production today (2009).

• Wind power is the fastest growing of the renewable energy sources.



Solar energy provides about 0.15% of the US energy production today (2009).

• 45.7% of new solar collectors are imported



The image shows the photovoltaic collectors on the front of the Unitarian Universalist Church of Palo Alto, California.

Photo courtesy of Byron Brown, Palo Alto CA, 2011



Collectively, these traits imply that each of these fuel sources cannot be implemented or deployed at anywhere near the rate or in the numbers that are required to meet our energy needs, either as replacement or as meeting added demand.

NIMBY = Not In My Back Yard

## HHH Public Health Impacts per TWh\* Lignite Oil Nuclear PV Coal Gas Wind Years of life lost: Nonradiological effects 138 167 359 42 9.1 58 2.7 Radiological effects: 16 Normal operation 0.015 Accidents Respiratory hospital 0.21 0.05 0.29 0.69 0.72 1.8 0.01 admissions Cerebrovascular hospital 1.8 4.4 0.51 0.11 0.70 0.03 1.7 admissions Congestive heart failure 0.80 0.84 2.1 0.24 0.05 0.33 0.02 Restricted activity days 4976 4751 12248 1446 314 1977 Days with bronchodilator 1303 1365 3361 397 543 usage Cough days in asthmatics 1562 3846 454 1492 98 621 28 Respiratory symptoms in 211 288 693 726 1786 45 13 Chronic bronchitis in children 115 135 333 39 11 54 2.4 Chronic cough in children 148 174 428 51 14 69 3.2 Nonfatal cancer 2.4 \*Kerwitt et al., "Risk Analysis" Vol. 18, No. 4 (1998).

Note: Giga(G) means  $10^9$  and Tera(T) means  $10^{12}$ .

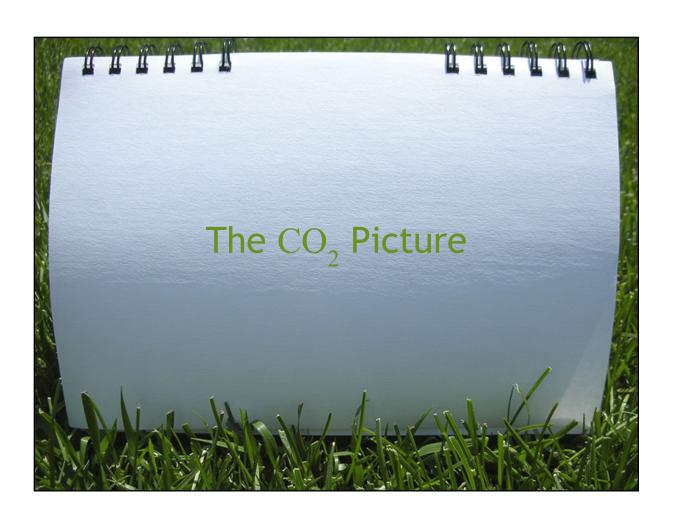
Any energy source must be safe in use and safe throughout its entire environmental cycle – fuel discovery, production, processing, consumption, emissions, recycling and waste disposal. This requires accurate, complete accounting of effects and costs without subsidy. Today, every energy source is subsidized in a variety of ways, especially the combustion sources – input activities, combustion methods and waste disposal are all subsidized via tax law plus limited law/environmental enforcement. Coal, for example, is subsidized by mining practice and ash-disposal inattention, plus known unregulated emissions now accounting for >13,000 deaths each year (NIH). Unaccounted-for subsidies are largely responsible for civilization's daunting environmental problems today, and into the future. Such accounting failures are themselves unsustainable.

For nuclear power, obvious safety issues are radiation and chemical exposures in all parts of the fuel-towaste path, explosive potential during fuel processing and use, and divers

ion of any materials for weapons, explosive or not. This table shows an interesting 1998 DoE international health comparison among power sources from acquiring all raw materials, through fabrication, operation, and all negative consequences of power output.

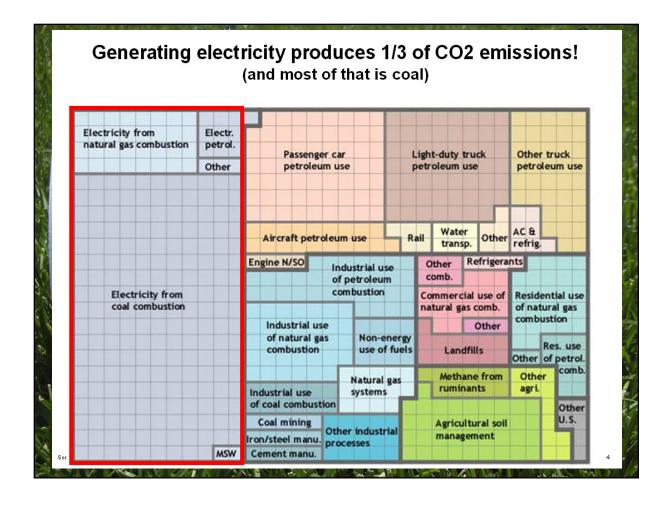
The performance of nuclear power has been excellent despite two serious civilian nuclear-power accidents – Three-Mile Island and Chernobyl. Both of those resulted from training and operational errors. As we hear too often, coal and oil extraction have more frequent, lethal events. In fact, an old joke says: "You can find a coal plant with a Geiger counter, but not a nuclear plant" – there's a great deal of Uranium in coal ash (plus various other toxins). What this table suggests are the health effects of running 1000 full-scale (1 GW) power plants per hour. Total world generation is >16 times that now (>16 TW), so even LWR (light water reactor) nuclear's advantage becomes even more dramatic. And Thorium can do still better.

This study predates Fukushima, the increased practice of hydrofracting and the affect of the toxic chemicals on the residents local to where it occurs.





Speaks for itself.



This is a graphical representation of where  $\ensuremath{\mathrm{CO_2}}$  emissions originate in the US.

The left lavender portion is the carbon dioxide given off in the production of electricity.

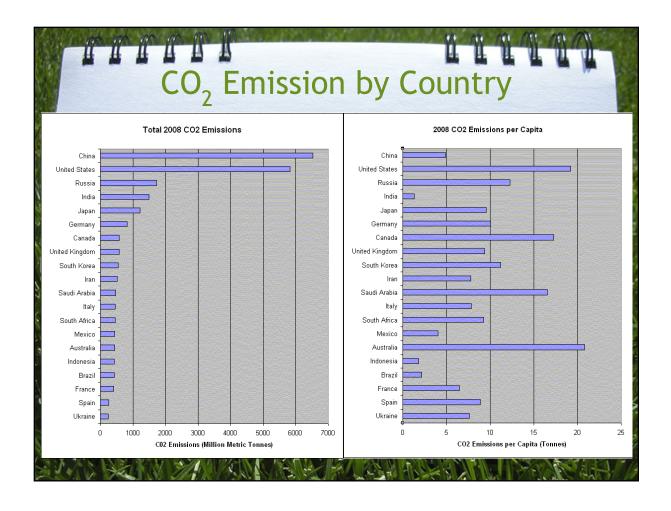
The  $CO_2$  given off in transportation is shown as yellow to light brown at the top half of the chart (middle to right).

The blue section in the lower central region measures industrial use.

The green squares are associated with agriculture.

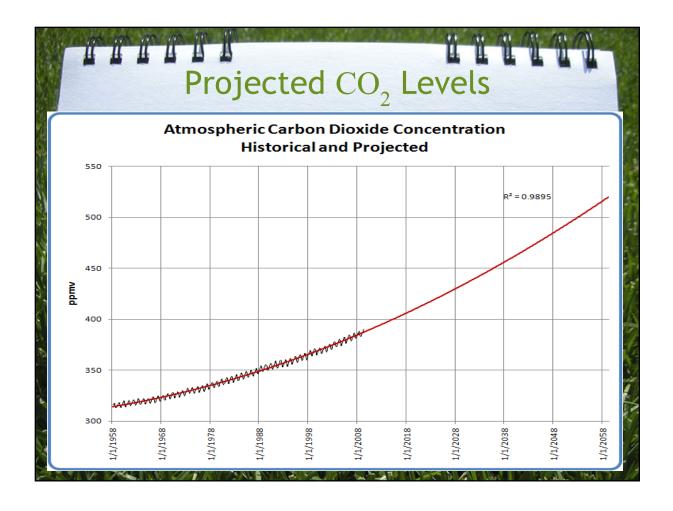
The reddish squares stand for other industrial and commercial usage

The blue-gray region in the lower right stands for residential use..



This chart compares total  ${\rm CO_2}$  emissions and emissions per capita for selected countries. As expected the  ${\rm CO_2}$  emissions per capita are higher for developed and developing countries.

China has taken over as the country with the highest CO<sub>2</sub> emissions.



US CO<sub>2</sub> emissions are expected to increase 25% over the next 25 years.

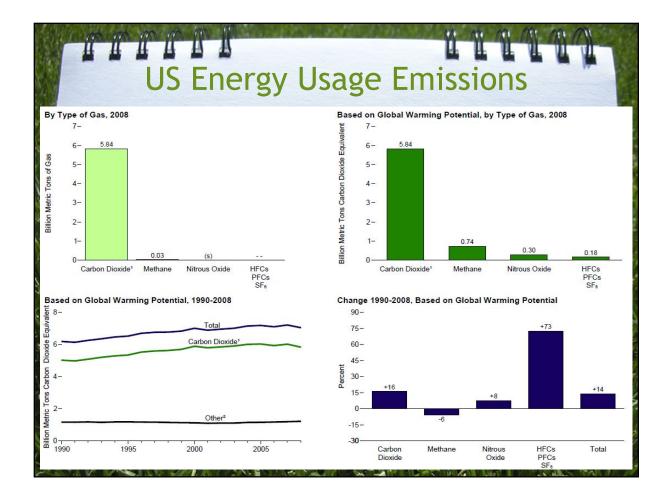
The **Keeling Curve** here is a <u>graph</u> which plots the ongoing change in concentration of <u>carbon dioxide in the Earth's atmosphere</u> since 1958. It is based on continuous measurements taken at the <u>Mauna Loa Observatory</u> in <u>Hawaii</u> under the supervision of <u>Charles David Keeling</u>. Keeling's measurements showed the first significant evidence of rapidly increasing carbon dioxide levels in the atmosphere. Keeling made the projection by curve fitting with to a second order polynomial.

According to Wikipedia, toxic effects of  ${\rm CO_2}$  vary by percentage concentration in the air.

- 1% can cause drowsiness with prolonged exposure.
- At 2%, it is mildly narcotic and causes increased blood pressure and pulse rate, and causes reduced hearing
- At about 5%, it causes stimulation of the respiratory center, dizziness, confusion and difficulty in breathing accompanied by headache and shortness of breath.Panic attack attacks may also occur at this concentration.
- At about 8%, it causes headache, sweating, dim vision, tremor and loss of consciousness after exposure for between five and ten minutes.

1% = 10,000 ppm

At what concentration does life become intolerable?



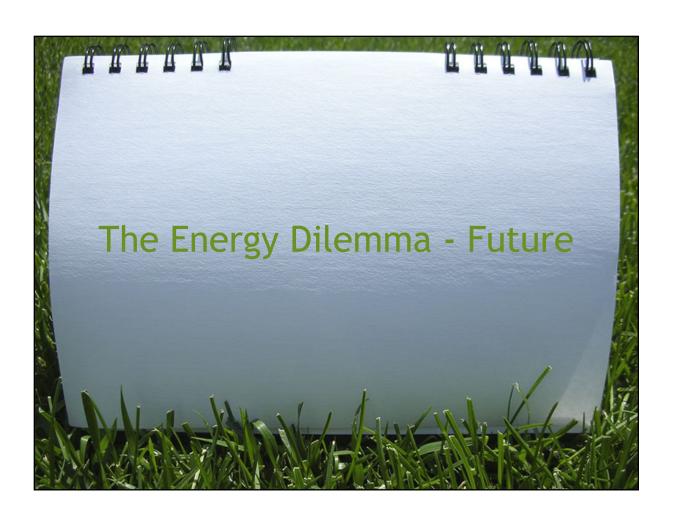
This chart compares  ${\rm CO_2}$  with other greenhouse gases. Typically, these others lag in overall emission volume. But often these others pack more damage (upper right). Also, fluorocarbons are growing at a much faster rate (lower right) globally.

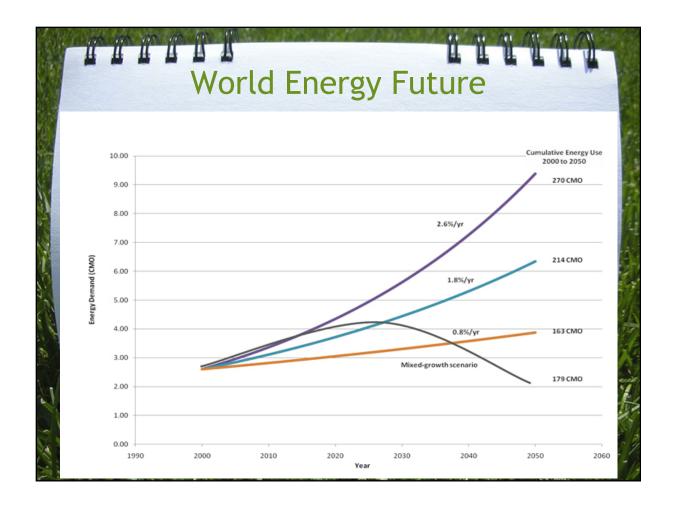
## Emission sources:

- Methane (CH4) Natural gas systems 24.2%
  Coal mining 11.1%
- Sulfur dioxide (SO<sub>2</sub>) -

Electric power sector (coal) - 93.7%

• Nitrous oxide (N2O) -Coal - 80.5%





## 1 CMO equals approximately 1750 GWyr.

An assumed growth rate is shown on each curve. But in 2006 India grew at 9%, China at 11%, and the world overall at 5.5% - all above the shown curves. Left unchecked, global demand in 2050 could easily be 2 - 3 times as much as shown in the top curve.

The fourth case (curved line) in which the high growth rate (2.6%/yr) is in effect initially but then slows as the world undertakes highly stringent measures to increase energy conservation and efficiency. Under this case, the growth rate reverses after 2030 such that by 2050 total energy use is 80% of that in 1980, or about 2.0 CMO/yr. Such a scenario might be required if we are to prevent atmospheric  $\mathrm{CO}_2$  concentration from exceeding 550 ppm and thus limiting the projected global warming to less than 3 °C. Naturally, to get on this path, we need to move aggressively right away.

	TITT			ewables		
	Source	1CMO/ Power	yr each Up time	by 2050 Amount	Rate	
	Hydro	18 GW	50%	200 dams	1/quarter	
	Nuclear	0.9 GW	90%	2500 plants	1/week	
	Solar CSP	0.9 GW	25%	7700 parks	3/week	
	Solar roofs	2.1 kW	20%	1 roof (10 sq m)	250k/day	
	Windmills	1.65 MW	35%	3M turbines	1200/week	
X						

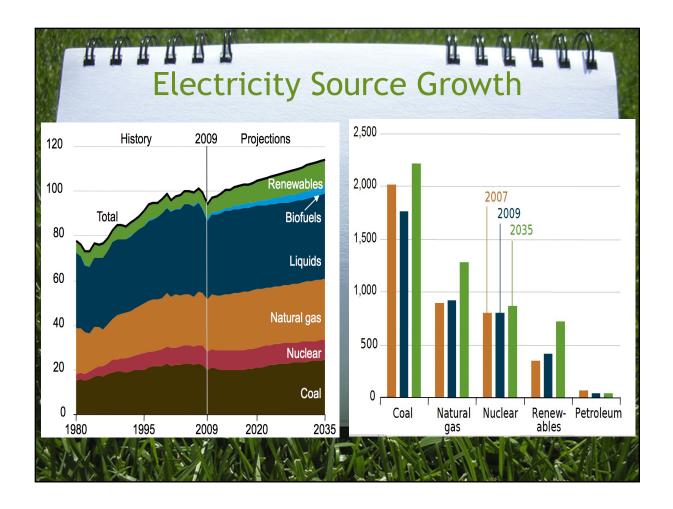
This table shows the number of installations needed for each power source to reach 1 CMO each by 2050. To reach a required 9 CMOs by 2050, we would need each of these fuel sources to produce 1 CMO each.

Do you see any hydro projects going on, let alone one per calendar quarter?

Are we building a nuclear plant per week? In the US, it can take a nuclear plant 20 years to get built and commissioned. Also, as a result of Fukushima, Germany and perhaps other countries have decided to phase out their nuclear plants.

Are we building and installing nearly enough solar parks or roof panels for 1 CMO?

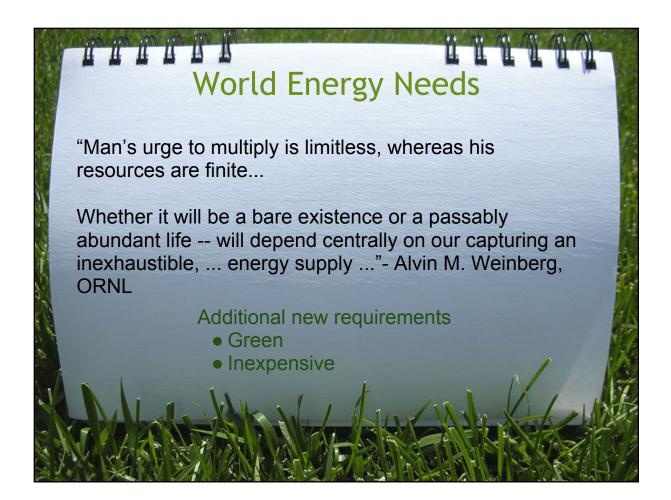
And we are certainly not installing 1200 high capacity windmills a week. Conclusion: Agressive renewable investments will not be able to cover additional electricity demand, nor could they replace a fossil fuel source if it went dry, as oil could.



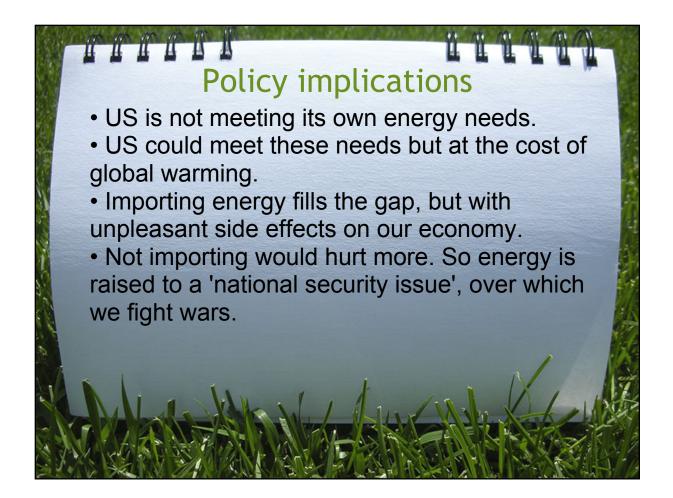
This graph shows the projected amount from different energy sources in 2035 used for US electricity generation.

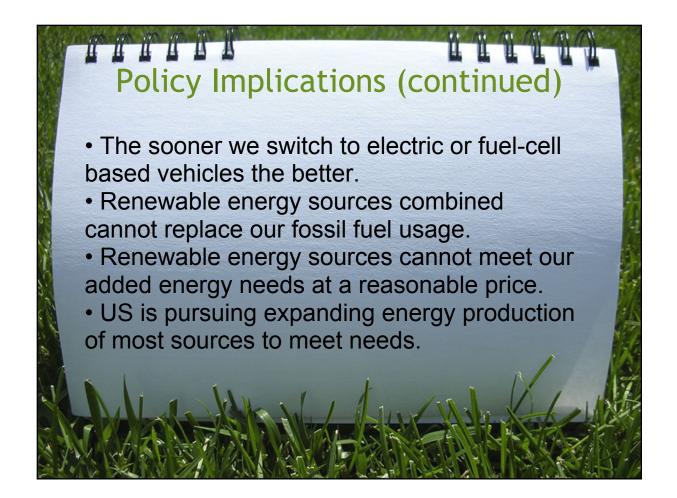
You will note the contribution of oil remains flat, if not actually shrinking slightly. The amount from nuclear only increases a small amount because it takes so long to bring a new plant online in the US.

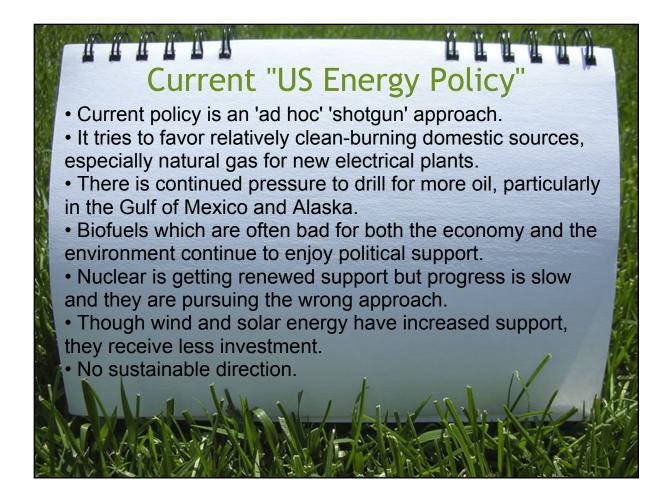
The big gains are in natural gas fueled power plants and coal plants, both fossil fuels and bringing more CO<sub>2</sub>. And thirdly renewables



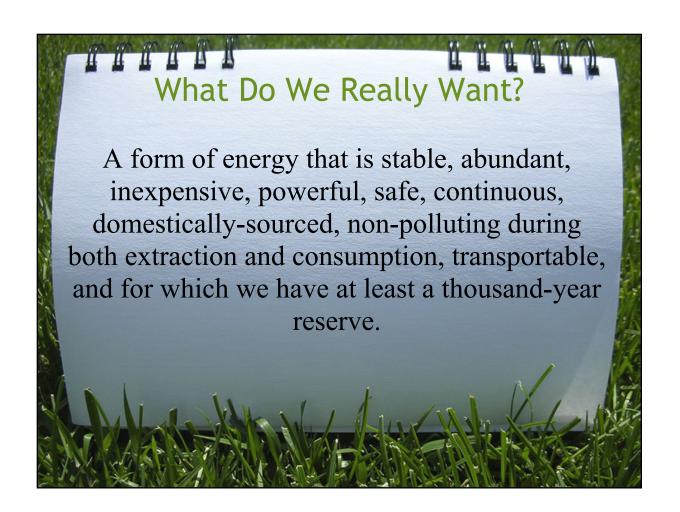


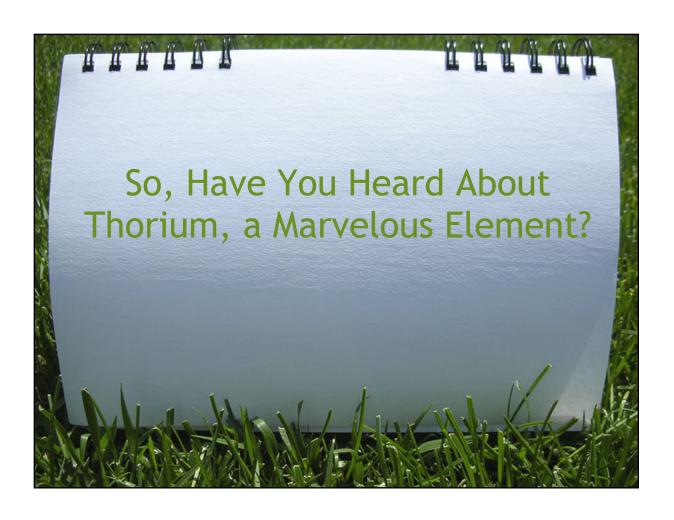






Actually, until energy officials hear the good news within, they had little choice other than an ad hoc, shotgun approach. Their fear was that they would not be able to keep up with demand. They had to develop all sources simultaneously.





Periodic Table of the Elements																		
Group #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period																		
1	1 H																	2 He
2	3	4											5	6	7	8	9	10
	Li	Be											В	С	N	0	F	Ne
3	11	12											13	14	15	16	17	18
	Na	Mg											Al	Si	Р	S	CI	Ar
4	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
·	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
	Rb	Sr	Υ	Zr	Nb	Мо	Тс	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te		Xe
6	55	56	*	72	73	74	75	76	77	78	79	80	81	82	83	84	1	86
	Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	П	Pb	Bi	Po	L	Rn
7	87	88 Ra	**		105 Db	106	107				111			114		116		118
	Fr	Ra		KI	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Out	Ouq	Uup	Oun	ous	Ouo
*100	thani	dee	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	
	* Lanthanides (Lanthanoids)		La	Ce	Pr		Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Ş
** Actinides		- 100	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	
(Actinoids)		Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	1	

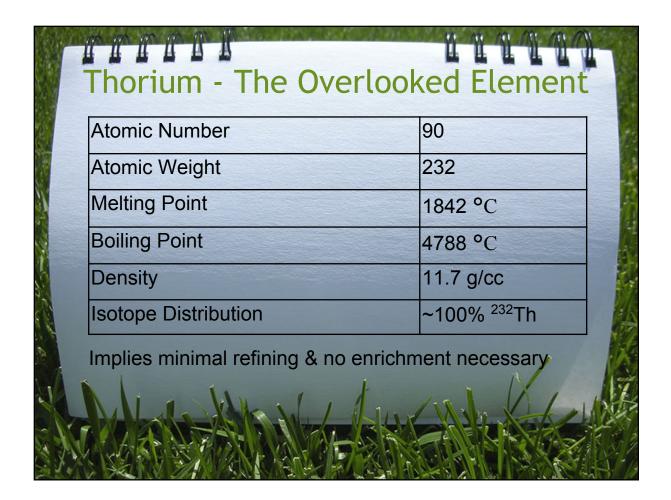
Thorium is in the lower left corner, element number or atomic number 90. Uranium is two elements to the right at number 92.

Fluoride is the first of the halides at number 9. Chemistry teaches us that the elements in this column (yellow) form strong chemical bonds because they are missing one electron from a full electron shell, that is, they are highly disposed to complete that shell with an element that has an extra electron. Precisely for this reason lithium (#3) fluoride and beryllium (#4) fluoride are used as moderators in a thorium reactor.

When exposed to a neutron source, an atom can absorb it (increasing its atomic weight) and creating a heaver isotope of that element. Different isotopes of the same element are difficult to separate chemically. But if you keep bombarding it with neutrons, it may absorb more until it gets to an unstable configuration, at which point, fission can occur forming two different elements of lower atomic number. A relatively large amount of energy is given off as part of this process.

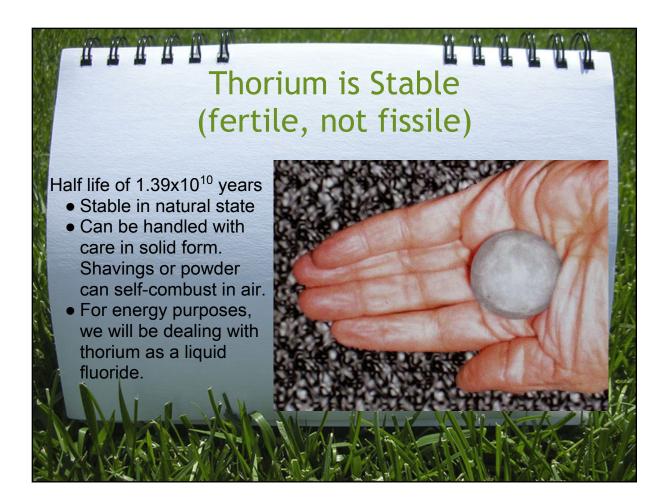
If the original heavier element absorbs another neutron before fission occurs, the element becomes a heavier isotope which can morph one of those neutrons into a higher number isotope or element. This is how you get plutonium and other higher actinides when you started with just uranium.

This progression is further complicated when you start with an element that has multiple isotopes. They all may behave differently when exposed to neutrons. One advantage of thorium is that it has a very high percentage of a single isotope. Fewer variations, fewer complications with which to contend.



For convenience, when we speak of thorium, we almost always mean <sup>232</sup>Th since this isotope makes up greater than 99.99% of naturally occurring thorium. There are a dozen other isotopes that result from other radiological processes, with more or fewer neutrons ranging from atomic mass 223 to 235. Many of these are very short lived.

The fact that thorium is virtually a single isotope simplifies everything. In mining, any thorium you find is good thorium. (Not quite true. Thorium can be found in different compounds/ores, and each would have its own separation process) You do not have to go through an elaborate isotope separation. It implies that your fuel preparation process is straightforward as well. It means that you don't have to worry about extra contaminants in the fuel cycle, nor when you need to separate fission products.



Pictured is a lifetime energy supply of thorium for a single person, including everything.

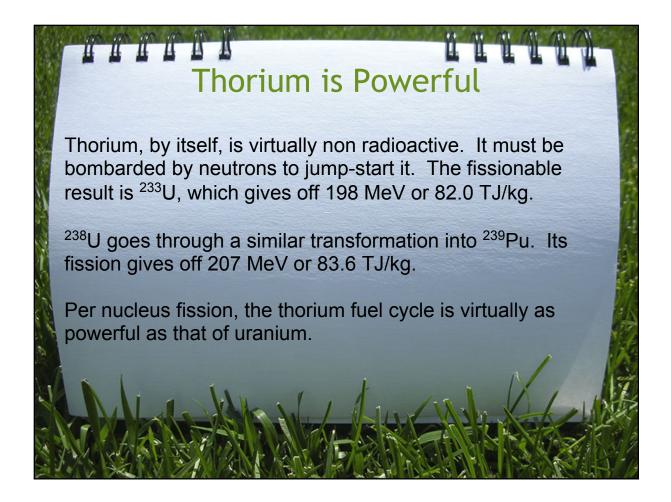
The half life of an isotope of an element is the amount of time needed for half the atoms of that isotope to decay into something else.

Fertile implies that there is a path to a fissile material which can go through fission, wherein nuclei can be split apart, releasing large quantities of energy. For thorium, that path is usually neutron bombardment.

Fissile implies that an atom is ready to go through fission, which is one type of radioactivity.

Powdered thorium metal or shavings are pyrophoric (susceptible to spontaneous combustion) in air, especially hot air.

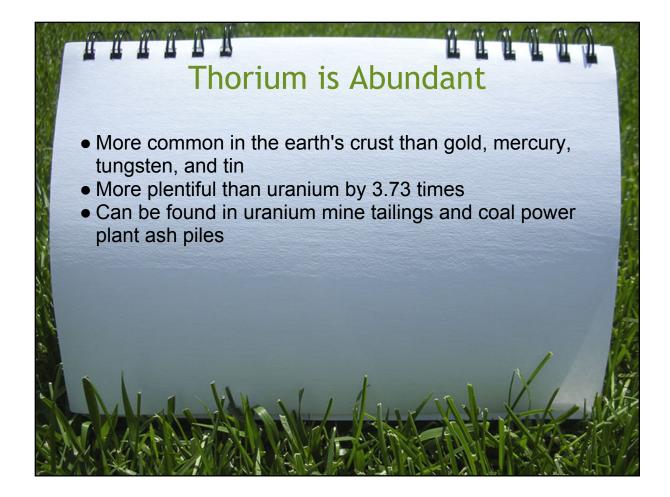
Thorium compounds are largely insoluble in solvents. But thorium is slightly water soluble (0.009 g/kg @ 25 °C, compared to 360 g/kg for NaCl (table salt)).



Note: The environment around us always has some radioactivity. Turn a Geiger counter on in your living room and you will hear it record radioactive events. You never have zero radioactivity. Radioactivity becomes an issue only when it is intense enough to destroy human cells in quantity.

J stands for joules, an energy unit.

MeV stands for million electron volts, another energy unit.



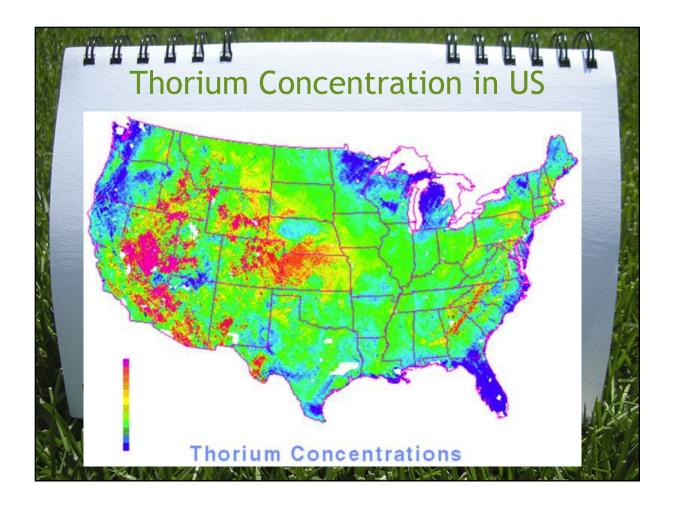
There is a fair chance that you have some thorium in your back yard, and front yard, and side yards.

The downside of thorium's abundance is that it has been implicated in a number of superfund clean up efforts. There is broad agreement that <sup>232</sup>Th makes up greater than 99.99% of naturally occurring thorium and that it is not radioactive. But it has been cited in a number of cases. Reports we have seen don't specify which isotope is being discussed, but all the other isotopes occur naturally in very small percentages. So what is the radioactive component here? Also, the cited cases focus on the refining of other metals from ores wherein thorium is also present. For example one of the cases was the result of a high-energy electron beam being used to melt uranium, whose ore is often co-resident with thorium. Perhaps it was that process that stimulated thorium to become radioactive.

High energy electrons were also used to increase Thorium purity in the past. We cannot report if this is an issue or not. We do not know if such eposure would drive <sup>232</sup>Th to a radioactive state. Adherence to current EPA and OSHA standards should help. And afterall, purified Thorium is not the ultimate goal. It is thorium fluoride. Perhaps there is a chemical shortcut that eliminates complicating steps.

	wide Abun		
Country	Tons	% of Total	
Australia	489,000	19	
USA	400,000	15	A
Turkey	344,000	13	À
India	319,000	12	
Brazil	302,000	12	
Venezuela	300,000	12	
Wash.	ALL AU		

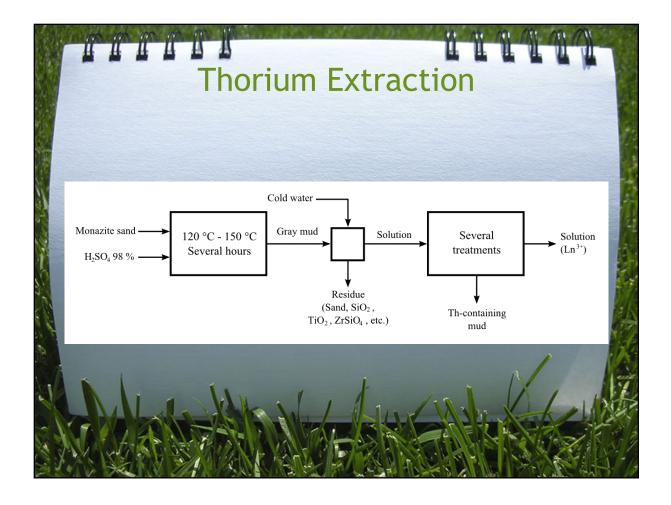
The estimate for the US and probably the others are very low. They weren't looking very hard back then. Since then, deposits in a single pass on the Idaho-Montana border have alone been projected to contain about four times as much Thorium as the US figure presented here.



Without extensive exploration, it is believed that the United States already has enough thorium to meet all its energy needs for the next thousand years, and then some.

How much might we find if we really tried?

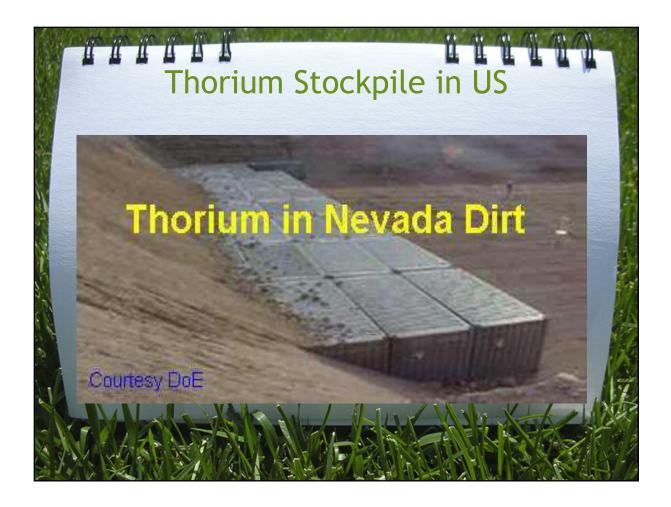
Note: This diagram appears to show thorium concentrations around the entire US map. This is believed to be just the outlining method used to depict only the map data, and not actual thorium concentrations.



The purpose of this slide is to show that the mining and process of recovering thorium from ore is already understood.

There are several possible Thorium ores.

- Here monazite which contains thorium phosphate (ThP $\mathrm{O_4}$ ), is depicted. Separation from monazite ore uses sulfuric acid.
- The ore is a found naturally or is a by-product of uranium mining and elsewhere. Because thorium can be extracted from uranium tailings or coal plant ash piles, no new mines would be required for some time.
- Another common ore is thorium dioxide (ThO $_2$ ) or previously called thoria or thorina. Thorium is extracted by calcium reduction, i.e. thorium dioxide and calcium are sequestered together at high temperature. ThO $_2$  + Ca => Th + CaO $_2$ . Thorium is initially recovered in powder form.
- All of these processes are chemical, i.e., not radioactive. The ore comes IN not radioactive and the thorium comes OUT not radioactive.



This photo shows a Thorium stockpile equivalent to all the energy needed to power the United States for over six years.

Given that programs don't start out at 100% production, this supply alone could easily handle US usage rates for at least the first 10 years.

Why was it buried? A good guess might be to keep it from oxidizing.

An article in the Worcester (MA) Telegram & Gazette (January 30, 1991) discussed the results of testing around this buried deposit. The ground water was found to be normal, i.e., no abnormal radioactivity.

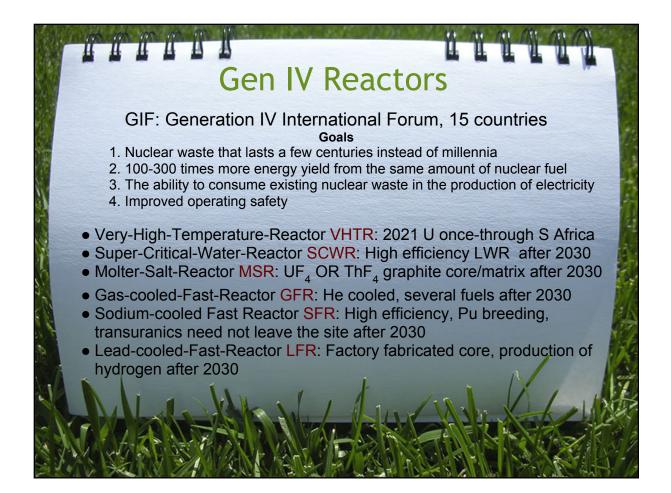




Fukushima 2011



Naturally, we also want the other benefits we have enjoyed from traditional nuclear energy plants, i.e., a reliable, inexpensive, source of power.

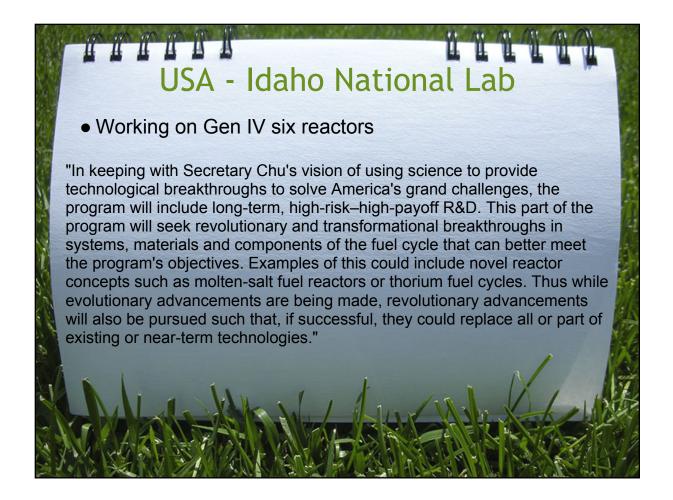


About a decade ago the nuclear industry came together and decided the important goals for the next generation of nuclear reactors. Those four general principles are displayed in the slide.

Based on that, efforts began to adapt these concepts to six different reactor types, also listed here. These projects span from making incremental improvements to traditional designs to totally new approaches.

For the most part, these efforts have been research projects, as opposed to product implementations.

It is past time to spawn products.



This slide contains a quote from Idaho National Lab on their interpretation of directives from Dr. Steven Chu, the Secretary of Energy for the Obama administration. It includes the concepts contained in this presentation. But it also includes work on the entire spectrum of challenges facing six different reactor designs.

While most of the research represented here is useful work, it seems a bit unfocused.

This presentation is not ashamed to predict a winner in this sweepstakes. We need to coalesce of the most promising design. We believe the LFTR approach discussed below is just that.

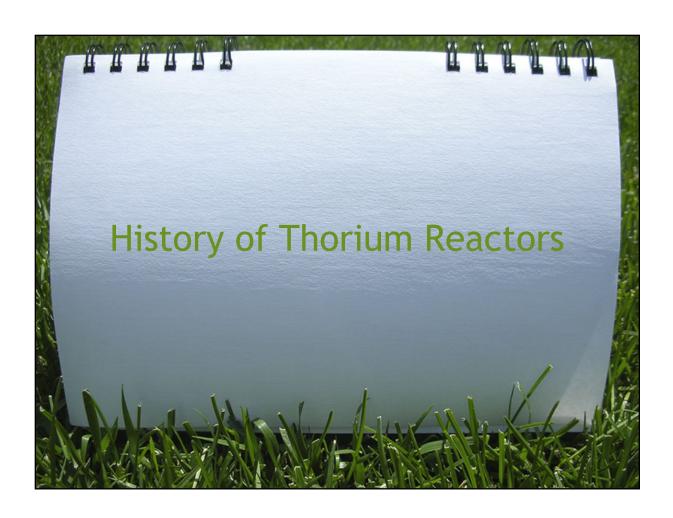


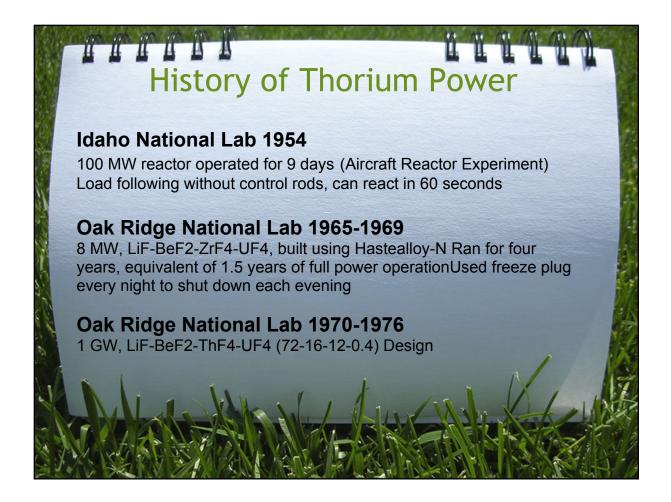
A recent report from Oak Ridge National Lab has conceded the benefits of a molten salt reactor design.

It maintains that more research is needed. Let's concede that point. Those areas can be defined and work should proceed apace. But there are plenty of other areas where design work on prototypes can begin in parallel.

The Manhattan and Apollo Projects did not progress by answering all questions one after another. They attacked all aspects at once with the directive to make it all work together in the end.

The benefits of accelerating our efforts will be obvious as the presentation progresses.





Extensive research into molten salt reactors started with the U.S. Aircraft Reactor Experiment (ARE) in support of the U.S. <u>Aircraft Nuclear Propulsion</u> program. The ARE was a 2.5 MW<sub>th</sub> nuclear reactor experiment designed to attain a high power density for use as an engine in a nuclear powered bomber. The project included several reactor experiments including high temperature reactor and engine tests collectively called the Heat Transfer Reactor Experiments: HTRE-1, HTRE-2, and HTRE-3 at the National Reactor Test Station (now <u>Idaho National Laboratory</u>) as well as an experimental high-temperature molten salt reactor at Oak Ridge National Laboratory - the ARE. The ARE used molten fluoride salt NaF-ZrF<sub>4</sub>-UF<sub>4</sub> (53-41-6 mol%) as fuel, was moderated by <u>beryllium oxide</u> (BeO), used liquid sodium as a secondary coolant, and had a peak temperature of 860 °C. It operated for 100 MW-hours over nine days in 1954. This experiment used <u>Inconel</u> 600 alloy for the metal structure and piping.

The MSRE was located at ORNL. Its piping, core vat and structural components were made from <a href="Hastelloy-N">Hastelloy-N</a> and its moderator was <a href="pyrolytic graphite">pyrolytic graphite</a>. It went critical in 1965 and ran for four years. The fuel for the MSRE was LiF-BeF<sub>2</sub>-ZrF<sub>4</sub>-UF<sub>4</sub> (65-30-5-0.1), the graphite core moderated it, and its secondary coolant was <a href="FLiBe">FLiBe</a> (2LiF-BeF<sub>2</sub>). It reached temperatures as high as 650 °C and operated for the equivalent of about 1.5 years of full power operation.

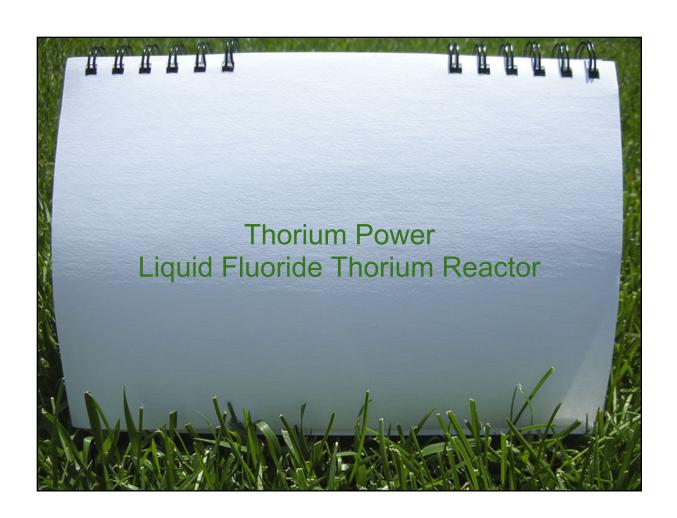
The third effort was a design only. The bulk of reactor funds were being redirected elsewhere. The design is essentially the same as that presented in the following slides.

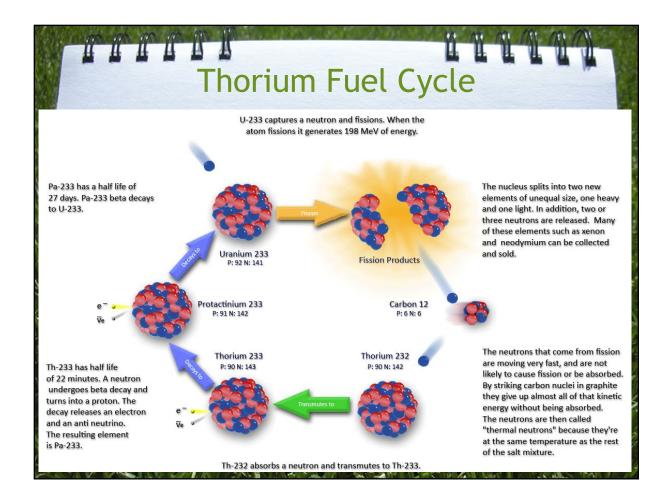


Many theories have been raised for why such a promising system was canceled. One theory is political: Oak Ridge was the only lab working on the MSR, while work on the sodium-cooled fast breeder, the competing technology, was being conducted with a much larger budget at several national labs.

Another theory was that it was personal. — Oak Ridge's director, Alvin Weinberg, had drawn the ire of the AEC by publicly raising safety concerns about pressurized water reactors.

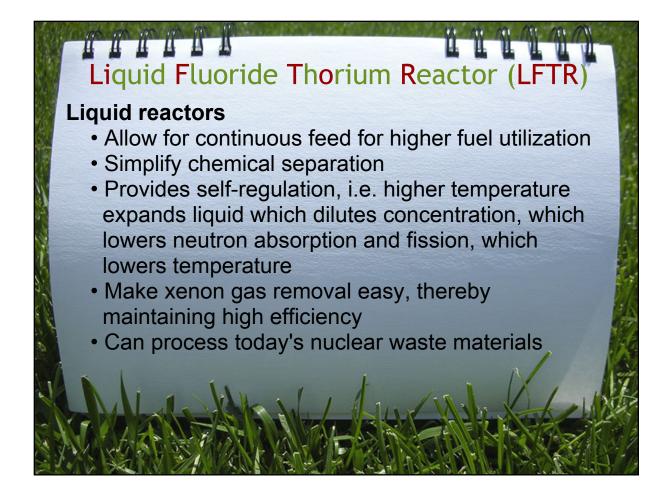
Finally, and more speculatively, is the theory that the MSR was killed because it didn't produce plutonium, which was a military objective





The fuel cycle starts with thorium being bombarded by thermal neutrons in the bottom right corner. The process is pretty self-explanatory from there.

The half life of  $^{233}\mathrm{U}$  is  $1.62 \times 10^5$  yr. i.e., pretty stable. It needs the extra neutron to cause fission.



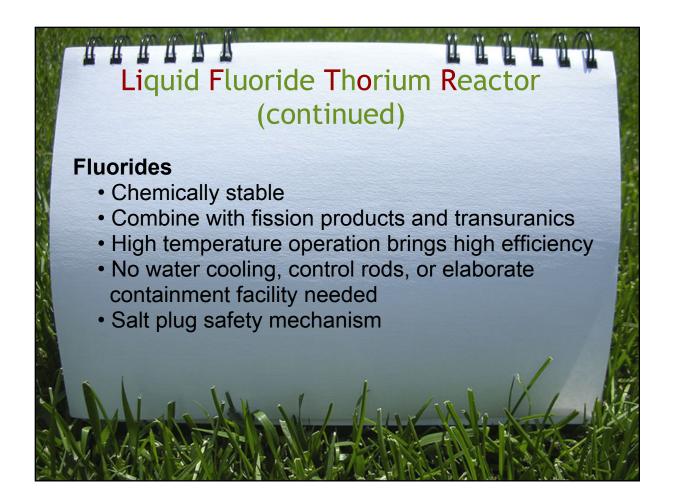
Liquid Fluoride Thorium Reactor (LFTR), is a class of Molten Salt Reactors (MSR)

From here on, we will be speaking first and foremost a LFTR desogn, that is, a Liquid Fluoride Thorium Reactor. The name correctly implies that each element brings something to the party.

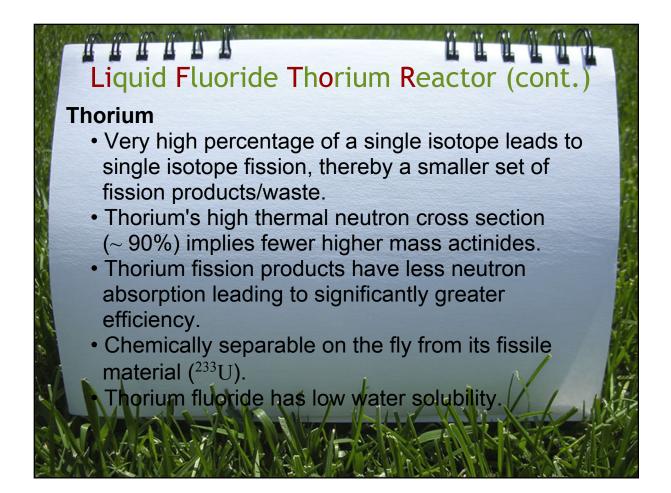
We will examine each in turn.

Xenon is a major consumer of neutrons, which slows down fission. It is a big problem in solid fuel reactors which operate at high pressures. By LFTR operators near normal atmospheric pressure. Xenon remains a gas and you just extract it from the top.

LFTR allows for the introduction of a 'poison pill', i.e. chemicals that permanently alter the chemical balance so that no fission can take place or will absorb all the neutrons you throw at it



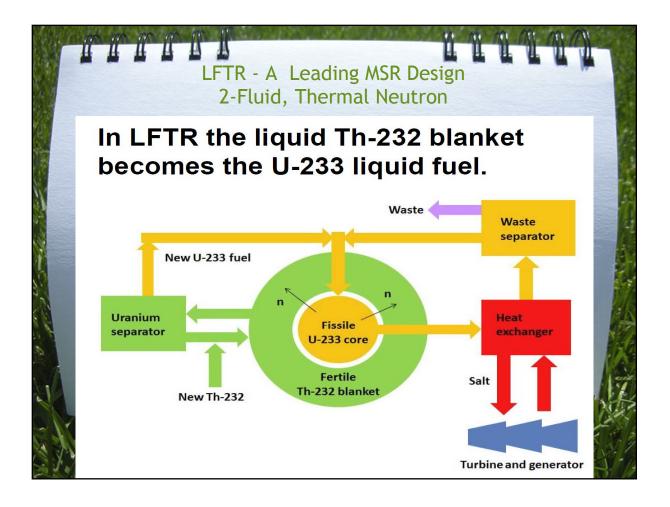
Self-explanatory



When we say Thorium fission products here, we really mean fission products of  $^{233}{\rm U}$  which is the fissible element/isotope of the thorium fuel cycle.

Implicitly, this is being compared to the fission products of the  $\rm ^{238}U/^{239}Pu$  fuel cycle.

The solubility per kg (liter)  $\rm\,H_2O\,$  at 25 °C of ThF $_4$  is 0.17 g compared to 360g of NaCl (table salt).



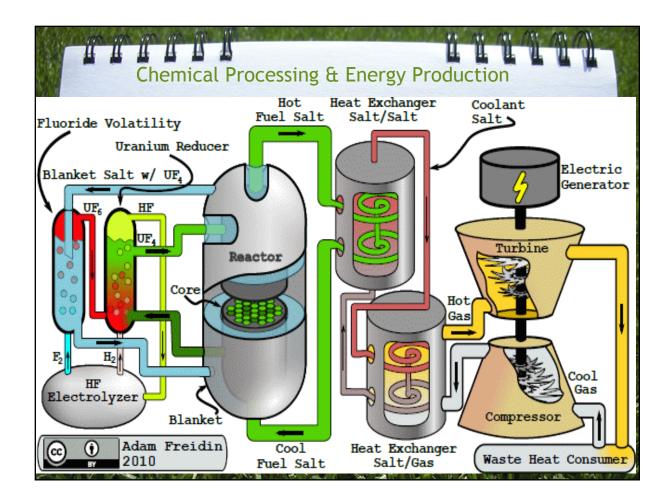
This LTFR diagram shows a basic spherical design. The reactor chamber is split into two parts, the core (yellow) where fission occurs and the blanket (green) where thorium fluoridegets bombarded by neutrons. A reactor of this design can run continuously.

New thorium fluoride is introduced through the bottom green line. The fuel cycle starts here with exposure to neutrons The blanket liquid is circulated through the uranium separator. Here uranium fluoride is extracted and sent to the core (yellow line). The remainder is returned to the core. The uranium in the chemical separator has a long half life. It needs to absorb another neutron in the core for fission to occur.

In the core, a <sup>233</sup>U atom typically gives off two neutrons. Geometry and concentrations are tuned to service continued fission and Thorium exposure in the blanket at desired rates. The wall between the core and the blanket contains graphite to slow the core neutrons so that the thorium absorption is more efficient. The graphite also helps to maintain a high core temperature.

It's the core that heats up. Fuel is pumped into the heat exchanger to drive a turbine and a subsequent electric generator. The cooled fuel returns to the core after going through a chemical waste separator.

For continuos operation, an equivalent mass of new fuel must be added at a rate equal to waste extraction.



## In this diagram:

The red line and everything to its right is not radioactive.

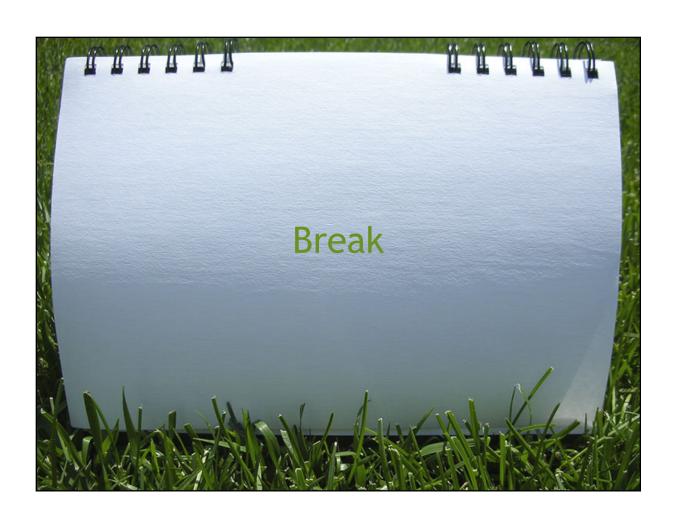
The "Hot Fuel Salt" is extracted from the core (green line shown at top).

New thorium fuel would be added to the blue line going into the bottom left of the blanket.

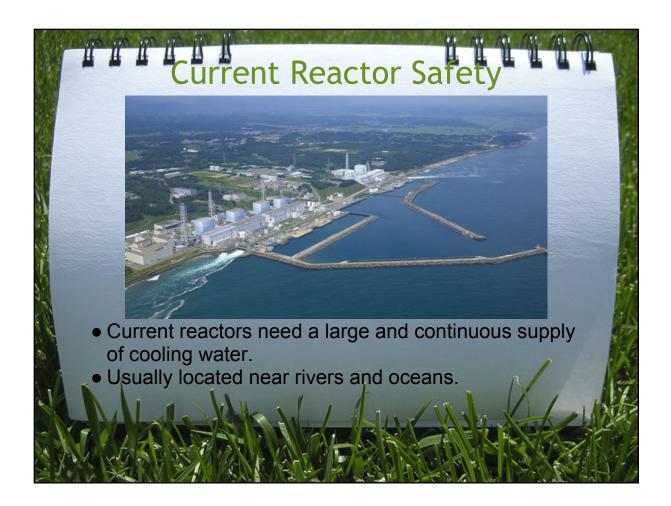
In the green "Cool Fuel Salt" line, most likely, fission products would be removed chemically, first just before it re-enters the core at the bottom of the reactor.

The chemical processing on the left demonstrates the uranium fluoride being separated from the thorium and protactinium salt in the blanket. The blanket probably also contains lithium fluoride and beryllium fluoride as stabilizers.

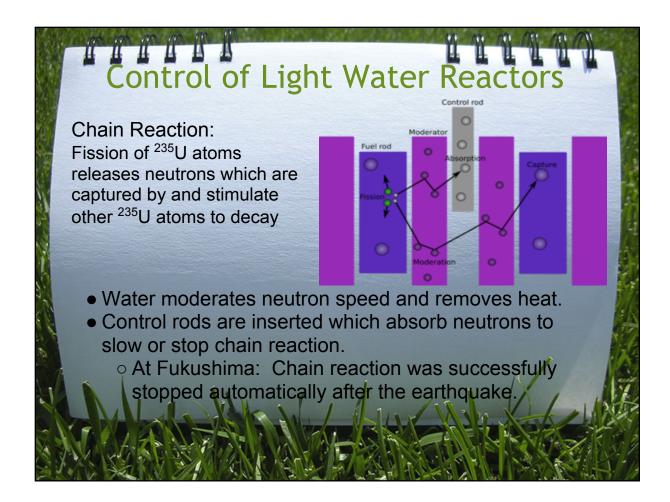
LFTRs will run at about 800 °C. This higher temperature operating range making electricity conversion factors approaching 45% versus the 33% of coal and older nuclear plants.





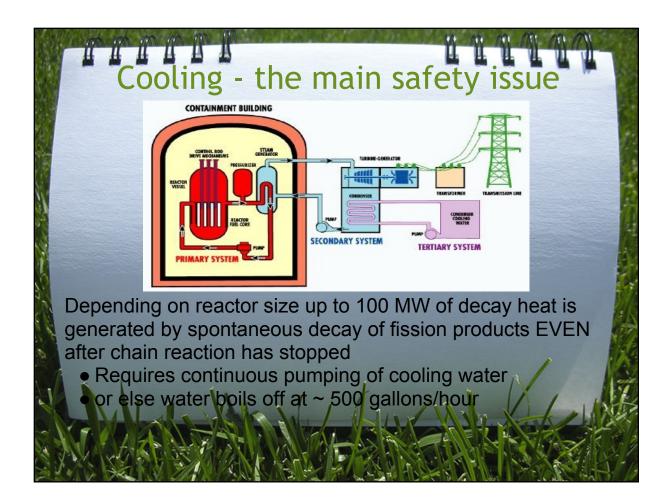


Self-explanatory



Emergency insertion of control rods is called a "SCRAM". It can be triggered by a number of unusual conditions including loss of connection to power grid.

If the control rods are remove too far or the water level gets too low, then the chain reaction will proceed at too high a rate. This would generate more heat than the water could cool. In this case the water would boil off and the fuel would melt. Most likely there would also be an explosion.

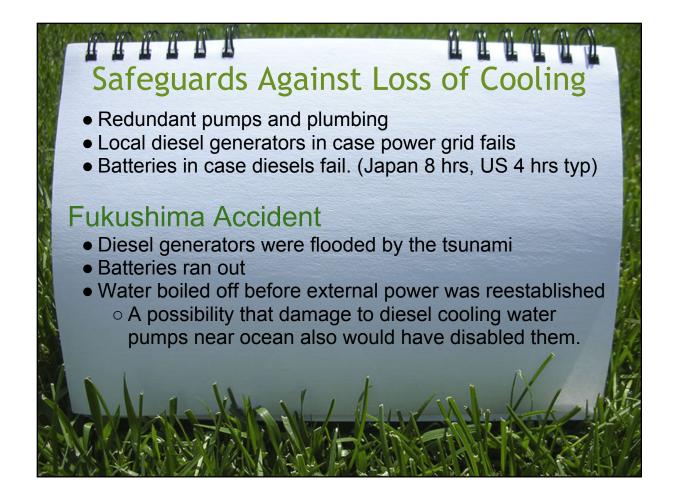


Self-explanatory

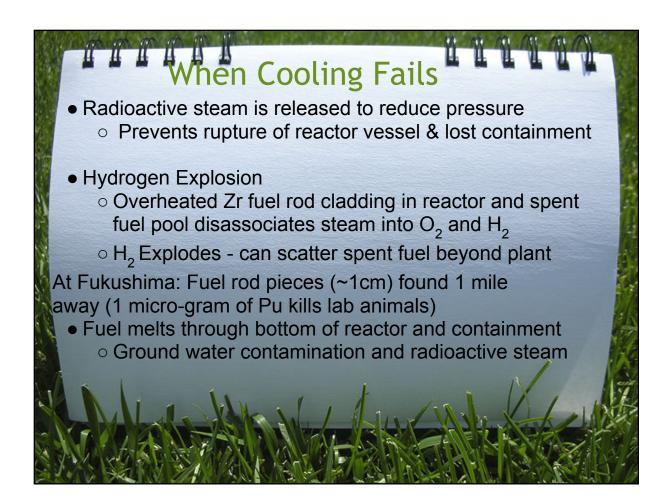


Spent fuel rod pool is in the far corner below the gantry crane in this illustration.

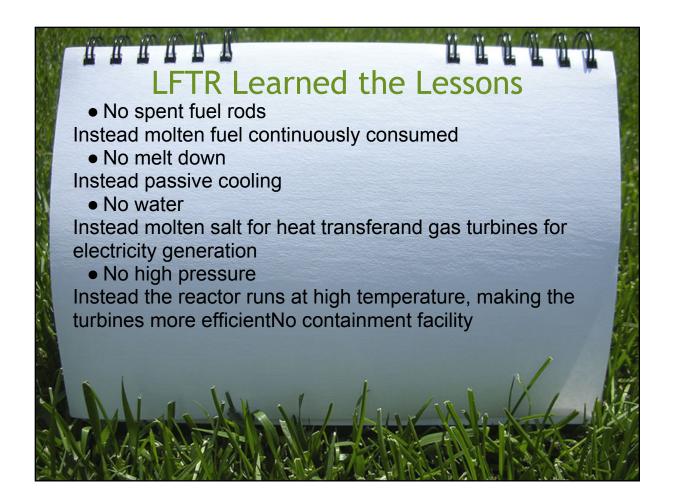
A really "spent" fuel rod has used 5% of its fuel. 1% to 3% is more typical.



Self-explanatory



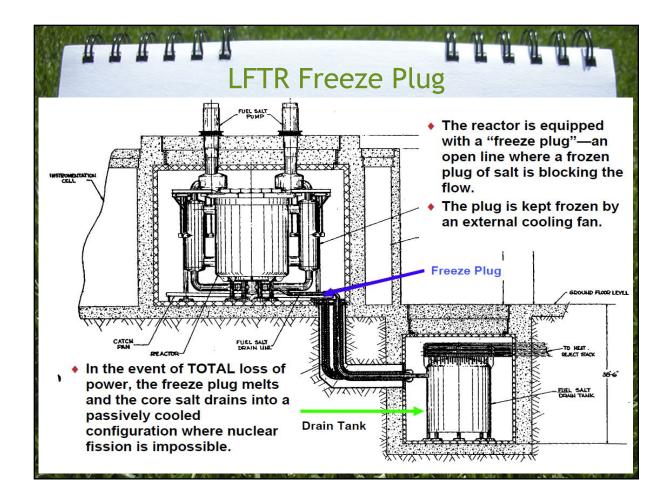
"Meltdown = China Syndrome"



If you compare the Fukushima failure mechanisms, you see that the LFTR design already compensates for these issues.



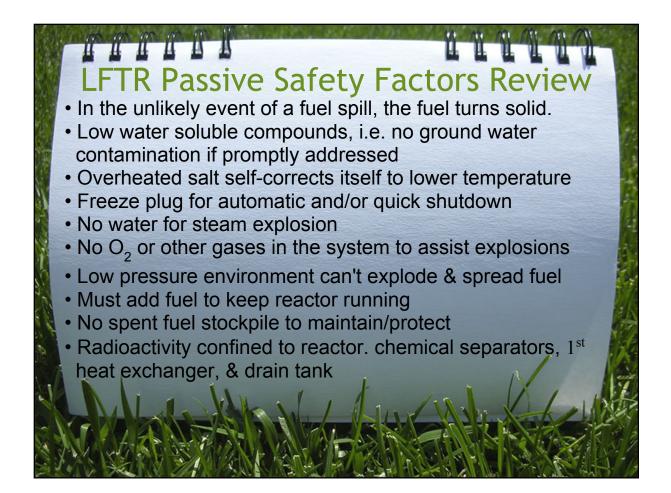
By passive safety we mean that if you do nothing, the situation improves itself. This varie significantly from today's light water reactors with which you must continually take active steps to maintain safety.



For those of you we might have trouble reading this, I will repeat its information.

The diagram shows a LFTR reactor and a drain tank only. The upper left chamber is the reactor (core + blanket). The lower right chamber is the drain tank. In the center is a "Freeze plug". This is an open line where a frozen plug of core salt blocks any outflow. The plug is kept frozen by an external cooling fan.

In the event of a total loss of power, the freeze plug melts and the core salt drains into a passively cooled drain tank where nuclear fission cannot occur. The core salt is spread out in a geometry that does not allow the chain reaction to continue. In other words, the reactor stops. The salt will remain a molten liquid for quite some time. Before it cools and freezes, you can pump it back into the core to restart the reactor.



Throughout this presentation, we have been referring to features that are part of the passive safety architecture, but just not calling them that.

Here we place them in shaper focus to demonstrate how broad and deep the safety runs.

Compare this to what we discussed about light water reactor designs.

Having said this, safety is a never-ending quest. We cannot assume any design is perfect. There can always be failures. We must be ever vigilant against them. But LFTR is a significant step toward systematic safety.

The features themselves are self explanatory. Non of these require external power or human intervention to happen.

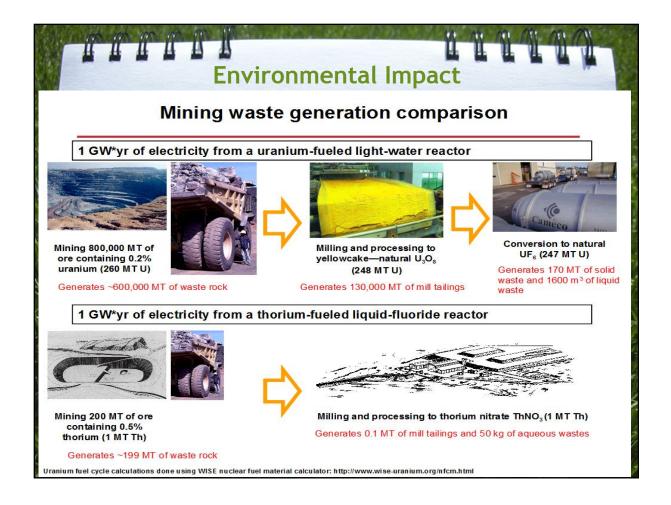


We will look at the waste in 2 ways.

The first two slides will look at the waste from ore extraction through power generation.

The third slide will take a closer look at the radioactive products.

The fourth slide will show comparatively the relative radioactive lives of the various products.



This slide and the next detail the environmental impact of the uranium energy cycle versus the thorium energy cycle viewed on 1 GWyr scale. The world currently consumes something over 16 GWyr currently.

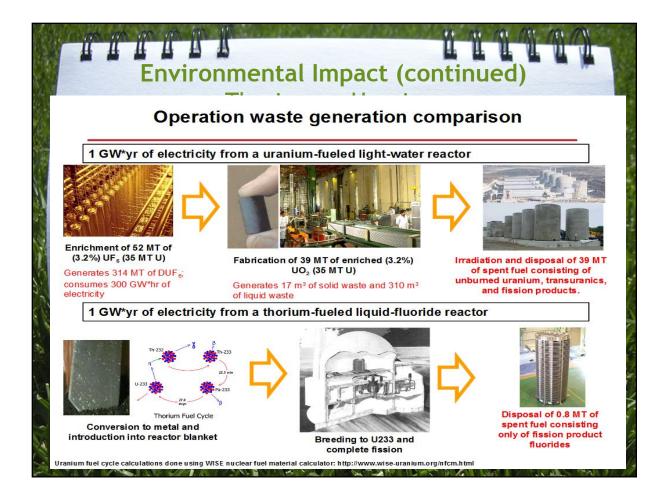
M T here stands for Metric Tonnes

# Ore mining/ milling & processing

Uranium: 800K M T @ 0.2% => 247 M T UF<sub>6</sub> + 730,170 M T solid and 1600 m<sup>3</sup> of liquid waste.

Thorium: 200 M T @ 0.5% => 1 M T ThNO<sub>3</sub> + 199.1 M T solid waste and 50 kg aqueous waste.

Thorium solid waste advantage for this set of steps: 3667 to 1.



## Enrichment/ fabrication/Irradiation/disposal - additional waste

#### **Uranium:**

Consumes 300 GWhr of electricity + 314 M T depleted UF<sub>6</sub> + 17 m<sup>3</sup> solid waste + 310 m<sup>3</sup> liquid waste + 39 M T spent fuel (radioactive fuel, transuranics, & fission products)

#### Thorium:

0.8 M T of fission product fluorides.

Thorium solid waste advantage: 363 to 1

This represents a significant difference in the amount of end products you would have to store and guard. Remember also that waste uranium products can also be consumed in a thorium reactor, that is, with a thorium reactor you can get uranium waste down to these smaller numbers.

At each and every phase, Thorium requires significantly less effort than uranium. This translates not only to less environmental damage, but also to safety and cost.

The uranium process also contains many more steps in a radioactive state. Thorium is only radioactive in the reactor and its waste products.

Put file miningwastegen2.png.webarchive here



Plutonium-239, or <sup>239</sup>Pu, in particular, when separated, is the world's most effective material for making nuclear bombs. The heavier actinides, when separated, can also be used to manufacture bomb-grade material, as can some of the other plutonium isotopes, as well as the <sup>235</sup>U. The fission products can be recycled, and have value outside of the nuclear energy industry.

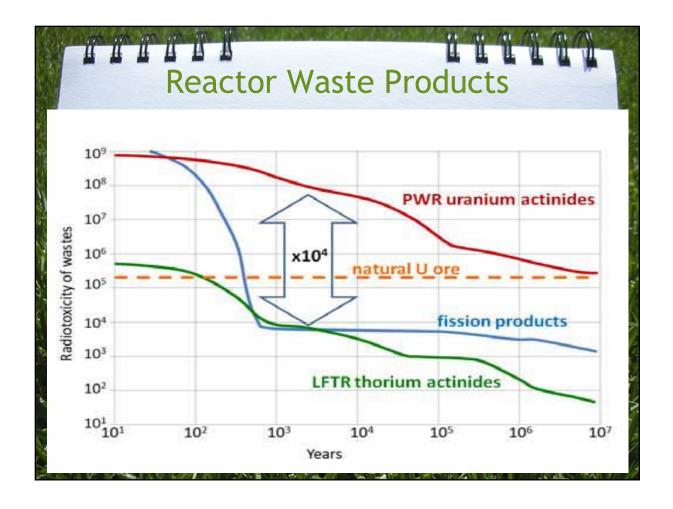
The thorium cycle has an entirely different waste profile. Noticeably missing are the plutonium and the heavier actinides. Noticeably evident is the <sup>233</sup>U. But in the LFTR environment, it is continuously re-fed into the core until it is consumed. Naturally, the reactor is feeding in more fuel, <sup>235</sup>U, to maintain the desired fission rate.

The complexity of the uranium cycle by-products means that you end up with a lot more different fission actinides with potentially multiple isotopes of each. Some are bound to be radioactive for a long time.

With thorium, we dodge the bullet. We have fewer, and fortunately, they are all relatively benign.

One hard thing to get used to is what it means to consume a nuclear fuel. We tend to think of it like burning logs in the fireplace. Perhaps you put in 20 lbs of logs and they burn down to about a pound or two of ash. But in this business, when you are done consuming the fuel, you have almost exactly the same mass of material with which you started. The energy released comes from splitting those atoms.

Ref: Hargraves & Moir, American Scientist, <u>Liquid Fluoride Thorium Reactors</u>, v. 98, July-August 2010, p308



From p55, Thorium\_RobertHargraves.pdf A slide comparing radiotoxicity

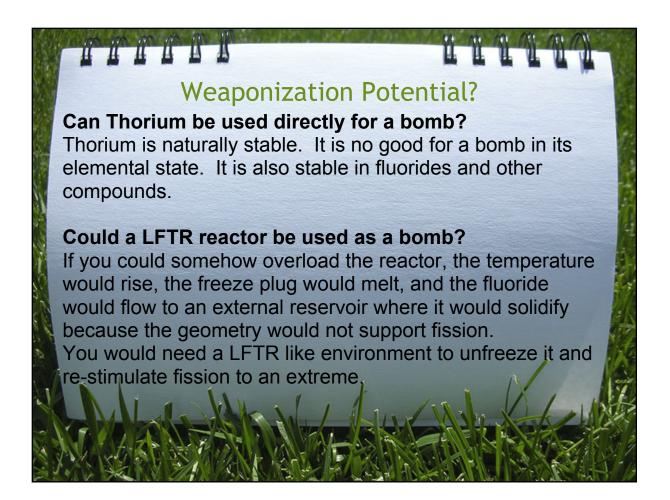
This graph (not exact) shows the radioactivity intensity of the wastes from both a plutonium light water reactor (PWR) and a lithum fuoride thorium reactor (LFTR) over time.

The blue line represents the radioactivity of fission products common to both cycles. The worst of these decays to background level (yellow line - U normal level) in about 350 years. A high percentage of these decay to safe levels in 10 years.

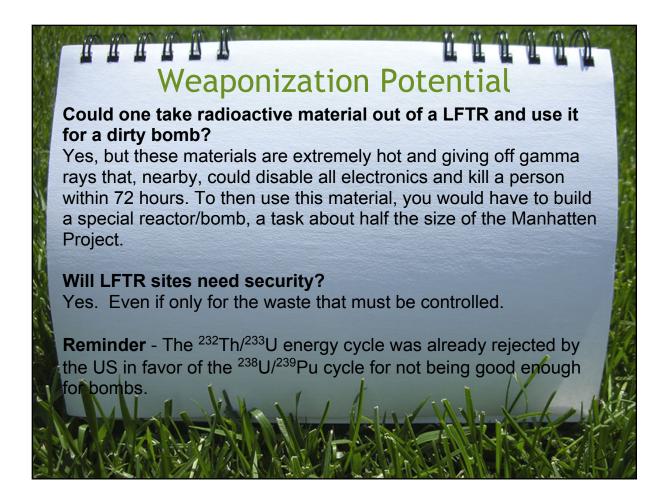
But the significant difference is between the radioactivity of the the heavy actinides produced in the plutonium process versus the lighter ones produced by LFTR, that is about 4 orders of magnitude.. In practice, This means that the Thorium products need sequestering on the order of 350 years versus 350,000 years fir the plutonium products.

Ref: Hargraves & Moir, American Scientist, <u>Liquid Fluoride Thorium</u> Reactors, v. 98, July-August 2010, p309





Self explanatory.



The Los Alamos National Laboratory (LANL) in the USA did successfully manufacture an experimental nuclear bomb, and in the process, they amply demonstrated that <sup>233</sup>U is far more difficult to construct into nuclear bombs than <sup>239</sup>Pu or minor actinides. The reason lies chiefly in the uranium-232 (<sup>232</sup>U) contamination that occurs naturally in all <sup>233</sup>U.

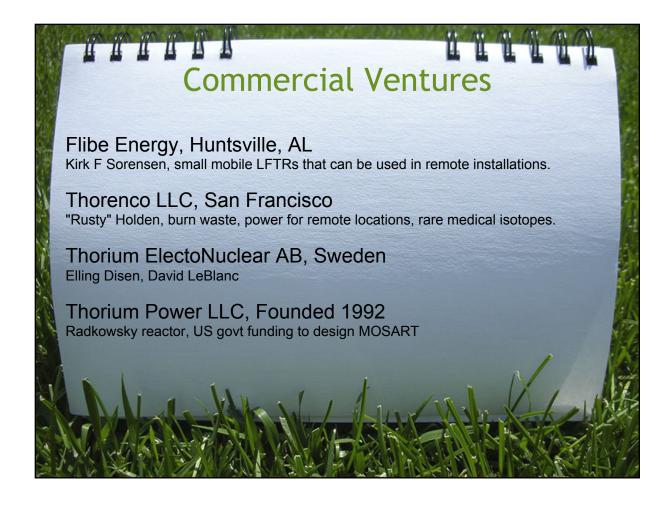




Resilient to natural disasters could use further explanation. LFTRs are scalable in size. For general utility, the optimal size maybe modules about the size of cargo containers. These are relatively small and coud be built to shake as a unit during an earthquake. The relatively small size reduces the torque along any given axis.

If the LFTR ends up under water, the control electronics will probably burn out. But if all fails, the fuel will solidify as it cools.





#### Flibeenergy.com Huntsville, Alabama

Kirk F. Sorensen, President and Chief Technical Officer, Flibe Energy.

A new company that will develop small modular reactors based on liquid-fluoride thorium reactor (LFTR) technology. Flibe Energy anticipates strategic collaboration with qualified nuclear equipment manufacturers to hasten the development and construction of the small mobile LFTRs that can be used in remote installations.

Lithium fluoride (LiF) and beryllium fluoride ( $BeF_2$ ) together form a solution often called "F-Li-Be", that is the ideal medium for nuclear chemical processing and reactor operation.

## Thorenco LLC, San Francisco http://thorenco.com/index.html

An Attorney-Inventor, Charles S. "Rusty" Holden founder of Thorenco LLC working with Lawrence Berkeley National Laboratory physicists. Thorenco LLC, founded in 2005, is developing three special reactors one to purify spent nuclear fuel, the second to produce cleaner power and heat at remote locations and one to produce medical isotopes in short supply.

He has a patented core design using metal matrix, not molten solids.

They are looking for investors.

### **Thorium Power LLC, founded 1992**

'If Nuclear Power Has a More Promising Future ... Seth Grae Wants to Be the One Leading the Charge'

They want to substitute Th fuel in current reactors to make the reactors UNATTRACTIVE for weapon production and use up existing <sup>239</sup>Pu stock piles.

Thorium Power grew out of the work of Alvin Radkowsky, a man who made a huge impact on the world, even though few people have ever heard of him.

"Since the early 1990s Russia has had a program to develop a thorium-uranium fuel, which more recently has moved to have a particular emphasis on utilisation of weapons-grade plutonium in a thorium-plutonium fuel.

The program is based at Moscow's Kurchatov Institute and involves the US company Thorium



See comments regarding China below in the Challenges section.



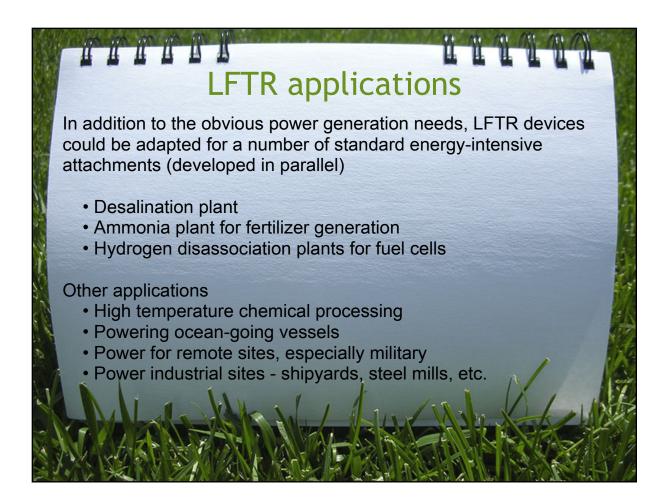


The purpose of this slide is to demonstrate that manufacturing efforts of this size and complexity are already underway in the aircraft industry. The concept of having an assembly line that produces a system a day is within reach.



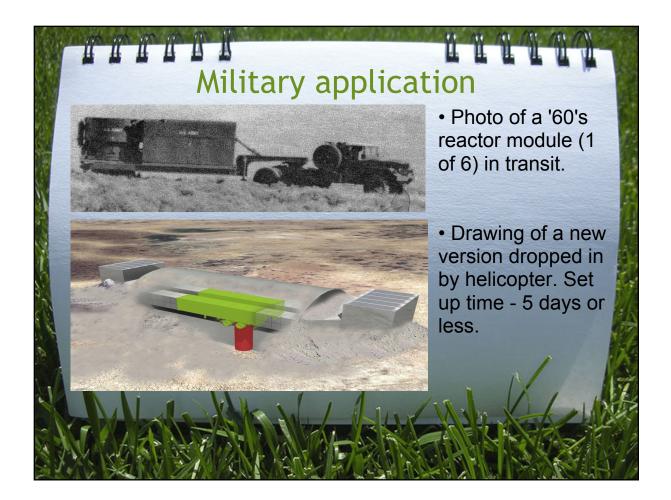
We need to get active on a big scale that has top priority.





Someone will want to power trains as well.





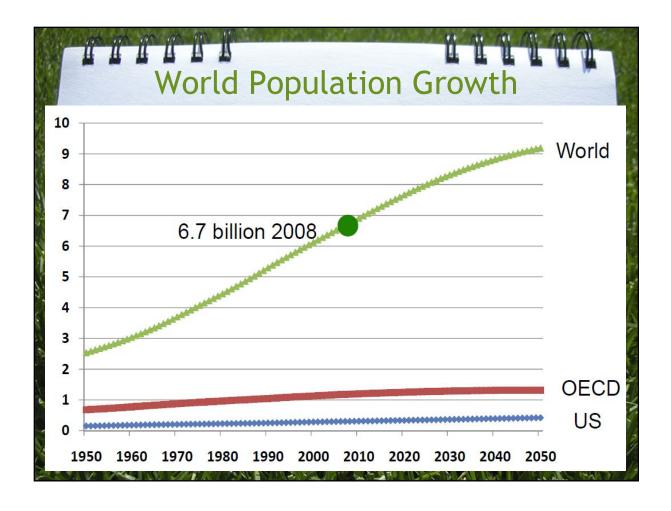
The military has the right idea here. Initial efforts should be designs for modularity, assembly line manufacturing, and shippability by truck, railroad, container ship or airplane.

This would serve us well for both military and non-military applications.

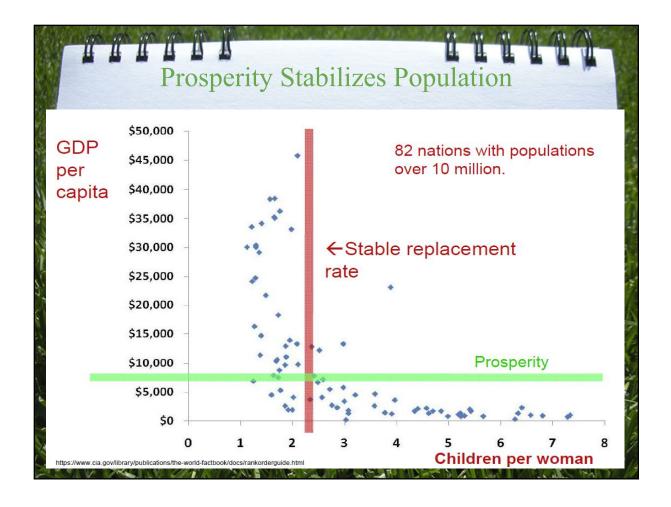




Naturally, all these lofty goals could not be accomplished at once. They would have to be prioritized. You might knock them off one after another. But one thing is clear. The longer you wait to begin and the slower you proceed, the worse our problems will become. It is wiser to begin ASAP and proceed with all dispatch.

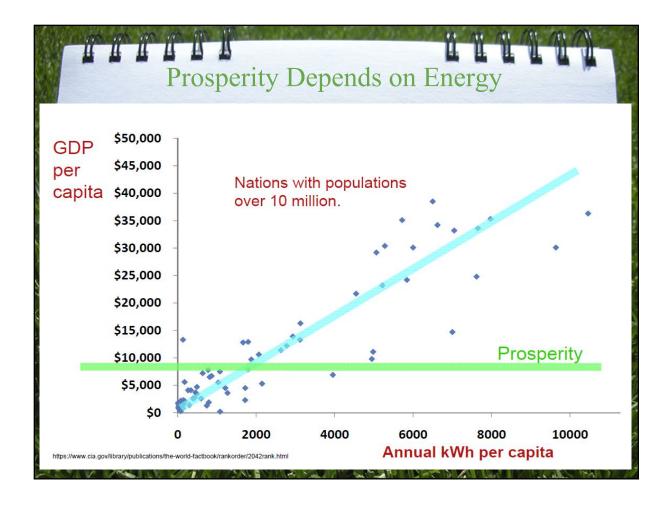


The world population is passing the 7 billion mark this month (Oct. 2011). As you can see, it is expected to reach the 9 billion mark around 2050. Since the US (blue line) and the developed countries (OECD - red line) have little growth, the population increase has been and will continue to come from third world countries, albeit it is expected to level off.



This is a simple chart showing the average number of children per woman in countries with populations over 10 million versus the GDP per capita for their country.

The empirical data shows that the countries whose women exceed the stable replacement rate of 2.3 births/woman almost always falls below the prosperity line. Conversely, those countries that average below the stable replacement line usually enjoy a higher standard of living if GPD per capita is a valid reflection of that concept, as most would contend.

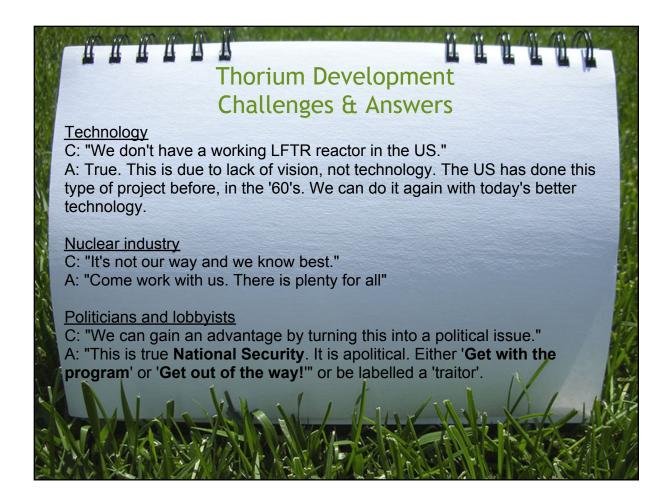


This chart demonstrates that energy/electricity usage is directly correlated to GDP, i.e., the higher the GDP the higher the energy usage, and vice versa.

Would higher energy availability decrease the number of children/woman and increase GDP and raise countries above the prosperity line? The data suggest this. But correlation is not causation. Would this really happen? One would have to try it to prove it either way.

But the vision is tantalizing. Do we have within reach the lynchpin to solve a lot of the third world's poverty problems? Certainly, this would not be the only prerequisite. But it may be the most influential. All through the magic of thorium power.

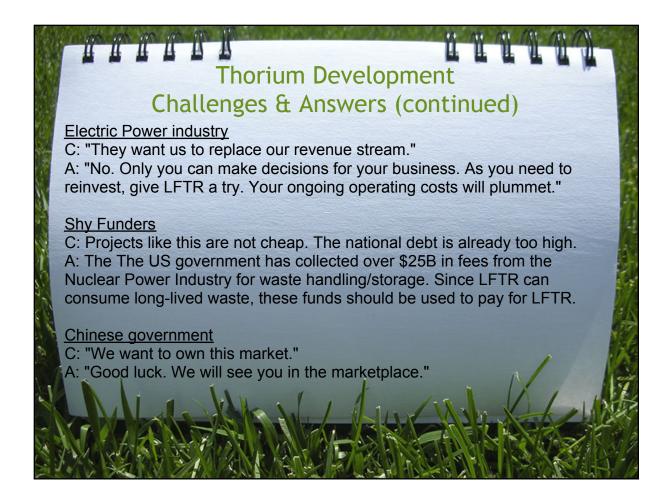




Technology: There will be challenges, set backs and bumps in the road, and maybe even schedule delays.. This is true of all sophisticated product development. We have to expect these because we have set the bar higher. But there does not seem to be a problem that is insurmountable.

Nuclear Industry: It is expected that engineers and scientists from the nuclear industry will be prime participants because they have lots of relevant expertise. The statement in the slide actually relates to those in the business and operational areas.

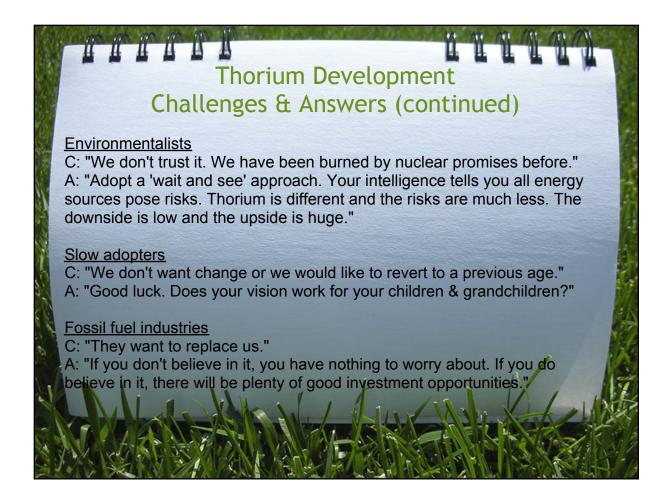
Politicians and lobbyists: These comments are directed at those who find excuses for never getting started or throwing irrelevant obstacles in the way to delay or sabotage the project. The point is that all must come with a 'can do' attitude. It is taken as a given that all substantive issues must be addressed and professionally resolved. Politicians certainly can raise such issues but are ill equipped to pass judgement on them.



Electric Power Industry: It is assumed that issues about thorium/LFTR development or programs should only come up when power companies have to make their next round of capital investments. That is a complicated process that they are best qualified to evaluate. But current feelings are that, excluding initial investments, that LFTR reactors can deliver electricity significantly below the \$0.11 /kWhr of today.

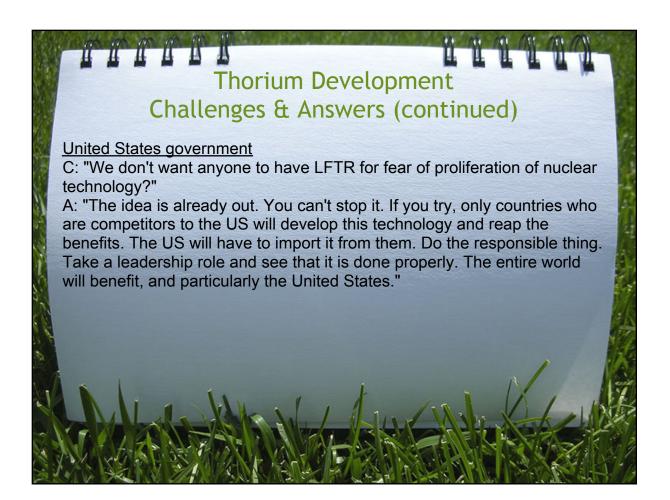
Shy Funders: Look at the projected benefits. This should be our highest energy priority. Would you rather have an American industry with exports? Or, do you want another country to reap the rewards? But it will still take a lot of education to convince the lawmakers.

Chinese government: In Jan 2011 the Chinese government publicly stated that they want to own all the patent rights for all this technology, and implicitly, to own this market. This should be taken seriously by American policy makers. They have already taken steps to monopolize the refining of rare earth metals many of which are needed for sophisticated high tech equipment, such as, computers, missiles, state-of-the-art batteries, stealth technology, and probably next generations nuclear reactors.

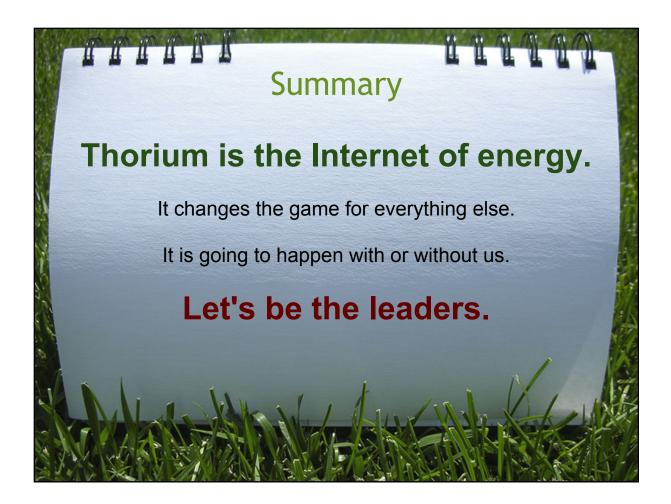


Environmentalists: In addition to all the passive safety features mentioned previously, a major significant difference is that LFTRs can be manufactured at a central site. This allows for uniform application of quality control on a standard design. This is in stark contrast to our currently licensed 104 custom designs with nearly 104 quality control construction standards and implementations.

Fossil fuel industry: They need to ask themselves what business are they really in. Are they in the fossil fuel business, or in the energy business? If it is the latter, they should consider hedging their bets.

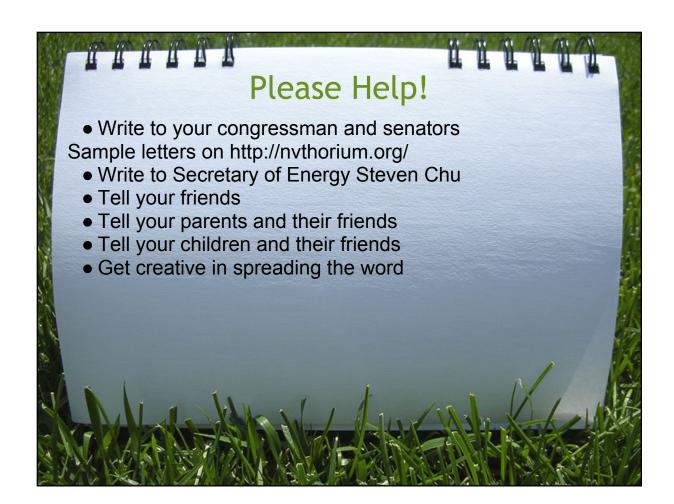






This is the 'greenist agenda' you will find.











Thank You for your consideration.

I threw in a few tag lines. I really don't think that they are hyperbole.

By "The Internet of Energy" is meant the thing that changes almost everything else.