11/19/06 REV. X

THINGS EVERYBODY SHOULD KNOW ABOUT ENERGY

SUMMARY

The U.S. Gross Domestic Product for 2006 will be $13.6 trillion, $45,300 per person. We will spend an average of $3,800 on energy for each adult and child in the U.S. 86% of our energy comes from fossil fuel. We will discharge 44,000 pounds of CO2 per person in 2006. The Department of Energy's Research & Development budget for non fossil energy sources (nuclear, hydrogen, solar, wind, hydroelectric, geothermal and biomass) is less than $0.7 billion, about $2.00 per American, in 2006.

We should be investing an amount equal to at least 5% of our energy budget on R&D for non fossil energy sources. That would be $191 per person, $57 billion per year. With this level of investment we can push every technology very hard. The best technologies, whatever they are, will emerge as leaders in the shortest possible time. The new technologies will tend to suppress rising fossil fuel cost. I believe the savings could surpass the annual R&D cost within 15 – 20 years, and save over $1,000 per year per person within 30 years, not to mention a large improvement in environment and quality of life with this approach.

ENERGY BASICS

In 2005 the United States consumed 4.04 billion megawatt hours (mWh.) of electric energy. Dividing that by the 296 million people in the United States then gives an average annual consumption of 13.6 mWh per American, about 1,550 watts, 24 hours a day. At $81 per mWh, a year's supply of electricity cost $1,100. Over an 80 year lifespan, a lifetime supply of electricity would cost $88,300.

If all of our electricity came from a single fuel source how much would be required for an average person in the U.S., what would it cost and how much CO2 would be released as a byproduct of that production?

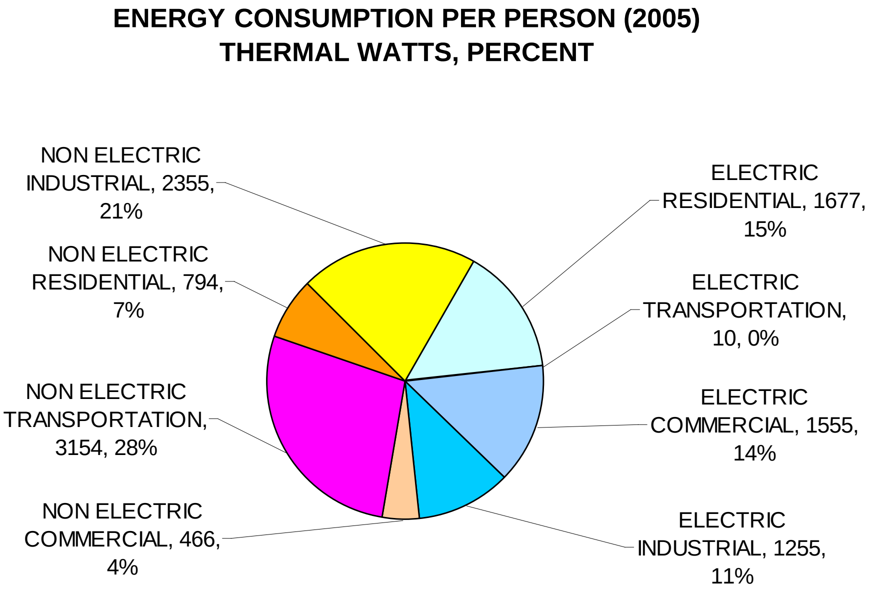
	Coal $31/TON	**Oil $49/BARREL**	**Natural Gas $7.45/KCF**	**Uranium $17/POUND**
Annual Amount	14,200 lb	17.2 barrels	115,000 cubic ft	0.723 lb
Annual Cost	$218	$841	$854	$11
Annual CO2 Production	30,600 lb	24,000 lb	13,400 lb	0 lb
Lifetime amount	1,140,000 lb	1,370 barrels	9,170,000 cubic ft	57.8 lb
Lifetime Cost	$17,500	$67,300	$68,300	$867
Lifetime CO2	2,440,000 lb	1,920,000 lb	1,070,000 lb	0 lb

URANIUM

Converting 5.4 ounces (0.34 lb) of Uranium to fission products will release enough heat to generate a lifetime supply of electricity for an average American with no CO2 emissions. Our primitive first generation nuclear plants split less than 1% of the Uranium mined to fuel them. In order to produce 5.4 ounces of fission products we mine 58 lb of Uranium.

Most electricity is made from the heat of burning fossil fuel or nuclear fission, by power plants with efficiencies ranging from 30 to 45%. Some electric power is lost in transmission. It takes 4,500 watts of source energy to generate our 1,550 watts of electrical power.

Electricity production accounts for about 40 % of all the energy that supports our lives. Most of the rest comes from the direct combustion of fossil fuel. Our total energy consumption is distributed as shown on the next page.



The total amount of source energy that supports our life is about 11,300 watts per person. Imagine the heat from 11 one thousand watt hair dryers running at maximum power 24 hours a day, for each of us, from cradle to grave.

We derive our energy from several sources as shown below.

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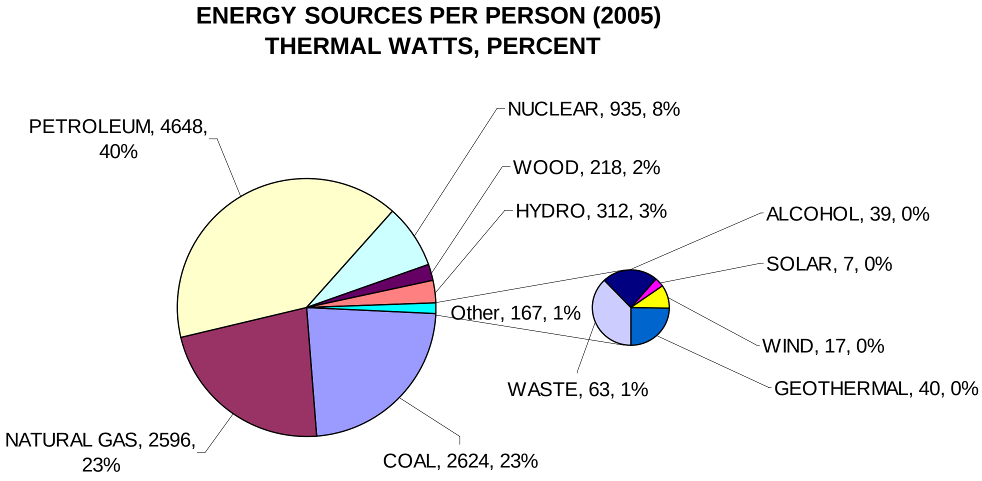


Fossil fuels account for 86 % of all the energy that supports our lives.

If we derived all of our energy from a single fuel source how much would the average American need?

	Coal $31/TON	**Oil $49/BARREL**	**Natural Gas $7.45/KCF**	**Uranium $17/POUND**
Annual Amount	33,800 lb	39.6 barrels	337,000 cubic ft	1.7 lb
Annual Cost	$519	$1,940	$2,510	$29
Annual CO2 Production	72,600 lb	55,200 lb	39,400 lb	0 lb
Lifetime amount	2,700,000 lb	3,170 barrels	26,900,000 cubic ft	137 lb
Lifetime Cost	$41,500	$155,200	$201,000	$2,330
Lifetime CO2	5,810,000 lb	4,420,000 lb	3,150,000 lb	0 lb

URANIUM

Converting 13 oz (0.8 lb) of uranium to fission products will release enough heat to generate a total lifetime supply of energy for one average American, with no CO2 emissions. To produce 13 oz of fission products using primitive first generation nuclear power plants we mine 137 lb of uranium.

Hydrogen

Hydrogen is often touted as the solution to our energy problems. It has important advantages;

- High energy content per pound
- Combustion product is water vapor
- Ideal fuel for fuel cells

There are also disadvantages;

- Flammable
- Difficult and expensive to store and transport
- Tendency to leak through tiny imperfections

- Low energy to volume ratio, fuel tanks are much larger and more expensive than fossil fuel tanks of equal energy content
- Multiple energy loosing transformations required for hydrogen systems offset the efficiency of fuel cells making overall efficiency little better than conventional systems

The biggest disadvantage of all is the fact that there are no hydrogen wells or hydrogen mines. Hydrogen must be extracted from water molecules or hydrocarbon fuel. The energy required to break water molecules apart, separate, store and transport the hydrogen must come from some other source. The source energy required is greater than the energy released when we reconstruct the water molecules in engines or fuel cells. Hydrogen is in essence a different kind of battery, not a source of energy.

For more details on hydrogen see the May 04 issue of Scientific American and the August 04 issue of Science.

By building a fission/electric/hydrogen energy system we can;

- Stop burning fossil resources and preserve them for other applications by future generations
- Dramatically cut CO2 emissions, mercury and other toxics
- Improve air and water quality
- Eliminate most causes of acid rain
- Stop buying foreign oil
- Reduce mining and drilling
- Preserve wilderness areas
- Desalinate sea water for arid locations
- Reduce draining of the Sierras and Rocky Mountains
- Restore wild rivers
- Have safer more comfortable homes and vehicles
- Reduce the cost of living

Advanced reactors can convert over 90% of mined uranium into fission products, increasing the utilization of uranium by a factor of 150, compared with our primitive first generation nuclear power plants. Using advanced reactors we can enjoy all of the benefits listed above and, at the same time, reduce uranium mining to 15 oz per lifetime, 3.3% of current uranium mining levels. A total energy lifetime supply of uranium costs $15, only 19 cents per year. For details on an advanced design see the 12/05 issue of Scientific American.

The oceans contain 4.5 billion tons of uranium, sufficient for over 30,000 years. In reality the oceans are continuously resupplied with uranium by the erosion of land, so the uranium supply is effectively unlimited.

WIND SOLAR & ETHANOL

It was a beautiful day for our snowshoe trip to the top of a 10,000 foot mountain, with fresh snow, deep blue cloudless sky, no wind, and temperature around 20 F, but it felt much warmer. I got some ribbing about being a nuclear engineer, mostly friendly, from the many environmentalists in the group. We reached the summit around noon and stopped for lunch. As we started to eat the normal chatter subsided until the only sound was of a young woman quietly sobbing. The leader went to her and asked what the problem was. “My feet are freezing.” She had worn canvas tennis shoes for her first snowshoeing experience, her shoes and socks became soaked with melted snow and now they were icing up “You’ll have to tough it out” he said, “I know” she said. We resumed eating in uncomfortable silence.

I walked over to her and said, “I might be able to warm up your feet”. I moved her to the center of the group where the sunlight was unobstructed. “Take off your shoes” I said. “No” she said, “why?” I asked, “Because I’ll have to put them back on” she said.

From childhood experience I knew that with the help of a campfire frozen tennis shoes can be transformed into giant flaming marshmallows with no sensation of warmth inside. NASA might have saved a lot of money on heat shield material by using old tennis shoes.

“I can’t get your feet warm wearing those shoes” I said. “I’m not taking them off” she said, “OK, let’s try it your way.”

I pulled out my high tech survival gear, a 55 gallon plastic garbage bag (black) and a disposable painters drop cloth (1/4 mil clear plastic). I inflated the bag, wadded it into a tight ball to wrinkle it, then inflated it again and had her put her feet inside. I unfolded the drop cloth, wadded up the plastic to wrinkle it, and then wrapped it loosely around the bag trapping a few layers of insulating air. “Give it some time” I said, trying to sound confident.

Several minutes went by and she stopped crying, a few more minutes and she said it wasn’t as cold, a few more minutes and she said it was warm, then hot, than very hot. “OK take your feet out”. She lay back flat on the ground, pulled her feet out of the bag and pointed them straight up. White clouds of water vapor billowed off her shoes and jeans. There was an audible gasp, not just mine, I touched the shoes and they were very hot. Others came up and touched them in amazement. A young man came forward eyes down, he sat next to the girl without a word and thrust his icy tennis shoes into the bag.

There was a Q&A session to explain the working principal of a solar oven. When their questions were answered I asked a question. “With all the solar buffs in the group why did it take a nuclear engineer to get her feet warm?” Silence. “In a rational world there is a place for solar energy, and a place for nuclear energy.” I don’t know if I made any converts but at least the ribbing stopped.

SOLAR

On the Sears web site you can buy a 3,600 watt gasoline powered generator for 590 dollars, 16 cents per watt of generating capacity. The problems are that fuel is expensive and the generator will probably be worn out in less than a year of continuous use. In 1980 solid state solar (photovoltaic) modules cost about $20 per watt. By 1996 they were down to $7 and in 2004 the price was $2.93 per watt.

Comparing cost per watt can be misleading. In 2005 nuclear power plants ran at a capacity factor of 90%. An average 1,000 megawatt nuclear power plant produced energy equivalent to a continuous 900 megawatts for the year. Solar cell ratings are for new cells with maximum solar flux perpendicular to the cell, at a relatively cool temperature, an ideal combination of conditions that rarely exists in real world applications. U.S. photovoltaic installations are concentrated in areas with ideal solar conditions and produce an average output equal to 15 % of rated power. If photovoltaic systems were distributed around the country in proportion to population they would deliver considerably reduced performance due to less optimum sun conditions where many people live.

What would it cost to replace the nuclear power plant with a photovoltaic plant? To achieve an average 900 MW with 15% average solar cell output and 0.95 inverter efficiency we would need an array with 6,170 MW peak output (900 MW / 0.15 / 0.95). At $2.93 per watt the array will cost $18.1 billion. In cold climates peak demand occurs in winter when days are short, sun angles are low and long periods of bad weather are common, a much bigger array would be required. We will need batteries to store excess power for night and periods of bad weather. Let’s assume the customers are willing to tolerate three blackouts a year, and an analysis of meteorological records shows that a two day supply of electricity will meet this criterion. We will need to store 63 million kilowatt hours of energy. At $136 per KWh the battery costs $8.6 Billion. We need a 5,000 MW battery charger, at 20 cents per watt that is $1 Billion. We will need a 1,000 MW inverter, at 80 cents per watt that is $800 Million. Add to this the cost of land (24,500 acres), construction, maintenance facilities, instrumentation and control systems, wiring, switchgear, administrative and engineering facilities, insurance, and the interest on the loan to build the plant, the total cost will be around $29 Billion.

Since we use 1,550 watts of electric power per person, this photovoltaic plant can supply all the electric power for 579,000 people. Each person's share of the cost would be $49,600. The interest payments on a 30 year loan at a 7% rate, is $4,000 per year per person. The battery has to be replaced every 6 to 10 years. It weighs 3.3 Billion pounds, mostly toxic lead and sulfuric acid. Each persons share weighs 5,790 pounds. Assuming a 25% discount for the recycled lead and the maximum 10 year life, the recurring cost will be $6.5 Billion, $11,200 per person, adding $808 per year to the interest payment. Add to that, about $500 per year for operating expenses, maintenance, depreciation, profit, taxes, insurance, etc. It adds up to $5,300 per person per year, $390 per mWh.

Obviously no one will build a solar power plant like the one described above. The recurring battery replacement cost alone far exceeds the cost of a nuclear power plant that will run nearly continuously at max rated power, rain or shine, wind or calm, and last 40 to 60 years, whereas the solar cells will probably have to be replaced in 25-30 years.

In contrast to the above design there is an appealing grass roots approach to solar energy production that attracts a loyal following. This popular vision for converting solar energy is a distributed system of small installations on each house, factory, shopping mall, school etc. Each system would have its own battery and associated equipment. In essence the power plant is broken down into small pieces and distributed across the community. The problem is, this does nothing to reduce the cost of the plant. Each building will need its own system design. Each heavy cable in the large solar plant will be replaced by dozens of smaller wires that must be installed and terminated. Each large inverter, battery and charger in the solar plant will be replaced by several smaller units that will require more money and time to buy, install and maintain. The cost to build and maintain a distributed plant sized to replace a nuclear plant will be much higher than the above estimate due to the many more hours required to design, manufacture, install and maintain 250,000 customized systems.

WIND

In 1935 the U.S. government passed the Rural Electrification Act (REA). It took money from people living in cities and used it to build uneconomically justifiable power lines to serve farmers in rural areas. A condition for accepting this subsidy was that farmers had to give up their alternate energy sources such as windmills.

You might think that the REA would be dismantled once the country was wired, but it is still going strong. Diehard supporters will tell you that without REA, farm children today would have to play computer games by candlelight.

Actually farmers are among the most productive and talented people in the country, also on average, among the wealthiest. A successful farmer is a good businessman, accountant, biologist, mechanic, heavy equipment operator, gambler and meteorologist. Left to their own devices each farmer would have found the best solution for his or her circumstances. Farmers would have developed windmills in windy areas, natural gas generators in areas with gas, water turbines in areas with running water etc. The United States would now have mature industries in each of these fields, more importantly, Americans would have a more realistic attitude about their capabilities.

Fortunately, other countries have taken a different viewpoint, notably the Netherlands, a country of 16.3 million people, about twice the area of New Jersey, has had a strong positive outlook on wind power for generations. Drive around the Netherlands and you will see windmills all over the place.

After more than three hundred years of evolution, state of the art windmills use advanced materials and engineering, and perform fairly close to theoretical maximum efficiency. Windmills will continue to improve in small increments as materials and technology evolve, but there is no room left for major breakthroughs, in sharp contrast to our primitive first generation nuclear power plants that extract less than 1% of the energy in the uranium mined to fuel them.

In 2005, 93% of Dutch electric power was generated by burning fossil fuel. Their 1,709 windmills produced 1.7%. Their single, small, primitive, 33 year old, first generation nuclear power plant produced 3.2%, nearly twice that of all their windmills combined. Their nuclear plant has produced $27 billion worth of electricity, and they are negotiating to extend its life to 60 years, about twice the life of windmills and solar cells.

The Dutch consume an average of 824 watts of electric power per person. The 1.7% generated by wind amounts to 14.3 watts per person. If the U.S. expands wind power to the same level as the Netherlands our 14.3 watts will amount to 0.92% of our electric power. It could be used to displace 41.2 watts of primary coal energy, 0.37 % of the 11,300 watts of primary energy consumed by the average American.

The real poster country for wind power is Denmark, a small collection of peninsulas and islands about twice the size of Massachusetts with a population of 5.4 million. Denmark has had a strong commitment to wind power for decades. In

1979 the government initiated a 30% subsidy for the cost of building windmills. In 1999 they guaranteed wind power producers 85% of retail, $90 per mWh, for all the power they could make. They imposed a tax on fossil fuel to provide an additional $38 per mWh to wind producers. Compare that with the cost to make electricity in the U.S. in 1999; hydroelectric $7 per mWh, coal $20 per mWh, natural gas turbine $39 per mWh, nuclear $19 per mWh.

If Denmark had issued these same huge incentives to nuclear power, they would be overflowing with generating capacity.

Denmark is to wind power what the perfect storm was to boating accidents. It has the, ideal combination of optimum factors.

- A population committed to wind power
- A government committed to wind power
- High energy prices
- Low energy consumption
- Large price guarantees
- Large government subsidies
- A small country with short transmission distances, each person lives within 50 miles of a shoreline
- Surrounding water creates mild winters and summers
- Excellent wind conditions for land and sea based wind farms year-round
- Mature in country wind turbine industry

In 2005 wind accounted for 18.5 % of the 751 watts per person Denmark used, 139 watts of wind power per person.

The United States lacks the ideal conditions of Denmark, but if we could somehow match their 139 watts per capita, it would be enough to displace 402 watts of primary coal energy, only 3.6% of the 11,300 watts that supports our lifestyle.

Denmark’s 139 watts of wind power per person is several times higher than any other country, but it pales in comparison to the 301 watts per person we currently get from our primitive first generation nuclear power plants, displacing 869 watts of primary coal energy per person. If Denmark matched our 300 watts per person of nuclear power they could save 52% of the fossil fuel they burn to generate electricity.

Calculate the size and price for a wind farm to replace a Billion watt nuclear power plant. Remember,

- Best wind conditions are in the spring and fall when utility loads are lowest
- Worst wind conditions are mid summer, when utility loads peak
- The best wind locations are in the plains states where population density is lowest. Most Americans live within a few hundred miles of a coast
- Wind power is very noisy in terms of sound, voltage and frequency
- Periods without substantial wind are often longer than two days
- Windmills are responsible for a large number of bird deaths
- Windmills rely on large conventionally powered grids for stability
- High winds require shutting down the wind farm to prevent damage
- If wind farms ever provide a substantial fraction of our power they will require expensive, energy consuming, power conditioning equipment and batteries, not included in today's cost estimates.

Conventional power plants are rated in megawatts. Wind and solar energy sources should be rated in terms of their average annual output, in megawatts. They are usually rated at peak output, four to seven times the average, or they are rated in terms of the number of homes they might supply, why is that?

In 2005 there were 296 million Americans living in 124 million homes, an average of 2.38 people per home. The average home uses 1,290 watts, 540 watts per person, 34% of the 1550 watts each person consumes. By quoting the equivalent number of homes an alternative energy facility might supply, they give the impression that the number of lives supported is three times the actual number.

You buy one third of the electricity that supports your life directly from the utility company, who pays for the rest? You do, every time you spend money. When you buy a loaf of bread you help pay the electric bills of the grocery, the baker, the farmer who grew the wheat and everybody else who contributed to creating that bread.

If you install enough solar and wind power equipment on your house to go off the grid, you replace one third of your electricity, 13% of all the energy that supports your life. You still have to pay the same as everybody else for the remaining 87%, which comes largely from fossil fuel. The cost of energy has a major impact on our cost of living and the quality of our lives.

Consider the following statements.

1 On average, this wind (or solar) farm produces as much electricity as is consumed by 1,000 homes.

2 This wind farm can supply electricity for 1000 homes if it is connected to a large grid with enough conventional power plant capacity to meet peak demand and provide free battery and power conditioning service to the wind farm.

3 699 of these wind farms connected to a huge grid with enough conventional power plant capacity to meet peak demand and provide free battery and power conditioning service, could replace one nuclear power plant.

Which statement is most impressive, they all describe the same wind farm. The point is that conventional power plants can run at 100% of rated power for months to years at a time, whereas wind and solar equipment typically averages 15% to 25% of rated capacity. Comparing data plate ratings, “installed capacity”, is misleading.

Utilities using wind or solar power must have enough excess conventional capacity on line to maintain voltage during a lull in the wind or when wind exceeds the design limit of the wind farm causing it to shut down, or when a cloud drifts over the solar plant. That excess capacity is called “spinning reserve”, and the fuel consumed to maintain spinning reserve is not being used in the most efficient way. The excess fuel burned to maintain spinning reserve and provide power conditioning for wind and solar plants should be charged to those plants, along with the resulting CO2. Wind and solar power plants are not totally renewable, or emission free.

Wind and solar power supporters claim these plants are close to break even cost at $60 to $100 per mWh, but building windmill and solar plants does not allow utility companies to dismantle any conventional generating capacity. The only savings is the fuel not consumed when the wind blows or the sun shines. Fuel costs in 2004 were $18 per mWh for coal, $45 per mWh for natural gas turbines, $4.60 per mWh for nuclear plants, zero for hydro plants. Your utilities ratio of these sources determines the real break even cost for which solar and wind power would have to sell to avoid increasing your electric bill or taxes. The average fuel cost for the United States in 2004 was $20.10 cents per mWh, the real break even price for wind and solar.

The three countries with the highest percentage of wind generated electricity are, Denmark 18.5 %, Germany 4.3%, and Netherlands 1.7%.

The three countries with the highest electricity prices in the world in 2005 were, Denmark $297 per mWh, Germany $229 per mWh, and Netherlands $236 per mWh. That same year U.S. residents paid $94 per mWh. France gets about 80% of its electricity from nuclear power; their cost was $141 per mWh.

I do not hold France up as an example for us to follow, they run their nuclear power industry like the US runs the post office. The fact that their big government program can produce so much energy at a somewhat affordable price hints at the enormous potential nuclear has in a healthy competitive arena.

Denmark has ideal conditions for windmills and is decades ahead of the U.S. in developing wind power. The lesson of Denmark is that we can lavish huge subsidies on wind and solar in their embryonic stage with modest impact on our economy, but as they grow the negative impact of the subsidies grows with them.

Imagine that for the last 20 years the U.S. government gave away windmills and solar cells free to anybody who wanted them. How different would things be today? Not much really, because the recurring cost of batteries to store electric power is far higher than the cost of generating it as needed by conventional means.

The biggest problem with wind and solar is that they are presented as unlimited sources of clean safe free energy. That message enables the public to avoid the decision to move ahead with nuclear power, thereby deepening our dependence on fossil fuel.

ETHANOL

To grow and process the corn for one gallon of ethanol takes 3,300 gallons of fresh water. Some of that water comes from underground aquifers that are being depleted. To fill a 20 gallon gas tank with E-85 (85% ethanol) requires 17 gallons of ethanol, the production of which consumed 56,700 gallons of water, 472,000 pounds of water.

Growing corn requires large quantities of nitrogen fertilizer which is made from natural gas, a non renewable resource. Nitrogen fertilizer imports have increased from 5% in 1991 to 50% in 2005.

Growing corn requires large quantities of potash fertilizer, a mineral deposit that is non renewable. Potash imports have increased to 90% of our consumption.

Growing corn requires large amounts of phosphate and lime, non renewable mineral deposits.

Growing corn requires pesticides and herbicides made from non renewable petroleum.

Growing and processing corn into ethanol consumes large amounts of fossil energy in the form of diesel fuel, gasoline, liquefied petroleum gas, natural gas and electricity made in large part from fossil fuel.

New ethanol plants are being designed to run on coal to avoid the high cost of natural gas.

The amount of fossil energy consumed per gallon of ethanol produced varies depending on assumptions and regional conditions. On average fossil energy consumed is about equal to the energy content of the ethanol.

The United States has lost about one third of its agricultural top soil in the last 200 years. The rate of top soil erosion is at least 6 times the rate that natural processes can replace it.

Streams and rivers are fouled by farm runoff containing fertilizer, insecticide, herbicide and top soil. Cost estimates for bio fuel do not include factors for pollution and erosion.

Humans have been consuming about 150 watts of bio fuel per person for over 200,000 years. Ironically the production of food in the United States consumes about seven times more fossil energy than the solar energy contained in the food.

Conclusions

Ethanol production is a non renewable, non sustainable industrial process. The numbers for bio diesel, switch grass, sugar cane, woodchips etc. are somewhat different, but the general conclusions remain the same.

If all of our agricultural assets were converted to energy production, leaving us with no food, it would replace only a modest fraction of the 11,300 watts we consume, even assuming a large improvement in agricultural energy efficiency.

The world’s food production system will be worn out in a very short span of geologic time. Trying to extract more energy from agricultural will accelerate that process with very little short term gain and great long term loss to future generations. This strategy is illogical and unethical.

Nuclear power had a honeymoon with the American people in its early days. The most enduring artifact of that honeymoon is the infamous phrase “Nuclear power will be too cheap to meter.” Ironically the cost of metering has dropped more than the cost of nuclear power. Wind, solar and ethanol are in their honeymoon phase now, and will remain so as long as they produce a small fraction of our energy, which is to say, the foreseeable future.

GLOBAL WARMING

Earth has a diameter of 7,930 miles. The concentration of solar power at our distance from the sun is 1,147 watts per square yard. Calculating the area of earth’s disk and multiplying by the solar flux gives the power intercepted by the earth, 175,500,000,000,000,000 watts. Dividing by earth’s population, 6.5 billion, reveals that earth receives 27 million watts of solar power for each human on the planet. That’s not just at high noon on a clear day, that’s 24 hours a day every day. Some of that energy is reflected back into space by clouds and the earth’s surface while the rest is absorbed and later reradiated into space along with a relatively small amount of heat emerging from earth’s interior.

Over the suns 11 year cycle its output varies about 0.1%, 27,000 watts per human. Over the long term it has probably varied much more. The 11,300 watts that support our lives equals 0.04% of our share of solar incidence. With such enormous energy flows going all the time, how can our puny 11,300 watts change the earth’s temperature significantly? It cannot. The concern is that some of the gasses we are releasing into the atmosphere, including carbon dioxide, are restricting the reradiation of energy into space. A net 1% increase in the retention of solar flux would be an additional 270,000 watts of heat per person.

The point is that every human on the planet can enjoy a lifestyle more energy intensive than our own as long as we do it in a way that does not interfere with the natural energy balance of the earth. Fission is the only process available that can supply sufficient power to eliminate most combustion of fossil resources, and meet the world’s energy needs at an affordable price.

If we continue on our present course what will the consequences be? The worst case theory is that the Midwest will become a dustbowl again, lakes and rivers will dry up, the U.S. will not be able to feed itself, tropical diseases will move north, West Nile virus is just the tip of the iceberg. The ice caps will melt, coastal cities and shorelines will be inundated, property losses will be huge. The country will be battered by frequent high energy storms. Around the world millions of people now living in poverty on coastal lowlands will die because they lack the resources to start a new life elsewhere.

At the other end of the spectrum, global warming may result in a collection of mild climatic changes around the world, with winners and losers. The winners will enjoy a better lifestyle and the losers will move or make adjustments. High CO2 concentrations and warmer temperatures in higher latitudes may result in an overall increase in world food production.

In the past, earth has proven to be more robust than people thought. There may be climatic feedback control mechanisms that will mitigate the effects of the vast quantities of CO2 created by our current energy systems. But what about those pesky ice ages? If earths mitigating mechanisms are so great why didn't they prevent the ice ages? I don't know, more importantly, nobody knows for sure, there are no experts in climatology, only students of climatology.

Today we are running a vast uncontrolled worldwide experiment in greenhouse gas emissions that might have horrific consequences for hundreds of millions, even billions of people. Nuclear power is the only proven technology available with the potential to end this experiment.

NUCLEAR WASTE

Some people say they cannot support nuclear power until we have a permanent solution for nuclear waste. The most important thing to remember about nuclear waste is this.

The main reason we have not implemented a permanent solution for nuclear waste is the fact that we do not need one.

Suppose we built a large coal fired power plant. We will need two or three train loads of coal each week to keep it running. Coal is not pure carbon, it contains many other materials including rock, mercury, sulfur, uranium, thorium, cadmium, arsenic, radium, iron, and lead. Ironically, if the trace quantities of radioactive uranium and thorium were converted to fission products, they would release several times more heat than burning the coal. Some hazardous materials go up the stack into the atmosphere and the rest ends up in several truckloads of ash and dust each hour. If we don't have a place to dispose of this waste our plant will soon be buried.

A nuclear plant can store 30 years of spent fuel in a medium sized swimming pool, so there is no pressing need for a permanent disposal site. The Department of

Energy estimates that there will be about 292,000 spent fuel assemblies by year 2040, containing about 557 million feet of fuel rods. Fuel rods are less than one half inch in diameter consisting of small non flammable non explosive ceramic pellets inside sealed metal tubes. Each Americans share in 2040 will be 18 inches long, accumulated over 70+ years, about one fourth the volume of a Chap Stick cap each year.

From a technical point of view there are numerous solutions that would work, but most politicians want to keep their job, and the key to that is to be well known while offending the smallest number of people. Any decision they make on nuclear waste will offend a substantial number of people, so the option to do nothing is preferred. Ironically they may have taken the best course for now.

BACKGROUND

Uranium

The earths crust and oceans contain atoms of uranium, a slightly radioactive metal 1.64 times the density of lead. Natural uranium consists primarily of two kinds of atoms, uranium 235 and uranium 238. Both have 92 protons in their nucleus, a small heavy collection of particles at the center of the atom, and 92 electrons forming a large cloud of negative charge surrounding the nucleus. Chemical reactions involve the trading or sharing of electrons, and since both kinds of uranium have the same electron structure, the two kinds of uranium cannot be separated by conventional chemical means.

When a uranium 235 nucleus absorbs a neutron it will most likely split into two large fragments releasing and an enormous amount of energy along with two or three neutrons and some radiation. The process is called fission, the large pieces are called fission products, and they are usually radioactive. If a sufficient concentration of uranium 235 atoms is present some neutrons released by fission will be absorbed by other uranium 235 nuclei, they, in turn, will likely fission, resulting in a self sustaining chain reaction.

Uranium 238 atoms will not support a chain reaction. When they absorb a neutron they will most likely go through a transition to become Plutonium 239, which can support a chain reaction.

Suppose we extract 6,000 lb. of natural uranium from the earth, enough to make a solid metal sphere 25.5 in. in diameter. It consists of 43 pounds of uranium 235, and 5,957 lb. of uranium 238. The concentration of uranium 235 atoms is too low to sustain a chain reaction because most neutrons are likely to be absorbed by uranium 238 atoms without causing fission. If we extract 4,766 lb. of uranium 238, the concentration of uranium 235 in the remaining 1,234 lb. will be 3.5%, suitable for use as reactor fuel. If we extract 5,954 lb. of uranium 238, we will have left 45 lb. of 95% uranium 235, sufficient to make a bomb.

The extracted material is called depleted uranium. Depleted uranium has commercial uses that take advantage of its high density including aircraft control counterweights, inertial weights in rotorcraft, armor piercing bullets, and radiation shielding. It can also be used to fuel advanced reactors.

The remaining product is called enriched uranium because its uranium 235 concentration is higher than that of natural uranium.

I once thought that radioactive atoms were like little radio transmitters spewing out a constant stream of radiation. I was completely wrong. A better analogy is to think of radioactive atoms as tiny sub nano firecrackers. Radioactive atoms emit no radiation at all until they reach end of life, then they explode in a spray of electromagnetic energy and/or particles. The process is called radioactive decay.

Each kind of radioactive atom has a characteristic rate of decay often described by the time required for one half of the atoms to decay (half life). After two half lives one fourth of the original atoms remain. After 10 half lives less then one in a thousand of the original atoms remain, after 20 half lives less then one in a million of the original radioactive atoms remain.

Nearly all of the uranium atoms on earth now were here when earth formed 4,700 million years ago, and none of them have produced any radiation. Only those uranium atoms that have decayed have produced radiation. When a uranium 238 atom decays it ejects an alpha particle (a helium nucleus consisting of two neutrons and two protons) and some gamma rays (electromagnetic energy similar to light but with much higher energy) with a release of 4.3 million electron volts (mev) of energy.

An electron volt (eV) is a small unit of energy useful for describing chemical and nuclear reactions. Chemical reactions, like combustion, involve a few eV per atom. The electrons illuminating a TV picture tube each have about 15,000 eV. Medical X rays have energies in the thousands of electron volts. Nuclear radiations have energies from thousands to millions of eV. Fission releases over 200 mev. Radiation from space can range over a billion eV.

The nucleus remaining after the uranium 238 decay is a thorium 234 nucleus. The thorium 234 nucleus is radioactive with a half life of 24 days. When it reaches end of life it will decay by ejecting a beta particle (an electron) thereby increasing the charge of the nucleus by one, creating a Protactinium 234 atom which is also radioactive.

The complete natural decay of one uranium 238 atom to stable lead 206 involves 14 decay events that release 8 alpha particles, 6 beta particles, and numerous gamma rays, with a total energy release of about 60 mev. Two of the more infamous decay products in this scheme are radium, which caused the horrific death of many luminous dial painters in the early days of nuclear technology, and radon gas, possibly responsible for tens of thousands of lung cancer deaths each year in this country alone.

The natural decay of a uranium 235 atom requires 11 steps including the emission of 7 alphas, 4 betas, numerous gammas and 56 mev of energy.

Plutonium

Like uranium 235, plutonium 239 is a heavy radioactive metal that can support a neutron chain reaction. It decays by alpha emission about 29,000 times faster than uranium 235, resulting in a half life of 24,110 years. It takes about a hundred thousand years for plutonium 239 to decay to the level of uranium ore.

Alpha particles are the civil war cannonballs of the nuclear world, not much range but they can do considerable damage up close. External alpha emitters are not a serious hazard because the dead cells on the surface of our skin can stop them. The main concern is that plutonium particles might become lodged in lung tissue, bombarding unshielded cells, possibly starting a cancer.

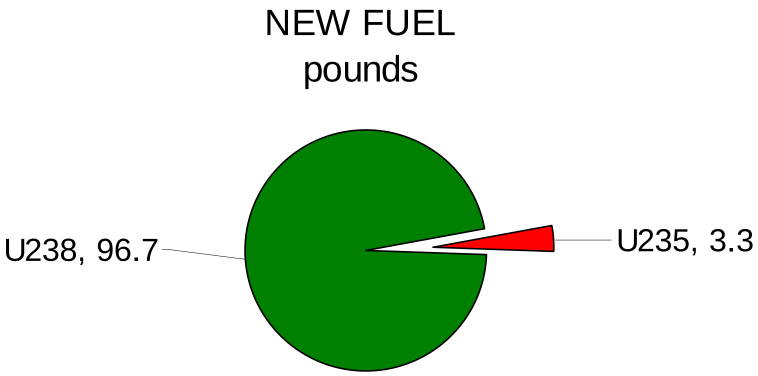
While new reactor fuel contains no plutonium, plutonium production from uranium 238 begins when the reactor starts up, and it is available for fission. Plutonium fission currently accounts for about 40% of all the power from our first generation reactors, 8% of all our electricity. Converting 13 ounces of plutonium to fission products will provide a lifetime supply of energy for one American.

We can extract the enormous amount of untapped energy in uranium 238 by converting it to plutonium 239 in advanced reactors and then into fission products.

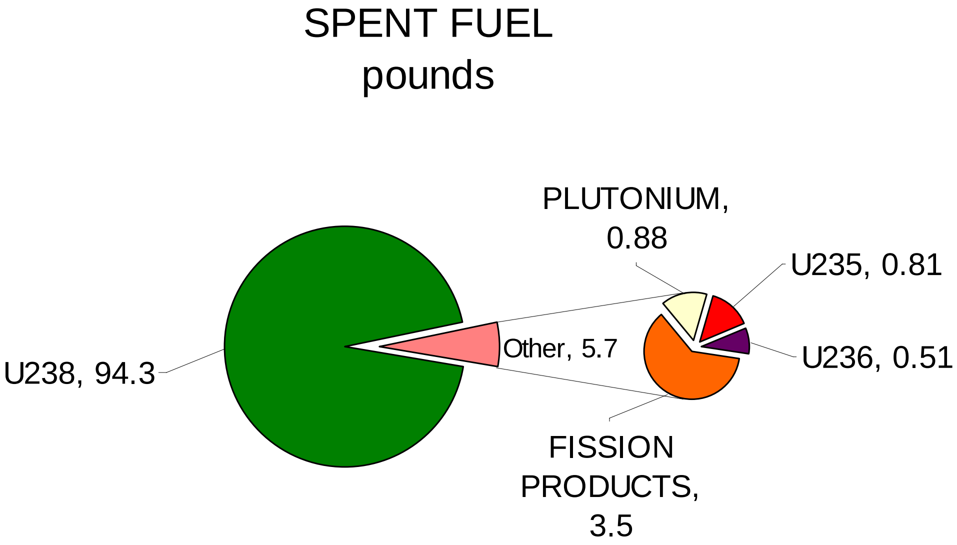
For the details on plutonium see chapter 13 of Dr. Bernard Cohen’s book at http://www.phyast.pitt.edu/~blc/book/

Fuel

Consider a 100 lb sample of reactor grade Uranium containing 96.7 lb of uranium 238 and 3.3 pounds of uranium 235.



It goes into a reactor where it is subjected to intense neutron bombardment. After three years it is removed. The composition of the spent fuel is shown below



The spent fuel has produced the equivalent of a lifetime supply of electricity for ten people, yet less than 4% of its potential energy has been extracted. Why remove fuel with so much potential energy remaining? Our primitive first generation reactors consume uranium 235 faster than they make plutonium. At some point the combined concentration of uranium 235 and plutonium 239 is not sufficient to maintain full power in the reactor, more uranium 235 must be added. To make room for new fuel the oldest third of the fuel is removed every 12 or 18 months.

Fission Products

There are at least 770 different kinds of atoms that may be produced when a uranium atom splits, most are radioactive. They generally decay to stable atoms through a chain of one to four decays.

Over 57 % of possible fission products have half lives shorter than one minute. They are subject to the possibility of decay from the moment they are created, they do not wait for reactor shutdown to begin decaying. Ten minutes after the reactor reaches full power these fission products are essentially in equilibrium, decaying as fast as they are being created. When the reactor is shutdown, over 99.9% of these fission products have decayed within 10 minutes. 82 % of possible fission products have half lives of less than one day. 6.6% have half lives between 1 day and 1 year, only 3.2% have half lives greater than 1 year, and 8% are not radioactive.

During the three years fuel spends in the reactor over 70% of the fission products decay to stable atoms, and most of the heat from those decays is used to make electricity.

Fresh fuel is made of naturally occurring materials and is slightly radioactive due to its uranium content. After three years in the intensely radioactive environment of a reactor, it is ironic to note that the discharge fuel contains fewer radioactive atoms than it did when new. That is because the number of uranium atoms consumed exceeds the number of fission product atoms that are still radioactive. Fresh spent fuel is intensely radioactive because the remaining radioactive fission products are decaying at a rate several hundred thousand times faster than the uranium atoms were. The good news is that the number of radioactive fission product atoms is dwindling rapidly on a geologic timescale. The fission products will be less radioactive than uranium ore within one half of one one-thousandth of one million years, (500 years).

Suppose we derived all our electricity from fission. An average American would be responsible for converting 5.3 ounces of uranium to nearly 5.3 ounces of fission products over an 80 year lifetime. During that life most fission products will decay to stable atoms, leaving 0.67 ounces of radioactive fission product atoms at end of life, not enough to fill a shot glass. If we derived all our energy from fission, an 80 year lifetime would convert 13 ounces of uranium into fission products and leave 1.63 ounces of radioactive atoms at end of life.

The natural decay of 13 ounces of natural uranium to stable lead produces about seven times the radiation produced by the decay of 13 ounces of fission products. In the end, the natural process leaves you with 13 ounces of lead that remain toxic forever, whereas most fission products decay to non toxic atoms.

The point is that nuclear reactors do not **make** nuclear waste, they **convert** long lived naturally occurring nuclear waste into short lived nuclear waste, while releasing enormous quantities of useful energy.

Natural Reactors

Uranium 238 has a half life of 4,468 million years, so 4,468 million years ago there were twice as many uranium 238 atoms as there are now. When the earth formed 4,700 million years ago there were 2.07 times as many uranium 238 atoms as there are now, so the 5,956 pounds of uranium 238 in our 6,000 pound sample of natural uranium, are the survivors from an original 12,350 pounds of uranium 238.

Uranium 235 has a half life of 704 million years, so when the earth formed 6.6 half lives ago there were 102 times as many uranium 235 atoms as there are now. The 43 pounds of uranium 235 in our 6,000 pound sample are the survivors from an original 4,424 pounds of uranium 235.

When earth formed, natural uranium had a uranium 235 content of 26%, over seven times more concentrated than our power reactor fuel. As recently as 1,700 million years ago, a uranium deposit at Oklo, in Gabon Africa, supported at least 17 natural reactors that operated off and on when the ore was flooded with ground water, splitting a large quantity of uranium atoms. Studies show that the plutonium and most fission products remained very close to their point of origin despite the presence of moving water and the lack of engineered barriers.

If the last chain reaction at Oklo stopped exactly 1,700 million years ago, we can say with certainty that for the last 1,699.9 million years, that site has been **less** radioactive than it would have been if those reactors had not formed. That is because without those reactors, the uranium they destroyed would still be generating radioactive decay products and toxic lead. In the same way man's nuclear power industry will leave the world less radioactive for most of its remaining life than it would have been without nuclear power.

The point is that the disposal of fission products is not a particularly new or difficult problem, though we can make it as difficult and expensive as we choose.

Recommendation

Ask a dozen experts to design a plan for the disposition of nuclear waste and you are likely to get a dozen different plans. Most likely, any of them will do the job if carefully implemented. Here is one possibility.

1 When fuel is removed from the reactor it goes into the spent fuel pool. Water is the ideal medium for fresh spent fuel because of water's excellent shielding characteristics, high heat capacity, and transparency.

2 After several years the heat rate is low. The fuel is transferred into dry cask storage, a hermetically sealed container, vacuumed to remove all trace of moisture, and then partially filled with helium, a non corrosive gas with good heat transfer properties. The cask is shielded by thick layers of concrete and steel.

3 Maintain a low level R&D program to incorporate advances in materials and technology into the development of a fully automated fuel recycling system.

4 Develop commercial applications for radioactive and non radioactive fission products.

5 As time goes by the value of the material in spent fuel increases while the cost of reprocessing decreases. When those two curves cross reprocessing becomes economically attractive and should begin.

6 Uranium and plutonium are recycled into advanced reactors, useful fission products are sold.

7 Unused waste is buried at sea.

Scientists at Woods Hole Oceanographic Institute were asked to look at ocean disposal for nuclear waste. Oceanographers spend most of their life on, in or near the sea. They love the ocean, so the idea of putting waste there was not appealing. Being good scientists they looked at the possibilities and found that the oceans contain large areas of deep dense mud ideally suited for retaining fission products. The containers will be designed to last far longer than the brief period of geologic time required for the fission products to decay to safe levels. If a container fails the mud will contain the fission products. If any fission products escape from the mud they will be quickly diluted to safe levels in the seawater which contains a huge mass of naturally occurring radioactive material, far greater than the amount produced by human activity.

Humans live on one fourth of the earth's surface. It makes sense to dispose of nuclear waste under a very small portion of the other three fourths.

The nuclear power industry contributes $1.00 per mWh to a government held fund to dispose of nuclear waste. The industry has paid in $24.8 billion, of which $6.6 billion has been spent, very inefficiently, to study a dry land repository.

CHERNOBYL AND THREE MILE ISLAND

Have you ever cringed at the sound of fingernails being dragged across a blackboard? That's the way nuclear engineers feel when they hear "Chernobyl and Three Mile Island" used in a sentence as if they were similar events.

One evening in the library at school I came across a magazine article on the then new RBMK 1000 reactor design to be built in the Soviet Union. There are many ways to split the uranium atom and it is interesting to see how teams from other countries have addressed the challenge. After a few minutes of reading, the hair on the back of my neck began to stand up. The Russians were taking two huge risks in the design of this reactor that would not be allowed in the U.S.. I asked a respected professor what he thought of the Russian technology. His response was "They are taking a big chance". Years later when reports came of a serious reactor accident in Russia it was disappointing but not a surprise.

In U.S. reactors fast moving neutrons slow down in collisions with the nuclei of water molecules, increasing the probability they will be absorbed by a uranium 235 atom and produce another fission. When water heats up or boils to steam, its density is reduced and the neutrons are not slowed as effectively, producing a negative impact on the reaction rate.

In the RBMK reactor, the slowing down function is provided by carbon atoms in the form of graphite blocks. Water runs in pipes through the core to extract heat, but is not needed to sustain the chain reaction, in fact the water has a small negative impact because some neutrons are absorbed by hydrogen nuclei in the water molecules. If the water turns to steam, water molecules are forced out of the reactor making more neutrons available to drive the chain reaction, increasing the power level. This positive feedback mechanism, called "positive void coefficient of reactivity", is not allowed in U.S. reactors. The Chernobyl designers recognized that this could cause a thermal runaway resulting in a massive steam explosion. They set limits on the operating parameters to keep the plant out of danger, however the operators at Chernobyl implemented an ill conceived experiment that put the plant at risk. When the procedure ran amuck operators should have immediately shut down the reactor, instead they pushed ahead with the test, improvising on the fly, and lost control. When they finally tried to shut it down a defect in the control rod design drove the reactor to about 100 times the design power level, a large quantity of water was converted to steam which blew the top off the reactor, dispersing about 50 tons of intensely radioactive material.

There were 28 fatalities from radiation in the first months, mostly firemen who were not warned of the high radiation and spent an extended time in the reactor building the night of the accident. The total number of fatalities at this time is under 100. Current estimates predict 4,000 – 10,000 cancer deaths from Chernobyl, in a population that will experience 150,000 cancer deaths from all other causes. Most deaths will occur more than 20 years in the future. Death toll estimates may drop as our knowledge of the effects of low level radiation improves, and as treatments for cancer improve.

U.S. power reactors are housed in a containment building consisting of miles of steel rebar as thick as a mans wrist, woven together like fabric in multiple layers three and a half to six feet thick, filled with high strength concrete. The inside surface is lined with an inner-tube of welded stainless steel plate. Such a building is very expensive and the Russians decided to save some money by installing the reactor in a conventional industrial building. If the Chernobyl reactor had a containment building appropriate for that reactor design, the release of radioactive material would have been minor. A plant with these design flaws could never have been licensed in the U.S..

No country is going to build another ship like the Titanic, using the same materials and engineering philosophy as the original. Likewise, no country will ever build another power reactor with a positive void coefficient of reactivity or a power reactor without a containment building. Even if humans use nuclear fission for several hundred years, it is likely that Chernobyl will be the worst nuclear power plant accident. To put this in perspective consider that the routine emissions from coal burning power plants kill over 20,000 people each year in the US alone and mercury from those plants damages the brains of newborn children all over the world. For details see;

http://www.cleartheair.org/dirtypower/docs/dirtyAir.pdf

If we did not have 103 reactors generating 20% of our electricity we would have 103 more fossil fuel plants, mostly coal, generating that power, taking another 4,000 to 5,000 lives each year. Every two years U.S. nuclear power plants save more lives than the Chernobyl accident is projected to take over 40 years.

China loses 6,000 coal miners each year to accidents, a drop in the bucket of health effects from burning that coal. We are getting more and more mercury cadmium and sulfur from China via the jet stream. To solve our pollution problems we need to solve the world's energy problem.

The Three Mile Island (TMI) accident began with a small leak in a key valve. The automatic protection system started pumps to replace the leaked water, however the operators lost track of what was happening inside the reactor, thought it was overfilling, and turned off the pumps. The water level dropped below the top of the fuel rods and heat from the decay of fission products destroyed the rods. When the next crew arrived for a shift change they took a fresh look at the instruments, recognized the conditions, and restarted the pumps, refilling the reactor vessel.

There are two schools of thought on the underlying cause of the accident. One idea is that instrumentation was not good enough for the operators to keep track of what was going on in the reactor. For example, a camera inside the reactor vessel would have shown the presence of steam bubbles in the cooling water long before any fuel damage occurred. Operators would have restarted the pumps, collapsing the bubbles, bringing the sequence of events to an end as a minor incident. The inside of a reactor vessel is a very harsh environment to maintain a camera, however instrumentation has improved a great deal since the accident. The other viewpoint is that training was too procedure oriented, not functionally oriented. There was plenty of information available in the control room. That, combined with a thorough understanding of how plant equipment works, and how water boils, would have prevented the accident.

The accident investigation showed that there was no danger of a hydrogen explosion in the reactor vessel and the fuel was not close to a complete melt down. Had it melted the core would have been contained and the consequences to the public would have been much the same.

The TMI accident released about 18 curies of iodine 131. A curie is a convenient measure of radioactivity. Between 1944 and 1972, the U.S. governments' plutonium production facilities at Hanford Washington released 740,000 curies of iodine, an average of 4 TMI accidents per day for 28 years. The worst day was December 2, 1949 when they conducted an experiment that intentionally released the equivalent of 500 TMI accidents without notifying the public.

The Chernobyl accident released 42 million curies of iodine 131, equivalent to 2.3 million TMIs, and it released large amounts of other fission products not released from TMI including the cesium 137 and strontium 90 that still contaminate land around Chernobyl.

Atmospheric testing of nuclear weapons at the Nevada Test Site, near Las Vegas, released 150 million curies of iodine 131 between 1952 and 1970, an average of over 1,200 TMI accidents per day for 18 years, not including the hazard from hundreds of other fission products and a very large quantity of plutonium released from the test site, not released from TMI.

Suppose Boeing built a new jumbo jet that can carry 1,000 people. We get on a flight departing Colorado Springs in a snow storm. The dyslexic pilot turns left when he should have turned right and slams into Pikes Peak. The new jet absorbs the energy of impact and all 1,000 people climb out, shaken but unhurt. How would you feel? You might be upset with the airline for sending you out with a pilot who doesn’t know left from right, and you would probably send a thank you note to Boeing for building a plane that can take so much punishment without hurting anybody. The TMI reactor was subjected to conditions way beyond its design basis and responded in a benign manner. I doubt that the folks who designed and built TMI got as many thank you notes as they deserved.

Chernobyl and TMI are very different accidents with different lessons. One lesson from TMI is that with careful conservative engineering and construction, first generation nuclear power plants can be reasonably safe. Advanced designs can be safer.

MOST IMPORTANT

The most important thing everybody should know about nuclear power is this.

We have yet to design the model T of nuclear power plants.

While the model T (1909-1927) seems crude by our standards, it was actually quite advanced compared to the first car, built by Karl Benz in 1885. Improvements included a 4 cylinder engine, spark advance, a transmission, 4 wheels with pneumatic tires, a steering wheel and many other significant innovations.

Each new technology has a life cycle. It starts with an idea, then a prototype. If the technology involves high energy and/or hazardous materials, the prototype is often the most dangerous example, but there is only one prototype, so its risk to society is low. Risk to the public is greatest when the immature technology is first deployed in large numbers.

During the early days of steam power, steam engines in England were blowing up and killing people so frequently that the government limited boiler pressure to 10 pounds per square inch. If that law were still in effect a power plant that takes two or three trainloads of coal each week would need 17 to 26 trainloads to produce the same power.

Early ships, cars, airplanes, heavy industries and medical procedures were far more dangerous than modern examples, yet previous generations embraced them, accepted the risk, and paid, sometimes with their lives, to evolve the safe technologies we take for granted now.

Today we should be designing fourth generation nuclear plants, building third generation plants, living off the energy of second generation plants and converting our first generation plants into museums. Today no two nuclear power plants are exactly alike. We have yet to build the model T of nuclear power plants. The irony is that our irrational fear of the N word has caused us to freeze nuclear power technology at its most dangerous stage of evolution for 30 years, yet it safely generates about 20% of our electricity.

THE MODEL T OF NUCLEAR POWER PLANTS

There are probably over a hundred ways to split the uranium atom. What are the odds that a submarine reactor on steroids is the best design for generating large quantities of stationary land based power?

One candidate for model T is the Floating Molten Salt Breeder Reactor (FMSBR). It uses a small quantity of thorium dissolved in a salt, a low viscosity liquid at high temperature, to support a chain reaction that heats the salt which in turn is used to generate steam to drive a turbine. There are several advantages and some disadvantages.

Advantages include

1. High thermal efficiency. Molten salt reactors can generate the high temperature high pressure steam needed for high thermal efficiency and the direct production of hydrogen using steam.

2. Molten salt does not have to be pressurized at high temperature. The reactor vessel is not a pressure vessel, so it does not need 5 inch thick walls.

3 No need to worry about a melt down accident because the fuel is always melted. Fission products do not accumulate as they do in solid fuel reactors. Volatile fission products are extracted as they are produced, they are the ones most likely to be released in an accident. Non volatile fission products are continuously filtered out in a small side stream process. Since it is the decay heat of fission products that drives the meltdown accident, their low concentration, and inherently safe design features, improve safety.

4 The reactor breeds its own fuel from thorium which is three times more abundant than uranium.

5 The cost of enriching uranium is eliminated.

6 The cost of manufacturing fuel assemblies is eliminated.

7 No plutonium production.

The primary disadvantage is that the on-line fuel processing technology to extract the non-volatile fission products has yet to be developed.

An experimental molten salt reactor was built and tested before research funding for nuclear power was cut off.

While the molten salt reactor is a long shot for model T honors one thing is certain. Whatever technology wins out, the first letter of the acronym will be F for Floating. Floating power plant technology will allow us to take advantage of the lesson taught by Henry Ford to improve productivity by using an assembly line.

Imagine that Boeing built airplanes in a swamp, outdoors, far away from any attractive place to live, using minimal tooling and equipment. Workers and equipment would be exposed to rain snow dust heat and insects. Very high salaries would be required to attract workers away from their families to work in harsh conditions. Productivity and quality would be low. The airplanes would be more expensive, less clean, less safe and less reliable than modern factory built planes. That is the way our first generation nuclear plants were built.

The floating nuclear plant production facility would consist of a canal 600 feet wide and a mile long, enclosed inside a building equipped with high quality lighting, heat, air conditioning, fire protection, communication systems, cranes and tooling, that provide a comfortable safe efficient work environment. The canal begins with a dry dock where a massive steel reinforced concrete barge is constructed. It is then floated down the canal for installation of modular equipment. Employees will have safe, reliable, permanent, high paying jobs in an attractive coastal location. The application of assembly line techniques will dramatically reduce man-hours, construction time and cost, while improving safety and quality. The completed plants will be towed to coastal or offshore sites, prepared in parallel with plant construction.

The biggest single element in the cost of conventional nuclear plants is the interest on the loan to build the plant, about 1/3 of the total cost, due to the decade or longer construction time. Floating plants will be produced initially at the rate of two per year ramping up to about six per year, eliminating most of the interest expense.

A facility to build floating nuclear power plants was actually built, for details see,

http://www.atomicinsights.com/aug96/Offshore.html

The United States has been an affluent nation for several generations. Listening to politicians talk about how unfair it is that high paying jobs are moving to other countries, one gets the impression that they think Americans have a divine right to high paying jobs, even if people in other parts of the world are qualified and willing to do the same job for much less.

The reality is that we enjoy our affluence because previous generations of Americans combined knowledge, creativity, abundant natural resources and hard work to make dramatic improvements in productivity, and to create new, highly desirable products. Now the rest of the world is catching up using the same methods. Some people are focused on protecting old jobs like making shoes and fabric. We can save some of those jobs by developing ways to produce those products using fewer hours than other countries, but the key to continued prosperity is to develop a continuous stream of new jobs, making new products that are highly desirable around the world, that can only be produced here, at least for a while. Floating nuclear power plants can be one of those products.

The United States is in a position to do for world energy what Boeing and Lockheed did for world transportation. By taking the lead in the production of floating nuclear power plants we can make clean safe inexpensive energy available all over the world. We can have the high paying jobs and control the technology. We can design the plants to be highly resistant to acts of terror and the diversion of nuclear material. We can insist that plants be subject to international inspection as a condition of sale or lease. We can sell or lease these plants at a cost that is much lower than traditional construction methods, eliminating the fig leaf of energy production to hide a nuclear weapons program.

We have wasted 30 years. If we continue to stand on the sidelines some other country, maybe Russia, China, Japan or Indonesia, will take the lead, we will have no control over key issues. Our safety and security may be compromised by the proliferation of inferior nuclear technology around the world. Will we act on this opportunity, or have we lost the will and/or the ability to lead the world in technology?

Competition is the key to evolving the technology quickly to achieve maximum safety and efficiency in the shortest time. In the past we had GE, Westinghouse, Combustion Engineering and General Atomics in competition, each with a different design. Our goal should be to revive a completive environment in the private sector. A big government program to develop a standard design would be the kiss of death, because it would freeze the technology at a low level of evolution.

RISK vs. BENEFIT

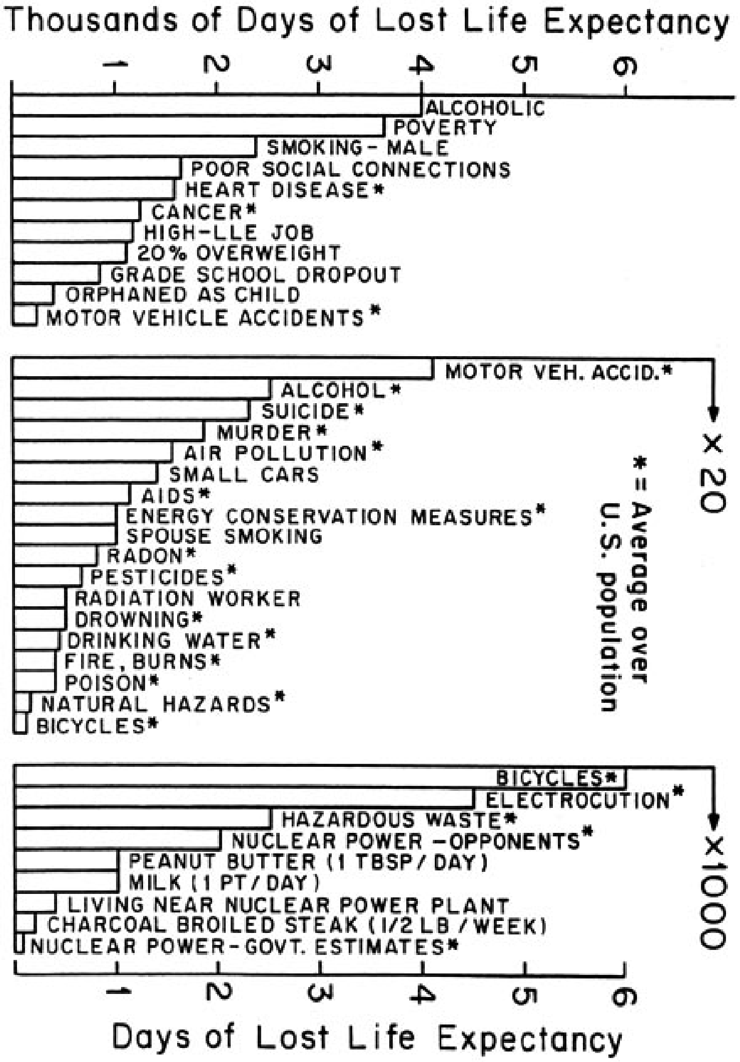
If nuclear power is such a good idea why has it stagnated for 30 years? That question can be answered on more than one level, but the most basic answer is that our education system has failed to teach us how to make logical informed choices about technology. In the absence of logic and facts we choose based on emotions, mostly fear, which often cause us to miss the best option.

The solution is to require a course in risk/benefit analysis in the high school curriculum. Students would calculate the risk, benefit and cost of the many options we have to choose from as we go through life. Once the majority of Americans are comfortable with this perspective they will require that TV, newspaper and magazine articles on technology issues include all the facts they need to make an informed choice. Here is an excerpt from a book by Dr. Bernard L. Cohen that provides a sample of issues that would be covered in such a course.

RISKS IN PERSPECTIVE

Risks are commonly stated in terms of probabilities of death at various ages, but to make them more understandable we express them as loss of life expectancy (LLE) (see Figure 1 below). (An LLE of one day does not mean that each person will die one day sooner but that the average shortening of each life is one day -- true if one person in a thousand dies 1,000 days earlier while 999 are unaffected.) The LLE for nuclear power is about one hour (0.04 day) according to most scientific estimates, or 1.5 days according to the Union of Concerned Scientists. The LLE for coal-burning pollution is about 13 days, from oil burning about 4.5 days, and from natural gas about 2.5 days. This makes the LLE from nuclear generation from 8 to 300 times less than from coal, 3 to 100 times less than from oil, and 1.7 to 60 times less than from natural gas. To put these numbers in perspective, we show in Figure 1 the LLE from some other common risks we face.[17] Notice that even energy conservation bears risks: radon trapped by tighter housing construction; smaller, riskier cars; more crimes and accidents in reduced lighting; etc. Any one of these items makes energy conservation much more risky than nuclear power.

Figure 1: Comparison of risks. Length of bar is LLE. Asterisk denotes average risk over the total US population; others refer to risks of those exposed or participating. The ordinate scale is shown at top. The length of the bars are multiplied by 20 in the center section and by 1,000 in the bottom section. The first bar in each section reproduces the last bar in the previous section, showing the effect of the scale change.



Far more important is the danger that over-zealous conservation may reduce our wealth. In the United States, well-to-do people live ten years longer than poor people. Producing wealth requires a lot of energy. Therefore, if conserving energy reduces wealth, the ultimate health risks from conservation would dwarf the few hours LLE from nuclear power.

Another way to put the risks of nuclear energy into perspective is to show what other risks they are equivalent to. To make this non-controversial, we use both the PRA and Union of Concerned Scientists estimates for risks of nuclear power, the latter in parentheses. The risks from having all electricity in the United States generated by nuclear power are equivalent to the following risks:

1. a regular smoker smoking one extra cigarette every 15 years (3 months);
2. an overweight person increasing his weight by 0.012 ounce (0.8 ounce);

For details on the risks and benefits of nuclear power including sample calculations see Dr. Cohen's book at

http://www.phyast.pitt.edu/~blc/book/

DISCUSSION

Spaceship earth is less than 8,000 miles in diameter and covered largely by water. With the appropriate use of technology it could be a near paradise for 500 million to 1 billion people, without putting too much stress on the other species that share this planet, but we are over 6 billion, headed for 10 billion, with two thirds living in poverty. Earth can never be paradise for 10 billion people, unless your idea of paradise is sitting in an air conditioned high rise apartment building, surfing the internet, eating insect pate. It will take a massive infusion of technology to provide a comfortable life for all those people while preserving whatever is left of the environment.

Some Americans think that energy is intrinsically harmful, that energy should be produced by politically correct boutique industries, and it should be consumed in the smallest possible increments. That's what most Americans will believe in the future because that is what children are being taught in school today.

Many species have some mechanism for self defense, long sharp teeth, claws, great speed, keen eyesight or a hard outer shell. We humans have only our brain. A human brain with inaccurate or incomplete information is a dangerous thing. The best that we can do for our children is to teach them the truth, the whole truth, and nothing but the truth.

The truth about energy is that the world is awash with huge flows of energy. Every human can enjoy an energy intensive lifestyle as long as we are careful not to disrupt nature's energy balance.

The principles of Economics 101 will prevail, in the future energy will be limited and expensive or abundant and cheap. Limited and cheap is not an option.

The environmentally correct vision of a renewable energy future requires the assumption that huge improvements will soon be made in the cost effectiveness of solar, wind, battery, fuel cell and other alternative energy technologies. These technologies have existed from several decades to hundreds of years, and very bright people have been trying to improve on them the whole time. They improved slowly, but have resisted all attempts to make dramatic cost reductions. What is the probability that major breakthroughs will improve the performance of these technologies by 10 to 100 fold in the next few years? Are you willing to bet the future of your grandchildren that several improbable breakthroughs will be made just in the nick of time?

High performance fuel cell technology is essential for the renewable option. It would also be a nice complement to nuclear power, but it is not necessary. If fuel cells do not work out, nuclear generated hydrogen can be cheap and abundant enough to run our transportation system using conventional internal combustion or sterling engines. That would raise the lifetime uranium requirement from 0.9 lb to 1.5 lb at a lifetime cost of $25.50, about 32 cents per year.

Some people say we should have an energy research and development program like the Manhattan Project that developed the first atomic bomb. I agree, but what does that really mean?

The Manhattan Project was not a bunch of aging lawyer/politicians in Washington DC sitting around a table saying "Let's put a secret laboratory in Los Alamos NM, a plutonium production reactor in Hanford WA, and a uranium enrichment plant in Oak Ridge TN. Then let's build a uranium 235 bomb using a sawed off cannon, and another bomb that uses shaped charges to compress a sphere of plutonium 239 metal to high density."

The real Manhattan Project was much simpler. The president selected General Leslie Groves, a brilliant man who built the Pentagon in 16 months, to be project manager. The president gave General Groves two things.

1. The best engineers and scientists in the free world

2 Unlimited check writing privileges on the US treasury

The team brainstormed every possible way to create the materials and technology for a weapon, then they explored each idea with analysis and experimentation. Most ideas were less than optimum or complete failures. They kept the best ideas and developed two working designs in three years.

After WW II a similar approach was taken at Edwards Air Force base to evolve aircraft technology. In two decades they went from piston powered propeller planes to supersonic jets to a hypersonic space plane. Many streets at Edwards are named after pilots who lost their lives pursuing that technology.

The point is that the road of progress is paved with stones of failure. We must develop new technology in order to advance our civilization in ways that will save many lives and improve the quality of life for future generations. The growing state of fear in the United States has paralyzed our ability to develop the new technologies we need to lead the world in this century.

The Department of Energy predicts that our dependence on fossil fuel will continue as far as they can see, from 86.0% fossil in 2004, to 86.3% fossil in 2030. CO2 output will increase from 5.9 billion metric tons now to 8.1 billion metric tons in 2030. By then we will be net importers of all types of fossil fuel including coal.

The U.S. Gross Domestic Product for 2006 will be $13.6 trillion, $45,300 per person. We will spend an average of $3,800 on energy for each person in the U.S. The Department of Energy’s Research & Development budget for non fossil energy sources (nuclear, hydrogen, solar, wind, hydroelectric, geothermal and biomass) is less than $0.7 billion, $2.07 per American.

We should be investing an amount equal to at least 5% of our energy budget on R&D for non fossil energy sources. That would be $191 per person, $57 billion per year. With this level of investment we can push every technology hard. The best technologies, whatever they are, will emerge as leaders in the shortest possible time. The new technologies will tend to suppress rising energy costs. I believe the savings could surpass the annual R&D cost within 15 – 20 years, and save over $1,000 per year per person within 30 years, not to mention a large improvement in the environment and quality of life with this approach.

Why push every technology if nuclear is the way to go?

1 I might be wrong.

2 This is a strategy any thoughtful person can support. If your preferred technology is best it will emerge as the leader in the shortest possible time.

3 Given the enormous stakes, the money spent on unsuccessful technology is cheap insurance to guarantee that the best technology gets developed as fast as possible.

4 R&D projects sometimes develop useful technology outside their original scope.

Over 20 billion people will be born this century, and several hundred million children will have abbreviated lives of enormous suffering if we do not solve the world's energy problem. It is the best form of foreign aid we can provide to the world.

Between 1970 and 1990 we completed an average of five nuclear power plants per year using labor intensive onsite construction techniques. We should triple that rate by building three facilities to mass produce floating nuclear power plants using second generation reactor designs that take advantage of our forty years of experience with first generation reactors. We can use the new production of cheap power to convert stationary consumers of natural gas and oil to nuclear, freeing up those resources for use in transportation, until hydrogen or battery technology becomes practical and affordable. We should also use nuclear power to process domestic sources of fossil fuel to increase production efficiency and lower emissions. This is the quickest way for the United States to become energy independent and dramatically reduce emissions.

There are many ways to split uranium and thorium atoms. We should be building experimental demonstration breeder reactors of each type to determine which designs have the most promise for large scale commercial power in the long run.

Where should this money come from? I have no idea, that is a political question, not an engineering question. I do know that the wars in Afghanistan and Iraq were not on any budget before they began, yet we are spending $120 billion in 2006 on them, $400 per person. There have been wars there for centuries without much effect, and I suspect the latest wars will merit a small paragraph in the history books 500 years from now. The transition to non fossil energy sources will be a major turning point in human history. We should pay whatever is needed to make it happen as quickly, efficiently and safely as possible. We should tell our politicians that support of this strategy is a condition for receiving our vote.

Our energy policy must include a rock solid foundation of proven technology that can meet our needs. Only fission satisfies that requirement. Using sea water uranium, first and second generation reactors can meet the world's energy needs for a few hundred years, advanced reactors can stretch that to over 30,000 years. If breakthroughs in other technologies come, things will only get better, if they do not, we will be OK.

The energy systems proposed here can be created by blending technology that has been available for decades. No breakthroughs are required to insure an abundant supply of clean, safe, inexpensive energy for thousands of years.

Fission, like fire, is not intrinsically good or evil. They are both natural processes that can be used for good or evil purposes. Fission is the only process at hand that can produce the huge amounts of clean safe and cheap energy we are going to need to provide a comfortable life for 10 billion people, while preserving fossil resources for the non energy applications of future generations.

Opinions will vary widely but facts are facts. If any of these facts are wrong please send a source of the correct information and I will make changes.

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