Peak Oil

What's It Going to Be Like on the Downside of the Curve?

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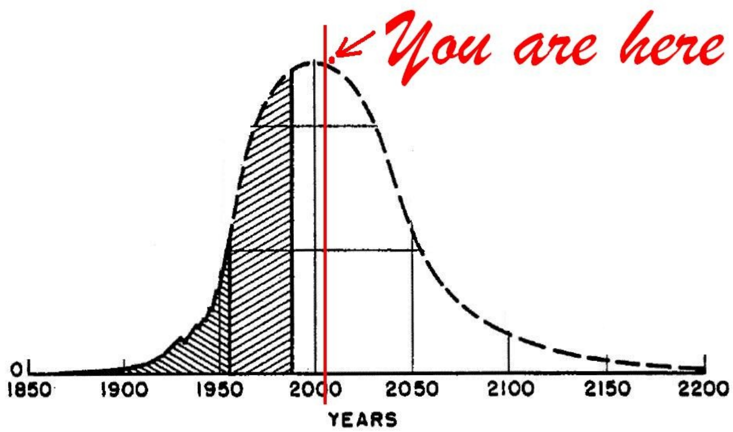

In 1956, M. King Hubbert, a prominent geologist, predicted that US oil production would peak around 1970. It was a shock to many that Dr. Hubbert would make this prediction, and it was even more of a shock when he turned out to be correct.[1]

More importantly, Hubbert predicted that oil production worldwide would peak around 2000. It appears the actual peak may have happened already.[2] We are moving into uncharted territory. All of the history of industrial society took place on the upside of the curve – dramatically increasing oil production for 100 years. The US is even worse prepared for this event than the 1970 peak.

In part, this article proposes conversion to a US economy powered carbon-free. I also make a proposal for how to get to a more detailed plan for this conversion, starting with California.

On one level, the answer is simple: Oil is going away, so we need to find other forms of energy to replace the oil. That is true enough, but the devil is in the details. It is going to be very challenging. Oil is to energy as gold is to metal. Oil has several special properties that make it almost irreplaceable.

Some commentators will say there is nothing to worry about because as oil becomes more scarce, the price will reach a level where alternative forms will become attractive. Those alternative forms will fill in as needed. *The market will take care of the problem automatically,* they say. I agree the market will force some adjustments. But how good are we at making gold from tin? The world will survive. But will I survive? Will you survive? Will the US survive? How will others around the world fare?

1 The US now produces about half as much oil as it did at the 1970 peak – also shown in Hubbert's curve. See http://www.hubbertpeak.com/hubbert/1956/1956.pdf Hubbert underestimated how much oil the US had, but it made little difference as to the timing of the peak. He also underestimated how much oil the world had, which makes the curve bigger but does not change the timing of the production peak very much.

2 World oil production reached a plateau in 2004, while the highest number of barrels produced in a year so far was in 2005. See http://www.eia.doe.gov/aer/txt/ptb1105.html If 2005 was not the precise peak, it makes little difference. For all practical purposes, peak oil has happened or is happening now.

What do the Economists Say About it?

Economists are notorious for weaving explanations for something that already happened. They are not so good at explaining what *will* happen. This is partly due to the fact that they don't understand the role of energy in the economy.

Case in point: Show me one economist who understood the implications of Hubbert's curve regarding the US oil production peak. You'd think you could find something – maybe by 1960 – like this somewhere:

> *I have reviewed the figures put forth by Dr. Hubbert and I concur that domestic oil production is likely to peak around 1970 as predicted. If we are going to avoid an energy shortfall, we need to identify and develop sources from which we are going to make up the difference. This will require substantial capital and time. We need to act now. Failure to do so could be very bad for the US economy. Etc.. etc...*

If economists understood Hubbert's presentation, this should have been an easy call.[3] Better yet, a team of prominent economists should have explained this to decision-makers in the government so that appropriate policies could have been developed. So, where were they? An explanation of this sometime around 1960-65 would have been very valuable. Explanations after the fact were not very useful. In the 1970s, we had long gas lines, an angry public, ten percent unemployment, ten percent inflation and recession. Oil went from around $3 per barrel in 1970 to about $35 in 1980.

If an economist's explanation to the 1970s is, essentially, "the market corrected itself," and their explanation of what to do now is "let the market decide," what good is the economist?

Unemployment and inflation like we had in the 1970s meant life savings wiped out for many; shattered lives; shattered careers; human misery and suffering. People don't really want to offer themselves as grist for some market correction. We need to formulate policy to mitigate some of the negative impacts.

Energy Value Theory

Not many people get Peak Oil. There are a few in Washington DC that are vocal about it, but they are met stone-faced.[4] Let's not create a panic, okay?

If you don't understand it yet, you should. I hope you will. I also hope you will find this information disturbing. This issue needs urgent widespread attention – more akin to a war effort than your average stimulus program.

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3 Nicholas Georgescu-Roegen, a Professor of Statistics, published *The Entropy Law and the Economic Process* in 1971. Georgescu-Roegen was also known as an economist and certainly understood peak oil. See http://www.amazon.com/Entropy-Law-Economic-Process/dp/1583486003/ref=ntt_at_ep_dpt_1 His student, Herman E. Daly is also an economist who understands the role of energy in the economy, but they are not mainstream.

4 Roscoe Bartlett, US Representative (R-Maryland), and Tom Udall (Dem in the House, now Senator from New Mexico) established the Congressional Peak Oil Caucus. Have you heard much about the Congressional Peak Oil Caucus? See http://bartlett.house.gov/Issues/Issue/?IssueID=2057 Also, they say, "A crash program will need the total participation of the American public like we had with WWII Victory Gardens, the technological focus of the Apollo Moon program and the urgency of the Manhattan project." http://energybulletin.net/node/22396

Before I explain energy value theory, I want to point out a couple of general things about energy.

- ***Energy means the ability to do work.***
- ***Machines don't do work: they are agents for the energy, which does the work.***

Energy value theory is the basis for an alternative form of economics. I first started writing, reading, and thinking about this 35 years ago.[5] I learned that Frederick Soddy, a famous scientist, expressed this view in the early 20th century. Many others have had this idea as well, and awareness of it is growing.

A lot of my readers already understand this and won't find much news here. They read this because they like reading about Peak Oil and energy value theory. Mostly, this article is aimed at people not already informed on this subject.

Here are the basic axioms of energy value theory, as I see it:

1) Energy is the only product that has *measurable* intrinsic value.
2) Energy imparts value to non-energy products
3) To spend money is to spend energy
4) Over any period of time, a monetary unit has a value that can be expressed in units of energy
5) Non-energy products are made using available energy which is a surplus from the process of producing energy
6) We refer to Energy Return on Investment (EROI, sometimes pronounced ee'-roy) as a ratio of the energy produced divided by the energy cost of producing the energy
7) "The flow of energy should be the primary concern of economics," as Frederick Soddy put it many years ago.[6]

The first axiom is maybe the hardest one for economists (and maybe others) to swallow. But it is really true and if you're going to understand the economy, you have to get this. Energy is the only thing with intrinsic value because it is the only thing for which there is a measurable expenditure.[7] Whatever else we spend, it took energy to get. This is true for all living things.

Here's is an example to illustrate: Suppose you are stranded on CastAway Island. You are by yourself and have a small hope of being rescued – surviving off the land (maybe spearing a fish or two now and then). Your economy can be described by **EA= EP-EC**, where EP is the energy you produce over a given period of time, and EC is the energy cost of producing EP. EA is the energy available to do things other than produce energy. It costs energy in order to have energy available, even for resting – you'll probably burn about 600 calories while asleep each night.

5 John Holdren was one of the first I discussed this with 35 years ago while at UC Berkeley. He already seemed familiar with the idea and pointed out some difficulties due to different forms of energy having different qualities. Holdren is now the president's science advisor.

6 See http://www.eoearth.org/article/value_theory beginning with the section on Energy Theory of Value. Also, see "Thermoeconomics" http://en.wikipedia.org/wiki/Thermoeconomics and http://billtotten.blogspot.com/2009/07/economic-thought-of-frederick-soddy.html

7 We may feel we spend time, and that our time is valuable. But we never paid for time. Time always involves an expenditure of energy, however. Energy is the thing we for which we have to pay.

Suppose one day while foraging for food, you find a treasure chest full of gold. Unless and until you are rescued, it has about as much value to you as a handful of sand. A coconut will have infinitively more value to you. If EA is zero or negative for some period of time, you will starve to death. You can't eat the gold, and the whole treasure chest won't buy you a single coconut. But aren't there other inputs just as necessary, like water? No. Generally, if you have energy, you can get water. Energy is the thing you must earn, even before water.

To illustrate the relationship between energy and money, I recommend table 1.5 of the Annual Review of Energy.[8] Among various key data, the table shows the number of BTUs represented by a dollar, and energy expenditures as a percentage of GDP. I've copied some data below from the table.

Selected data from *AER Table 1.5 Energy Consumption, Expenditures...*

Year	Energy Consumption (quads)	Energy Expenditure ($millions)	GDP ($billions nominal)	BTUs per 2005 dollar (thousands)	Energy Expenditure % of GDP	EROI calculated
1999	96.812	556,509	9,353.5	8.98	5.9	16.9
2000	98.970	687,587	9,951.5	8.82	6.9	14.5
2001	96.316	694,515	10,286.2	8.49	6.8	14.7
2002	97.853	661,902	10,642.3	8.47	6.2	16.1
2003	98.131	754,668	11,142.1	8.29	6.8	14.7
2004	100.313	869,112	11,867.8	8.18	7.3	13.7
2005	100.445	1,045,465	12,638.4	7.95	8.3	12.0
2006	99.790	1,158,483	13,398.9	7.69	8.6	11.6
2007	101.527	1,233,058	14,077.6	7.66	8.8	11.4
2008	99.402	*1,411,922	14,441.4	7.47	9.9	10.1
2009	94.578	NA	14,256.3	7.28	NA	

I inserted the last column showing average EROI, Energy Return On Investment, which is the inverse of the previous column (Energy Expenditures as a percentage of GDP).

One revealing number is missing (* Energy expenditures for 2008 is "NA" in Table 1.5) from the chart, which I was able to find in the latest State Energy data table.[9] From this table, we find that energy expenditures have grown to $1.412 trillion. This is significant because it shows that energy has become one tenth of our $14 trillion economy. As of 2008, average EROI is down to 10, from about 11 just the year before.

Average EROI dropped from 17 to 10 in about a decade (1999 to 2008). This is alarming because if we desire energy to be available at a certain level, we have to increase production of energy

8 See pg 13 http://www.eia.doe.gov/aer/pdf/aer.pdf Much of this article is based on numbers from this report. I recommend downloading a copy of the report for easy reference.
9 See http://www.eia.gov/emeu/states/hf.jsp?incfile=sep_prices/total/pr_tot_us.html&mstate=UNITED STATES

when the cost of producing that energy increases. If we can't increase energy production, we are going to feel the economy contract. After peak oil, *until we are significantly replacing oil with alternative energy*, we can expect to see higher energy expenditures at a higher percentage of GDP (lower EROI) and a contracting economy. This is what we are experiencing now.

The energy consumption shown in Table 1.5 roughly corresponds to energy produced (EP) in the equation **EA=EP-EC**. Even though much of this energy is imported, we paid money for it, which represents energy. So, we spent energy to get it whether we produced it or imported it.

We can calculate EA by taking the energy expenditures and multiplying by BTUs per dollar. For example, in 1999, it cost us about 5.8 quads[10] to get the 96.8 quads. So the energy available (EA) in 1999 would be about 91 quads. EA for 2008 equals 89.8 quads. In other words, less energy was available for the non-energy sectors of the economy: the economy contracted even though GDP rose substantially (23% in 2005 dollars) from 1999 to 2008. When we have the energy expenditures figure for 2009, clearly, EA, the Energy Available, will be even less.

We can use data in Table 1.5 to calculate EROI for given forms of energy if we know their price.

$$\text{EROI} = \frac{\text{BTUs per unit}}{\text{BTUs per dollar} \times \text{price per unit}}$$

If we try a few examples, we can quickly see that oil is dragging us down. We are getting a decent EROI from most every other form we use (including renewables). Oil used to yield an excellent EROI. Not any more.

For example, if we plug in the numbers for a 1996 inflation adjusted cost for a barrel of oil ($25.47) when a dollar represented 9980 BTUs, we get EROI = 22.8 [11] A 2007 barrel of oil ($60.47) yields an EROI of 12.5. Considering retail prices (which is our main interest), EROI after refining to gasoline is not very good. A three-dollar gallon of gasoline has an EROI of about 5.8.[12] If the oil came from a deep water off shore rig, EROI is much worse still.

Electricity from the sun is not bad with an EROI of about 11 and getting better.[13] Wind comes out with EROI over 20. Hydro is the all time EROI champion (over 50).[14] Once we get to an economy based on renewable energy, EROI will stabilize. In the mean time, EROI is a problem.

10 $ 652,378,000,000 * 8,980 BTUs per dollar=5.851 quads (nominal energy expenditures converted to 2005 USD)

11 5,800,000 / (9980 * 25.47)

12 114000 / (7280 * 2.68) … three dollars in 2010 adjusted to 2005 is 2.68

13 That's 10100/(7280 * .13) using estimated heat rate of 10,100 per kWh and commercial rate of 13 cents per kWh. Solar is replacing expensive peak power. How expensive is 13 cents? If we express the total energy consumed in US in kwh instead of quads, and divide by total energy expenditures, average cost is over 14 cents/kwh.

14 See Appendix A pg 375 of AER, which explains, *"There is no generally accepted practice for measuring the thermal conversion rates for power plants that generate electricity from hydro, wind, photovoltaic, or solar thermal energy sources. Therefore, EIA calculates a rate factor that is equal to the annual average heat rate factor for fossil-fueled power plants in the United States. "* The heat rate I use here for electricity, 10100, is in line with what the government uses and roughly equates to the BTUs needed to produce a kwh of electricity at 34 percent efficiency. This probably understates the value of of electricity generated with renewable energy because over 75% of the energy from oil for motor vehicles is lost as waste heat.

An economy depending mainly on fossil fuels is going to see EROI get progressively worse.[15]

I've prepared a chart below to show why *declining* EROI is so bad. This chart reflects a goal of having 100 units of energy[16] available to the economy. The column to note is labeled "EP Increase." I am showing the percentage energy production (EP) must increase – from the previous step down – with a drop in EROI to maintain the desired level of available energy (EA).

EROI SCENARIOS

EA	EP	EC	Percent of GDP	EP Increase	EROI
100	106.25	6.25	5.9		17
100	106.67	6.67	6.3	<1 %	16
100	107.1	7.1	6.6	<1 %	15
100	107.7	7.7	7.1	<1 %	14
100	108.4	8.4	7.7	<1 %	13
100	109.1	9.1	8.3	<1 %	12
100	110	10	9	1%	11
100	111	11	9.9	1%	10
100	112.5	12.5	11	1.35%	9
100	114.3	14.3	12.5	1.60%	8
100	116.7	16.7	14.3	2.10%	7
100	120	20	16.7	2.83%	6
100	125	25	20	4.17%	5
100	133	33	25	6.40%	4
100	150	50	33	12.80%	3

Note that with the recent decrease of average EROI from 11 to 10, in order to support the same level of energy use – making the same 100 quads of energy available for the non-energy economy – we would have had to increase energy production about one quad per year. A quad (quadrillion BTUs) is an enormous amount of energy, equal to about 172 million barrels of oil, or 50 million tons of coal. There is just no way to get that much additional energy in short order.

15 This is especially true post-peak oil. We invariably produce fuel that is easiest to get. Over time, a given site will yield less and less even if we spend the same or more to extract the fuel. Then, we move to the next site where we have to dig a little deeper and work a little harder to get the fuel. Eventually, we move to sites way off shore, dig miles down, it becomes so expensive that it's a complete waste of time, money, and energy.

16 In applying these figures to the US economy, the unit of energy roughly corresponds to a quad (one quadrillion BTUs … that's a one with fifteen zeros). We are not quite using this much energy now, but with a reasonable growth rate ***including rapid alternative energy development,*** we would be using that much as some future point. Note that in government statistics, EC is given in terms of dollars while EP is given in dollars and units of energy. No matter what units of energy are used, the ratio of EP to EC will be the same as GDP to energy cost in dollars.

Logistically, even if we were willing to withstand the environmental impacts, it would have been very difficult to quickly increase coal production much. We did not increase production at all and we simply got by with less, which entailed higher unemployment among other things.

EROI will continue to decline for some years (any rebound would be small and temporary). This is inevitable. This trend is also irreversible as long as we are depending heavily on fossil fuels.

How low can EROI go? It depends on how soon we begin a serious conversion to renewable energy. I did not include EROI equal to 2 in the table. This would roughly correspond to returning to the caves to live – also implies economic collapse and massive population reduction. People living with EROI 2 would be able to feed themselves but have little energy left to sustain much other economic activity – more akin to the world of Mad Max than anything we recognize today as civilization. I estimate that EROI 3 would roughly correspond to early industrial society – most people would be farmers, as it was in the 19th century.

The problem with sliding down the peak oil curve without a plan is that things will get worse faster. It might be physically possible to gradually return to an agrarian society, but we can't do it rapidly. A rapidly contracting economy will have many angry unemployed people. Considering that it took only a decade to drop from EROI 17 to EROI 10, could we drop to 5 or worse in the next decade? Who knows what that would be like, and who wants to find out?

In the aftermath of the 1970 US oil peak, we experienced EROI of 7.3 (1981, Table 1.5 of AER, energy 13.7% of GDP). That was not good (high unemployment, high inflation[17]), but we survived it. We got out of the downward spiral when oil prices collapsed in 1985-1986.

We experienced the 1970 peak with training wheels on. The training wheels are off now. Back then, as we began to use less imported oil, there was pressure on the oil exporters to get the US back as a customer. Since they had few other customers for their oil, they had to drop their prices.

Not anymore. Now, it is different. There are many more customers – big ones, too, like China and India (2.5 billion people and growing). And there are fewer exporters: Several countries that used to be exporters have become importers since their own production has peaked. Some of the largest oil fields in the world are going dry faster than anticipated.[18] The US does not have anywhere to go for increasing oil imports. It's all downhill from here.

Even Saudi Arabia's huge Ghawar oil field is going south. Most of the oil from Saudi Arabia comes from this single enormous mother-of-all oil fields. They've been pumping it ravenously for 59 years. The decline in production from there is likely to be steep, as has been seen with some of the other large oil fields around the world.

Indonesia used to be a member of OPEC (Organization of Petroleum-Exporting Countries). As their oil production declined and their consumption increased, they reached a point where they were using all of their oil. It is not that oil from Indonesia became more expensive for the US to purchase: *It became unavailable.*

17 The prime interest rate hit an all-time high of 21.5% in DEC of 1980.
18 Production at Mexico's huge Cantarell oil field – the largest field in North America – has dropped 70% in recent years. *The rate of decline is accelerating.* See http://www.eia.doe.gov/cabs/Mexico/Oil.html

China used to be a major exporter. Now they compete with the US for the remaining oil. *"Venezuela is sending increasing volumes of oil exports to China that were once bound for the United States...."* [19] Oil is not only becoming more expensive for the US, it's going to become *unavailable* to the US. It doesn't matter how much oil is still left in the world if all the oil producing countries are using all they produce. Within a few years, the only oil exporting countries will be a handful of Persian Gulf countries.

Drill Baby Drill

Some have suggested that we just need to try harder to find the oil. If only those pesky environmentalists would get out of the way, we'd find plenty of oil.

There are just a few problems with this call to action. First of all, this was essentially the response to the 1970 peak. Richard Nixon called for "energy independence by the end of the decade." Nixon said, in effect, "Drill Baby Drill." That's what we did. In the 1970s, the US stepped up efforts to find more oil. Oil production still declined steadily.

There are few endeavors to which so much money, time, and energy have been thrown. We have applied great scientific and engineering talent to finding the oil. "Drill Baby Drill" has already been the standing policy over the 40 years since US oil production peaked. Have a look at Table 4.9 (pg 115) of the AER. Exploration and development expenditures by the major US energy companies continue to increase dramatically – 97.9 billion dollars in 2008 alone (irrespective of the latest Drill Baby Drill exhortations), up from a mere 27.4 billion dollars in 2003.

These extraordinary efforts to get the oil out of the ground only mean that the remaining oil will not last as long.

Oil is now just too expensive. Stepping up the drilling beyond the already frenetic pace will make oil even more expensive. Alternative forms are less expensive and ready to replace oil. The reason most everyone still fills up their tank with the fossil fuel is due to the huge investment we have in vehicles and infrastructure dedicated to this mode. Entrenched interests, too, are not anxious to do something that might cause them to lose some advantage.

Somehow, we have to break the cycle. We have to invest in new energy and an infrastructure that will enable us to utilize the new energy.

Energy Conservation

Profligate energy consumption was probably never a good idea, but when energy was cheap (high EROI), we could get away with it. When energy becomes expensive (lower EROI), we are forced to conserve.

As long as we are married to fossil fuels, EROI will continue to drop. With each drop in EROI, we have to increase energy production to keep the economy at the same level of activity. On the downside of the Peak Oil curve, it is nearly impossible to increase production of fossil fuels. So, we simply have to get by with less and less each year until we can get alternatives going in a big way.

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19 See http://in.reuters.com/article/idINN0311592120100903

Sometimes we hear, “the best way to produce new energy is conservation.” **This is wrong!** There is an important distinction between energy conservation and energy production. If you install good insulation on a hot water pipe, you can save energy. That investment conserves energy, but does not *produce* energy. If the water going through the pipe is at ambient temperature, the insulation does nothing. It takes some energy input to make the water hot in the first place.

With energy conservation, we can make non-renewable energy last a little longer. ***It does not solve the problem***. We only solve the problem by replacing fossil fuels with alternative energy.

Richard Heinberg is one of the better authors / analysts speaking out about peak oil, but like many others, he is wrong on conservation. For example, he said that,

> *I don't think we're going to be able to grow renewable energy fast enough to replace fossil fuels... that's why energy conservation, energy efficiency, curtailment of energy use – these things have to occupy center stage in our energy transition policy.*[20]

Let's suppose we all adopted some “curtailment of energy use” policies and agreed to cut our recreational driving by half. Suppose you have always gone once a month or so to your favorite lake, and now you are only going to go every other month. By the time you get there, you might discover that a lot of people that used to work at the lake are not there anymore. The boat rental shop might be closed altogether because it was barely making a profit before and now there isn't enough business to continue. So, they closed and the workers are now unemployed. Restaurants, gas stations, drug stores, and various other businesses you might stop at on the way to the lake will see visitor business cut in half, so there will be layoffs and closures there too. A widespread application of “energy curtailment” would mean widespread unemployment and a whole set of new problems associated with that.

There is another big problem with putting energy conservation/efficiency first: Post fossil fuel society will be shaped by the energy technology we adopt, just as oil shaped what we have now. We can't very well know what energy efficiency measures to do until we have a better definition of the direction we are going.

It's like if your boss told you you're getting a promotion, and the company is going to send you to one of three places: Hawaii, Kansas, or Siberia. If you need a new wardrobe, you might want to wait to find out which direction you are going.

Los Angeles was shaped by cheap oil. Did you know that in 1923, Los Angeles was producing one-quarter of the world's oil?[21] Before the oil boom, they had a good public transit system. Cheap oil meant that everyone would be driving cars instead. Public transit was scrapped and they built freeways. Over the decades, LA got cars and suburbia – farms were gone. Working out the new shape of Los Angeles is going to depend on how energy resources are developed.

To a certain extent, we've been forced to conserve whether we like it or not. There is still lots of room for improvement, but we are clearly doing more with less. Since about 1984, US GDP has

20 Go to 4:30 into this video http://www.youtube.com/watch?v=YMwU9qRMtPo
21 Los Angeles oil production peaked at about 68 million barrels of oil per year. Although largely depleted, LA oil wells now produce about 1.5 million barrels per year, or about enough energy to power the US for one hour.

doubled (adjusting for inflation) while the amount of energy we are using only went up about 25 percent. Instead of flying cars, we got hybrids.

Now we are coming up on some major changes. Some people say we can't grow renewable energy fast enough. This is wrong. California has many large solar energy projects[22] that will add about 5000 megawatts to the grid in the next few years. Soon, when demand peaks on the hottest day of the year, over ten percent of California's electricity will be from direct solar. This is just the start and there is no reason this could not be greatly expanded.

Many thousands of construction jobs will be created for these projects, and thousands of permanent jobs will remain after construction is completed. Millions more people need work. There is no reason renewable energy plant construction should not be multiplied many-fold and soon – in California and around the US. *This is not a time to curtail activities. It is time to replace an obsolete and failing energy infrastructure.*

Coal

How many times have we heard that the "US is the Saudi Arabia of coal?" There is just a little bit of irony in that US coal production and Saudi oil production may have peaked around the same time.[23] Coal can produce cheap electricity, if you ignore massive external costs, but that's about it.

US coal production has been flat for around 20 years with 2009 production slightly less than the previous 5 years (Table 7.2 AER, pg 209). Table 7.6 of AER shows that in 2000 we were producing about 7 short tons of coal for each employee-hour. By 2009, that 7 tons had dropped to 5.6 per employee-hour. We're putting more people to work on it, but getting less out of it.

Coal was a staple of the industrial revolution... in the 18th and 19th century. We should be looking to phase it out as soon as possible in this new millennium.[24]

We have a great deal of coal, but most of it will never be of any use to the economy. Coal has about half the energy value of gasoline by weight, and your car can't use it anyway. It is possible to reform coal into fuels that you can use, but that is so expensive it is not worth it. Cleaner burning higher quality anthracite coal is becoming scarce and too expensive for wide use.

Besides the appalling rate of toxic particulate matter spewed into the air, and massive CO2 emissions, coal kills people who mine it. Dozens of miners die on the job each year, and approximately 700 die annually from black lung disease. [25]

Environmentally, coal is catastrophic. Whole mountains are blown to bits and reduced to rubble

22 See http://www.energy.ca.gov/siting/solar/index.html This does not include projects under 50 megawatts
23 See http://www.theoildrum.com/node/2325 I mentioned Saudi Arabia as a natural partner for solar energy conversion in my 2001 open letter to President Bush. See http://www.safeenergyassociation.org/ad/solarletter.html It was interesting to hear recently that Saudi Arabia now has a goal of 10 percent solar by 2020. See http://in.reuters.com/article/idINLDE64I27X20100519
24 There are signs that coal's days are numbered. TVA recently announced they will cut back on using coal. See http://wyia.org/newsworthy/tva-announces-plans-stop-burning-coal-in-nine-electric-generating-units/
25 The percentage of miners with black lung disease has generally declined over the last 100 years, but there has been an increase in recent years. See http://www.msha.gov/S&HINFO/BlackLung/2009Charts/PercentofMiners.pdf

in surface mining operations.[26] Workers deserve better than the boom-bust cycle that follows every coal mining operation.[27]

Clean coal? Go down to the store and try to buy some. They don't have it. No one does.

Natural Gas

Natural gas is trumpeted as an alternative to oil, but if you think that's going to replace oil, think again. Natural gas EROI (about 24 wholesale, half that retail) is better than oil right now, but it will only get worse. And the faster we use it, EROI will get worse faster.

Looking at table 6.4 (pg 193) of the Annual Energy Review,[28] we can see that while the number of gas wells has gone from about 100,000 to 500,000 since 1960, the amount of gas being produced from each well has dropped drastically (high of 435,000 cubic feet per well per day, to around 103,000 today). It can only get worse as we continue to deplete this resource. Natural gas prices can only get worse in the long run.

In other words, we are frantically drilling gas wells at a faster and faster rate while getting less and less from each well – one fourth as much as we used to get. Does this sound like a resource we should plan to depend on indefinitely?

Natural gas can work short-term as a transportation fuel although it is inferior to gasoline (and Diesel fuel) in many ways. Generally, if you convert a vehicle from gasoline to natural gas, you will have less power and lower driving range. This tends to work best for short-haul vehicles, and, indeed, quite a few buses and trucks have already been converted to run on natural gas.[29]

Another problem with reliance on natural gas: Aging pipeline infrastructure. There are hundreds of thousands of miles of natural gas pipelines around the country – much of it 50 years old or more. A recent disaster in California underscores this problem.[30] If we start replacing the pipes now, there probably won't be natural gas to put in them by the time we're done. We need to re-think. We need to replace all the old pipes, but we should upgrade for hydrogen compatibility while we're at it (hydrogen requires relining of gas pipes or new pipes altogether).

Nuclear or Solar

It is worth noting that the paper by Dr. Hubbert,[31] with which I began this article, is titled "*Nuclear Energy and the Fossil Fuels.*" His paper could be summarized as, "Fossil fuels are a temporary resource. We need to move to a permanent solution, namely, nuclear energy."

While Hubbert's paper is mostly correct, we have the advantage of 54 years of history to see a

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26 See http://mountainjustice.org/facts/steps.php
27 See http://www.youtube.com/watch?v=RVHBp3TWR34&
28 See page 193 http://www.eia.doe.gov/aer/pdf/aer.pdf
29 See http://www.americanprogress.org/issues/2010/04/american_fuel.html
30 Around 40 homes recently blew up and 8 people killed, many injured. It is expected to cost PG&E $100 million to settle the claims. How will PG&E get the money? Ultimately, it is going to come from their customers, no matter how it is characterized. See http://www.msnbc.msn.com/id/39159597/ns/us_news-life/ PG&E warns there are more faulty old pipes: http://www.mercurynews.com/breaking-news/ci_16119712?nclick_check=1
31 Meet the late, great, Dr. Hubbert on YouTube: http://www.youtube.com/watch?v=ImV1voi41YY

few things he got wrong. He was way too optimistic about the commercial viability of nuclear power, at one point saying (pg 31 of his 1956 paper), "In the subsequent discussion it will be assumed that complete breeding will have become the standard practice within the comparatively near future." He also completely ignored the safety issues. Could he have foreseen that India would obtain nuclear technology under the "Atoms for Peace" program, then, a decade later test a nuclear bomb calling it a "peaceful nuclear explosion?"

Looking beyond the age of fossil fuels – assuming humanity makes it that long – we're going to wind up with an economy powered by nuclear and/or solar (wind is included as indirect solar). These are the only two sources that are sufficiently large.

Of the two, only solar is certain to be adequate. With existing technology, it is possible to produce all 100 quads of energy (in all forms) currently used in the US per year with less than one percent of our land area dedicated to solar energy production. While some early proposals for solar conversion suggested one (or a few) mega sites in the Southwest desert to power the whole country,[32] it is generally accepted that renewable energy production should be decentralized for better reliability, security, and efficiency. Renewable energy is available everywhere in one form or another.

The potential success of nuclear depends on advances in technology. We don't have any breeder reactors working in the US[33] and nuclear fusion researchers haven't achieved anything remotely resembling a proof-of-concept. Current nuclear technology[34] depends on uranium fuel, which the US does not have.[35] Over eighty percent of nuclear fuel used in the US is imported.

For the moment, suffice it to say that there are some issues to be worked out no matter what direction we decide.

What Do We Do when the Sun Doesn't Shine? (or there is more power generated than we use)

This is one of the most persistent questions we hear. We will know that we are getting somewhere with the educational process when people stop asking this question. In the mean time, it has to be answered over and over.

The short answer is that energy can be stored. Fossil fuel is stored solar energy. People say, "someone needs to figure out a way to store the energy from renewable sources so we can use it when we need it." This is untrue. Energy storage technology is mature and well-understood. We

32 GE says, "Electricity to power the entire U.S. Could be generated if just 7 percent of Arizona was covered with GE's photovoltaic modules." This echoes an old idea. Let's just say GE is emphasizing the large potential of solar energy. See http://www.ge.com/products_services/energy.html

33 A much-troubled breeder in Japan was recently restarted, after being down for repairs for 14 years. They hope to have it ready for commercial use by 2013, See http://news.sciencemag.org/scienceinsider/2010/05/japan-restarts-troubled-breeder-.html

34 Current nuclear technology is expensive, too. We have to compare what nuclear is expected to cost now, not what we paid 30 years ago. An MIT study said we could expect to pay $4000 (2007 dollars) per kilowatt. See http://web.mit.edu/nuclearpower/pdf/nuclearpower-update2009.pdf More recent estimates go to $8000 per kilowatt. The history of nuclear power plant construction shows massive cost overruns. I am using $9000 per kilowatt (or $9 billion for a 1000 MW plant) in my example, which is pretty conservative. See http://scitizen.com/future-energies/how-much-will-new-nuclear-power-plants-cost-_a-14-2287.html

35 US Dept of Energy says there is a 10-year supply of $50 per pound uranium – 23 year supply if $100. See http://www.eia.doe.gov/cneaf/nuclear/page/reserves/ures.html

don't currently store wind power or grid-connected solar power because there is no need to do so. It is all absorbed into the grid.

I don't know how many times someone has told me (knowing I'm a fan of renewable energy) that they drove by a wind farm and were dismayed. A lot of the turbines were not turning and some of them were being repaired. It just doesn't look reliable or economic.

Consider that in California, the time when we need the absolute greatest amount of electricity happens in late afternoon on the hottest day of the year – usually in July or August. This happens to be about 60,000 megawatts of power. Regulations require there to be a reserve above that. So, we have the capability to generate over 70,000 megawatts. As I write this, the state is only using about 31,000 megawatts and the peak expected today is only a couple thousand megawatts above that. So, statewide, today, most of the generating capacity in the state is not used.

In fact, most of the time, we are using less than half of what we are capable of generating. This means that at any given time, most of the 1000 or so power plants in California[36] are idle. Some of the "peaker" power plants only run for a few hours during peak power times in the summer. If a power plant runs for 876 hours during the year (figure there are 8,760 hours in a year), we say the capacity factor is 10 percent. That is, it only produces 10 percent as much as it would have if it ran all the time.

Power plant capacity factors go from 90 percent for large baseload power plants, to zero (or nearly zero) for plants that don't run unless there are outages (planned or unplanned) around the time of the peak load in the summer. It is just the way it is: power demand varies minute by minute from season to season. Wind turbines are reliable. They perform as expected.

Wind is variable but not unreliable. In California, the capacity factor for wind machines averages 30 percent. It tends to be about 20 percent in the Fall and Winter, and about 40 percent in the Spring and Summer. If you happen to see them at a time when they are not doing much, that's pretty normal. As of 2000, the 1600 megawatts installed here represented more than half of the wind power installed in the US. Since then, US wind power has grown to 38,000 megawatts.[37]

Nuclear proponents also use the line, "solar is unreliable, unlike nuclear which is always available day or night." This is also grossly misleading. There is nothing more reliable to humanity than the sun. The day the sun becomes unreliable is the day life on earth ends – a day expected some billions of years from now.

The fact that we have had abundant naturally occurring stored energy (fossil fuel) is a freak of nature which happens to exist in the time we are living. Fossil fuel will be going away, and, soon, practically speaking, there will be no easily accessible naturally occurring stored energy available (other than some forms of renewable energy). We can still have stored energy but we will have to build additional facilities to produce it and use it. It really isn't a big deal and adds only a few percent to the cost of the energy we use (okay, a few percent of $1.4 trillion per year is a lot).

Another common mis-perception is that some *new thing* needs to be invented. This is not true.

36 See "Database of California Power Plants" on this page: http://www.energy.ca.gov/sitingcases/index.html
37 See http://www.windpoweringamerica.gov/wind_installed_capacity.asp

What people really want is cheap energy. They want to go to the gas station and fill up with $1 per gallon (or less) gasoline. And they want it always to be like that. Preferably, someone would invent device that would go straight to the gas pump from some infinite source under the ground. Well, it isn't that way and it never will be that way. Somehow, we have to come to grips with what is really happening, and what is really possible. What's possible is pretty good and reasonably close to what everyone really wants, if we choose to make the investment.

All of the basic technology we need has been in existence for some decades. Conversion to alternative energy is a matter of deploying some mature, well-understood technology on a large scale. Some things we are going to see may appear new, but they are really old technologies that are becoming commonly available. It is hard to predict the exact result of mass production, but it is safe to say that continued improvements in price and performance can be expected over time.

In comparing the nuclear path and the solar path, it is not really the variability of solar that is the issue. It is *the variability of demand.* Over the course of the day, demand changes constantly. Generally demand is very low in the early morning and reaches a peak in the late afternoon. The variability of demand is also a problem for nuclear because a nuclear power plant cannot increase or decrease output depending on demand. Nuclear plants have to run full blast all the time.

If we accept that fossil fuels are going away, and that solar and nuclear are the major options, we might want to consider what would be involved converting to one or the other. For the moment, I'm going to focus on California. What would it take to make the switch?

Two Possible Paths for a California Free of Fossil Fuels

	Nuclear	**Solar (and Wind)**
Production Facilities	100 x 1000 megawatt plants	3000 100 megawatt plants
Peak Total	100,000 megawatts	300,000 megawatts
Capacity Factor	90 percent	30 percent[38]
Total Annual Energy	788 billion MWh or 8 quads	788 billion MWh or 8 quads
Capital Cost per kW	$9,000	$3,000
Total Capital Cost	$900 billion	$900 billion

For the sake of argument, let's suppose all the political, financial, siting, and NIMBY (Not In My Back Yard) hurdles could be quickly overcome. Also, assume this capacity is added to existing non-fossil energy in California (around 14,000 megawatts peak; nuclear, hydro, bio, geothermal, solar, and wind already exist). All fossil-fueled power plants are to be phased out in any case.

Given what I've pointed out about the electrical demand, this should be easy to see about a potential future nuclear-based California: Since electrical demand goes from about 24,000

38 The 30 percent capacity factor is higher than existing solar-electric installations, but very reasonable. It is likely that large solar power plants will be solar-thermal, which store some heat so they can continue generating even after the sun goes down. See the write up for this project, which is expected to be built soon – based on the successful Solar Two DOE demonstration plant. http://www.energy.ca.gov/sitingcases/ricesolar/index.html This plant has a 34 percent capacity factor. Capacity factors of over 50 are possible for solar thermal plants of the future that will have larger heat storage tanks. For wind power, 30 percent capacity factor is normal in California.

megawatts in the early morning to about 60,000 megawatts on the afternoon of hottest day, and electrical production for nuclear California would be a constant 100,000 megawatts, there would always be an excess of electricity. We would need to do something with anywhere from 40,000 megawatts to 76,000 megawatts that is not needed at any given moment in the grid.[39]

For a variety of reasons, most of the power from the nuclear plants would go to generating hydrogen.[40] Hydrogen will then be used as a general purpose fuel, like we use oil and natural gas.

We may as well put this on our to-do list no matter what our energy future: *We need to install a large new hydrogen pipeline network.* The old natural gas pipeline network needs to be replaced anyway.[41] According to a report[42] from Argonne National Laboratory,

> *While hydrogen may be transported in a number of possible forms, pipelines currently appear to be the most economical means of moving it in large quantities over great distances.*

With a large enough hydrogen pipeline network, it is likely that no additional storage would be needed. That is, the pipeline would store all the hydrogen since the pressure could be varied (hydrogen gas is highly compressible). At any time, the pipeline could hold several times as much hydrogen as another time by increasing the pressure in the line. As long as the pressure level in the pipe is maintained between the minimum needed to provide service, and the maximum it can safely take, the volume of hydrogen in the pipe can vary greatly.

Very likely, you'd be running your car on hydrogen[43] (this does not preclude battery-powered cars). The pipelines would be run to all 10,000 or so fueling stations in the state.

In addition to the pipeline network, there would be a need for new power transmission lines once the nuclear plants are sited. Nuclear power plants need cooling water so they are normally sited

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39 Of course, demand will change over the years – electrification of transportation (battery powered cars will need charging, and new electric light rail systems need power) will eat up some of the power. These numbers are rough estimates to start with.

40 The way hydrogen is typically generated is by using electricity in a process call electrolysis to split water (H2O) into hydrogen and oxygen. There are also heat-driven processes that may be used with nuclear, and/or concentrated solar energy, that can split hydrogen from water.

41 It may be that the hydrogen pipelines can also carry natural gas during the transition (not at the same time... the new pipes could first carry natural gas until hydrogen production ramps up).

42 See Overview of Interstate Hydrogen Pipeline Systems, INTRODUCTION, pg 1 http://corridoreis.anl.gov/documents/docs/technical/APT_61012_EVS_TM_08_2.pdf

43 In the not too distant future, your car will be running on electricity or hydrogen. It's is probably too expensive to convert your present vehicle. It is not a big extra cost to mass produce new cars (with internal combustion engines) to burn hydrogen. Fuel cells to run your car also use hydrogen, but are too expensive right now. See http://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/ Battery powered cars are also possible, but consider that the Tesla car has a 900-pound $35,000 battery pack. The Honda Clarity fuel cells weigh about 150 pounds. See http://automobiles.honda.com/fcx-clarity/specifications.aspx Honda is betting heavily on fuel cells and they seem more likely to become affordable with mass production than the 900-pound battery pack. A hybrid electric/fuel cell/internal combustion powered car is also possible. Say fuel cells dropped to $300 per kilowatt: that's too expensive for a 100 kw engine, but you could have a 5-kw fuel cell charging a modest battery pack (say 300 pounds) so that around town, the car would be all electric. On the highway, the internal combustion engine would kick in. This hybrid would only need hydrogen, never needing to be plugged into an electric power source. It would be slightly more complicated and expensive than current hybrids, but it would be much more efficient and use no fossil fuel. Beside Tesla and Honda, GM and Ford are working on fuel cell and electric vehicles.

near large bodies of water,[44] which would be the Pacific Ocean in the case of California.

The hydrogen pipelines and transmission lines are very expensive long-term projects. I only included the cost of the power plants in the table above.

If we take the solar path, there would be many similarities to the nuclear path. The lights go on no matter what time of day you flip the switch. There would also be plenty of fuel for your car at the fueling station.

We would achieve these things in a slightly different way with solar. If we assume that 20 percent of the 300,000 megawatts would be from wind, that means that up to 240,000 megawatts would be available at peak hours in the summer using solar[45] – at the same time peak demand hits. With nuclear, there would be plenty of electricity to meet the 60,000 megawatt electric grid peak, but the transportation system is also peaking around that time and nuclear would also be providing all the energy for that. So, a lot of energy will have to be stored up for that.

Right now, peak power is very expensive. In the solar scenario, peak power would be cheap since there is an abundance of solar energy at peak hours. This should be good for business since, currently, industrial users have to pay more based on time of use. Businesses are generally most active at peak hours and that's when there will be the greatest abundance of energy. The rate structure should be favorable in this regard.

One small operational difference: The state currently has 7 generating plants totaling about 4000 megawatts using **pumped hydro storage**. The utilities use them to pump water up into an upper reservoir during off-peak hours (when electricity is cheapest) so they can use the hydro turbines to generate cheap power at peak hours. With the nuclear scenario, pumped hydro would not be used because there would be no such advantage. In the solar scenario, the pumped hydro would be useful but the usage model would be reversed: there will be plenty of power at peak times but we could use the power at night. So they would pump the water in the day, then generate the power at night. It might be that no additional storage would be needed. Between existing non-fossil baseload, hydro, wind, pumped hydro, imports from Palo Verde nuclear and Washington hydro, it might be enough to cover the basic 24,000 megawatts needed all the time. If that's not enough, we could expand pumped hydro (California has many reservoirs and lakes) or convert some existing gas-fired power plants to burn hydrogen. Given that we'd be building the hydrogen pipeline network, it would be cheap to convert some existing natural gas powered plants (in the long run, it would probably be more efficient to have the additional pumped hydro).[46]

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44 The Palo Verde nuclear plant (largest in the US) in Arizona is a notable exception. It is in the middle of nowhere, with no body of water nearby. It uses 20 billion gallons of treated wastewater each year. There aren't many places inland in California where we could find this much water. Palo Verde is also notable to the California example because it is partly owned by three California power companies, namely, Southern California Edison, Southern California Public Power Authority and the Los Angeles Dept. of Water & Power. California currently imports some of its power from this plant. http://en.wikipedia.org/wiki/Palo_Verde_Nuclear_Generating_Station

45 Mostly it would be solar thermal, but photovoltaic (PV) would also be used. For this example, figure 80,000 megawatts from PV, 160,000 solar thermal, and 60,000 wind.

46 This depends somewhat on how cheaply hydrogen can be generated with high temperature processes. If hydrogen can be produced cheaply this way, then it might be more economical to burn the hydrogen for the make-up electricity needed (instead of building new pumped hydro). See pg 17 of this presentation: http://files.harc.edu/Projects/CultivateGreen/Events/20070212/SolarTowerBriefing.pdf

Whether nuclear or solar, some seasonal storage will be needed. In the nuclear scenario, an excess of energy would be available in the spring and fall. In the solar scenario, an excess would be generated in the summer. If we can't jam enough hydrogen into the pipeline, then it could be pumped into underground caverns (it is unlikely that storage in tanks or liquefaction of hydrogen would be very economical). In any case, whether we go nuclear or solar, there should be plenty of energy available 24 hours a day, 7 days a week, year-round. With both nuclear and solar, the capital cost of the power plants is high (about the same) while operating and maintenance would be low. Both would require large investments in transmission lines, hydrogen pipelines, and hydrogen facilities (like filling stations).

So, what's the difference between a nuclear-based economy and a solar-based[47] economy?

- ***Timing:*** In the example scenarios, I supposed that nuclear or solar – 8 quads per year worth – could be built right away. In the real world, nuclear will take a very very long time. There is currently a moratorium on building new nuclear plants in California. Assuming the most optimistic time line for getting that lifted, it could not happen in less than a year (extremely unlikely). Then it would be at least 10 years before the first new nuclear plant would be running. In the mean time, nuclear plant construction would be an enormous sinkhole of time and resources while no energy is being produced, all while the economy is likely to be getting worse.[48] Solar, on the other hand, is happening now. Thousands of megawatts will be coming on line next year and could continue every year after that for many years to come. Solar production can be ramped up rapidly now and you don't need a nuclear engineering degree and nuclear security clearances to help.
- ***Fuel cycle:*** Nuclear fission power plants would be a temporary measure. Nuclear fuel is cheap now, but 100 new power plants in California would significantly increase worldwide demand for scarce uranium. With 100 plants, California alone would have 20 percent of worldwide nuclear capacity.[49] China has 24 nuclear power plants under construction right now. Russia has 11 being built. There are many others being built around the world. Solar, on the other hand, is a permanent solution. The fuel is always free. If China and India start using solar a lot, it does not lessen our supply. The materials used in solar plant construction are fairly common and can be recycled. There is no radioactive waste to be disposed of. The federal government still says they are going to take care of the radioactive waste from nuclear plants, but it is not happening now, yet.
- ***Costs:*** Solar power plants have been getting less expensive as more have been built. The fuel is always free. The economics of solar are okay now (we can probably achieve at

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47 When I described the facilities for the solar scenario in the "Two Possible Paths for a California Free of Fossil Fuels," table I wrote, "3000 100 megawatt plants." This was just to simplify the math. It could also read, "thousands or even millions of solar and wind power installations – including solar water and space heating – that range from a kilowatt or two, to hundreds or even thousands of megawatts. The total energy produced over the year would be the same as 100 1000-megawatt nuclear power units."

48 A massive California nuclear construction project might be endangered by a bad economy, as befell the Washington Public Power Supply System (WPPSS) project, aka "Whoops project." With the US economy at one of the worst points in modern history (1981), WPPSS abandoned construction of several nuclear plants after sinking many billions into their construction. When high inflation hits, cost overruns are inevitable. A bad economy is going to favor projects that don't take so long to construct and penalize ones that take a long time. See http://www.historylink.org/index.cfm?DisplayPage=output.cfm&File_Id=5482

49 Tally of nuclear plants worldwide. See http://www.euronuclear.org/info/encyclopedia/n/nuclear-power-plant-world-wide.htm

least EROI=22 for plant production costs in the near term and it will improve over time). The cost of nuclear power now may or may not be okay, but the long term economics of nuclear depend entirely on future technology, the cost of which is unknown. We do know that breeders are more difficult and problematic – none are working in the US currently. Nuclear Fusion is completely unknown since not a single kilowatt hour of electricity has ever been produced that way despite billions in R&D over the past 60 years.

- ***Safety and Security:*** While the safety record of nuclear in the US is excellent, we know that nuclear plants have been on lists of terrorists' targets, including the Palo Verde plant in Arizona.[50] They say they are safe, but nuclear generating plants have never been tested by a determined and well-financed attacker. If an attacker could force a nuclear meltdown with cleverly placed explosives, the impact could be devastating over a wide area.[51] If California were to install 100 nuclear plants, we have to also recognize them as 100 potential terrorist targets. At what cost? Solar is diffuse, which is a disadvantage in some ways, but from a safety and security standpoint, it is excellent. Having solar panels and wind turbines scattered all over the state also means that any energy plant destruction – by nature, accident, or purposely caused – will have little impact on the overall system. Solar and wind are modular and can be continually renewed, replaced and repaired essentially forever, unlimited – for many generations to come.
- ***Water and land use:*** Nuclear plants require a tremendous amount of cooling water. Solar plants use some water but far less than nuclear. Wind turbines don't use water. Most of the nuclear plants built in California, including the 4 units now operating, have been built along the coast so they can utilize ocean water for coolant. Nuclear plants use much less land than solar plants, but the land they use tends to be much more valuable. It would be a great challenge to find 100 sites along the coast of California for the nuclear plants. Solar plants would take up about 1.5 percent[52] of California's land area – mostly remote desert land. A lot of the solar can co-exist – especially PV panels – with land and buildings used for various other purposes. Cows can graze around the base of a wind turbine.
- ***Environmental issues:*** There is no doubt that either the solar path or nuclear path would involve significant ecological disturbances. However, there is no better energy option for supporting modern society. The environmental impact of solar and nuclear pale in comparison to coal. Oil and natural gas has had, and continue to have, a huge negative impact on the habitability of planet earth. Wind turbines kill some birds. Other forms of energy kills birds, people, and all sorts of other life forms. To a certain extent, wildlife can be protected. For example, in the Altamont pass in California (where wind power first became commercialized), they have found that by installing fewer but larger turbines (higher off the ground) a lot fewer birds get killed and just as much electricity is produced. Other mitigating strategies must be employed to minimize environmental impacts, but zero environmental impact is not possible in any case. Perhaps a compromise with environmentalists could include an absolute limit on the percentage of land that could ever be dedicated to renewable energy production – perhaps 2 percent – whether

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50 See http://www.foxnews.com/story/0,2933,81692,00.html

51 The Chernobyl accident happened 24 years ago and the area around the plant – for an 18 mile radius – is still off limits. Many killed or sickened by radiation; 300,000 people displaced; environmental devastation; See http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/chernobyl-bg.html

52 I often say that enough solar power can be produced using less than one percent of the US land area. This is true too, but the percentage would be a little higher in California because we have so many people and so much industry – more energy use per square mile than most states.

solar or wind. Maybe some wildlife will have to be relocated. Once the renewable energy infrastructure is built out, ecological sustainability will be permanently established – a little different than we have now, but sustainable and non-polluting.

- ***NIMBY resistance***: Both nuclear and solar face significant NIMBY issues while trying to rapidly expand. People tend to say, “Fine, we need the energy. Just don't build it here.” This is why a significant public education effort needs to be undertaken. A broad consensus needs to be achieved before either path can be undertaken.

What Happened to the Last 15 Trillion We Spent on Fossil Fuels?

Okay, here is a quiz:

How much do you think Americans should spend, in total, on energy (in 2010 US dollars) over the next 20 years?

A. 5 trillion
B. 10 trillion
C. 20 trillion
D. 40 trillion or more

[The rest of this page left blank so you can think about it without having my answer in front of you. Proceed to the next page after you come up with an answer of your own.]

The best answer, without a doubt, is D, 40 trillion or more. This is only slightly subjective. If you are a reconstructionist (secular or religious) and feel the world must be destroyed in order to be renewed, then answer A (5 trillion) would be best.

At our current rate, the US will spend about $4.5 trillion on energy over just the next 3 years. So, if you are giving the US an energy budget of $5 trillion over the next 20 years, that's about the same as saying the US will cease to function and should most likely get ripped to shreds.

Answers B and C imply a massive contraction of the US economy – assuming we could survive any of these levels of contraction at all. We currently have about 10 percent unemployed, after a mild contraction in recent years. If we had a 20-year energy budget of $10 trillion, most people would be unemployed within a few years. The US withstood 25 percent unemployment in the 1930s – the Great Depression. We can probably withstand that level again or worse. How much worse before the system is ripped to shreds by angry masses? Your guess is as good as mine.

There exists, I believe, a level of unemployment that the system simply cannot withstand. People tend to have no trouble knowing there are starving people in the world... as long as they are not knocking on the door.

How did I come up with $40 trillion? I took the most recent number (from 2008, $1.4 trillion) and ran 20-year totals using a couple of very conservative trial percentages for rate of increase, two and three percent, and got 35 and 40 trillion respectively (for 2009 through 2028).[53]

In a fossil fuel based economy, especially post-peak, we are in a grow or die situation. That is, we need to increase the energy sector just to stay where we are at in terms of non-energy economic activity. When we reach the point we use renewable energy only, a steady-state economy is possible – not now, however. A two percent per year increase is probably not enough. We have averaged over 3 percent per year over the last 20 years and I believe we need to do at least that much if only to limp along.

If we do the things we should in order to replace fossil fuels, we will have a high level of economic activity and growth. Energy expenditures could easily be far more than $40 trillion, and that would be a good thing. After a complete transition to renewable energy has been achieved, energy expenditures would not need to go up at all – we would only be spending on operating and maintenance of the energy plants and distribution system.

I prepared the following table to give a better idea of the numbers involved and to clarify the urgency. We can say that in the 1990s, we were awash in cheap oil, still riding the wave from the oil price crash of 1985-86. The economy improved and we were spending less on energy even while using more energy (per capita energy consumption only went up slightly but the population and economy were growing). By 2000, the fantasy-land of cheap oil was fading.

Of the nearly $18 trillion we spent on energy in this 20-year period, around $15 trillion went to pay for fossil fuels. We pulled it out of our energy bank and burned it up like there was no

53 Here is a spreadsheet in pdf format showing these figures: http://www.safeenergyassociation.org/ad/cumulative-expenditures.pdf If you want the spreadsheet in a format you can edit, you can download it here (need to have OpenOffice to use it): http://www.safeenergyassociation.org/ad/cumulative-expenditures.ods

tomorrow. Here is Exhibit A in my case for why I believe we are at the peak of oil production worldwide right now. These are statistics for the US, but since we use over 20 percent of the world's energy, and we buy much of it from all over the planet from global multi-national corporations, it is pretty representative of what is happening worldwide. If we're at the peak, you'd expect to see large efforts to get more energy but no more energy being produced. This is exactly what the numbers show.

Energy consumed and what we paid for it (adjusted to 2010 dollars) for 20-year period 1989 – 2008 from latest US Department of Energy data

Large increase in energy: no increase in cost (1989–1999)

Very large increase in cost of energy: no increase in quantity of energy (2000–2008)

Very high rate of increase in cost of energy (% Increase, 11.42 through 10.20)

Year	Quads	Energy Expenditure	% Increase
1989	84.9	770,317,000,000	1.71
1990	84.7	789,162,000,000	2.45
	84.6	754,077,000,000	-4.45
	86.0	739,829,000,000	-1.89
	87.6	741,806,000,000	0.27
	89.3	742,545,000,000	0.10
1995	91.2	736,226,000,000	-0.85
	94.2	779,036,000,000	5.81
	94.8	770,844,000,000	-1.05
	95.2	703,842,000,000	-8.69
	96.8	729,094,000,000	3.59
2000	99.0	869,599,000,000	19.27
	96.3	856,094,000,000	-1.55
	97.9	803,648,000,000	-6.13
	98.1	895,448,000,000	11.42
	100.3	1,006,567,000,000	12.41
2005	100.4	1,170,194,000,000	16.26
	99.8	1,255,606,000,000	7.30
	101.5	1,299,141,000,000	3.47
2008	99.4	1,431,655,000,000	10.20

		$17,844,730,000,000	

The only experience we have remotely resembling this occurred in the 1970s and early 1980s. *This time, it is not US production that has peaked, it is worldwide production that has peaked.* Back then, an oil price collapse would happen because so many other countries had so much oil, and there weren't many competitors for the oil.

Over the most recent six years for which with have energy expenditure data (2003-2008), we have been averaging increases of around 10 percent per year. We cannot sustain 10 percent per year increases. It is absolutely impossible. As energy becomes more expensive, EROI goes down. As EROI goes down, we have to increase energy production just to maintain our level of economic activity. It is nearly impossible to increase production of fossil fuels at this point – maybe slightly, maybe temporarily, but it is a losing battle. If we stick with fossil fuels, we will be facing economic collapse. If you think ten percent unemployment is bad, what about twenty percent? And that will look like the golden age when unemployment reaches seventy percent.

Let the Market Decide

The purpose of government was described in the Declaration of Independence: “that to secure these rights, governments are instituted.”

Government is there is protect the rights of the people. Where we have issues involving air quality, water quality, economic opportunity, access to public resources, public land use, preservation of resources for future generations, public safety, and public health, the government must act on behalf of the people to secure our rights. The government must act to correct bad policies or lack of policies. Energy is intertwined with all of these issues.

When it comes to energy, “Let the Market Decide” is not a valid position. There are too many energy issues involving public safety and public welfare – rights of the people. The government must be involved actively. This is not to exclude private enterprise. Business will do most of the work and put up most of the money. Government must define the playing field, set the rules, and play referee for participating businesses.

This is not simply a task for the federal government. Large solar power plants under construction now in California and elsewhere show cooperation between federal, state, and local government.

California has been the leader in renewable energy for quite a long time. California is also by far the largest state population-wise. This is not to say other states should not take leadership roles as well, and indeed they have. Texas has great potential for wind and solar and is taking some initiative.

We also need a less anemic federal energy plan, but for a variety of reasons, a state-by-state plan is necessary. Each individual state has different demographic and geographic characteristics that will require a different plan. It would help if state plans were coordinated with a federal plan.

Safe Energy Roadmap for California

I live in California (near the State Capitol), and I plan to introduce a resolution in the State Legislature (I'm looking for an author). I am tentatively calling it the *Safe Energy Roadmap*. The resolution will call for a series of hearings to discuss California's path to a 100% safe energy system, and call for a report to be produced. The report will support future legislation that may be needed. Who would conduct the hearings, who would write the report, and to whom the report would be directed are open for discussion.[54]

We have already had calls for a 20 percent Renewable Portfolio Standard (RPS) and Governor Arnold Schwarzenegger has issued an Executive Order[55] for a 33 percent RPS by 2020. These are excellent and necessary steps. However, we also need a longer-term vision of where we are going. I think the hearings should discuss the 20 percent and 33 percent milestones and also look at what needs to be done to reach milestones at 40 percent, 50 percent, and so on up to 100 percent.

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54 My guess is that the Senate and Assembly energy committees would be conducting joint hearings and other committees may be involved. I also guess the report would be addressed to the Governor, but I won't really know until I get an author.

55 See http://gov.ca.gov/press-release/13273/

Safe Energy Proposal for California

Here are just a few items I think should be a part of the longer-term vision for California:

- Phase out the use of all fossil fuels by 2040
- Phase out nuclear fission power plants by end of this century
- Aggressive phase-in of wind and solar
- Electrification of transportation wherever feasible
- Hydrogen pipeline grid installed statewide, including connections to all vehicle fueling stations

Benefits

- Permanently stabilized cost and supply of energy
- No air pollution from fossil fuel burning
- No CO2 emissions
- No other fossil fuel related pollution
- Improved health and safety
- Jobs
- Replacement of dangerous, aging natural gas pipelines

Cost

While there will be a substantial investment required, the conversion will save Californians money. As it stands, Californians are spending approximately $146 billion per year on energy[56] – about ninety percent of that on fossil fuels. At current rates and at current dollars, this would amount to $4 trillion spent over the next 20 years or $7 trillion over the next 30 years.

We should be able to finance the transition in such a way that we spend less than these amounts for total energy expenditures and wind up with the desired complete phase out of fossil fuels. Most of the investment would be private money, while the state government would encourage local investment as much as possible, including investments by local governments.

United States Energy Policy

While a detailed safe energy plan for California will be complex, a similar plan for the US would be vastly more complicated still. Nonetheless, the same general principles outlined above should be the same for the entire US. In addition, we need a way to get energy from west to east.

In general, solar energy is more readily available out west while there is more intense energy usage out east. On the following page, I have a picture (courtesy of geology.com) of the US at night so you can see where the lights are. The picture (from NREL) below that shows the best places for the big concentrating solar power plants. Notice that the yellow and red are all in the west. We are going to need the hydrogen pipeline nationwide to get energy from west to east.

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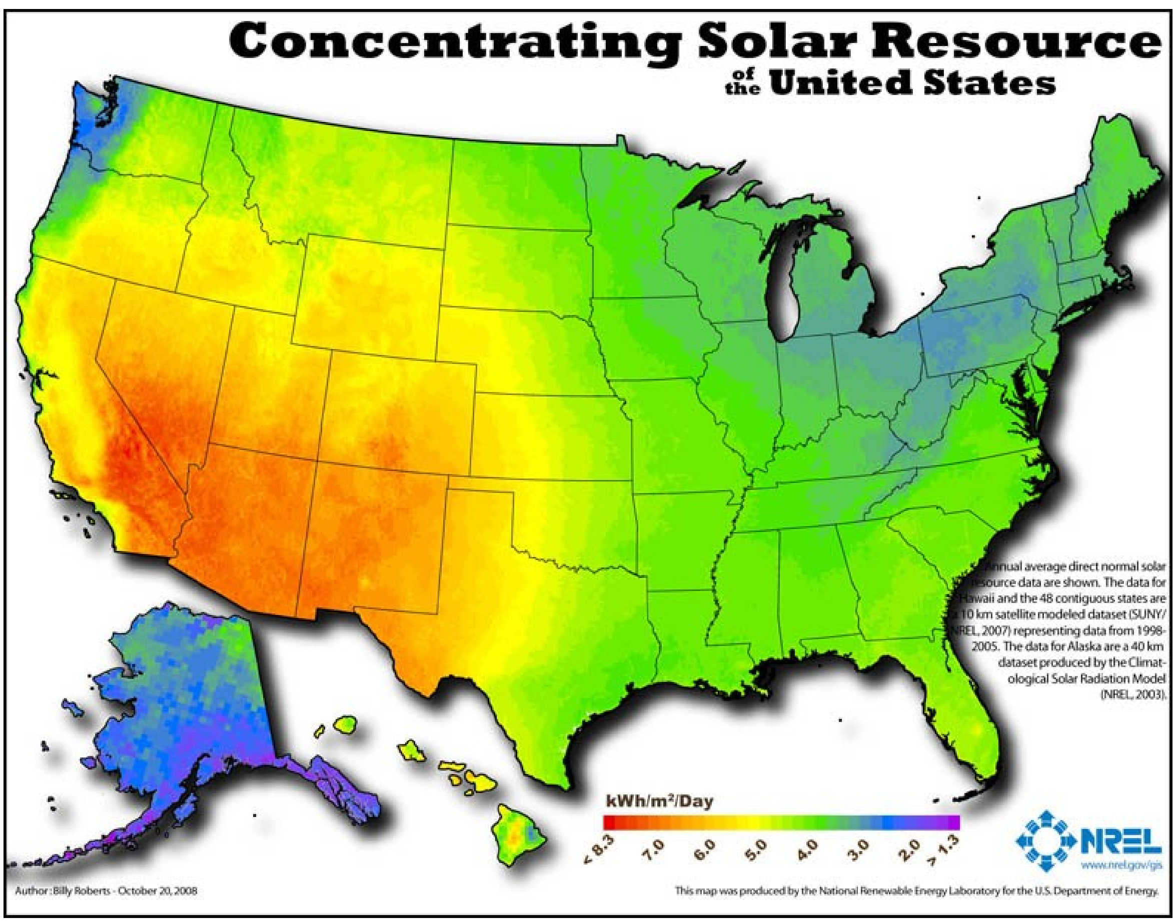
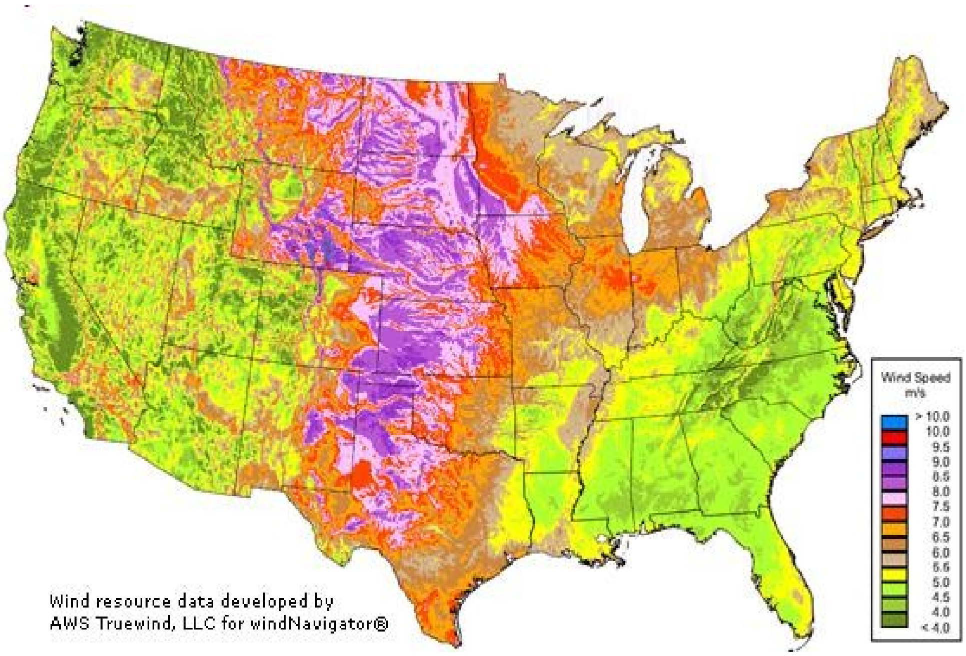
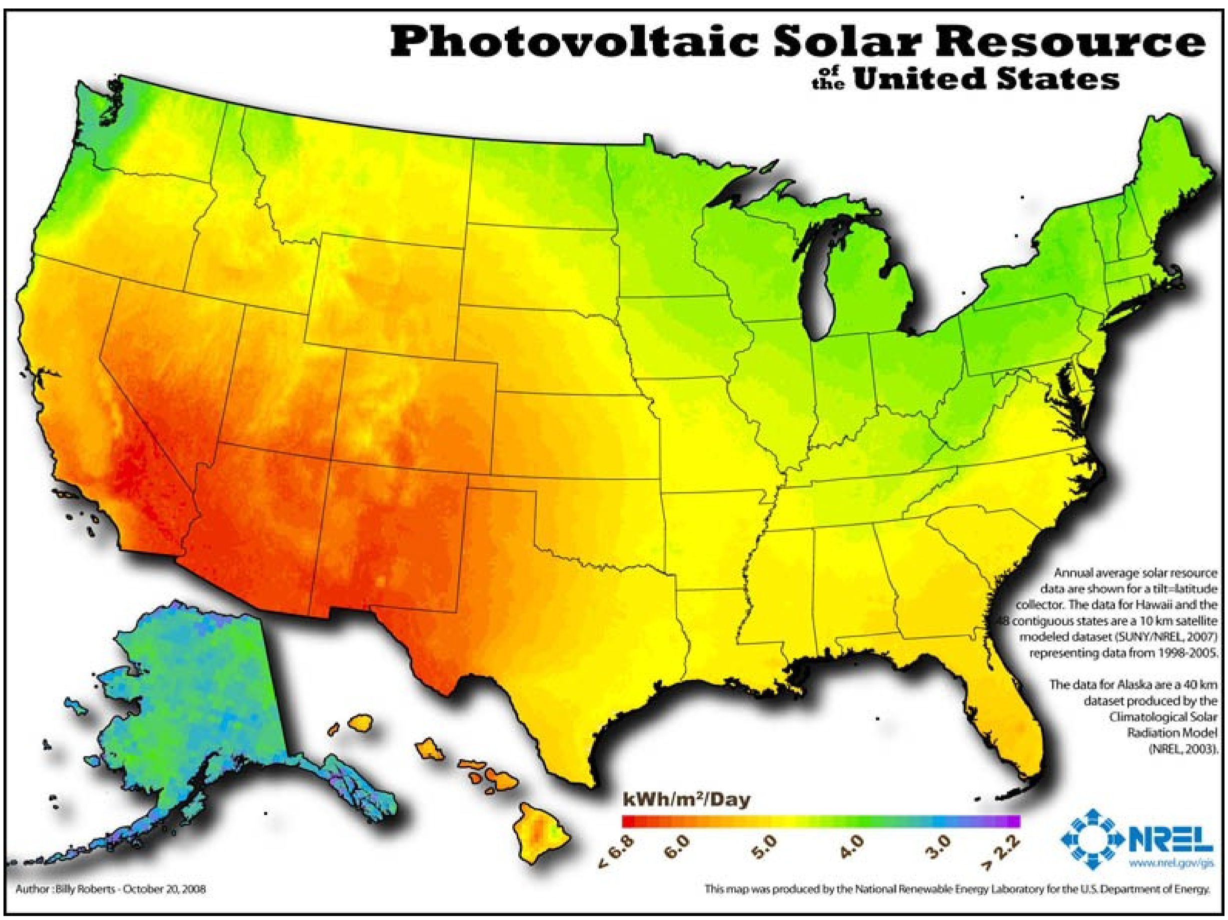
56 See table 1.6, page 13 http://www.eia.doe.gov/aer/pdf/aer.pdf considering that expenditures have gone up about 15 percent per capita since the latest figure given and CA has population of about 38 million. The $4 trillion figure includes 3.3 percent escalation per year (about the average rate of increase over the last 20 years). Or, roughly figure that California is one-tenth of the US economy.



Concentrating Solar Resource
of the United States
Annual average direct normal solar resource data are shown. The data for Hawaii and the 48 contiguous states are a 10 km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2005. The data for Alaska are a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).
kWh/m²/Day
< 8.3
7.0
6.0
5.0
4.0
3.0
2.0
> 1.3
NREL
www.nrel.gov/gis
Author: Billy Roberts - October 20, 2008
This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.

The potential for wind and photovoltaic power is more widely available than concentrating solar. There is a great swath of land from Texas to the Canadian boarder for wind (purple and red).

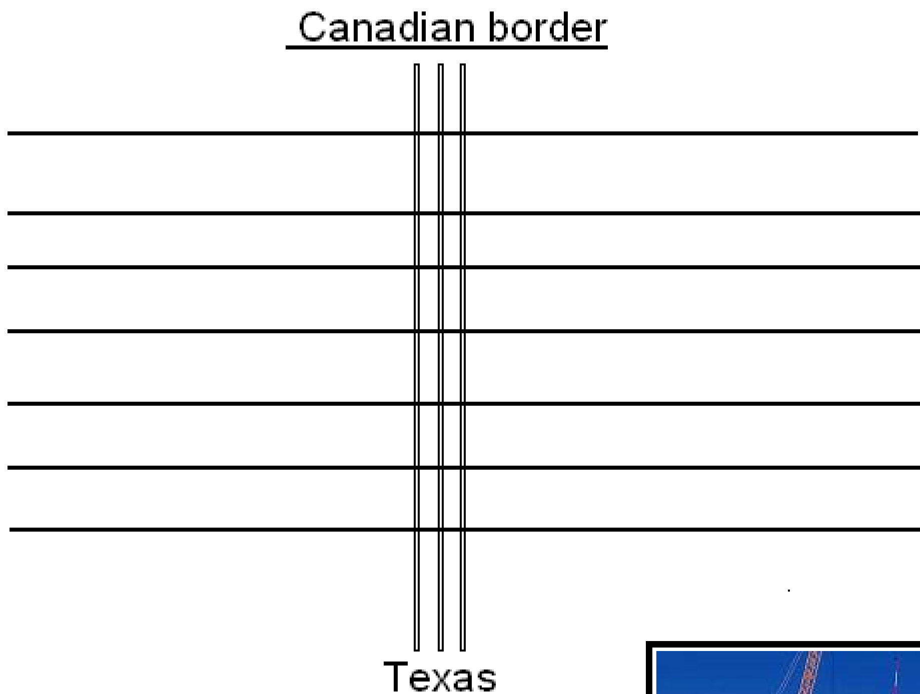




An idea for a hydrogen pipeline backbone

In this section, I present an idea that seems to make sense to me but in no way diminishes the rest of this article in case there is a better idea to accomplish the same thing. I am presenting it to help readers visualize how a renewable energy based United States might work.

Looking at the wind power map with this stretch of windy land from Texas up through the Dakotas – including parts of Montana and Minnesota – suggests to me there could be a kind of backbone for the hydrogen pipeline grid with wind turbines running near the pipes.



I suggest three pipes going north and south. This way, among other advantages, if one (or even two) of the pipelines is down for repairs, it still functions. Roughly speaking, the three north and south pipes would run through the TX/OK panhandle.

I have the pipes all straight. Of course, they would follow whatever path is needed. I just drew it to give an idea. The length from north to south would be about 1200 miles. The width would vary from maybe 150 miles to the width of North Dakota. If the average width were 200 miles, this corridor would be around 240,000 square miles. Let's say we install 120,000 wind turbines in this area on the scale of the Enercon model E-126[57] (pictured to the right. This turbine is rated at six megawatts but is supposed to go up to seven megawatts soon). In this area, a 33 percent capacity factor is reasonable.

57 See http://www.enercon.de/www/en/windblatt.nsf/vwAnzeige/66BD14BABA22BCA2C12573A7003FA82E/$FILE/WB-0407-en.pdf

In this design, the 120,000 turbines would be connected to the electrical grid, but would mainly just pump hydrogen into the pipeline. At times when all the machines are running at full capacity, the power output would equal 840 nuclear power plants. So, only a small percentage of the power would be used nearby.

I derived some of the data that follows from a paper by Idaho National Laboratory, and U.S. Department of Energy National Laboratory. The paper is titled *Feasibility Study of Hydrogen Production at Existing Nuclear Power Plants.*[58] It has one of the more detailed recent estimations for generating hydrogen from electricity on a large-scale.

The most relevant estimates are given in Appendix G (Plant Design for 1500 kg H2/day) and Appendix H (1 kg per second). Interestingly, the much-larger facility described in H has about the same costs per unit as the one in G.

I would include hydrogen generating plants like G and H to handle output from the turbines. This would add about $500 per kilowatt to the capital cost. Then add another $500 for electric power transmission, water for the hydrogen plant, power conditioning (flywheel storage, frequency regulation[59]). Assuming an installed cost for the wind turbine of $2000 per kilowatt before the hydrogen plant and other additional requirements, that would make a total of about $3000 per kilowatt, capital cost.

So each machine would cost about $21 million installed with hydrogen generating capability. If we put three machines per square mile, that would take about 40,000 of the 240,000 square miles in this area. The actual area taken out of production (for farming, etc) would be very much smaller, because the turbine bases, facilities, and the access roads only take maybe 3 percent of the area. So the dedicated area would only total about 1200 square miles.

Each turbine would produce an average of about 44 kilograms of compressed hydrogen per hour.[60] What do we get for that? Forty-six billion kilograms of hydrogen per year pumped into the pipeline grid. That is enough hydrogen to run 220 million hydrogen powered cars.

This measure alone would replace something like 13 percent of our current energy consumption at a cost of about 2.5 trillion dollars. Given an energy budget of $40 trillion over the next 20 years, this should be doable. We would be replacing the fossil fuel with renewable energy at a cost less than what we would expect to pay for the fossil fuel. Even including the cost of replacing all the natural gas lines with the hydrogen pipeline ($300 billion, estimated) grid,[61] it is still under 3 trillion. We'll have to gradually replace all our cars, but we have to do that anyway.

The hydrogen pipeline grid means that solar and wind production, intermittent as they may be, get absorbed into the grid all the time. We need to keep the pressure in the pipeline within acceptable limits, but a great deal of the storage requirement can be handled by the pipeline itself. We can also connect the pipeline grid to under ground caverns for additional storage as needed. Having many energy producers connected to the power grid and pipeline grid evens out supply.

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58 See http://www.inl.gov/technicalpublications/Documents/4310610.pdf

59 See http://www.beaconpower.com/products/about-flywheels.asp

60 7000 kw x .33 equals 2310. According to this report, we can expect 52.4 kwh per kg of hydrogen. 2310/52.4=44

61 Replacing 300,000 miles of pipe at one million dollars per mile is 300 billion dollars.

Solar and the Persian Gulf Oil Producing Countries

Currently, there are four Persian Gulf countries that are especially important oil exporters for the US, namely, Saudi Arabia, Kuwait, Iraq, and United Arab Emirates.[62] They produce a lot of oil, they export a lot of oil, and they are also addicted to their own product. The day they are using all the oil they produce is the day the US cannot import oil from anywhere.

They have a lot of oil, and they also have a lot of money, a lot of desert land, and a lot of solar energy beating down on the sand. What if we got them interested in converting their own economies to 100% solar? They are already showing some interest. Why might they be interested? Perhaps to prepare for a future when they do not have oil. It would make their own reserves last longer, too. This would also give the rest of the world, including the US, more time to withdraw from oil addiction.

The better we are doing with our own solar energy systems, the more impressed they will be and the more likely they will be to build their own large-scale solar installations. We should invite them to see the solar power plants being constructed in California.

Sound far fetched? Nine years ago (shortly after 9-11), I wrote an open letter[63] to President Bush urging that he get moving on solar conversion. Toward the end of the letter, I suggested that Saudi Arabia might be interested in solar. I got a lot of people to sign the letter, including quite a few scientists and engineers from around the world. I distributed the letter widely and included quite a few people in Saudi Arabia. Recently, I noticed Saudi Arabia announced their goal of ten percent of their power coming from solar by 2020.[64]

What did my letter have to do with it? Nothing, I assume. But they did get the message somehow. I never received any acknowledgement from anyone there (I did receive an acknowledgement from Vice President Cheney's office,[65] two years after sending the letter).

With this article, I expand on what I wrote before: I believe all the oil exporters should go for solar in a big way. Interestingly, they tend to be in areas that receive intense sunshine. It would be best for everyone, and would also help with CO2 reduction worldwide.

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62 See the 2007 US GAO report on Peak Oil: http://www.gao.gov/new.items/d07283.pdf Pg 16 has an estimate of world oil reserves by country. The report concludes (pg 38), ***"The prospect of a peak in oil production presents problems of global proportion whose consequences will depend critically on our preparedness. The consequences would be most dire if a peak occurred soon, without warning, and were followed by a sharp decline in oil production because alternative energy sources, particularly for transportation, are not yet available in large quantities. Such a peak would require sharp reductions in oil consumption, and the competition for increasingly scarce energy would drive up prices, possibly to unprecedented levels, causing severe economic damage. While these consequences would be felt globally, the United States, as the largest consumer of oil and one of the nations most heavily dependent of oil for transportation, may be especially vulnerable among the industrialized nations of the world."***

63 See http://www.safeenergyassociation.org/ad/solarletter.html

64 See http://in.reuters.com/article/idINLDE64I27X20100519

65 See http://www.safeenergyassociation.org/ad/cheney2003.pdf I enjoyed the opening sentence, "This is a note to acknowledge the letter that you sent to Vice President Cheney some time ago." Actually, the letter was addressed to President Bush. I cc'd the Vice President, as well as quite a few other officials in the government.

Conclusion

Solar Two DOE demonstration project near Barstow, CA – a baby compared to commercial plants soon-to-be
Photo courtesy of Sandia Labs

We are on the precipice of another energy crisis, which is potentially much worse than what we saw in the 1970s. I wrote this article because I believe that energy value theory provides a way to understand, grapple with, and ultimately master the situation. My intended audience includes policy makers, business people, investors, and anyone else with the patience to wade through this complicated subject.

History is not on our side. We are not good at avoiding crises. A tear-less joyful energy conversion program to avert this disaster does not seem likely. We tend to need to see widespread human suffering before we do anything major.

The response to anyone explaining to government officials the likely outcome of unregulated large-scale mechanized farming in the Great Plains was, “let's wait and see if you're right.” It took the Dust Bowl to get the Soil Conservation Act.

The energy crisis of the 1970s was as predictable as the Dust Bowl. In fact, the looming peak of US oil production was well-described and well-understood during the 1950s. The government's response was, “let's wait and see if you're right.” Why do we do that? Is it because we thrive on the drama of death, destruction, and catastrophe?

Once oil production peaked in the US in 1970, decline was inevitable. There was no way to explore fast enough or drill fast enough to make make up for declining production at existing wells. We were able to make up for declining domestic production by increasing imports.

But now, worldwide production has peaked. To a certain extent, we can turn to natural gas and coal, but that's a losing proposition as well – temporary and ugly at best. The age of fossil fuels is on the way out.

As long as we remain addicted to fossil fuels, they will become more expensive (lower Energy Return On Investment, or EROI) and we must produce more of it just to stay at the same level of economic activity. Since we are unlikely to increase fossil fuel production, we will experience economic contractions: many things we used to do will no longer be supported by the available energy. Unemployment will be higher – perhaps unbearably high.

Nuclear power has yielded a fairly good EROI but there is no way to significantly increase energy production from nuclear plants in the near term. It takes about 10 years for a nuclear plant to come on line after the decision has been made to build one. In the mean time, nuclear plant construction will be a drain on resources.

The only way out of this downward spiral in the near term is to make large investments in renewable energy. Gasoline powered cars have to go away.[66] But will we do it?

Given the demonstrated industrial capabilities of the United States, there is no doubt that a complete conversion to non-fossil energy could be accomplished quickly. In the early 1940s, the federal government ordered the building of hundreds of thousands of military aircraft, millions of tons of bombs, and a plethora of other vehicles, ships, guns, and tanks. Huge Liberty-class merchant ships taking 6 months to build in 1941 were being turned out one per day by 1945.

The feat of building all the wind turbines the US would need for a 100% renewable energy economy is probably less demanding technically and resource-wise than building the 300,000 military aircraft built for the war. And we built all those aircraft in a matter of five years, while dramatically improving performance of the machines. The billions of square feet of solar panels needed would be no major task compared to the tens of thousands of war ships we built. We needed to put millions of unemployed people to work on these tasks during the war. We did that, too, and all of it in five years. We have more unemployed people than that now.[67]

But that was a command economy. We do not have a command economy now, and we should probably not hope for one. We cannot ask for and should not expect the level of sacrifice and hardship endured by military people as well as everyday citizens during the WW II years. We are highly unlikely to accomplish a similar transformation in 5 years, even though it is possible.

Somewhere between the 5-year miracle transformation and a coal-smoke-blanketed centuries-long misery-ridden slog, there must be a happy medium – 20 to 30 years to make the change. If enough people can be convinced, it will certainly be done.

✦✦✦✦✦✦✦✦✦✦

66 The need for the hydrogen pipeline grid is one of the major points in this article. We will need hydrogen powered cars, whether fuel cell or internal combustion. We will also need electric cars. The electric cars could become an integral part of the electric grid. In a solar powered economy, we will want to charge the cars during the day. The proportion of electric and hydrogen powered cars will need to be continually balanced over time. I mentioned the Tesla as an example of an electric car. The Chevy Volt may be a little closer to large-scale production. Chevy is also working on fuel cell powered cars. Ford and others are also working on fuel cell and electric cars. Mention of specific brands (like Enercon) is not meant as an endorsement. GE, a US company, is also a major wind co.

67 There were about 8 million unemployed in the US when WW II started. The number of unemployed in the US today is about 15 million (see http://www.bls.gov/news.release/empsit.nr0.htm), about the same number as the height of the Great Depression in 1933. The percentage of unemployed in 1933 was much higher – about 25 %.