Topic: The quixotic search for energy solutions

Another Don Quixote Thanksgiving. Every year at Thanksgiving[1], we look in-depth at an issue that affects markets and portfolios. Last year, we examined the unraveling situation in Europe. Unfortunately, most concerns we expressed last year have been borne out, and are getting much worse (I spent the weekend reading legal documents on a Eurozone break-up, just in case). Like Don Quixote, Europe went on its journey for all the wrong reasons, adopting a half-pregnant monetary union to support a political objective that had arguably already been achieved by 1955[2]. This year, a look at something just as worrying in the long run as the fiscal problems of the West: **the search for energy solutions**. This journey has been fraught with similarly quixotic dead ends, fairy tales and blunders ignoring economic (and thermodynamic) realities. This is important to us, since energy cost and availability is central to how we think about growth, profits, stability and our portfolio investments.

As part of this effort, I made a pilgrimage to Manitoba to spend a day with Vaclav Smil. Vaclav is one of the world's foremost experts on energy, and has written over 30 books and 300 papers on the subject (he's #49 on Foreign Policy's list of the 100 most influential thinkers). Vaclav's book "*Energy Myths and Realities*" should be required reading for politicians or regulators impacting energy policy. We start with an unflinching look at these realities before turning to solutions, and some potentially encouraging developments, which have less to do with how electricity is generated, and more to do with how it might be stored.

"A dream is a wish your heart makes" (*Cinderella*)

Over the last 50 years, a lot of proposed solutions have not panned out as expected. While the process of discovery and invention *always* includes large doses of failure, energy policy is different than say, cell phones or VCRs, since more public money, time and effort are spent on them. Hopes are raised, and as a result, less flashy but more reliable solutions are sometimes postponed or avoided altogether. Here are a few memorable predictions of our energy future:

- *1945*. Oak Ridge National Laboratory nuclear physicists Weinberg and Soodak predict that nuclear breeders will be man's ultimate energy source; a decade later, the chairman of the US Atomic Energy Commission predict it would be "too cheap to meter"
- *1973*. "Let this be our national goal: At the end of this decade, in the year 1980, the United States will not be dependent on any other country for the energy we need to provide our jobs, to heat our homes, and to keep our transportation moving." Richard Nixon
- *1978*. "Through modeling of supply and demand for over 200 US utilities it was projected that, by the year 2000, almost 60% of US cars could be electrified, and that only 17% of the recharging power would come from petroleum."
- *1979*. An influential Harvard Business School study projects that by 2000, the US could satisfy 20% of its energy needs through solar
- *1980*. Physicist Bent Sorenson predicts that 49% of America's energy could come from renewable sources by the year 2005
- *1994*. Hypercar Center established, whose lightweight material and design would yield 200 mpg cars with a 95% decline in pollution
- *1994*. InterTechnology Corporation predicts that solar energy would supply 36% of America's industrial process heat by 2000
- *1995*. Energy consultant and physicist Alfred Cavallo projects that wind could have a capacity factor of 60%, which when combined with compressed air storage, would rise to 70 – 95%[3]
- *1999*. US Department of Energy hopes to sequester 1 billion tonnes of carbon per year by 2025
- *2000*. Fuel cell companies announce 250-kilowatt production plants that can fit into a conference room and produce energy at 10 cents per kilowatt hour, with the goal of 6 cents by 2003
- *2008*. "Today I challenge our nation to commit to producing 100% of our electricity from renewable energy and truly clean carbon-free sources within 10 years. This goal is achievable, affordable and transformative." Al Gore
- *2009*. Gene scientist Craig Venter announces plans to develop next-generation biofuels from algae in a partnership with Exxon Mobil

How have things turned out? There are no commercial nuclear breeders on anyone's horizon; global nuclear capacity is only 20% of the Atomic Energy Agency's 1970 forecast; the Hypercar is nowhere to be seen; solar and wind make up a miniscule portion of US electricity generation; wind capacity factors range from 20%-30%; the US is reliant for 50% of its oil from foreign sources; 70% of US electricity generation comes from coal and natural gas; fuel cells haven't worked as expected; hybrids are 2% of US car sales; "clean coal" is mostly a blueprint; and Venter announced that his team failed to find naturally occurring algae that can be converted into commercial-scale biofuel (they will now work with synthetic strains instead)[4].

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[1] Some clients tell me it is helpful to have something to read this weekend, when/if family gatherings become unwieldy, or aggravating.

[2] A few years ago, Swedish and Dutch politicians mobilizing support for the EU Constitution referred to "Yes" votes as necessary tribute to the dead from the Second World War, and more urgently, to avoid the pre-war divisions which led to it. Conflict between European empires existed for hundreds of years (1871-1914 was the only period of peace until 1945), so the idea of a united Europe would have seemed appealing in 1945. However, **conditions for securing a lasting peace within Western Europe were arguably *already in place* by 1954**.

[3] A 2005 paper from Stanford raised expectations further by estimating **theoretical wind power** at 72 TW, 30x global electricity production.

[4] **Algae** are inefficient photosynthetic reactors (they do not consume CO_2 when the sun isn't shining), and allocate only a tiny fraction of captured solar energy into lipid production. A 2007 study by Krassen Dimitrov at the University of Queensland predicted GreenFuel's demise in advance, claiming that the company estimated its photosynthetic efficiency at almost double the maximum theoretical rate, and could only be profitable at $800 per barrel of oil. Genetic improvements of plant life have historically focused on disease resistance and modifying the split between production of "fruit vs. stem"; it is used less often to increase growth rates of biomass itself.

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Today's US energy reality: electricity generation

Before exploring why some of these ideas did not pan out, let's look at where the US is right now in electricity generation. The table below shows each energy source; its installed capacity; the electricity this capacity generated in 2010 and percent of total generation; its capacity factor; and its long-term levelized cost for new construction, estimated by the Energy Information Agency. Capacity factors are important since they measure the intermittency of each source (capacity factor = actual generation relative to potential maximum generation). Baseload natural gas plants can run at higher factors than 28%; this number reflects the fact that many gas plants are used as "peaking" facilities to provide short-term energy during periods of elevated demand.

As stated above, fossil fuels dominate, followed by nuclear. Hydroelectric is next (efficient and cheap, but most large-scale sites are already in use); followed by non-hydroelectric renewable energy, which across all categories makes up less than 5%, in part due to their low capacity factors. Non-hydroelectric renewable energy is a similarly small component of the country's *overall* energy use, a broader category which includes transportation fuels[5].

Energy Information Agency	Installed base 2010 MW	Electricity gen in 2010 mm MWh	% of total gen.	Implied capacity factor	EIA Levelized cost 2016 per MWh	<---Levelized cost incorporates upfront and ongoing capital costs, cost of capital, fuel and other operating costs, capacity factor and related power transmission investments (in 2009 dollars) for new construction
Coal	316,800	1,847	45.4%	67%	$95 - $110	Abundant and cheap, but with a substantial range of environmental problems
Natural gas	407,028	988	24.3%	28%	$60 - $70	Capacity factors understate potential utilization
Nuclear	101,167	807	19.8%	91%	$114	Efficient once built; very expensive to build (costs rising sharply in recent decades)
Hydro	78,825	260	6.4%	38%	$86	Most viable sites already in use after incentives in the 1960s-1980s
Wind	39,135	95	2.3%	28%	$97	Low capacity factor, maturing technology; cost more than doubles offshore
Biomass/wood	11,406	56	1.4%	56%	$112	Expensive to aggregate and collect; high capital costs relative to energy density
Geothermal	2,405	18	0.4%	85%	$102	Very expensive, except near areas with active geothermal reservoirs
Solar PV/CSP	941	1	0.0%	15%	$210 - $312	Expensive, low capacity factors; this segment is commercial (non-res) installations

Energy Conversions 101

What went wrong with renewables? Theories generally fall into 3 buckets: (i) why bother, since there are plenty of fossil fuels; (ii) renewable energy would have a larger share if it benefitted from the massive R&D put into things like nuclear; and (iii) renewables have thermodynamic, structural and practical limitations that inhibit their ability to represent much larger shares of electricity or transportation fuel production. While (i) and (ii) have some merit[6], it is hard to escape (iii). *Energy Conversions 101* is meant to show why, using examples[7] that I expanded from Vaclav's narrative (unit equalities on p.8).

Question #1: How much more electricity would the US need if it switched to electric cars?

200	watt hours per km for average electric car
20,000	km driven per car per year
245,000,000	number of US passeneger cars
980,000,000	MWh for US passeneger cars per year, all electric
980	TWh for US passenger cars per year, all electric
10%	+ Increase due to battery self-discharge
1,078	TWh for US passenger cars per year
4,325	TWh of US electricity production
25%	Incremental electricity need

Implication: This is incremental *generation*, not *capacity*, since *some* existing facilities could produce more. But it's still a huge increase in generation, and the cost will depend on where you plan to get the electricity from, and when. Gasoline is used on site; electricity is generated offsite and then moved across what is perhaps the worst electrical grid in the OECD. Note that we did not include transmission losses here; if we did, generation requirements would be higher. This also ignores electric car battery life issues (heat, cold, etc) and the rising cost of rare earth metals needed for electric cars.

Question #2: Do electric cars require less energy than gasoline powered cars? If not, what might the other benefits of electric cars be?

4.4	MWh per electric car per year (see assumptions in #1)
Now let's figure out the PRIMARY energy needed to make this electricity...	
60%	Efficiency loss of generation process (avg for US coal and nat gas generation)
10%	Electricity transmission losses
12.2	MWh of primary energy required per car per year
44,000	Megajoules of energy per electric car per year (3,600 MJ=1 MWh)
2.2	Megajoules per car per year per km driven
15.9	km/liter for electric car when the primary energy (coal or gas used to generate electricity) is expressed in gasoline equivalents (35 MJ=1 L)
37.4	Primary energy requirement of electric car, expressed in miles per gallon

Implication: In other words, **primary energy** required to power electric cars is not that different from high mpg gasoline cars, which exist already. Depending on how electricity is generated, there *could* be some emissions benefits (but not if coal is the primary source of electricity, as it is now). There would be much less depedence on foreign oil, a US objective for decades. But some benefits could also be obtained through a high mileage fleet, perhaps less of an undertaking than switching to electric cars. If efficiency losses from electricity conversion in coal, nuclear or gas plants were reduced from 60% to 50%, that would help the thermodynamics of electric cars substantially; but that's a big if.

[5] Domestically produced and imported biofuels make up around 14% of US liquid fuels consumption.
[6] The nuclear industry was the recipient of 96 percent of all funds appropriated by Congress for energy R&D between 1945 and 1998.
[7] These examples are of course assumption-dependent; I tried to be conservative. I am sure you will let me know if I wasn't.

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Question #3: What if the world ends up relying on coal for the next 100 years, and seeks to prevent further increases in carbon emissions. How large an undertaking is it to bury 15% of all CO_2 emissions?

33.2	billion tonnes of CO_2 emissions (2010)
5.0	Sequestration target, billions of tonnes
Now let's shrink the CO_2 by compressing it before burying it…	
0.80	Compressed gas density, tonnes per cubic meter
6.2	Volume of compressed CO_2 to bury, billions of cubic meters
3.9	Amount of global crude oil extraction, billions of tonnes (2010)
0.85	Density of crude oil, tonnes per cubic meter
4.6	Volume of global crude oil extracted, bn cubic meters (2010)

Implication: Capturing a small portion of CO_2 emissions requires a compression/transportation/storage industry whose throughput is greater than the one used for oil extraction; and without the benefit that oil provides as an energy input. Coal-fired plant capital costs could rise 40%-75% (as per IPCC), and their electricity consumption could rise by 30%-40% for CCS particulate removal and flue gas desulfurization. Unlikely in time to prevent a further rise in CO_2 emissions; unexplored legal and NIMBY issues as well.

Question #4: What would be the reduction in gasoline needs if the entire U.S. corn harvest not already used for ethanol were repurposed for more ethanol?

160,000,000	US corn harvest, tonnes, 2010, not already used for ethanol
159,667,200,000	US corn harvest, kg, not already used for ethanol
0.40	Conversion ratio, liters of ethanol per kg
63,866,880,000	Liters of converted ethanol
67%	Energy density of ethanol relative to gasoline
42,699,571,200	Effective gasoline-equivalent savings (liters)
521,845,394,389	Liters of total US gasoline consumption in 2010
8%	Reduction in gasoline needs by repurposing entire corn harvest

Implication: Benefits of corn ethanol appear to be close to their maximum production level. There is of course the issue of ethanol's "energy return on investment" (EROI), for which estimates range from 0.8:1 to 1.6:1. Charles Hall at SUNY ESF (originator of the EROI concept in the 1970's) published recent EROIs for oil (10-20); Tar sands and Shale Oil (3-5); Nuclear (5-15) and Wind (15-20, but that excludes the cost of back-up peaking plants). In that context, the EROI for corn ethanol, which excludes the various layers of subsidies involved, is well below the fully loaded economic benefits of other fuel sources.

Question #5: What about cellulosic ethanol? And what about using spent coffee grounds?

225,000,000	Tonnes of US corn stover, annual
224,532,000,000	kg of US corn stover (using conversion factors from #4)
40%	Amount that can be removed without destroying soil
89,812,800,000	Stover removed
30%	Efficiency losses (evaporation, transportation, etc)
62,868,960,000	Remaining dry stover of uniform condition for conversion
0.34	*Theoretical* conversion ratio, liters of ethanol per kg of stover
21,375,446,400	Liters of ethanol produced from stover
14,291,012,736	Gasoline-equivalent ethanol from stover (see #4)
2.74%	Percent of gasoline needs reduced from conversion of stover
And another fun fact…..	
0.16%	Percent of global diesel fuel production offset by somehow gathering all of the world's spent coffee grounds and then converting them into biodiesel

Implication: Apart from Brazilian sugarcane, which grows 365 days a year and needs no irrigation or fertilizer (it self-fertilizes), biofuels are challenged due to the cost of aggregation, low energy densities and high energy extraction costs. For algae limitations, see note 3.

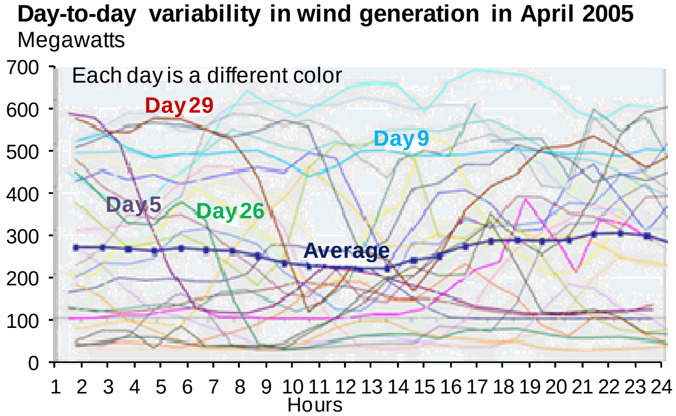
Question #6: How much area would be needed for a quarter of US electricity generation to come from wind?

2.3%	Wind as a % of electricity generation
10	Growth factor
23%	Target wind generation
95,000,000	Existing wind generation, MWh, 2010
950,000,000	Target MWh
28%	Wind capacity factor
387,312	Required incremental MW of wind
2	watts per meter squared required for wind farms
193,656	square km of required area
And on the need for expensive HVDC transmission lines…	
30,099,000	US population living in prime wind and/or solar states [AZ, OK, NE, WY, CO, ND, SD, KS, IA, MT, NM + Northern TX]
309,350,000	US population

Implication: 194 thousand square km is about the entire area of Nebraska. It would be a massive undertaking which requires, as stated earlier, hundreds of billions of dollars for new transmission lines. To be clear, land under wind turbines still have many practical economic uses. The larger issues are transmission and intermittency, as described below.

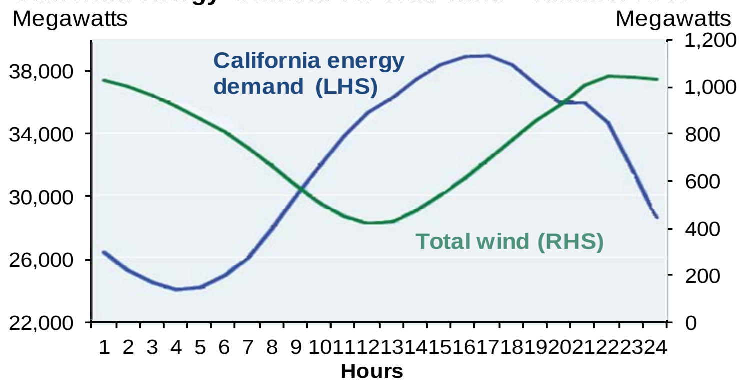
As for wind, let's put aside concerns about space requirements and transmission lines. Let's also put aside problems of wind's reliance on rare earths like neodymium for its turbine magnets (neodymium prices **quadrupled** this year, and that's with wind still making up *less than 3%* of global electricity generation). Let's also put aside debris (from birds/insects), ice storms and other natural elements that reduce wind farm efficiency. **The reason to put them aside: if wind were more reliable, like hydropower, it could justify a lot more expense and effort. Unfortunately, wind is not that reliable**. The first chart is the "Mona Lisa" of wind unreliability, measured at one of California's largest wind farms. The second is from the California Independent System Operator, showing how wind power tends to be low when power demand is high (and vice-versa).

Day-to-day variability in wind generation in April 2005



Source: Electric Power Research Institute. As measured in Tehachapi, CA

California energy demand vs. total wind - summer 2006



Source: California Independent System Operator, Integration of Renewable Resources, November 2007.

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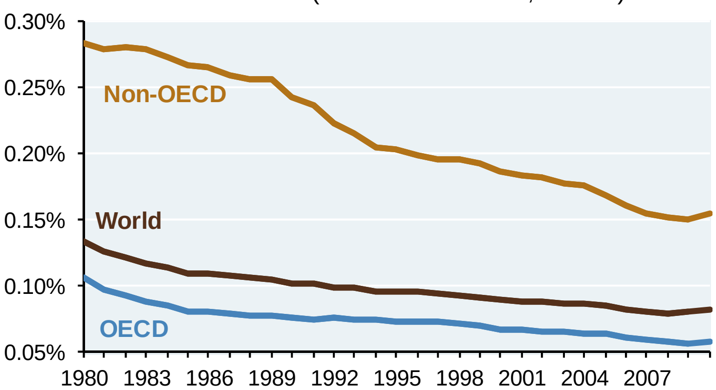
Wind should play an important role, but unless there is a high-voltage, high-capacity, high-density grid to accompany it (as in Northern Europe), or electricity storage, **the variability of wind means that co-located natural gas peaking plants are needed as well**. The cost of such natural gas plants are rarely factored into the all-in costs of wind, but perhaps they should be.

These exercises are important, since unfounded expectations might lead to suboptimal policy choices. One example: the Keystone Pipeline extension, which the President has opted not to consider until after 2012. The US imports more oil from Canada than from any other country. With the extension, the Keystone system would account for 13% of US petroleum imports. The pipeline has been opposed on environmental grounds, but the extension itself would only add 1% to the entire network of crude oil and refined product pipelines already criss-crossing the US. Moving petroleum products by rail or truck instead is more expensive and riskier. If the US does not provide a market for the Alberta tar sands oil, it could end up on tankers to China; and the US will end up importing more of its energy needs from the Persian Gulf and Venezuela. Could misperceptions about wind, solar and biofuel[8] feasibility explain why some people are opposed to this extension? Unclear.

<u>**The art of the possible**</u>

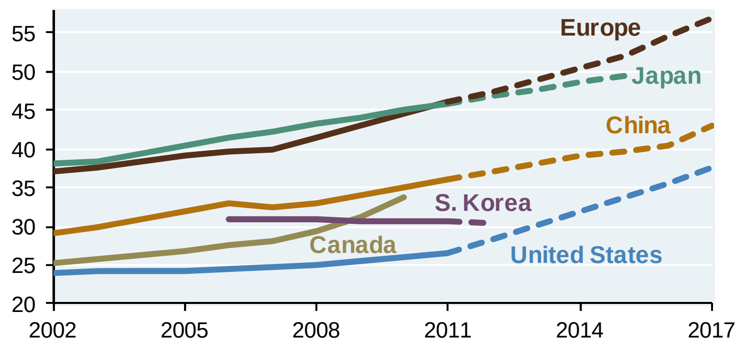
Now let's take a (desperately needed) look at some good news. Over the last 3 decades, the oil intensity of the developed world has been falling, followed by non-OECD countries (see first chart). **This is not meant to suggest that declining availability of cheap crude oil isn't a problem, since it is.** There are lots of studies showing rapid declines in the production rate of existing crude oil fields, and that the discovery of new fields is (a) not keeping up, and (b) are located where marginal costs of extraction are considerably higher. No need to repeat them here. But oil's importance to economic growth has been declining over time, and there is no reason to believe that these improvements have completely run their course.

Oil intensity declining worldwide
Billions of barrels/real GDP (constant 2000 USD, trillions)



Source: ISI Group, International Energy Agency, World Bank.

Actual and projected fuel economy for new passenger vehicles by country, Miles per gallon



Source: The International Council on Clean Transportation, United Nations Department of Economic and Social Affairs.

There is also room for reduced fuel consumption, although here's another case where energy fairy tales might have postponed smart policy choices. While waiting for a holy grail, the US left fuel efficiency standards unchanged from 1983 (light trucks) and 1987 (cars) until 2010. Chrysler head Lee Iacocca said this in 1986 when Ford/GM lobbied the Reagan Administration to lower ("CAFE") fuel efficiency standards: "**We are about to put up a tombstone that says, 'Here lies America's energy policy'. CAFE protects American jobs. If CAFE is weakened now, come the next energy crunch, American car makers will not be able to meet demand for fuel-efficient cars**." Well, the rest of the world kept on truckin' as he suggested, and have more efficient fleets (see chart). If the US fleet were 30% more efficient, US gasoline consumption could fall by 40 billion gallons per year (~1 billion barrels). For context, the US imports 0.36 billion barrels of crude per year from Venezuela, and 0.62 billion from the Persian Gulf. The US just increased fuel efficiency standards, but it will take time to make an impact.

Other possible good news includes ongoing research by Daimler Engine Research Labs on improving gasoline engines, something the world should not give up on just yet. Prototypes with fewer cylinders and smaller displacement may yield a car with both lower fuel consumption and lower emissions, eventually at fuel efficiencies greater than hybrids like the Prius. The US Recovery Act included $100 million for Advanced Combustion Engine Research and Development; it could be money well spent. One example the DoE is working on: semiconductors, powered by the heat exiting the car in its exhaust pipe, used to create electricity and power the car's accessories, which are usually powered by belts driven by the car's engine.

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[8] Here's one view on biodesel from Giampetro (Barcelona) and Mayumi (Tokushima), authors of "*The Biofuel Delusion*" [2009]: "The promise of biofuels as a replacement to fossil fuels is in fact a mirage that, if followed, risks leaving us short of power, short of food, destroying biodiversity and doing as much damage to the climate as ever."

The other good news relates to the discovery of new natural gas reserves. US shale gas production is up 14-fold over the last decade, and the EIA projects that by 2035, the US will no longer be a gas importer. Yes, the Energy Department recently slashed estimates of gas in the Marcellus Basin from 410 trillion cubic feet to 84 trillion; this followed the latest survey by the US Geological Survey, which last estimated the basin at 2 trillion cubic feet in 2002. However, the historical imprecision of peak oil/gas estimates make it a difficult science. To be clear, shale gas production will be critical; EIA projections to 2035 assume that rising shale gas production will offset declines in almost every other gas category (see p. 7). Deep sea gas reserves are a potential positive, but marginal costs may be an issue. As for shale gas exploration and radium (naturally occurring and surfaced in sometimes dangerous concentrations), and fracking chemicals themselves, the cost of natural gas electricity appears low enough to absorb costs related to wastewater collection and treatment. Eventually, replacements will be needed for fossil fuels. What "art of the possible" solutions do is give the world more time to find them. **In the meantime, many scientists would prefer to put as much emphasis on efficiency as on new technologies**. Examples include 95% efficient natural gas furnaces, LED/fluorescent lighting and more insulation. The largest direct energy saver in a 2010 report by the Pacific Northwest National Laboratory for the Department of Energy: **deployment of diagnostic devices in residential and commercial buildings to manage HVAC systems and lighting.**

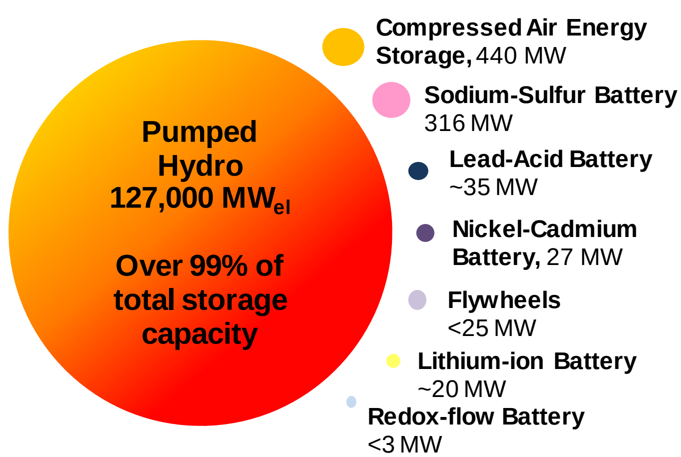
<u>A potential game-changer: electricity storage that works, in commercial scale</u>

What would potentially change the energy equation is **storage**. The world has been *generating* commercially available electricity for over a hundred years, but as things stand now, the world has almost no electricity *storage*. The benefits of electricity storage, if it could be implemented, are self-evident:

- increased cost-effectiveness of intermittent solar and wind power, and lower electricity costs, since electricity produced by wind at night could be stored and sold during the day; and electricity produced during sunny days could be stored and sold during cloudy spells. There are obvious tie-ins to the feasibility and cost of electric cars
- lower required **peak** production capacities of large urban power systems, by drawing on stored electricity reserves
- deferral or avoidance of costly upgrades to the transmission grid. As per the North American Electricity Reliability Corporation, only 27% of grid upgrades relate to integrating renewable energy. Almost half are designed to improve overall reliability, due to fluctuating loads (since the grid has to accommodate peak loads, and not just average ones)
- reduced consumption of fossil fuels which power most stand-by generators

Unfortunately, battery storage has moved along at a snail's pace. Moore's Law on doubling semiconductor capacity is something of a distraction; technology improvements over 15-18 months are hard to find anywhere EXCEPT semiconductors. Solar photovoltaic cell efficiency has doubled over 15-18 *years*; and battery storage has progressed even more slowly as it relates to commercial-scale applications[9] (rather than lithium ion applications for cell phone and laptops). As a reminder, electricity is simply defined as the movement of electrons, which can only be "stored" as potential energy, for example via large height or chemical gradients (e.g., batteries).

The accompanying chart shows the existing state of commercial-scale electricity storage; **it's all about pumped hydro**[10], a process that uses cheaper electricity at night to pump water uphill into a reservoir basin, and then releases the water during the day to power a hydro-electric generator. The other technologies are an afterthought, at least right now. Note that more energy is expended in pumping the energy uphill than is generated by releasing it downhill; the economic value derives from much higher electricity prices during the day. Around 10%-20% of the potential pumped hydro energy is lost over time through evaporation and conversion losses.



Source: Fraunhofer Institute, EPRI, Electricity Storage Technology Options, 2010.

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[9] Companies like A123 produce commercial scale batteries, but they are primarily for grid-smoothing. A123's lithium ion batteries are meant to store energy for *fractions* of an hour, rather than for hours or days.

[10] Most pumped hydro facilities are designed to run for 10 hours uninterrupted (before being empty). Assuming 127 GW of installed capacity, that means that 1,270 GWh of electricity would be produced before their reservoirs ran dry. That amount of stored electricity is 0.0064% of annual global generation. That is a *very* small supply; inventory storage for crude oil is 10%-12% of annual production.

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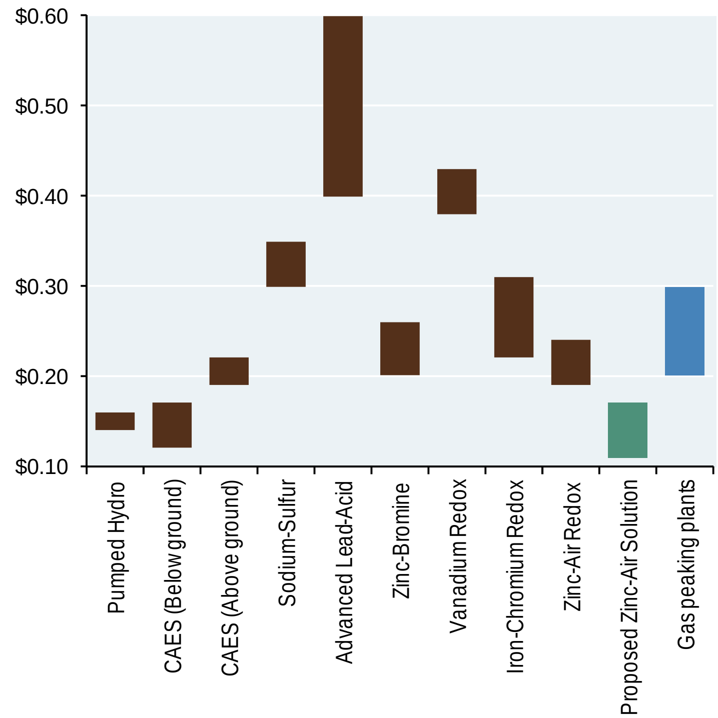
There's no room to go through the complexities of the storage technologies shown below. Here are a couple of generalizations:

- Less expensive options like pumped hydro and compressed air storage require favorable sites with the right geology, which are rare in nature and expensive to build from scratch (and often not located near electricity demand centers), and in the case of compressed air, require co-located gas turbines for compression
- Many battery-based technologies suffer from high upfront capital or operating costs; low energy storage volumes; delayed response times; safety issues (such as zinc bromine); or short lives (limited number of recharge cycles)

I had a meeting a few weeks ago which was notable for its optimism and enthusiasm. I met with the managers of Eos Energy Storage, which is working on a zinc air battery solution which aims to conquer all of the obstacles outlined in the second bullet point above. If the Eos projections bear out, they will offer battery storage at a capital cost of ~$160 per kWh, in the form of a 1 MW battery that is the size of a 40 foot shipping container (for 6 MWh of storage). As with the table on page 2, the concept of "levelized cost" synthesizes upfront costs, financing costs, useful life, fuel costs and ongoing maintenance expenses. Rather than looking projections of capital costs per kWh, levelized cost comparisons are more useful. As shown, Eos aims to be the cheapest option that can be scaled, and flexibly and safely located where needed. Note as well that they expect to be cheaper than natural gas peaking plants. This is a relevant benchmark, since most utilities rely on natural gas peaking plants to meet daily peak load requirements and to compensate for intermittent renewable generation of wind and solar. If storage works, the need for lots of peaking facilities could disappear.

Eos has a prototype of its Zinc-Air technology that has run around 2,000 cycles so far; we should all pray either for their success, or for the success of similar efforts undertaken by their competitors. Based on the outcome of energy dreams shown on p.1, we should always be skeptical of breakthrough claims, given the complexity of the challenge. Let's hope for the best.

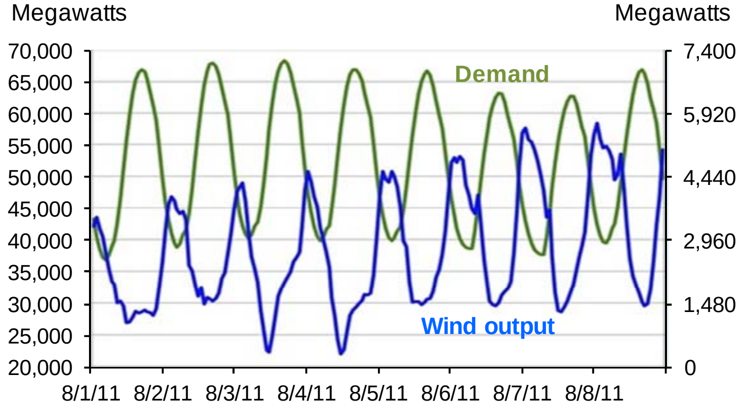
The cost of electricity storage options
Range of levelized costs, $ per kWh



Source: EPRI, Electricity Energy Storage Technology Options, 2010, Eos. CAES: Compressed Air Energy Storage.

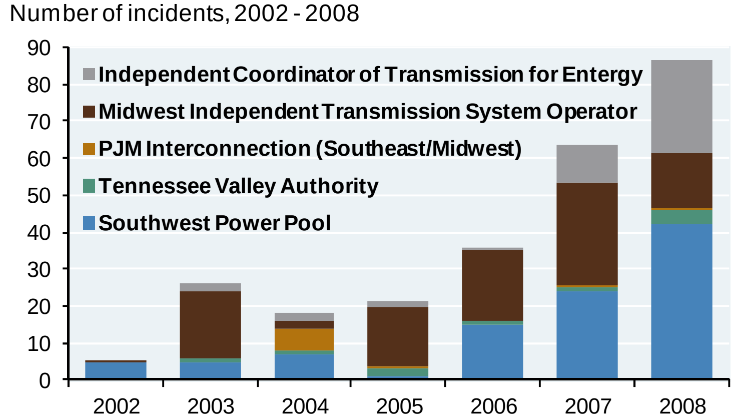
Here's another look at the financial rewards to anyone who can figure this out. Note how demands on the Texas electricity grid (ERCOT) are almost 100% inversely correlated with when the wind blows. Either ERCOT gets connected to the national grid, storage solutions are invented, or a lot of wind energy continues to be underutilized. On the right, what happens when 70% of the grid's transmission lines, transformers and circuit breakers are 25-30 years old: **rising congestion problems, signified by rising loading relief requests**. Grid storage has the potential to alleviate some of this congestion.

Texas electricity demand vs. actual wind output
Megawatts Megawatts



Source: Electric Reliability Council of Texas.

Transmission loading relief requests
Number of incidents, 2002 - 2008



Source: North American Electric Reliability Corporation.

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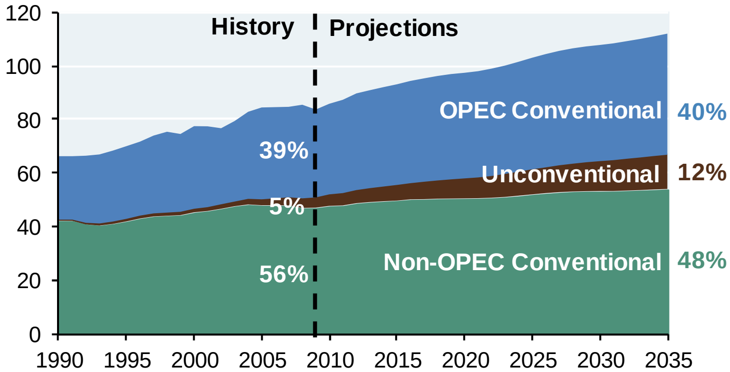
<u>A setback for nuclear, and some investment consequences</u>

The saddest energy moment of the year was the failure of the Fukushima Dai-ichi nuclear power plant in March. Weaknesses of the original design and actions taken in the immediate aftermath of a massive tsunami combined to produce a disaster: the latest studies show emissions of radioactive cesium that are equal to half of the release from Chernobyl. The concept of nuclear power is one of man's greatest achievements, but generating it safely and in a cost-effective way (including decommissioning) makes it a difficult undertaking. In some ways, **nuclear's goose was cooked by 1992**, when the cost of building a 1 GW plant rose by a factor of 5 (in real terms) from 1972. Before he died, father of the hydrogen bomb Edward Teller's last paper argued that nuclear power plants (molten salt reactors, specifically) do not belong on the surface of the earth, and belong underground instead, to deal with the clean-up and failure, if it happened. And that's from one of nuclear power's greatest supporters.

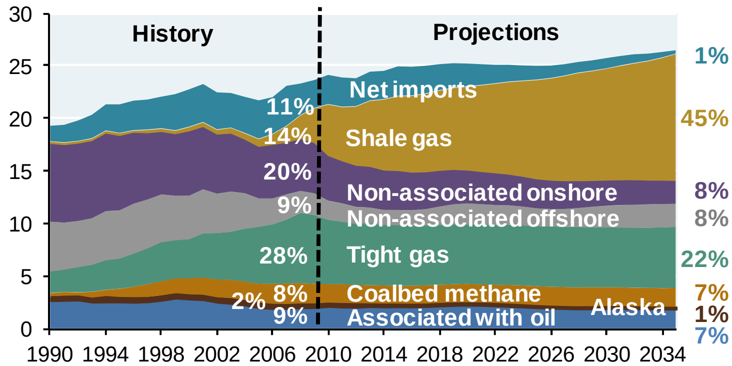
From a broader perspective, the era of cheap oil appears to be over. As shown below in the first chart, almost the entire future increase in oil supplies projected by the EIA are based on unconventional supplies (tar sands, deep-sea drilling, enhanced oil recovery, oil shale, etc.), with the word "*unconventional*" being shorthand for "*more expensive*". As for natural gas, as shown in the second chart, EIA projections assume that rising U.S. shale gas production, with all its uncertainties in terms of associated costs, will offset declines in almost every other category. It is hard to precisely quantify the speed bump on growth that this creates for the world, and as things stand right now, **deleveraging of household, corporate and sovereign balance sheets in the US and Europe is a much bigger risk for financial markets**. As I write this, Italy has entered an acute state of distress; its credit default swap spreads are now at levels which prompted bank runs in Greece and Ireland. In the long run, as we outline return expectations for the future, uncertainties related to energy availability are yet another reason why price-to-earnings multiples may remain well below their historic averages. A break in the chain of unfulfilled promises from breakthrough technologies will be needed to alter this view.

Global liquids production
Million barrels per day



Source: U.S. Energy Information Administration.

US dry gas production
Trillion cubic feet per year



Source: Energy Information Administration.

Absent an unexpected renaissance in cheap and abundant nuclear power, or unexpected solar breakthroughs[11], we seem to be in for another 20-30 years of reliance on fossil fuels. As a result, that's how our own energy-related investments have been positioned. Given the risks and returns associated with energy investing, a lot our exposure has been executed through private investments rather than public markets. Across the full range of energy-related investments in our private equity portfolios, roughly 70%-80% are related to conventional energy, and the remainder to a variety of renewable strategies.

Conventional energy investments. The majority of our conventional energy investments are "upstream" (exploration and production of oil and natural gas). The remainder are in midstream assets (pipelines/storage) and services, with very little in downstream assets (refining). On natural gas, new finds have been rewarding, even with natural gas prices at current (low) levels, since large major oil and gas companies aggregate proven reserves, and are willing to pay a premium for them given their long term horizons. On crude oil, many of our investments focus on so-called "renaissance" plays, which entail older, mostly depleted fields which majors sell as they reshuffle their reserve mix to higher-growth assets. Service companies include firms providing enhanced oil recovery, fracking and waste-water management. Other servicing investments are related to deep-

[11] **On Solar Energy.** The EIA projects that even after further investment and expansion, commercial (non-residential) solar power will make up less than 1% of US electricity generation in 2035. Solar power suffers from intermittency, low electricity conversion rates, and the recognition that real-life installations have higher operating and maintenance expenses than previously thought. A paper presented this year at the Syracuse Biophysical Economics Conference by an operator of solar plants in Spain estimates that after taking unexpected operating expenses into account, the energy return on investment for solar is closer to 3 than to 8.

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sea fields recently discovered off the coast of Brazil. We have discussed these projects before (EoTM September 2009). The sub-salt fields in Brazil lay 7 kilometers below the surface of the ocean, beneath a thick salt canopy in the Lower Tertiary region. Oil extraction can be quite complicated due to the low permeability and porosity of the salt canopy, and tar pockets. Our investments in this region are linked to providing services, rather than owning exploration and production assets themselves. Overall, our experience in conventional energy investments has generally been positive.

Renewable energy investments. Our experience with renewable energy investing has much more mixed, for many of the reasons outlined in this paper. Some wind projects have worked well, while others (in the UK and in upstate New York) have not, mostly a function of less windy conditions than project managers anticipated. As with conventional energy, some of the better wind projects are related to providing services (constructing offshore wind farms, development for purposes of sale), rather than taking ongoing operating risk. Weather played a negative role as well: higher than expected precipitation in Brazil negatively affected our investments in sugar cane ethanol. Solar projects are on track (utility-scale projects in the US and Europe, and a company providing distributed solar solutions to small business), although both are highly dependent on continued subsidies. Natural gas discoveries have effectively raised the efficiency hurdle rate for renewable projects, and fiscal problems in the West may reduce the subsidies that underpin many renewable projects and valuations.

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Notes

Vaclav Smil is a Distinguished Professor in the Faculty of Environment at the University of Manitoba in Winnipeg and a Fellow of the Royal Society of Canada. His interdisciplinary research has included the studies of energy systems (resources, conversions, and impacts), environmental change (particularly global biogeochemical cycles), and the history of technical advances and interactions among energy, environment, food, economy, and population. He is the author of thirty books and more than three hundred papers on these subjects and has lectured widely in North America, Europe, and Asia. He is also noted by Foreign Policy magazine as #49 on its list of the 100 most influential thinkers in the world.

Citations

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For more information on Eos and zinc-air battery storage, see www.eosenergystorage.com

Acronyms

CAFE	Corporate average fuel economy
ERCOT	Electricity Reliability Council of Texas
EPRI	Electric Power Research Institute
HVDC	High voltage direct current
NIMBY	Not in my backyard!
EROI	Energy return on energy invested
IPCC	Intergovernmental Panel on Climate Change
CCS	Carbon capture and storage
CO_2	Carbon dioxide
EIA	Energy Information Agency
IEA	International Energy Agency
IAEA	International Atomic Energy Agency
PV	Photovoltaic solar
CSP	Concentrated solar power (the parabola version)
DoE	Department of Energy
SUNY ESF	State of New York, College of Environmental Science and Forestry
HVAC	Heating, ventilation and air conditioning

Conversions used in examples 1-6

1 megawatt	=	1,000,000	watts
1 terawatt	=	1,000,000	megawatts
1 petawatt	=	1,000	terawatts
1 megawatt	=	1,000	kilowatts
1 megawatt hour	=	3,600	megajoules
1 gigajoule	=	1,000	megajoules
1 liter gasoline	=	35	megajoules
1 mile	=	1.609	kilometers
1 gallon	=	3.785	liters
1 unit of carbon	=	3.7	units of CO_2
1 metric tonne	=	2,200	pounds
1 pound	=	0.4536	kg
1 barrel	=	42	gallons of gasoline
1 btu	=	1,055	joules

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