I’ll try to fill the main gap in our conversation so far—economics and competition—and thus to explain why new nuclear build is uncompetitive, isn’t needed to back up or to outpace the growth of far cheaper alternatives, and isn’t an effective way to protect the climate, so we don’t even reach such questions as whether it’s safe and nonproliferative.
Peter Bradford referred to the prevalent myth that nuclear power was flourishing until the Three Mile Island accident. Actually, 4–5 years before that accident, U.S. nuclear orders fell tenfold and never recovered. *
40% of U.S. nuclear-unit cancellations occurred before 1979, due to those pre-Three-Mile-Island economic challenges.

Koomey and Hultman’s definitive causal analysis showed with this graph that two-fifths of the nuclear cancellations occurred before 1979, leaving many other units teetering on the brink and soon to be cancelled as well. The bad economics that had already made nuclear power fizzle are also explained in *Business Week’s* scathing ten-page cover story on Christmas 1978, three months before TMI. It began: “One by one, the lights are going out for the U.S. nuclear power industry. Reactor orders have plummeted from a high of 41 in 1973 to zero this year.” (Actually the nation’s last two orders came a few days later.) And it found that for lack of a business case, “the U.S. nuclear industry is apt to contract dramatically, and it may collapse altogether.” That’s exactly what happened.
A new myth that a vibrant global nuclear renaissance was cut short by the Fukushima Daiichi accident is equally widespread and equally false. * Global nuclear retirements had already exceeded additions for two of the three years before Fukushima, again due to bad economics. So let’s look at those economics. *
Many existing U.S. reactors are now uneconomic just to operate. Reactors are promoted as costly to build but cheap to run. Yet as Daniel Allegretti ably described, many existing, long-paid-for U.S. reactors are now starting to be shut down because just their operating cost can no longer compete with wholesale power prices, typically depressed by gas-fired plants or windpower. This graph from my Bulletin of the Atomic Scientists article a year ago summarizes nuclear-industry data on the operating costs of all U.S. PWRs. Both within and between the four quartiles, each with 25 reactors, the operating costs vary widely, especially for major repairs or renovations—called “net capital additions” because they’re capitalized rather than expensed. These expenditures may fix failing old components, or may invest to increase the unit’s output or lifetime, or both, but the industry hasn’t publicly stated the mix of these causes. Suspicions are growing, though, that like an old car, some reactors are no longer worth fixing, or fixing them is too risky a bet that nothing else expensive will break for a long time. Last year, U.S. utilities bit that bullet and terminated 14 operating or planned units. Many more are reportedly at risk of closure this year.
This rise in real operating costs, chiefly for net capital additions (blue), steepened in 2008 and again in 2011, despite major improvements in the industry’s operating prowess and institutional learning. That seems consistent with age-related deterioration. And of course since the operating costs driving the shutdowns are a small fraction of the capital cost of building new reactors, their economic case is even weaker...*
US PWR capital costs have repeated their unhappy history

All-in (total project) costs are normally ~2× the overnight costs shown

Sources: historic: Drs. J.G. Koomey & N.E. Hultman, En. Pol. 35:5630–5642 (2007); projected: original sources, checked and reanalyzed by Molly M. Ward (RMI) in August 2010 in the graphical style of Prof. Mark Cooper (Vermont Law School)

...especially because their capital costs have stood up on end. This graph, in the format pioneered by Prof. Mark Cooper, combines the historic evolution of real overnight capital cost per net installed watt (the yellow dots) with the evolution of projections from various sources. The apparent rapid escalation around six years ago turns out to have been due not, as claimed, to the runup in commodity prices, which would explain only about 1% of total project cost, but rather to shifting definitions. The early, low estimates were mere marketing claims by vendors and promoters; the buyer would take all the price risk. The later estimates were firm or fixed costs, so the seller would take most or all of the price risk and thus had an incentive to estimate more realistically. *
A reasonable and honest conclusion...

“What is clear is that it is completely impossible to produce definitive estimates for new nuclear costs at this time…”


Apparent steep escalation reflected *who bears the risk* of capital-cost overruns

Amid such steep escalation and prohibitive capital cost, as the industry’s Steve Kidd rightly said, nobody really knows what new reactors would cost to build. Impressively low costs have been claimed for new Korean and Chinese reactors, but not yet transparently demonstrated, so the capital markets haven’t chosen to bet their own money. Since August 2005, the United States has offered 100+% construction subsidies for new nuclear plants, plus operating subsidies slightly bigger than windpower’s, without making a single reactor financeable with private risk capital. [The five under construction are being built under special laws that transfer all cost and all risk to the customers or taxpayers or both.] *
French nuclear power’s “unlearning curve” (no country has yet clearly demonstrated an actual nuclear learning curve)


Unfortunately, despite strong and devoted effort, nobody has shown how to overcome nuclear power’s prohibitive costs. No country has yet demonstrated a “learning curve” where building more plants makes them cheaper. The French program’s more than doubled real capital cost and construction time resembles the even stronger U.S. escalation whose fundamental causes, driven by the growth itself, were understood decades ago. Advocates of small modular reactors claim series factory production can overcome their higher capital cost (reactors don’t scale down well), but there’s no evidence this is true. Even if it were, small modular renewables, which do scale down well, are decades ahead in exploiting their enormous economies of mass production, so reactors could never catch up.

Hypothetical new (or, usually, revived old) kinds of reactors can’t win either, because even if the nuclear ~35% of the plant’s total capital cost were free, the non-nuclear ~65% would still be grossly uncompetitive, as we’ll see.
But even more importantly, **what are nuclear power’s competitors?**

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**Conventional theology:**

- Only other central thermal plants (coal, combined-cycle gas)
  - Efficiency and renewables are worthy but minor
  - Variable renewables (wind and photovoltaics) are not “24/7” or “baseload” and hence can contribute little “reliable” supply without huge backup or bulk-power-storage costs
  - Carbon pricing will benefit nuclear power

---

**Heresy based on observed market behavior:**

- Not central plants, which are *all* uncompetitive, but **negawatts** (saved electricity) and **micropower** (cogeneration + renewables – big hydro)
  - They’re cheaper, faster, more reliable, more attractive to investors, eclipsing nuclear, and winning wherever they’re allowed to compete
  - Variable renewables can cost-effectively provide reliable power with little or no bulk storage, if properly diversified, forecasted, and integrated—and can scale at least as fast as nuclear power
  - Carbon pricing benefits them and nuclear equally, and fueled cogeneration partially

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But *uncompetitive with what?* That’s the crux. * The nuclear industry claims its only realistic competitors are other central thermal power plants * burning coal or gas. But in fact, the evidence shows that its * arguments for excluding other competitors aren’t valid, and that * all central thermal plants cannot compete in the U.S., or probably anywhere else, with end-use efficiency, no- or low-carbon cogeneration, or carbon-free renewables. So I’ll next summarize those overlooked but potent competitors’ cost, reliability, speed, and cost-effectiveness for displacing fossil carbon emissions. *
1. Efficiency and renewables are far cheaper

The cheapest competitor is more efficient use of electricity. U.S. use of electricity peaked in 2007, then fell 2.4% while real GDP grew 6%. In 2012 alone, almost unnoticed, weather-adjusted electricity use per dollar of real GDP fell 3.4%—equivalent to increasing U.S. nuclear output by 130 TWh or one-sixth in a single year. Utilities’ “new normal” is stagnant or declining demand as efficiency outpaces economic growth. The resulting revenue erosion will heighten incentives for decoupling and shared savings, accelerating utilities’ efficiency efforts ($7b in 2013) as they did for gas.

As we’ll see later, over 4,000 program-years of experience in 31 states reveal average costs of efficiency around 2¢/kWh. Well-designed negawatts now cost only a third as much as in 1980—especially when integrative design is included, as it often makes very large savings cost less than small or no savings, turning diminishing returns into expanding returns. That’s how our retrofit of the Empire State Building is saving two-fifths of its energy with a 3-y payback; how our latest deep retrofit of a big office building is saving 70% cost-effectively; and how our Reinventing Fire analysis found a 75% reduction in U.S. electric intensity would have a technical cost of only 0.64¢/kWh based solely on private internal costs and benefits, and all meeting market hurdle rates. We showed how U.S. buildings’ energy productivity could triple to quadruple with a 33% Internal Rate of Return, and how industrial energy productivity could double with a 21% IRR. No wonder the IEA estimates the world is investing ~$0.15–0.3b/y in energy efficiency—and that’s still a gross underinvestment.
Renewable Energy’s Costs Continue to Plummet
Wind and photovoltaics: U.S. real capital cost trends

As for modern renewables, here on a logarithmic scale are the declining real market prices of photovoltaic modules (blue) and windfarms (green). Mass-producing these modular renewables makes them cheaper, so they grow faster, so they get cheaper, so they grow faster. In 20 states today, entrepreneurs can put solar power on your roof with no money down and beat your utility bill. Soon they’ll offer cash back. Some recently contracted utility-scale solar systems have a total installed cost of $1.50/W, and some developers expect to be at or below $1.30 by year-end as they apply and improve the streamlined installation methods already common in Germany and Australia. That’s how, last year, Solar City’s installed system costs fell 30% even though its module prices rose 3%. Already 10–15% of Hawai’ian homes use solar power, and many are dropping off the grid because solar plus full battery storage is cheaper. RMI’s new report “The Economics of Grid Defection” shows such “utility in a box” or “virtual utility” offerings will reach retail grid parity across the country well within the lifetimes of existing utility assets. *
Wind and even solar power in good sites now sell for well below the levelized cost of electricity from new combined-cycle gas plants.

**Utility-scale photovoltaics**

- **2006 (7 MW, 1 contract)**
- **2009 (1,066 MW, 14 contracts)**
- **2008 (770 MW, 3 contracts)**
- **2010 (1,193 MW, 21 contracts)**
- **2011 (463 MW, 7 contracts)**
- **2012 (590 MW, 5 contracts)**
- **2013 (135 MW, 5 contracts)**

**Windpower**

![Windpower chart](chart.png)

**DOE, 2012 Wind Technologies Market Report**
DOE/GO-102013-3948 (Aug 2013), p. 50

**LBNL, Utility-Scale Solar 2012**
LBNL-6408e (Sep 2013), p. 24

...so these modern renewables are manyfold cheaper than nuclear power, and even beat the levelized cost of combined-cycle natural-gas generation.

The Power Purchase Agreements that profitably sell the output of U.S. photovoltaic power and windpower projects, typically at constant nominal price and hence declining real price, empirically show dramatic and continuing price drops. Solar power in 2013 sold at levelized prices ~5–5.5¢/kWh (now just below 5¢) with a 30% Federal subsidy, corresponding to an unsubsidized price ~7¢ and falling. Midwestern windpower in 2013 sold for around 2–2½¢/kWh with Federal subsidy, ~4–5¢ without it, and falling. These prices are consistently beating new combined-cycle gas plants in the marketplace today. By the way, grid integration of variable renewables typically costs a few tenths of a cent, even for very large wind fractions, and are probably lower than the uncounted grid integration costs of central thermal plants. [For example, most studies find windpower needs balancing reserves equivalent to ≤5% of wind capacity—one-third of the reserve margin and spinning reserve normally required for large thermal generating units.] *
2. Renewables can deliver similar or better service and reliability

Yet many people still claim solar cells and windpower are too “variable” to produce much electricity reliably, because we can’t cheaply store huge amounts for when the sun doesn’t shine or the wind doesn’t blow. *That’s a myth. We don’t need a storage breakthrough or supposedly “24/7,” “baseload” coal and nuclear plants to keep the lights on.*
We won’t need big thermal plants to keep the lights on

“I think baseload capacity is going to become an anachronism....You don’t need fossil fuel or nuclear [plants] that run all the time....We may not need any [more], ever.”

—Jon Wellinghoff, Chairman
Federal Energy Regulatory Commission
22 April 2009

America’s * chief utility regulator said so five years ago. Here’s why he was right. *
Variable Renewables Can Be Forecasted At Least as Accurately as Electricity Demand
France, December 2011: *forecasted* vs. *actual* (1 day later)

First, “variable” does not mean “unpredictable.” We can predict solar and windpower at least as accurately as demand: * in this stormy winter month, forecast output from all French windfarms almost exactly * matched their actual output a day later. The small remaining errors vanished in the hours before actual dispatch. *
Those giant plants are shut down about 10–12% of the time, losing a billion watts in milliseconds, often for weeks or months, * often without warning. The grid handles * this intermittence by backing up * failed plants with working plants. *
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In the same way, but often more cheaply, the grid can manage the forecastable variation of solar and windpower by combining them with renewables in other places or of other kinds. Let me show you how this can work.*
The varying loads on the isolated Texas grid get smaller and less peaky with profitably efficient use. Now let’s make that electricity 86% from wind and photovoltaics, and 14% from other, dispatchable renewables like geothermal, small hydro, solar thermal electric, and burning feedlot biogas, urban wastes, and obsolete energy studies. The resulting diversified, all-renewable supply leaves surpluses to charge up ice-storage air-conditioners and smart electric autos, both assumed here to be fully built out by 2050. Then recovering that distributed storage when needed and filling the last gaps with unobtrusively flexible demand makes all the moving parts fit together: now we can deliver 100% renewable electricity every hour of the year, with no bulk storage and with only 5% left over.
Using such choreography, some European countries, without adding bulk storage, are already delivering 25–58%-renewable electricity far more reliable than America’s. Iowa and South Dakota, too, are over one-fourth windpowered today. So they and Europe have far transcended renewable power’s supposed reliability limits. Whatever exists is possible.
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Choreographing ~2/3-renewable U.S. el., summer 2050

The National Renewable Energy Lab has also choreographed reliable, up to 80–90% renewable electricity for the lower 48 United States.

Bottom line: Bulk electricity storage and fossil-fueled backup are the costliest flexibility resources, so we’d use them last, not first. A breakthrough in cheap bulk storage would be helpful but not vital. We needn’t wait for it—and the market isn’t waiting. *
About 98–99% of power failures originate in the grid, so distributed supply that bypasses the grid can boost day-to-day reliability. Denmark has nearly completed its transition from centralized power stations, mainly burning coal, to distributed wind turbines (86% owned by farmers and their communities) and cogeneration (often burning agricultural wastes). Partly in consequence, Denmark has Europe’s most reliable power, slightly ahead of Germany’s and about ten times more reliable than America’s.

Denmark is also reorganizing its grid in a highly resilient “cellular” architecture that makes cascading blackouts impossible. A similar approach reduced Cuba’s serious blackout days from 224 in 2005 to zero in 2007, and sustained vital services the next year when two hurricanes in two weeks shredded the eastern grid.
In contrast, the normally reliable nuclear fleet’s occasionally unresilient behavior is illustrated by Fukushima Daiichi (and four years earlier by the earthquake that shut down the the world’s largest nuclear plant, the 7-unit Kashiwazaki-Kariwa complex, some of which is still down); by mass deratings and shutdowns in U.S. and European droughts and heat waves; and by the Northeast Blackout in 2003. As shown here, nine U.S. reactors, running perfectly, automatically scrambled for safety, but then took 12 days to regain full power, and in the first few days, produced practically nothing because xenon and samarium poisoning robbed the reactivity needed for restart with stable and homogeneous neutron flux. This “anti-peaker” attribute of being assuredly unavailable when most needed has no parallel in diversified portfolios of modern renewables.*
Next, let’s examine recent claims that only nuclear power can scale up fast enough to meet global electricity needs, or protect the climate timely, or both. The data show the opposite.
Worldwide, starting in 2008, half of all new generating capacity has been renewable. This graph shows the amount of wind and photovoltaic generating capacity added worldwide in each year. In 2012, renewables were 49% of new U.S. and 69% of new European capacity, so America now has more solar jobs than coal or steel jobs. Also in 2012, China generated more windpower than nuclear power, and more new electricity from non-hydro renewables than from fossil fuels plus nuclear power. In 2013, China added more photovoltaic capacity than the U.S. has.

In each of the past three years, these modern renewables got a quarter-trillion dollars of global private investment and added >80 GW. In 2011 (or 2008 if we include small hydro) they surpassed the total global installed capacity of nuclear power, whose dwindling annual net additions, as I noted earlier, had turned negative even before Fukushima. In contrast, global orders for nuclear and coal plants keep fading because they cost too much and have too much financial risk to attract investors. Gas-plant investments held up better, but only because most buyers foolishly bet on the gas’s bare commodity spot price without including the market value of gas’s price volatility, which roughly doubles its risk-adjusted price.
Nuclear and micropower generation have more than swapped roles, reflecting market perceptions of their relative costs and risks ("micropower" = cogeneration + renewables – big hydro)

Cogenerating electricity with useful heat is another big competitor to central stations. Cogeneration combines with a smaller amount of renewables, excluding big hydro, to make up the “micropower” (as The Economist magazine calls it) that since 2000 has more than swapped its share of global electricity generation with nuclear power. Due to sparse and heterogeneous data, I won’t further analyze cogeneration here, but that’s a major conservatism, because it’s already outproducing nuclear power, has a strong business case, continues rapid growth, and is low- to no-carbon depending on its heat source.

Renewables scale faster than nuclear

Global installed electric generating capacity, 2006–2013

Definitions of * installed nuclear capacity depend on uprates and rerates, on * whether and * when retirements are counted, and on whether one assumes, as the * IAEA optimistically does, that all ~50 GW of Japanese capacity that’s been shut down for over two years will return to service even though their owners think at least ~30 GW won’t. But under all definitions, nuclear capacity has at best held steady over the past seven years, while * renewables excluding big hydro have tripled their capacity. The average kilowatt of nuclear capacity produces about twice as much annual electricity as the average kilowatt of renewable capacity (excluding big hydro), but based on these global trends...*
Renewables scale faster than nuclear

Global installed electric generating capacity, 2006–2013

Q2 2014 forecast:
- renewables production (900GW, ≥0.38CF)
- nuclear production (400GW, 0.8CF)

those renewables, which the nuclear industry doesn’t even acknowledge as a serious competitor, should surpass its own annual electricity production sometime during 2014.
This is happening because mass-produced renewables scale up in a fundamentally different way. Traditionally, we built giant cathedral-like power plants, each costing billions of dollars and taking many years to license and build—9.4 years for the average nuclear plant in the past decade [through July 2013]. But now approximately each year, you can build a factory that produces each year thereafter enough solar cells to generate each year thereafter as much electricity as your “cathedral” ultimately will. So solar output scales up incredibly quickly. Photovoltaics worldwide are scaling faster than cellphones.

Indeed, modular, short-lead-time technologies accessible to many market actors can add more total capacity sooner than big, long-lead-time technologies requiring specialized institutions. RMI’s motto is “In God we trust”; all others bring data.” So here are the data....*
Since 1950, the nuclear units (blue) and capacity (green) that the IAEA lists as “under construction” worldwide have peaked, declined, and modestly rebounded. The 72 units so listed [as of 22 March 2014]—including about a half-dozen listed for >20 years—are 68% in four centrally planned and rather untransparent power systems (China, Russia, India, and Korea), often building designs with unknown Western licensability. Another five U.S. units enjoy special nonmarket conditions. Ten other countries have one or two units each. Many of these 72 under-construction units are late, most have no official startup date, and not a single one was chosen by a competitive or analytic process that fairly compared them with the modern slate of available alternatives.

But leaving economics aside and focusing solely on speed, what got built in global nuclear power’s most aggressive phase when this under-construction slope was steepest?
In the peak year 1985, nearly 32 GW of gross nuclear capacity was added to the grid worldwide. The most successful three-year period, 1984–86, added nearly 92 GW. In contrast, non-hydro renewables added 88 GW in 2012 and 251 GW during 2011–13, adding capacity more than 2.7x as fast as nuclear’s all-time high. But average capacity factors are nearer 2.1 than 2.7 times higher for nuclear than for non-big-hydro renewables, which have therefore lately been adding more electrical output each year than nuclear power ever did.

**Maximum global capacity (GW$_e$) ever added to the grid using April 2014 preliminary Bloomberg New Energy Finance data for 2013**

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<thead>
<tr>
<th></th>
<th>during</th>
<th>renewables (including small hydro &lt;50MW)</th>
<th>during</th>
<th>renewable / nuclear ratio</th>
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<tr>
<td>nuclear</td>
<td>1985</td>
<td>88</td>
<td>2012</td>
<td>2.77</td>
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<td>31.8</td>
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<tr>
<td>91.8</td>
<td>1984–86</td>
<td>251</td>
<td>2012–14</td>
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Comparing electricity outputs since 1950, we see that the steepest part of nuclear power’s growth curve had a similar slope to non-hydro renewables’ recent growth. But then nuclear growth flattened and reversed as its costs rose for the reasons explained in the ’80s, while renewables are growing ever faster as their costs fall for today’s equally durable reasons. If we add the output from small hydro up to 50 MW, we see even stronger growth for all renewables excluding big hydro—which, by the way, is even larger and also growing rapidly, but is omitted here as a conservatism.
The national nuclear histories of * Sweden, * France, and * Belgium illustrate how nuclear power needed decades of institution- and capability-building before it could yield any significant output. In contrast, as we see for * Germany, mass-produced renewables can get out of the starting-blocks far sooner by exploiting globally marketed commodity equipment, fungible installation skills, rapidly evolving business models and channels, and choices by millions of diverse actors—or, in the case of * China, a determined central government driving aggressive, mainly private, industry. China’s output from renewables excluding all hydro matches that of the other triumph of central planning, the French nuclear program. Adding * small hydro, in which China leads the world, Chinese renewable output in 2013 was nearly three times China’s nuclear output [~112TWh/y] and is about to surpass France’s nuclear output.

France and China show broadly comparable slopes of electricity production growth for the world’s most aggressive nuclear and non-hydro-renewable programs, respectively. Also, Germany’s renewables, 25% of electricity consumption last year, already far outproduce Europe’s most ambitious nuclear programs except, of course, that of France, whose policy for 40 years was not to maximize competition but to prevent it. *
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Here’s a different lens on these data: after a long windup and initial growth spurt, nuclear power’s share of electricity consumed in *Sweden, *France, and *Belgium is slipping, while the renewable share in *Denmark, *Portugal, and *Spain is growing to respectable size—even without hydropower, which would bring Portugal to 58% and Spain to 45% in 2013. But all these graphs don’t show two other big, competitive, and fast-growing distributed resources: renewables *plus* efficiency *plus* cogeneration, all growing together, are far faster than renewables alone, and together leave any central-station solution in the dust. If we had better negawatt data, we could graph that trifecta.
Even with all lifetime extensions approved through July 2013, planned global nuclear additions can’t offset retirements after 2016.

Nuclear power also has to run ever faster to stay in the same place as its 1970s and 1980s growth turns into a bulge of retirements. After the next few years, retirements will exceed all planned or conceivable global nuclear additions, even with all license extensions as shown here. Power reactors’ terminal decline will be over by about 2060—and in view of both competition and aging, this projection by Mycle Schneider is more likely to overstate its longevity than its brevity.

*Source: Mycle Schneider et al., World Nuclear Industry Status Report 2013, based on IAEA-PRIS data and Schneider’s analysis. The graph is based on all Japanese reactors except the 10 Fukushima Daiichi and Daini units’ returning to operation—a highly conservative assumption.
4. For climate protection, efficiency and renewables are far more effective solutions than new nuclear build, which indeed is counterproductive.
Carbon emissions saved by replacing coal-fired electricity

Emissions in gCO₂/kWh delivered electricity of coal replaced

methane leakage*

Source: Reinventing Fire (2011), omitting in all cases the indirect emissions embodied in construction materials. Any methane emissions from the coal system is omitted but would make displacing coal more worthwhile. *Using 20-year Global Warming Potential of 83 for methane from IPCC’s AR5, p 714.

Displacing 1 kWh of coal-fired electricity displaces the same amount of carbon emission regardless of which carbon-free substitute is chosen. (Gas-fired generation emits carbon but less than coal-fired generation, so gas plants can also save carbon if not too much * methane leaks.) *

Carbon-free substitutes, whether nuclear or renewable or efficiency, would all be equally advantaged by pricing carbon. But they’re not all equally effective at saving carbon, for two reasons: first, technologies that can be built sooner and scaled up faster will save more carbon over time, and second, technologies that save more carbon per dollar invested will buy more solution.
Different ways of displacing delivered coal-fired electricity also have different economic costs. This graph compares a range of current costs of delivered electricity, using Lazard’s conservatively low estimates for thermal plants—especially nuclear, where the latest reality check is the market price for the proposed new British nuclear station (after subsidies that the EU says may cost more than the plant). Farther to the right are the 2013 market prices for U.S. solar and windpower, shown in blue with and in red without their temporary federal subsidies—which are generally less than the permanent subsidies received by the big thermal plants shown to their left. And at the far right are placeholders, which I’ll fill in momentarily, for the costs of using electricity more efficiently.

If we now take the reciprocal of all these ¢/kWh costs of delivered electricity,... *

N.B. Delivered costs include:
Loss factor of 0.9258 for each series but energy efficiency.
T&D costs of 4.26 2013¢
Firming and integration cost of 0.11 2013¢ for coal, nuclear and natural gas and 0.43 2013¢ for wind (none for solar).

...we get the * number of delivered kWh you can make or save by buying one dollar’s worth of each alternative. Now combining this graph with the earlier graph of how much coal–fired carbon each kWh displaces will show how much carbon we can displace by investing a dollar in each alternative. *
Effectiveness of saving carbon by displacing coal-fired electricity

Here’s the resulting “climate figure of merit” range. New-build * nuclear power’s * market price makes it about as cost-effective a carbon-saver as a new combined-cycle gas plant with * 1½% gas leakage, or about 3–5x worse than new solar or windpower in good U.S. sites. Cogeneration, not shown, ranges from about 4x better than nuclear if it’s gas-fired and in buildings (but less with methane leakage) to about 10x better than nuclear (more with methane leakage) if run on industrial waste heat.

Thus as the costliest option, new nuclear build is the least effective supply-side carbon-saver per dollar—and also per year, because it’s slower than its cheaper competitors. *
But to compare the costs of the * best buy—energy efficiency, which beats any kind of supply—we must * rescale the whole graph by sixfold. Here are recent data on efficiency’s costs. Measured large-scale utility program costs are listed in boldface. In lightface are some detailed, empirically based analyses of the average cost of saving far more electricity than all U.S. reactors make. Either way, efficiency is clearly cheaper than average nuclear operating costs, which exceed 4¢/kWh at the busbar and 8¢ delivered. Thus overall, for saving coal plants’ carbon emissions, efficiency is about 10–50x more cost-effective than new nuclear build—or about 2–12x more cost-effective than just operating the average U.S. nuclear plant.
Thus new-build nuclear power is...

• ... not an effective means of climate protection, which it actually reduces and retards compared to buying more effective options instead

• ... not needed for a reliable grid largely or wholly renewably powered

• ... unable to scale faster than its carbon-free competitors

• ... incapable of saving money or supporting a reasoned business case—especially if one understands what its real competitors are

So why build it?

So whether you choose efficiency, cogeneration, or renewables, just being nearly carbon-free does * not make new nuclear build an effective climate solution. Rather, because it saves ~3–50x less carbon per dollar than its main competitors, and deploys slower, new nuclear build reduces and retards climate protection. If climate is a problem, we must invest judiciously, not indiscriminately, to get the most solution per dollar and per year. Anything less makes the problem worse.

Nor do we need nuclear power to * offset PVs’ and windpower’s variability, or to * scale faster than renewables, or to * save or make money, because, as we’ve seen, nuclear power cannot do any of these things. So * there is no reason to build more nuclear plants. Capital markets, seeing big new costs and risks without offsetting benefits, * long ago reached the same conclusion.

Existing nuclear plants, a future idea whose time has passed, will simply retire; the only choice is how quickly and at what cost to whom. End of story.