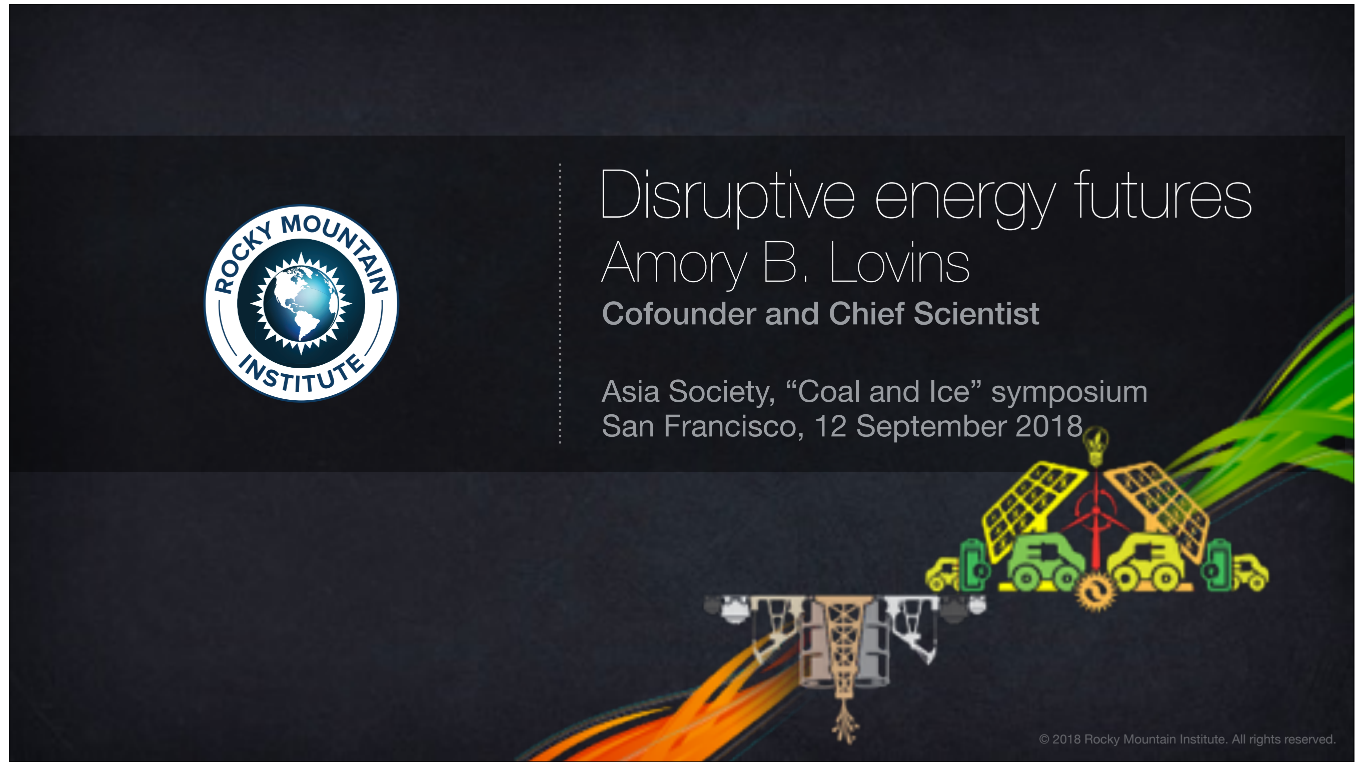

ROCKY MOUNTAIN
INSTITUTE



Thank you for the honor of sketching the energy transformation that can profitably abate the climate change not already committed.
The biggest sector in the economy, energy, is undergoing the world’s greatest economic transformation in centuries.
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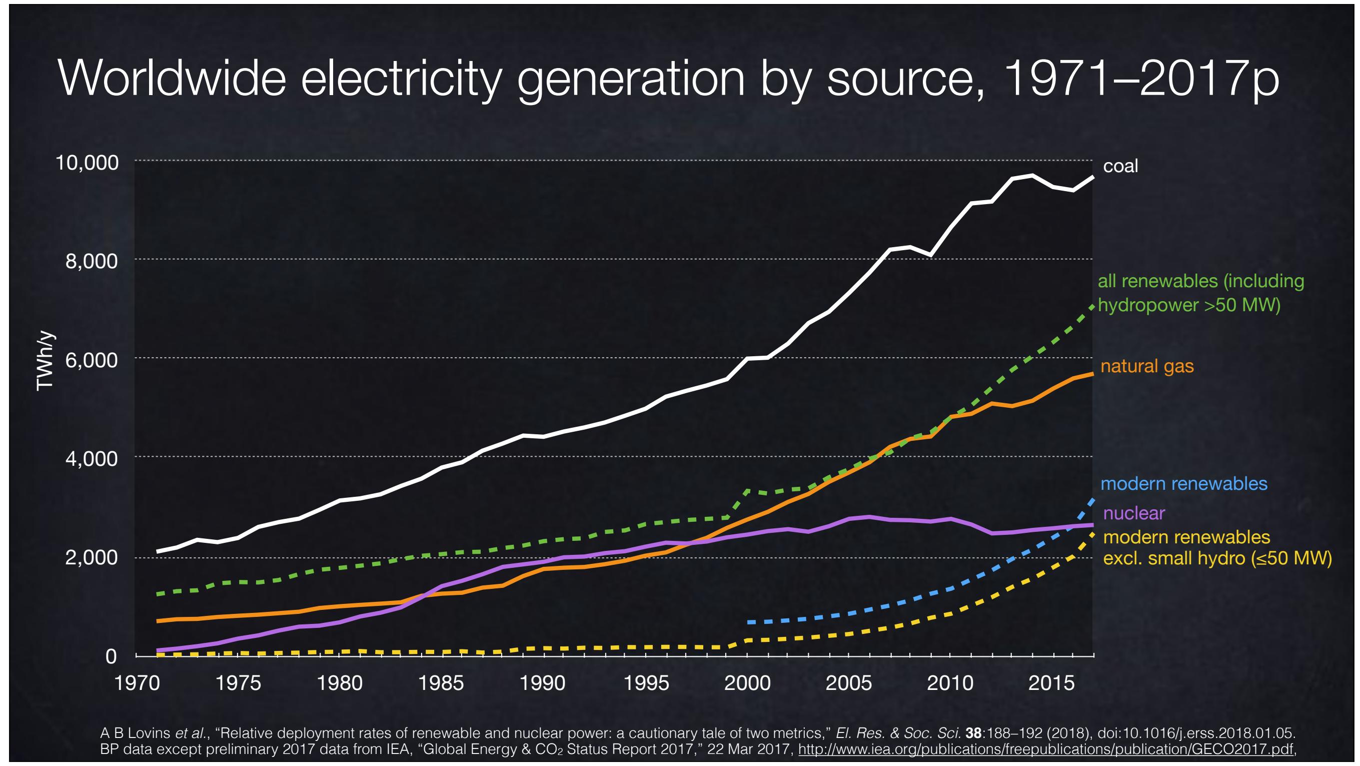
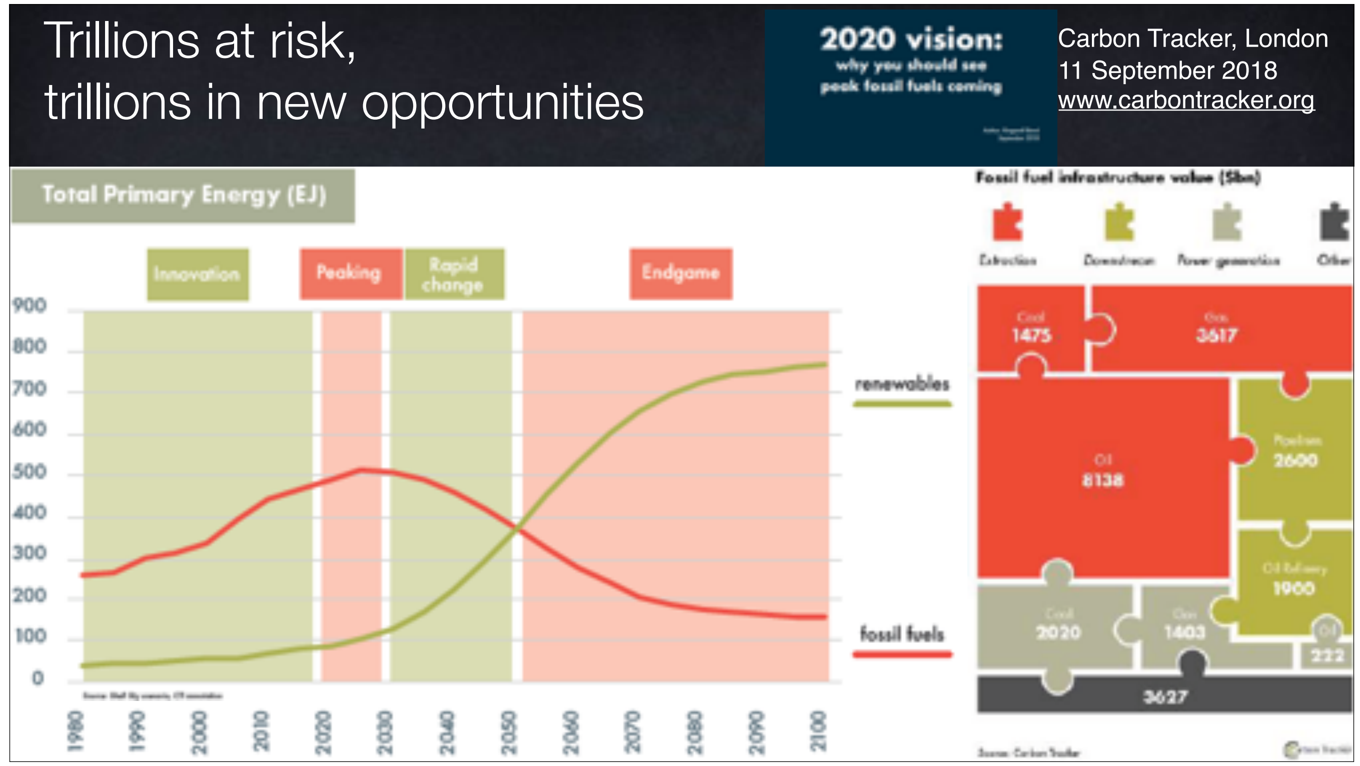


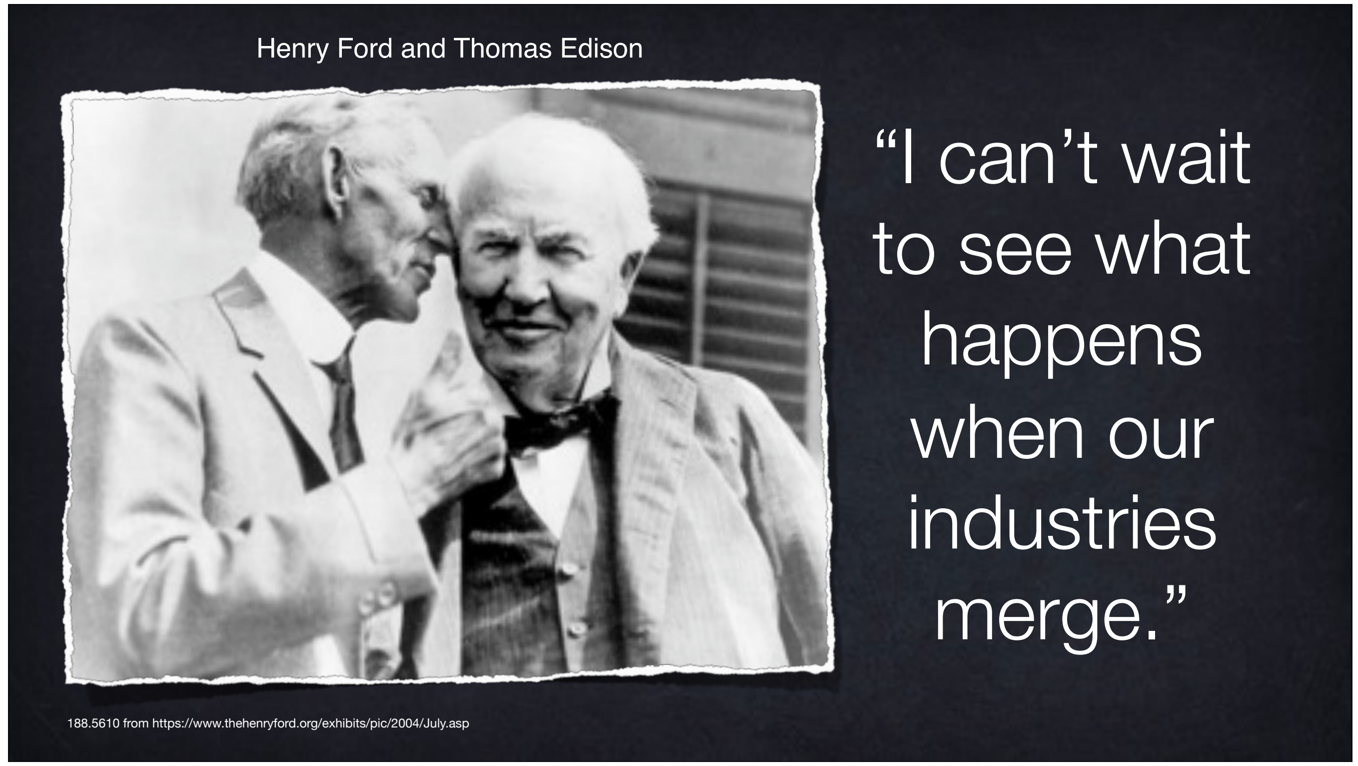
Our story starts with electricity, whose production uses 43% of global energy and accounts for 71% of its growth in the past five years. But electric generation is rapidly shifting to renewable sources, whether including big hydro (green), only small hydro (blue), or none (yellow). Modern renewables quietly passed a trillion watts of installed capacity a year ago. That took ~15 y; the International Renewable Energy Agency says the next trillion watts will take ~4 y. And as renewable electricity gets relentlessly cheaper, it's starting to push fossil fuels out of their bigger markets for heat and mobility. *



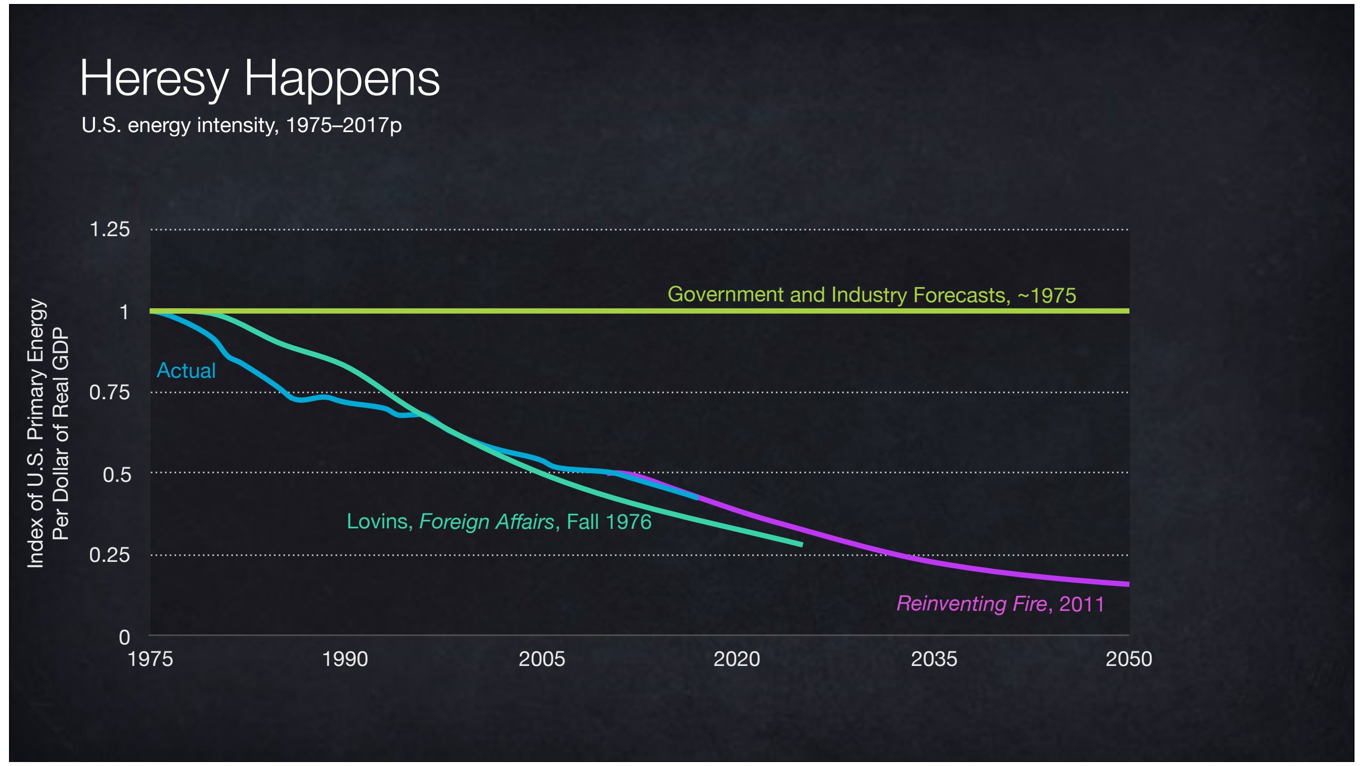
Three weeks ago, a study by Kingsmill Bond at Carbon Tracker argued that in the 2020s, probably in the next ~4–5 y, renewables will * offset growth in *all* fossil fuels, tipping them into irreversible decline. That fossil-fuel endgame * puts at risk ~$25t of energy infrastructure; national economies dependent on oil and gas rents; and firms that compose up to a fourth of equity indices and debt markets, including non-energy sectors like autos, steel, capital goods, and banking. In this structural decline, says Bond, “Entire sectors…can expect price declines, greater competition, restructuring, stranded assets[,] and market derating.” And these risks won’t wait for the distant fossil-fuel endgame; they’re here and now.

Coal demand peaked in 2014, bankrupting the biggest private coal company (Peabody) two years later. In the six years from 2007, when modern renewables made just 3% of Europe’s electricity, they made thermal-electricity demand peak, shattered the utilities’ business model, destroyed two-thirds of their market cap, and forced $150b of power-plant writedowns. In the past few years, renewable competition broke GE’s and Siemens’ vaunted gas-fired power plant businesses. And suddenly 4 million electric vehicles are on the road, adding a million every six months, and poised to meet all growth in car sales as they reach price parity in the early 2020s, so scornful automakers, significantly underperforming the S&P500, have scrambled for a $90b catchup play. /

So let’s explore how all these trends are closely connected and what that means for your portfolios. *



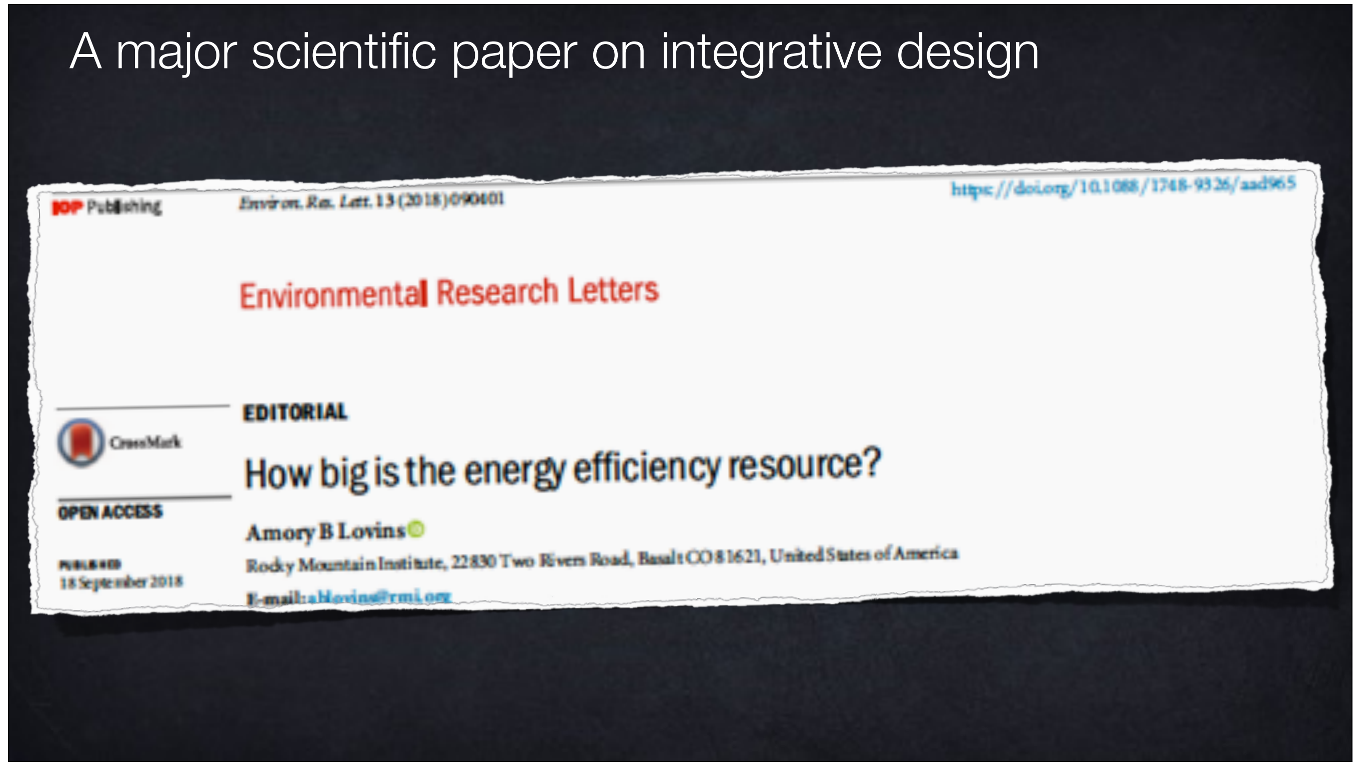
Ford’s auto industry, Edison’s electricity industry, and Rockefeller’s oil industry changed the world. If Ford and Edison took a very long nap on one of their car-camping holidays together, woke up, and saw their businesses today, they’d recognize almost everything except the electronics. Yet their industries face vast disruptions, as 21st-Century technology and speed collide head-on with 20th- and even 19th-Century institutions, rules, and cultures.
Now the first two of these three great industries are coming together to eat the third. As we might imagine * Ford mischievously muttering to Edison, let’s see what happens when electricity displaces gasoline, then those electric cars add flexibility and cheap distributed storage that help the grid accept variable solar and windpower, while the electric cars make batteries cheap, enabling distributed solar power everywhere—all replacing giant power stations and their fossil fuels. *



Energy savings now deliver more global energy services than oil. The US since 1975 has saved 30x as much cumulative energy (two-thirds through better technology) as renewables' growth added. Energy savings offset two-thirds of economic growth, so only one-third as much renewable energy is needed to make fossil-fuel use peak and decline as if efficiency were constant. The more efficiency accelerates, the sooner that tipping point will be reached.

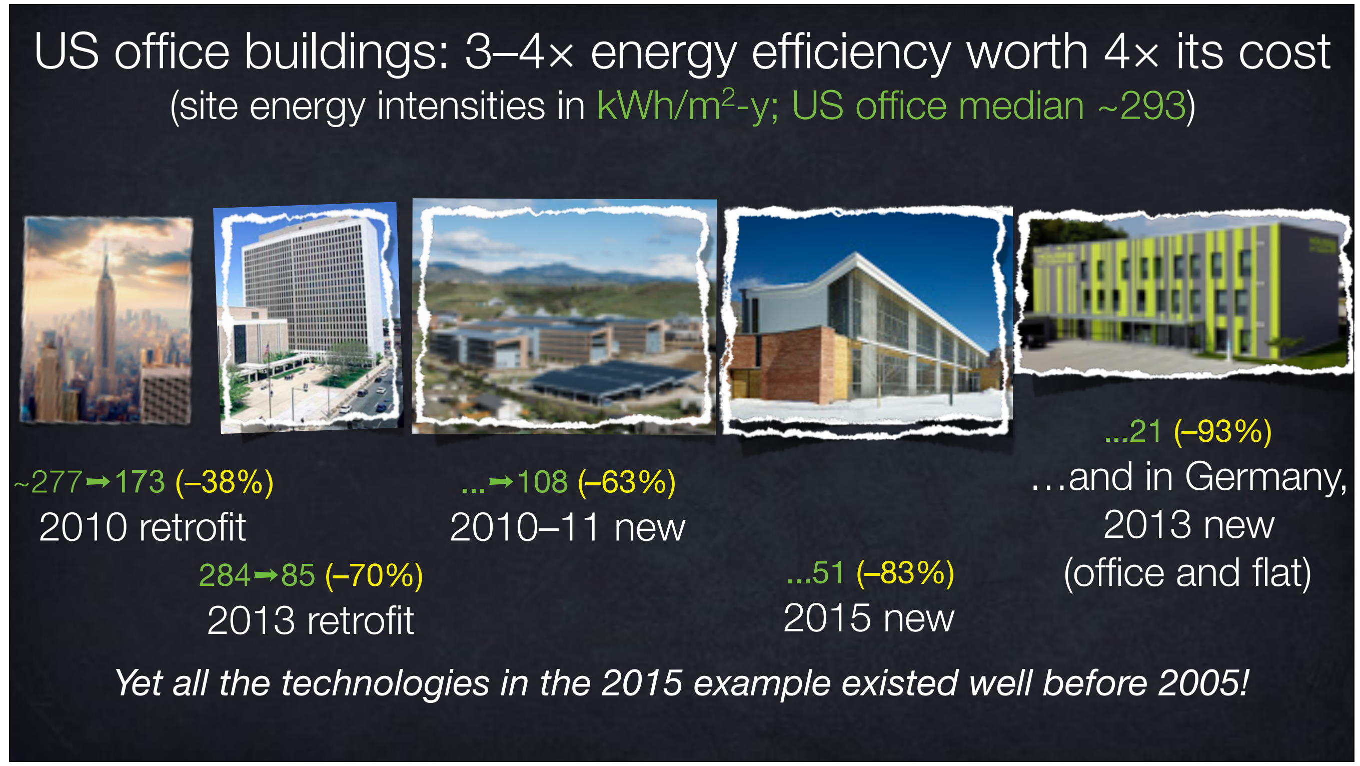
But efficiency is just getting started. In 1975, US government and industry all insisted the * energy needed to make a dollar of GDP couldn't fall. * A year later, I heretically suggested it could drop 72% in 50 years. * So far it's dropped 57% in 42 years. Yet just the innovations already added by 2010 * can save *another* threefold, twice what I originally thought, at a third the real cost.

Today that looks conservative, partly because optimizing buildings, factories, and vehicles as whole systems can often make very big energy savings cost *less* than small or no savings, turning diminishing returns into *increasing* returns.*

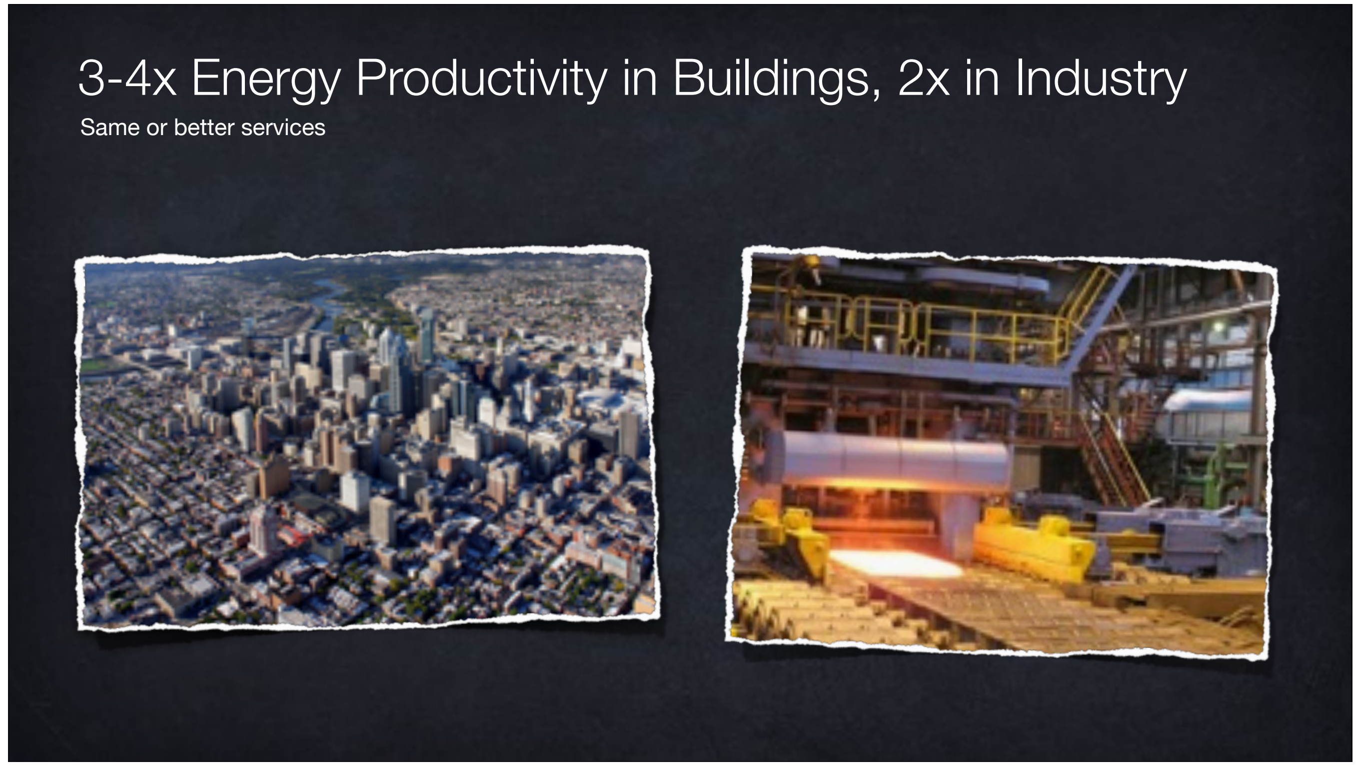


This big surprise is documented in a new peer-reviewed paper I published 18 Sep—just search for “How big is the energy efficiency resource?” It describes “integrative design.” But what’s that? *

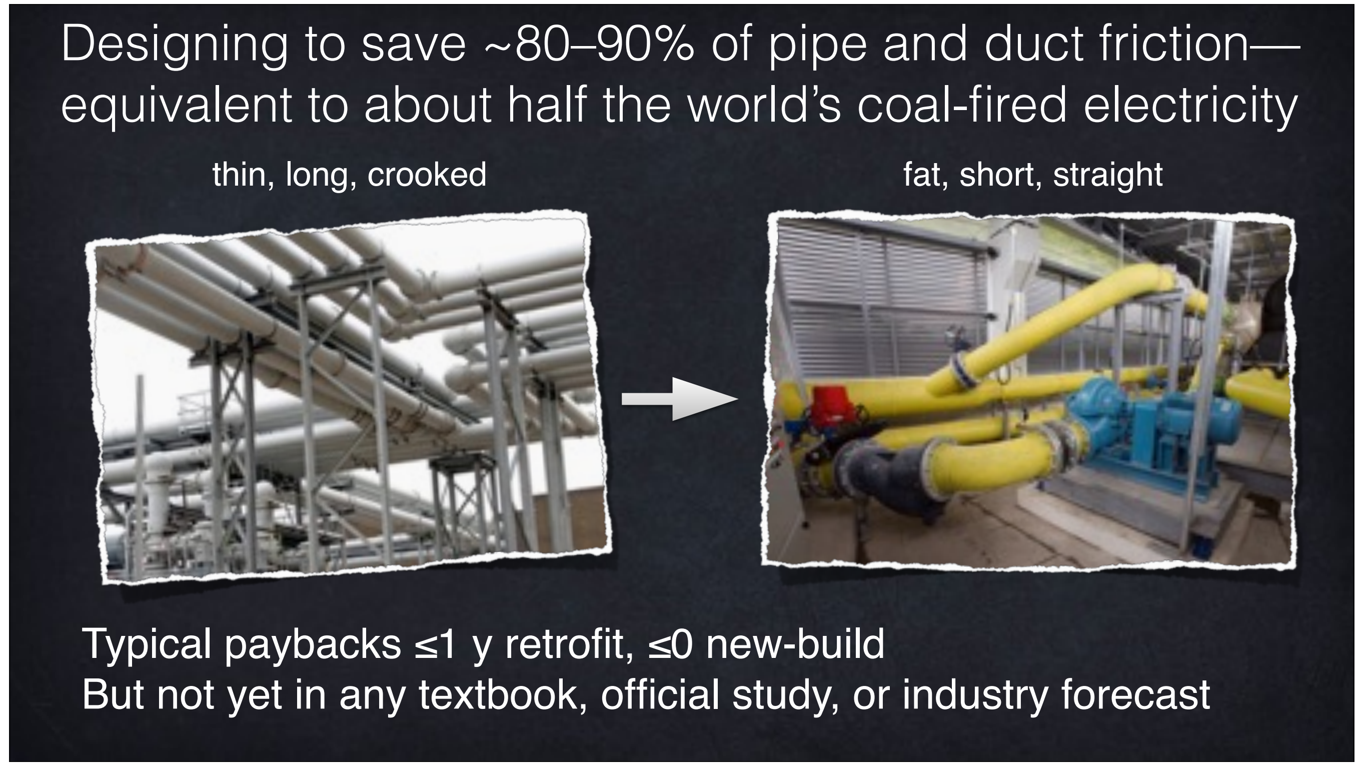
* My wife Judy and I live here, 2200 m / 7100’ up in the Colorado Rockies near Aspen, where * temperatures used to dip as low as –44˚C / –47˚F. But our house does no combustion (that’s so 20th-Century). Superinsulation, ventilation heat recovery, and superwindows that insulate like 16–22 sheets of glass (but look like 2 and cost less than 3) make it 99% passive-solar heated, 1% active-solar. The efficiency added less construction cost than eliminating the heating system subtracted, making the house slightly cheaper to build. Saving also ~90% of its household electricity, 99% of its water-heating energy, and half the water raised the total payback time to 10 months with 1983 technologies; today’s are better and cheaper.
The central * atrium, seen here in a February snowstorm, has produced * 74 passive-solar banana crops. Without needing to look like this, our house helped inspire over 1.8 million European passive buildings (two-thirds of them retrofits) that likewise have no heating and roughly normal construction cost. * This works from Old Snowmass to Bangkok—a climate range that includes nearly everyone on earth—but wherever you live, integrative design gives many benefits from each expenditure: this white arch *[point]* has 12 functions but only one cost. *



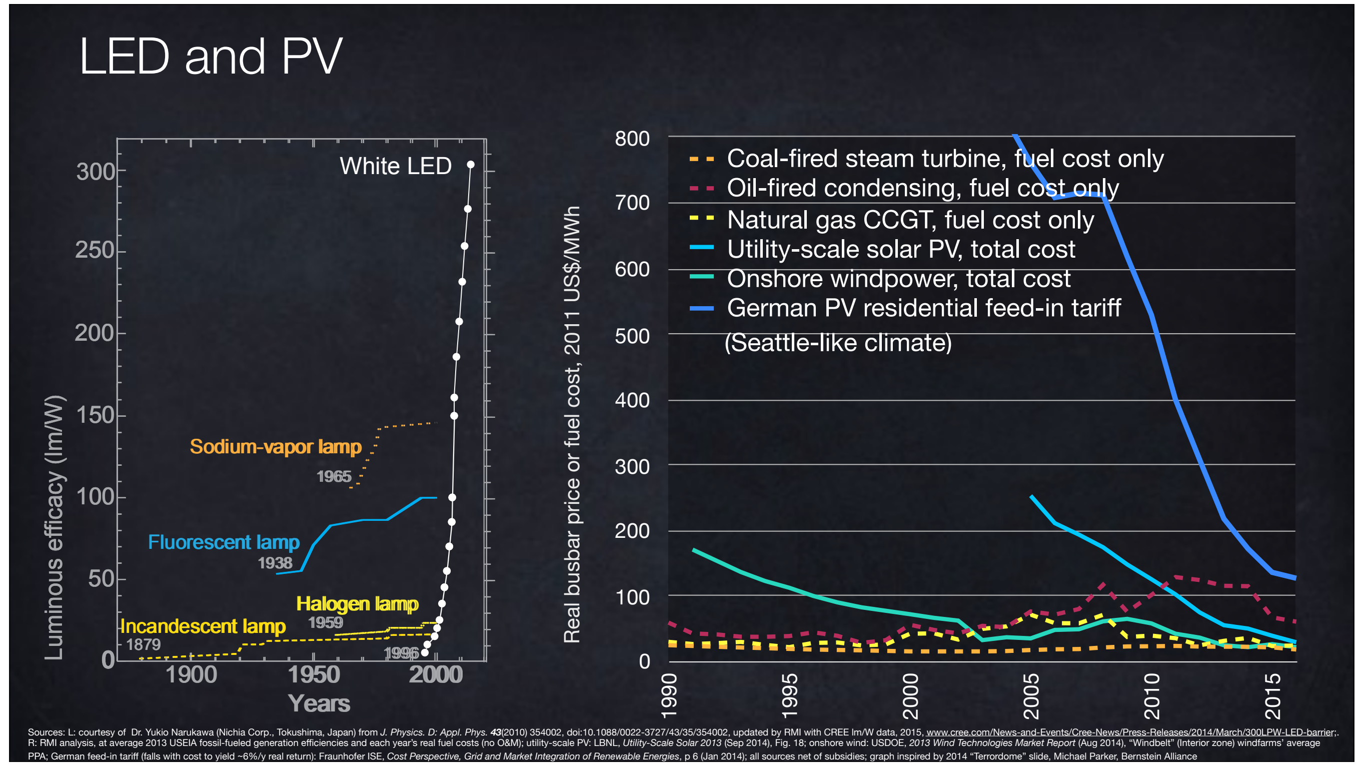
Integrative design is how our * Empire State Building retrofit saved 38% of its energy with a 3-year payback. But three years later, our * cost-effective Denver retrofit saved *70%*, making this half-century-old Federal complex more efficient than the * then-best *new* US office—which in turn is * less than half as efficient as our own net-positive, no-mechanicals office in the coldest climate zone. In milder Seattle, the Bullitt Center uses a fourth less energy [~38 kWh/m^{2}y] than ours, and * now a Bavarian building is using *three-fifths* less energy than ours! Yet all these technologies existed over a decade ago; what's * mainly improved is not technology but *design*—the way we choose and combine technologies. *



By 2050 at historically reasonable rates, US buildings, which use ¾ of electricity, can become 3–4x more efficient, saving *$1.4 trillion net* with a 33% Internal Rate of Return, so those savings are worth four times their costs. * And industry can accelerate too, doubling *its* energy productivity with a 21% IRR. (Industrial process heat, like heavy transport, is not uniquely difficult to decarbonize—just *differently* difficult.) *



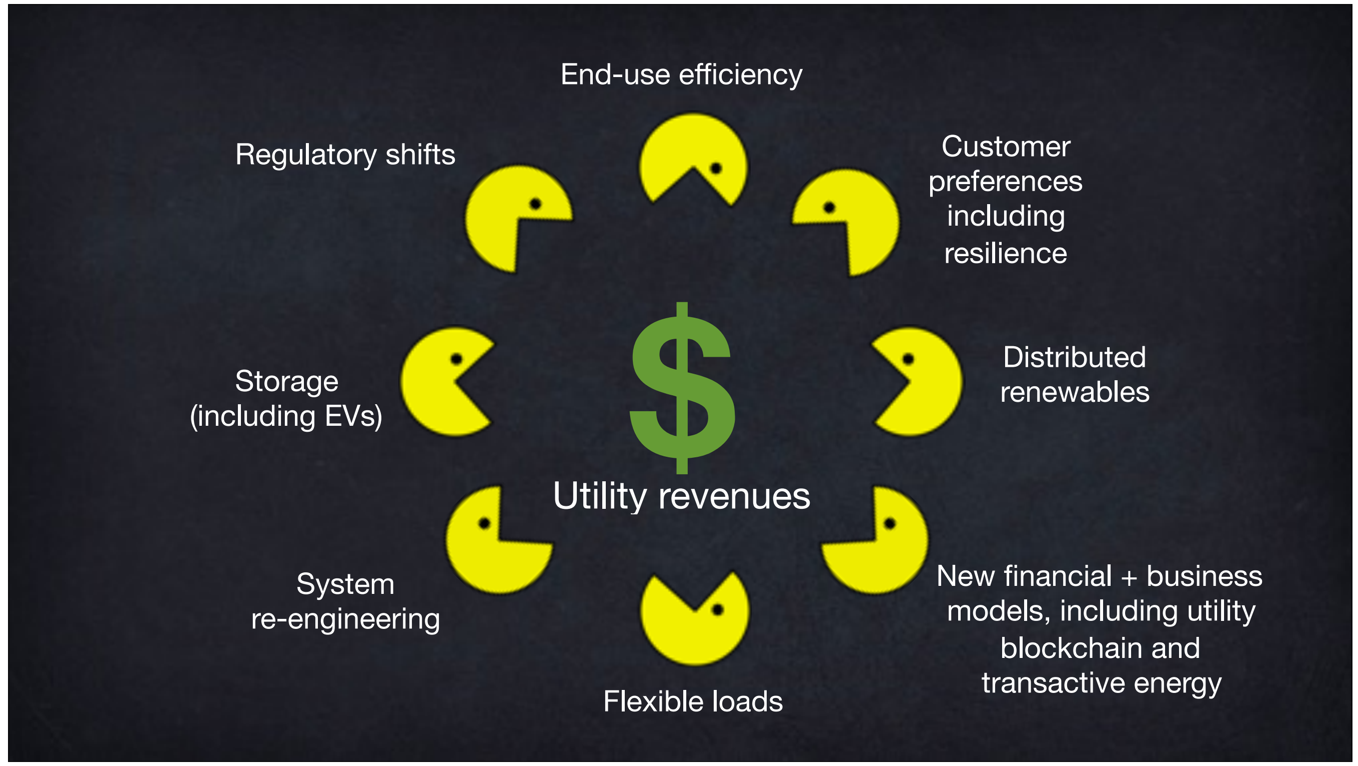
Three-fifths of electricity runs motors, mostly in industry, half to drive pumps and fans. * Better pipe and duct design, saving ~80–90% of friction, could save roughly half the world's coal-fired electricity with * extremely juicy returns. Such rearrangement of designers' mental furniture remains officially unnoticed, though, because it's not a technology; it's a *design* method. And as we'll see later, such integrative design also applies to the biggest use of oil —mobility. *



Both technology *and* design are moving efficiency into fast-forward. * Prior lighting * improvements are being * swept away as LEDs each decade get 30x more efficient, 20x brighter, and 10x cheaper. Soon they'll save an eighth of the world's electricity—and pry open an old crack in electric utilities' business model.

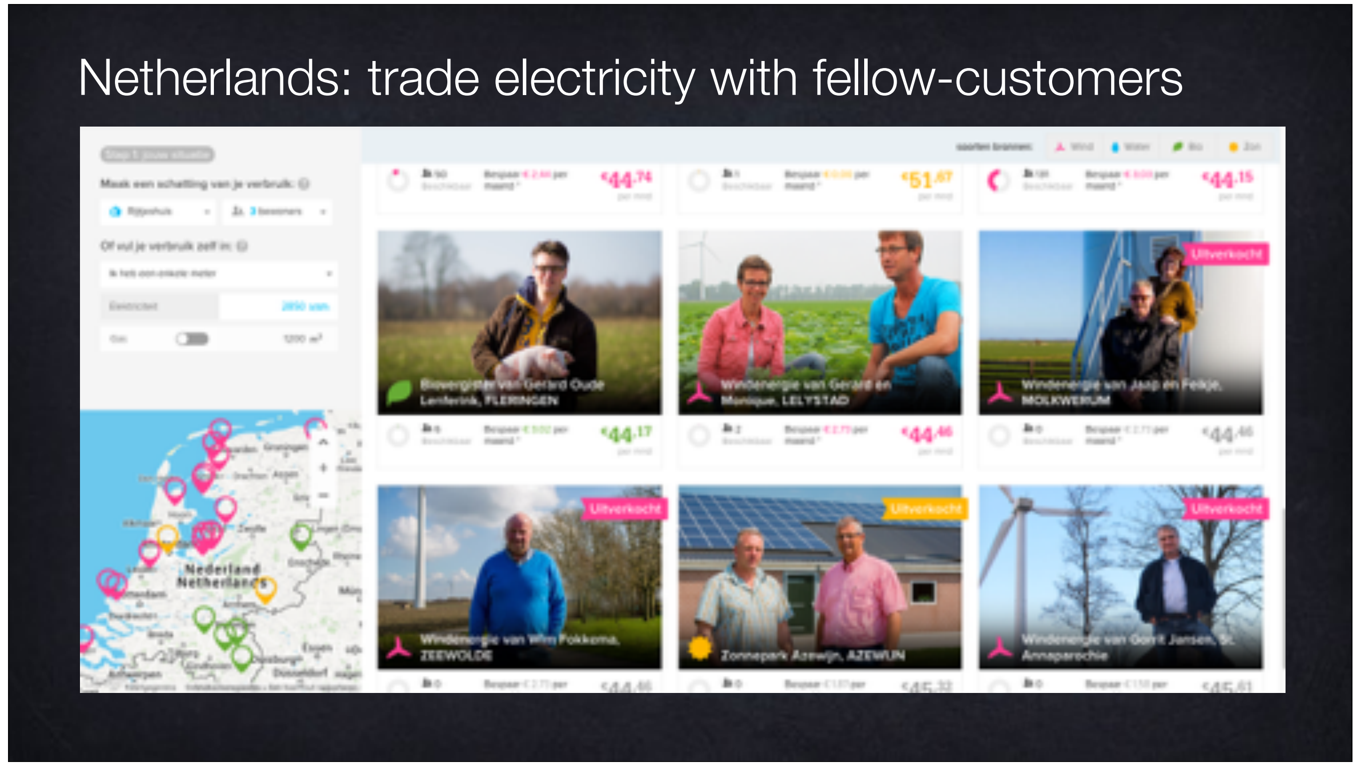
You see, Thomas Edison didn't sell electricity; he sold light, so improvements in lighting efficiency would cut his *costs*. But in 1892, utilities switched to selling kWh, so efficient use cuts their *revenues*. Utilities sell a commodity, but customers want an infrastructure or a service, like hot showers and cold beer. Oil and gas companies use the same flawed business model, selling molecules, not services like mobility and comfort. /

What else changes that fast? LEDs backwards are * PVs (photovoltaics). [They're now less capital-intensive than Arctic oil.] Their prices' recent meteorite strike has made solar and windpower cost less than the fossil fuels fed into US power stations (the dashed lines), often making old coal, gas, and nuclear plants uneconomic just to run. In India, two-fifths of existing coal plants are already stranded assets, and all planned units not yet built are pre-stranded assets. China has cancelled hundreds of coal plants, and runs existing ones ~2½% less each year. *

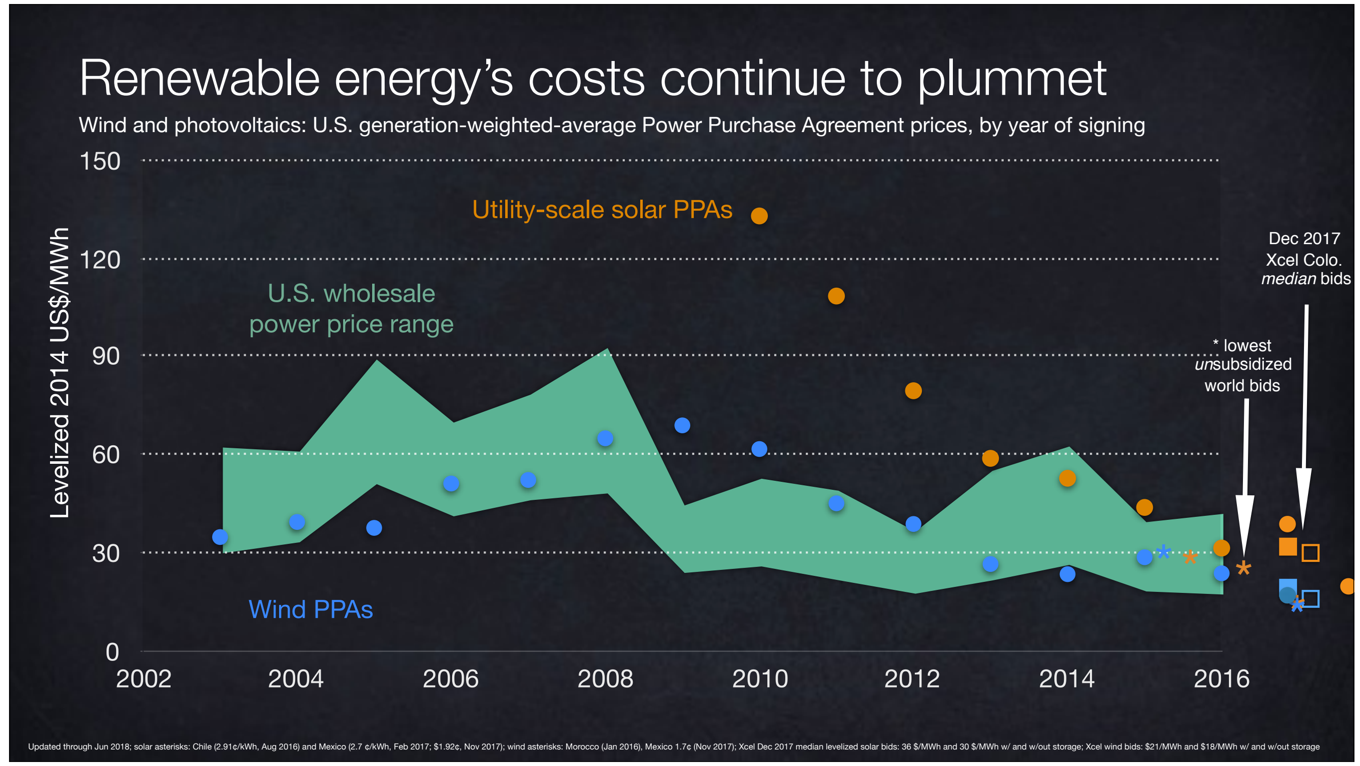


Indeed, powerful * disruptors are * converging on the * electricity industry from at * least *eight* directions. These “eight PACmen of the apocalypse,” with more coming over the hill, don’t just add; they exponentiate. They’re not lone wolves; they hunt in packs, they multiply quickly, and they can gobble half of utility revenues in the 2020s. Together they’re creating an alien competitive landscape, faster than many firms’ cultures can cope.

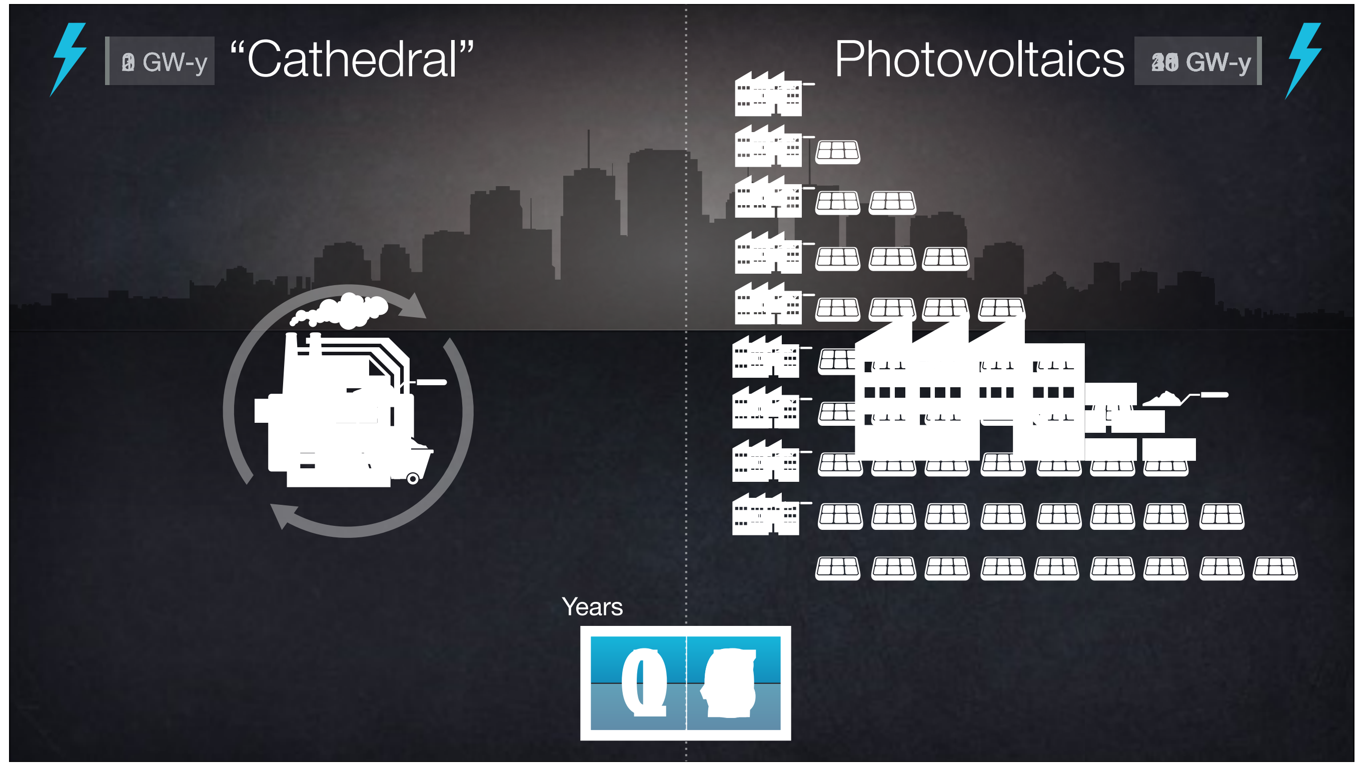
It’s usually a good idea to sell customers what they want before someone else does, and customers are figuring out that they can use far less electricity more productively and timely, produce their own, and even trade it with each other. *



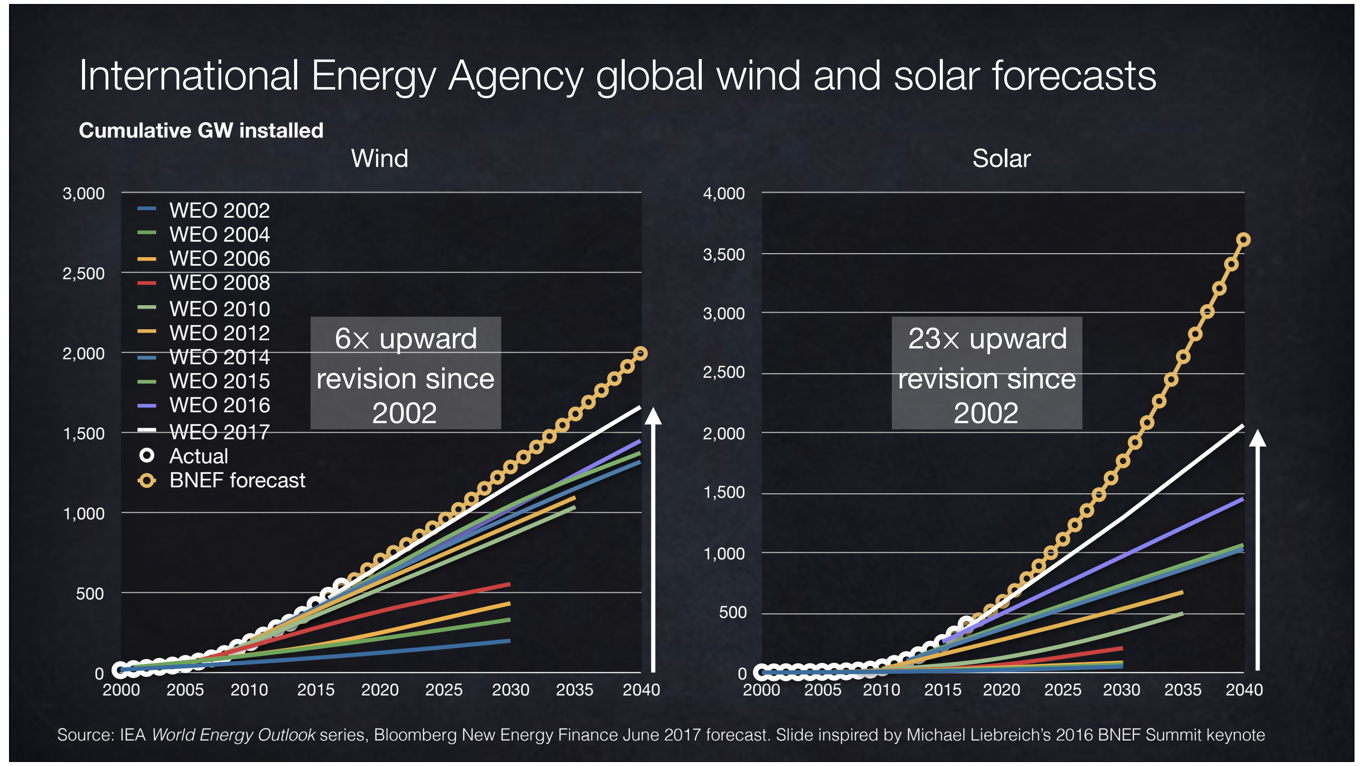
Dutch customers can buy renewable electricity directly *from other customers* on this peer-to-peer website of Vandebron, literally “from the source”. A utility executive I know bought his electricity from the guy in the upper left because the price was right and it’s a really cute piglet—then he got a long handwritten Christmas card from his electricity supplier. What big utility can dream of such customer intimacy? Oink! *



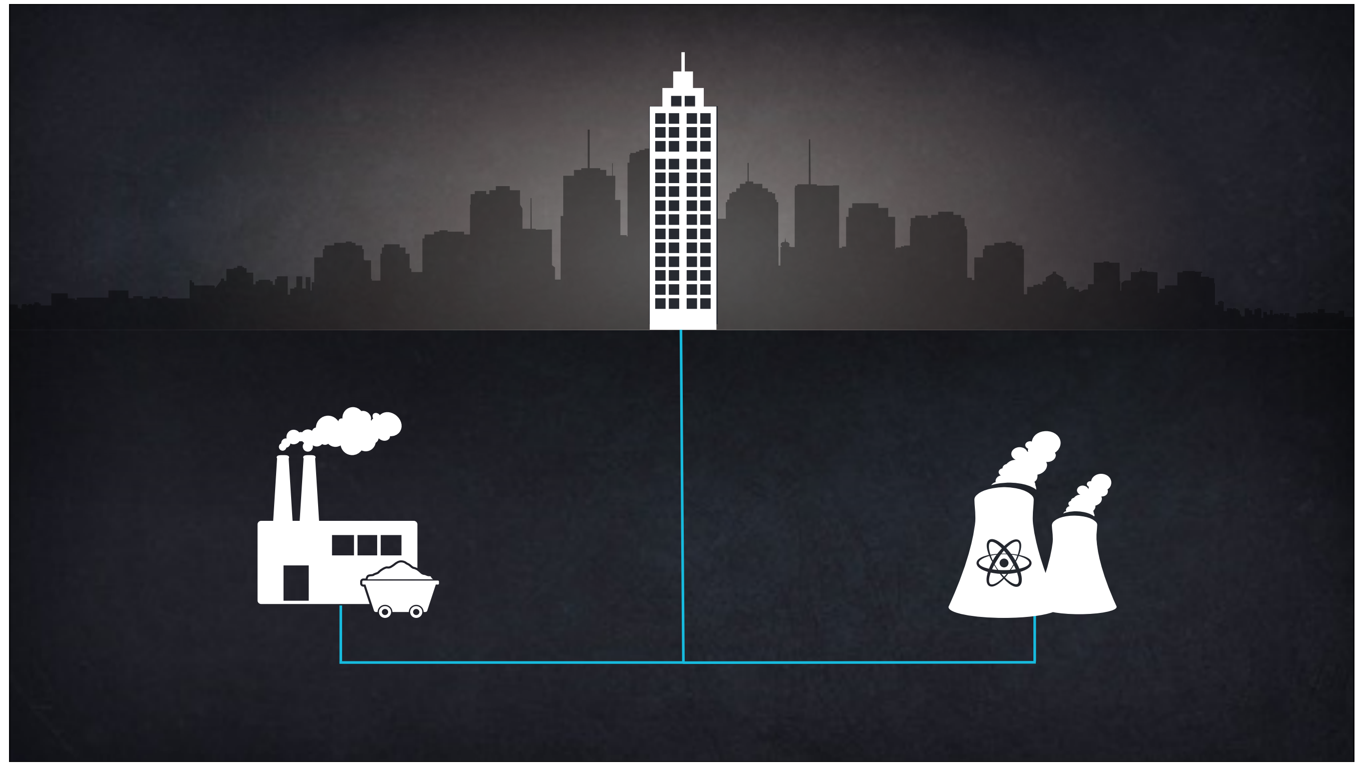
Last year, modern renewables were 64% of the world's total net additions of generating capacity, thanks to their * powerful business case. US wholesale electricity prices now widely exceed the average long-term fixed prices of * wind and * solar power. In Colorado, the *median* bids last December for 30 renewable GW were the hollow squares [$18/MWh for wind and under $30 for PV] without storage or the filled squares [at $21 and $36] *including* storage. * Renewables at or below $30/MWh, the asterisks, are winning in *un*subsidized global markets, and costs keep falling through $20 toward $10. In 2016 alone, low bids fell 37% for Mexican solar power and 43% for European *off*shore wind—all in <1 y. Last November, Mexico's unsubsidized low bids were $19 for PVs, $17 for windpower. Developing nations already dominate those global investment, and by 2020, renewables will beat fossil fuels in every major region on Earth.*



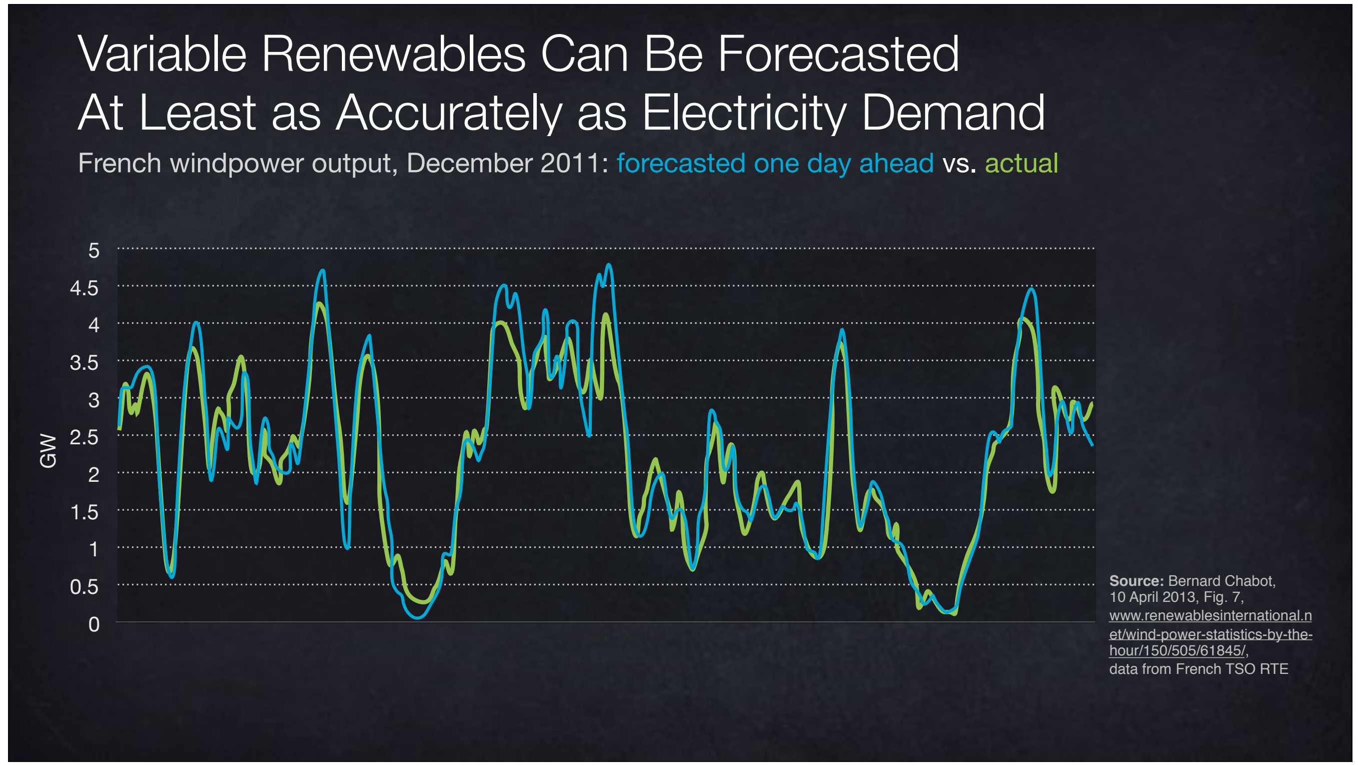
[animation plays for 17s] *Modern renewables also scale up in a fundamentally different way*. Traditionally, we built giant cathedral-like power plants, each costing billions of dollars and taking many years to license and build. But now *each* year, similar investment can build a factory that produces *each year thereafter* enough solar cells to generate *each year thereafter* as much electricity as your “cathedral” ultimately will. So solar output worldwide is scaling faster than cellphones. In 2013, China added more PV capacity than the US had added cumulatively in the previous 59 years. In 2016, China added twice that much—three football fields per hour—including 11 billion watts in June alone. Last year [2017], China added more PVs in June than the US added all year. *



But when renewables get cheaper, we buy more, so they get cheaper, so we buy more. Such increasing returns keep outrunning forecasters, as in these forecast fans from the International Energy Agency, raised 6x [5.9x] for windpower and 23x for PVs in 15 years, yet still falling short of reality. Today's solar capacity [in January 2017—401 GW, vs 539 GW wind] is *>40x* IEA's 2002 forecast, and solar power alone added more capacity last year than all fossil-fueled generators combined. To the inattentive folks who call solar and wind "emerging" technologies, perhaps relevant decades hence, I'd ask: What part of "They just took two-thirds of your global market" don't you get? *



Yet we’re still told that only coal, gas, and nuclear stations can keep the lights on, because they’re “24/7,” while windpower and PVs are “variable” and hence unreliable. *

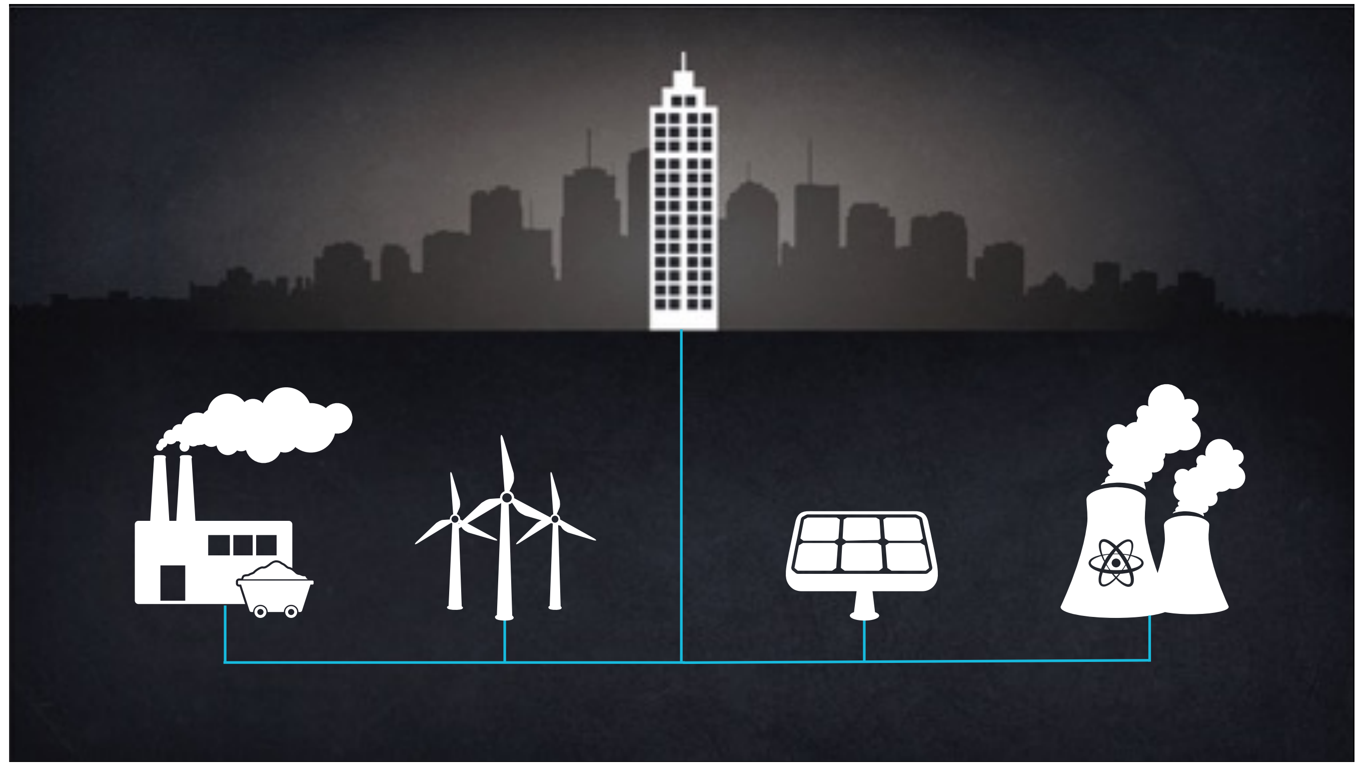


But “variable” doesn’t mean “unpredictable.” Here’s how accurately * the French grid operator in one stormy winter month forecast a day ahead the * actual output of the country’s windfarms. I’ll bet they wish they could forecast demand that accurately! *

Indeed, we *built* the grid *because no* generator is 24/7. They all break. When a giant * plant fails, you lose * a billion watts in milliseconds, often abruptly for weeks or months. * Grids manage this intermittence by backing up failed plants with working plants, * and in exactly the same way, but often at lower cost, grids can manage the forecastable variations of solar and windpower....

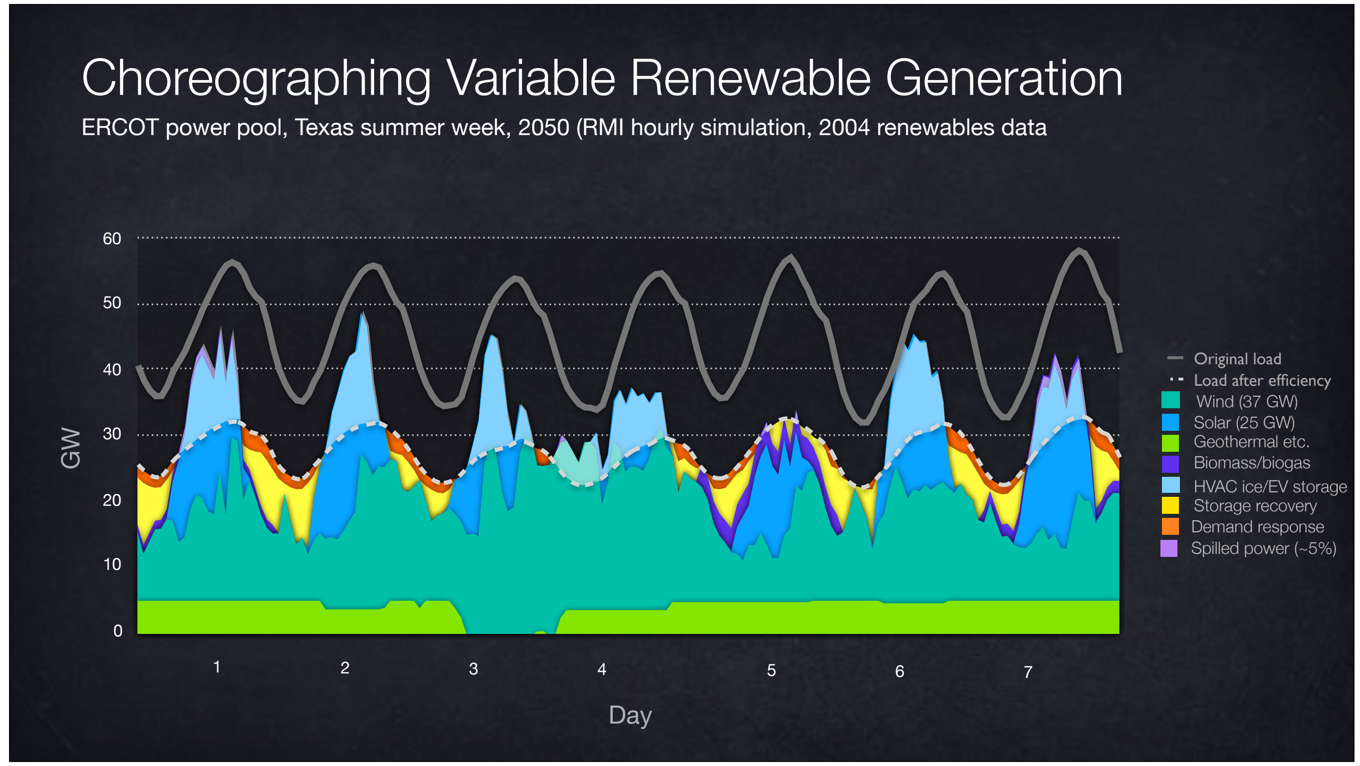
[automated transition continues…]

[Of course, *every* kind of electricity generator fails, for different reasons and with * different lumpiness, predictability, duration, and consequences.]

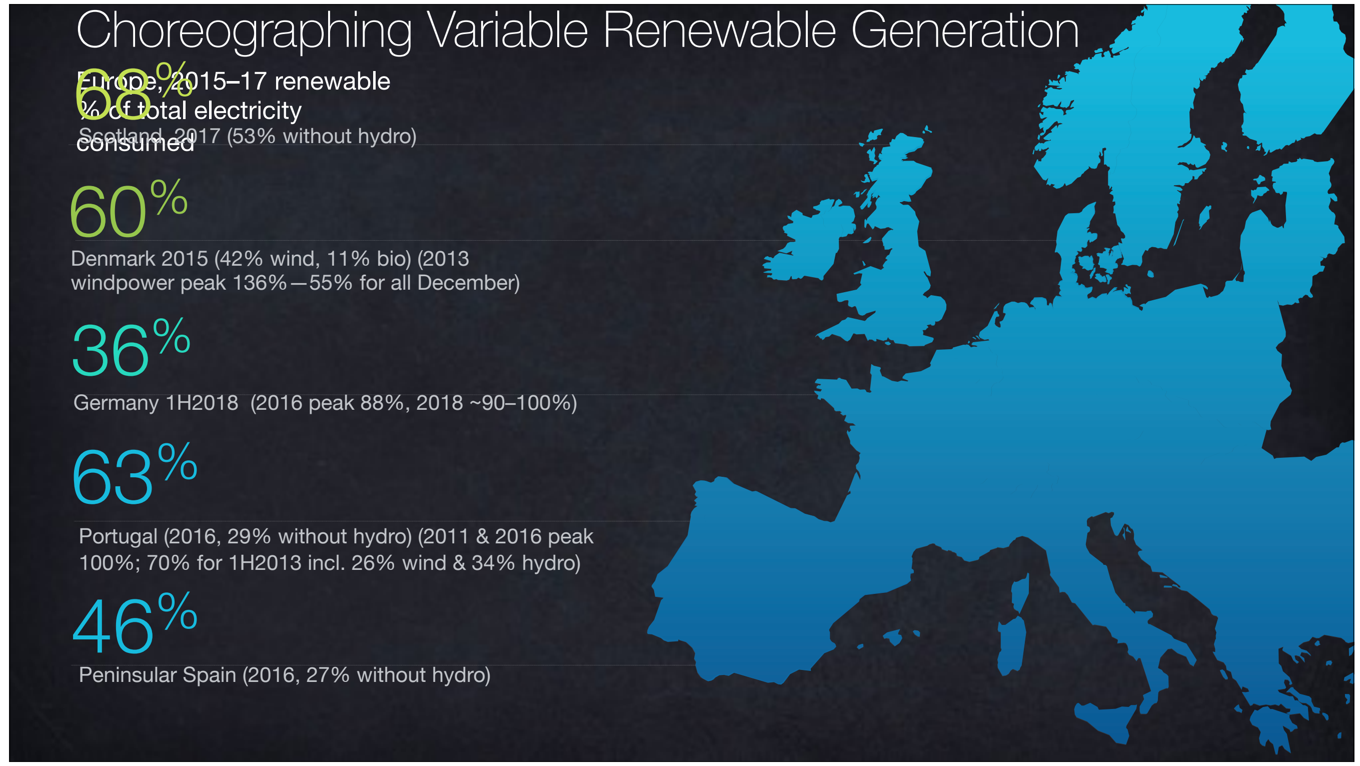


[and in exactly the same way, but often at lower cost, grids can manage the forecastable variations of solar and windpower]…by backing up those variable renewables with a portfolio of *other renewables*, of other types or in other places, all forecasted, integrated, and diversified. So in Texas... *

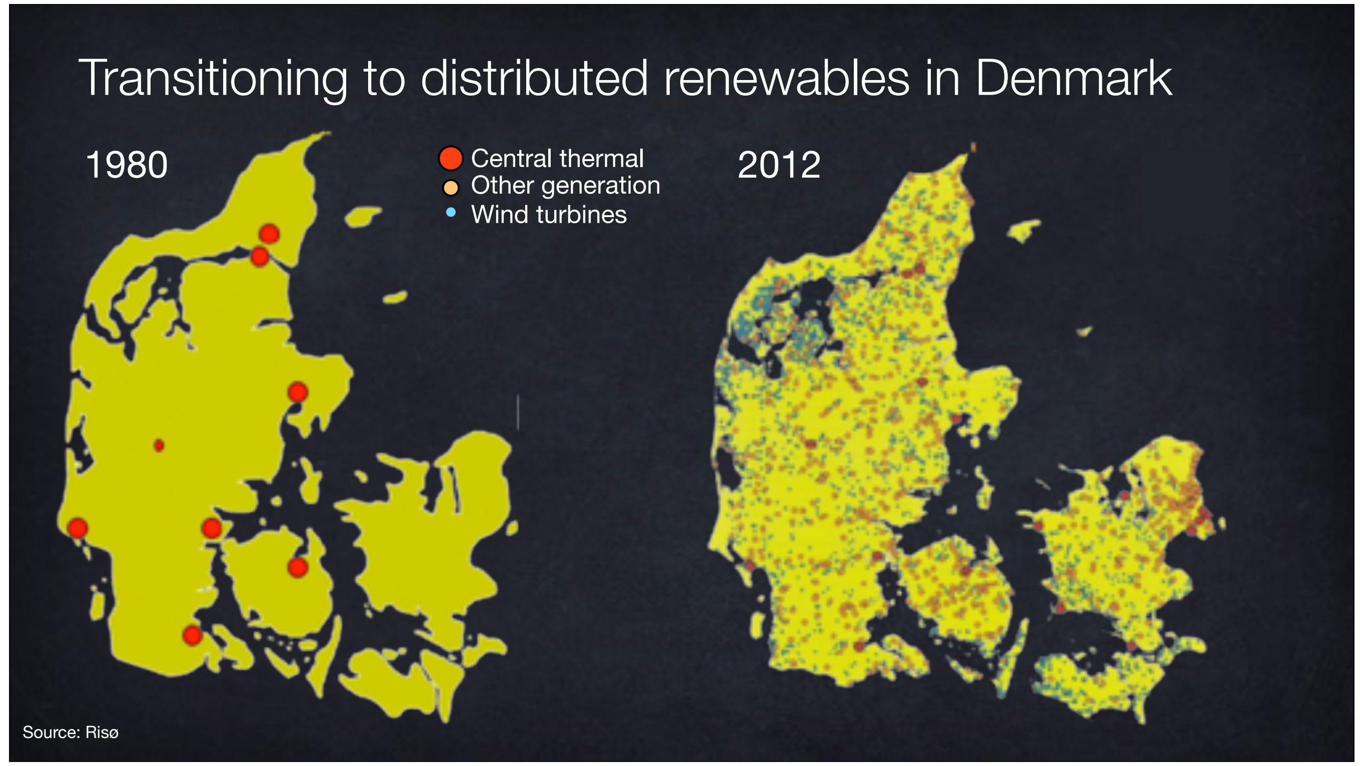
[adjust length of animation if needed—can't continue to slide 51 until animation ends]



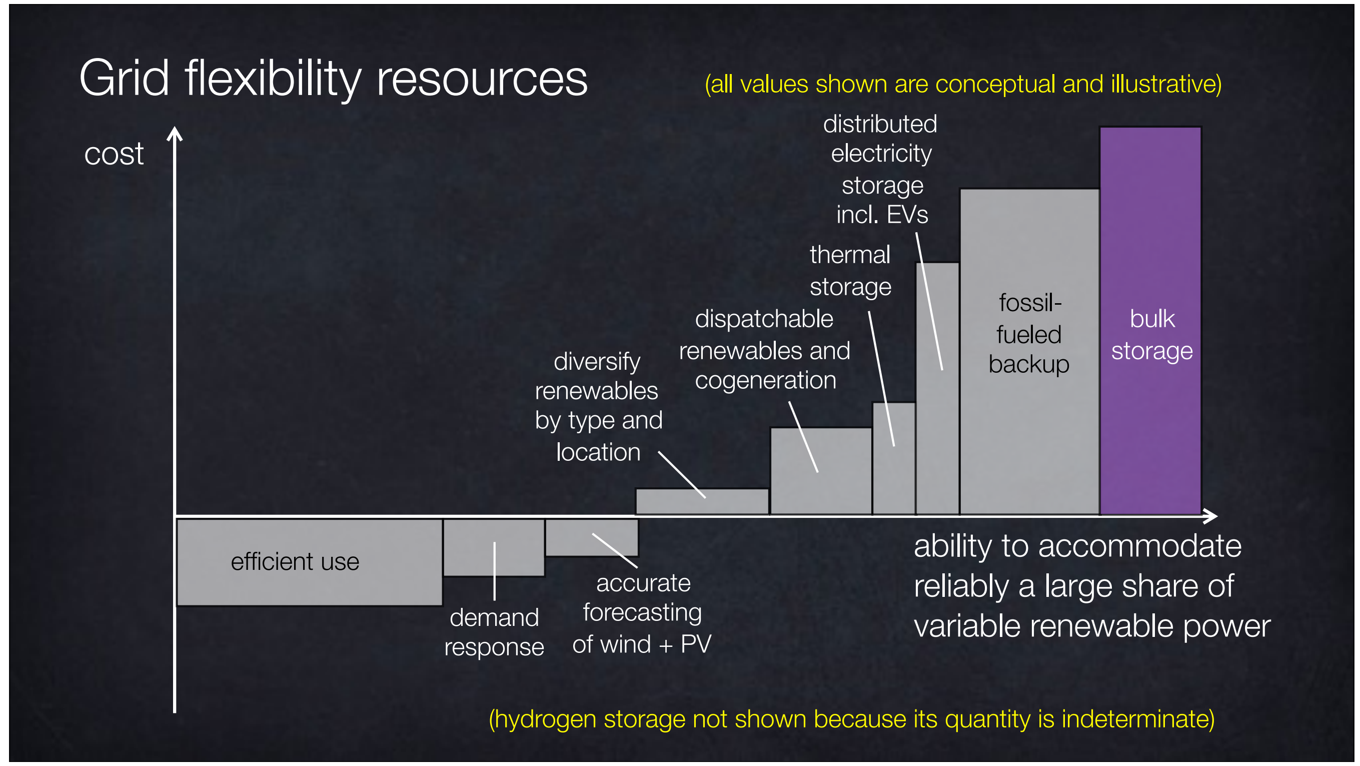
...whose * grid has no big hydro dams and is not connected to the rest of the country, a 2050 summer week's expected loads can get much * smaller and less peaky with efficient use. Then we can make 86% of the annual electricity with * wind and * PVs, and 14% from * *dispatchable* * renewables. This 100% renewable supply can then match the load by putting surplus electricity into * two kinds of distributed storage worth buying anyway—ice-storage air-conditioning and smart charging of electric autos—then * recovering that energy when needed, and * filling the last gaps with unobtrusively flexible demand. That yields 100% renewable electricity every hour of the year, with * only ~5% left over, so the economics should be excellent even at today's prices. *



Some grid operators do such choreography today. * Germany, Italy, and Britain are about one-third renewably powered [, Ireland and France about one-fifth]. * But four *other* * European countries with * modest or no hydropower meet about * *half to two-thirds* of their electricity needs from renewables, adding no bulk storage and with superior reliability—for Denmark and Germany, ~10x US reliability. The ultrareliable former East German utility [50Hertz] is 42% wind- and solar-powered [53% from all renewables,] and, says its CEO, could do 60–70% without adding bulk storage. So as my colleague Clay Stranger says, the operators have learned to run these grids the way a conductor leads a symphony orchestra: no instrument plays all the time, but the ensemble continuously makes beautiful music. *



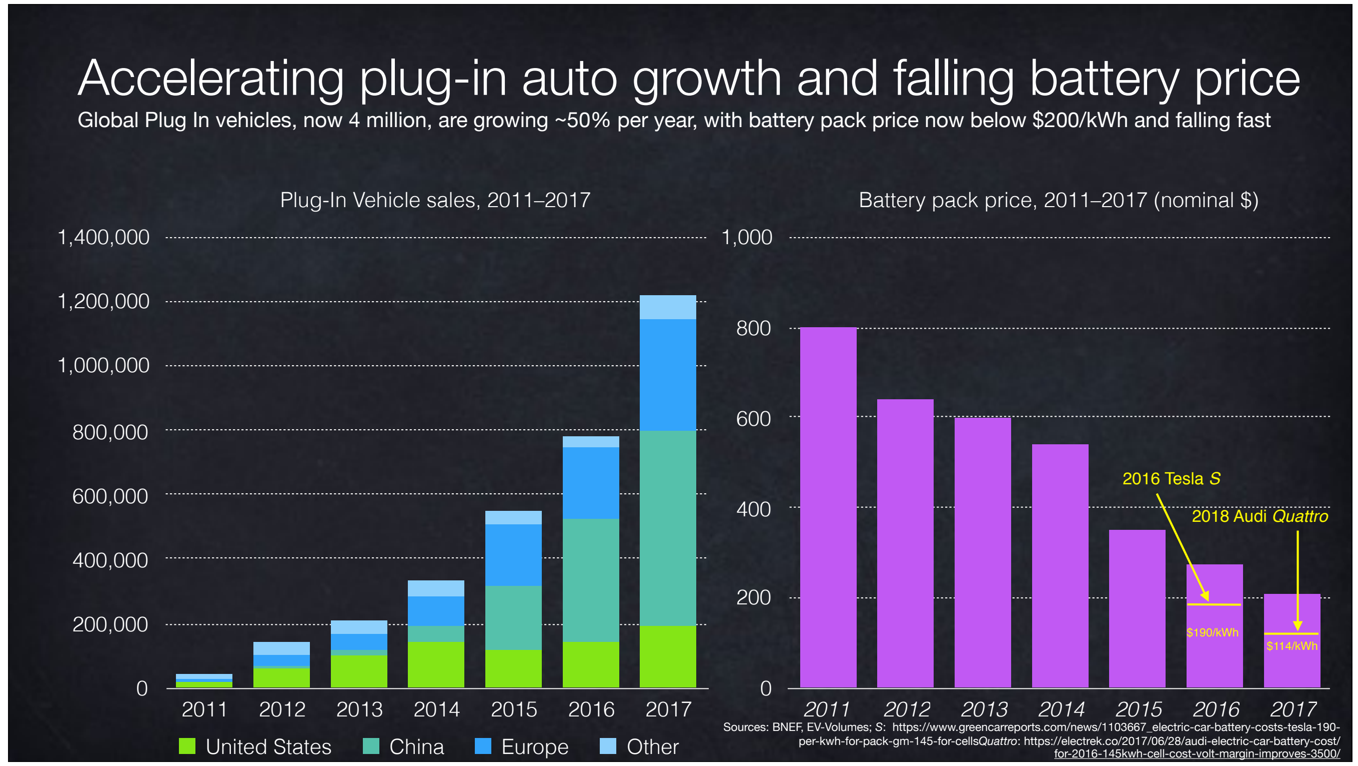
A harbinger of our electric future could be Denmark, which in three decades shifted from centralized power stations (red) to distributed wind turbines (blue) and mostly-ag-waste cogeneration (brown). Central electricity-only plants' 1980 output is now 99.9% gone [2016]. While GDP grew 72%, Denmark used 24% less electricity over twice as efficiently, and cut its carbon intensity 64% in 12 years [to 2016] [as electricity-generating use of oil fell 88% and coal 73%] while renewable output rose >10x. Profits, reliability, and resilience all improved. Denmark is heading for all-renewable total energy—and experimenting with resillient grid architectures that keep the lights on even if the powerlines go down. *



So we have not just one way (bulk storage, in magenta) but about *ten* ways to make the grid flexible and renewable, sketched in order of increasing cost. Your actual costs will vary, but bulk storage comes last, not first, so we needn't wait for a storage miracle (though some are emerging), and the market isn't waiting. Just the second of these little boxes is so powerful that it plus smart electric-car charging could match loads to supply in a solar-powered Texas, cut the daily load range in half, save a fourth of nonrenewable capacity, make renewables a third more valuable, and pay back in about five months. *

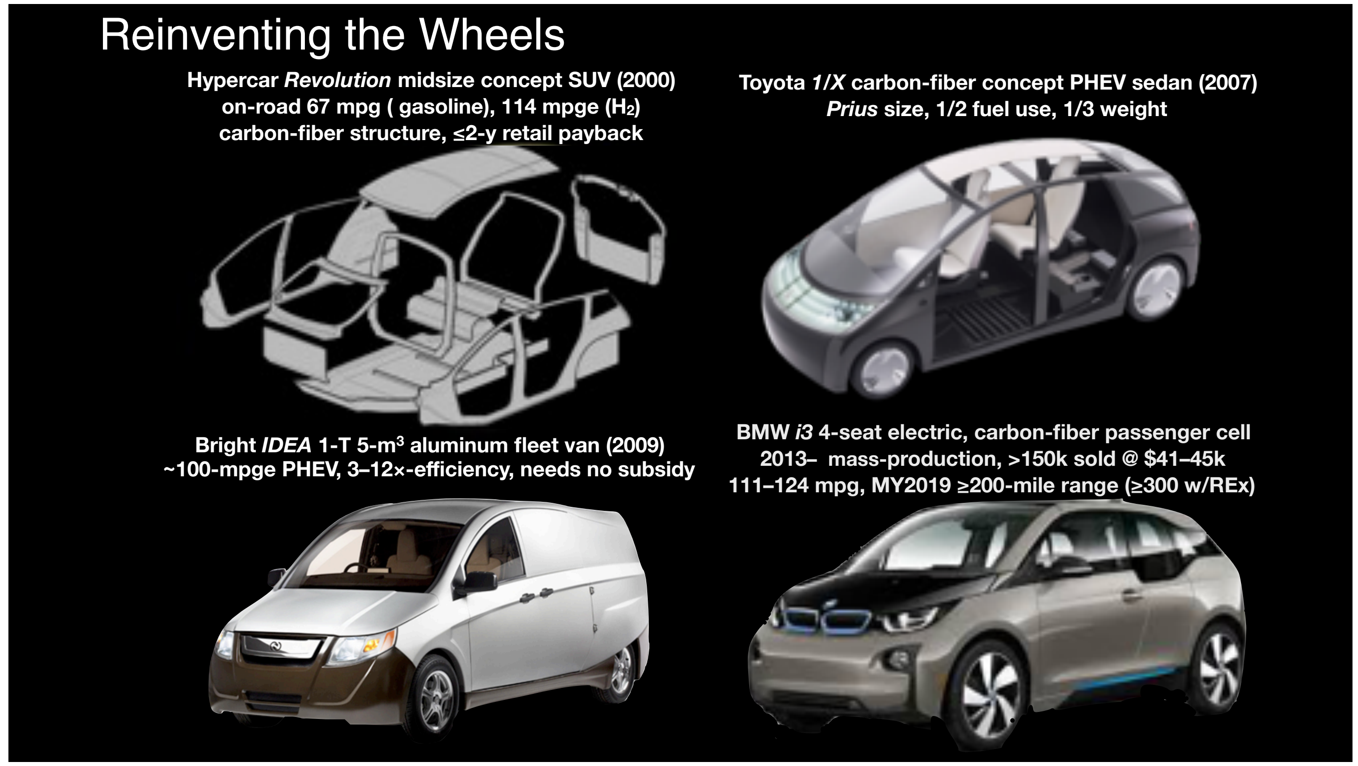
A billion people *have* no powerlines, no electricity, and little prospect of getting or affording it on family incomes of $2 a day or less. So they use kerosene lamps that kill 4 million people a year, would rank eighth among nations in carbon emissions, and burn $38 billion worth of kerosene a year—one-fifth of global lighting's total cost—to deliver, very inefficiently, one-*thousandth* of the world's light. /

But now we can banish darkness so daughters and sons can learn to read. An entrepreneurial village woman can sell or lease an * integrated PV/LED/lithium-battery/smart-chip lighting package *[demonstrate]* that runs 10–150 hours on each day's sunlight, pays back in weeks to months against kerosene, and can be microfinanced by scratchcards or via the smartphone it recharges. Eliminating kerosene is like getting a month's extra income every year forever. *



Richer people are getting off oil too. China last year [2017] sold * more electric vehicles than the world sold the year before, so lithium battery costs are * plummeting. Now India and Germany are targeting 100% EVs by 2030. Most forecasts didn't fully count that, nor four other EV accelerators:
- ultralighting, which can save up to ⅔ of the batteries;
- feebates, similar to the policies that made ⅓ of Norway's new cars electric—*50x* the U.S. share;
- shareable, autonomous, and mobility-as-a-service business models [whose high asset utilization] that strongly advantage[s] electric traction; and
- monetizing EVs' value to the electric grid to earn back up to half the sticker price. *

As batteries' rapid price drop continues, EVs in the early 2020s will match the sticker price of today's autos. By then if not sooner, new battery chemistries should have scaled production using no lithium, no cobalt, nothing scarce or flammable or toxic, with comparable or better performance and manyfold lower cost. Abundant cheap batteries imply vast distributed storage and demand flexibility, distributed solar everywhere that works 24/7 for less than an extra ¢/kWh, hence the end of thermal power plants, gas-industry distress, and perhaps the grid's becoming a stranded asset. Bypassing the grid, as wireless phones bypassed telco copper, gives utility executives nightmares and venture capitalists sweet dreams. *

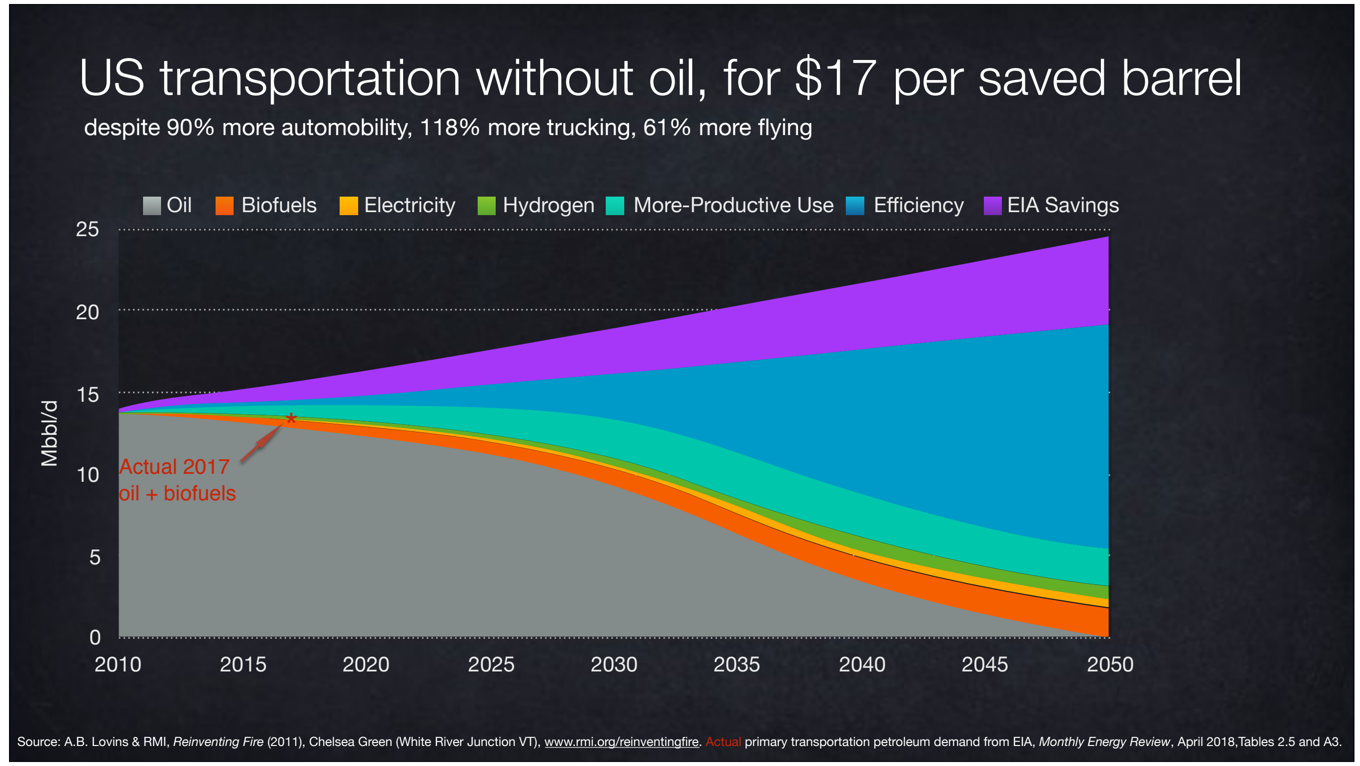


What about automobiles? Two-thirds of the energy needed to move a typical car is caused by its *weight*, saved weight can snowball severalfold, and saving one unit of energy at the wheels saves ~6 units at the fuel tank—huge leverage. The ultralight carbon-fiber electrified cars that I invented 27 y ago, we * designed with industry 18 y ago as a halved-weight SUV, and Toyota * used our methods 11 y ago * to design as a 70%-lighter plug-in hybrid, * entered the market in 2013. The profitable * 124-mpge model I drive pays for its carbon fiber by needing *fewer batteries* (which then charge faster).

Our improved manufacturing process let us make this **[demonstrate]** ultralight "carbon cap," tougher than titanium, in one minute a dozen years ago. That technology, which we sold to a Tier One, can now make a complex 2x2m carbon-fiber part in one minute. Making all autos this way would save far more oil than Saudi Arabia lifts. Saving each barrel costs <$10, soon <0, because the ultralighting is approximately free—paid for by a two-thirds-smaller propulsion system and by * radically simpler and cheaper automaking. But * even with *aluminum*, a one-ton-lighter, subsidy-free hybrid fleet van, like this model we developed and road-tested nine years ago, could save a fifth of US auto fuel. *

Efficient and electric autos are morphing from PIGS—Personal Internal-combustion Gasoline Steel-dominated vehicles—to * SEALS—Shareable Electric Autonomous Lightweight Service vehicles. These two changes in technology and three in business model are all simultaneous and mutually reinforcing. Technologies cost-effective today can also make big trucks 3–4x more efficient and airplanes 3–5x—even more with electricity or hydrogen. *

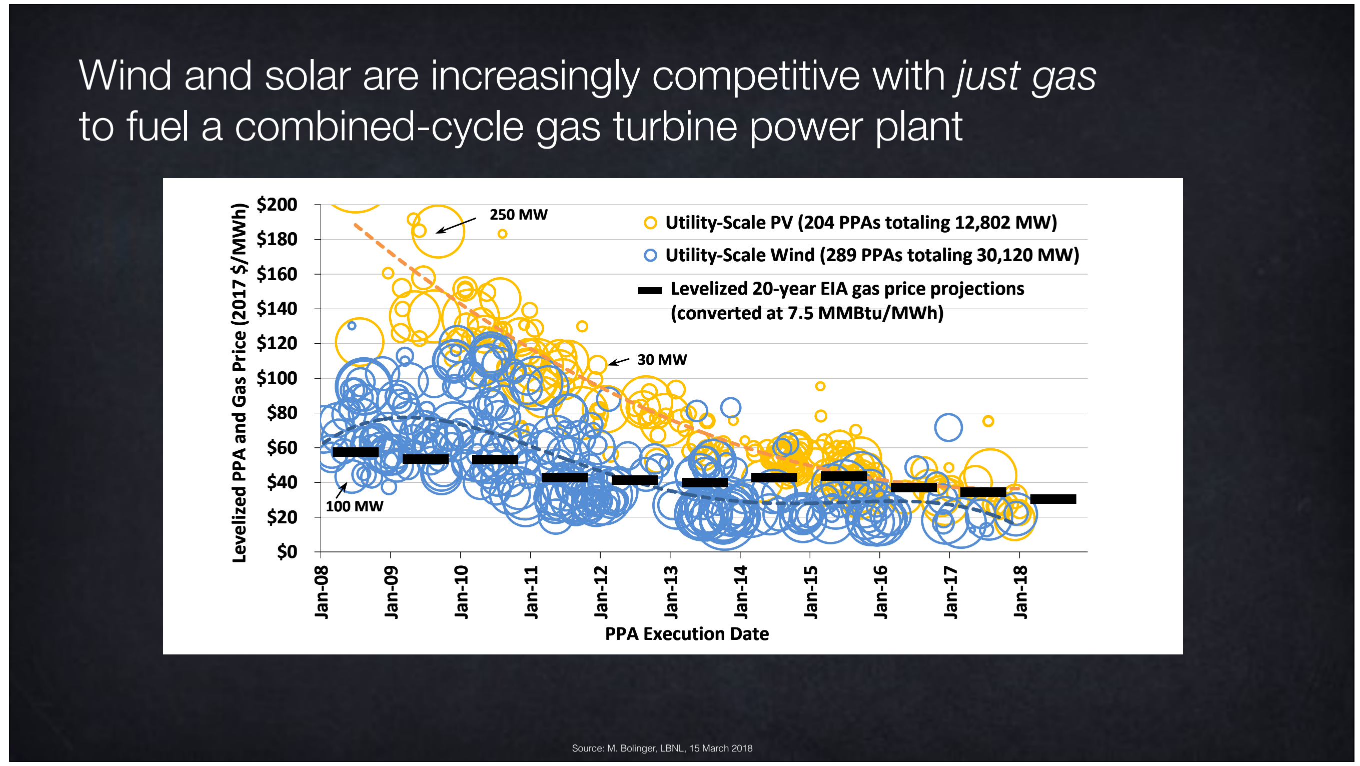
India and China are radically speeding this global mobility revolution as the US nears peak car ownership in the next five years, so a perfect storm is brewing for the oil, steel, and car industries. *



Even without most of today's mobility revolution, the US can greatly enhance mobility (see subtitle) while * phasing out oil with an Internal Rate of Return >17%.

We can first get efficient by * technologies included or * overlooked in the official forecast, * and use vehicles more productively. Then we can switch fuels, but there's not much left to switch. Superefficient autos can use any mixture of * hydrogen fuel cells, * electricity, and * advanced biofuels [; they're all straightforward at such modest quantities, the market will figure out which wins in which niches, and we needn't know that now]. Heavy trucks and airplanes can realistically use advanced biofuels or hydrogen, or trucks could even burn natural gas, but no vehicles will need oil. Any biofuels needed could be made two-thirds from wastes, without displacing cropland or harming climate or soil. * So far, this vision looks on track. *

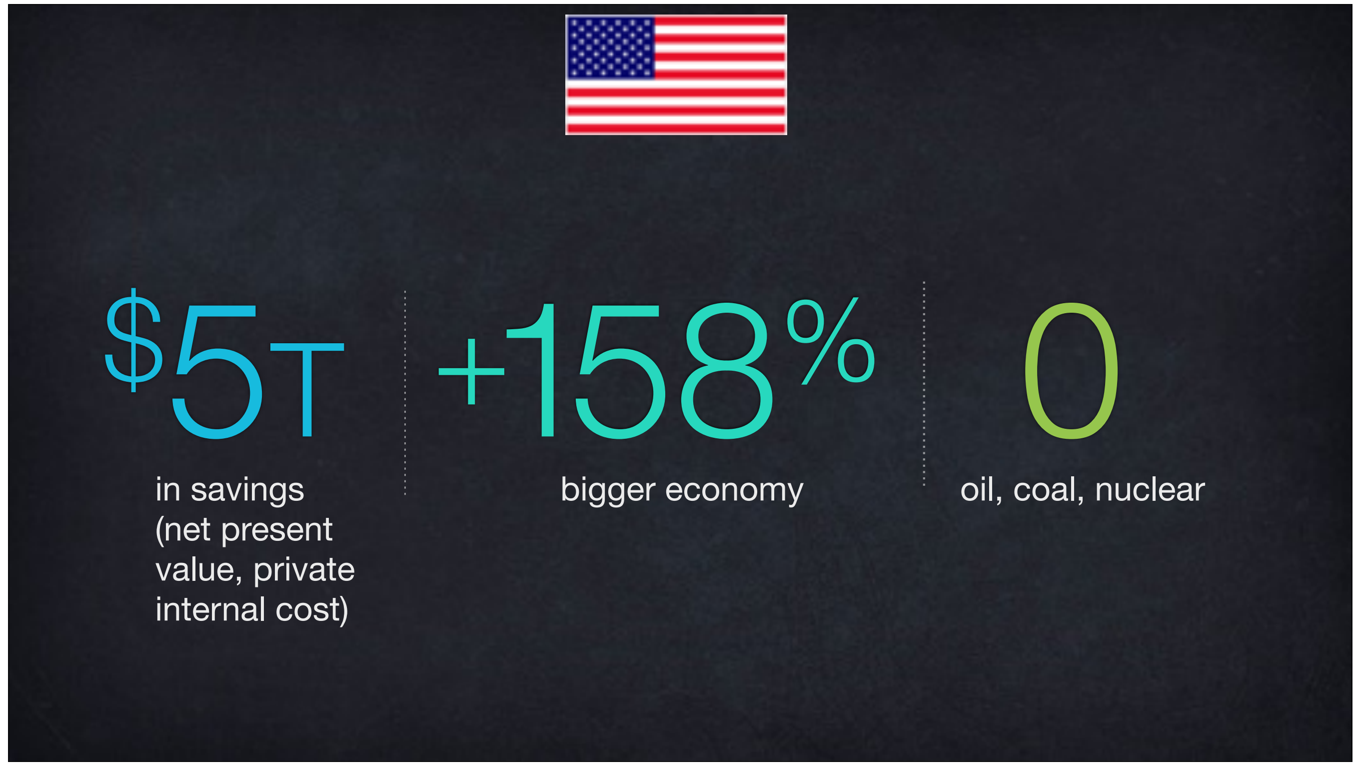
[53–110-km/L, or 125-240 mpg]



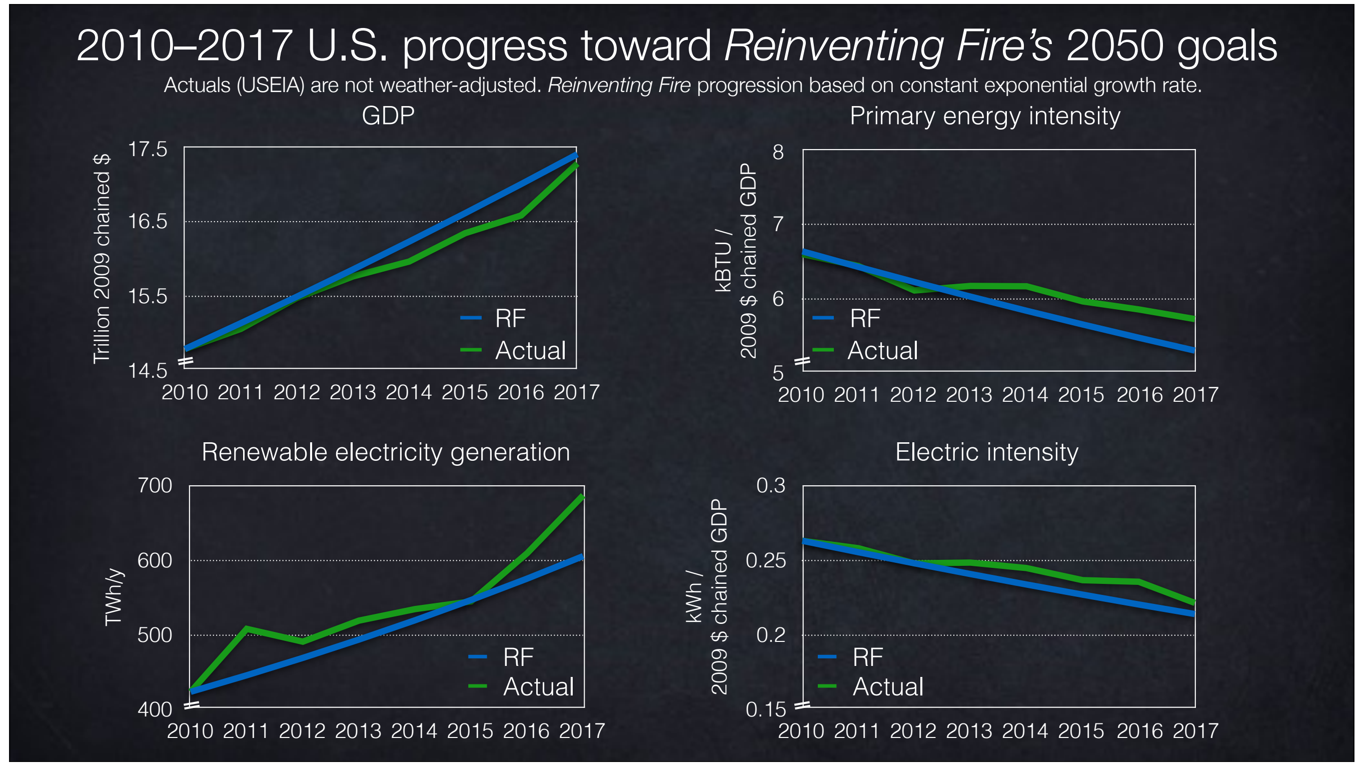
Many oil companies have therefore been shifting their strategy toward natural gas, but gas is in deep trouble even against *un*subsidized renewables today, *without* costing gas's CO_2 and methane emissions or its price volatility. New renewables even beat the heavy dashed line—the *gas cost alone* for existing plants, which must therefore run fewer hours. [Digitization, renewables, and new business models will move the power system's asset utilization from 50% to 80–90% and drive marginal cost to near zero.] Everything a new combined-cycle gas plant can do—energy, capacity, ramping/flexibility, other grid services—can be done faster, better, and cheaper by carbon-free demand-side, renewable, and storage portfolios. In the US alone, this could strand $112b of new gas plants now planned and >$0.5t of gas supply to fuel them. I hope those won't be *your* dollars.

Gas's heat markets are equally under threat [from deep building retrofits, smart electrification, superefficient new heat pumps and stoves, and innovative industrial processes]. Even petrochemical growth is at risk [from plastics backlash, smart materials cycles, and biofeedstocks]. With no safe market, global gas demand could dwindle in step with oil demand, not decades later. *

Assembling all these opportunities, our 2011 US business book *Reinventing Fire* * rigorously showed how to triple efficiency and quintuple renewables by 2050, needing no oil, coal, or nuclear energy and one-third less natural gas… *



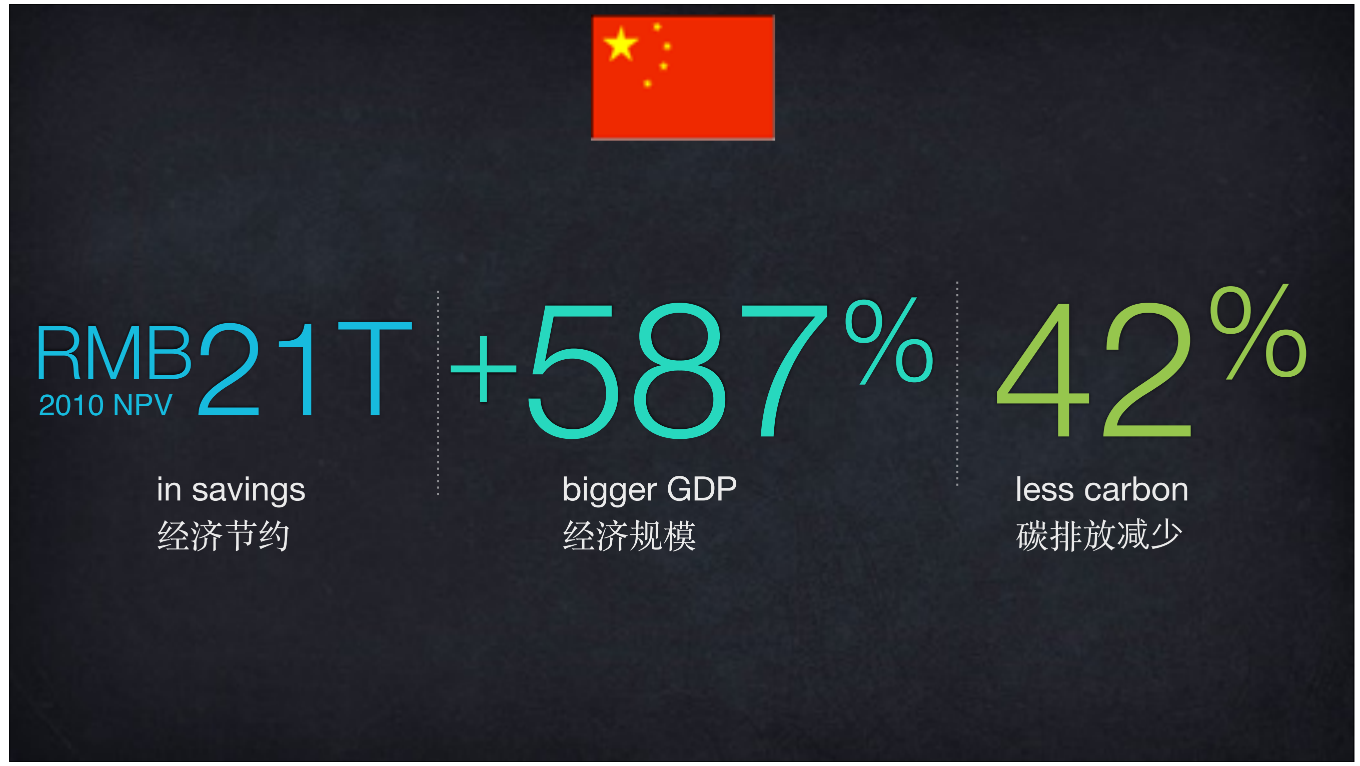
….to save $5 trillion NPV (assuming zero carbon price), grow the economy 2.6-fold, strengthen national security, and cut fossil carbon emissions 82–86% —with no new inventions nor Acts of Congress, but with smart city and state policies, led by business for profit. *



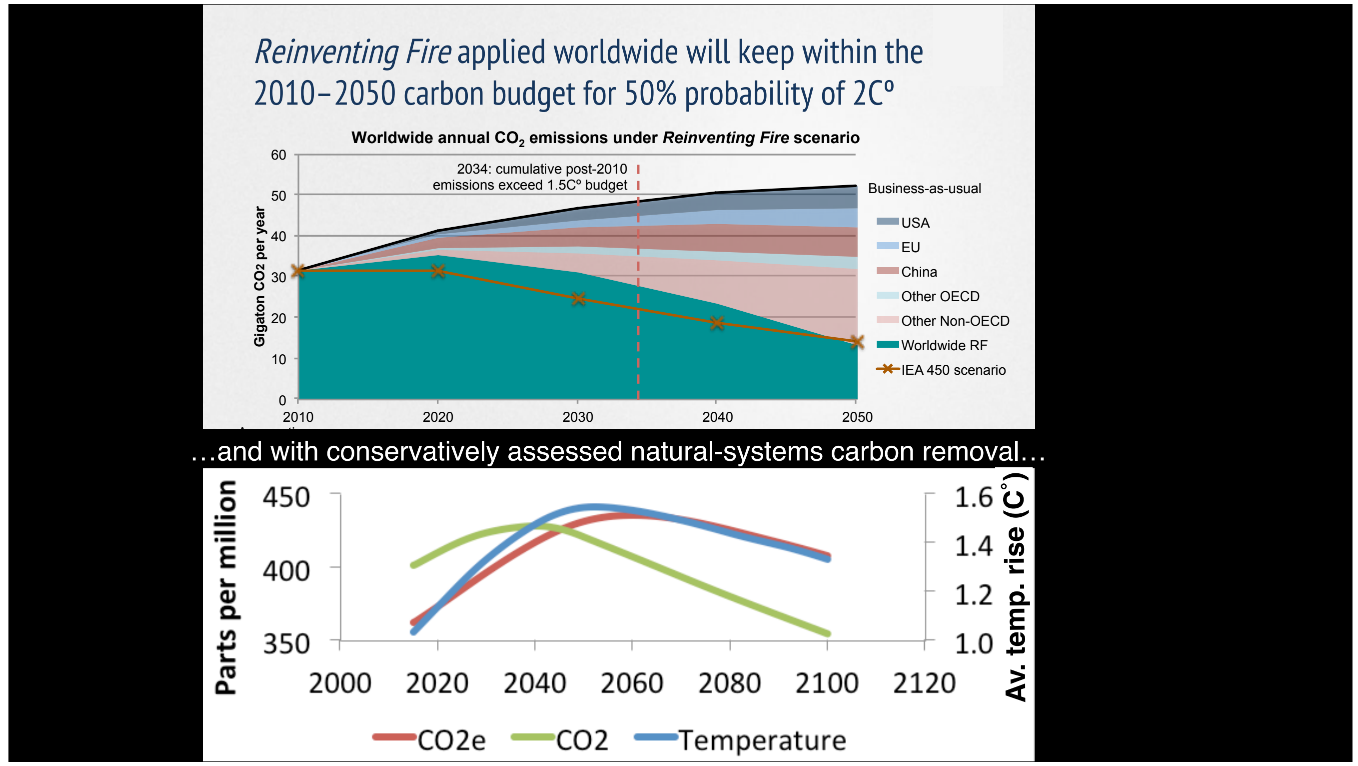
The first seven years of this 40-year journey are nicely on track (green actual vs. blue proposed)—probably because the private sector smells the $5 trillion on the table. That's exactly what should be happening. *

These best buys are also the most * effective * solutions to * big *global* * problems that hazard *every* country's security and prosperity. And if you like *any* of *Reinventing Fire*'s outcomes, you can support the transition without needing to like *every* outcome or agree about which outcome is most important. Focusing on outcomes, not motives, can turn gridlock and conflict into a unifying solution to our common energy challenge. *

Stimulated by those US findings, at the G20 in 2016, the Energy Research Institute of China's National Development and Reform Commission published its roadmap for China's energy revolution, aided by Berkeley Lab, Energy Foundation China, and Rocky Mountain Institute. *



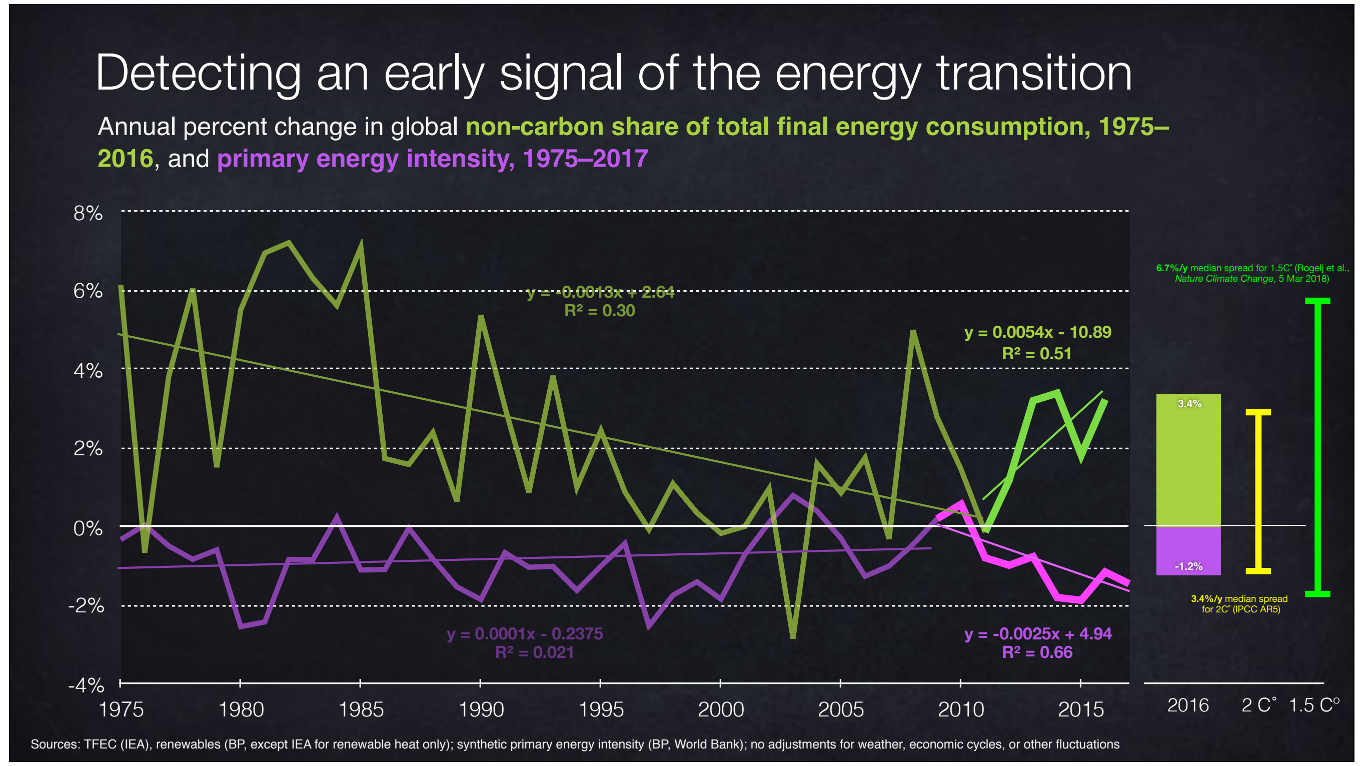
It details how China can save >$3 trillion, run a 7x bigger economy in 2050 than in 2010 while using today's energy 7x more productively, shift supply two-thirds off fossil fuels (83% in the electricity sector [, with 69% of generation coming from renewables]), emit 42% less carbon, burn 80% less coal, and get 13x more GDP from each ton of fossil carbon. This roadmap strongly informed the 13th Five Year Plan, whose energy authors were our Steering Committee. Energy savings *plus* renewables are decarbonizing the world 4x faster together than renewables alone, and China is the world leader in both. *



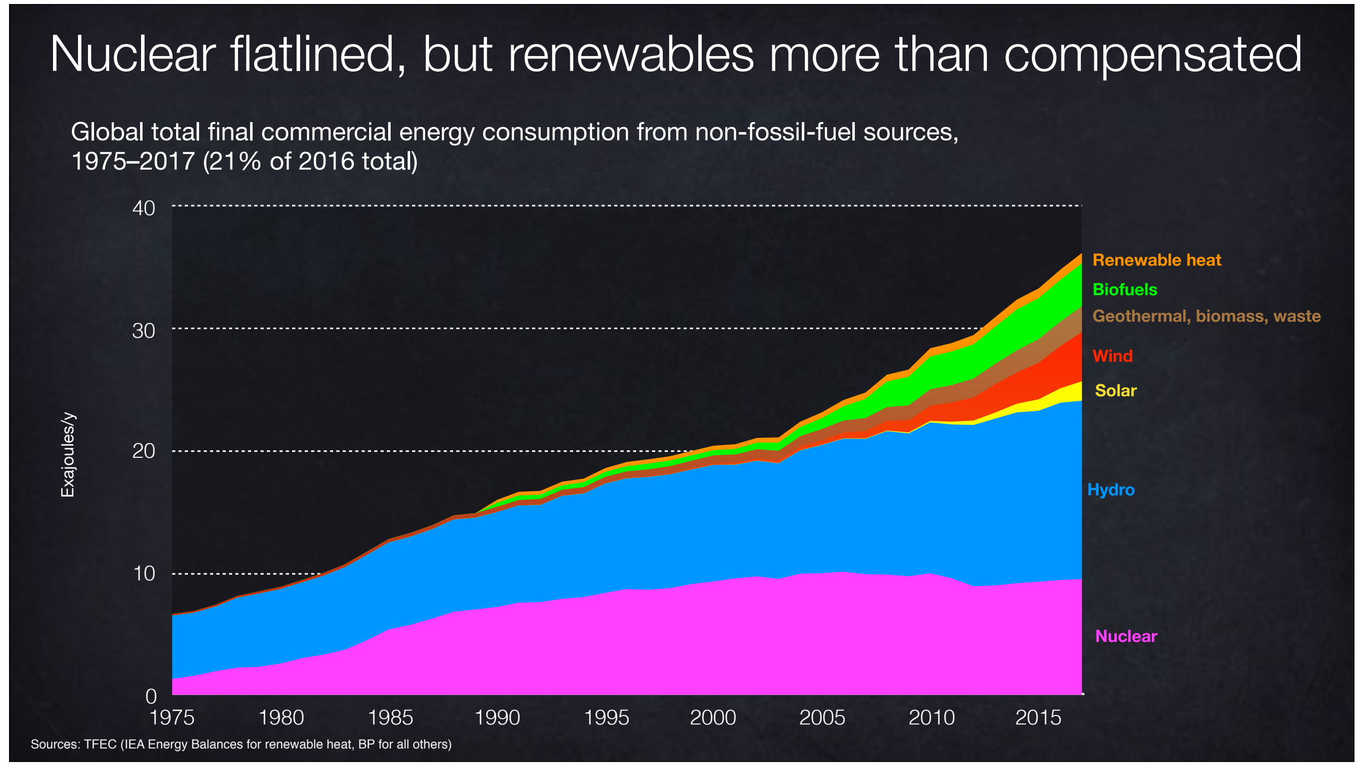
Extrapolating these on-track US, adopted Chinese, and similar European findings to the *other* half of the world could achieve a global ~2° climate trajectory while providing the same or better energy services ~$18 trillion *cheaper*. * Reinvesting in natural-systems carbon removal could then reach ~1.5°, still with trillions of dollars left over, plus huge positive externalities. Making climate protection not costly but profitable should simplify the politics. *

[Assumptions:

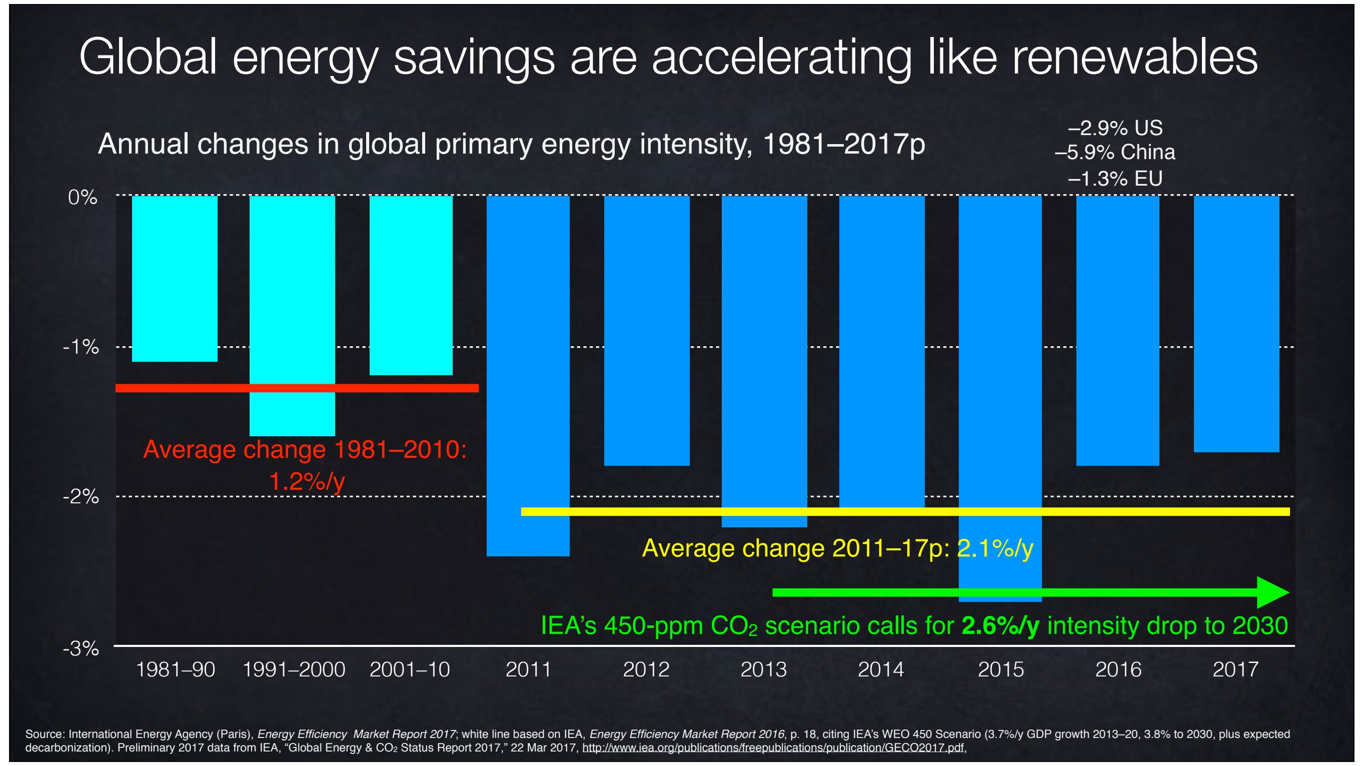
- CO2 emissions are calculated using RF:US, RF:C, and EU Roadmap 2050. Other OECD is calculated from US and Other Non-OECD from China RF trajectories.
- CO2 budget is calculated by ETH Zürich from IPCC data and assumptions for non-CO2 emissions to define an energy-related CO2 budget.
- Cumulative CO2 emissions 2010–50 under RF scenario are 1121 GT by 2050, 79 GT below the 1200 GT 201050 carbon budget for 50% probability of ≤2C° av temp chg, but 331 GT above the ≤1.5C° budget.]



How's this shift going so far? The *NY Times Magazine*'s feature warning of only a 5% chance of staying within 2° assumed that we'll decarbonize the global economy [at an average rate of just 1.9% a year—] two-fifths *slower* than we've actually averaged after 2010, when the pace abruptly picked up. Most climate models focus on earlier decades when the rates of decarbonizing energy supply and using less energy per dollar of GDP were faltering. [The carbon-free share of final energy consumption rose from ~9% to ~19% during 1975–2010, while the world used 16% less energy to make a dollar of GDP. Though * both shifts were in the right direction, * their rates of change, shown here in green and magenta, were faltering.] But * now we're on our way toward 2 and even 1.5° global warming. To stay below 2° [through ~2100], * we must sustain a ~3.4%/y *combined* improvement in these two variables through 2050 (the yellow line); to stay below 1.5°, twice that fast, or ~6.7%/y (the green line). So we're moving past the 2° goal and accelerating, the two terms are pretty fungible, and with neither despair *nor* complacency, we must double down on what makes sense and makes money. But first let's just check if these apparent new trends are real, since the datasets are small and noisy. *

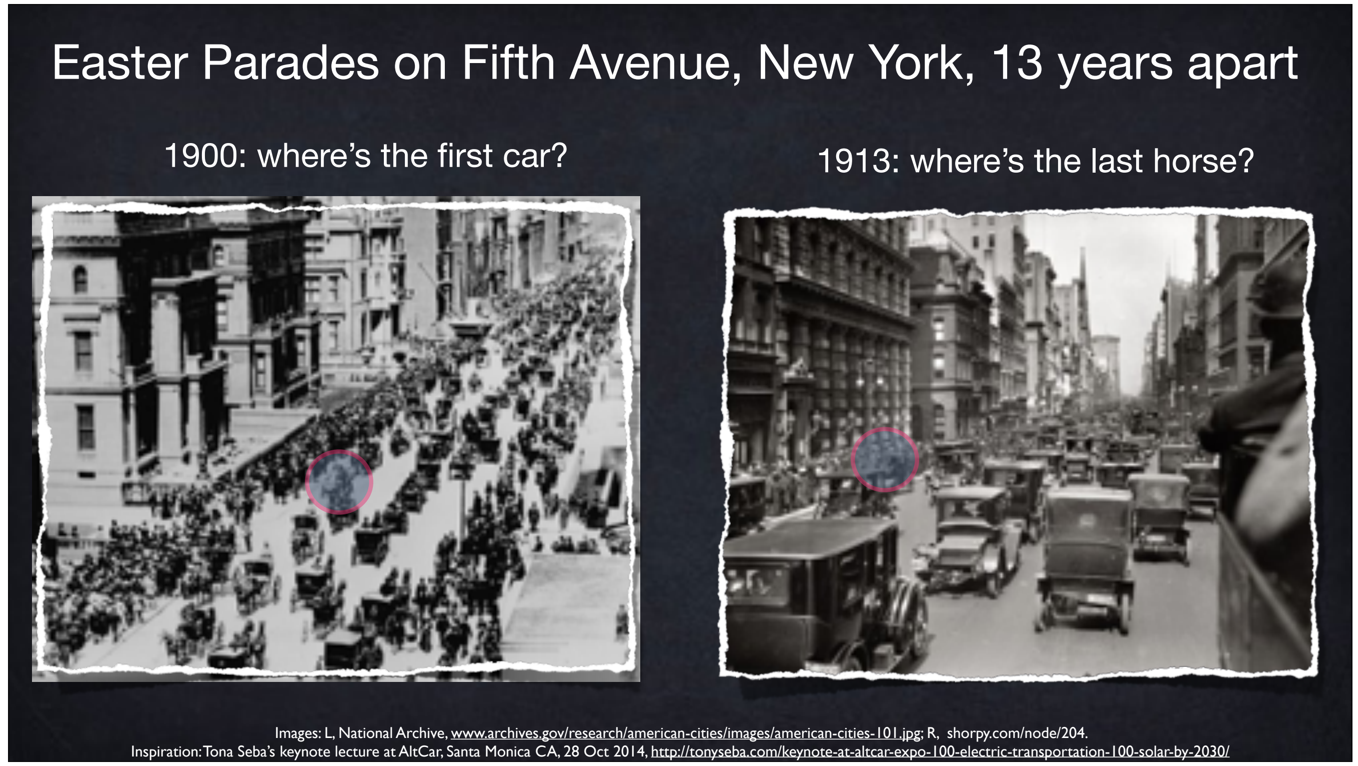


Looking first at supply of carbon-free final energy, * nuclear power's decline was more than offset by * growth in big [>50 MW] hydropower and * especially in *new* renewables—PVs, windpower, and * others [making electricity or mobility fuels and heat]. These big, fast additions break sharply with previous trends. *



On the demand side, the International Energy Agency says annual decreases in global energy intensity accelerated from the red average in the past three decades to the yellow line in this decade—a sudden gain of a percentage point per year. This has brought the world * two-thirds of the way to the green pace required for IEA's [450-ppm or 50% odds of] 2C° scenario. During 2014–16, energy savings *plus* a third as much supply decarbonization even offset *all* global GDP growth, holding CO_2 emissions flat. Now we must regain and sustain that pace. (The high oil prices driven by current Iran policy should help.) *

These trends deeply threaten incumbent energy suppliers. Their managers have understandably focused on the need for * price to exceed cost. But many forgot the *other* part of the business condition: that * *value must exceed price*. If competitors offer a superior value proposition and grab your revenues, it doesn’t matter if you can profitably sell what your ex-customers are no longer buying. Managing this risk and the rapid cultural change it requires is a formidable leadership challenge. As Jack Welch said, “If the rate of change on the outside is greater than the rate of change on the inside, the end is near.” *



When that value proposition shifts, markets can flip with breaktaking speed. On Fifth Avenue, in 1900 you have to look hard for the * first car. * *Just 13 years later* you have to look harder for * the last horse. The national non-farm horse market had peaked in 1910 when there were only 3% as many cars as horses. The horse-and-buggy industry thought it had many decades to adapt, but the *Model T* got 62% cheaper in 13 years [1908–21]. Car-owning households soared from 8% to ~80% in a decade to 1928, three-fourths financed by a GM and DuPont financial innovation called "car loans." Today's PV modules just got *80%* cheaper in *five* years, that's accelerating, 75% of California rooftop solar is innovatively financed, and Ford's and Edison's industries are merging to eat Rockefeller's industry. /

Horse-and-buggy thinking is dangerous but still common: as the late ex-oilman Maurice Strong said, "Not all the fossils are in the fuel." But DuPont's ex-Chairman Edgar Woolard reminds us that firms hampered by old thinking "...won't be a problem, because they simply won't be around long term."

The pace of transformation is thus set not by incumbents but by insurgents, who aren't inhibited by incumbents' business models, legacy assets, or cultures. Moreover, *investors* flee even before customers do, because capital markets keenly sniff out disruption. Once the capital markets think an industry is in or even headed for the toaster, they don't wait for the toast to get done before they decapitalize the disruptees and invest in their successors. *

危机 危機

http://pinyin.info/chinese/crisis.html

Hence this conversation about the energy transformation's risks and rewards. This Chinese word for "crisis" [or "dangerous critical moment]," wēijī, combines "dangerous" or "precarious" not with "opportunity" as mistranslated on over a million Webpages, but with "crucial point," with connotations of critical timing, quick-wittedness, and resourcefulness. As prudent and active investors at this unique tipping point, you'll need those attributes to foresee and forestall enormous stranded assets and balance-sheet deterioration for incumbents in many sectors. The sooner you act, the less systemic risk to the whole financial system. / Not only new technologies matter but also new design methods, business models, and financial innovations. The new energy system will also bring lower capital intensity and far higher capital velocity, so shifting investment from megawatts to negawatts could free up perhaps a fifth of the world's development capital for other urgent needs—the biggest macroeconomic lever we know for development. And if the $6 trillion of smart money already divested from hydrocarbon companies doesn't yet include yours, then please encourage those firms to outperform on profitable abatement of deliberate methane emissions from flares and engineered vents. That can boost profits by tens of billions of dollars a year and cut business risk while rapidly cranking down the global thermostat. The supermajors or service companies that first transcend compliance mentality and roll up this urgent global business opportunity to abate methane will be heroes to their shareholders and to the world. *

One last thought: The energy transformation isn't just fundamental; it's *ele*mental. The first Industrial Revolution was the Age of Carbon, creating our prosperity—and the world's mightiest industries—from coal and oil and gas. But now that obsolete Age of Carbon is giving way to the modern * Age of Silicon. Silicon microchips, telecommunications, and software turn people from isolated to networked, systems from dumb to smart, and energy from analog to digital and potentially from dirigiste to democratized. Silicon power electronics make electricity interconvertible and precisely applicable, replacing fiery molecules with obedient electrons. And silicon solar cells enable the ascent of energy from mining the fires of hell to harvesting the breath and radiance of heaven. *

So I respectfully suggest that your fiduciary responsibility and opportunity is to enable the new energy system, not protect the old. Then the global energy transformation can move at the pace and cost of software, not of infrastructure, and can be not constrained by the inertia of incumbents but sped by the ambition of insurgents.

Thank you all for your good work and your kind attention. *