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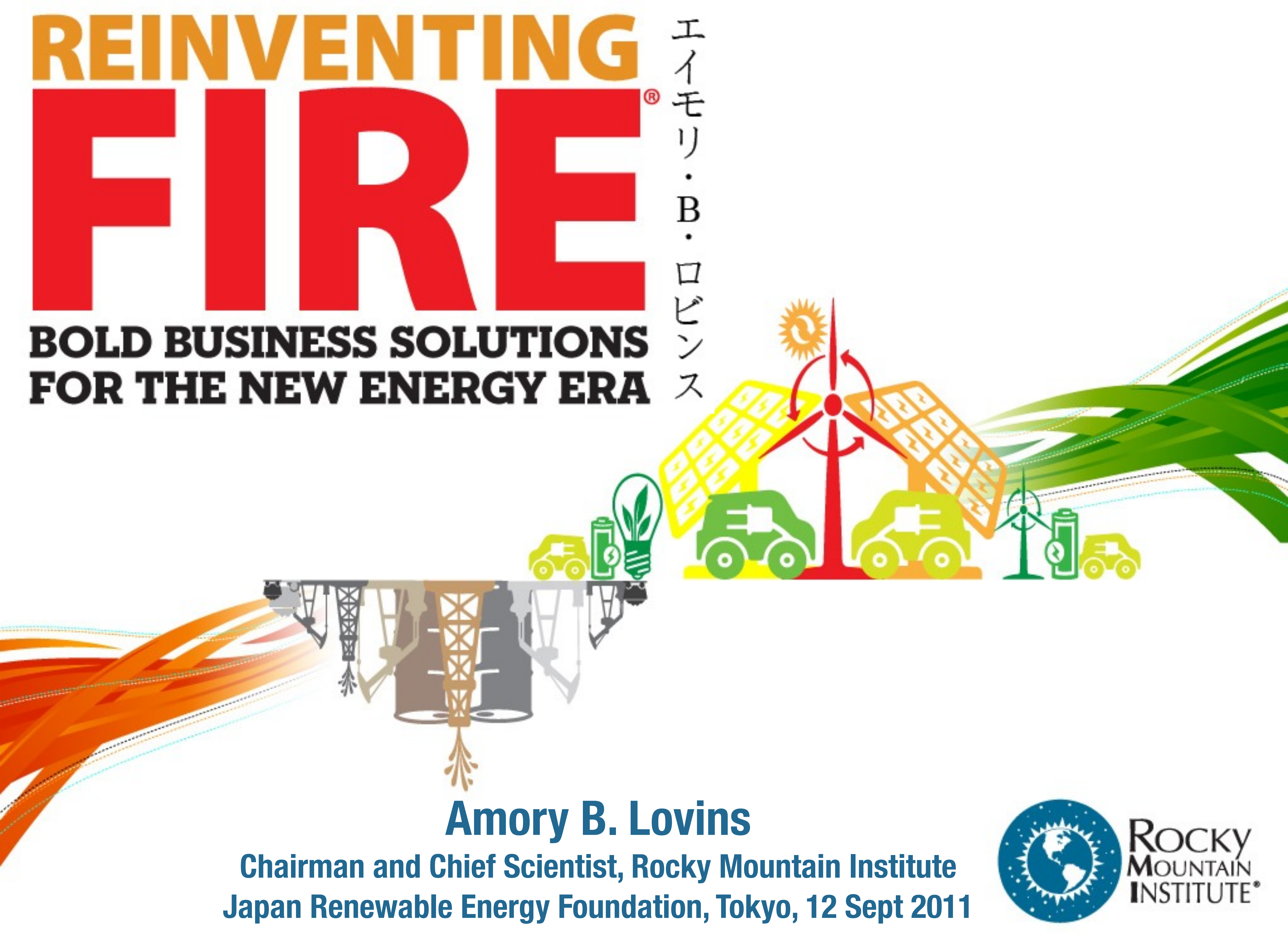
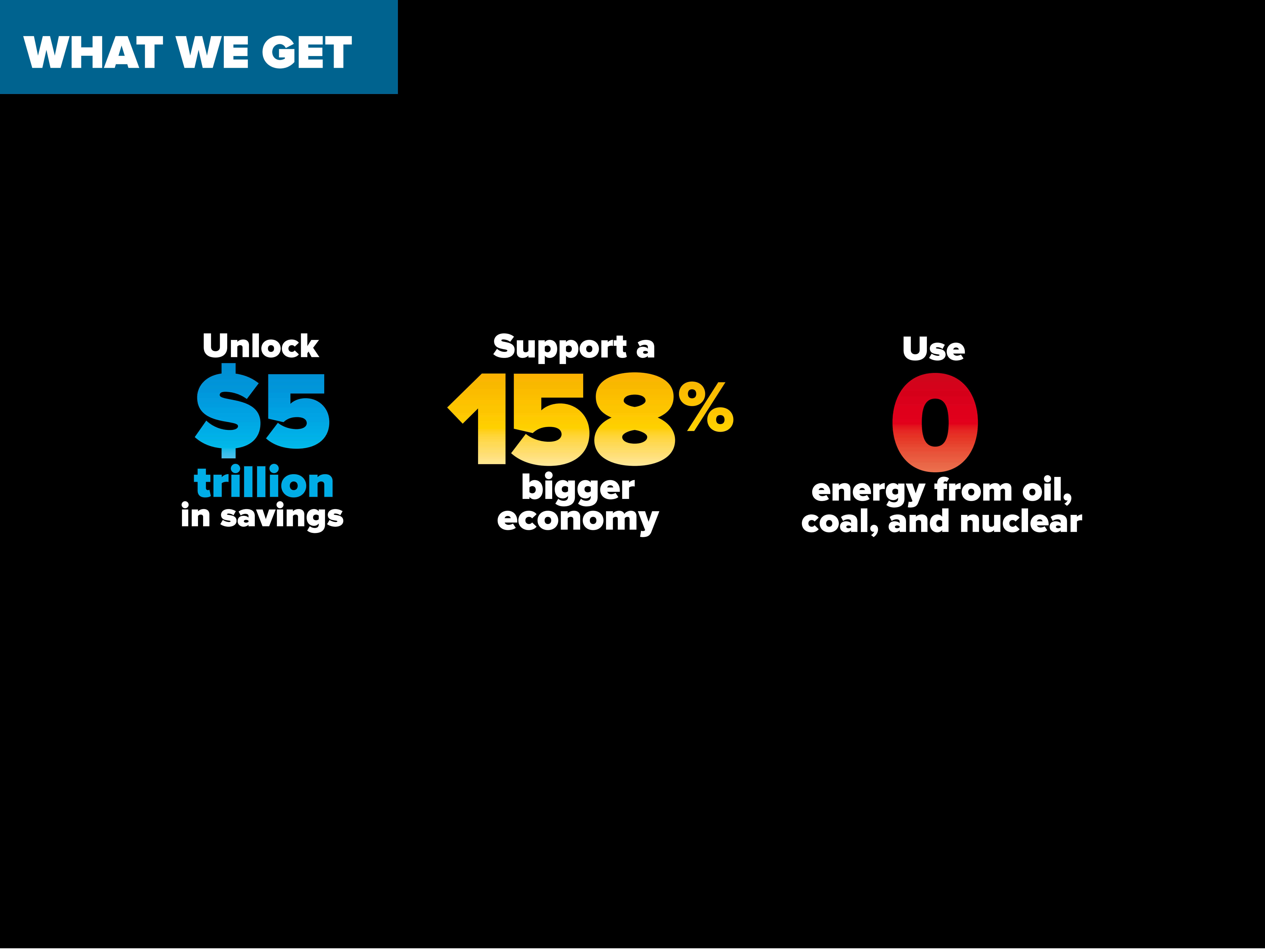


Rocky Mountain Institute's strategic focus is on shifting the United States (to start with) completely from oil and coal to efficient use and renewable energy by 2050. Our peer-reviewed "grand synthesis" called Reinventing Fire, to be published 27 October, will show how this ambitious transition can be led by business for profit. Today you'll get a very quick preview of how saving and displacing fossil fuels can work better and cost less than buying and burning them.

A better picture

Technology + Policy + Design + Strategy

Most analysts say such big energy shifts need just * technology and policy. But * adding two even bigger plays— * integrative design, and business innovation via new business models and competitive strategies—can create extraordinarily rewarding and disruptive business opportunities.



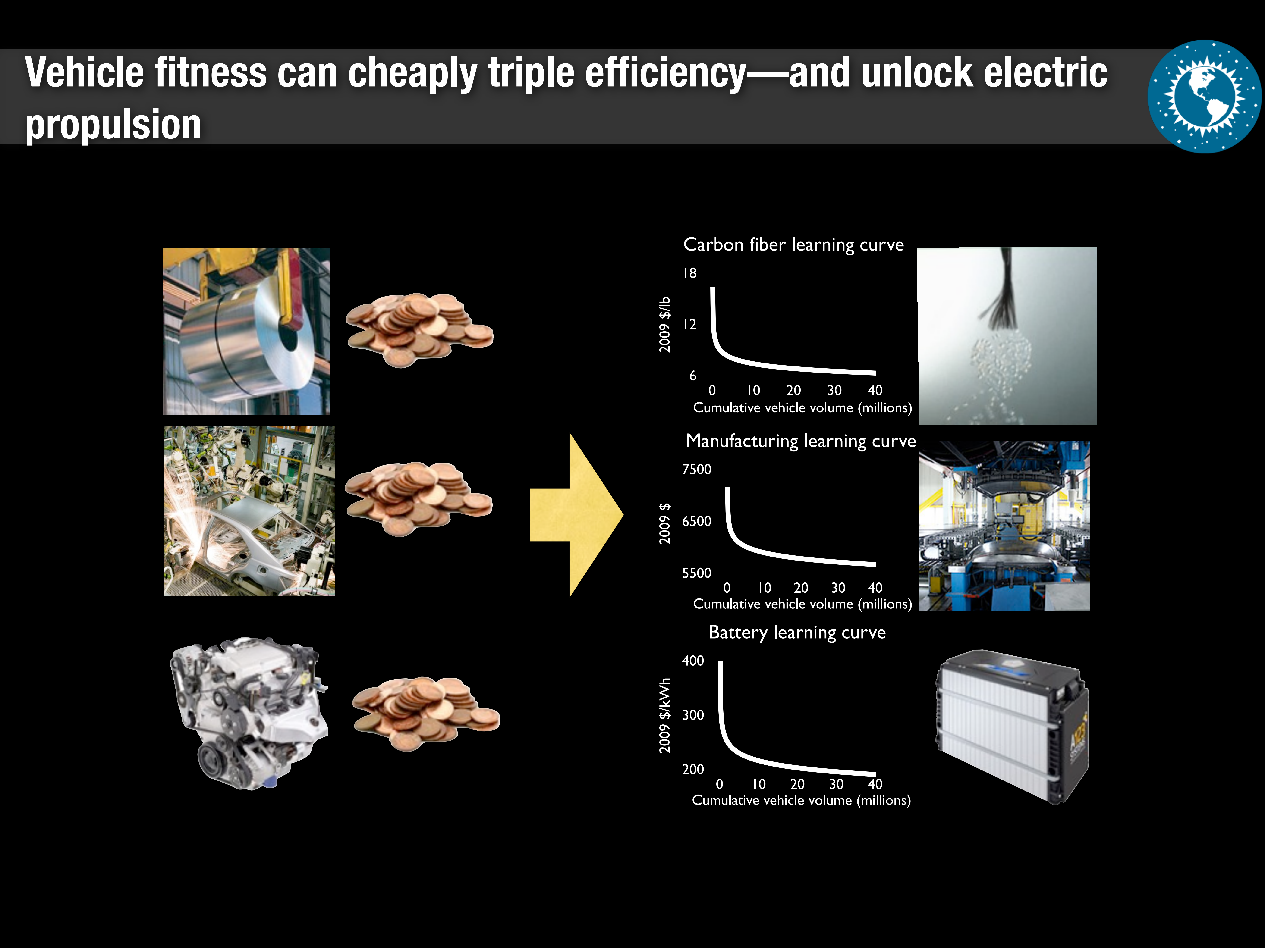
I’ll summarize how to save $5 trillion net present value by running the officially projected 2050 United States economy—2.6 times today’s—with no oil, no coal, one-third less natural gas, and no nuclear power. This will require no new inventions, and no new national taxes, mandates, subsidies, or laws (so it can be done despite political gridlock), and it assumes that carbon emissions and all other externalities are worth zero—a conservatively low estimate.

As I’ll explain, despite the many differences between the U.S. and Japan, I think Japan has similar or even better opportunities to follow an analogous path, and I am deeply grateful to Son-san for proposing it.


There are two big narratives here—oil and electricity. Oil and power stations each release two-fifths of U.S. and global fossil carbon. Nearly three-fourths of U.S. electricity powers buildings, and the same fraction of petroleum fuels transportation. The remaining electricity and oil run factories. Thus very efficient vehicles, buildings, and factories are a key to getting off oil and coal. This is also true in Japan, which imports not just half its oil like the United States but <u>all</u> its oil.

Vehicle fitness can cheaply triple efficiency—and unlock electric propulsion

Automobiles use three-fifths of U.S. mobility fuel. So how can we make autos oil-free? Two-thirds of the energy needed to move a typical car is caused by its weight. For the past quarter-century, though, * epidemic obesity has made America's two-ton steel autos gain weight twice as fast as their drivers! But ultralight, ultrastrong * materials, like carbon-fiber composites, can make * dramatic weight savings snowball and can make autos * simpler and cheaper to build. Lighter, * more slippery autos need less force to move them, so their * propulsion system shrinks. Such "vehicle fitness" then makes * electric cars affordable because their batteries or fuel cells get * smaller, lighter, and cheaper. Superefficient electric autos will ultimately sell for prices within about 1–2% of today's autos, and will cost *far* less to drive.



These innovations can transform automakers from wringing tiny savings out of Victorian steel-stamping and engines to the * steeply falling costs of three mutually reinforcing technologies—advanced materials, manufacturing, and propulsion.

Vehicle fitness can cheaply triple efficiency—and unlock electric propulsion

The result will be as *[automatic *]* gamechanging as shifting from small refinements in * mechanical typewriters to the dramatic Moore’s-Law-driven gains in * computers. Computers and electronics are now America’s biggest industry; typewriter-makers have vanished.

So vehicle fitness opens a new automotive competitive strategy to double oil savings in 40 years, thereby making affordable the electrification that can save the rest. China will lead if others don’t, and leaders will beat laggards, just as Toyota’s *hiyaku* into hybrids 14 years ago is still challenging competitors to catch up—only faster, because hybrids have only one learning curve, not three.

Bright *IDEA* 1-T 5-m^3 van (2009)
3–12×-efficiency plug-in hybrid, needs no subsidy

Hypercar *Revolution* SUV (2000)
28.5 km/L (48.5 w/H_2), 2-y payback at U.S. fuel prices

Toyota *1/X* sedan (2007)
***Prius* size, 1/2 fuel use, 1/3 weight (420 kg)**

Such breakthrough vehicles are rapidly emerging.
* Two years ago, RMI’s fifth spinoff Bright Automotive, now partnered with General Motors, showed this 3–12x-more-fuel-efficient aluminum van. Unlike other plug-in hybrids, it needs no subsidy to attract fleet buyers, because its fitness eliminated most of its costly batteries. But what if we make it even lighter?
* Back in 2000, my team and two European industry partners designed this uncompromised, safe, high-performance, carbon-fiber, midsize suburban assault vehicle. It saved over half the weight and nearly three-fourths of the gasoline (or 84% using fuel cells).
* Toyota’s carbon-fiber plug-in-hybrid concept car is as spacious as a *Prius* but with half its fuel use and <u>one-third</u> its weight. The day before it was shown, Toray, the world’s biggest maker of carbon fiber announced a ¥30-billion factory to “mass-produce carbon-fiber car parts for Toyota,” and later added four more automakers.
But now electrified carbon-fiber concepts are moving to the market.

Volume production of electrified carbon-fiber cars is slated to start in 2012–13

VW *XL1* 2-seat plug-in hybrid (2011), 795 kg, 98 km/$L_{gasoline}$, 2013 production

BMW *i3* 4-seat battery-electric hatchback with range-extender option (2011), 1250 kg, 2013 production

* This year, Volkswagen showed this 98 km/L carbon-fiber 2-seater slated for 2013 production.
* BMW also announced 2013 midvolume production of its roomier *i3* carbon-fiber 4-seat electric hatchback, and confirmed that its carbon fiber was paid for by needing fewer batteries. The firm's CEO says, "We do not intend to be a typewriter-maker."
Audi says it aims to beat VW and BMW to market by a year.

Radically simplified manufacturing

14 parts, ~99% less tooling cost
no body shop, perhaps no paint shop
2/3 smaller powertrain

Ultralighting is the biggest automotive gamechanger, because only 0.3% of a typical car's fuel energy moves the driver, and saving one unit of energy at the wheels saves *seven* units of fuel at the tank.

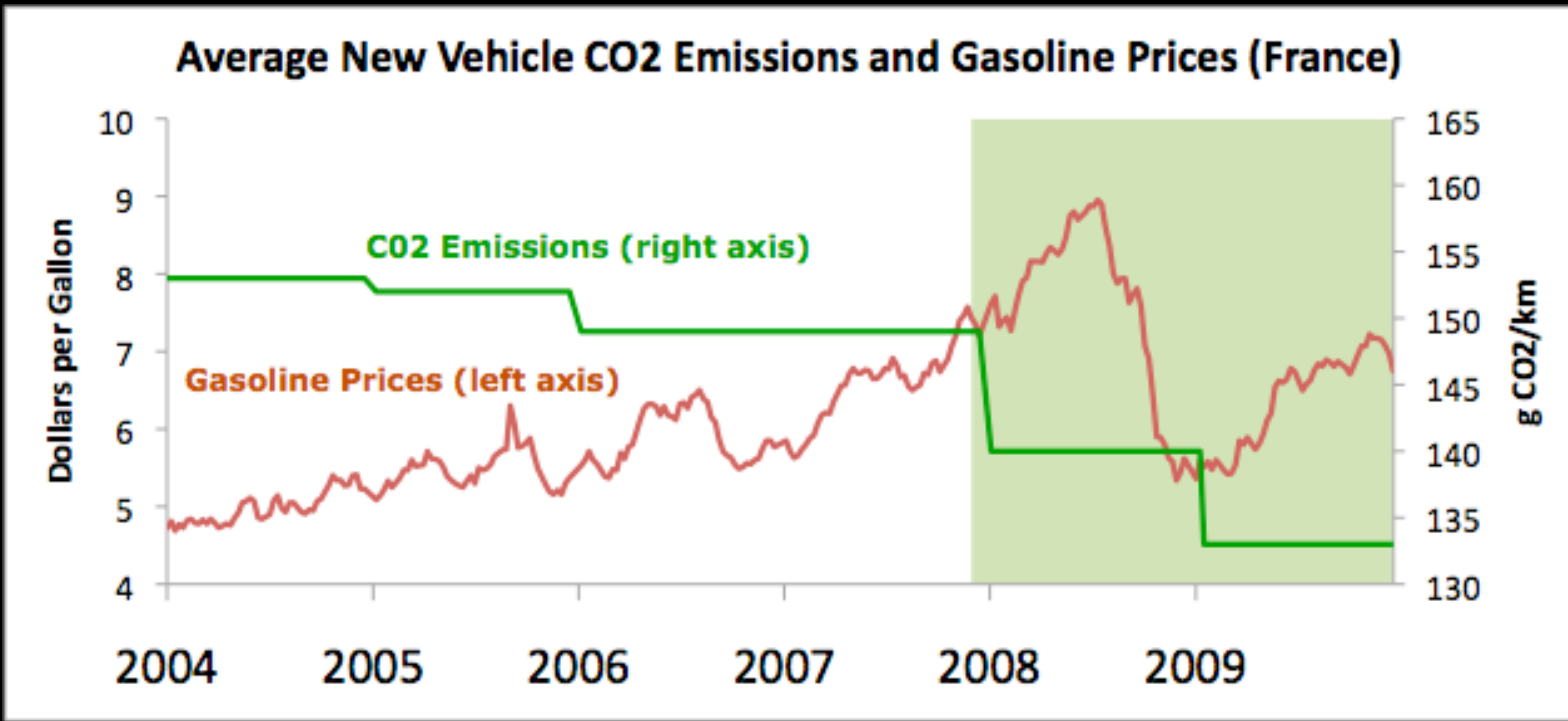
But integratively designed, ultralight, ultrasafe autos need *not* cost more to build.

* That airframe-inspired SUV body design has just 14 parts, each made with one low-pressure dieset—saving ~95–99% of the $0.3-billion tooling cost. Each part can be lifted in one or two hands with no hoist. * The parts snap precisely together for bonding without the robotic body shop. Laying color in the mold can nearly eliminate the paint shop. There go the two hardest, costliest steps in automaking. * The propulsion system is also two-thirds smaller, hence lighter and cheaper. All these savings pay for the carbon fiber, making the ultralighting roughly free. And carbon fiber itself is probably about to get much cheaper.

New U.S. and foreign manufacturing technology can make affordable carbon-composite structures in less than one minute

New manufacturing technology from RMI’s fourth spinoff (shown here under test at the Japanese government’s composites center at Todai) or its competitors can make carbon-fiber parts like this test piece *[“ring” prop]*, tougher than titanium, in <u>just one minute</u>, scaling to automotive cost and speed with aerospace performance. Building all U.S. autos this way would be like finding a Saudi Arabia under Detroit, because ultralighting saves half the weight and half the fuel; the car becomes peppier but safer (because this material absorbs 12x more crash energy per kg than steel); yet the auto costs about the same to make.

Federal, state, or regional policy can unlock this potential



To reach volumes that make batteries and fuel cells readily affordable, we need a “feebate”—rebates for efficient new autos, paid for by fees on inefficient autos. Europe has five successful feebate programs. The biggest is in France. In its first two years, it nearly doubled the market share of the most efficient models, cut the share of the least efficient models by two-thirds, and tripled the speed of improving automotive efficiency.

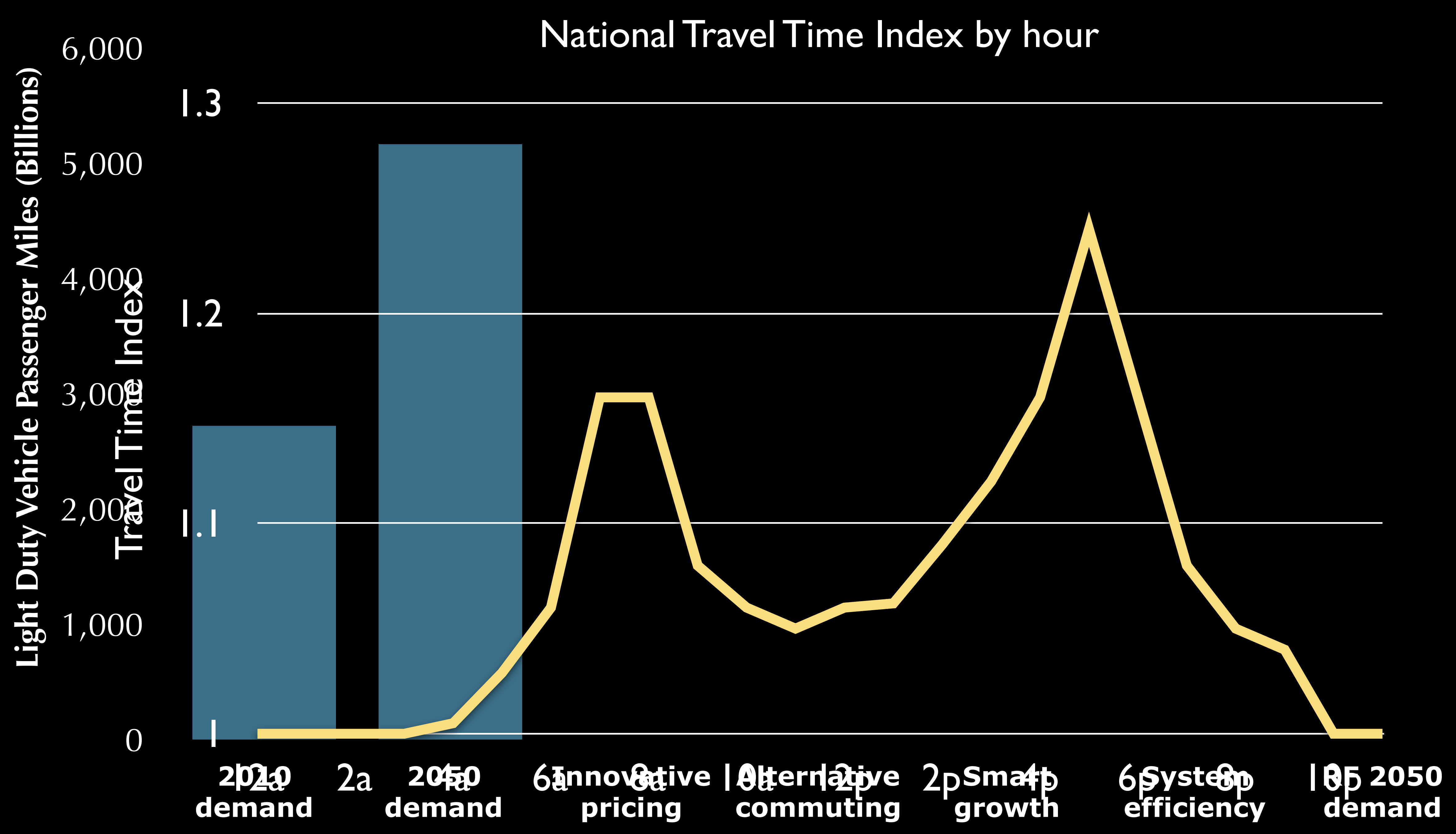
Temporary U.S. feebates, phasing out by 2035, could unlock $2-trillion gross oil savings—rising to $3 trillion if smart fleet purchases speed the retooling.

Tripled-efficiency trucks and planes can also pay back quickly

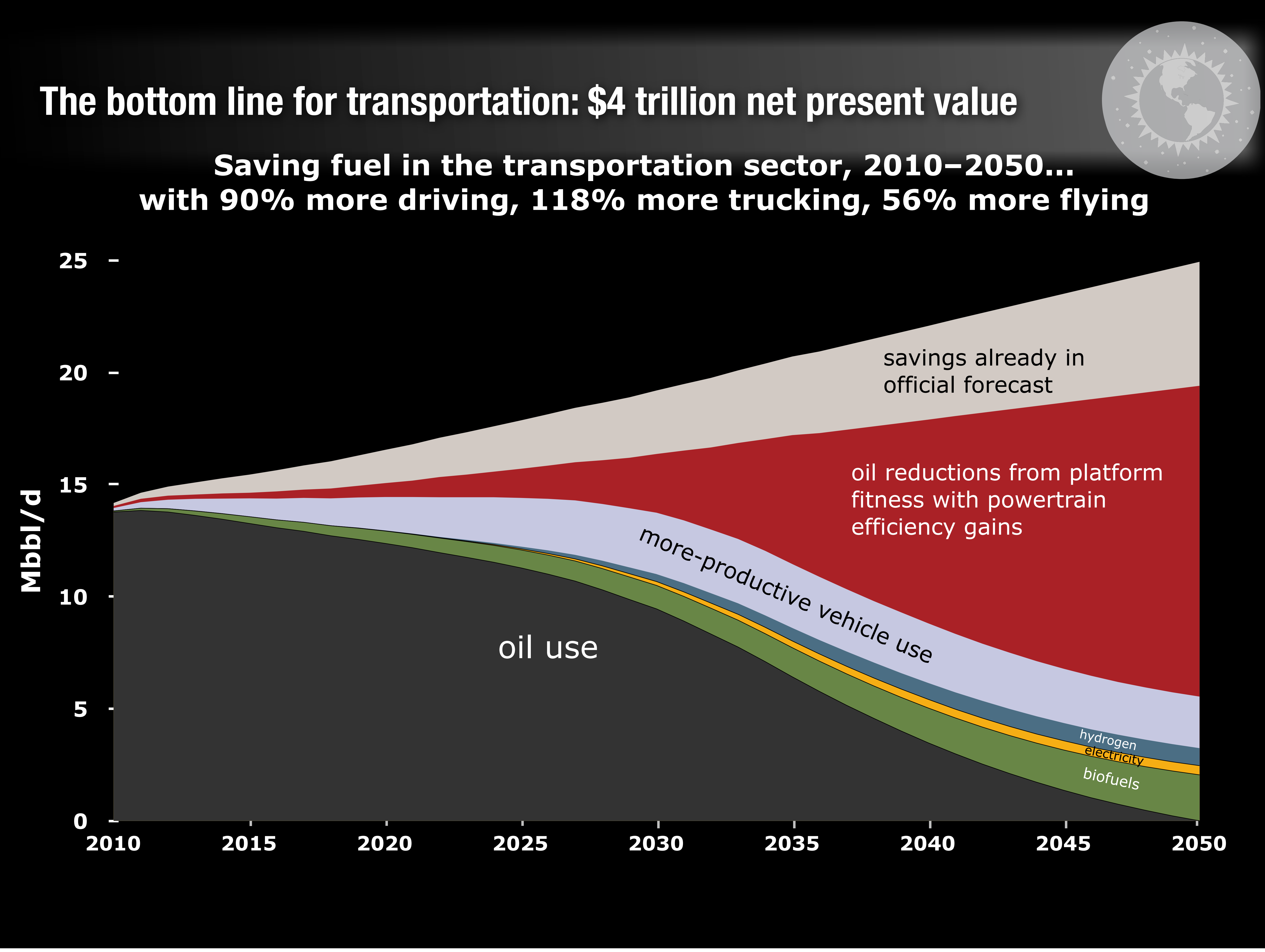
The same physics and business logic apply to other vehicles. Saving half of 18-wheel trucks' fuel at one-fourth its cost is becoming a reality. (Including smarter logistics, Walmart already saved 60% of its trucks' fuel use in the past five years.) Next, if we can harmonize state standards, we can raise that one-half technological saving to two-thirds by hooking two trailers to one tractor, with better safety and less road wear. Also in the cards are doubled- and tripled-efficiency aircraft. These planes and trucks can save the United States another $0.9 trillion net present value.

A parallel military revolution in energy efficiency will accelerate these civilian advances in much the way that military R&D created the Internet, GPS, and the jet-engine and microchip industries. This time, the results can include negamissions in the Persian Gulf—Mission Unnecessary. The warfighters love that idea.

Revolutions in how vehicles are not just made but also *used*



As we design and build vehicles better, we can also use them smarter.
If this weekday traffic-congestion graph were an electricity loadshape, we'd try to flatten it with IT-enabled demand response and smart-grid techniques. * Not yet doing this for U.S. road traffic is wasting many billions of dollars per year through idle people, idle vehicles, and idle roads. * But now we can charge real-time driving costs per km, not per liter; * use smart IT to enhance transit and empower car- and ride-sharing; * allow lucrative smart-growth real-estate models, so people are already where they want to be; and use *intelligent transportation systems to make traffic free-flowing. Together, these approaches have the * proven potential to give us the same or better access with 46 to * 84% less driving, saving another $0.4 trillion.
Even more disruptive will be solutions-economy business models, like ZIPcar, that lease a mobility or access service instead of selling cars. This could boost autos' 4% asset utilization by perhaps an order of magnitude.
Even heavy trucks can save 33% of their ton-km, and another $1/3 trillion, by intensifying recent trends in smarter logistics, fewer tons hauled fewer km, and better coordination with rail freight.



Put all these things together and 40 years hence, 36% more Americans can enjoy the greatly enhanced mobility of a 158% bigger economy, yet use no oil and save $4 trillion net, including fuel infrastructure bought or avoided.

Those 53–110-km/L-equivalent autos can use any mixture of electricity, hydrogen fuel cells, and advanced biofuels. 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 the U.S. might need, at most 3 Mb/d, could be made without displacing cropland or harming climate or soil fertility.

“We must leave oil before it leaves us.”

—Fatih Birol, Chief Economist, International Energy Agency, 2008

My team speeds these oil savings by “institutional acupuncture”—seeing where the business logic is congested and not flowing properly, then sticking needles in it to get it flowing. Our partners range from Ford to Wal-Mart to the Pentagon. I think most of the six sectors we need to transform are already at or past the “tipping point” where this long effort starts getting easier. Boeing converted its *787 Dreamliner*’s leapfrog efficiency into a powerful competitive strategy. Now Boeing Commercial Airplanes’ former CEO has led Ford to become a top lightweighter and the world’s second most profitable automaker.
In 2009, mainstream analysts even began to see “peak oil”—not in <u>supply</u> but in <u>demand</u>. ExxonMobil agreed U.S. gasoline use had peaked in 2007 and will only decline. Dan Yergin said <u>all industrialized countries’ oil</u> use had peaked in 2005 and will only decline. Deutsche Bank forecast <u>world</u> oil use will peak around 2016, then by 2030 fall to 8% below today’s level.

In short, oil is becoming uncompetitive even at low prices before it becomes unavailable even at high prices! Japanese automakers have helped start this revolution. Now they have the opportunity to lead its completion and thus rebuild their own strength.

Less than 1% of U.S. oil, but 95% of U.S. coal, makes electricity. Yet the auto and electricity problems are far easier to solve together than separately, because superefficient electrified autos, rather than burdening the grid, can become a key asset by providing flexible demand and distributed storage.

So our second big story is about saving electricity, then making it differently. These twin revolutions promise more numerous, diverse, and profound disruptions in electricity than in any other sector. It will be a challenging transition: 21st-Century technology and speed are colliding with 20th- and 19th-Century institutions and cultures to create the most perilous and rewarding inflection point since the Internet.

Today, most of our electricity is wasted (even in Japan), and efficiency technologies keep improving faster than they're applied, making the potential savings ever bigger and cheaper. Over the next 40 years, smarter building technologies and operations can save about *half* of U.S. buildings' electricity and gas, worth over *$1.4 trillion net*. The savings are 4x the costs. Implementation needs systematic barrier-busting, mature delivery by well-trained people, and owners' paying attention. Surprisingly, this opportunity is probably even bigger in Japan, which despite its often very efficient industry still has rather inefficient buildings.

But an even more disruptive innovation can boost existing buildings' energy saving to over *70%*. It's called "integrative design." It can often make very *large* energy savings cost *less* than small or no savings, turning diminishing returns into *expanding* returns. For example...

Lovins GreenHome, Old Snowmass, Colorado, 1984

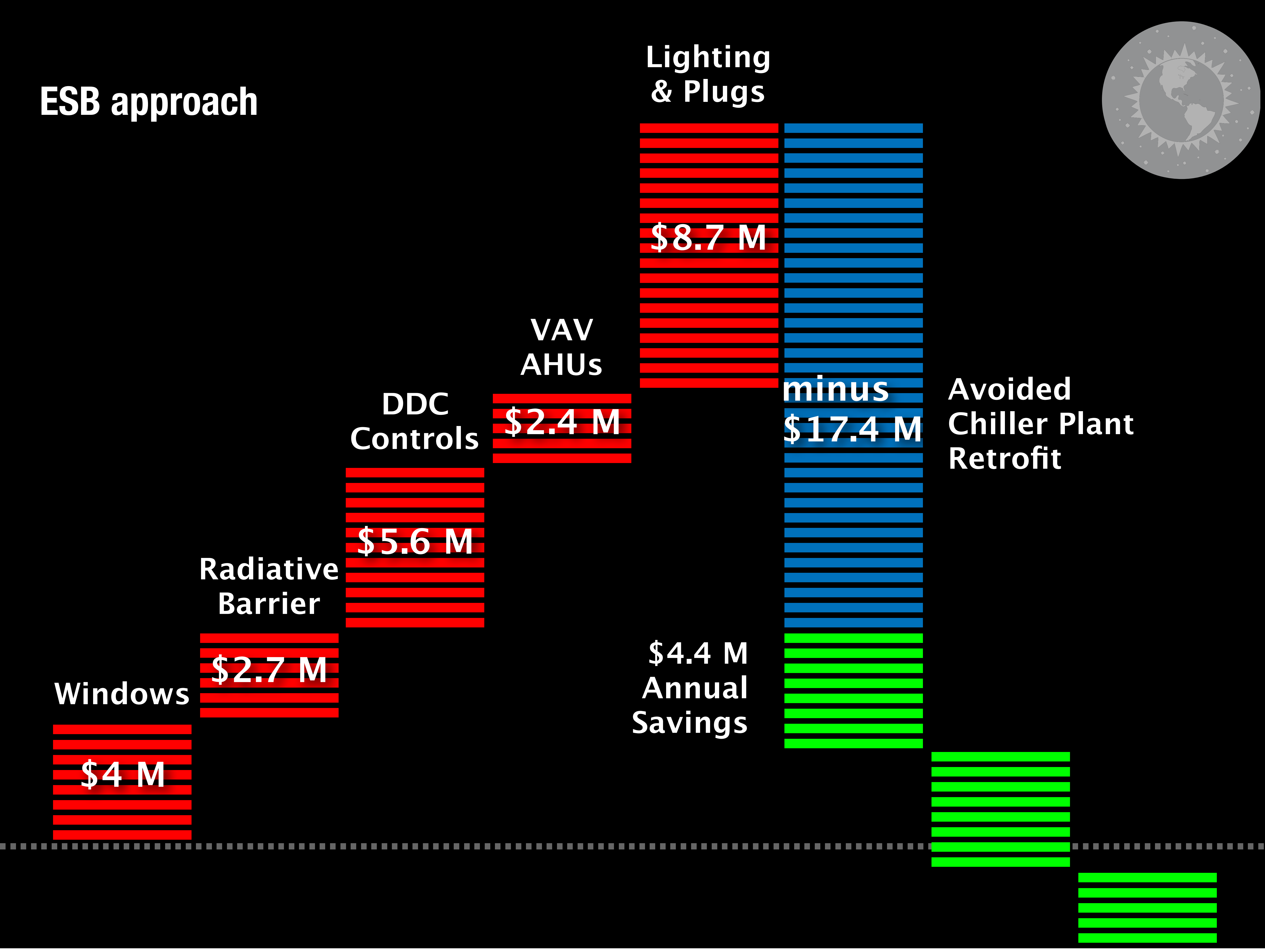
–44˚C with no heating/cooling equipment, yet *lower* construction cost

* Our 1984 house at 2200 m elevation, where winter temperatures have dipped as low as –44˚C, helped inspire 25,000 European buildings that need no heating, yet have about normal construction cost. And they needn't look like this to work like this.

* Inside we’re ripening our 36th banana crop with no furnace. In 1984, this house saved 99% of its space- and water-heating energy and 90% of its electricity with a 10-month payback. Today’s technologies, which we've just retrofitted, are even better. The design approach works in any climate...including eliminating air-conditioning up to at least +46˚C with lower construction cost and better comfort. A similar approach in a new house in Bangkok saved 90% of the air-conditioning energy with better comfort and normal construction cost.

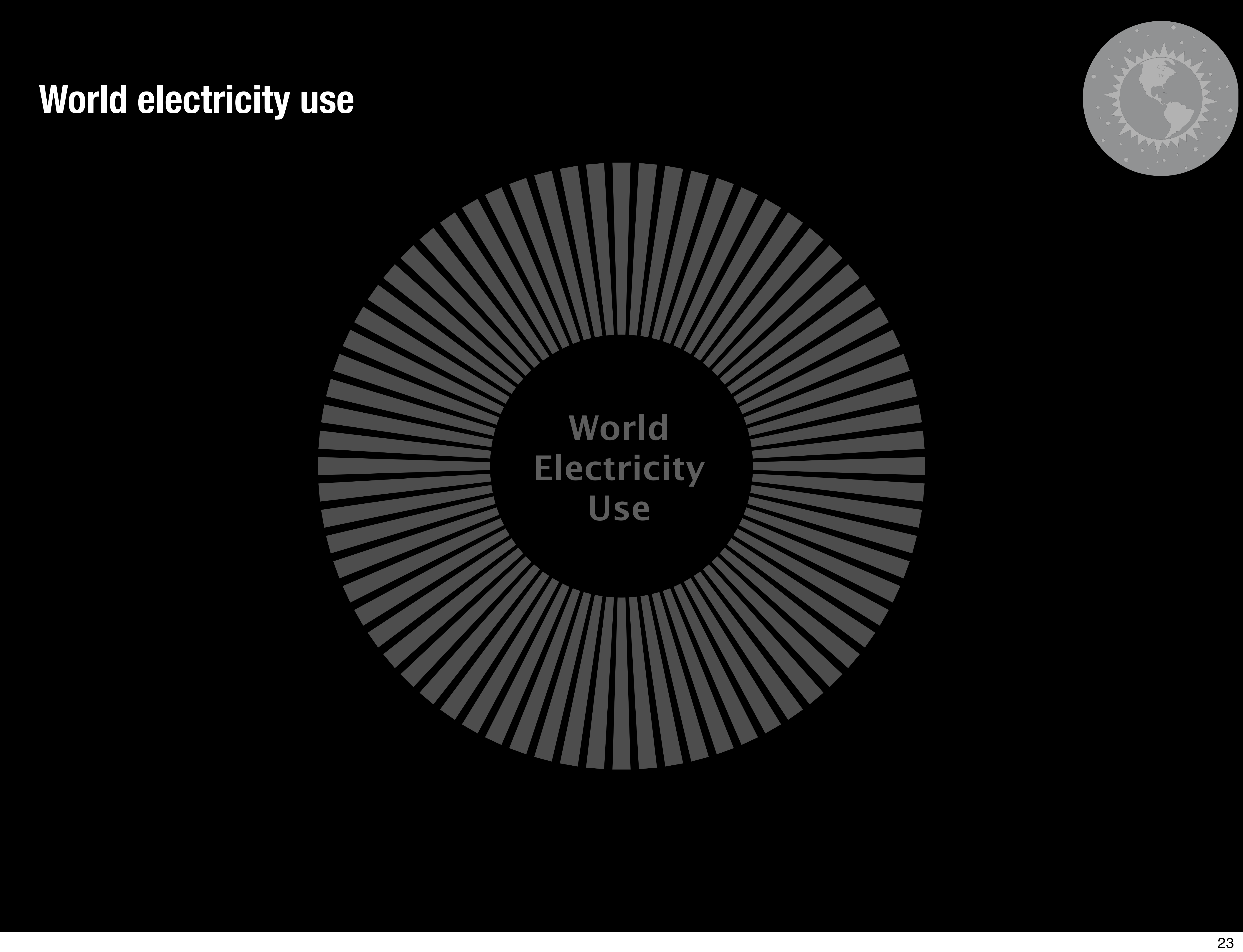
The key is integrative design that gives multiple benefits from single expenditures. For example, this arch **[in the upper left corner]** has 12 functions but only one cost.

This also works for big buildings, old and new. Last year’s retrofit is saving over 40% of the Empire State Building’s energy. Remanufacturing its 6,500 windows onsite into superwindows that are almost perfect in letting in light without heat, plus... *



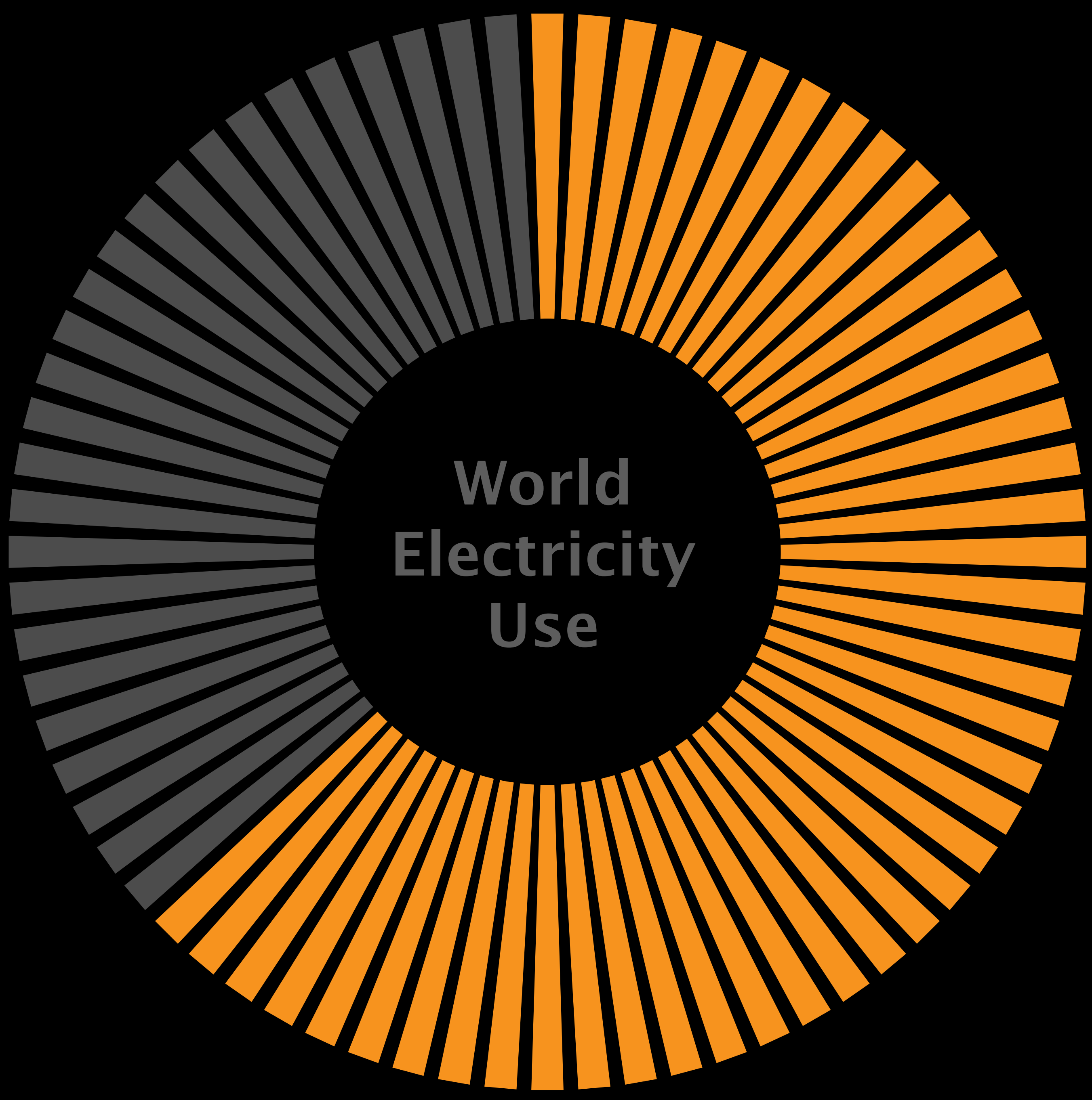
...better lights and office equipment, cut the peak cooling load by one-third. Then instead of replacing and expanding the old chillers, we could renovate and reduce them, * saving $17 million of capital cost that helped pay for the other improvements * and cut the payback to three years.

Similarly retrofitting a 20-year-old glass office tower near Chicago could save three-quarters of its energy at slightly lower cost than the routine 20-year renovation that saves nothing! Japan has many big buildings ready for this treatment.



In U.S. industry, the same approach can further increase the half-trillion dollars of low-hanging efficiency fruit that's fallen down and is mushing up around our ankles. For example,... *

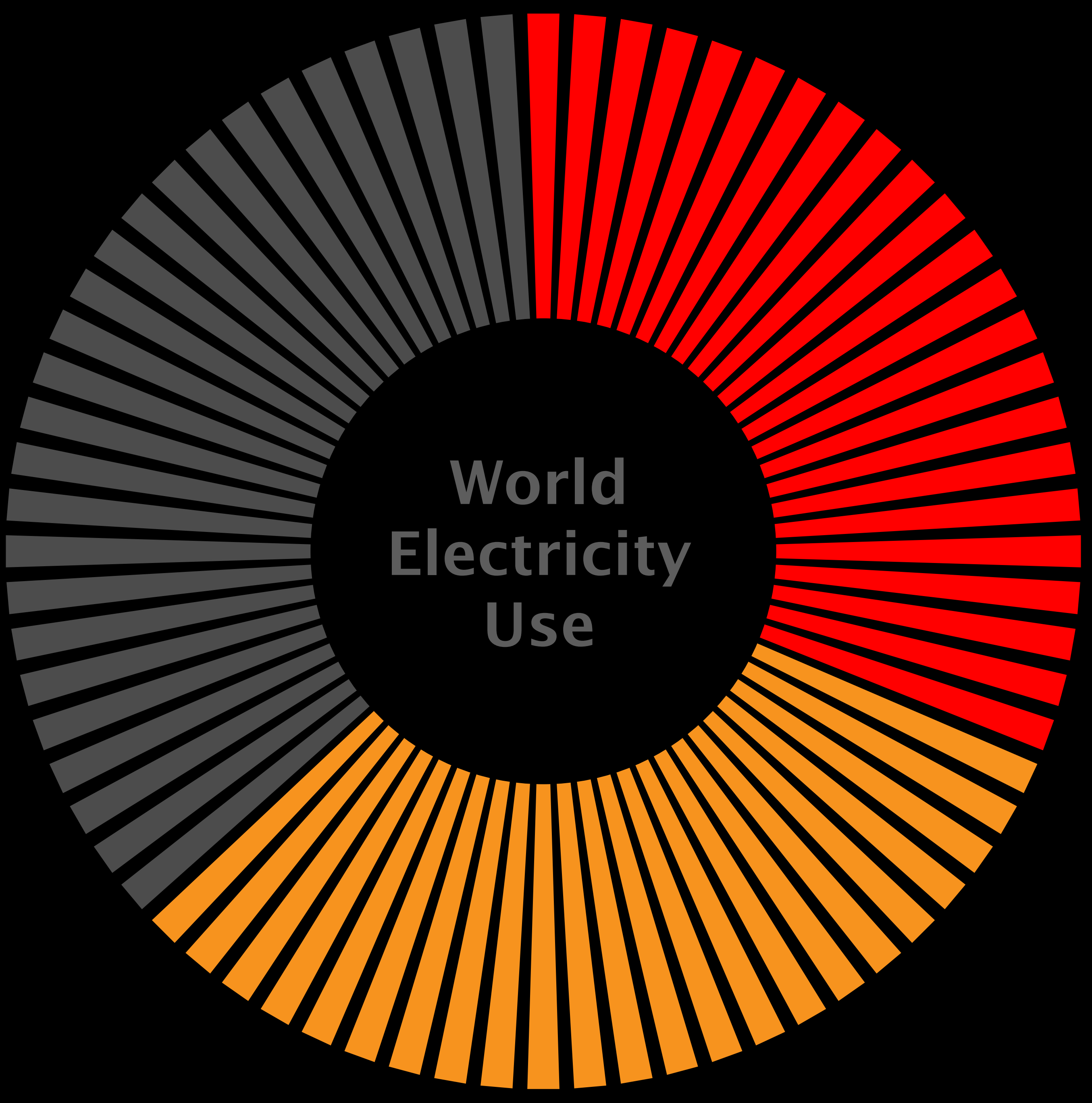
World electricity use



60% Motors

...three-fifths of the world's electricity runs motors. *

World electricity use

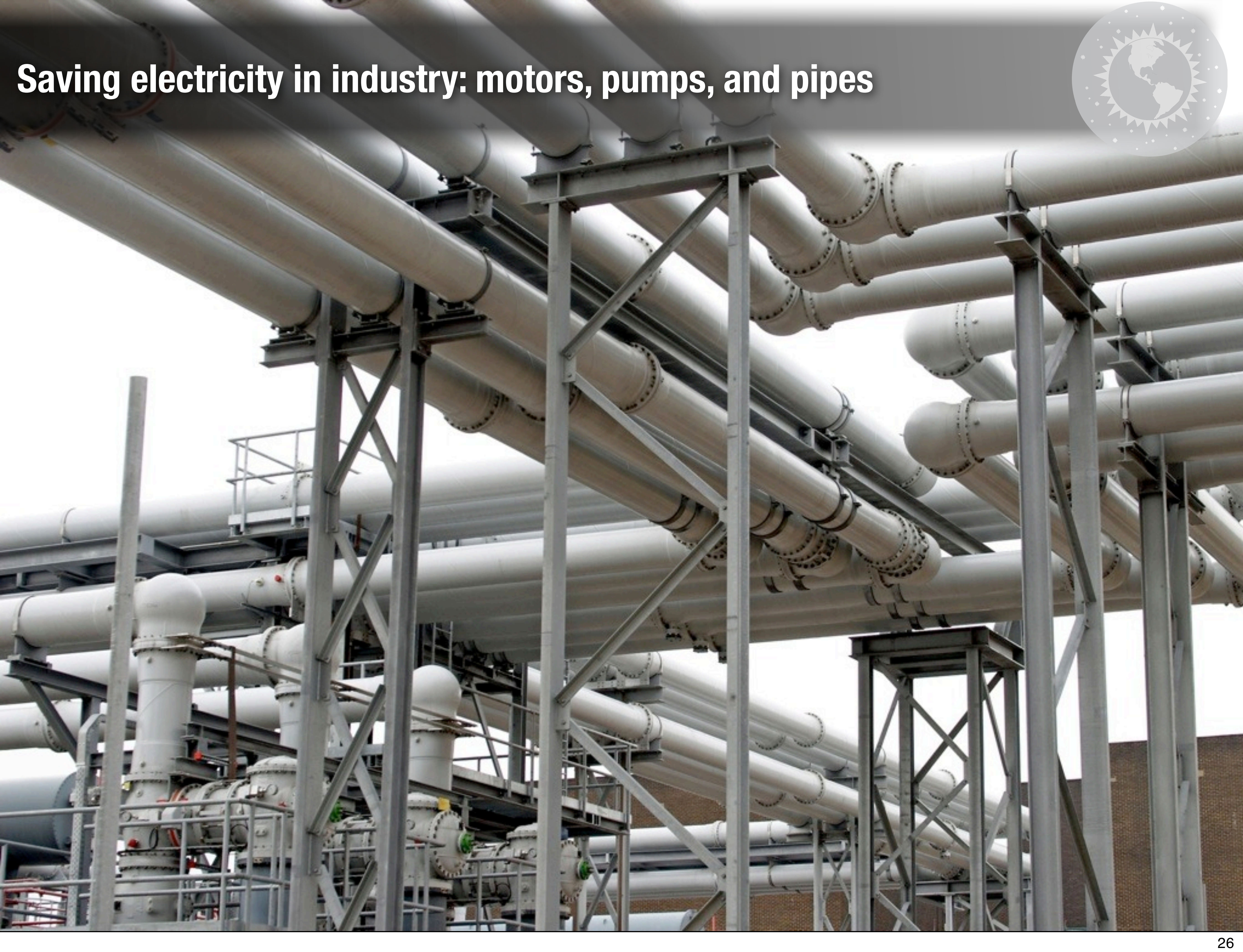


30% Pumps and Fans

Half of that runs pumps and fans.

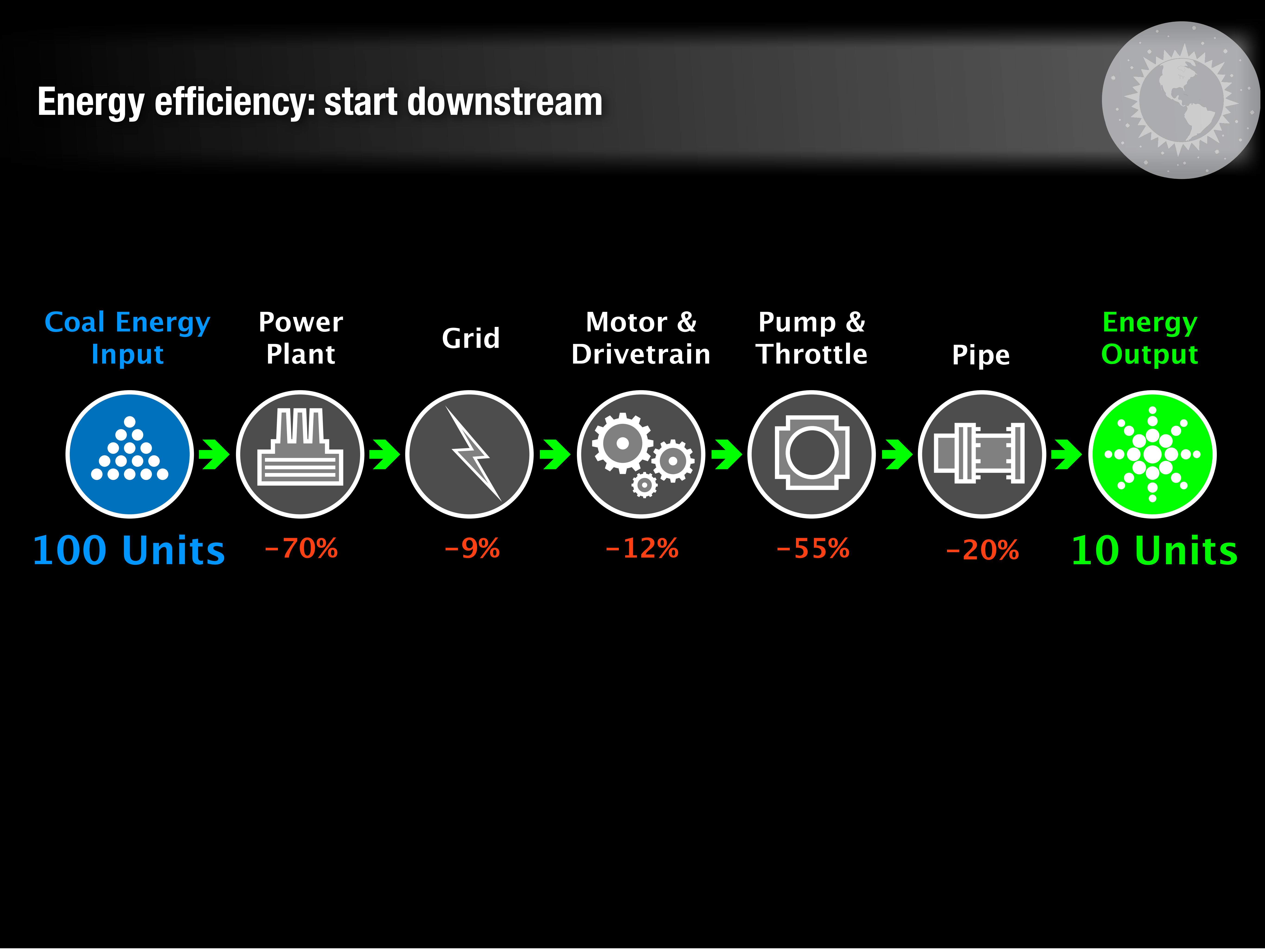
We can save about half of all motor energy with a one-year payback by retrofitting 35 integrated improvements.

But first we should stop wasting most of the energy used by the pumps, fans, and other motor-driven devices. For example, pumps—the biggest use of motors—... *



...move liquids through pipes. A Dutch colleague redesigned a typical industrial pumping loop to use at least 86% less pumping energy, and cost less to build, just by replacing long, thin, crooked pipes... *

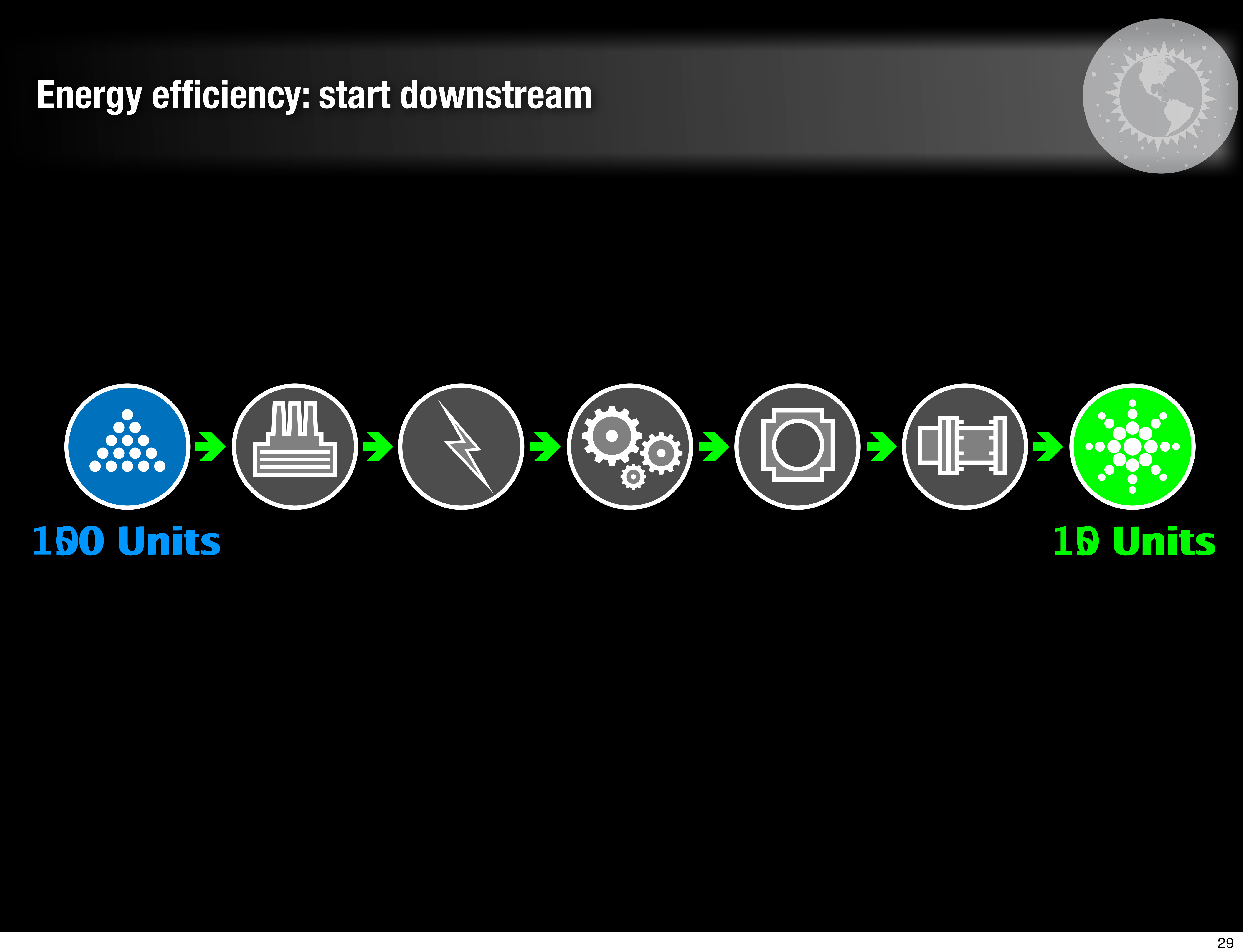
...with fat, short, straight pipes. That’s how this recent design in Singapore saved 69% of normal pumping energy at lower construction cost. In our own house, the same method in some new piping cut friction by about 97%.



So what do such savings mean for the electricity that’s 60% used in motors?

* From the coal burned in the power plant * to the end use, many successive losses compound, so only * a tenth of the energy in the coal comes out the pipe as flow.

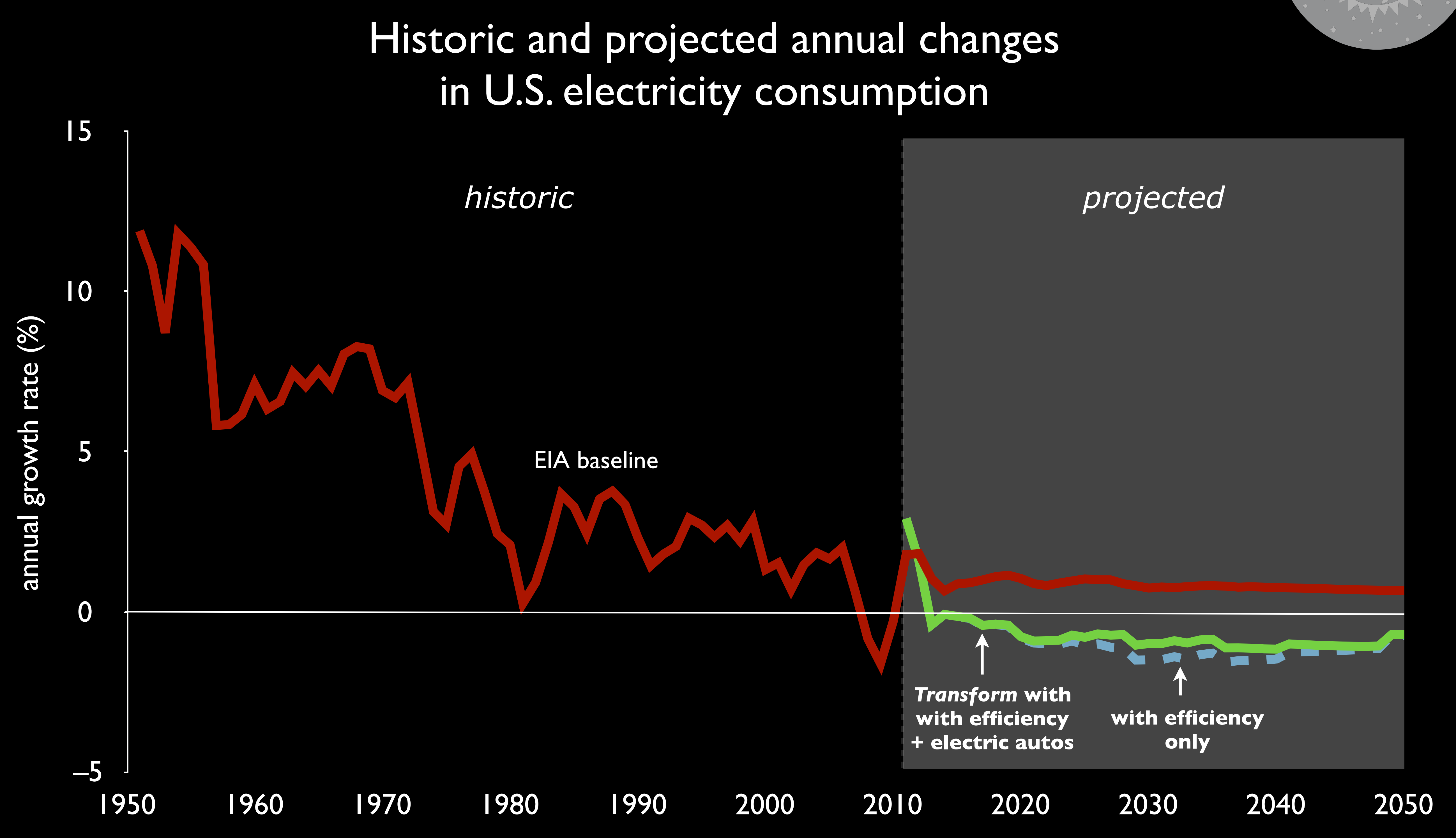
But now turn that around backwards,... *



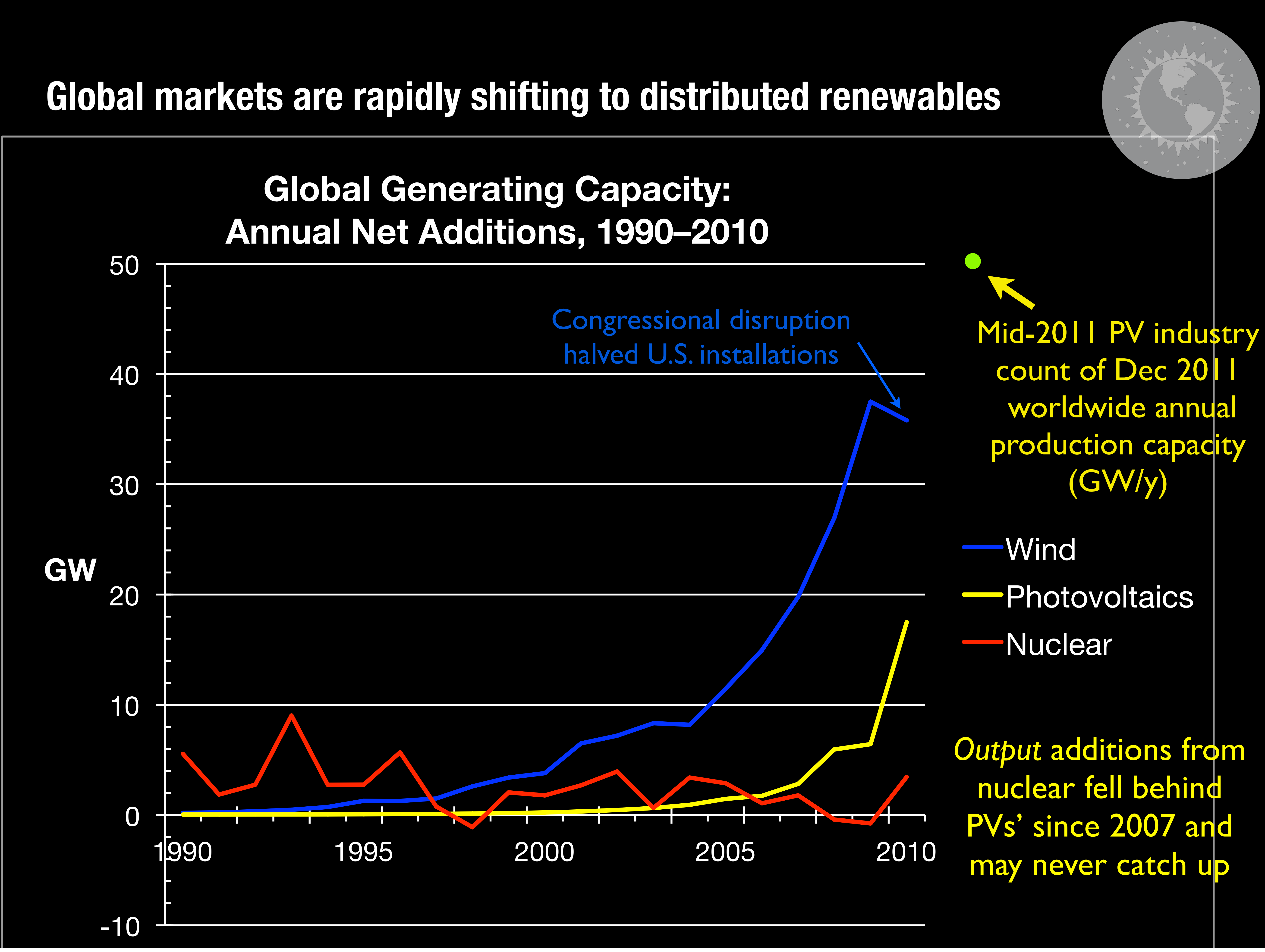
...so those compounding <u>losses</u> turn into compounding <u>savings</u>, and * every unit of flow or friction you save in the pipes saves * <u>10</u> units of coal, cost, and emissions at the power station. Also, as you go back upstream, each component gets progressively <u>smaller</u> and cheaper, so you save the most <u>capital</u> cost too.

My team has lately found such snowballing energy savings in more than $30 billion worth of industrial redesigns in 29 diverse sectors, from data centers and chip fabs to mines and refineries. Typically our retrofit designs save about 30–60% of the energy with 2–3-y paybacks, while our new-facility designs save around 40–90+% with *lower* capital cost. I think much of Japanese industry has a broadly similar efficiency potential.

Electricity needs will flatten or decline as efficiency gains speed



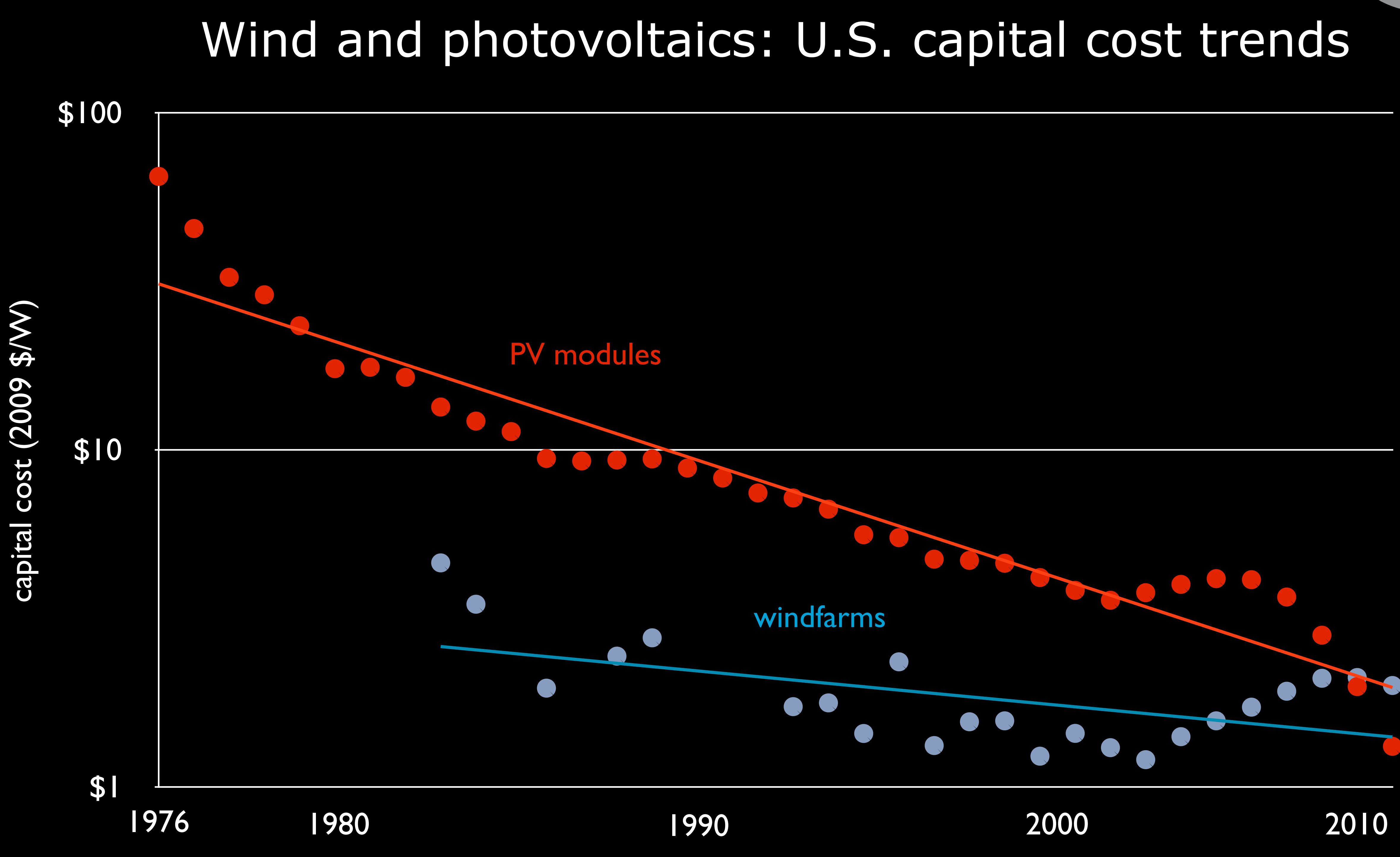
As efficiency matches or outpaces economic growth, the rate of growth in U.S. electricity use, which has rather consistently fallen for 60 years, will turn slightly negative despite electrified autos. This will ease and speed the shift to new ways to produce electricity.



That global shift is dramatic. Wind and solar power are growing explosively worldwide, while central stations' orders wither because they cost too much and have too much financial risk. Nuclear expansion can scarcely keep pace with retirements, and since 2007 has added less annual output than photovoltaics, the smallest and costliest of the renewables. But by the end of this year, the world will probably be able to produce about 50 GW of PVs per year. If this capability didn't grow further—though it's sustained 65% annual growth—that's still enough to displace the peak output of all nuclear plants now under construction every 15 months, and their annual output every five years, before a reactor begun now could be built, and at a lower cost by the time it could be built. Indeed, California's private utilities just bought over 4 GW of PVs that beat the benchmark wholesale price, and forward prices for bulk modules in mid-2012 are just $1 a watt.

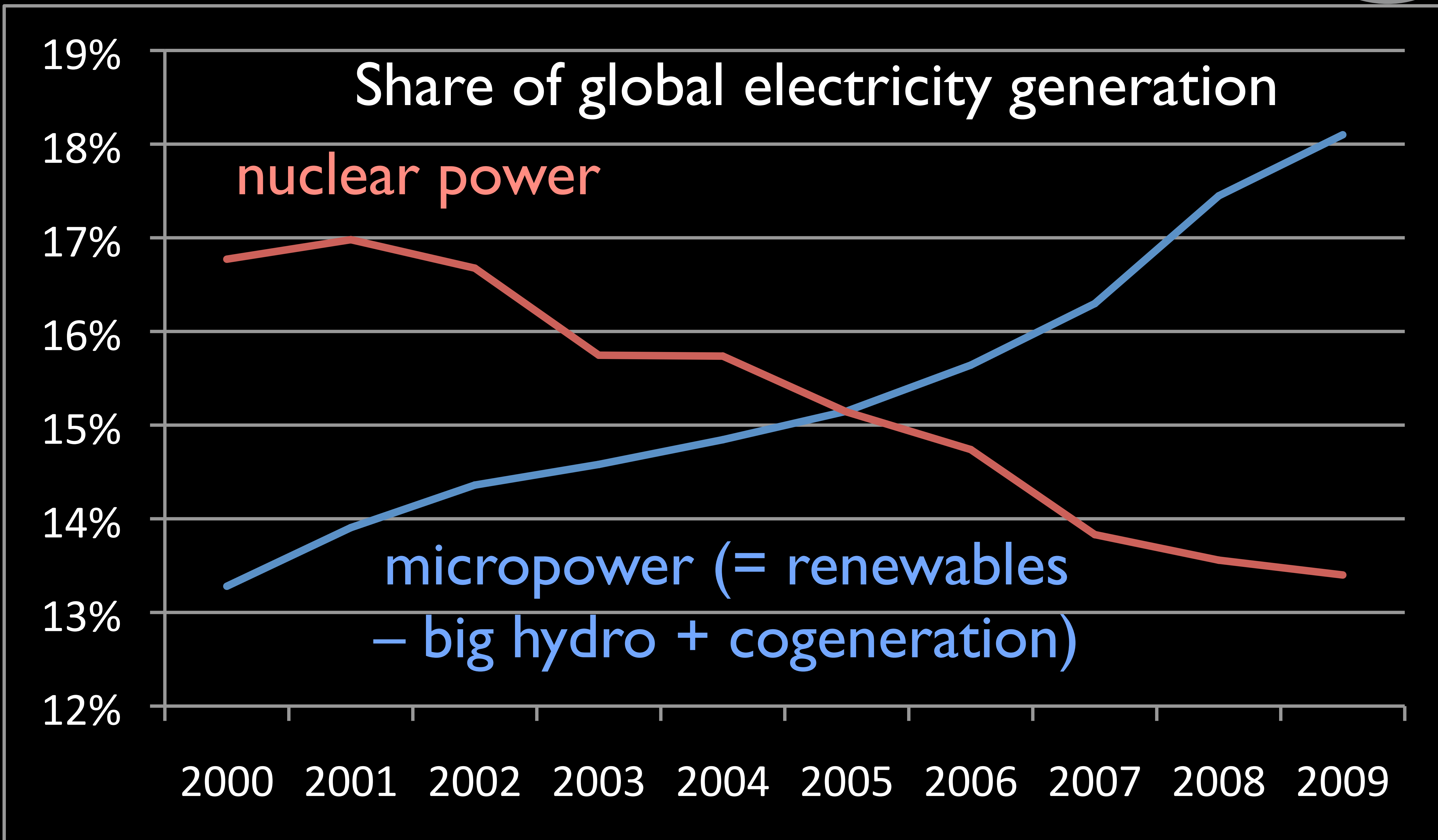
This renewable power revolution, the biggest infrastructure shift in history, is led by China, which is now #1 in five renewable technologies, aims to be in all, and in 2010 blew past its original 2020 windpower target, installing nearly half the world's added windpower capacity.

Dramatic drops in renewable energy's cost continue



Renewables' explosive growth drives and is driven by steep learning curves like these. Recent price bulges, as suppliers struggled to catch up with soaring demand, have now disappeared (solar last year, windpower this year). Countries with consistent policies, like Germany for solar and Denmark for wind, also report installed system costs tens of percent lower than the U.S. And some U.S. windpower contracts have been written this year for as little as $0.03/kWh, net of a one-cent subsidy.

Nuclear and micropower generation have more than swapped roles, mainly due to market perceptions of their relative costs and risks



Sources: nuclear and total: *BP Statistical Review of World Energy 2010*; micropower: RMI analysis from industry sources (<u>www.rmi.org/rmi/Library/2010-06_MicropowerDatabase</u>). BP generation data are gross, renewables generally net (understating their relative share).

Power sources that get their economies from mass production, not from giant units, have swapped their share of global electricity production with nuclear power's share. In 2008, "micropower" made <u>91%</u> of the world's <u>new</u> electricity, and renewables added half the world's new generating capacity.

Last year alone, renewables except big hydro got $151 billion of private investment, added 60 billion watts, and surpassed global nuclear capacity. New U.S. nuclear plants, if any, are 100+% subsidized, but they still can't raise a penny of private capital, because they have no business case.

Fortunately, the 45% of U.S. electricity that's made from coal can be cost-effectively displaced more than 23 times over without nuclear power (and more than displaced at less than just its operating cost. Indeed, all coal <u>and</u> nuclear generation can be displaced more than 16 times over. But we need do it only once.
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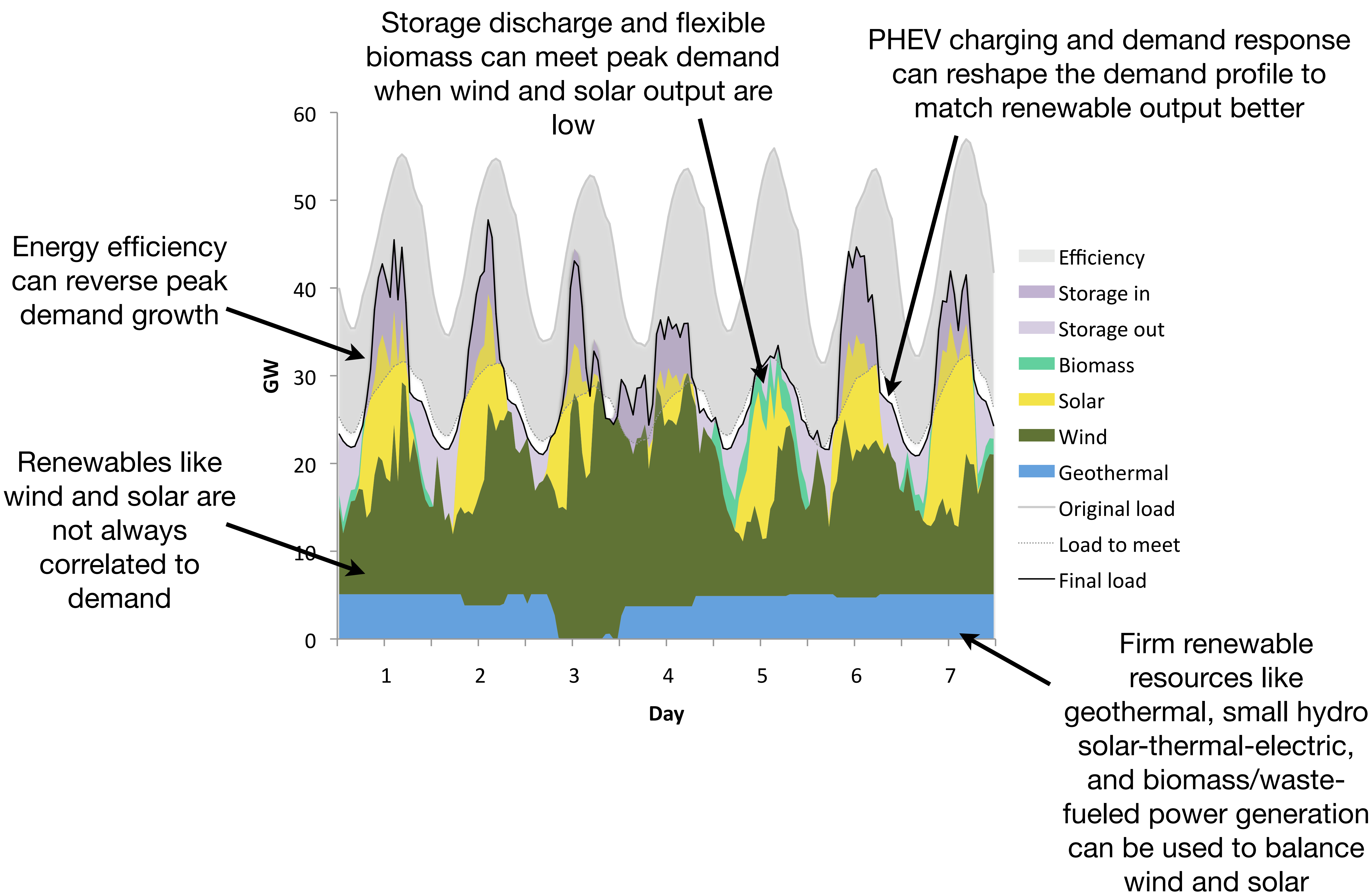
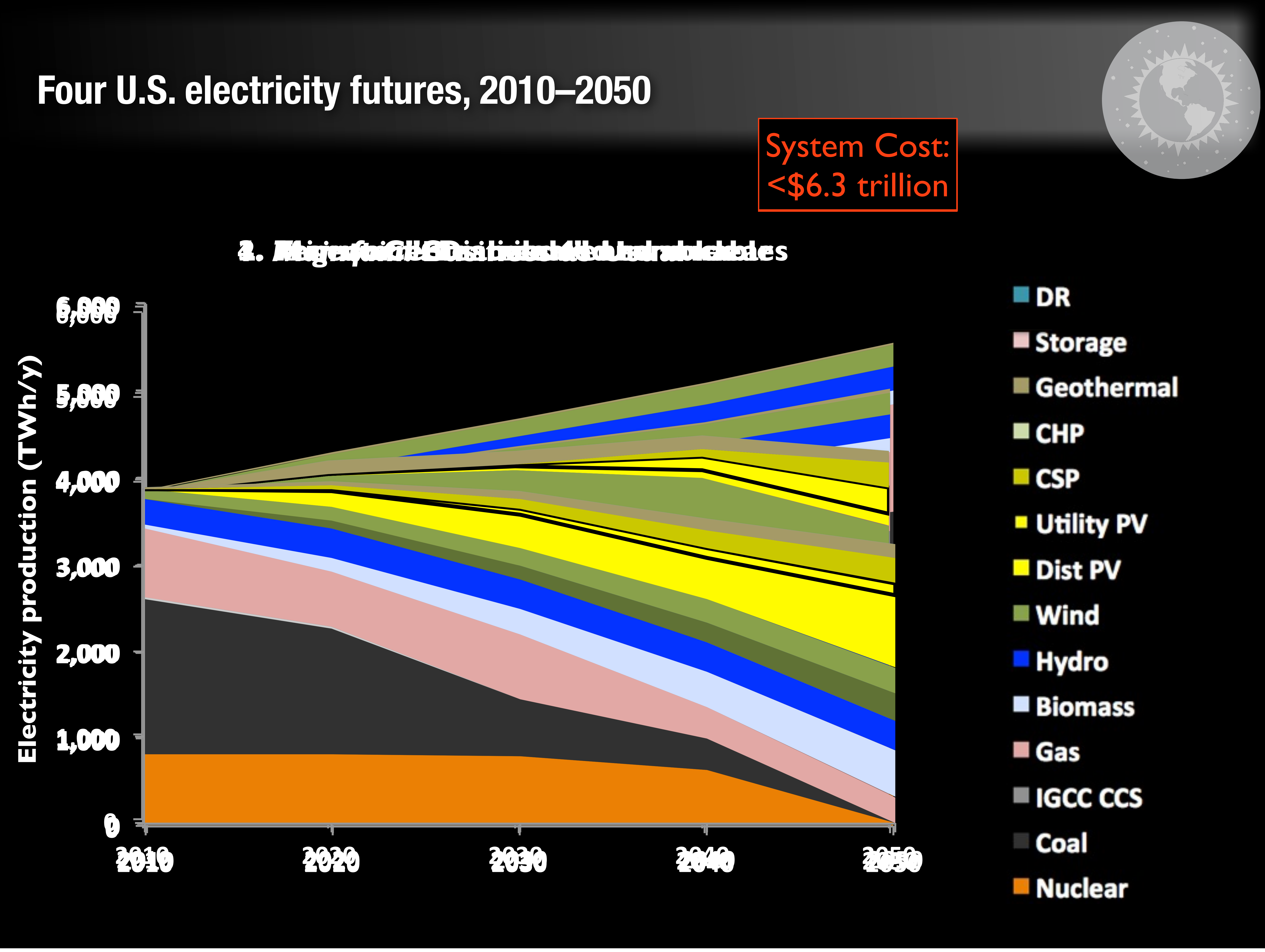


We're often told that only coal and nuclear plants can keep the lights on, because they're "24/7," while windpower and photovoltaics are variable and hence unreliable. Actually, no generator is 24/7. They all fail. Coal and nuclear plants fail ~10–14% of the time, losing a billion watts in milliseconds, often for weeks or months and without warning. Grids routinely handle this intermittence by backing up failed plants with working ones, and can handle solar and wind's forecastable variations in just the same way. My team's hourly simulations have shown that very large renewable fractions can deliver highly reliable power when forecasted, integrated, and diversified by type and location.

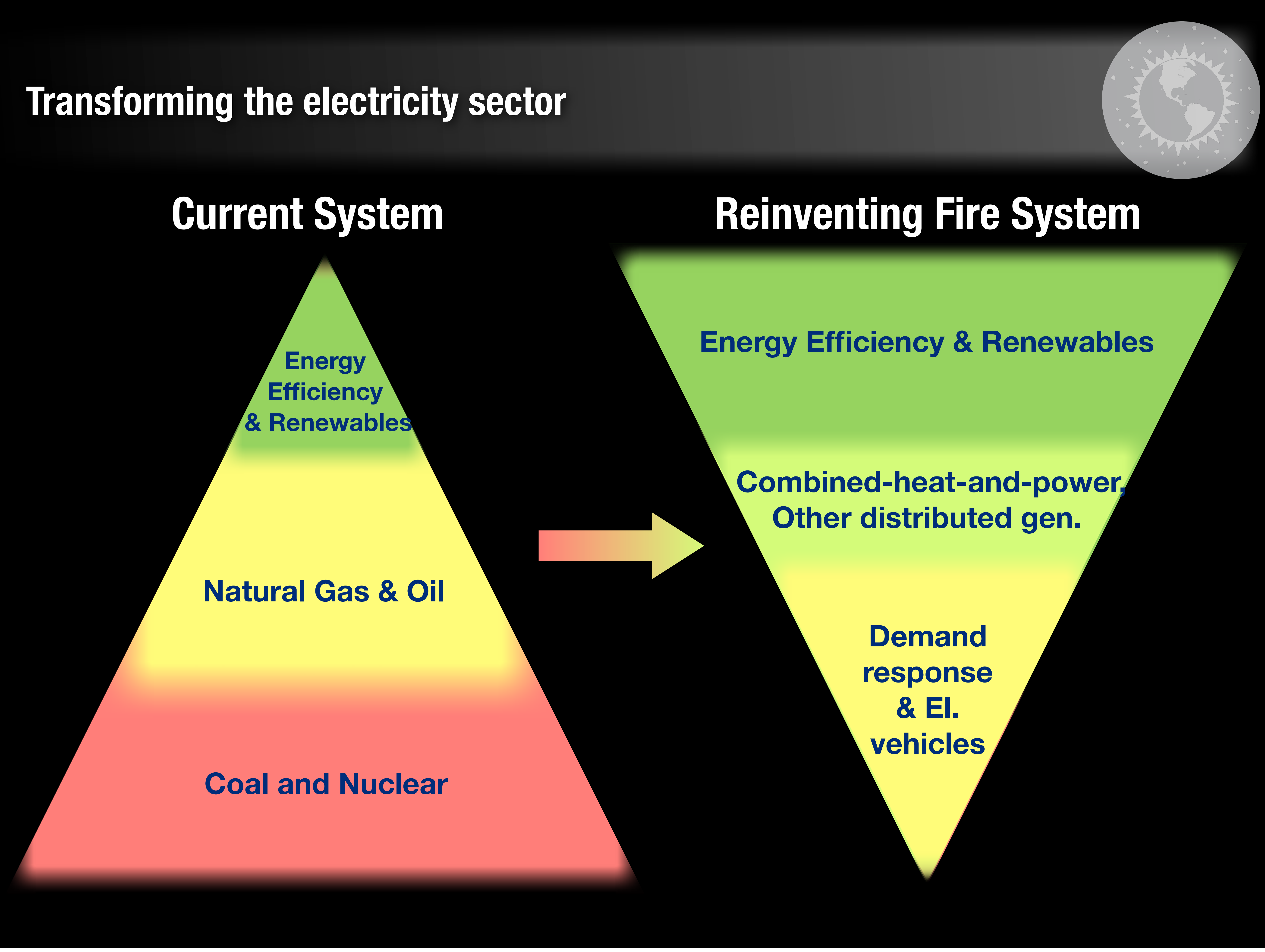
For example, after * efficiency makes Texas summer electric loads smaller and less peaky, we can install * wind and solar power. They won't exactly match the load, but flexible demand and smart charging and discharging of electrified autos can mesh all the moving parts even with 86% variable renewables—or even more if we use more of the demand-response resource. * The other 14% or less can come from dispatchable renewables like geothermal, small hydro, solar-thermal-electric, or feedlot biogas burned in existing gas turbines.

Some utilities already integrate variable renewables in this way. That's how four German states last year got 43–52% of all their electricity from windpower. Such proven choreography of variable and flexible resources can reliably serve steady loads not in the traditional way—giant fossil-fueled and nuclear plants—but with newer resources that meet even better the classical criterion for so-called "baseload" plants: that they have the lowest operating cost, so they're dispatched whenever available.



Reinventing Fire explores four U.S. electricity futures that differ little in cost— * the red box at the upper right—but differ greatly in risk. This Business-as-Usual future has high financial, fuel, and climate risks, and its overcentralized grid is vulnerable to cascading and potentially nation-shattering blackouts caused by natural disaster or terrorist attack. Now let's change its three big components—from the bottom up, nuclear, coal, and gas. * Using nuclear and so-called "clean coal" to reduce climate risk would cost more, intensify the technical and financial risks, and retain all the other risks. Or we could get climate-safe power without that extra cost by * quintupling today's utility-scale renewable capacity so it meets 80-90% of our needs by 2050—ultimately 100%. This would sustain or improve reliability, cut technology risk, and reduce blackouts. * Finally, letting distributed generators compete fairly with centralized ones could nearly eliminate the grave blackout risk by organizing the grid into local "microgrids" that normally interconnect but can stand alone at need. This resilient future would cost about the same as Business-as-Usual, but would manage all its risks and maximize customer choice, entrepreneurial opportunity, and innovation.

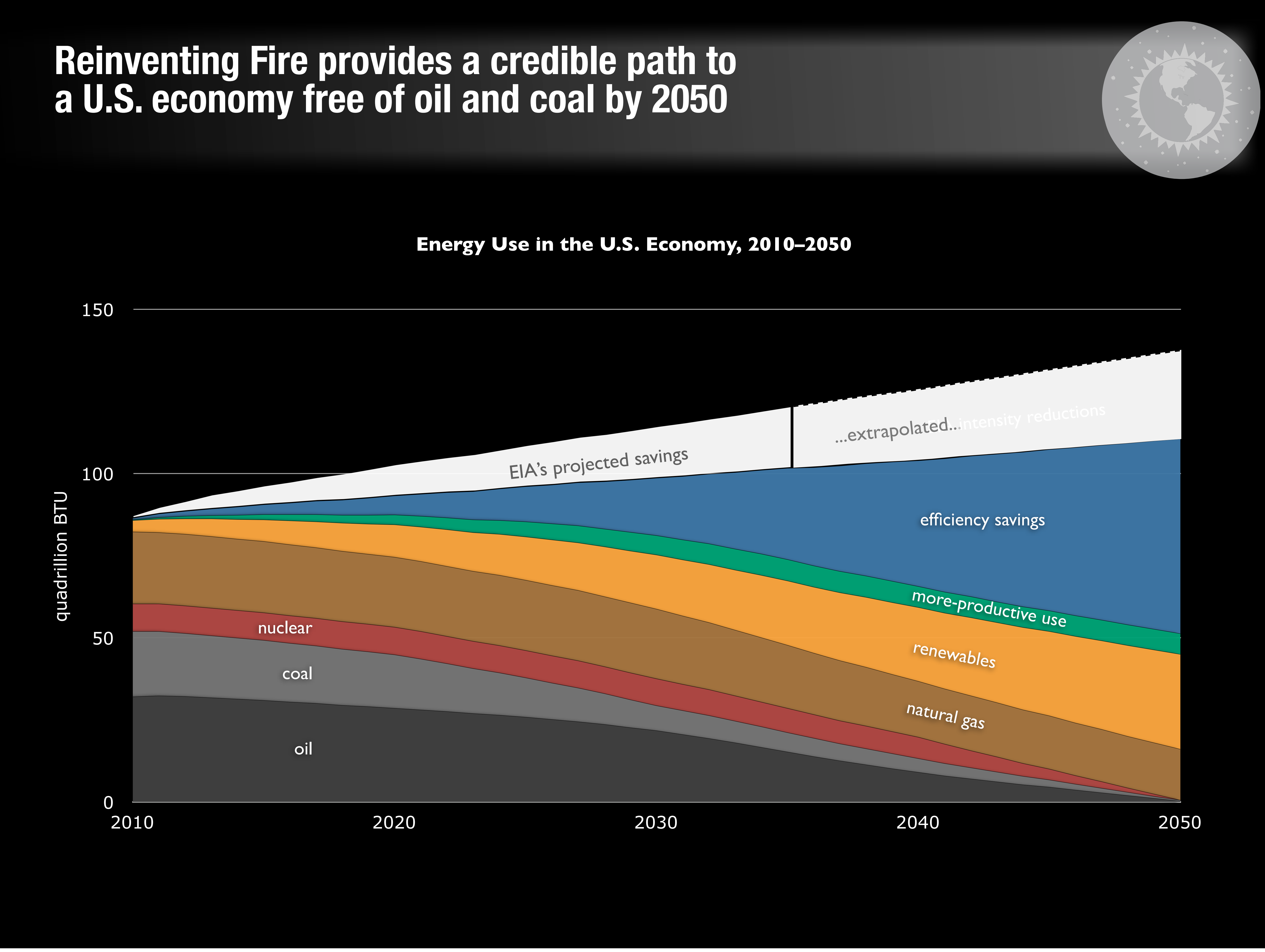
These transitions to renewable power require difficult regulatory reforms, barrier-busting for efficient use, a smart grid, maybe adding transmission, and purging obstacles to fair competition and interconnection. Public policy can speed or slow powerful market trends. Will incumbent utilities risk bypass even worse than what cellphones did to wireline phone companies, or will they innovate to build the 21st-Century electricity system?



Together, these transformations in efficient use and diverse, dispersed, renewable supply are starting to flip the whole electricity sector on its head. * Traditionally, utilities built giant coal and nuclear plants, augmented them with big gas plants, and bought a little efficiency and renewables. Those utilities were rewarded, as they still are in 36 of the United States and all of Japan, for selling more electricity. But now—especially where regulators reward cutting customers' *bills*— * the market is shifting massively towards efficiency, renewables, cogeneration, and ways to [automatic *] blend them all together reliably—with much less transmission and with little or no bulk electricity storage.

These best buys are also the most effective solutions to climate change, nuclear proliferation, energy insecurity, and energy poverty.

Now combine the *electricity* and *oil* revolutions, the supporting efficiency revolutions in buildings and industry, and similar opportunities with natural gas and directly burned coal, and you have the *really big* story... *



...Reinventing Fire! This synthesis shows how business—motivated by profit, supported by civil society and mindful markets, enabled and sped by smart policies—can lead the United States completely off oil and coal by 2050, and natural gas thereafter. Efficient use of energy in transportation, buildings, and industry, smarter use of energy services, and fuel-switching can save $5 trillion in net present value while resolving the electricity sector's serious security, financial, and climate risks. Business can lead this transition and compete for the prize. Our energy future is not fate but choice.

REINVENTING
FIRE®

RMI.org
ablovins@rmi.org

Rocky Mountain Institute®

The rich synthesis I've sketched drives Rocky Mountain Institute's portfolio of implementation initiatives. Four are already underway—in deep retrofit of commercial buildings, superefficient but same-cost new production housing, next-generation electric utilities, and Factor Ten Engineering for radical efficiency in industry and in all sectors. We've spun off a fifth initiative in heavy trucks. We're exploring an initiative in civil and military fleet vehicles supported by our Project Get Ready, which is speeding deployment of electric-vehicle infrastructure in over 16 cities.

What you've heard here rests on very detailed practical experience and empirical evidence. I think it reflects where the smart companies are headed. Of course, there's still much old thinking: not all the fossils are in the fuel. But as DuPont's former Chairman Edgar Woolard said in another context, firms hampered by old thinking "...won't be a problem, because they simply won't be around long term." And if you think anything I've said sounds too good to be true, just remember Marshall McLuhan's remark: "Only puny secrets need protection. Big discoveries are protected by public incredulity."

Some say Japan cannot do such a thing. Five years ago, the Yomiuri Shimbun even said, “Japan’s energy efficiency level is unlikely to improve much, since it is already the best in the world.” But having observed Japan and learned from my Japanese colleagues for the past 40 years, I have a different view. Perhaps the writer forgot that kaizen applies also to energy; that Japanese industry is still the world’s best at kaizen; and that despite the political gridlock that afflicts both our countries, the amazingly cohesive Japanese people have a unique ability to carry out a new consensus with astounding speed. Today, three-fourths of Japanese people agree we need an energy leapfrog, a hiyaku — and we know that Japanese frogs jump too, because Bashô told us so: * furu ike ya / kawazu tobikomu / mizu no oto.

Please consider how you can grasp the opportunities for that big jump, and help make the world richer, fairer, cooler, and safer, by together reinventing fire. For we are the people we have been waiting for—and Japan could become the leader the world is waiting for.

Four years ago I had the honor to receive the Blue Planet Prize from Their Imperial Highnesses Prince Akishino and Princess Kiko. I responded with these words: [read text]

Thank you for your good work and your kind attention. * Go seichô arigatô gozai masu!