EYE ON THE MARKET • ENERGY OUTLOOK 2019

Mountains and Molehills:

Achievements and Distractions on the Road to Decarbonization

J.P. MORGAN PRIVATE BANK

Mountains and Molehills. The Green New Deal mandates zero net emissions for the US by 2030 for the entire energy sector (not just from electricity generation), and does so while phasing out nuclear power and relying heavily on carbon sequestration by forests. This sets a goal that cannot be achieved. At best, the Green New Deal is a slogan to galvanize support for change; at worst, it's a sign of how little work its proponents have done. This year's paper gets into the details of where energy comes from, how it's used, and the de-carbonization challenges facing the world's industrialized and emerging economies. Additional topics include the latest research on wildfires, and Trump's War on Science.

J.P.Morgan

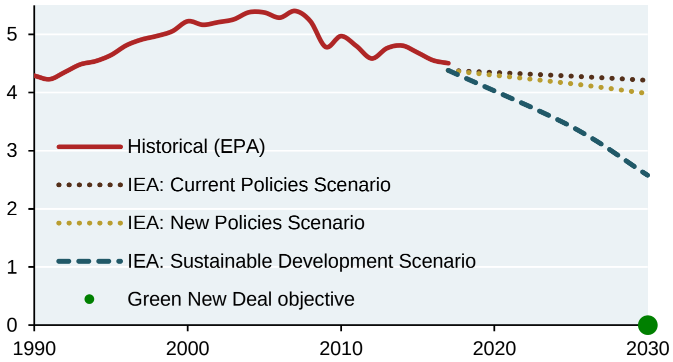
Preamble on the Green New Deal

There has been progress de-carbonizing electricity due to declining wind and solar power costs. However, de-carbonization of industry, transport, agriculture and buildings, the sectors which consume over 2/3 of fossil fuels, has been minimal given the technical, physical and practical challenges in the way. To assert that the US can reach zero net emissions by 2030, as the Green New Deal does, and for the entire energy sector (not just from electricity generation), and while phasing out nuclear power and relying heavily on carbon sequestration by forests[1], sets a goal that cannot in our view be achieved. **We agree with our science advisor Vaclav Smil that Green New Deal goals are not in the realm of the possible, that they do not appear grounded in existing scholarship on energy de-carbonization, and that they are not a useful foundation for a serious policy discussion**.

Some on the right are accused of being "intellectually bankrupt" on climate issues, and I do see evidence of that. But being intellectually dishonest about the viability of the Green New Deal does no one any favors either[2]. At best, it's a slogan to galvanize support for change; at worst, it's a sign of how little work its proponents have done. This year's paper gets into the details of where energy comes from, how it's used, and the de-carbonization challenges facing the world's industrialized and emerging economies.

Michael Cembalest
JP Morgan Asset Management

The Green New Deal objective, in context
US CO_2 emissions (net), gigatonnes per year



Source: US EPA, IEA World Energy Outlook, JPMAM 2018. Net of land use, land-use change and forestry carbon sinks. The CO_2 decline from 2007 to 2017 was due in roughly equal parts to declining energy use, the transition from coal to natural gas, and the increase in wind and other renewables.

Why the Green New Deal's 2030 goal is unattainable

Consider the International Energy Agency's "Sustainable Development" scenario for the US (blue dotted line), in which:

- overall US primary energy use declines to 1988 levels
- solar generation grows by a factor of 11x
- wind generation grows by a factor of 5x
- nuclear generation is unchanged (no decommissioning)
- 90% decline in coal use for power and heat (industrial sector switches to solar thermal and geothermal energy)
- electric vehicles reach 40%-50% of the passenger fleet from today's 1%-2% levels
- oil use declines by 50% due to electric vehicles and 40% improvement in gasoline/diesel mileage per gallon
- 60% decline in truck CO_2 emissions per tonne of freight
- energy intensity of res./comm. buildings declines by 30%

In this **highly transformational scenario**, which would require a Herculean effort to accomplish, US net emissions of CO_2 decline by 40% by 2030, and not to zero as imagined by the Green New Deal

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[1] **Net vs Gross**. The Green New Deal proposes removing CO_2 from the atmosphere via afforestation, allowing for a small amount of gross CO_2 emissions to remain. See page 12 for more on sequestration through forest management.

[2] Keep in mind what happened to Stanford's Mark Jacobson and his **100% US renewable electricity plan** for 2050, which is magnitudes less ambitious than the Green New Deal. The Jacobson plan was thoroughly rebutted and rebuked in 2017 by a team of 21 energy scientists and policymakers in the Proceedings of the National Academy of Sciences. We went through the details last year, since so many media outlets report on the Jacobson plan as a viable, realistic solution (as the NY Times continues to do). A link to our discussion can be found on page 5.

Mountains and Molehills: Achievements and Distractions on the Road to De-Carbonization

Executive Summary

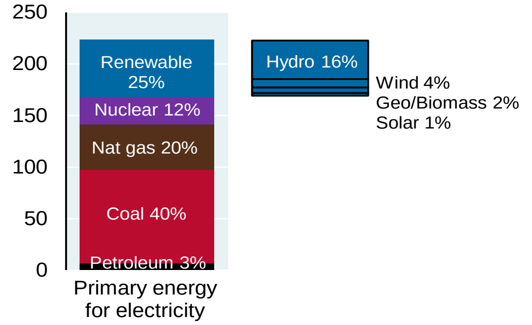
Impressive global wind and solar milestones have been reached in the last few years: declining upfront capital costs, electricity auction prices comparable to natural gas, rising capacity factors and capacity additions which have exceeded coal and natural gas for the 5th year in a row. These trends, shown on page 6, are the by-product of scale, innovation and plenty of subsidies.

Here's the "but": electricity **is less than 20%** of global energy consumption. Unless progress is made reducing direct fossil fuel use by industry and transport, de-carbonization goals might not be met in the timeframes often cited. Let's take a closer look.

The first chart shows **primary energy** used to generate electricity on a global basis, measured in "quads" (quadrillion BTUs). In 2017, the renewable share reached 25%. Hydroelectric power accounted for 16%, and wind and solar combined accounted for 5%, up from 0.5% in 2004.

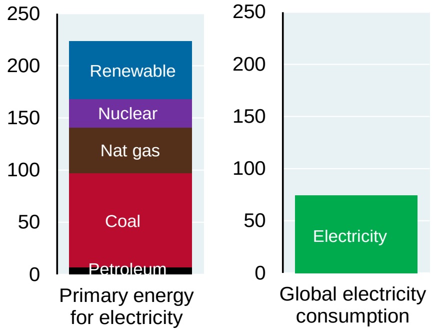
The second chart shows **how electricity gets generated**: 225 quads of primary energy are required to generate 75 quads of electricity. Where did the rest go? 150 quads are lost to thermal conversion[3], power plant consumption and transmission.

Primary energy for electricity: 25% renewable, mostly from hydropower with growing shares from wind...
quadrillion BTU, global



Source: Energy Information Administration, JPMAM. 2017.

...thermal conversion and transmission losses reduce end-user electricity to 1/3 of its primary energy inputs...



Source: Energy Information Administration, JPMAM. 2017.

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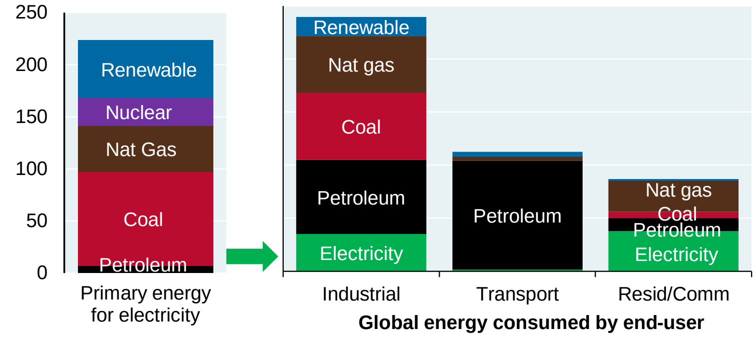
[3] **Thermal conversion** losses vary by technology and age. Most US coal plants have thermal efficiency rates of 32%-38%, while natural gas combined cycle power plant efficiency rates are closer to 50%, with record ratings of about 60% for the latest additions. Of the factors mentioned above, thermal conversion is by far the biggest source of energy loss, accounting for 90% of the gap between primary energy and electricity consumed.

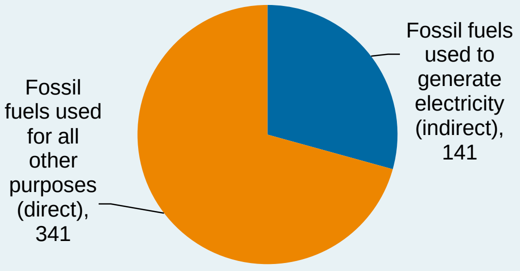
While fossil fuels are used to generate electricity, they're also used to power combustion engines, for heating/smelting and as raw materials. In the third chart, we break down global energy consumption into the three major users of energy (industry, transportation and residential/commercial buildings), and their energy sources. **These charts highlight the limits of just de-carbonizing the electricity grid.**

...at which point electricity only represents 17% of total energy consumed, the remainder being direct energy use
quadrillion BTU, global



Source: Energy Information Administration, JPMAM. 2017.

Electricity accounts for less than one third of global fossil fuel consumption
Quadrillion BTU, global

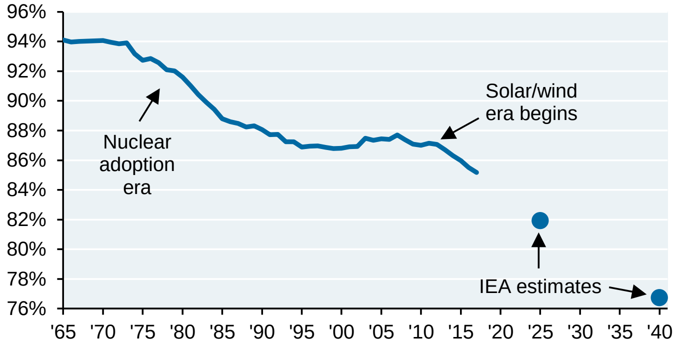


Source: EIA, JPMAM. 2017.

- Electricity is only 17% of global final energy consumption, and accounts for less than one third of global fossil fuel use
- Globally, the industrial sector is the largest user of energy and is heavily reliant on direct fossil fuel use; transportation is almost 100% reliant on petroleum products
- Fossil fuels accounted for **~85%** of global primary energy in 2017. Starting in 2010, fossil fuel shares began to decline at the rate of 0.25% per year, mostly due to the rise in renewable power generation
- Energy solutions need to be designed for increasingly urbanized societies, rendering discussions about "off-the-grid" approaches much less relevant

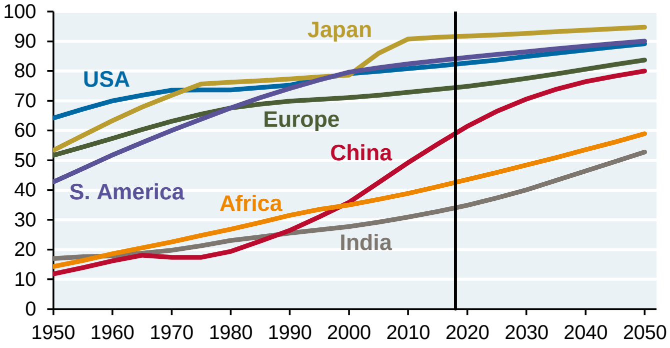
While these statistics are global, electricity shares of total energy use and fossil fuel shares are similar in the US, China and Europe[4]. Hence the challenges Germany faces as it aims for a 40% decline in emissions by 2030, and challenges the US faces with any plan that aims for *zero* net emissions by the same year.

The world uses fossil fuels for ~85% of its energy
% of global primary energy consumption from coal, oil and nat gas



Source: BP Statistical Review of World Energy. 2018.

Living for the city: global urbanization trends
% of total population



Source: UN World Urbanization Prospects. 2018, forecast to 2050.

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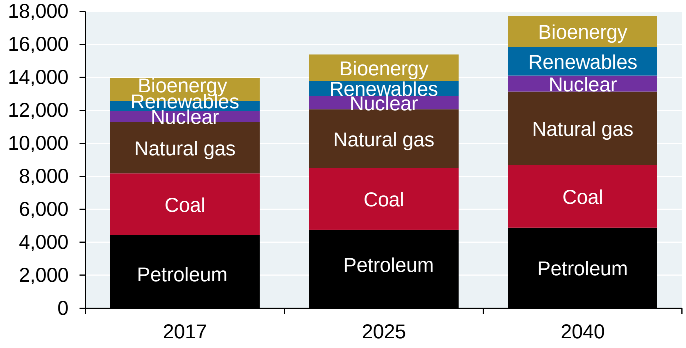
[4] **Some significant differences**: the US uses more energy for transport than for industry, and industrial/power sectors are more reliant on natural gas than coal. In China, these patterns are reversed. In both countries, the electricity share of energy use is less than 20%, and fossil fuels account for more than 80% of primary energy use.

Where does that leave us? With hard-to-reach de-carbonization targets, for two main reasons:

- **The energy mix doesn't change that fast**. Over 125 countries have renewable energy regulations in place for the power sector, up from 50 a decade ago. But even if renewable sources rose to 50% of electricity generation, fossil fuels could still represent ~70% of *total* energy use unless transport and industry decarbonize as well. On transportation, the IEA has one of the most optimistic EV forecasts. However, its New Policies Scenario for 2040 does not show substantial de-carbonization of global energy use: while coal plateaus and renewable energy doubles, natural gas meets most of the world's growing energy demand. Petroleum use doesn't decline either, despite the anticipated rise of EVs. Even when including bioenergy[5], the IEA renewable share forecast expands from 14% in 2016 to just 20% by 2040. While CO_2 emissions grow more slowly in this scenario, they still rise.
- **Increased energy use**. The IEA projects global energy demand to rise by ~25% from 2017 to 2040 as emerging economy increases dwarf energy use reductions forecast for Europe and Japan.

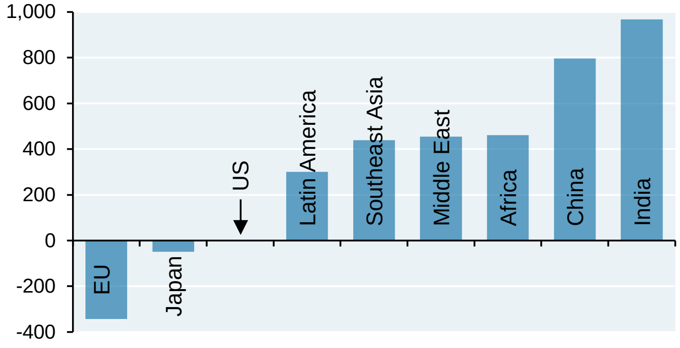
Hard to reach de-carbonization targets argue in our view for significant funds spent on **flood prevention/ remediation projects**, which we discussed in detail last year (see link on page 5).

IEA projections only show modest renewable increase by 2040, Global primary energy use, Mtoe



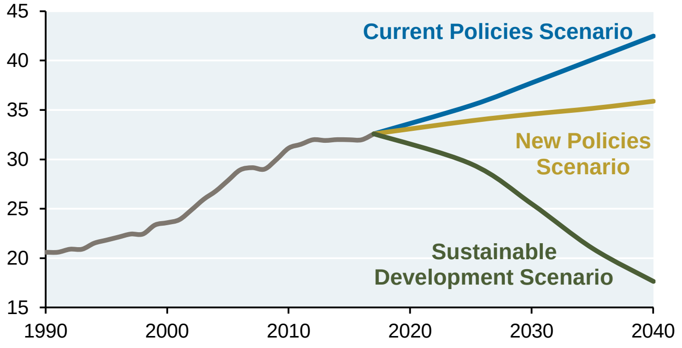
Source: International Energy Agency New Policies Scenario. 2018.

Projected change in primary energy use by region
Mtoe, IEA New Policies Scenario 2017-2040



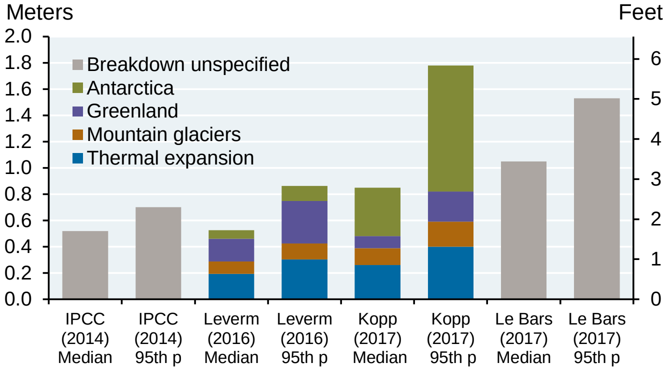
Source: International Energy Agency World Energy Outlook. 2018.

Global CO_2 emissions from primary energy demand
Gigatonnes per year



Source: International Energy Agency World Energy Outlook. 2018.

Sea level rise forecast for the year 2100 under IPCC scenario closest to IEA Current Policies Scenario



Source: IPCC, Levermann et al, Kopp et al, Le Bars et al assuming RCP 4.5

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[5] **Bioenergy** provides 10% of the world's primary energy. It may sound "green", but ~50% of bioenergy is consumed in developing countries for cooking and heating, using open fires or cookstoves with considerable negative impact on health (smoke pollution) and environment (deforestation). The remainder represents modern bioenergy used for heat, and smaller amounts used for transportation and electricity. Even modern biomass is not as green as you might think; we wrote about this in 2017. **As a result, bioenergy is different from hydro, wind and solar, which is why we show it separately in the chart.**

With this backdrop, we look this year at "**Mountains vs Molehills**": what could provide substantial pathways for de-carbonization, and what might end up being distractions along the way. While renewable penetration of the grid will continue to rise, the charts on page 3 cast considerable doubt on the viability of German (Energiewende) and US "Green New Deal" de-carbonization timetables, particularly if nuclear power is not considered a permanent part of the solution.

Table of Contents

Renewable energy milestones Page 6
Comments from our technical advisor Vaclav Smil Page 7

[1] De-carbonization of Industry Page 8
Electrification of industrial heat and pressure is technically possible, but costs of such a transition could be prohibitive given the cost of electricity vs direct use of gas. New electrochemical means of chemical production are promising but in their infancy

[2] Mountains vs Molehills Page 11
The media has reported with great excitement on CO_2 sequestration through both forests and underground geological storage; cellulosic ethanol; lithium ion batteries and supercapacitors for distributed energy storage; and new ways to create aluminum. But how impactful will they really be?

[3] Germany and Energiewende Page 18
A dispassionate assessment of the world's most ambitious de-carbonization policy

[4] Wildfires Page 24
Anthropogenic climate change has roughly doubled the number of US hectares burned

[5] Trump's War on Science Page 27
Making America's government scientifically illiterate again

Sources Page 28

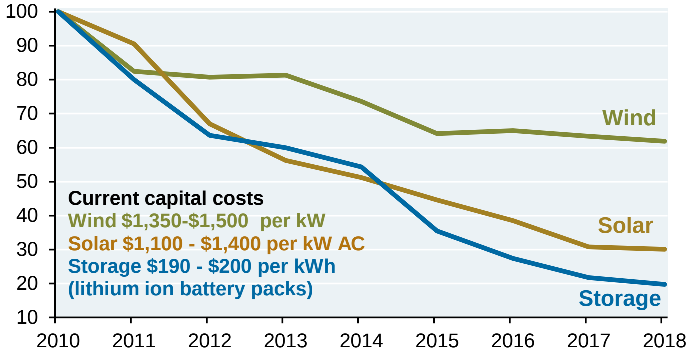
Links to select topics from prior *Eye on the Market* energy editions

- Electric vehicles: a 2% or a 20% solution? (2018)
- High voltage direct current lines: China leads, US lags (2018)
- The Dream Team rebuttal of the Jacobson "100% renewable electricity by 2050" plan
- Better safe than sorry: sea level rise, coastal exposure and flood mitigation (2018)
- Hydraulic fracturing: the latest from the EPA and some conflicting views from its Advisory Board (2017)
- Forest biomass: not as green as you might think (2017)
- The myth of carbon-free college campuses (2017)
- Distributed solar power and utility billing changes which increase the cost (2016)
- US hydropower: how much potential for expansion? (2016)
- Nuclear power: skyrocketing costs in the developed world (2014 and 2015)

Executive Summary supplementary materials: renewable energy milestones

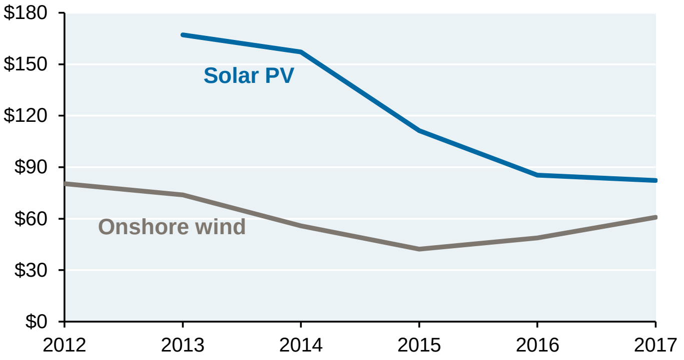
- The last decade has seen impressive declines in capital costs of solar/wind power and energy storage. While improvements in storage costs have slowed over the last couple of years, our contacts at the Electric Power Research Institute believe that cell engineering and scale improvements will continue in the years ahead, with battery pack storage costs possibly reaching $100 per kWh by 2025.
- In the US, onshore wind auction prices have declined to 2 cents per kWh (mostly for projects in the Midwest wind corridor), and even offshore wind prices have fallen to new lows, reaching 6.5 cents per kWh in a 2018 Massachusetts project
- Rising US wind capacity factors reflect larger rotor diameters, higher hub heights and locations with better wind speeds
- Modest increases in US solar capacity factors reflect increasing use of tracking rather than fixed tilt panels, and greater inverter loading ratios to maximize AC generation. Capacity factors have reached 30% in California and the Southwest

Declining upfront capital costs of wind, solar & storage
Index of upfront capital costs, 2010 prices = 100



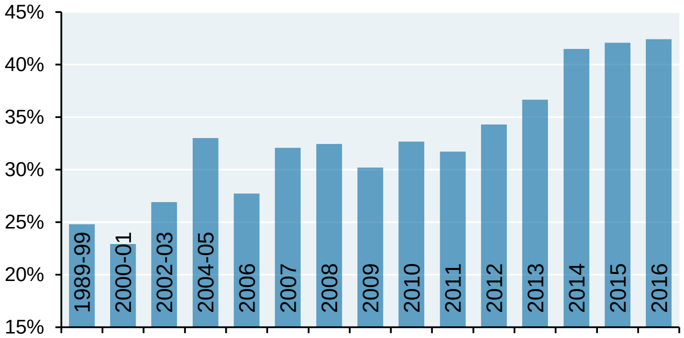
Source: EIA, NREL, Lazard, UCS, BNEF, JPMAM. December 2018.

Average global solar photovoltaic and wind auction prices
US$ per MWh



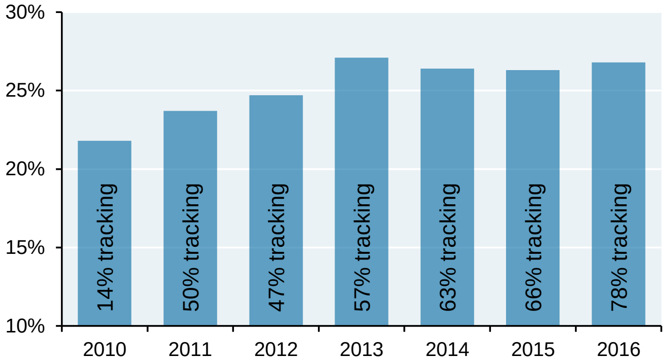
Source: International Energy Agency. 2017.

US wind capacity factors by project vintage year
Weighted-average capacity factor measured in 2017



Source: Lawrence Berkeley National Laboratory. 2018.

US solar capacity factors by project vintage year
Mean net AC capacity factor, from project inception to 2017



Source: Lawrence Berkeley National Laboratory. 2018.

Why all the focus on de-carbonization?

I asked Vaclav to articulate for our clients why de-carbonization is so important. His response is useful for those who are convinced by consensus views on climate science, and for those still on the fence:

"Underlying all of the recent moves toward renewable energy is the conviction that such a transition should be accelerated in order to avoid some of the worst consequences of rapid anthropogenic global warming. Combustion of fossil fuels is the single largest contributor to man-made emissions of CO_2 which, in turn, is the most important greenhouse gas released by human activities. While our computer models are not good enough to offer reliable predictions of many possible environmental, health, economic and political effects of global warming by 2050 (and even less so by 2100), we know that energy transitions are inherently protracted affairs and hence, acting as risk minimizers, we should proceed with the de-carbonization of our overwhelmingly carbon-based electricity supply – but we must also appraise the real costs of this shift. This report is a small contribution toward that goal."

Acknowledgements: our technical advisor Vaclav Smil

As always, our energy *Eye on the Market* was overseen by **Vaclav Smil**, Distinguished Professor Emeritus in the Faculty of Environment at the University of Manitoba and a Fellow of the Royal Society of Canada. His inter-disciplinary research includes studies of energy systems (resources, conversions, and impacts), environmental change (particularly global biogeochemical cycles), and the history of technical advances and interactions among energy, environment, food, economy, and population. He is the author of more than 40 books (the latest one, *Growth*, will be published by the MIT Press in September) and more than 400 papers on these subjects and has lectured widely in North America, Europe, and Asia. In 2010, *Foreign Policy* magazine listed him among the 100 most influential global thinkers. In 2015, he received the OPEC award for research, and is described by Bill Gates as his favorite author.

Acronyms used in this paper

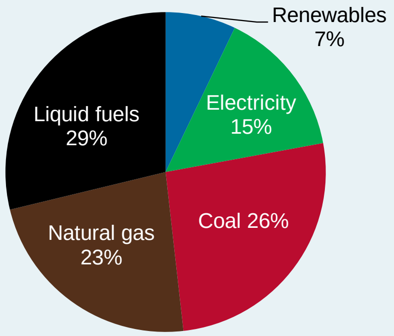
AC alternating current; **BTU** British thermal unit; **BTX** benzene/toluene/xylene; **CCS** carbon capture and storage; **CO_2** carbon dioxide; **DC** direct current; **EIA** Energy Information Agency; **EPA** Environmental Protection Agency; **ERCOT** Electric Reliability Council of Texas; **EV** electric vehicle; **GHG** greenhouse gas emissions; **GW** gigawatt; **GWh** gigawatt-hour; **IEA** International Energy Agency; **IPCC** Intergovernmental Panel on Climate Change; **IRENA** International Renewable Energy Agency; **ISO** independent system operator; **kg** kilogram; **km** kilometer; **kW** kilowatt; **kWh** kilowatt-hour; **L** liter; **MJ** megajoule; **MMT** million metric tons; **Mt** metric tonnes; **Mtoe** million tons of oil equivalent; **MW** megawatt; **MWh** megawatt-hour; **NREL** National Renewable Energy Lab; **TWh** terawatt hour; **VAT** value added tax; **Wh** watt-hour

[1] Decarbonizing the industrial sector

So far, de-carbonization has been achieved primarily via renewable electricity generation; de-carbonization of industrial and transport energy use has been much slower. Last year, we discussed de-carbonization of transport through electric vehicles. This year, we look at de-carbonization of the industrial sector, which is the largest global user of energy. This would require **two distinct steps**: substitution of electricity for direct thermal heat and pressure, and much greater renewable penetration on the grid. Some background:

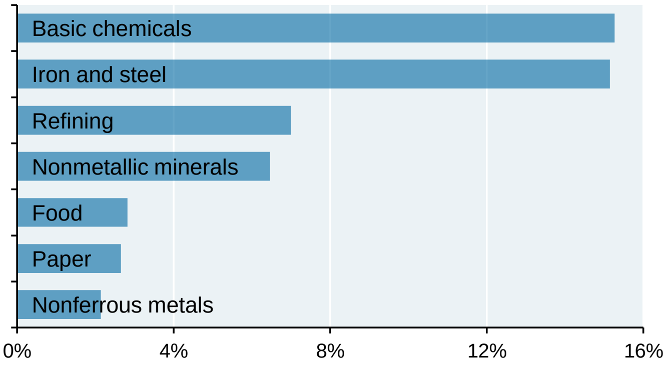
- The industrial sector uses fossil fuels for oil refining and the manufacture of chemicals, iron, steel, paper and food, which collectively form the backbone of modern society. Fossil fuels are used as raw material inputs, and to supply high-temperature heat and pressure (see tables and next page for examples)
- Only 15% of industrial energy use is derived from electricity; the rest is mostly direct fossil fuel use for heat and pressure. **Why isn't electricity used more widely?** It's *feasible* for things like paper, glass, cement and non-ferrous metals[6]. However, as shown in the 3rd chart, the cost of electricity for industrial users is **3x-5x higher per unit of energy** than natural gas. Such a switch would also require large capacity investments in new power generation. Even if such costs were borne, in countries like Germany and China, coal represents such a large share of electricity generation that substituting electricity for natural gas could currently *increase* emissions rather than reduce them

Industrial sector: electricity only 15% of energy use
Global industrial sector energy consumption by source, %



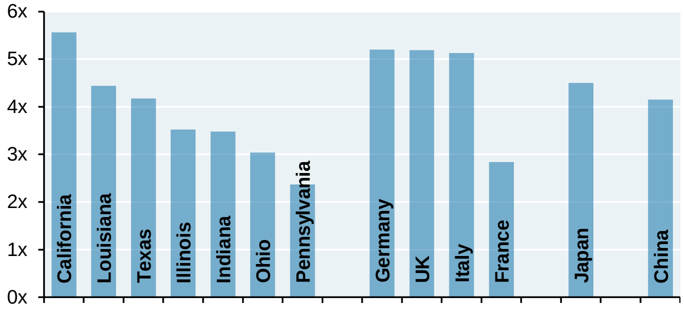
Source: Energy Information Administration. 2017.

Global industrial sector energy consumption by product
% of total



Source: Energy Information Administration, JPMAM. 2016.

Electricity is 3x-5x more expensive than natural gas
Ratio of electricity price to natural gas price for industrial users per MJ of energy



Source: EIA, Eurostat, IAEE, CEIC, IFPEN, JPMAM. 2018. The 7 US states shown are the largest industrial users of US primary energy.

Industrial use of fossil fuels as raw materials

Metallurgical coke	→	Pig (cast) iron smelting (carbon source), which eventually becomes steel
Methane	→	Synthesis of ammonia (hydrogen source), mostly used for fertilizing crops
Methane, naphtha and ethane	→	Synthesis of plastics (sources of monomers)
Heavy petroleum products	→	Production of carbon black (rubber filler), used in tires & other industrial products

Industrial use of fossil fuels to generate process heat

Construction materials (cement, bricks, tiles, glass, kiln-dried timber)
Production of petrochemicals, synthesis of plastics, food/beverage
Smelting of iron ores in blast furnaces

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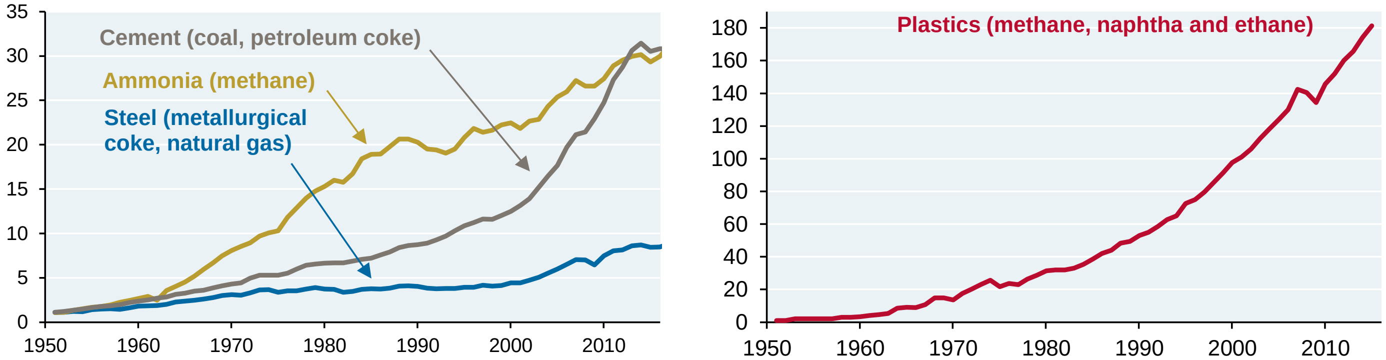
[6] A theoretical 2018 paper from the Wupperstal Institute in Germany estimated that **in the absence of cost considerations**, 100% of German industrial steam use could be replaced with electricity, and that 25% of industrial fuel use could be displaced with electricity as well.

Here's some history on the four industrial pillars of modern society: cement, steel, ammonia and plastics. While their production growth has slowed in the last 2 years due slower growth in China, the IEA expects consumption of all 4 to rise by 2050 (cement by 12%, steel by 30%, ammonia by 60% and plastics by 150%). On the importance of ammonia: only half of the world's population could be sustained without it, given its critical role in the food supply as an input into fertilizer[7].

The 4 industrial pillars of modern society and their primary carbon-based inputs

Production index, 1950 = 1

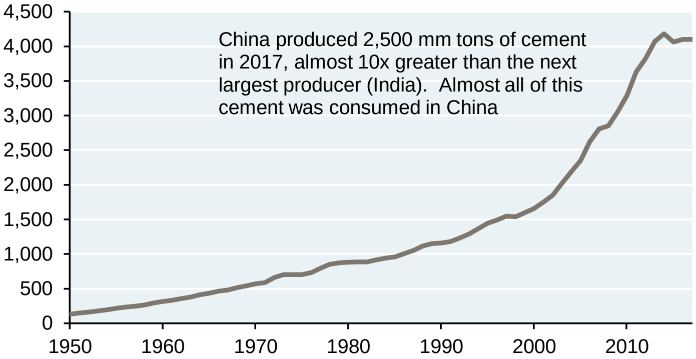
Production index, 1950 = 1



Source: US Geological Survey, Science Advances, World Steel Association. 2018.

Cement

Million tonnes



China produced 2,500 mm tons of cement in 2017, almost 10x greater than the next largest producer (India). Almost all of this cement was consumed in China

Source: US Geological Survey. 2018.

Steel

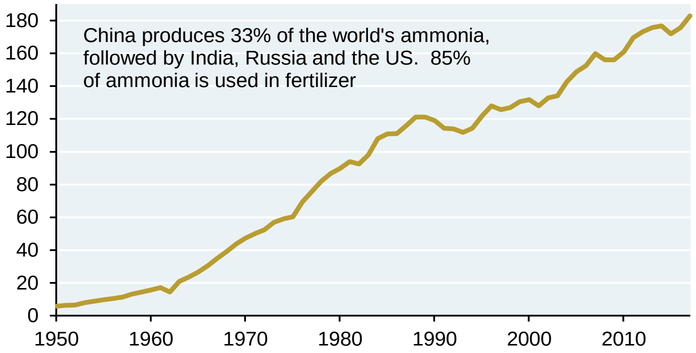
Million tonnes

China produced 50% of the world's steel in 2017, up from 36% in 2007

Source: World Steel Association. 2018.

Ammonia

Million tonnes

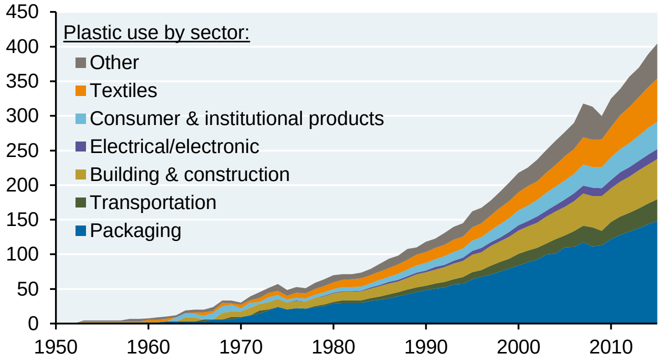


China produces 33% of the world's ammonia, followed by India, Russia and the US. 85% of ammonia is used in fertilizer

Source: US Geological Survey. 2018.

Plastics

Million tonnes



Source: Science Advances. 2017.

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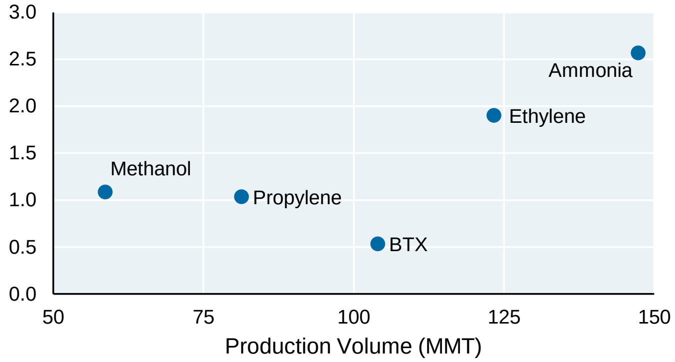
[7] Between 40% and 70% of ammonia (reactive nitrogen) applied in fertilizer is **lost** globally due to leaching, erosion or de-nitrification. Minimizing usage losses is just as important to de-carbonization goals as fuel substitution or other changes in the ammonia production process.

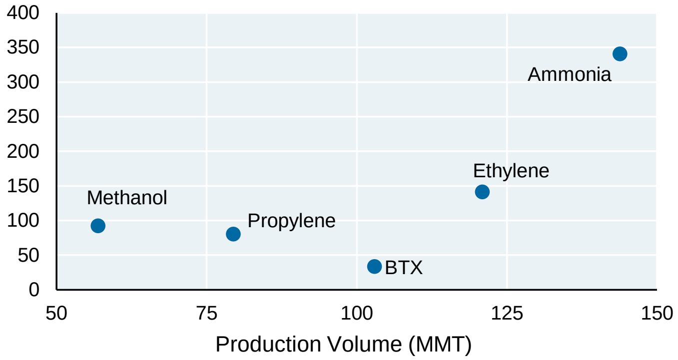
The production of **ammonia** and other chemical compounds requires a lot of energy, and creates a lot of greenhouse gas emissions (GHG), making them interesting candidates for de-carbonization.

Energy consumption and production for major chemicals
Consumption, exajoules



Source: Schiffer and Manthiram. 2018.

GHG emissions and production for major chemicals
GHG Emissions (MMT CO_2-equivalent)



Source: Schiffer and Manthiram. 2018.

Ammonia is produced via a **thermochemical** reaction which combines nitrogen and hydrogen. Its carbon intensity results from production of these inputs: nitrogen separation from air consumes large amounts of electrical power, and hydrogen production from methane[8] consumes energy as process heat, and also emits CO_2. Additional carbon intensity results from ammonia synthesis itself, which requires temperatures of ~450°C and ~200 bars of pressure.

Energy scientists have been examining an alternative: an **electrochemical** reaction that uses nitrogen and water as inputs, and relies on electricity rather than pressure to drive the reaction. This approach could reduce GHG emissions, since hydrogen would be obtained from water rather than from steam reformation of methane, and since electricity (powered by co-located renewables) could function as the energy source needed for the reaction. Other benefits: lower temperatures at which the chemical reaction could take place, and generation of oxygen as an output rather than carbon dioxide. **The problem: scientists are still searching for the best choice of materials for the necessary anode and cathode**. Some experiments show promising results, but there's a big gap between lab-scale research and industrial processes; viability at scale is a key consideration.

The bottom line: partial electrification of heat and pressure is feasible but very expensive compared to the cost of direct fossil fuel use, and would require substantial investment in new renewable generation capacity in order to reduce emissions. Electrochemical production of chemical compounds like ammonia is promising, but still on the drawing board; and any new methods would need to be used in China to have much of an impact. For Green New Deal advocates: de-carbonizing industrial energy use is more easily said than done.

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[8] Hydrogen could also be obtained through electrolysis of water, but...

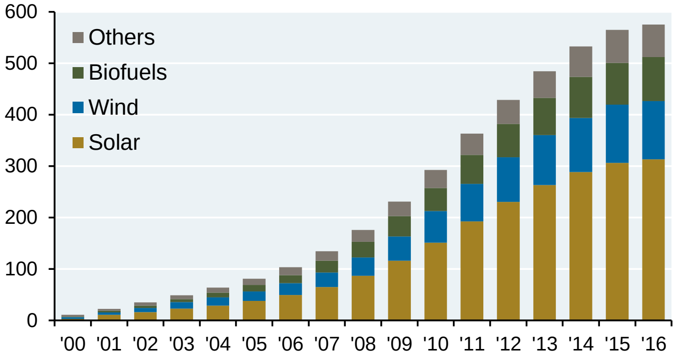
- **Only 4% of hydrogen was produced via electrolysis in 2016** (IRENA); the rest came from steam reformation or gasification of fossil fuels. Primary obstacle: the high cost of electrolysis
- A 2017 paper (International Journal of Hydrogen Energy) cited hydrogen costs that were 5x higher when obtained via electrolysis compared to steam reformation of natural gas, assuming 10 cents per kWh for industrial electricity
- A separate 2018 paper cited the need for another 75% decline in electrolyzer capital costs to $100 per kW and electricity costs of 1-2 cents per kWh in order for electrolysis to be cheaper than steam methane reforming as a means of obtaining hydrogen
- There are demonstration plants in Europe/Japan using renewables to source hydrogen via electrolysis and provide heat/pressure for the reaction. It remains to be seen how their capital/operating costs compare to existing plants

[2] Mountains vs Molehills

The renewable energy revolution has given birth to a lot of great ideas and innovations, with a surge in global renewable energy patents since 2009. But for every idea that transforms the energy landscape, there are more that succeed from a business perspective but do not move the needle on de-carbonization, and others that don't succeed on either front. Wave energy, fuel cells, algae-based fuels, liquid fuels from methane, kite energy, cold fusion, liquid fluoride thorium reactors…these are all topics that clients have asked about, but which are not anywhere near large-scale commercialization. The hype with which these ideas are discussed in the press often obscures how difficult such commercialization would be.

As a result, we've added a "Mountains vs Molehills" section to briefly assess five popular energy topics with respect to their **practical potential for significant de-carbonization over the next 10-15 years**. We graded each topic with a de-carbonization score that ranges from 1 (molehill) to 5 (mountain).

Global cumulative renewable energy patents
Thousands



Source: International Renewable Energy Agency. 2016.

Mountains or Molehills?

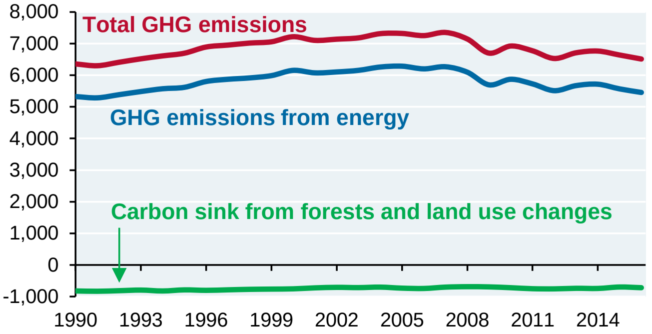
a) Carbon sequestration via reforestation
b) Carbon capture and storage (underground)
c) Cellulosic ethanol
d) Distributed energy storage via graphene-based supercapacitors
e) Carbon-free smelting of aluminum

a. Forest management as a means of sequestering additional amounts of carbon

All US forestland encompasses around 750 mm acres and captures 10% of US GHG emissions each year[9]. In 1850, there were 900 mm acres, but returning to this level is unlikely given conversion of forested areas into highways, infrastructure and farmland, and given the 6x growth in US population since then. Ideas for sequestration involve replanting cleared forests, and converting cropland and pastureland.

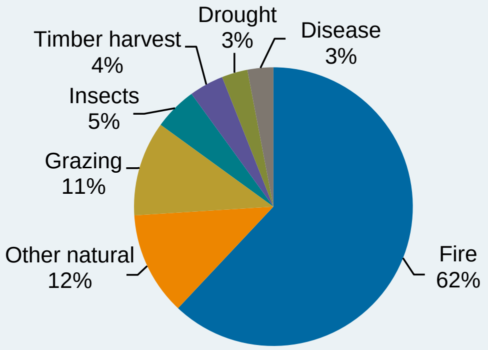
US forests offset 10% of annual GHG emissions

Million metric tons of CO_2 equivalents per year



Source: US EPA. 2017. Total emissions include agriculture, waste and industrial processes such as chemical, metal and mineral production.

Cleared US forestland by disturbance source, 2014



Source: Al Sample, Journal of Forestry. 2017.

Reforestation refers to replanting of cleared areas which do not require a land use change. A 2017 Journal of Forestry study analyzed 20 million acres of land which has been cleared due to wildfires, insect outbreaks and other disturbances. The study estimated its sequestration potential at 50 million metric tons (MMT) of GHG per year, which could offset almost **1% of annual US GHG emissions.** Reforesting 20 million acres split evenly between private and public land would be a major undertaking; in 2017, the US Forest Service reforested just 122 ***thousand*** acres. Reforestation is needed to offset: (a) aging US forests which absorb less carbon over time; (b) CO_2 released from wildfires, which has averaged 60 - 80 MMT per year since 2013; and (c) the impact of severe hurricanes, one example being Hurricane Michael which destroyed 3 million acres of trees in Florida in 2018.

Afforestation refers to trees planted in previously unforested areas. The concept: carbon payments could incent US farmers to convert cropland and pastures into forests. A 2018 study published in the National Academy of Sciences estimated the potential for 150 MMT of CO_2 sequestered each year, assuming a CO_2 price of $15 per tonne. To be clear, this would be another large undertaking, requiring the conversion of 7-10 million acres of cropland and pastureland. The study's sequestration estimates are lower than prior ones, since they incorporate the need to avoid large adverse social/environmental/economic impacts, the complex reality of farmer decision-making[10], and competing demands for food/biofuels/real estate.

Bottom line: reforestation and afforestation are low-tech solutions that can and do work, but plans to achieve additional sequestration of 3% of annual US GHG emissions would entail substantial costs and private sector participation on an unprecedented scale

Grade: 

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[9] **Greenhouse gas emissions** include carbon dioxide, methane, nitrous oxide and fluorinated gases. In the US, the breakdown of GHG emissions is 82% CO_2, 10% CH_4, 5% NO_x and 3% F-gases.

[10] For example, **converting farmers** lose the optionality of benefitting from higher crop prices; bear the entire risk of wildfire and disease; and often bear the currently high cost of CO_2 sequestration verification (which could decline with the advent of NASA satellite technology monitoring).

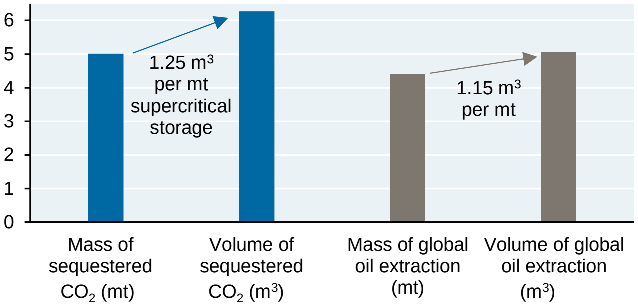
b. Carbon capture and storage (storing CO_2 emissions underground)

Forests are a low-tech approach to sequestration; underground storage through carbon capture (CCS) is a higher-tech one. A 2018 Congressional bill creating tax credits for CO_2 sequestration[11] raised hopes that underground storage will finally become a meaningful part of the de-carbonization solution. Furthermore, recent studies cite little evidence of CO_2 leakage, high confidence in the geological integrity of underground reservoirs[12], and reinforce the importance of CCS to de-carbonization pathways even if leakage occurs.

Even so, history offers reasons for caution. Despite all the hype[13], by the end of 2018, CCS facilities in operation captured and stored **just 0.1% of the world's CO_2 emissions**. Let's put aside issues of large cost overruns and failures of bellwether projects[14], the Department of Energy withdrawing support from large projects (FutureGen), project cancellations in Europe, legal uncertainties about liability associated with CO_2 leaks, and the ~30% energy drag on coal facilities required to perform CCS in the first place. Let's assume these problems are solved via innovation and legislation (aggressive assumption, for sure). The bigger problem with CCS is the scope required to make a difference. To see why, let's assume that the world aims to sequester just 15% of global CO_2 emissions each year, which would be around 5 gigatons.

Compare the volume bars in the chart: to capture 15% of global CO_2 emissions, a CCS compression/transportation/storage industry would have to be able to handle 6 billion cubic meters of CO_2 every year, which is **even greater than the volume of annual global oil transportation and refining**, which has taken 100 years to build; and that's without the benefit that oil provides as an input to transportation and industry. There may be applications where CCS makes sense (enhanced oil recovery, and meeting small amounts of commercial CO_2 demand). But as a big picture solution to CO_2 emissions, CCS scale requirements are very daunting[15]. We'd be very surprised if global CCS exceeded 5% of CO_2 by 2030.

To capture 15% of global CO_2 emissions, CCS would have to be larger than the global oil ecosystem
Billions (metric tons for mass, cubic meters for volume)



Source: BP, JPMAM. 2018. Mt = metric tons, m^3 = cubic meters

Grade: ▲△△△△

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[11] The 2018 bill established **tax credits** of \$35 per tonne of CO_2 sequestered as part of enhanced oil recovery operations, and \$50 per tonne of CO_2 sequestered in geological formations in the absence of oil recovery. To be clear, CCS involves storing *CO_2* underground, while forests store *carbon* and release oxygen back into the atmosphere.

[12] Studies on reservoir reliability include a January 2019 *Scientific Reports* study analyzing 400,000 years of evidence from a naturally-occurring faulted CO_2 reservoir in Arizona, and a 2018 study in *Nature Communications*.

[13] A study from Monash University found substantial evidence of **CCS hype**: a surge in peer-reviewed CCS papers, a much smaller increase in patents, evidence of rising costs and a huge gap between expected and actual project starts.

[14] **Kemper fiasco**. The Kemper Clean Coal plant in Mississippi was supposed to be the world's largest, converting cheap lignite coal into natural gas to generate electricity, and capturing CO_2 for use in enhanced oil recovery at nearby fields. As of July 2016, the plant was more than two years behind schedule, more than \$4 billion over its budget of \$2.4 billion and still not operational. In July 2017, Southern Company and Mississippi Power announced they had **suspended all coal gasification and carbon capture operations** at Kemper and would use natural gas instead. Kemper identified issues with its CCS technology, including design flaws that caused leaks.

[15] The same scale challenges apply to other de-carbonization ideas like "**enhanced weathering**", which would require the mining and distribution of billions of tons of silicate rock each year (even more than the tonnage of annual mining of cement and iron ore) with the goal of having these rocks react with CO_2, extracting it from the atmosphere.

c. Cellulosic ethanol

A good friend is a producer for the news program *60 Minutes*, and she recently produced a segment on a company working on cellulosic ethanol. Its approach: use electron beam accelerators to break down cellulose in plant material, rather than using sulfuric acid or steam explosions. The former head of MIT's chemical engineering department is on the company's board, along with a former Shell Oil executive and a former US Secretary of Energy. Sounds promising, right?

It pays to be skeptical here. The history of cellulosic ethanol is littered with exaggerated hype and failed expectations[16]. While US cellulosic ethanol production rose from 2.2 mm gallons in 2015 to 10 mm gallons in 2017, the capacity of these plants is 88 mm gallons, which in turn is 0.06% of annual US gasoline consumption. A big part of the challenge: corn stover has a volumetric density that is just 6% of gasoline. After accounting for that and ethanol's lower *energy* density vs gasoline, the storage and transportation capacity of a cellulosic ethanol ecosystem would need to be **110x** larger than its gasoline counterpart. That's expensive to build, particularly if you have to also spend money breaking down cellulose.

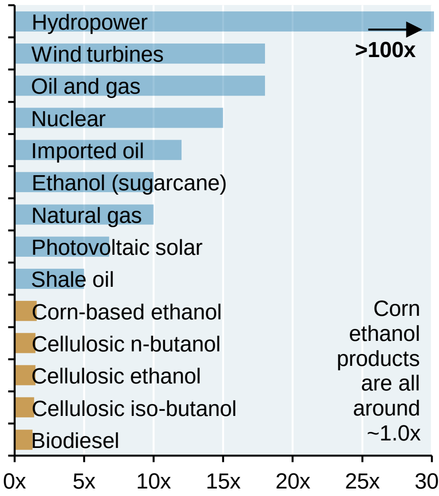
Even so, let's assume the company can lower the cost of cellulosic ethanol production…how much gasoline demand could it displace each year? Let's use an aggressive assumption that all available US corn stover would be used to produce cellulosic ethanol. After accounting for stover that must be plowed back into the soil to maintain its productivity, an assumed haircut for harvesting/evaporation/transportation loss, the conversion ratio of stover into ethanol and energy density differentials, we estimate that cellulosic ethanol could displace just **5%** of US gasoline consumption. Of course, there are other sources of biomass that could be used other than corn stover, but our assumption is optimistic enough regarding available feedstock. *Feasible*, yes. *Likely impact*, very small. One last thing: **energy return on investment** for all forms of corn ethanol are pretty low, as shown on the right.

What % of US gasoline consumption could be displaced by cellulosic ethanol? Around 5%

Description	Value
Stover to grain ratio	1:1
Midpoint stover removal percentage	40%
Metric tons of US corn production	385,000,000
Metric tons of stover available	154,000,000
Kg, annual corn stover	154,000,000,000
Haircut for harvesting, evaporation and transportation loss	15%
Kg, stover left over for conversion to cellulosic ethanol	130,900,000,000
L/kg, conversion ratio of stover to cellulosic ethanol	0.32
Liters of ethanol produced from annual corn stover	41,888,000,000
Energy density of cellulosic ethanol relative to gasoline	66%
Gasoline equivalent liters of cellulosic ethanol	27,771,744,000
Gasoline equivalent gallons of cellulosic ethanol	7,336,541,449
Gallons of US gasoline consumption in 2017	142,980,000,000
% of total gasoline consumption from cellulosic ethanol	**5%**

Sources: Penn State Department of Crop and Soil Sciences; University of Illinois Department of Agricultural and Consumer Economics; Vaclav Smil; David Pimentel (Cornell); Alternative Fuels Data Center, EIA, US Grains Council, JPMAM. 2017.

US Energy Return on Investment



Source: Tao et al, National Renewable Energy Lab; Biofuels, Bioproducts and Biorefining Journal. 2013.

Grade: ▲△△△△

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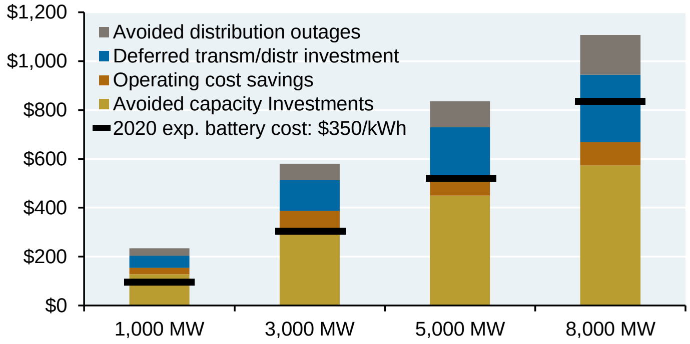
[16] **Cellulosic ethanol hype** includes a 2006 presentation from venture capitalist Vinod Khosla entitled "*Biofuels: Think Outside the Barrel*", that predicted 24.8 **billion** gallons of cellulosic ethanol production by 2017; it was around 10 **million** instead. Companies that built cellulosic ethanol plants include DuPont, Abengoa, INEOS Bio, Range Fuels, Cello Energy, etc. Most of these plants are no longer in operation.

d. Graphene-based supercapacitors for distributed energy storage

Distributed energy storage is critical for achieving greater penetration of renewable energy. The reason: transmission infrastructure is both expensive and politically difficult to build, and in many parts of the world, wind/solar/hydro resources are situated far from urban population centers. This is one of the challenges facing Germany, as we discuss later. As a result, locally distributed energy storage could increase the productivity of renewable energy by reducing the cost of new transmission investment, reducing the need for investment in peaker plant capacity, avoiding distribution outages and reducing peaker plant fuel consumption. The question is whether the economic benefits of energy storage outweigh its costs.

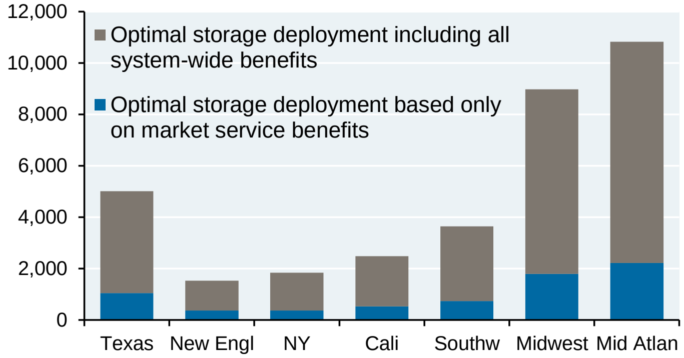
Texas utility Oncor commissioned a study by the Brattle Group to estimate system-wide costs and benefits of distributed storage. As shown in the first chart, the sum of potential benefits are estimated to be greater than costs[17] across different levels of deployment. However, the marginal utility of storage declines as penetration increases since there are typically a limited number of high-cost peaker and transmission projects avoided.

Estimated benefits of storage outweight costs in ERCOT study, US$ millions per year



Source: The Brattle Group. 2018.

Optimal storage levels depend on regulatory changes that allow full benefits to be realized, MW of storage



Source: The Brattle Group. 2018.

An important caveat: the easiest storage benefits to capture are related to market services like energy arbitrage, peaker capacity and frequency regulation. There's a **hornet's nest of issues** that would have to be solved in order to capture the rest, due to restrictions on utility ownership/operation of storage, valuation of customer-level benefits, dispatch priorities, contractual conflicts, etc. The second chart shows lower optimal storage levels by region if the only benefits captured are related to market services.

So, on paper, lithium ion battery storage costs have declined enough to merit inclusion in the grid. As of today, however, utility-scale battery storage is still in its infancy. As of 2017, there was just 1 GW of grid battery storage in the US, compared to 22 GW of pumped hydroelectric storage (most of which was built in the 1970s and 1980s)[18]. Furthermore, both forms of energy storage combined only supplied 0.6% of US electricity in 2017. Currently, 86% of battery capacity is based on lithium ion chemistry, with the remainder split between nickel, sodium and lead acid. If you read green energy blogs, there's a lot of excitement about the potential for graphene-based supercapacitors for energy storage. Let's take a look.

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[17] The cost of individual lithium ion packs is approaching $200 per kWh. However, when using batteries for **utility-scale grid energy storage**, there are additional costs, including DC to AC inverters, power conditioning hardware, software, meters and land/construction costs. We consider $350 per kWh as a reasonable utility-scale estimate.

[18] Similarly, 96% of the global 159 GW in energy storage capacity is based on pumped hydro.

Supercapacitors store energy as a static charge, rather than as an electrochemical reaction as batteries do. They can offer more durability than lithium ion batteries (particularly for remote locations with extreme temperatures[19]), faster charging times (ideal for intraday frequency regulation, generator bridging or short term power reserves) and less lifetime performance degradation[20]. Commercial providers of super-capacitors also claim to have improved their energy density, though they still trail lithium ion batteries substantially in this regard. Costs are higher than lithium ion, but this is before mass production scaling. Tesla's acquisition of Maxwell Technologies could be a sign of greater commercialization potential. To rebalance microgrids, Maxwell claims that a few minutes of supercapacitor storage could replace hours of backup provided by traditional batteries.

Comparison for utility-scale energy storage applications

Feature	Supercapacitors	Lithium ion batteries
Life cycle	1,000,000	2,000 to 10,000
Upfront capital cost	$500 per kWh (w/o production scaling)	$350 per kWh
Round trip DC eff. excluding DC/AC conversion	99% (constant over life)	90% to 99% (degrades over life)
Useable Capacity (% of rated capacity)	100% (constant over life); in practice, 75%-80% (does not degrade)	70% to 90% (degrades over life)
Temperature Range	-30^{0}C to 85^{0}C	0^{0}C to 40^{0}C (higher with climate control)
Max. rate of charge/discharge*	50C	0.25C to 4C
Thermal Runaway	No Risk	Risk greater than zero
Energy Density (Wh/kg, system level)	5 to 30, up to 150 in lab studies	150 to 260 with potential for 400-500
Disposal costs/environmental issues	Given the longer life of supercapacitors, disposal issues are deferred vs lithium ion. As a carbon-based product, graphene appears much less toxic than lithium ion. However, studies do show substantial human and environmental impacts from graphene exposure.	

Source: Electric Power Research Institute, Maxwell Technologies, National Graphene Institute (Manchester, UK), Argonne National Lab. 2018. * C-rates measure speed of charge/discharge. A 1C rating implies charge/discharge in one hour, 2C in 30 minutes, 3C in 20 minutes, 0.50C in 2 hours, etc.

Bottom line: utility-scale battery storage is in its infancy. There are still engineering issues to be solved regarding degradation, maintenance and durability. On paper, declining lithium ion costs may justify battery storage as a replacement for peaker plants in some places. However, substantial changes in rules and incentives are needed to unlock their full economic value. Supercapacitors offer promise in frequency regulation and remote applications, and can serve as complements to a lithium ion storage system for short bursts of high power. But like any unscaled new idea, it's too soon to project their broader impact on energy storage and GHG emissions. I can imagine the scores below improving by 2025 if production scaling drives either cost below $200 per kWh.

Grade: Lithium ion based utility-scale battery storage: △△▲△△

Grade: Supercapacitors: ▲△△△△

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[19] One example: South Dakota based Northwestern Energy has partnered with Kilowatt Labs on supercapacitor storage given the high cost of transmission in a low-density region servicing 1 million people across 300,000 sq miles.

[20] On **lithium ion battery degradation:** According to the Brattle Group, the French utility EDF de-rated its Illinois-based storage project by 30%, and US utility AES announced a "huge de-rate" of its own storage capacity. Such degradation may be real-life confirmation of experiments and simulations by NREL that indicate substantial potential lithium ion capacity loss due to high temperatures, pressure and other mechanical/thermal stress.

e. “Carbon-free” aluminum smelting

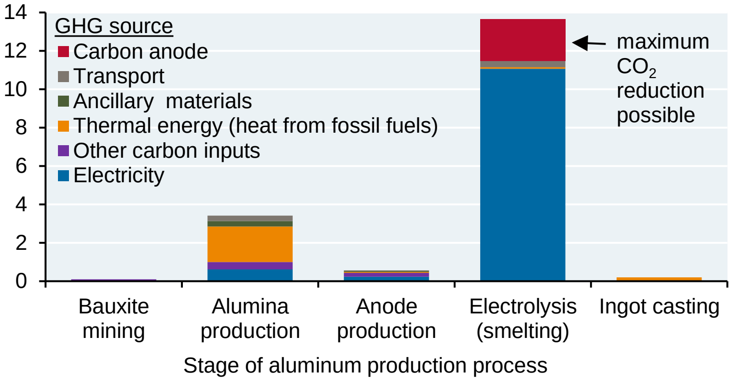
In May 2018, I came across a very exciting headline: “**Apple paves the way for breakthrough carbon-free aluminum smelting method…Apple Played Crucial Role in Development of Joint Venture that Could Change Global Manufacturing**”. That sounds pretty transformational, so I wasted no time in reading it. The idea involved is ingenious, but the scope and impact are less than what I was expecting.

Background: Apple financed a joint venture between Alcoa and Rio Tinto to explore ways of eliminating the need for a carbon-based anode during the process of aluminum electrolysis (the method by which aluminum oxide is converted into aluminum). The venture appears to have succeeded in developing an advanced conductive material that releases oxygen instead of CO_2 as a by-product of aluminum electrolysis. This is great news and a testament to their ingenuity. However, the new approach would only reduce GHG emissions on the margin. The chart below explains why.

Each step in the process used to create aluminum, from bauxite mining to ingot casting, involves GHG emissions with the most energy-intensive step resulting from electrolysis. **Around 84% of GHG emissions from aluminum electrolysis (smelting) are derived from electricity generation; only 16% result from the use of the carbon anode**. When broadening the discussion to the entire aluminum production process, the carbon anode only accounts for ~10% of its GHG emissions.

The elimination of the carbon anode in aluminum production could at its upper bound eliminate 138 million tons of CO_2 each year, assuming 63 million tons of annual global production. If so, that upper bound would reduce annual global CO_2 emissions by around 0.4% if adopted universally by producers. The approach might also be adapted for other de-carbonization processes. However, I would not describe the new idea as “carbon-free smelting”, nor would I describe it as “changing global manufacturing”.

Only 16% of electrolysis emissions result from carbon anode, Tonnes of CO_2 equivalent per tonne of aluminum produced



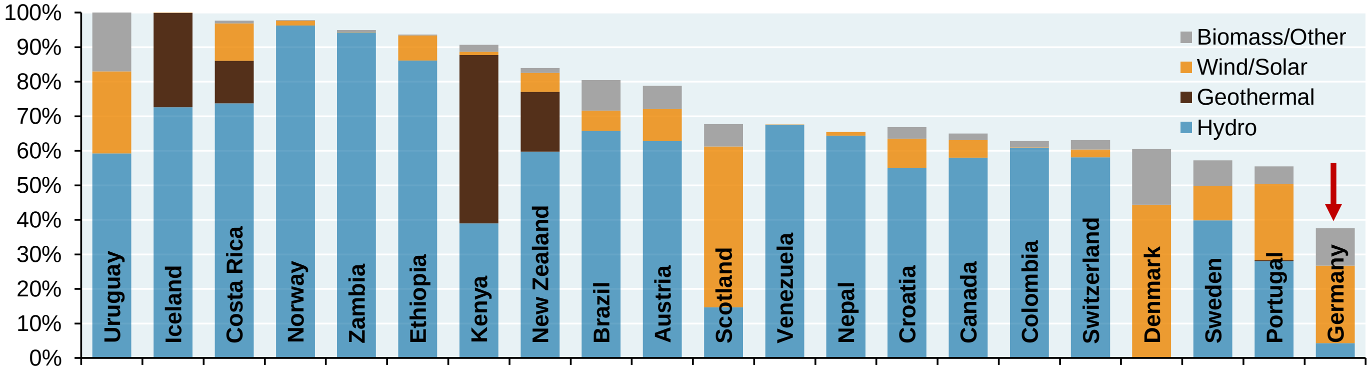
Source: International Aluminum Institute. June 2017.

Grade: △▲△△△

[3] Germany and Energiewende: a dispassionate assessment

If you look for opinions on Germany's Energiewende transition, you'll find articles that cite great success, and other articles like "*Energiewende: A disaster in the making*"[21]. The achievements and limitations of Energiewende are important to understand: Germany is seeking to generate 65% of its electricity from renewable energy without heavily relying on hydropower, as most countries with high shares of renewable power generation do (Denmark and Scotland are exceptions, and have among the highest ratio of coastline to land area in the world).

Countries with high renewable shares of electricity generally rely heavily on hydropower and geothermal energy
Percentage of electricity generation from all renewable sources



Source: IRENA, German Federal Ministry for Economic Affairs and Energy. Based on 2016/2017 electricity generation.

A few ground rules on what *doesn't* matter to me about Energiewende:

- I don't consider strains on German utilities to be a problem unless they lead to blackouts, brownouts or other substantial disruptions to the German economy (which aren't happening so far, see page 19)
- GHG emission comparisons shouldn't be established vs a year like 2009, when a global recession depressed output and associated emissions
- The fact that China's GHG increases could offset annual Energiewende savings in a few weeks is not an indictment of Energiewende per se
- Citing the numbers of birds killed by wind farms should be done in a proper context, as fossil-fueled generation produces its own (broader) set of environmental impacts

Here's what *does* matter to me in assessing Energiewende goals:

- The cost so far, measured by household and corporate electricity prices, subsidies and taxes
- What additional costs will be needed for transmission and/or distributed storage necessary to meet the 65% goal, and whether such costs and land-use requirements are viable politically
- What will Germany's GHG emissions look like once they are based on the new system (wind/solar backed up by coal plants, and without the nuclear power which once provided 30% of generation)

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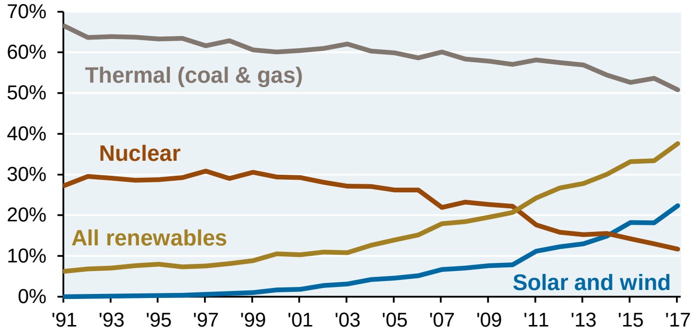
[21] Examples of **downbeat** articles on Energiwende:

- "*Germany's Energiewende: A disaster in the making*", Fritz Vahrenholdt, Global Warming Policy Foundation, 2017
- "*Why aren't renewables decreasing Germany's carbon emissions*", Forbes, October 2017.
- "*Energiewende: A tale of increasing costs and decreasing willingness to pay*", IAEE Energy Forum, 2017.
- "*Germany's Green Energy shift is more Fizzle than Sizzle*", Politico, October 2018.

What has Energiewende accomplished so far?

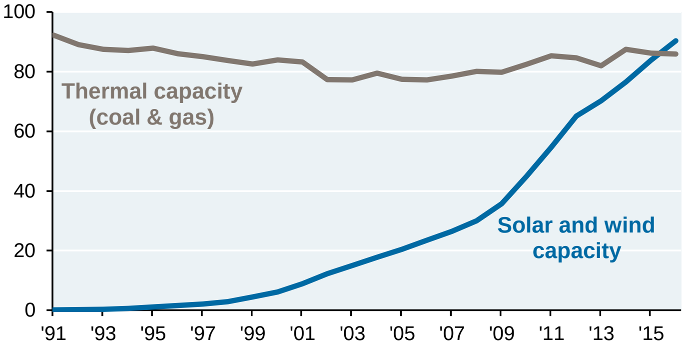
Energiewende's primary impact has been the substitution of solar and wind for thermal and nuclear power generation. When including all forms of renewables, Germany's renewable generation reached 38% in 2017, which is quite an achievement for a country with only a 4% hydropower share.

Renewables and the decline in thermal and nuclear generation, Share of total electricity generation, Germany



Source: German Federal Ministry for Economic Affairs and Energy. 2017.
All renewables includes solar, wind, hydro, biomass and waste.

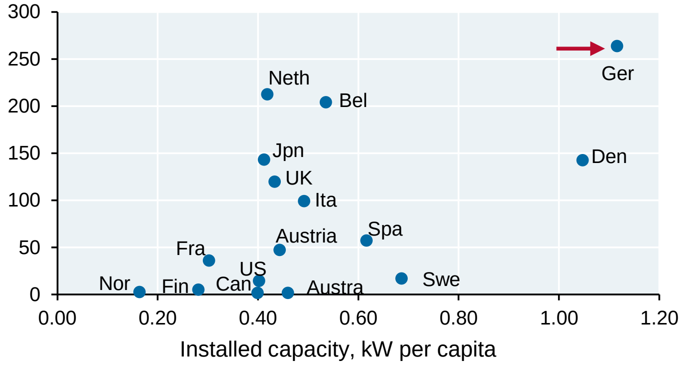
Germany's wind and solar capacity build-out now matches its thermal capacity, with more to come, GW



Source: German Federal Ministry for Economic Affairs and Energy. 2017.

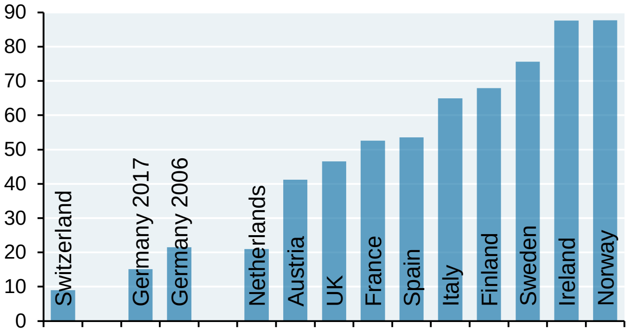
Germany's wind and solar footprint is the largest in the developed world when measured vs population and land area, and this is before Germany shoots for 65% renewable generation by 2030. High wind/solar penetration rates sometimes raise concerns about grid reliability, but so far, this hasn't been a problem. German power outages are actually *down* since 2006, and Germany's 15 minute average annual outage figure for 2017 was practically the lowest in Europe by a wide margin.

Germany has the largest wind/solar footprint
Installed capacity, kW per square km



Source: BP Statistical Review of World Energy. 2018.

Average annual power supply interruption
2016 minutes (including exceptional events)

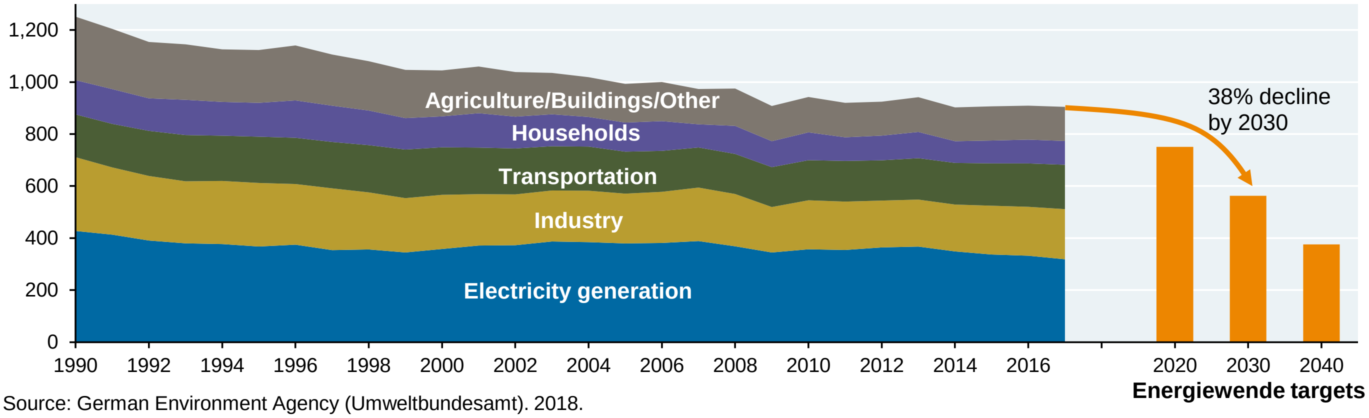


Source: Council of European Energy Regulators Benchmarking Report, 2018. The following countries had interruptions over 100 minutes per year: Bulgaria, Latvia, Greece, Estonia, Croatia, Poland and Romania. According to the EIA, the comparable US figure was 128 minutes.

What about GHG emissions? Progress is slower than Germany was hoping for. The Energiewende goal is a reduction in GHG emissions of 40% vs a 1990 baseline by 2020; the decline plateaued at 28% instead. The primary reasons for the plateau:

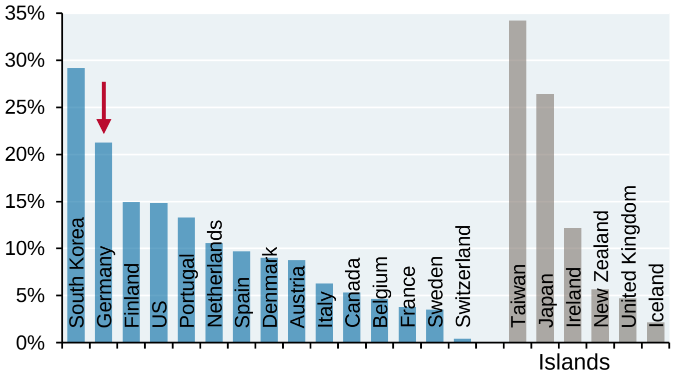
- While solar and wind generation ***capacity*** now matches thermal capacity, solar and wind intermittency result in lower relative amounts of renewable electricity ***generation***
- The renewable share of electricity generation rose from 10% in 2001 to 38% in 2017, but GHG emissions from electricity only declined by 14%. The explanation: during the same period, the **nuclear** share of generation dropped by 17%, slowing the decline in reliance on coal. Germany still has one of the highest coal shares of primary energy of all developed non-island nations, and its decline will continue to be gradual if Germany's last 7 nuclear plants are de-commissioned as planned by 2022
- There was a large GHG decline following the **collapse of East Germany's** inefficient power and industrial sectors; this process was mostly played out by the year 2000
- **Electricity generation is only 40% of total primary energy use in Germany**. Transportation emissions are roughly unchanged since 1990, as increased kilometers traveled offset improvements in vehicle efficiency, and since electric vehicles were only 1.5% of total German car registrations in 2017. Industrial and agricultural GHG emissions are also roughly unchanged since 2000.
- Germany considered a levy on coal plants emitting more than a certain amount of CO_2, but backtracked after union and utility protests. Further GHG reductions may have to come from incentives for industry to invest in more efficient machinery (uncertain benefits and timing)

German GHG emissions decline has stalled since 2008
GHG emissions by sector, million tonnes of carbon dioxide equivalents



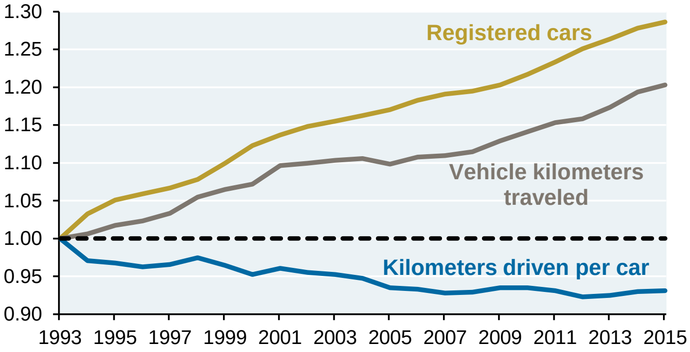
Source: German Environment Agency (Umweltbundesamt). 2018.

Coal as % of primary energy in developed economies



Source: BP Statistical Review of World Energy. 2018.

Germany: more cars offset benefits from more efficient engines and more efficient use; Index, 1993 = 1.0

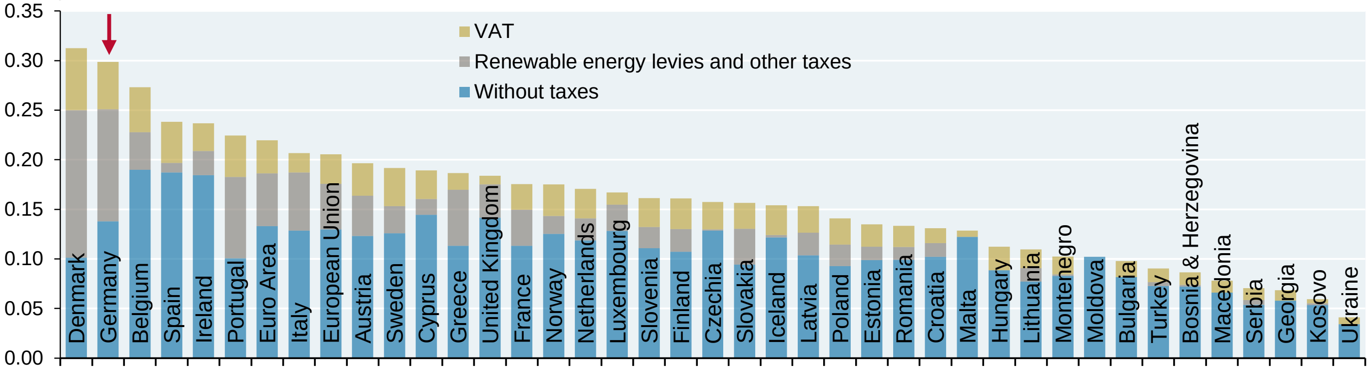


Source: German Aerospace Center Instititue of Transport Research. 2017.

The biggest Energiewende question relates to costs incurred so far, costs that still remain (due to transmission infrastructure and substitutes for nuclear power), and the political willpower needed to finance them. German household electricity costs are among the highest in Europe, and this is *before* additional transmission, nuclear substitution and higher renewable penetration costs are incurred. German household incomes are similar to France, Ireland and the UK, in which case higher German electricity prices are also higher in relative terms. However, Italian and Spanish household incomes are lower, so their real burdens are closer to Germany than they appear in the chart.

Electricity prices for household consumers

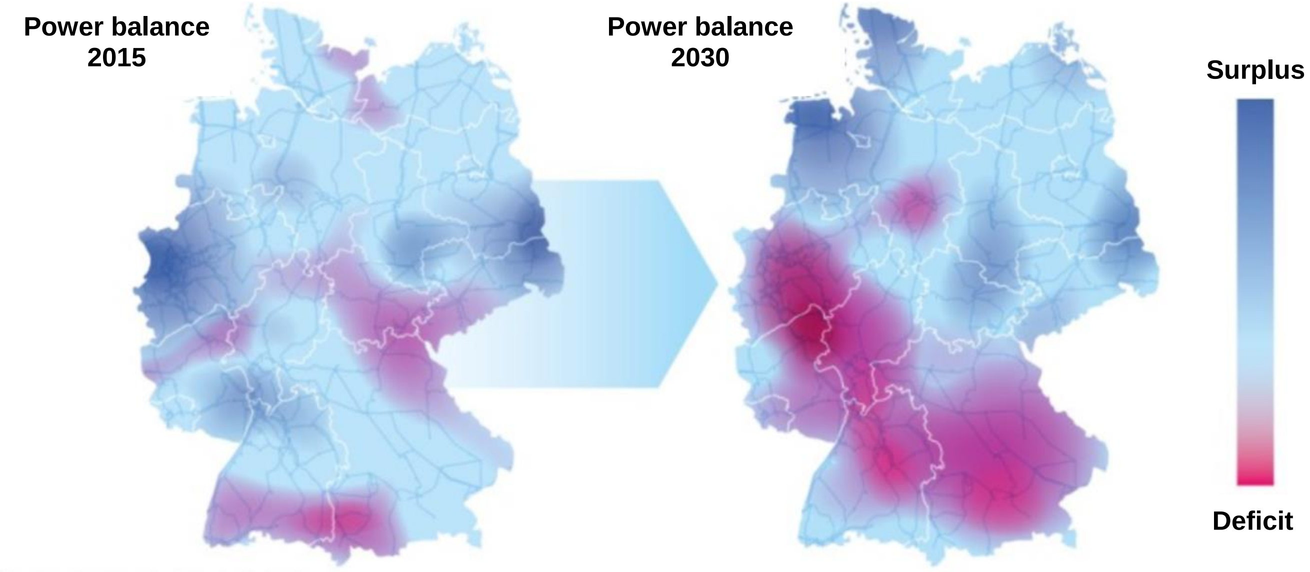
EUR per kWh



Source: Eurostat, Q2 2018.

Here's a visual of the **supply-demand gap** today, and the one that may exist in 2030. The growing purple supply deficit reflects the expected gap between wind supply in the North and energy demand from population centers in the South.

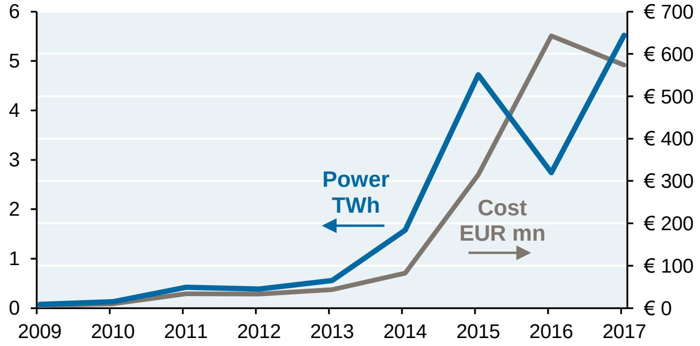
German regional power deficits expected to rise by 2030



Source: Ampriron GmbH. 2015.

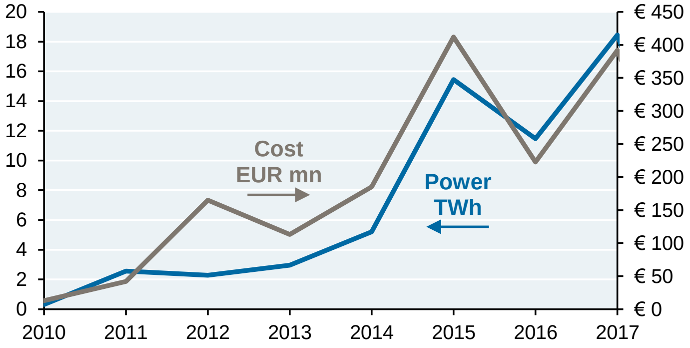
The current supply-demand gap has already resulted in a rise in **discarded renewable production** (which results in feed-in tariff payments to wind producers to compensate them anyway), and in "**redispatch costs**" required to compensate Southern power producers to generate electricity at times of low electricity prices. According to the German Federal Network Agency, annual tariff and redispatch costs due to grid stabilization efforts could rise to EUR 1 billion by 2020, and that's before nuclear plants are shut down, and before increased EV penetration in Germany[22].

Discarded renewable production for which German wind and solar producers are still paid



Source: Bundesnetzagentur Monitoring Reports. 2017.

Redispatches: grid shortages which require extra payments to above-market producers



Source: BDEW, Bundesnetzagentur Monitoring Reports. 2017.

German grid imbalances are not just a problem for Germany. German grid congestion is already putting pressure on Eastern European grids through unwanted power surges and blockages at the border. New cross-border connections to Belgium and Scandinavia may reduce some of these pressures.

To reduce curtailed renewable generation and re-dispatch costs, Germany will need to upgrade its transmission infrastructure. This includes upgrades to large transmission lines, and also to the low and medium voltage distribution grid that incorporates storage capacity and electric cars. The latest estimates we have seen: a need for 4,650 km of transmission lines by 2025, **only 900 km of which have been built so far**. As in the US, this process has been bogged down by citizen protests affected by transmission line construction, as well as by German states (e.g., Thuringia) that are suing in an effort to have them relocated to neighboring states. Burying cables underground might reduce the political disputes, but at a substantial increase in cost. More wind turbines could be built in the South, but so far, this has been met with a lot of political resistance.

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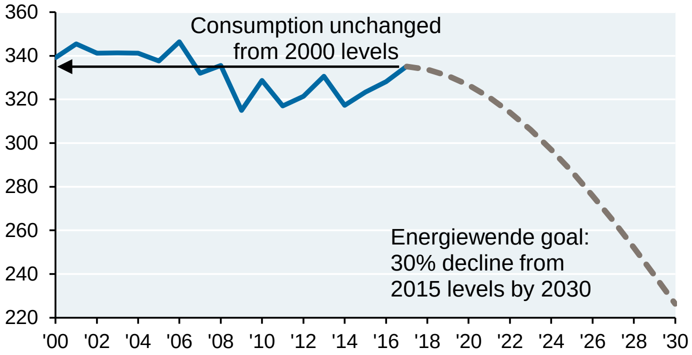
[22] If 30% of Germans bought EVs and plugged them in to recharge when they get home from work, consultancy Oliver Wyman estimates that Germany's electricity grid could collapse. Much greater grid management planning would be needed for EVs to function as electricity storage devices in connection with surplus renewable generation.

Energiewende's goals are much broader than the electricity grid. One key objective is a 30% decline in primary energy use from 2015 to 2030. The challenge, as illustrated in the first chart: German primary energy use is basically **unchanged** since the year 2000, casting considerable doubt on this 2030 goal. German energy *efficiency* has improved (along with other developed nations), but overall energy use has been roughly constant.

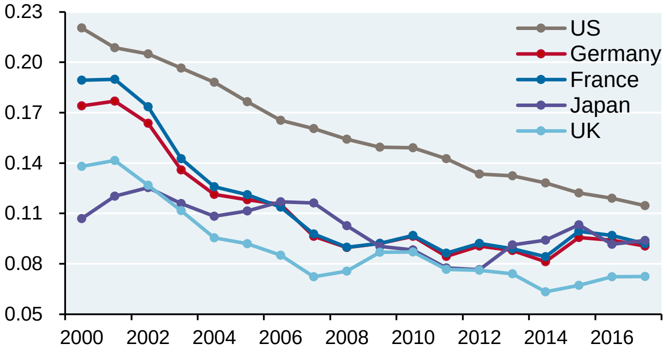
Germany primary energy consumption, Mtoe



Source: BP Statistical Review of World Energy, JPMAM. 2018. Dotted line indicates pathway needed to reach 30% primary energy decline goal.

Energy intensity

Mtoe of primary energy per unit of nominal GDP



Source: BP Statistical Review of World Energy, Haver, JPMAM. 2018.

In the latest self-assessment of Energiewende by the Federal Government's Expert Commission, the **lack of progress outside power generation is readily acknowledged**. The assessment assigned the lowest grades ("unlikely to meet 2020 target") to transportation energy use, changes in the fuel mix, expansion of transmission grids and overall primary energy use.

So, here's the bottom line on Energiewende:

- Can Germany reach 65% renewable power generation by 2030? Sure, but it may require considerable further increases in electricity prices and other economic costs[23], **and** increased political will to build the transmission infrastructure necessary to get there. As a reminder, 80% of the necessary transmission infrastructure is still on the drawing board
- Will Germany be able to cut GHG emissions in half by 2040, which relies in part on a 30% decline in primary energy use? Highly unlikely, given the very slow pace of de-carbonization apart from the electricity grid, and the extent to which greater *demand* for energy offsets improvements in energy intensity, improved gas mileage in cars/planes, more energy efficient devices/machinery/buildings, etc
- Germany's newly announced goal of phasing out all coal/lignite by 2038 seems completely unrealistic given all the issues explained above

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[23] German regulators may consider 35 cents/kWh as a resistance point for households in terms of what they would be willing to pay for electricity, particularly since energy taxes are regressive by nature. If so, Germany may have to increase electricity prices on its **industrial users instead**, whose prices are also close to the highest in the industrialized world at 12.5 to 15.5 cents per kWh. While nuclear decommissioning costs may not show up in electricity prices directly, they are also a large cost borne someplace in the energy ecosystem.

[4] US wildfires: anthropogenic climate change and risks for utilities in fire-prone areas

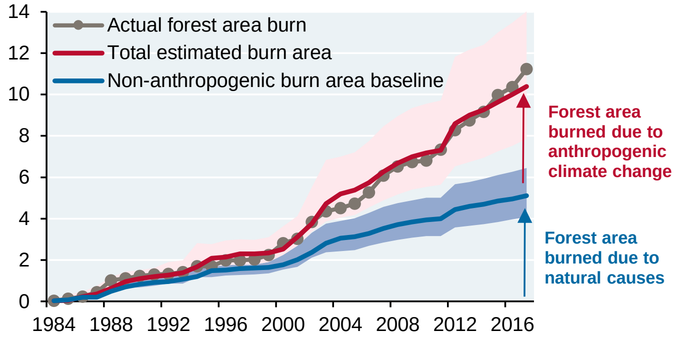
Given the collapse in PG&E stock in the wake of two severe wildfire seasons, we wanted to assess risks that such catastrophic events recur in the future. In other words, were 2017 and 2018 anomalous fire seasons, or are such risks something that investors need to be mindful of in the future? Based on the latest research, owning utilities in fire-prone areas looks to be fraught with risk that isn't going away.

PG&E's market capitalization after two years of wildfires
US$ billions

Source: Bloomberg. March 13, 2019.

Recent wildfire research attempts to identify the degree to which man-made climate change contributes to forest fire activity. The approach: use historical data to determine a "non-anthropogenic baseline", which is the amount of hectares that would probably have burned anyway absent any climate change, and due to natural causes. One recent example comes from a 2016 paper from researchers at Columbia's Lamont Doherty Earth Observatory and the University of Idaho. Their "natural burn area" baseline is shown in blue; the gray dots show the actual amounts burned; and the red line shows the estimated total burn area. As you can see, **total hectares burned were roughly double their "natural" baseline estimate**.

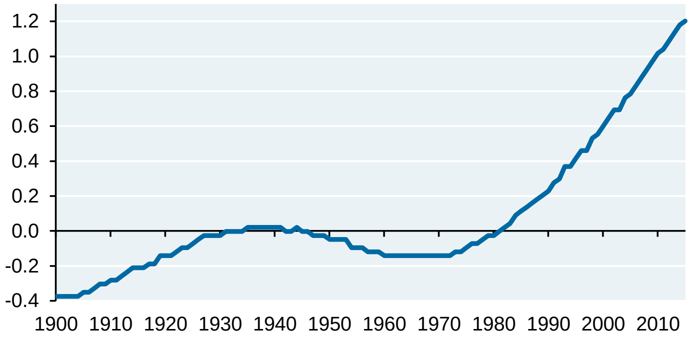
Climate change responsible for a doubling of burn area
Millions of hectares of US forest fires, cumulative



Source: Abatzoglou and Williams. 2016. Shaded areas are 95% confidence intervals.

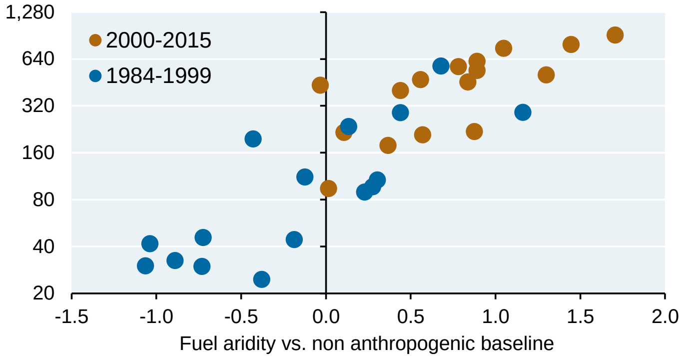
Here's another look. The first chart shows an estimate of the increase in temperature in Western forest regions due to human activities. The recent temperature increase corresponds to an increase in the "**fuel aridity**" of Western forests (fuel aridity is a blend of different combustibility measures that rise as climate impacts intensify[24]). As the fuel aridity of Western forests rose, the hectares of US forests that burned in wildfires rose as well, and by an exponential amount as the Y axis is in log scale (second chart). These charts illustrate the connection many forestry scientists see between man-made climate change (which drives up fuel aridity) and wildfire severity.

Estimated temperature change in Western forest region due to human activities, Degrees Celsius



Source: Abatzoglou and Williams. 2016.

US forest fire area versus fuel aridity by year
Forest fire area, thousands of hectares



Source: Abatzoglou and Williams. 2016.

Climate change is not the only way that humans affect wildfire severity; humans also start a lot of fires, whether intentionally or not. When looking at the numbers of fires and at the number of hectares burned, humans account for 84% of the former and almost half of the latter. Natural causes such as lightning account for the rest. The table below is for the period 1992-2012; fire frequency peaked around 1980, and has been declining since due to fewer instances of arson, fewer controlled burns becoming uncontrolled, and fewer cigarette ignitions.

Humans start most fires and account for almost half of all forest area burned

	Number of fires			Area burned (hectares)		
	Human	Lightning	Human %	Human	Lightning	Human %
Mediterranean California	87,274	2,855	97%	2,143,282	253,210	89%
Northern Forests	61,673	2,574	96%	302,561	82,721	79%
Eastern Temperate Forests	815,499	44,859	95%	3,827,045	829,293	82%
Marine West Coast Forests	14,586	925	94%	19,251	27,291	41%
Great Plains	134,944	17,586	88%	3,992,557	2,564,955	61%
Southern Semiarid Highlands	7,504	2,167	78%	340,873	254,418	57%
Tropical Wet Forests	4,832	1,917	72%	357,150	350,477	50%
North American Desert	55,422	52,044	52%	2,394,677	8,880,691	21%
Northwest Forested Mountains	76,735	94,017	45%	1,895,622	5,731,733	25%
Temperate Sierras	13,607	26,502	34%	754,393	1,152,064	40%
Total Continental US	1,272,076	245,446	84%	16,027,412	20,126,852	44%

Source: Balch et al University of Boulder, January 2017, for the period 1992-2012.

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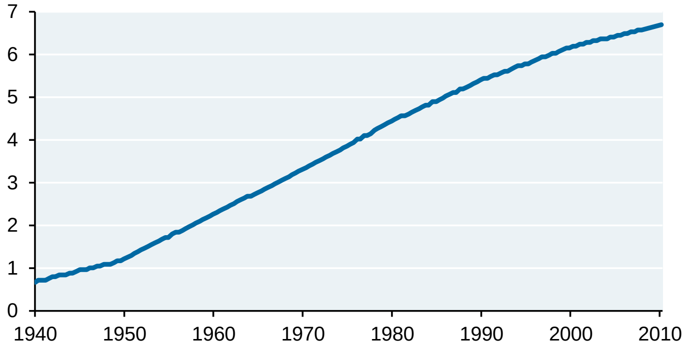
[24] **Fuel aridity** is a composite based on 8 measures of potential forest fire risk and intensity: the energy release component, the Fire Weather Index, the vapor pressure deficit, the climatic water deficit, the Palmer drought severity index, the Forest Fire danger index, the Keetch–Byram drought index and reference potential evapotranspiration.

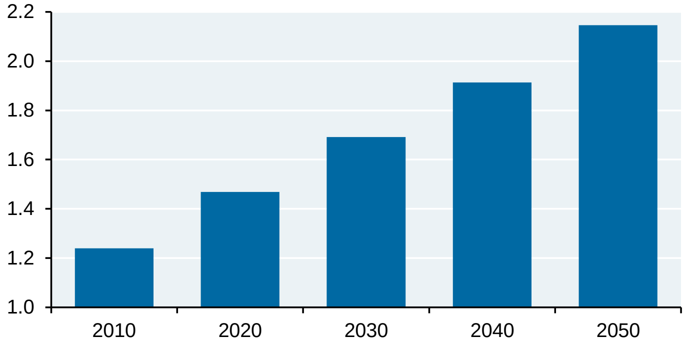
Part of the reason for the increase in wildfires and the resulting economic damages: **increased housing growth in fire-prone areas, and an increase in fire suppression policies**. The number of US homes and land area prone to wildfire impacts has increased by nearly 1350% since 1940. The first chart shows the number of homes in the Western US deemed to have "medium to very high" fire risk. A recent study looked at California specifically and future housing settlement in fire prone areas. The authors estimate that California's residential development will replace nearly 12 million acres of forests and agricultural lands by 2050, increasing the number of houses in "very high" wildfire severity zones by nearly 1 million.

Total homes located in "medium to very high risk" wildfire zones in western US, Millions of homes



Source: Strader (Villanova), *Natural Hazards*. 2018.

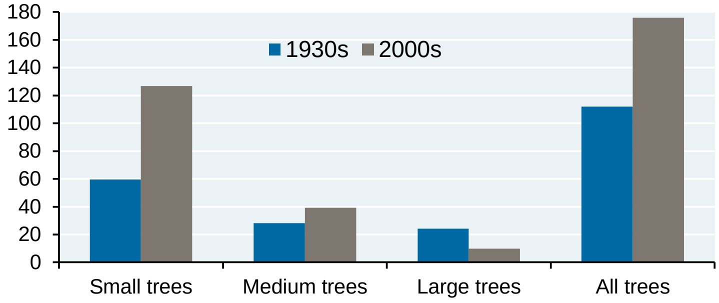
California homes located in "very high risk" wildfire zones
Millions of homes



Source: Mann et al. 2014. Chart depicts "Rural Growth" scenario.

On **fire suppression**: in some fire suppressed ecosystems, certain shade-intolerant and more fire-resistant species such as Ponderosa pine can be outcompeted by shade-tolerant and less fire-resistant species such as Douglas fir. The result: a less fire-resistant forest. And by contributing to buildup of woody debris, these ecosystems are at risk of high-intensity "catastrophic" fires and soil erosion. As shown below, some forests in Northern California have become much denser since the 1930's, reflecting *in part* the impact of fire suppression approaches. To be clear, the 1940-1980 cool/wet period in the West also contributed to denser forests of smaller trees since there were fewer wildfires and more moisture for tree regeneration[25].

California Headwater forests have become denser
Trees per acre



Source: Public Policy Institute of California, UC Berkeley. 2017.
Survey regions include Sierra Nevada highlands and southern Cascade ranges. Trees are categorized as small if they are 4-12 inches diameter at breast height, medium at 13-24 inches and large over 24 inches.

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[25] Ponderosa pine and western larch may suffer 50% of their circumference damaged by fire and survive whereas other tree species such as Douglas fir may die with only 25% of their circumference damaged. Sources for this section include the University of Montana College of Forestry and Conservation, and the Montana State University Forest Ecology and Management department.

[5] Trump’s War on Science: Making America’s government scientifically illiterate again

Law professor Albert Lin at UC Davis wrote a piece in 2018 on Trump’s “War on Science”[26]. I thought it was interesting, and list below some of the salvos in this war that Lin cited. Any one of these items can be explained away; their cumulative impact is what is so striking.

- As of August 2018, Trump had failed to appoint a Presidential science advisor[27], and the President’s Council of Advisers on Science and Technology, an advisory group that has existed since 1933, was unpopulated and unstaffed. An economics professor and former talk radio host with no science background was nominated to a Dep’t of Agriculture position which requires “specialized training or significant experience in agricultural research and education”; and the AccuWeather CEO was nominated as head of the National Oceanic and Atmospheric Administration.
- The EPA relies on advisory boards to inform its activities, including the Board of Scientific Counselors (BOSC) and the Science Advisory Board (SAB). In June 2017, the EPA announced it would not renew BOSC members with expiring appointments, cancelled its upcoming meetings, and departed from precedent by declining to renew SAB members. The EPA issued a directive barring scientists that receive EPA grants from serving on committees. Recent SAB appointees include climate skeptics and recipients of industry funding (one attracted attention by downplaying risks of exposure to mercury). Science advisory committees have fewer members and have met less frequently than at any time since the government began collecting data in 1997, and the SAB has not issued a single new report since 2016
- Trump’s EPA director proposed including scientists in its policy forums that lack expertise in climate science, as well as non-scientists with clearly articulated views against any climate policy
- The Trump administration wants to prohibit the EPA from issuing rules based on studies that contain “confidential information”. As a result, health studies based on confidential patient medical histories could not be used to determine government policy.
- The EPA, the FDA and the Dep’t of the Interior have had fewer meetings under Trump than their charters require; across the Federal gov’t, advisory committees working on climate issues have been dissolved or allowed to expire. The EPA blocked one of its scientists from giving a keynote address on climate issues affecting Rhode Island’s Narragansett Bay
- Online access to climate change data at the EPA, the Dep’t of the Interior and other agencies had been curbed, and references to climate change disappeared from agency websites. Researchers have been asked to remove the words “climate change” and “global warming” from Federal grant proposals. The Trump Administration reduced official estimates of the cost of carbon from $42 per ton to $1-$6
- The Interior Dep’t top climate change official was reassigned to an office that collects oil and gas royalty payments. Other senior Interior Dep’t staffers with scientific expertise were similarly reassigned due to their work on climate issues. Hundreds of EPA officials left the agency under Trump’s first year
- In one rulemaking, the Trump EPA cited a source as scientific support that was not a scientific study at all, and in another, the administration criticized a prior rule for “placing too much emphasis on information and conclusions from a scientific report”
- I ran out of room to talk about looser rules on toxic air pollution, methane flaring, vehicle fuel economy, flood standards, coal plant emissions, continental shelf drilling and a collapse in EPA enforcement

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[26] “*President Trump’s War on Regulatory Science*”, Albert C Lin, University of San Diego – Davis Law School, Harvard Environmental Law Review, forthcoming, written August 2018.

[27] In February 2019, a Presidential Science Advisor was finally appointed, approved and sworn in. The White House Office of Science and Technology Policy remains at 1/3 of Obama era staffing.

Sources

Executive Summary

BP Statistical Review of World Energy, BP, June 2018

International Energy Outlook 2016, Energy Information Administration, May 2016

International Energy Outlook 2017, Energy Information Administration, September 2017

Lazard's Levelized Cost of Energy Analysis – Version 12.0, Lazard, November 2018

"*The environmental case for natural gas*", Gould/McGlade, International Energy Agency. October 2017

REN21 Global Status Report, *Renewables 2018*

Utility-Scale Solar: 2018 Edition, Bollinger & Seel, Lawrence Berkeley National Laboratory. September 2018

World Energy Outlook 2018, International Energy Agency, 2018

World Urbanization Prospects: The 2018 Revision, United Nations, 2018

2017 Wind Technologies Market Report, Wiser & Bollinger, Lawrence Berkeley National Laboratory, 2018

[#1] De-carbonization of Industry

"*Electrification and Decarbonization of the Chemical Industry*", Schiffer & Manthiram, Joule, Sep 2017

"*50 year trends in nitrogen use efficiency of world cropping systems*", Lassaletta et al (Université Pierre et Marie Curie), Environmental Research Letters, 2014

"*How many people does synthetic fertilizer feed?*", Oxford Martin Programme on Global Development, Global Change Data Lab, November 2017

"*Hydrogen: A brief overview on its sources, production and environmental impact*", International Journal of Hydrogen Energy, S. Baykara, March 2018

"*Hydrogen at Scale*", Journal of the Electrochemical Society, Pivovar et al, Spring 2018

Hydrogen from Renewable Power, IRENA, 2018

"*Progress in the Electrochemical Synthesis of Ammonia*", Kyriakou et al, Catalysis Today, May 2017

[#2] Mountains vs Molehills

Reforestation and afforestation:

"Estimates of Carbon Mitigation Potential from Agricultural and Forestry Activities", Johnson et al, Congressional Research Service, January 2010

"Inventory of US Greenhouse Gas emissions and sinks, 1990-2017", EPA, 2018.

"Negative Emissions Technologies and Reliable Sequestration", National Academy of Sciences, October 2018

"Potential for Additional Carbon Sequestration through Regeneration of Nonstocked Forest Land in the United States", Alaric Sample, Journal of Forestry, July 2017

"U.S. Tree Planting for Carbon Sequestration", Gorte, Congressional Research Service, May 2009

Clean coal:

"*CO_2 Emissions Reached an All-Time High in 2018*", Harvey, Scientific American, December 2018

"*420,000 year assessment of fault leakage rates show geological carbon storage is secure*", Miocic et al, Scientific Reports, January 2019

"*Estimating geological CO_2 storage security*", Alcalde et al, Nature Communications, June 2018

"*How America's clean coal dream unravelled*", The Guardian, March 2, 2018

"*Hype among low-carbon technologies: carbon capture and storage in comparison*", Arranz (Monash University), Global Environmental Change, November 2016

"*New large-scale CCS facilities added to Global CCS database*", Global CCS Institute, November 2018

"*Piles of Dirty Secrets Behind a Model 'Clean Coal' Project*", Urbina, New York Times, July 2016

"$7.5 billion Kemper power plant suspends coal gasification", ArsTechnica, June 28, 2017

Cellulosic ethanol:

"*Cellulosic Ethanol Falling Far Short of Hype*", Rapier, Forbes, February 2018

"*Techno-economic analysis and life-cycle assessment of cellulosic isobutanol and comparison with cellulosic ethanol and n-butanol*", Tao et al, Biofuels Bioproducts and Biorefining, January 2014

"*The Unlikely, Eccentric Inventory Turning Inedible Plant Life into Fuel*", 60 Minutes (CBS), January 2019

Supercapacitors and lithium ion batteries:

"*A Brief Review of Current Lithium Ion Battery Technology*", A Ulvestad, Argonne National Labs, March 2018

"*Graphene supercapacitor with both high power and energy density*", Yang (Ohio State) et al, Nanotechnology Magazine, October 2017

Market and Regulatory Advances in Electricity Storage, Pfeifenberger et al, The Brattle Group, May 2018

The Economic Potential for Energy Storage in Nevada, Pfeifenberger et al, Brattle Group, October 2018

"*Toxicology of Graphene-Based Nanomaterials*", Lalwani et al, Advanced Drug Delivery Reviews, October 2016

US Battery Storage Market Trends, Energy Information Administration, May 2018

Aluminium smelting:

"*Apple paves the way for breakthrough carbon-free aluminium smelting method*", Apple.com, May 2018

Life Cycle Inventory Data and Environmental Metrics for the Primary Aluminium Industry, International Aluminium Institute, June 2017

[#3] Germany and Energiewende

CEER Benchmarking Report 6.1 on Electricity and Gas Supply, Council of European Energy Regulators, July 2018

"*Energiewende hinges on unblocking the power grid*", Appunn, Clean Energy Wire, April 2018

Energiewende 2030: The Big Picture, Agora Energiewende, April 2018

"*German carbon emissions rise in 2016 despite coal use drop*", Wettengel, Clean Energy Wire, December 2016

"*Germany's electricity grid stable amid energy transition*", Amelang & Schlandt, Clean Energy Wire, November 2018

"*Germany's greenhouse gas emissions and climate targets*", Appunn, Clean Energy Wire, July 2018

"*Redispatch in Deutschland*", BDEW Bundesverband der Energie- und Wasserwirtschaft, February 2018

Bundesnetzagentur Network Monitoring Reports, Year end 2017, Year end 2018, Q1 2018

[#4] Wildfires

"*Human-started wildfires expand the fire niche across the United States*", Balch et al (University of Colorado/Boulder Earth Lab), PNAS, January 2017

"*Impact of anthropogenic climate change on wildfire across western US forests*", Abatzoglou (University of Idaho) and Williams (Lamont Doherty Earth Observatory), PNAS, October 2016

"*Improving the Health of California's Headwater Forests*", Bustic et al, Public Policy Institute of California, Sep 2017

"*Modeling residential development in California from 2000 to 2050: Integrating wildfire risk, wildland and agricultural encroachment*", Mann et al (George Washington University), Land Use Policy, June 2014

"*Spatiotemporal changes in conterminous US wildfire exposure from 1940 to 2010*", Strader (Villanova University), Natural Hazards, February 2018

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