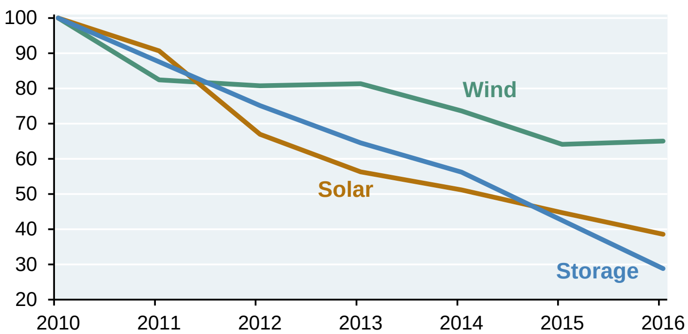
Many Rivers to Cross: Decarbonization breakthroughs and challenges

Executive Summary

The last three years have seen impressive declines in the capital cost of solar power, energy storage and to a lesser extent, wind. The impact of these changes can be seen in several ways:

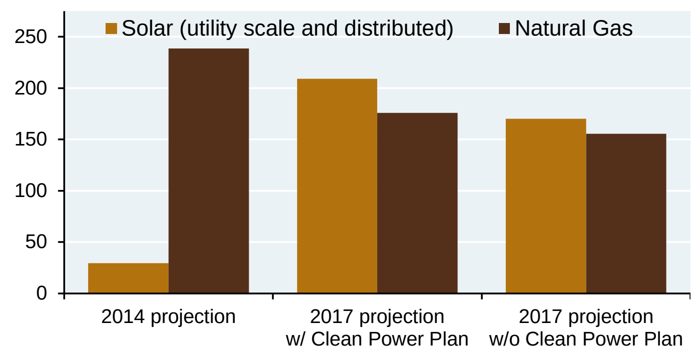
- wind and solar reaching 5% of global electricity generation in 2016 (up from 0.5% in 2004), alongside 17% from hydropower
- a large increase in projected US solar capacity by the Energy Information Administration compared to its 2014 projections
- solar power auction prices around the world converging below $100 per MWh (10 cents per kWh), most of which benefits from some level of government subsidy[1]
- continued growth in US renewable energy capacity additions, which in 2013-2015 exceeded non-renewable capacity additions
- projections from the International Energy Agency indicating that on a global basis, renewable energy will surpass coal as the largest generation source for electricity by 2035, and within the OECD, by 2020. In these IEA forecasts, renewables meet 30%-40% of electricity demand by 2040

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



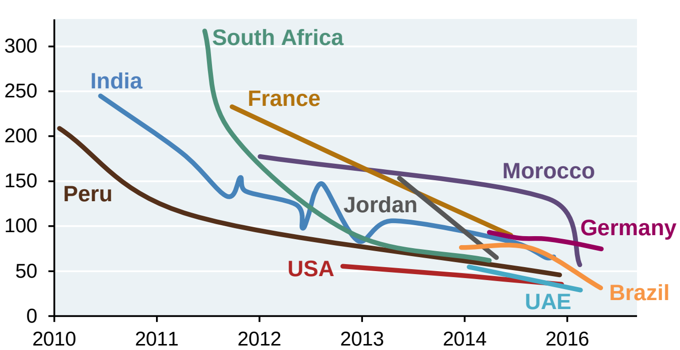
Source: EIA, NREL, Lazard, UBS, Nykvist, et. al. December 2016.
Storage proxied by electric vehicle battery packs.

Since 2014, a big jump in EIA solar capacity projections
Gigawatts of US capacity projected for the period 2016-2040



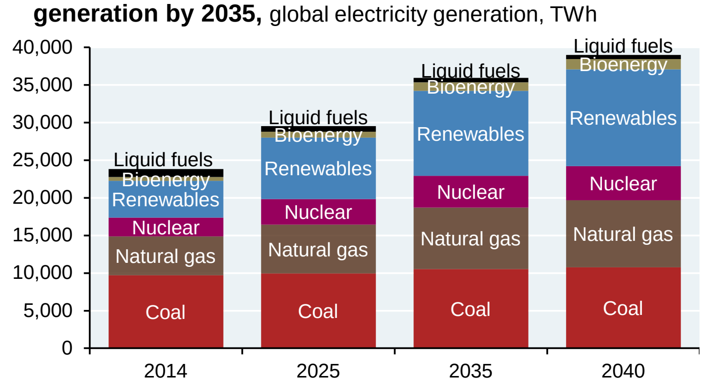
Source: Energy Information Administration. 2017.

Global solar auction prices converging below $100/MWh
US$/MWh



Source: International Renewable Energy Agency. 2017.

IEA: globally, renewables to overtake coal-fired electr. generation by 2035, global electricity generation, TWh

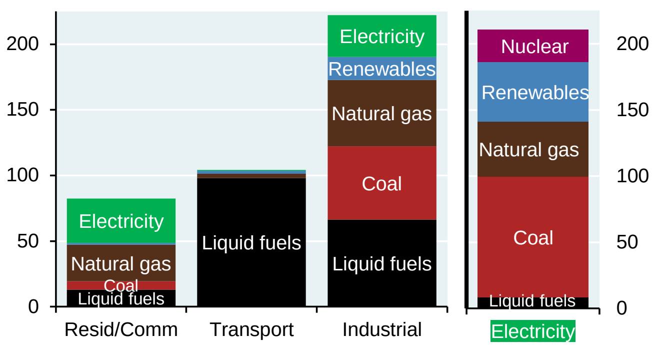


Source: International Energy Agency New Policies Scenario. 2016.

[1] According to the IEA, 100% of global solar power relies on subsidies; by 2040, that is expected to fall to ~50%.

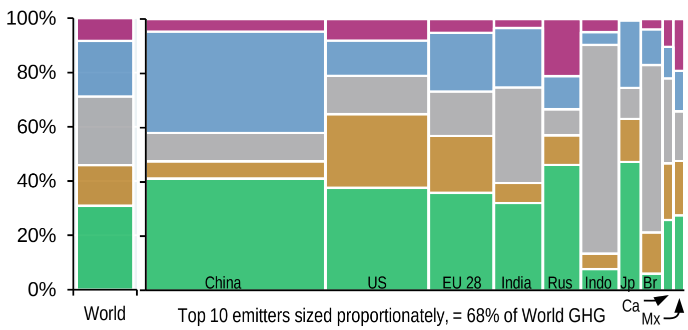
There are plenty of rivers still to cross in achieving greater decarbonization of electricity, including better assessments of backup thermal power needs and high voltage transmission line costs; we will discuss those later. **From a greenhouse gas perspective, however, the larger challenge is that electricity accounts for only 30% of fossil fuel use (first chart[2]), and a similar amount of greenhouse gas emissions (second chart)**. In other words, renewables have made inroads in electricity generation, but are not widely used as direct energy sources in transportation, by industry, and in homes/buildings.

Renewables: so far, primarily impacting electricity
Global energy use by end-user and source, quadrillion BTU



Source: Energy Information Administration, JPMAM. 2016.

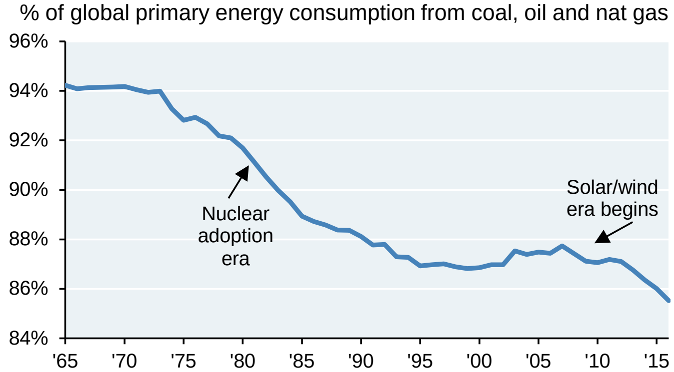
Greenhouse gas emissions by sector & country, % of total



Source: CAIT Climate Data, World Resources Institute, JPMAM. 2013.
Global GHG emissions: 76% carbon dioxide,16% methane, nitrous oxide 6%.

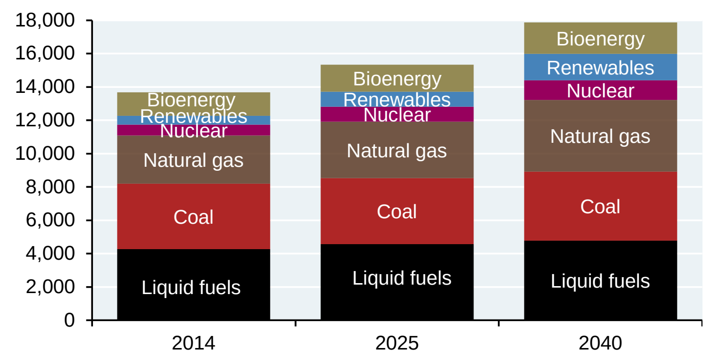
The gradual pace of renewable energy adoption can also be seen in the next chart, which shows how the world **still uses fossil fuels for 85% of its primary energy**. Even if renewable energy were to meet 1/3 of global electricity demand in 2040, it still might only represent 20% of global energy consumption, and that *includes* bioenergy[3] alongside wind, solar and hydro.

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. 2016.

IEA: Renewables at 20% of primary energy by 2040
Global primary energy use by source, mm tonnes of oil equivalents



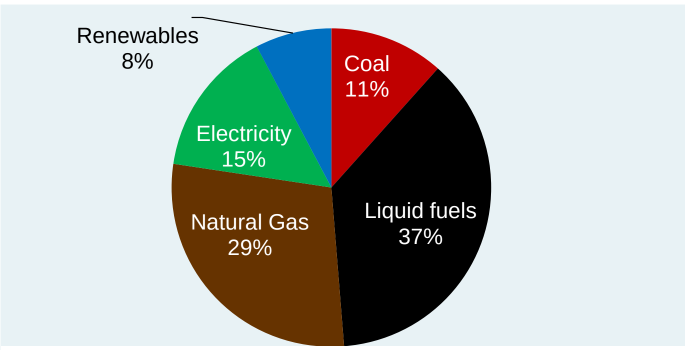
Source: International Energy Agency New Policies Scenario. 2016.

[2] ***Understanding the chart.*** The chart above shows energy use in homes/buildings, in transportation and by industry. The fuel composition of electricity generation is also shown. Total fossil fuel use is equal to fossil fuels used for electricity (31% of the total), plus fossil fuels used directly by end-users (69%). Note that over 200 quads of primary energy are used to create 66 quads of electricity; the difference is **lost** in conversion and transmission. The chart is global; the OECD version looks almost identical.

[3] **Bioenergy** provides 10% of the world's energy. **Around 85%** of bioenergy is consumed in developing countries for cooking and heating, using very inefficient open fires or simple cookstoves with considerable impact on health (smoke pollution) and environment (deforestation). The remainder represents modern bioenergy used for heat, and smaller amounts for transportation and electricity. As a result, current bioenergy practices are quite different from hydro, wind and solar. **Including bioenergy as "renewable" is not the most straightforward thing to do**.

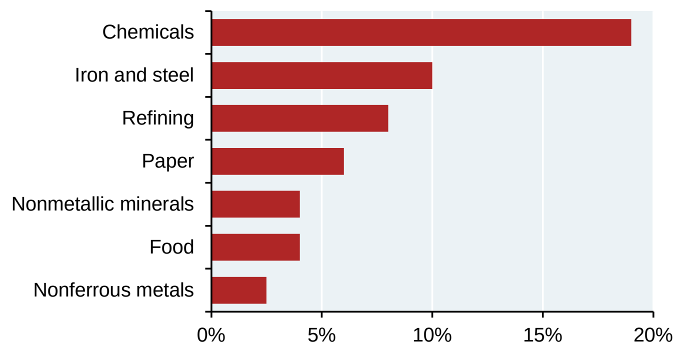
A good example of the decarbonization challenge: **the industrial sector**. Only 15% of OECD industrial energy use is derived from electricity, and its direct renewable use is small; decarbonization of the grid will only go so far in reducing industrial emissions. What does the industrial sector do with the energy? The chart on the right shows some of the larger uses. The manufacture of chemicals, iron, steel, paper, food, etc and oil refining form the backbone of modern society, and is harder to decarbonize.

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



Source: Energy Information Administration. 2016.

OECD industrial sector energy consumption by product
% of total



Source: Energy Information Administration. 2016.

The industrial sector requires carbon-based inputs as raw materials, and also as sources of very high and consistent heat for processing of construction materials and smelting:

Industrial use of fossil fuels as raw materials

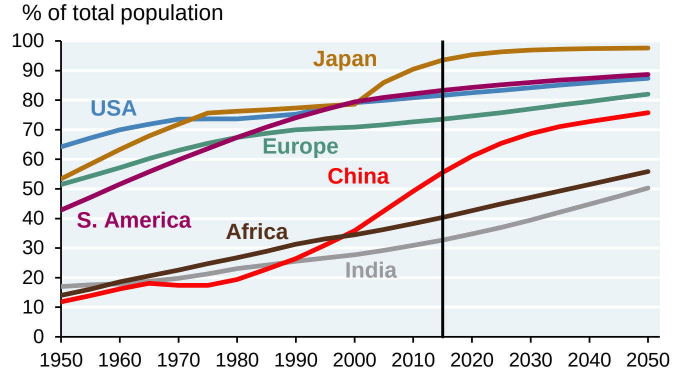
Metallurgical coke	→	Pig (cast) iron smelting (carbon source), which eventually becomes steel
Methane	→	Synthesis of ammonia (hydrogen source), mostly used for fertilizing crops
Methane, naphtha and ethane	→	Synthesis of plastics (sources of monomers)
Heavy petroleum products	→	Production of carbon black (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 and beverage industries
Smelting of iron ores in blast furnaces

Something else to keep in mind: energy solutions need to be designed for a world that is **increasingly urbanizing**. "Off the grid" solutions and distributed solar power may provide economic options in some locations, but are less likely to move the needle when considering modern urban energy requirements and low renewable energy densities.

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



Source: World Bank World Development Indicators. 2015, forecast to 2050.

Why all the focus on decarbonization?

I asked Vaclav Smil a few years ago to articulate for our clients why decarbonization is an important initiative. His response is useful context for both those who are convinced by consensus views on climate science, and also for those who are 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."

What about Trump's decision to pull out of the Paris Climate Accord?

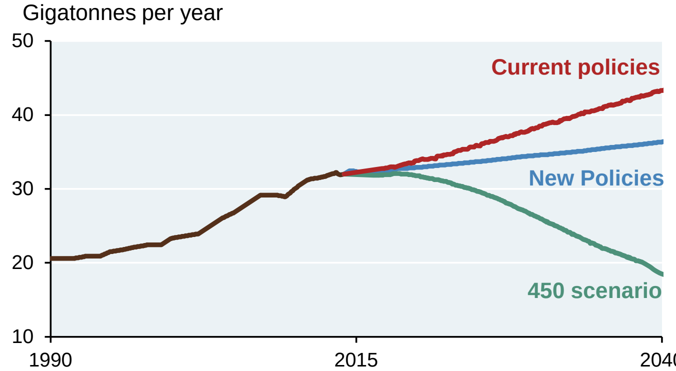
Trump's decision to pull the US out of the non-binding, voluntary Paris Climate Accord was received poorly by many climate scientists, but it may not be that impactful. The EPA cannot scrap Obama's Clean Power Plan, since the US Supreme Court has ruled that CO_2 is a pollutant to be regulated. Second, ongoing technological change and economics are the more likely drivers of emissions reductions than the Paris Accord terms. The US had agreed to targets that were likely to be met anyway. Of the 6 largest CO_2 emitters, the US experienced the largest decline in emissions per capita from 2000 to 2015, in large part due to switching from coal to natural gas. The bottom line: the Paris Accord decision may not have that much of an impact on the trajectory of US energy intensity, fuel mix or CO_2 emissions, despite the message inherent in the decision.

What's behind the gap between different global carbon scenarios?

In the Executive Summary, energy and electricity projections through the year 2040 are based on the IEA's **New Policies** scenario. This scenario incorporates existing energy policies as well as additional measures likely to be implemented based on climate pledges submitted for the 2015 UN Climate Change Conference. The IEA projects that in this scenario, energy-related CO_2 emissions grow more slowly than in the baseline case, but still rise from 32 gigatonnes of CO_2 in 2015 to 37 gigatonnes in 2040.

The IEA also models a case that reduces CO_2 emissions sharply by 2040, but this case would require a **sea change** in energy policies across the OECD and emerging economies. In this "450" scenario, global electricity generation from solar and wind grows by a factor of 7x; nuclear generation expands by 60%; and 1/3 of coal/natural gas power generation is overlaid with carbon capture and storage technology. In this scenario, before the end of the century, all emissions from fuel combustion are either captured and stored, or offset by technologies that remove carbon from the atmosphere.

Global CO_2 emissions from primary energy demand
Gigatonnes per year



Source: International Energy Agency. 2016.

With that backdrop, we focus this year on issues that touch in some way on decarbonization: milestones, obstacles, misunderstandings, risks and what lies ahead.

Michael Cembalest
JP Morgan Asset Management

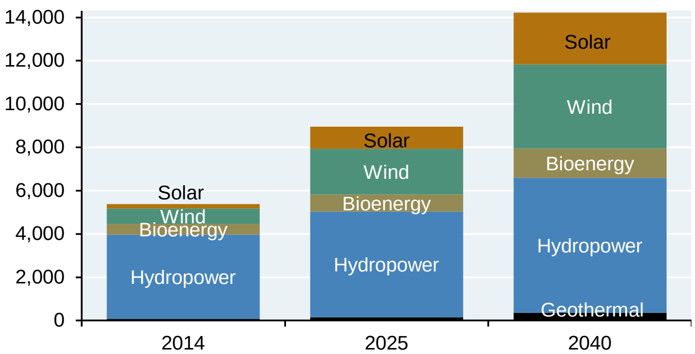
Acknowledgements: our technical advisor Vaclav Smil

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 40 books (the latest ones, *Energy Transitions* and *Energy and Civilization* were published earlier this year) 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.

Executive Summary supplementary materials

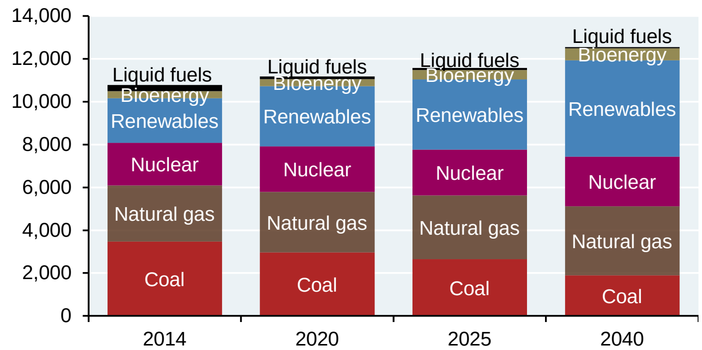
- *Renewable electricity generation*: hydropower makes up the vast majority of renewable generation on a global basis. The IEA projects that hydropower will still represent ~50% in 2040
- *Electricity generation*: the IEA projects that in the OECD, renewables will overtake coal around 2020
- *Transportation*: most passenger transportation energy consumption is related to light vehicles. Electric car penetration has to-date **sharply underperformed prior expectations**; it remains to be seen how quickly the decline in battery pack costs shown on page 7 in section 1 will translate into greater EV/PHEV penetration, which as of 2015, stood at just ~1%, both in the US and globally
- *CO_2 emissions by region*: whether emissions meet projected climate-related targets will depend a lot on mitigation efforts in developing economies, and in particular China, which as of 2015 still used coal for 2/3 of its primary energy

IEA: hydro dominates renewables now, but wind and solar expected to grow, global electricity generation, TWh



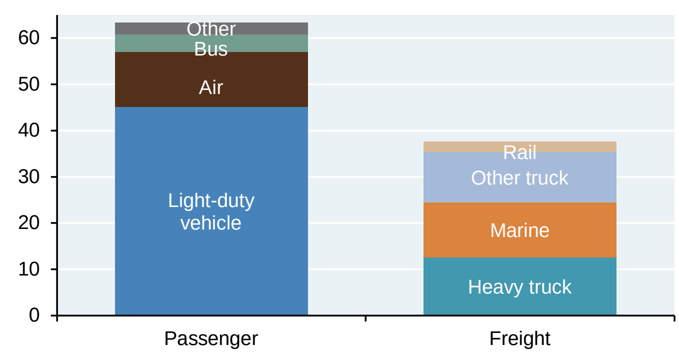
Source: International Energy Agency New Policies Scenario. 2016.

IEA: in the OECD, renewables to overtake coal-fired electricity generation by 2020, Terawatthours



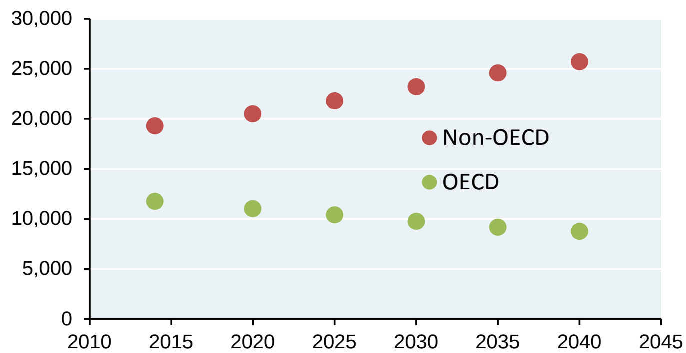
Source: International Energy Agency New Policies Scenario. 2016.

World transportation energy consumption by mode
Quadrillion Btu



Source: Energy Information Administration. 2016.

CO_2 emissions from OECD and non-OECD countries
Million metric tonnes



Source: International Energy Agency New Policies Scenario. 2016.