POLICY *Brief*

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What we need to know about the pace of decarbonization

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Editor's Note: *University of Manitoba professor Vaclav Smil is regarded as an international authority on the history of energy transitions. Science Magazine calls him "the man who has quietly shaped how the world thinks about energy." In the words of Bill Gates "there is no author whose books I look forward to more than Vaclav Smil." In this Policy Brief, adapted from his research article in a recent edition of Substantia, an International Journal of the History of Chemistry, Dr. Smil explores the challenge of decarbonization. He argues the proper recognition of energetic, engineering and economic realities means that decarbonization of global energy supply will be much more difficult and will take much longer than is often assumed by uncritical proponents of "green" solutions. With the Government of Canada committed to a net-zero carbon future by 2050, Dr. Smil provides important insight into the magnitude and complexities of the challenge we face, both domestically and globally.*

Dale Eisler, Editor, JSGS Policy Briefs

Energy transitions have been among the key defining processes of human evolution. The first millennia-long transition was from the reliance on traditional biofuels such as wood, charcoal, crop residues and animate sources of energy derived from human and animal muscles, to increasingly common reliance on inanimate energy converters. They included water wheels, wind mills and better harnessed draft animals for fieldwork and transportation.

Transition to fossil fuels to produce heat, thermal electricity and kinetic energy began in England during the 16th century. It took hold in Europe and North America only after 1800, and in most of Asia only after 1950. This transition has been accompanied by increasing reliance on primary electricity, dominated by hydroelectricity since the 1880s, with nuclear generation contributing since the late 1950s. The transition from traditional biofuels to fossil fuels has resulted in gradual relative decarbonization, but also in enormous growth in absolute emissions of CO_2.

This decarbonization that has resulted due to the move away from traditional biofuels to hydroelectricity and fossil fuels that dominate today is best traced by the increasing hydrogen-to-carbon ratios of major fuels. They rise from no more than 0.5 for wood and 1.0 for coal, to 1.8 for the lightest refined fuels and to 4.0 for methane, the dominant constituent of natural gas. The reverse order applies to CO_2

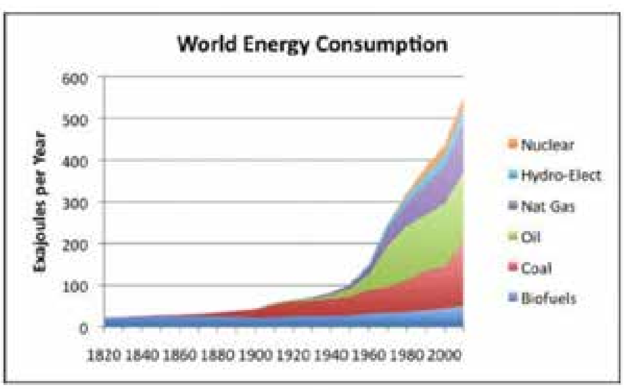
emissions per unit of energy. Combustion of natural gas produces less than 60 kilograms of CO_2 per gigajoule (kg CO_2/GJ) while the rates for liquid hydrocarbons are between 70-75 kg/GJ. For bituminous coal the rate is typically 95 kg/GJ, for low-quality lignite it is 100 kg/GJ, and wood combustion releases up to 110 kg CO_2/GJ.

As the global energy transition progressed, coal consumption overtook the burning of traditional biofuels and it was, in turn, surpassed by the combined mass of hydrocarbons (crude oils and natural gases). The rising share of primary electricity, much of it generated by hydro power, has further reduced the average carbon intensity of the world's primary energy supply. But this relative decline has been accompanied by an almost uninterrupted growth of absolute CO_2 emissions.

Growth of CO_2 in the atmosphere

Combustion of fossil fuels contributed just eight million tonnes (Mt) of carbon in 1800, 534 Mt in 1900, 6.77 billion tonnes (Gt) in 2000 and 9.14 Gt in 2018. These emissions have been the principal reason for the rising atmospheric concentration of CO_2, from 285 parts per million (ppm) in 1850 to 369.6 ppm in the year 2000 and to 408.5 ppm in 2018. In turn, these rising concentrations have been the principal reason for the gradual increase of average tropospheric temperature that has, so far, amounted to about 0.8C. But that level would, in the absence of any remedial actions, surpass 2C or even 3C in a matter of decades and result in rapid anthropogenic global warming.

Figure 1: World Energy Consumption



World Energy Consumption (1820-2000) by Source, Based on Vaclav Smil Book [Smil V. - Energy Transitions: History, Requirements and Prospects. Santa Barbara, CA, 2010] estimates, together with BP Statistical Data for 1965 and subsequent years.

Past energy transitions were driven by a variety of factors. They ranged from the need for higher unit power and better conversion efficiency, to more affordable supply and reduced environmental impacts—for example natural gas is a much cleaner fuel than coal. In contrast to previous energy transitions, today's quest for decarbonization is not primarily driven by resource shortages or technical imperatives. The reality is most existing conversions are highly efficient and also very reliable. The objective to decarbonize the economy has one dominant goal: limiting the extent of global warming. The goal is to establish a new global energy system. It would be devoid of any combustion of carbon-containing fuels or a world with net-zero carbon emissions where a limited amount

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of fossil fuel combustion would be negated by the removal and sequestration of the gas from the atmosphere resulting in no additional carbon releases.

So, how have we done so far?

Concerns about anthropogenic global warming have existed since the late 19th century. But they began to receive wider public attention during the 1980s, and particularly when the first United Nations Framework Convention on Climate Change was signed in 1992. It was followed by the Kyoto Protocol of 1997 and its latest global endeavor was the 2015 Paris Agreement, which included nationally determined contributions designed "to combat climate change and to accelerate and intensify the actions and investments needed for a sustainable low carbon future", as stated by the United nations Climate Change Convention of 2019.

Numerous meetings and assorted pledges aside, what has actually taken place since 1992?

The most important fact is that during those decades of rising concerns about global warming the world has been running towards fossil carbon, not moving away from it. Since 1992 absolute emissions of CO_2 from fossil fuel combustion have declined significantly, by nearly 20 per cent in the European Union, and have grown only marginally—in each case by about 5 per cent—in the US and Japan. But these accomplishments have not set the world on the road to decarbonization as emissions have nearly tripled in Asia, largely because the Chinese combustion of fossil fuels has almost quadrupled. As a result, global emissions of CO_2 increased by more than 60 per cent since 1992, setting yet another record in 2018.

Historians of energy transitions are not surprised by this development. That's because history shows that neither the dominant sources of primary energy, nor the common energy converters can be displaced rapidly and completely in short periods of time. The high degree of the global dependence on fossil carbon and the enormous scale of the fuel-dominated global energy system mean that the unfolding energy transition towards decarbonization will inevitably follow the progress of all previous large-scale primary energy shifts. In other words it will be a gradual, prolonged affair.

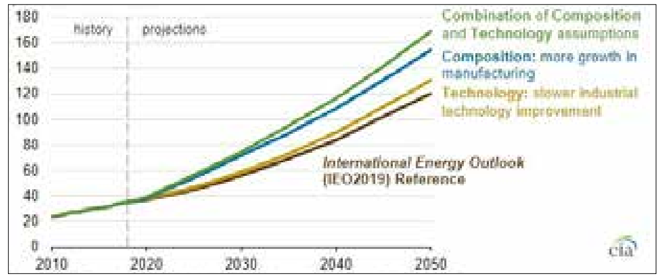
At the turn of the 19th century, traditional biomass fuels supplied all but a tiny share of the world's primary energy. A century later their share was about 50 per cent, and at the beginning of the 21st century still accounted for nearly 10 per cent. This means that even after more than two centuries the world has not completed the shift from traditional biofuels to modern sources of primary energy. Coal's share of global primary energy supply has been in retreat for generations as the reliance on hydrocarbons has grown, but the fuel still supplies nearly 30 per cent of the total requirement. That is still more than natural gas, whose commercial extraction began about 150 years ago. In absolute terms, its output is more than eight times larger than it was in 1900 when the fuel dominated the global energy supply. While most economies began reducing their crude oil reliance after OPEC's large price increases of the 1970s, it remains the dominant primary energy source, supplying almost 40 per cent of the world's total.

An energy transition that is unprecedented

To put this into perspective, the unfolding transition to non-carbon energies has to take place on unprecedented scales. Consider that annual extraction of fossil fuels includes about 7.7 Gt of coal, 4.4 Gt of crude oil and 3.7 trillion cubic metres of natural gas. Unlike all other previous shifts in primary energy use, decarbonisation can achieve its goal only when it succeeds on a global scale. Even instant decarbonisation in a major advanced economy makes little difference if GHG emissions from other sources and countries keep rising. The reality is that after three decades, the unfolding transition is still in its earliest stage and the relative shift has been minor. In 1990, fossil fuels supplied 91.3 per cent of the world's primary energy and by 2017 their share was still 90.4 per cent.

Moreover, if the decarbonization of global electricity generation were to proceed at an unprecedented pace, only the availability of affordable, massive-scale electricity storage would make it possible to envisage a reliable system that could rely solely on intermittent renewable energies of solar radiation and wind. Even securing just three- days-worth of storage for a megacity of more than 10 million people that would be cut off from its intermittent renewable sources—which is a common occurrence during the monsoonal season in Asia with heavily overcast skies and high winds—would be prohibitively expensive by using today's commercial batteries. Setting aside exaggerated media claims, a technological breakthrough meeting that requirement appears unlikely in the near future as pumped hydro storage, which was originally introduced during the 1890s, remains today the only way to store electricity at gigawatt scale. And even major advances toward large-scale electricity storage would not be enough to bring about rapid decarbonization of the global energy supply as electricity generation accounts for no more than 20 per cent of total final energy consumption. As well, decarbonizing transportation, heating, agriculture and industrial production is considerably more difficult than installing new intermittent capacities, connecting them with major load centers and securing the required back-up supply.

Figure 2: India's primary energy consumption in four IEO2019 cases (2010-205) quadrillion British thermal units



Source: U.S. Energy Information Administration, International Energy Outlook 2019

Electrification of passenger cars is in its earliest stage, with 5.4 million electric vehicles on the road by the end of 2018, still less than 0.2 per cent of all vehicles registered worldwide. More than a century after they were first seen as the best road transportation choice, electric cars are finally ascendant. But even under the most optimistic circumstances it will take many decades to accomplish the transition from internal combustion engines. The International Energy Agency sees 160-200 million electric vehicles by 2030, BP expects 320 million by 2040 and my best forecast (based on a polynomial regression) is for 360 million in 2040. But by that time there might be about 2 billion vehicles on the road globally compared to about 1.25 billion today. Hence even 400 million electric cars would be just 20 per cent of the total. Forecasting the future adoption of hydrogen-fueled vehicles is even more uncertain, making it is difficult to see how even the most likely combined progression of electric and hydrogen cars would completely eliminate internal combustion engines before 2040, or even soon after.

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Given the energy density of today's best commercial batteries, the electrification of trucking, shipping and flying is even more challenging. The key to understanding the fundamental difficulty is to compare the energy density of the best Li-ion batteries with the energy density of diesel fuels used in trucking and shipping. Today Li-ion batteries have energy density of up to 260 watt-hour per kilogram (wh/kg) and could reach up to 500 wh/kg in the future. The energy density of diesel and aviation kerosene is 12,600 wh/kg and 12,800 wh/kg. In other words, 50 times the energy density of our best commercial batteries. So shipping and flying present particularly insurmountable challenges as only high energy density fuels can power massive container ships and high-capacity airliners.

While air conditioning is powered by electricity, seasonal heating in cold parts of Eurasia and North America now relies overwhelmingly on natural gas delivered by large-diameter trunk lines and dense networks of smaller-diameter distribution lines serving more than a half billion customers. Obviously, replacing this fuel supply and abandoning this extensive infrastructure will not be achieved over a single generation. And even more intractable challenges come with the decarbonization of industries producing what I call the four pillars of modern civilization: ammonia, cement, steels and plastics.

Another critical factor to consider is the enormous energy, food and material needs of emerging economies. China's population of 1.39 billion will soon be surpassed by India, which has a per capita use about 25 per cent that of China's. According to the National Institute for Transforming India, the country's total primary energy consumption is forecast to increase nearly fivefold by 2047, with coal remaining the dominant fuel.

Conclusion

In conclusion, the verdict—based on the history of past energy transitions, on the unprecedented scales of the unfolding shift, on the limits of alternative pathways, and on the enormous and immediate energy needs of billions of people in low-income countries—is clear. Designing hypothetical roadmaps outlining complete elimination of fossil carbon from the global energy supply by 2050 is nothing but an exercise in wishful thinking that ignores fundamental physical realities. And it is no less unrealistic to propose legislation, as has been done in the US Congress, claiming that such a shift can be accomplished in the US by 2030. Such claims are simply too extreme to be defended as aspirational. The complete decarbonization of the global energy supply will be an extremely challenging undertaking of an unprecedented scale and complexity that will not be accomplished—even in the case of sustained, dedicated and extraordinarily costly commitment—in a matter of a few decades.

Sources

Smil, V. 2019. What we need to know about the pace of decarbonization. *Substantia*. http://vaclavsmil.com/wp-content/uploads/2020/01/Substantia.pdf

Ashida, Y. et al. 2019. Molybdenum-catalysed ammonia production and samarium diiodide and alcohols or water. *Nature* 5686:536-540.

Boden, T. et al. 2017. Global CO2 Emissions from Fossil-Fuel Burning, Cement Manufacture and Gas Flaring: 1751-2014, Oakridge, TN: ORNL

BP (British Petroleum) 2018. BP Statistical Review of World Energy. London: BP

Insideevs. 2019. EV Sales Scorecard. https://insideevs.com/news/344006/monthly-plug-in-report-card-archive/

International Energy Agency 2018. Global EV Outlook 2018. Paris: IEA

International Energy Agency 2019, Global Energy and CO2 Status Report, Paris: IEA

IPCC 2014. AR5 Synthesis Report: Climate Change 2014. Geneva: IPCC

Jacobson, M.Z. et al 2017. 100 per cent Clean and Renewable Wind, Water and Sunlight (WWS) All Sector Energy Roadmaps for 139 Countries of the World. Joule doi:10.1016/j.joule.2017.07.00

NASA 2019a. Global Mean CO2 Mixing Ratios (ppm): Observations. https://data.giss.nasa.gov/modelforce/ghgases/Fig1A.ext.txt

NASA 2019b. World of Change: Global Temperatures. https://earthobservatory.nasa.gov/worldofchange/DecadalTemp

NOAA 2019. Trends in Atmospheric Carbon Dixoide. https//www.esrl.noaa.gov/gmd/ccgg/trends/data.html

Ocasio-Cortez, A. 2019. Resolution Recognizing the duty of the Federal Government to create a Green New Deal. Washington, D.C.: The US House of Representatives

PBL (Netherlands Environmental Assessment Agency). 2018. Trends in Global CO2 and Total Greehnouse Gas Emissions: 2018 Report

Smil, V. 2016. Still the Iron Age: Iron and Steel in the Modern World. Amsterdam:. Elsevier.

Smil, V. 2017a. Energy Transitions: Global and National Perspectives. Santa Barbara, CA: Praeger

Smil, V. 2017b. Energy and Civilization: A History. Cambridge, MA: The MIT Press

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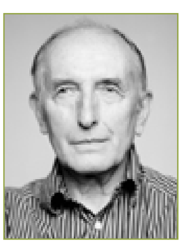

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