



Aspen Global Change Institute Energy Project

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GETTING TO NEAR ZERO: EMISSION PATHS AND ENERGY TECHNOLOGIES

The international goal of holding the change in global average temperature to 2°C or less above preindustrial temperatures was reaffirmed by the recent UN Conference of the Parties (COP 21) agreement in Paris. This global target requires nothing short of a radical transformation of the global energy system. As part of the Paris Agreement, countries proposed post-2020 goals for emissions reduction. A new paper by Rogelj (2016) shows that these Intended Nationally Determined Contributions (INDCs) fall short of the 2°C goal raising global temperatures 2.6 to 3.1°C by 2100. However, the INDCs represent an historic step whereby countries are agreeing to tackle the climate challenge and the pledged commitments can be ramped up to include greater rates of emission reduction post 2020.

Two strategies of how to achieve near zero emissions to stay at or below 2°C include: 1) large-scale implementation of bioenergy with carbon capture and storage (BECCS) and 2) massive deployment of renewable technologies, such as wind, solar, and hydropower. In order to meet the target, both approaches assume varying degrees of other emission reduction approaches such as demand management, smarter grids, land management, and increased energy efficiency.

The Near Zero Challenge

The IPCC uses integrated assessment models (IAMs), which include consideration of population, economic growth, types of energy sources (carbon intensity), how efficiently energy is utilized in the economy (energy intensity), and other factors such as land use. These scenarios result in IAM modeled output of future emissions. The emission scenarios, called representative concentration pathways (RCPs), are inputs to climate and earth system models to produce projections of future climate. Generally, higher emissions pathways equate to higher temperature projections. The required path to achieve the COP 21 goal is near zero net emissions of CO₂ by 2100.

Getting near zero emissions is a very large departure from the present fossil fuel-dominated

global energy system, which currently produces over 35 billion tons of CO₂ emissions annually. Once peak emissions are achieved, steep reductions must follow if the 2°C goal is to be met. Of the over 1,000 modeled emission pathways produced for the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5 2013, 2014), only about 100 pathways produced future atmospheric concentrations of CO₂ low enough (between 430 – 480 ppm) to achieve the goal by the end of the century.

BECCS

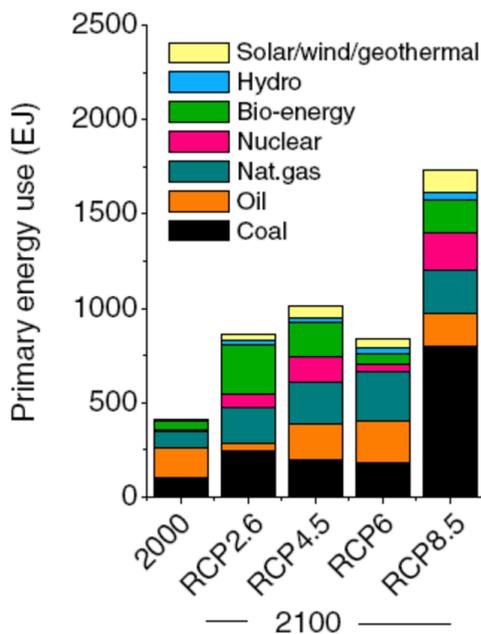
Most of the IPCC model runs in the 5th Assessment that keep the global average temperature at or below the 2 °C goal utilize BECCS. In general, the longer steep emission reductions are delayed, the greater the amount of negative emissions required to reach the 2°C goal. In the RCP 2.6 scenario, net emissions go negative after about 2070.

BECCS can produce negative emissions because, in addition to using biomass grown for bioenergy production, it also includes additional technologies for capturing CO₂ as a flue gas, compressing it, and burying it underground. Since the biomass acquires CO₂ from the atmosphere while it is growing, but isn't returned to the atmosphere when it is burned, this results in a negative emission. When negative emissions exceed continued CO₂ emissions from fossil combustion, the result is net negative emissions.

Although BECCS offer a means of removing carbon from the atmosphere, large-scale BECCS as envisioned requires appropriation of significant land area. Anticipated impacts of such land use include the possibility of lower food security, biodiversity loss, and biomass crop sustainability issues such as nutrient depletion. Another concern, which is applicable for any carbon capture

and sequestration (CCS) project, whether applied to bioenergy or fossil energy, is the security of the sequestered CO₂ over time to remain underground (Fuss, 2014; IPCC AR5 2013, 2014).

Energy sources at years 2000 and 2100



The following figure shows that in both of the two lowest IPCC RCPs (RCP 2.6 and 4.5) there is a significant amount of fossil fuel and bioenergy still utilized by 2100. Because of the continued fossil fuel use in RCP 2.6, it relies heavily on bioenergy, and meets its target of radiative forcing of the climate of 2.6 watts per m² by employing BECCS to achieve net negative emissions (Van Vuuren 2011).

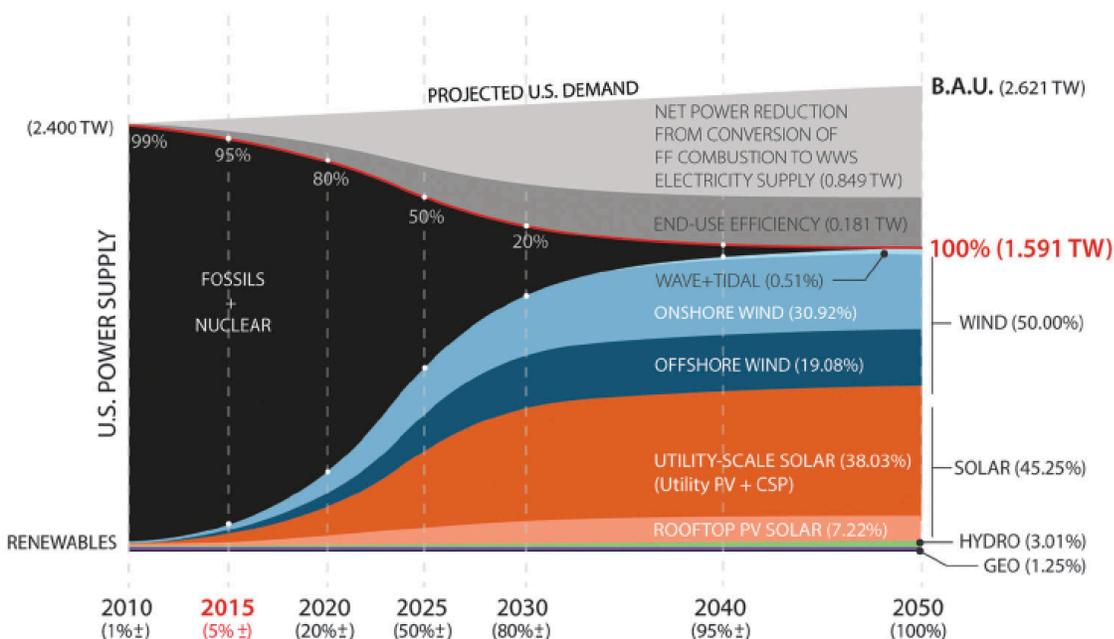
The IPCC emission scenarios and subsequent climate model output didn't include scenarios that envisioned rapid deployment of existing renewable technologies, such as those envisioned by Jacobson et al.

Massive Renewables

Alternative approaches to near zero emissions rely on a diverse approach to the reduction of carbon intensity in the global energy system. Approaches include both major improvements in efficiency as well as a diverse mix of energy sources, such as nuclear, the full suite of renewables, and carbon capture of fossil sources. Demand management, smart grids, greater electrification, and various combinations of centralized and decentralized distribution strategies are being proposed along with different approaches to energy storage and the production of energy carriers in the form of renewable fuels or hydrogen.

Mark Jacobson and his team at Stanford University (with participation from other institutions) developed an approach that is based upon massive deployment of renewables. Named WWS (for wind, water, and sunlight), the Jacobson plan relies on renewable energy sources combined with a greater percentage of electrification in the energy system. Jacobson et al. have produced scenarios for the world (Jacobson 2011, 2016 in preparation) and for the U.S. (Jacobson 2015) that achieve 100 percent conversion of primary energy to renewable sources.

For the U.S., Jacobson et al. envision the WWS roadmap would be technically possible by 2050. Part of this strategy relies on electrolysis to produce hydrogen for end-use requirements that cannot be met directly with electricity, such as some industrial and transportation applications. The following figure (Figure 5, Jacobson 2015) shows the transition from the present fossil fuel and nuclear dominated system to the WWS scheme.

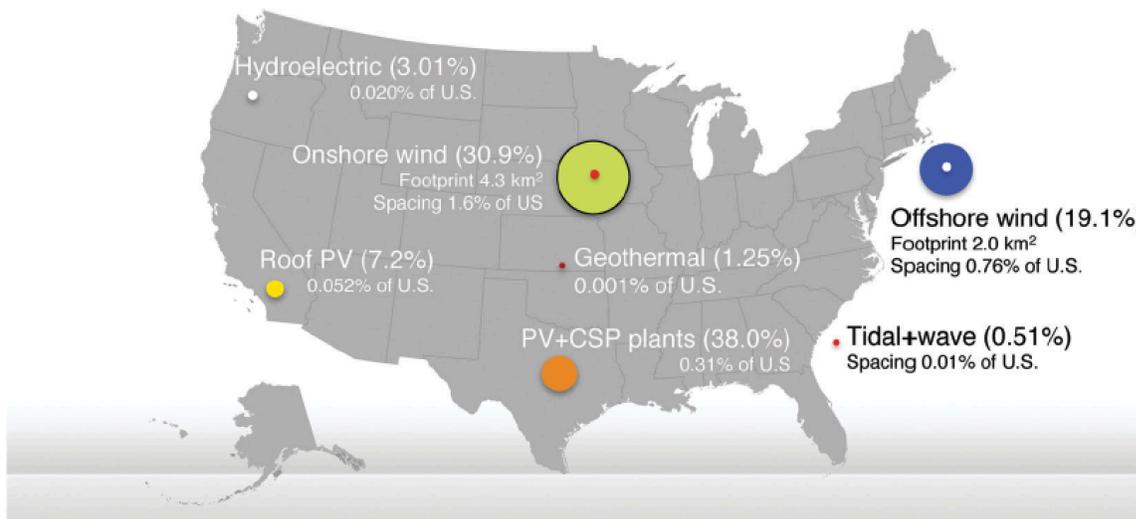


In the figure it is important to note that a significant reduction from the projected power in 2050 of 2.621 TW based upon Business as Usual (BAU) is achieved by supplying electricity directly from renewable electric rather than the thermal conversion of fossil fuel or nuclear-based

thermal to electric. This represents a power savings of 0.849 TW, or about 32%. In addition, there is a savings of 0.181 TW, or an additional 7%, in end-use efficiency improvements. The result of these combined savings reduces U.S power from the projected 2.621 TW to 1.591 TW. The combination of sources from the figure supplying this 1.591 TW are dominated by onshore and offshore wind (50%) and utility-scale PV (45.25%), with additional rooftop PV (7.22%) and a small contribution of 3% hydro and 1.25% geothermal.

In this study, the cost of achieving WWS for the U.S. is less than the savings. Jacobson et al. calculate that jobs lost in conventional energy sector will be more than made up for by jobs generated in renewables. Co-benefits include cleaner air and avoided health costs and mortalities associated with air pollution. Additionally, the WWS plan estimates benefits of avoiding global warming impacts by 2050 attributable to the U.S. remaining on a conventional energy system path.

The areal extent of the massive renewable deployment for the U.S. is shown in the following figure (Figure 1, Jacobson 2015).



The circles represent the total area for the spacing of the devices in the WWS roadmap. Dots in the center of the circles represent the area of the device footprint without consideration of spacing. Circle and dot locations do not represent actual location placement, only areal extent (see Jacobson 2015 for more detail).

The WWS roadmap has an ambitious timeline with 80 to 85% conversion to renewables by 2030, and 100% by 2050. Obstacles include the inertia in the existing system, vested interest in the current energy system, obtaining zoning and rights-of-way needed, updates to regulatory structures, and lack of public understanding—not only in what technology can achieve, but also in more complete understanding of the global warming impacts that will be avoided.

A recent study by MacDonald et al. (2016) explored large-scale deployment of wind and solar from both the standpoint of the wind and solar physical resource, their distance to demand

centers, and costs. Their work corroborated at least part of the WWS scheme finding that the U.S. electricity sector "...can be reduced 80% relative to 1990 levels, without an increase in the levelized cost of electricity." This finding also noted that this was possible with existing technologies and without requiring storage.

This WWS approach applied to the global energy system and the approach represented by the IPCC RCP 2.6 scenario with BECCS provide possible futures that achieve the 2° C goal. The rate of the transition from a dirty to clean global energy system takes time and commitment. The longer emissions continue to climb, the steeper the rate of emission reductions need to be to achieve the goal of stabilizing the Earth's climate close to the 2° C target.

Rogelj, J., et al. (2016). "Paris Agreement climate proposals need a boost to keep warming well below 2 °C." *Nature* **534**(7609): 631-639.

Fuss, S., et al. 2014. Betting on negative emissions. *Nature Clim. Change* 4 (10): 850-853.

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Jacobson, M. Z., et al. 2015. "100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 United States." *Energy & Environmental Science* 8 (7): 2093-2117.

MacDonald, A. E., et al. 2016. "Future cost-competitive electricity systems and their impact on US CO2 emissions." *Nature Clim. Change* 6(5): 526-531.