Repowering 100% of all Energy in the United States and the World for 100% of the People at Low Cost With Clean and Renewable Wind, Water, and Sunlight (WWS)

By Mark Z. Jacobson
Stanford University
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What Are The Problems?

Three of the greatest problems facing humanity today are air pollution mortality, global warming, and energy insecurity.

Air pollution kills 4-7 million people prematurely each year worldwide and 65,000 per year in the United States, costing the world and U.S. about $23 trillion per year and $600 billion per year, respectively.

Global warming and its increases in sea-level, coastal flooding, air pollution; heat stress, heat stroke, and disease; agricultural losses; severe storminess and drought; and ocean coral and fish losses costs the world trillions of dollars per year today and will cost $29 trillion per year by 2050.

Third, because fossil fuels are limited resources that are often mined far away and require continuous drilling, extracting them leads to international conflict and land/water despoilment, and their finite supply is increasingly causing national and international economic, social, and political instability.

How Do We Solve The Problems?

At Stanford University and the University of California at Berkeley, we researchers, along with dozens of students and other researchers from around the world in the areas of engineering, transportation, renewable energy, atmospheric sciences, and economics, and in collaboration with The Solutions Project, have developed roadmaps

http://web.stanford.edu/group/efmh/jacobson/Articles/I/WWS-50-USState-plans.html

http://thesolutionsproject.org

to transition all energy in the 50 United States and 139 countries (representing more than 99% of all emissions) to 100% clean, renewable energy for all purposes.

The idea behind the roadmaps is simply to electrify everything and provide the electricity with clean, renewable energy, namely wind, water, and sunlight (WWS). By everything, we mean transportation, heating/cooling, and industry. In the end, we will use no natural gas,

coal with carbon capture, biofuels, or nuclear power. We will use no combustion and will virtually eliminate emissions of pollutant gases and particles.

Will We Need Storage And Long-Distance Transmission?

We will need some low-cost storage to store electricity, heat, and cold for when the wind is not blowing and the sun is not shining. Fortunately, low-cost storage technologies already exist. For electricity, we have concentrated solar power with storage, pumped hydroelectric storage, and existing hydroelectric dams, which are like big batteries. Batteries themselves will also be used to store electricity, particularly in cars, although we may not need so many batteries to store electricity because other low-cost electricity storage exists plus electrifying all energy sectors makes it easier to match power demand with supply.

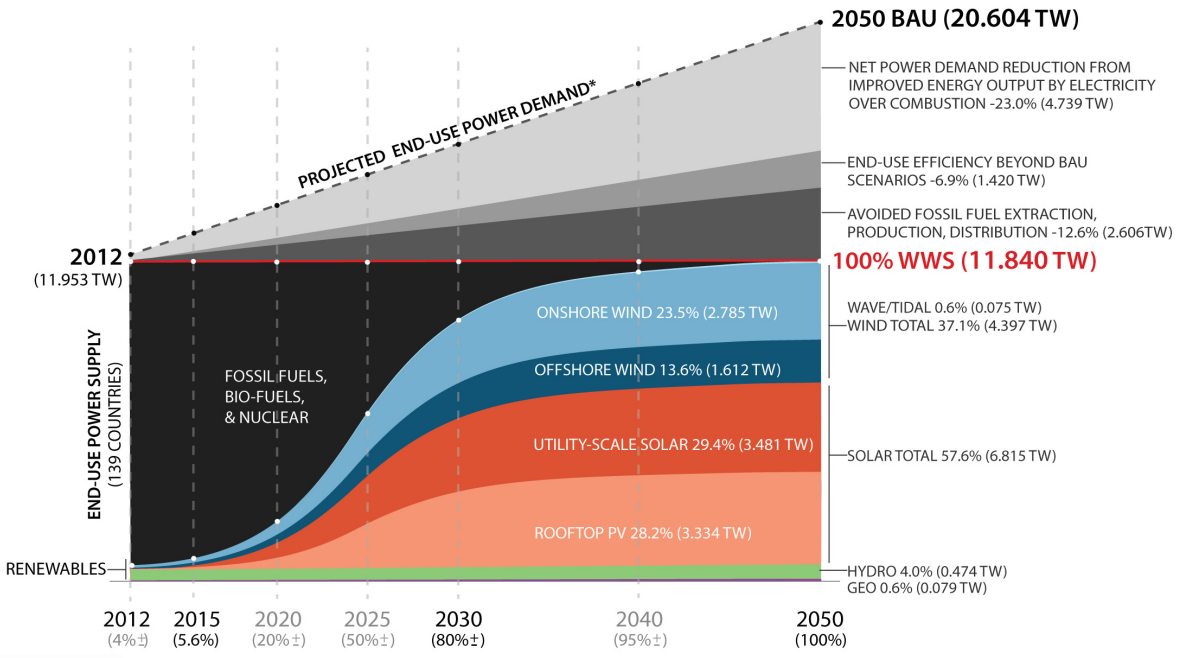
Further, we will store heat in water and underground rocks. We will store cold in water and ice. We will also use excess wind and solar to produce hydrogen, which is a form of storage. Hydrogen will then be used for long-distance trucks, ships, and planes.

Another way to ensure that electricity is available when people need it is to connect wind and solar long distance on the transmission grid. This allows wind or solar electricity to be brought to a city from far away when wind and solar resources are currently low.

Timeline For Conversion

The roadmaps envision 80% transition to WWS by 2030 and 100% by 2050.

Change in 139-country end-use power demand upon conversion from conventional fuels to WWS between 2012 and 2050.



Karl Burkart

What Are The WWS Technologies We Would Use?

The technologies proposed for use in each energy sector include the following:

Electricity. We will use onshore and offshore wind turbines, solar photovoltaics (PV) on rooftops and in large arrays on the ground, concentrated solar power (CSP), geothermal, power, existing hydroelectric power (no new dams), tidal power, and wave power.

Transportation. All transportation will be with battery electric (BE) vehicles and BE-hydrogen fuel cell (HFC) hybrid vehicles, where the hydrogen is produced by passing electricity through water. BEs will dominate all light-duty ground transportation, construction machines, agricultural equipment, short-distance trains, short-distance boats and ships (e.g., ferries, speedboats), and aircraft traveling less than 1000 km. BE-HFC hybrids will dominate long-distance trucks, trains, ships, and aircraft.

Heating and cooling. Air heating and cooling in buildings will be powered by ground-, air-, and water-source electric heat pumps. Water heating in buildings will be generated by heat pumps with an electric resistance element for low temperatures and/or solar hot water preheating. Cook stoves will be electric induction.

Industry. High-temperature industrial processes will be powered by arc furnaces, induction furnaces, and dielectric heaters, all of which will run on WWS electricity.

What Can You Do?

Individuals can

a) Electrify everything by eliminating gas in your home and gasoline/ diesel in your car.
b) Use electric heat pumps for air and water heating instead of gas heaters.
c) Use an electric induction cooktop stove instead of a gas stove.
d) Use an electric dryer instead of a gas dryer.
e) Put solar on your roof.
f) Use batteries to store some of your solar electricity.
g) Replace your gasoline or diesel car with an electric car.
h) Weatherize your home by sealing leaks and adding insulation.
i) Use LED light bulbs wherever possible.
j) Telecommute and speak remotely instead of flying on an airplane.
k) Encourage elected officials to support clean, renewable energy and efficiency.
l) Vote for policy makers who support these goals.

What Are The Benefits Of Transitioning?

If these technologies are used to replace 100% of the energy infrastructure of the 50 United States and 139 countries examined by 2050, the transition will result in the following benefits:

1) WWS will reduce world power demand by ~42.5% because (a) WWS electricity is more efficient than combustion, (b) WWS eliminates the energy needed to mine, transport, and/or process fossil fuels, uranium, and biofuels, and (c) WWS end-use efficiency exceeds business-as-usual end-use efficiency.

2) Converting will create ~1.9 million more permanent, full-time jobs than it will lose in the United States and ~24.3 million more net jobs than lost over the 139 countries.

3) The direct cost of electricity in a 100% WWS world will be similar or less than in a fossil fuel world; however, conversion to WWS will result in significant health, climate, and security benefits, summarized next.

4) Converting will eliminate ~65,000 air pollution premature deaths in the United States and 4-7 million/yr worldwide. It will save ~$23 trillion/yr in 2050 health costs in 2013 dollars. The health cost savings translates to 12.8 ¢/kWh.

5) Converting will save ~$29 trillion/yr in 2050 climate costs in 2013 dollars, which translates to 15.8 ¢/kWh.

6) Another way to look at it is that transitioning will save each person ~$85yr in fuel costs, ~2,600yr in air-pollution-damage cost, and ~$3,200/yr in climate cost.

7) Transitioning will require only 0.22% of the 139-country land area for new footprint on the ground, mostly for non-rooftop solar, and 0.92% of the land area for spacing between onshore wind turbines. The latter land can be used for multiple purposes.

8) Transitioning will reduce international conflict over energy because the roadmaps will make each country will largely energy independent.

9) Transitioning will increase access to distributed energy, reducing energy poverty for 4 billion people worldwide

10) Transitioning will reduce risk of large-scale system disruption caused by power outages or terrorism because much of the world power supply will be decentralized.

11) Transitioning should avoid global temperatures from rising more than 1.5ºC since 1870.

Finally, converting to 100% WWS is technically and economically feasible. The main barriers are social and political.

Links And Resources

Papers and spreadsheets summarizing the 50-state and 139-country roadmaps:
http://web.stanford.edu/group/efmh/jacobson/Articles/I/WWS-50-USState-plans.html

Paper on keeping the grid reliable with 100% WWS
http://web.stanford.edu/group/efmh/jacobson/Articles/I/CombiningRenew/CONUSGridIntegration.pdf

Infographic maps for the 50-state and 139-country roadmaps:
www.thesolutionsproject.org and 100.org

Updates to the roadmaps can be found by following on twitter:
@mzjacobson