Stanford study lists energy sources best to worst

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Wind, water and sun beat biofuels, nuclear and coal for clean energy, Stanford researcher says.

The best ways to improve energy security, mitigate global warming and reduce the number of deaths caused by air pollution are blowing in the wind and rippling in the water, not growing on prairies or glowing inside nuclear power plants, says Mark Z. Jacobson, a professor of civil and environmental engineering at Stanford. And "clean coal," which involves capturing carbon emissions and sequestering them in the earth, is not clean at all, he asserts.

Jacobson has conducted the first quantitative, scientific evaluation of the proposed, major, energy-related solutions by assessing not only their potential for delivering energy for electricity and vehicles, but also their impacts on global warming, human health, energy security, water supply, space requirements, wildlife, water pollution, reliability and sustainability. His findings indicate that the options that are getting the most attention are between 25 to 1,000 times more polluting than the best available options.

"The energy alternatives that are good are not the ones that people have been talking about the most. And some options that have been proposed are just downright awful," Jacobson said. "Ethanol-based biofuels will actually cause more harm to human health, wildlife, water supply and land use than current fossil fuels." He added that ethanol may also emit more global-warming pollutants than fossil fuels, according to the latest scientific studies.

The raw energy sources that Jacobson found to be the most promising are, in order, wind, concentrated solar (the use of mirrors to heat a fluid), geothermal, tidal, solar photovoltaics (rooftop solar panels), wave and hydroelectric. He recommends against nuclear, coal with carbon capture and sequestration, corn ethanol and cellulosic ethanol, which is made of prairie grass. In fact, he found cellulosic ethanol was worse than corn ethanol because it results in more air pollution, requires more land to produce and causes more damage to wildlife. The paper with his findings will be published in the next issue of Energy and Environmental Science but is available online now. Jacobson is also director of the Atmosphere/Energy Program at Stanford.

To place the various alternatives on an equal footing, Jacobson first made his comparisons among the energy sources by calculating the impacts as if each alternative alone were used to

power all the vehicles in the United States, assuming only "new-technology" vehicles were being used. Such vehicles include battery electric vehicles (BEVs), hydrogen fuel cell vehicles (HFCVs), and "flex-fuel" vehicles that could run on a high blend of ethanol called E85.

Wind was by far the most promising, Jacobson said, owing to a better-than 99 percent reduction in carbon and air pollution emissions; the consumption of less than 3 square kilometers of land for the turbine footprints to run the entire U.S. vehicle fleet (given the fleet is composed of battery-electric vehicles);l the savings of about 15,000 lives per year from premature air-pollution-related deaths from vehicle exhaust in the United States; and virtually no water consumption. By contrast, corn and cellulosic ethanol will continue to cause more than 15,000 air pollution-related deaths in the country per year, Jacobson asserted.

Because the wind turbines would require a modest amount of spacing between them to allow room for the blades to spin, wind farms would occupy about 0.5 percent of all U.S. land, but this amount is more than 30 times less than that required for growing corn or grasses for ethanol. Land between turbines on wind farms would be simultaneously available as farmland or pasture or could be left as open space.

Indeed, a battery-powered U.S. vehicle fleet could be charged by 73,000 to 144,000 5-megawatt wind turbines, fewer than the 300,000 airplanes the U.S. produced during World War II and far easier to build. Additional turbines could provide electricity for other energy needs.

"There is a lot of talk among politicians that we need a massive jobs program to pull the economy out of the current recession," Jacobson said. "Well, putting people to work building wind turbines, solar plants, geothermal plants, electric vehicles and transmission lines would not only create jobs but would also reduce costs due to health care, crop damage and climate damage from current vehicle and electric power pollution, as well as provide the world with a truly unlimited supply of clean power."

Jacobson said that while some people are under the impression that wind and wave power are too variable to provide steady amounts of electricity, his research group has already shown in previous research that by properly coordinating the energy output from wind farms in different locations, the potential problem with variability can be overcome and a steady supply of baseline power delivered to users.

Jacobson's research is particularly timely in light of the growing push to develop biofuels, which he calculated to be the worst of the available alternatives. In their effort to obtain a federal bailout, the Big Three Detroit automakers are increasingly touting their efforts and programs in the biofuels realm, and federal research dollars have been supporting a growing number of biofuel-research efforts.

"That is exactly the wrong place to be spending our money. Biofuels are the most damaging choice we could make in our efforts to move away from using fossil fuels," Jacobson said. "We should be spending to promote energy technologies that cause significant reductions in carbon

emissions and air-pollution mortality, not technologies that have either marginal benefits or no benefits at all".

"Obviously, wind alone isn't the solution," Jacobson said. "It's got to be a package deal, with energy also being produced by other sources such as solar, tidal, wave and geothermal power."

During the recent presidential campaign, nuclear power and clean coal were often touted as energy solutions that should be pursued, but nuclear power and coal with carbon capture and sequestration were Jacobson's lowest-ranked choices after biofuels. "Coal with carbon sequestration emits 60- to 110-times more carbon and air pollution than wind energy, and nuclear emits about 25-times more carbon and air pollution than wind energy," Jacobson said. Although carbon-capture equipment reduces 85-90 percent of the carbon exhaust from a coal-fired power plant, it has no impact on the carbon resulting from the mining or transport of the coal or on the exhaust of other air pollutants. In fact, because carbon capture requires a roughly 25-percent increase in energy from the coal plant, about 25 percent more coal is needed, increasing mountaintop removal and increasing non-carbon air pollution from power plants, he said.

Nuclear power poses other risks. Jacobson said it is likely that if the United States were to move more heavily into nuclear power, then other nations would demand to be able to use that option.

"Once you have a nuclear energy facility, it's straightforward to start refining uranium in that facility, which is what Iran is doing and Venezuela is planning to do," Jacobson said. "The potential for terrorists to obtain a nuclear weapon or for states to develop nuclear weapons that could be used in limited regional wars will certainly increase with an increase in the number of nuclear energy facilities worldwide." Jacobson calculated that if one small nuclear bomb exploded, the carbon emissions from the burning of a large city would be modest, but the death rate for one such event would be twice as large as the current vehicle air pollution death rate summed over 30 years.

Finally, both coal and nuclear energy plants take much longer to plan, permit and construct than do most of the other new energy sources that Jacobson's study recommends. The result would be even more emissions from existing nuclear and coal power sources as people continue to use comparatively "dirty" electricity while waiting for the new energy sources to come online, Jacobson said.

Jacobson received no funding from any interest group, company or government agency.

Energy and vehicle options, from best to worst, according to Jacobson's calculations:

Best to worst electric power sources:

1. Wind power
2. concentrated solar power (CSP)
3. geothermal power
4. tidal power

5. solar photovoltaics (PV)
6. wave power
7. hydroelectric power
8. a tie between nuclear power and coal with carbon capture and sequestration (CCS).

Best to worst vehicle options:

1. Wind-BEVs (battery electric vehicles)
2. wind-HFCVs (hydrogen fuel cell vehicles)
3.CSP-BEVs
4. geothermal-BEVs
5. tidal-BEVs
6. solar PV-BEVs
7. Wave-BEVs
8.hydroelectric-BEVs
9. a tie between nuclear-BEVs and coal-CCS-BEVs
11. corn-E85
12.cellulosic-E85.

Hydrogen fuel cell vehicles were examined only when powered by wind energy, but they could be combined with other electric power sources. Although HFCVs require about three times more energy than do BEVs (BEVs are very efficient), HFCVs are still very clean and more efficient than pure gasoline, and wind-HFCVs still resulted in the second-highest overall ranking. HFCVs have an advantage in that they can be refueled faster than can BEVs (although BEV charging is getting faster). Thus, HFCVs may be useful for long trips (more than 250 miles) while BEVs more useful for trips less than 250 miles. An ideal combination may be a BEV-HFCV hybrid.