Photovoltaics beat biofuels at converting sun's energy to miles driven

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In 2005, President George W. Bush and American corn farmers saw corn ethanol as a promising fossil fuel substitute that would reduce both American dependence on foreign oil and greenhouse gas emissions. Accordingly, the 2005 energy bill mandated that 4 billion gallons of renewable fuel be added to the gasoline supply in 2006. That rose to 4.7 billion gallons in 2007 and 7.5 billion in 2012.

Since then, life cycle assessments (LCAs) have shown that corn ethanol has modest if any effect on reducing CO2 emissions and may actually increase them, while posing a threat to natural habitats and food supplies, as food stocks are turned to fuel and marginal lands are put under the plough to keep up with demand. In 2010, fuel ethanol consumed 40 percent of U.S. corn production, and 2012 prices are at record highs. Since the U.S. also accounts for 40 percent of the world's corn, U.S. ethanol production has affected corn prices around the planet.

As electric vehicles (EVs) increasingly enter the market and charging stations are built to serve them, EVs are competing with alternative-fuel vehicles. Using electricity generated by coal-fired plants to power the cars defeats the purpose to some extent, but what if the energy comes from the ultimate clean and renewable source – the sun itself? How would that compete with ethanol in terms of land use, life-cycle emissions, and even cost?

The question, says UCSB Bren School of Environmental Science & Management Professor and LCA expert Roland Geyer, is which makes more sense, growing fuel crops to supply alternative-fuel vehicles with ethanol and other biofuels or using photovoltaics (PV) to directly power battery electric vehicles (BEV)?

"The energy source for biofuels is the sun, through photosynthesis," he says. "The energy source for solar power is also the sun. Which is better?"

To find out, Geyer joined former BrenSchool researcher David Stoms and James Kallaos, of the Norwegian University of Science and Technology, to model the relative efficiencies of the technologies at converting a given amount of sunlight to miles driven.

The results, which appear in a paper titled "Spatially Explicit Life Cycle Assessment of Sun-to-Wheels Transportation Pathways in the U.S." and published in the Dec. 26 issue of the journal *Environmental Science & Technology*, showed photovoltaics (PV) to be much more efficient than biomass at turning sunlight into energy to fuel a car.

"PV is orders of magnitude more efficient than biofuels pathways in terms of land use – 30, 50, even 200 times more efficient – depending on the specific crop and local conditions," says Geyer. "You get the same amount of energy using much less land, and PV doesn't require farm land."

The researchers examined three ways of using sunlight to power cars: a) the traditional method of converting corn or other plants to ethanol; b) converting energy crops into electricity for BEVs rather than producing ethanol; and C) using PVs to convert sunlight directly into electricity for BEVs.

Because land-use decisions are local, Geyer explains, he and his colleagues examined five prominent "sun-to-wheels" energy conversion pathways – ethanol from corn or switchgrass for internal combustion vehicles, electricity from corn or switchgrass for BEVs, and PV electricity for BEVs – for every county in the contiguous United States.

Focusing the LCA on three key impacts – direct land use, life cycle greenhouse gas (GHG) emissions, and fossil fuel requirements – the researchers identified PV electricity for battery electric vehicles as the superior sun-to-wheels conversion method.

"Even the most efficient biomass-based pathway…requires 29 times more land than the PV-based alternative in the same locations," the authors write. "PV BEV systems also have the lowest life-cycle GHG emissions throughout the U.S. and the lowest fossil fuel inputs, except in locations that have very high hypothetical switchgrass yields of 16 or more tons per hectare."

PV conversion also has lower GHG emissions throughout the life cycle than do cellulosic biofuels, even in the most optimistic scenario for the latter. "The bottleneck for biofuels is photosynthesis," Geyer says. "It's at best 1-percent efficient at converting sunlight to crop, while today's thin-film PV is at least 10-percent efficient at converting sunlight to electricity.

Finally, while cost was not a key component of the study, Geyer says, "The cost of solar power is dropping, and our quick calculations suggests that with the federal tax credit, electric vehicles are already competitive."

What does this mean for the future?

"What it says to me is that by continuing to throw money into biofuels, we're barking up the wrong tree," Geyer explains. "That's because of a fundamental constraint, which is the relative inefficiency of photosynthesis. And we can't say that right now, biofuels aren't so great but they'll be better in five years. That fundamental problem for biofuels will not go away, while solar EVs will just continue to get more efficient and cheaper. If they're already looking better than biofuels, in five years the gap will be even greater. A search for a silver bullet is under way through "synthetic photosynthesis," but using genetic engineering to improve the efficiency of photosynthesis is a pipe dream. If there is a silver bullet in energy, I think it's solar power."

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