On the Water Consumption for Transportation Fuels

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Driving light duty vehicles (LDV) on most alternative fuels and energy sources will consume more water per mile driven than by driving on gasoline and diesel[1]. The exceptions are using compressed natural gas with natural gas powered pumps, electricity derived from non-thermal renewable electricity (e.g. solar PV and wind), and hydrogen derived from either electrolysis of water using non-thermal renewable electricity or steam methane reforming. To effectively plan for the environmental consequences of moving from high energy density petroleum to lower quality fossil fuels and biomass, we must not unduly distribute fuels with low energy return on investment. Water consumption is just one environmental attribute for focus, but an important one from a quantity and quality perspective.

In 2003 the average fuel efficiency of the U.S. LDV fleet was 20.5 mpg of gasoline. These gasoline vehicles consume, via embodied water in mining and refining, 0.1-0.2 gallons of water per mile (gal H_2O/mile). Using tar sands, coal, and oil shale converted to liquids consumes 0.3-0.5 gal H_2O/mile. If using electricity from the average U.S. generation mix, driving a car using an electric motor from a battery consumes 0.2-0.3 gal H_2O/mile. If the grid electricity is used for electrolysis of water to create hydrogen, using that hydrogen in a fuel cell vehicle results in consumption of 0.4-0.5 gal H_2O/mile. Using non-thermal renewable electricity for electric and fuel cell vehicles consumes less than 0.05 gal H_2O/mile, and obtaining the hydrogen from steam methane reforming of natural gas consumes just under 0.1 gal H_2O/mile.

The other major category of potential LDV fuels is biofuels. If the biomass feedstock is irrigated, using so-called "blue water" from aquifers and reservoirs, the water consumption for corn-based ethanol (E85) and soy-based biodiesel is orders of magnitude higher than other fuels with U.S. averages of 28 and 8 gal H_2O/mile, respectively. Note that only 10% of soy and 15-20% of corn bushels are irrigated in the U.S. However, some highly irritating regions of the U.S. could embody over 100 gal H_2O/mile by growing irrigated corn converted to E85. Cellulosic-based irrigated grasses could result in 1-9 gal H_2O/mile of consumption. Without irrigation, fueling today's fleet of LDVs using E85 ethanol and soy biodiesel would consume 0.1-0.4 gal H_2O/mile, comparable to unconventional fossil conversions.

For almost any product or application, but certainly for agriculture, the embodied water is essentially transferred to drier regions. For instance, in providing food aid to developing nations, the U.S. essentially becomes a net exporter of water – that is water embodied in the exported food. If a given region does not have the climate, or irrigation water source,

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[1] King, C. W. and Webber M. E. Water Intensity of Transportation. *Env. Sci. & Tech.* Online 9/24/08 at: http://pubs.acs.org/cgi-bin/abstract.cgi/esthag/asap/abs/es800367m.html.

for growing a certain crop, importing that crop may be a good option. However, should the irrigation water be drawn from a fossil aquifer, the same crop grown under a different circumstance will not be sustainable in the long term and should be considered a fossil fuel itself simply based upon its supply chain, or life cycle. The irrigation of biomass represents the growing of that biomass in areas with insufficient rainfall. This relationship itself does not necessarily imply a lack of sustainability. For instance, diverting nearby river water into a reservoir can create a stable supply source that can withstand the normal climactic variations in rainfall.

The embodied water concept for agriculture can also be applied to biofuels but with additional focus upon thermodynamics and energy return on investment (EROI). Many regions may import some sugar cane-based ethanol from Brazil, yet don't have the climate to grow the sugar cane. Because of the relatively high EROI of cane ethanol over corn ethanol, international shipping can make sense. Thus, the history, or supply chain, of the biofuel is important, not just its final properties. The supply chain of fossil fuels will also become more important over time as lesser quality resources are extracted. There was no need to pay attention to EROI from the early coal beds and oil wells because they so clearly allowed increased lifestyle and leisure relative to the world before the industrial revolution.

In the concept of moving to non-petroleum fuel sources, the Renewables Fuels Standard (RFS) of the Energy Independence and Security Act (EISA) of 2007 has been both good and bad from a policy perspective:

> *Bad* in the sense that the RFS initially pushes a feedstock-fuel combination, corn ethanol, that has detrimental environmental consequence in terms of nutrient runoff and low EROI. But, the consequences of runoff can be minimized by not over-fertilizing, more widespread use of better tilling practices, and buffer strips next to major rivers.
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> *Good* in the sense that the RFS has pushed forward the scrutiny of how we use energy resources, biomass included, and focused much attention on how we can create better biomass to fuel conversions. It has also raised worldwide awareness on the ethics of how agricultural land should be used: food, fuel, or both?

Today, the struggle for new fuel supplies is clouded because it is not obvious what options best provide for increased or even continued levels of lifestyle and leisure. What is more obvious is that there are geographic regions that can sustainably grow certain kinds of biomass that other regions simply cannot. Unconventional fossil resources such as tar sands and oil shale have lower EROI and higher water consumption needs than conventional petroleum. The need for more water in industrial fuel systems is an indicator of moving to lower energy efficient sources.

Lawmakers creating future policy regarding agriculture and energy need to be cognizant that the tie between energy and water will only increase into the future. Generally, energy sources with lower energy density tend to require more water for mining, farming, refining, and processing. Certainly an increase in vehicle fuel efficiency decreases the "gallons of water per mile" traveled, but in then end, fresh water sustainability is measured on only one "per" basis: "gallons of water per Earth".