Rebound effect, alternative fuels and LCA

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The increased demand for a fuel or service that results from the efficiency induced price reduction is called the rebound effect (Khazzoom, 1980). Understanding the magnitude of this effect is important in determining the potential effectiveness of efficiency driven climate mitigation strategies since anticipated energy savings and concomitant reduction in greenhouse gas (GHG) emissions can be eroded. Although the definition of rebound concerns efficiency, a similar market response can arise when an alternative fuels replaces its fossil fuel based counterpart. Since most alternative fuel production processes produce co-products that also enter the market, additional market mediated impacts can be observed. These market responses can profoundly impact the results of a fuel's lifecycle GHG emissions. Here, we explore the issues related to the "rebound" impacts regarding alternative fuel adoption within the life-cycle assessment framework.

Alternative fuels can be fossil based or derived from biomass (Figure 1). Fossil based alternatives are those derived from natural gas or coal. Natural gas can be used directly as compressed natural gas (CNG) or as liquid petroleum gas (LPG) using the natural gas liquids from wet gas production. Coal and natural gas can be gasified and catalytically converted (Fischer Tropsch liquids; FTL) to distillate or naphtha. These intermediates can be blended with conventional gasoline or diesel fuel. Biomass can be converted to an array of fuels such as low molecular weight alcohols (methanol, ethanol, butanol) or hydrocarbon-like molecules either via thermogenic or fermentative routes. Biomass can also be converted via gasification and FTL to distillate and naphtha or using pyrolysis to bio-oil. The bio-oil must be taken to a refinery for processing.

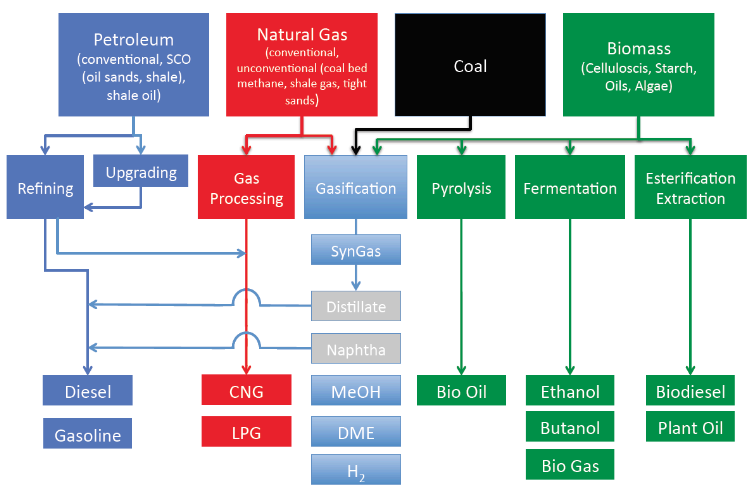

Figure 1. Example Fuel and Alternative Fuel Pathways (modified from Festal. 2008)

Life-cycle assessment (LCA) endeavors to characterize the environmental impacts of a product or service throughout its life cycle, from the extraction of raw materials through manufacturing, use, and disposal (Williams *et al.*, 2009). LCA has become an important and prevalent tool for environmental policy makers, playing a crucial role in the development of the California Low Carbon Fuel Standard (Farrell and Sperling, 2007), the national Renewable Fuel Standard in the Energy Independence and Security Act of 2007 (EISA, 2007), as well as international biofuel policies, particularly in the UK (Renewable Transport Fuels Obligation, RTFO) and the European Union's Renewable Energy Directive, RED. These policies promote the use of biofuels and other alternative fuels to achieve life-cycle greenhouse gas reductions relative to fossil fuels.

Analysis of the CO_2 mitigation potential of alternative fuels using LCA can be very sensitive to rebound effects. Rebound effects are especially relevant for impacts of allocation procedures based on system expansion or displacement and the market mediated changes that result from the alternative fuel replacing the incumbent fuel (Figure 2 for illustration). Two possible examples are shown. First, the alternative fuel displaces the incumbent fuel (Market Displacement). The second is through the interaction of co-products in the market place (Allocation Displacement).

As an example of market displacement, in 2010 the U.S. used 13 billion gallons of corn ethanol, displacing about 9 billion gallons of gasoline. Studies have shown the increased use of ethanol results in price reductions of the blended fuel (Du and Hayes, 2009; NREL, 2008). As a result, gasoline use is reduced per mile driven (an efficiency gain relative to gasoline use), plausibly leading to oil use reduction. These changes can result in direct, indirect, and economy wide rebound effects. On the other hand, if ethanol is more expensive than gasoline, then the increased cost of the blend reverses the sign of the direct impacts. This scenario was modeled by Rajagopal *et al*. (2011). They showed that a corn ethanol mandate of 7.5% resulted in a 5-6% increase in blended fuel price, a 2-3% decrease in blended fuel use, and an 8-9% decrease in petroleum use nationally. However, a different picture emerges in the rest of the world (ROW). World oil prices decreased by 2 to 3% and consumption increased by almost 1%. Overall global fuel use decreased by slightly more than 1%. When one examines the impact on GHG emissions, national emissions decreased by 0.22 to 0.25 Gt CO_2 but this was offset to some extent by the increased fuel use in the ROW. The result was a net decrease overall of 0.12 to 0.13 Gt CO_2, as well as a virtual subsidy of the ROW petroleum consumption.

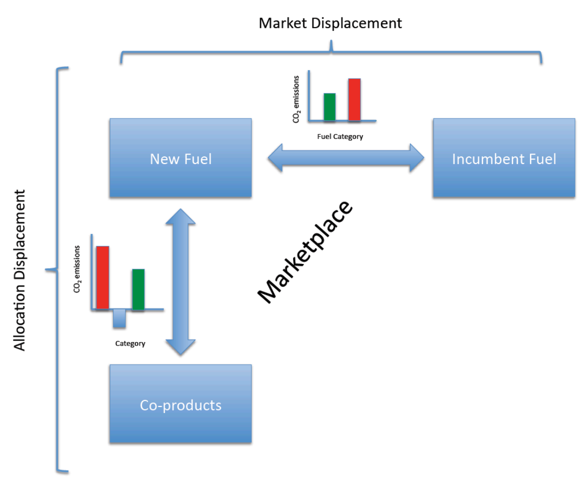

Figure 2. How LCA of fuels can interact with the marketplace.

In multiple product processes that requires allocation of associated energy use and GHG emissions across a production slate (a formalism in LCA), the analyst must use one or more allocation methods including those based on mass, energy or even price (Allocation Displacement, Figure 2). ISO 14001 suggests that if the process cannot be disaggregated to allow for direct allocation (see Kim and Overcash, 2000 for an example in an ammonia plant), then the system under study should be expanded to include competing processes for making the product or a similar product for which the co-product might compete within the marketplace. By comparing these additional life cycles, “credits” can be determined assuming marketplace displacement. A good example of system expansion approach is the study of corn ethanol production by Kim and Dale (2002). Here, the system was expanded to include soybean production and the production of soy oil and meal. These products can provide similar services in the marketplace as by-products produced during corn ethanol production. The authors used “correlation factors” to determine displacement ratios, which describe the amount of co-product that could displace the competitor based on equivalent functionality. All told, the system expansion technique reduced the energy attributed to ethanol production. If corn products replace other sources of oil and protein animal feed, then rebound effects could possibly have a GHG impact via increased meat production. Economy-wide rebound effects could also result in additional GHG emissions.

Another interesting rebound/LCA impact is related to coal to liquids LCA GHG emissions. Coal to liquids (CTL) is a process where coal is gasified and the resulting syngas is converted by Fischer-Tropsh (FT) chemistry to fuels similar to current gasoline, diesel, jet fuel and waxes. Changing operating conditions can alter the product mix toward more gasoline or more diesel. Jaramillo *et al*. (2008) conducted an LCA of this technology for a system optimized to maximize diesel or gasoline production. In both cases the greenhouse gas emission virtually doubled versus current gasoline or diesel production. The use of carbon capture and storage (CCS) could bring CTL in line with petroleum diesel and gasoline production. NETL (2009) preformed a similar analysis but considered diesel production the product of choice and did not model the process required to upgrade FT liquids to gasoline but rather produced naphtha for the petrochemical market. They assumed naphtha would displace petroleum naphtha and credited the CTL process with GHG emissions offset via system expansion. No economic analysis was performed to justify this displacement. Taking these emissions credits and using CCS resulted in diesel fuel that had 5% less emissions than petroleum-based diesel. However, if FT naphtha replaced petroleum naphtha in the marketplace then there will likely be a reallocation of refinery products or a simple rebound effect in the “naphtha” marketplace. In the refinery the naphtha could be used to make more gasoline resulting in more gasoline supply, crude supply could be reduced make less naphtha resulting in a reduction of oil use, or even new processes could be added (i.e. oligomerization) to make diesel fuel, a highly coveted market in the U.S. In all approaches the “saved naphtha is ultimately burned and CO_2 is released into the environment.

In this paper, we show some interesting market mediated impacts that can take place with the adoption of an alternative fuel. Rebound effect can impact prices, fuel use, and possibly the system GHG production, offsetting much of the perceived savings in GHG emissions.

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