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Estimating Social Costs for Various Fuel Strategies for Transit Buses

Mark Henning
Cleveland State University, m.d.henning@csuohio.edu

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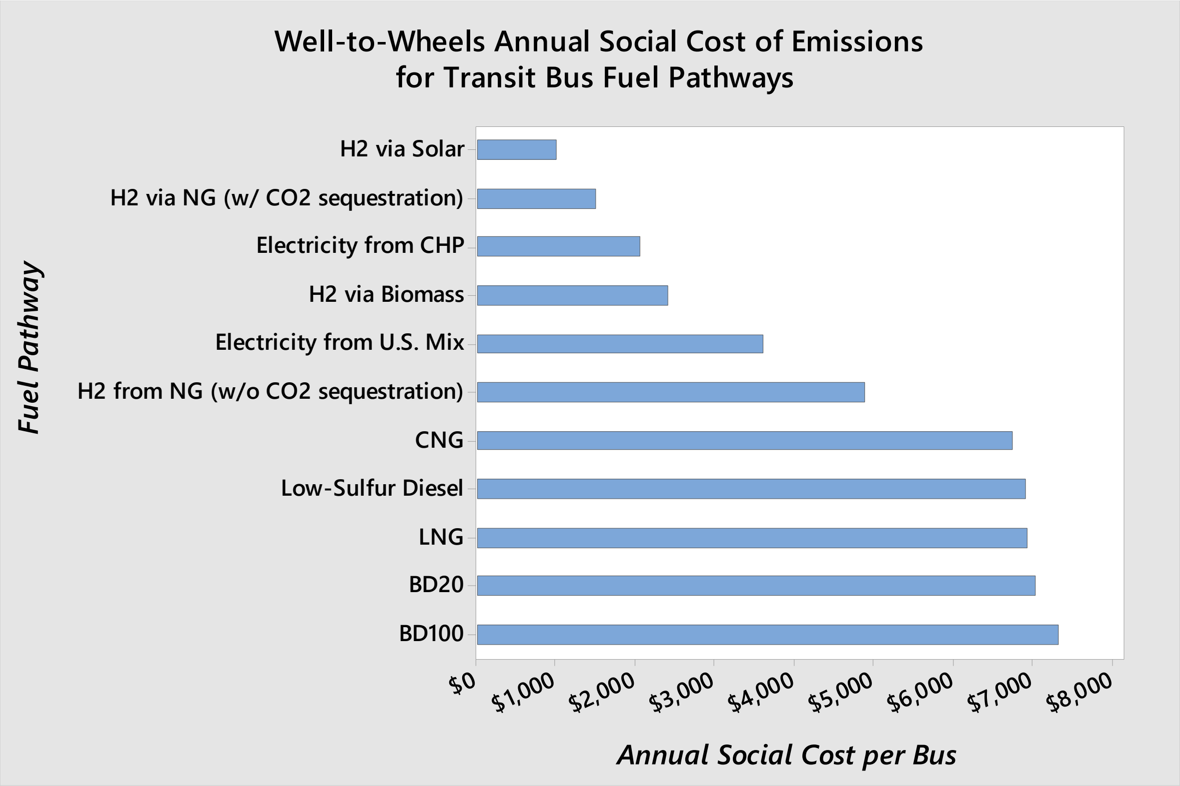
Estimating Social Costs for Various Fuel Strategies for Transit Buses

Public transit agencies, such as Stark Area Regional Transit Authority in Canton, Ohio, which operates a fleet of hydrogen fuel cell buses, are beginning to take leadership in identifying best fuel strategies for transportation systems. As a result, it is important for these agencies to consider what pathways will inflict the least cost to society. A common way to do this is to look at "social cost" calculators, which identify and monetize the external costs of fuel consumption, beyond the price paid for the fuel.[1] Using one such model, we determined that the fuel with the lowest social cost is hydrogen developed through solar power, using an electrolyser, or from reformed natural gas, with CO2 sequestration.

Using Argonne National Laboratory's *Greenhouse gases, Regulated Emissions, and Energy use in Transportation* (GREET) model, we estimated the social cost of pollutant emissions for a selection of fuel pathways used in heavy duty transit buses.[2] We looked not only at the emissions related to operations for different transit bus fuel technologies, but also at the emissions associated with producing a given type of fuel and getting it to a filling location (i.e. Well-to-Pump). This analysis of the comprehensive lifecycle emissions resulted in a measurement of the total annual social cost per bus for different fuel technologies.



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[1] *Social cost* is based on a number of factors, including a pollutant's quantified monetary impact on: human health, particularly morbidity and mortality rates; changes in energy demand (via cooling and heating); changes in agricultural output and forestry due to alterations in average temperature, precipitation levels, and CO2 fertilization; property lost to sea level rise; increased coastal storm damage; and changes in fresh water availability. *See* footnote 4 below. *See also* https://www.washingtonpost.com/news/energy-environment/wp/2016/01/29/the-staggering-economic-cost-of-air-pollution/?utm_term=.c12ad97db97f

[2] https://greet.es.anl.gov/

As the chart illustrates, even hydrogen generation from renewable energy sources has an associated amount of emissions when viewed from a comprehensive cradle-to-grave perspective of production and consumption. In the case of hydrogen production using solar energy via electrolysis, at least 80% of the CO_2-equivalent emissions (nearly 2,000 grams of CO_2-equivalent emissions per kilogram of hydrogen made) is a result of manufacturing the PV (photo voltaic) modules and transporting the hydrogen to the filling station.[3]

Our analysis included the following fuel pathways for transit buses (with abbreviations in parentheses):[4]

- Low-sulfur diesel from crude oil;
- Biodiesel, including both 100% biodiesel from soybeans (BD100), and a 20/80 biodiesel/low-sulfur diesel blend (BD20);
- Electricity, including the mix of generation technologies used for the United States on average (Electricity from U.S. Mix), and electricity generation using Combined Heat and Power (Electricity from CHP) which is known to be more efficient than conventional electricity generation;[5]
- Gaseous Hydrogen (via pipeline), including production from natural gas with CO2 sequestration (H2 via NG w/ CO2 Sequestration), production from natural gas without CO2 sequestration (H2 via NG w/o CO2 Sequestration), production using solar energy for electrolysis (H2 via Solar), and production using biomass gasification (H2 via Biomass);
- Compressed natural gas (CNG) from North American natural gas; and
- Liquid natural gas (LNG) from North American natural gas.

For each transit bus fuel pathway, Argonne's GREET model provides an estimate of the amount of different pollutants emitted per mile traveled. Using common guidelines on the social costs per unit mass for major pollutants, we were able to determine a cents-per-mile value of the damages caused by carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), particulate matter ($PM_{2.5}$), volatile organic compounds (VOC), and nitrogen oxides (NOx).[6] These costs account for damage both to the environment and to human health. As an example, the following table shows the per-mile lifecycle social costs for buses that use low-sulfur diesel.

Pollutant	Social Cost per Mile
CO_2	\$0.1500
CH_4	\$0.0052

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[3] *See* Cetinkaya, E., Dincer, I., & Naterer, G. F. (2012). Life cycle assessment of various hydrogen production methods. *International journal of hydrogen energy*, *37*(3), 2071-2080.

[4] Argonne describes *pathways* as the series of steps for fuel production. *See* https://greet.es.anl.gov/files/2011ws-greetnet-intro

[5] https://www.epa.gov/sites/production/files/2015-07/documents/combined_heat_and_power_frequently_asked_questions.pdf

[6] *See* New York University's Institute for Policy Integrity's *The Social Cost of Greenhouse Gases and State Policy* at https://policyintegrity.org/files/publications/SCC_State_Guidance.pdf. *See also* U.S. Department of Transportation's 2018 *Benefit-Cost Analysis Guidance for Discretionary Grant Programs* at https://www.transportation.gov/sites/dot.gov/files/docs/mission/office-policy/transportation-policy/14091/benefit-cost-analysis-guidance-2018.pdf

N_2O	\$0.0002
$PM_{2.5}$	\$0.0306
VOC	\$0.0007
NOx	\$0.0192
Total	\$0.2029

The total per-mile rate representing the combined social cost of pollutant emissions for the different fuel pathways was multiplied by the national average for annual vehicle miles traveled per transit bus to arrive at an estimate of the yearly net economic costs of emissions for a single bus under the various fuel technologies.[7] The range of values seen in the bar chart are comparable to the social cost of carbon per bus per year that researchers at Columbia University determined for New York City Transit's fleet of diesel, hybrid diesel, and CNG buses.[8]

While hydrogen production via solar or steam reforming of natural gas with carbon capture would appear to minimize the externality imposed by transit buses, the measures of economic damage used here are only a portion of the investigation required to understand the investment tradeoffs between different fuel pathways. In a future discussion, we will undertake a financial analysis that compares the same fuel pathways for transit buses based on their capital cost, payback period, and net present value.

By: Mark Henning, Research Associate, Renewable Hydrogen Fuel Cell Collaborative and Midwest Hydrogen Center for Excellence

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[7] The average transit bus travels 34,503 miles annually according to the Federal Highway Administration. *See* https://afdc.energy.gov/data/10309

[8] *See* http://www.columbia.edu/~ja3041/Electric%20Bus%20Analysis%20for%20NYC%20Transit%20by%20J%20Aber%20Columbia%20University%20-%20May%202016.pdf