Rail Module Expansion in GREET™

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1. Introduction

The Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET™) model includes various pathways of transportation fuel and light duty vehicle combinations for well-to-wheels (WTW) analysis. Recently, GREET was expanded to include well-to-wake (WTWa) analysis for aviation fuel and aircraft combinations (Elgowainy et al. 2012), and to well-to-hull (WTH) analysis for marine fuel and vessel combinations (Adom et al. 2013). In GREET1_2014, a rail module is newly implemented for a freight rail and four classes of passenger rail. This memo documents the data sources and calculation of energy intensity for each rail class, and the GREET expansion for the rail module.

2. Data Source and Calculation of Energy Intensity

2.1. Data Source and Calculation Process

GREET's railroad module include a freight rail and four classes of passenger rail. For freight railroad, the data for total revenue ton-miles and fuel consumption by year are obtained from Railroad Facts 2013 published by Association of American Railroads (2014). The energy intensity per ton-mile for freight railroad is calculated as follows.

$$\text{Energy Intensity for Freight Railroad} = \frac{\text{Fuel Use} \times \text{Lower Heating Value}}{\text{Revenue Ton Miles}}.$$

The four types of passenger rail include Intercity Rail (Amtrak), Commuter Rail, Light Rail Transit and Heavy Rail Transit. For Amtrak, the data on fuel use are obtained from Transportation Energy Data Book: Edition 33 (Davis et al. 2014). For all other operating types, the fuel use data are obtained from 2014 Public Transportation Fact Book (APTA 2014). Furthermore, the passenger-mile data for all rail types are obtained from 2014 Public Transportation Fact Book (APTA 2014). The Public Transportation Fact Book is based on the National Transit Database by Federal Transit Administration (FTA 2014), which provides passenger miles and fuel consumptions by each transit agency. Therefore, the energy intensity per passenger-mile for passenger rail can be estimated directly using the equation below.

$$\text{Energy Intensity} = \frac{\text{Fuel Use} \times \text{Lower Heating Value}}{\text{Passenger Miles}}.$$

2.2. Energy Intensity

Using the data sources and methodology discussed above, the energy intensity are calculated and listed in Tables 1 to 4. GREET's default lower heating value for diesel (128,450 Btu/gal) is used for the fuel heating value. While each of freight rails (diesel) and transit rails (electricity) consumes a single fuel, intercity and commuter rails consume both diesel and electricity. For commuter rails, the passenger miles and fuel consumptions by each agency in the National Transit Database show that six agencies among 24 agencies, including the four largest agencies (MTA Metro-North Railroad, MTA Long Island Rail Road, New Jersey Transit Corporation and Illinois' Metra Rail), report the consumptions of both diesel and electricity combined without separating diesel and electric mileage. The passenger mileage by these six agencies accounts for about 75% of total passenger mileage reported by all agencies. Since diesel and electric mileages are not given separately, we could not calculate separate energy intensities for passenger-miles on diesel and electricity. In other words, the diesel and electricity consumption were added and divided by the total passenger miles for commuter rail to calculate a combined total energy intensity per passenger mile for that rail class (Table 3).

Table 1 Energy Intensity for Freight Rail

Year	Fuel Use	Ton-Miles (Millions)	Energy Intensity (Btu/Ton-Mile)
	Diesel (Thousand Gallons)		
1995	3,503,096	1,305,688	345
2000	3,720,107	1,465,960	326
2005	4,119,879	1,696,425	312
2010	3,519,021	1,691,004	267
2012	3,634,025	1,712,567	273

Table 2 Energy Intensity for Passenger Intercity Rail (Amtrak)

Year	Fuel Use		Revenue Passenger-miles (Millions)	Energy Intensity (Btu/Passenger-mile)		
	Diesel (Thousand Gallons)	Electricity (Thousand kWh)		Total	Diesel Share	Electricity Share
1995	72,371	335,818	5,401	2,364	72.8%	27.2%
2000	94,968	470,170	5,574	3,061	71.5%	28.5%
2005	65,477	531,377	5,381	2,584	60.5%	39.5%
2010	63,474	558,662	6,420	2,170	58.5%	41.5%
2012	63,058	549,201	6,804	2,025	58.8%	41.2%

Table 3 Energy Intensity for Passenger Commuter Rail

Year	Fuel Use		Revenue Passenger-miles (Millions)	Energy Intensity (Btu/Passenger-mile)		
	Diesel (Thousand Gallons)	Electricity (Million kWh)		Total	Diesel Share	Electricity Share
1995	63,064	1,253	8,244	2,554	38.5%	61.5%
2000	70,818	1,370	9,402	2,474	39.1%	60.9%
2005	76,714	1,484	9,473	2,660	39.1%	60.9%
2010	93,200	1,797	10,874	2,810	39.2%	60.8%
2012	94,000	1,808	11,181	2,752	39.2%	60.8%

Table 4 Energy Intensity for Passenger Light and Heavy Transit Rail

Year	Fuel Use Electricity (Million kWh)		Passenger-miles (Millions)		Energy Intensity (Btu/Passenger-mile)	
	Light Transit Rail	Heavy Transit Rail	Light Transit Rail	Heavy Transit Rail	Light Transit Rail	Heavy Transit Rail
1995	288	3,401	860	10,559	3,462	3,330
2000	563	3,549	1,356	13,844	4,293	2,650
2005	571	3,769	1,700	14,418	3,473	2,703
2010	749	3,780	2,173	16,407	3,564	2,382
2011	789	3,854	2,203	17,317	3,703	2,301

3. GREET Expansion for Rail Module

3.1. Fuel and Feedstock

The baseline locomotive fuels are diesel and electricity. Additional possible alternative fuels for rail application in GREET include liquefied natural gas (LNG), liquefied petroleum gas (LPG), dimethyl ester (DME), Fischer-Tropsch diesel (FTD), biodiesel, renewable diesel, renewable gasoline and liquid hydrogen. For each of these alternative fuels, several potential pathways and feedstocks exist, which are summarized in Table 5. We assume that diesel fuel consumption in Tables 1 to 4 can be displaced with alternative fuels while electricity consumptions may not be displaced by any of these alternatives because the liquid fuel combustion in urban areas is heavily regulated to control air quality.

Table 5 Fuel and Feedstock Combinations for Locomotive Fuels in GREET

Fuel	Feedstock
Diesel	Crude Oil, Hydroprocessed Pyrolysis Oil
LNG	Conventional, Shale Gas
LPG	Crude Oil, Natural Gas
DME	Natural Gas, Flared Gas, Biomass or Coal via Gasification
FTD	Natural Gas, Flared Gas, Natural Gas/Biomass Biomass, Coal or Coal/Biomass via Gasification
Biodiesel	Soybean, Palm, Rapeseed, Jatropha, Camelina, Algae
Renewable Diesel	
Renewable Gasoline	
Liquid Hydrogen	Natural Gas vis Steam Methane Reforming, Solar Photovoltaic, Nuclear (Thermo-Chemical Cracking of Water), Electrolysis with Nuclear HTGR, Coal or Biomass via Gasification, Coke Oven Gas
Liquid Hydrogen (Distributed)	Natural Gas, Electrolysis, Ethanol, Methanol
Electricity	U.S. Mix, North American Electric Reliability Corporation (NERC) Regional Mix Natural Gas Power Plants, Oil Power Plants, Coal Power Plants, Nuclear Power Plants, Hydroelectric Power Plants, Natural Gas Combined Cycle Power Plants, Geothermal Power Plants

3.2. PTW Emissions

We set the baseline fuel type as petroleum diesel and adopt the associated emission factors for locomotives from GREET^{TM} emission factors database. Table 6 Shows the GREET emission fctors per million Btu of diesel consumption in locomotives.

Table 6 PTW Emissions for Baseline Fuel Type (Diesel) Use in Locomotives (Grams per Million Btu)

VOC	CO	NOx	PM_{10}	$PM_{2.5}$	BC	OC	CH_4	N_2O
58.4	207	1,140	30.3	29.4	2.47	26.0	6.82	2.13

Then, PTW emissions for alternative fuel types can be calculated from the emission factor ratios presented in Table 7 by fuel type relative to baseline fuel in locomotive operation. Many of these emission factor ratios are estimates from other combustion applications and may not be representative of the actual ratios for the locomotive application. We are pursuing emissions data for these alternative fuels that are more relevant to the locomotive application for future refinement of the ratios in Table 7. Note that SOx and CO_2 emissions are not included in Table 7 since they are calculated by the sulfur and carbon contents in each of the alternative fuels (see Table 8).

Table 7 PTW Emission Ratios by Fuel Type Relative to Baseline Fuel

	LNG	LPG	DME	FTD, Biodiesel, Renewable Diesel Renewable Gasoline	Hydrogen	Electricity
VOC	100%	100%	100%	100%	0%	0%
CO	50%	50%	100%	100%	0%	0%
NOx	100%	100%	50%	100%	75%	0%
PM_{10}	10%	10%	70%	100%	0%	0%
$PM_{2.5}$	10%	10%	70%	100%	0%	0%
BC	10%	10%	70%	100%	0%	0%
OC	10%	10%	70%	100%	0%	0%
CH_4	2000%	100%	100%	100%	0%	0%
N2O	100%	100%	100%	100%	0%	0%

Table 8 Properties of Locomotive Fuels

	Lower Heating Value (Btu/gal)	Density (g/gal)	Carbon Ratio	Sulfur Ratio (ppm)
Diesel	128,450	3,167	86.5%	200
LNG	74,720	1,621	75.0%	0
LPG	84,950	1,923	82.0%	0
DME	68,930	2,518	52.2%	0
FTD	123,670	3,017	85.3%	0
Biodiesel	119,550	3,361	77.6%	0
Renewable Diesel	122,887	2,948	87.1%	0
Renewable Gasoline	115,983	2,830	84.0%	0
Hydrogen	30,500	268	0.0%	0

3.3. Energy Consumption Ratio

The energy consumption ratios by alternative fuels relative to baseline diesel in locomotive operation are not known. Therefore, we estimated the fuel economy ratios by alternative fuels relative to baseline diesel in locomotive operation based on fuel economies of baseline diesel and alternative-fueled passenger cars in GREET. We are pursuing energy consumption data for these alternative fuels that are more relevant to the locomotive application for future refinement of the ratios in Table 9.

Table 9 Energy Consumption Ratios by Alternative Fuels Relative to Baseline Diesel in Locomotive Operation

	LNG	LPG	DME, FTD, Biodiesel, Renewable Diesel	Renewable Gasoline	Hydrogen	Electricity
Energy Consumption Ratio	120%	120%	100%	120%	100%	30%

References

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