Update of Electricity Generation Mix and Crude Oil Share

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1. Background

Electricity and petroleum products from crude oil (e.g., gasoline, diesel, jet, residual oil and liquefied petroleum gas) are the baseline energy products that are used in various fuel production pathways. Therefore, the energy and emissions intensities of electricity and petroleum products are critical for life-cycle analysis (LCA) of transportations fuels, or well-to-wheels (WTW) analysis. These energy and emissions intensities of electricity and petroleum products depend highly on the electricity generation mixes and the crude oil share to the U.S. refineries, respectively, which change over time and vary by region. Therefore, we continuously investigate and update the electricity generation mixes and the crude oil share to the U.S. refineries in our LCA model (namely, the Greenhouse gases, Regulated Emissions, and Energy use in Transportation [GREET®] model). For the updates of these mixes to the GREET 2016 model, this technical memo documents the data sources and the methodologies at the national and regional levels.

2. Development of Electric Generation Mix

In the GREET model, electricity generation is categorized by its energy sources – coal, petroleum, natural gas, nuclear, biomass, hydroelectric, geothermal, wind, solar, and others. Also, because the share varies by region the electric generation mixes for major regions can be evaluated in addition to the national averaged electricity generation mix. North American Electric Reliability Corporation (NERC) divides the North America electric utility system into eight major regions – Florida Reliability Coordinating Council (FRCC), Midwest Reliability Organization (MRO), Northeast Power Coordinating Council (NPCC), Reliability First Corporation (RFC), SERC Reliability Corporation (SERC), Southwest Power Pool, RE (SPP), Texas Reliability Entity (TRE), and Western Electricity Coordinating Council (WECC). The facilities and systems in each NERC region are interconnected for system reliability in electricity energy transmission network. Other than these regions, electric generation mixes for Hawaii (HI) and Alaska (AK), are also included in GREET.

The primary data source for electricity generation mixes is the statistical data and projections by the U.S. Energy Information Administration (U.S. EIA). For the eight NERC regions in the contiguous U.S., Annual Energy Outlook (AEO) provides the historic data and projections of the United States energy markets for coming decades, which include electricity generations by the eight NERC regions and by fuel types (EIA 2016a). Based on these data, the electric generation mixes were calculated for the eight NERC regions by 2040. On the other hand, AEO does not provide the projections of HI and AK. Thus, the historic data about the electricity generation in these states are used to update the generation mix up to year 2014 (EIA 2016c). Note that the generation mixes of these states for the future years are assumed to be the same as those in 2014 due to lack of projection.

Table 1 provides the electric generation mixes of the U.S., eight NERC regions and three states (California [CA], AK and HI) by 2040.

Table 1. Electric Generation Mix of the U.S., Eight NERC Regions and Three States (EIA 2016a)

U.S. Mix	Residual Oil	Natural Gas	Coal	Nuclear	Biomass	Hydroelectric	Geothermal	Wind	Solar PV	Others
2014	0.7%	26.2%	39.8%	20.2%	0.4%	6.8%	0.4%	4.6%	0.4%	0.4%
2015	0.6%	31.9%	34.3%	20.4%	0.2%	6.3%	0.4%	4.8%	0.6%	0.5%
2020	0.3%	27.1%	34.2%	19.3%	0.2%	7.4%	0.5%	9.1%	1.3%	0.5%
2025	0.3%	30.5%	28.0%	18.9%	0.3%	7.1%	0.8%	10.8%	2.7%	0.5%
2030	0.2%	36.3%	22.3%	18.4%	0.3%	6.9%	1.0%	10.6%	3.4%	0.5%
2035	0.2%	36.0%	21.3%	17.7%	0.3%	6.7%	1.2%	10.2%	5.9%	0.5%
2040	0.2%	37.6%	19.4%	16.9%	0.4%	6.4%	1.2%	10.0%	7.5%	0.5%
FRCC Mix	Residual Oil	Natural Gas	Coal	Nuclear	Biomass	Hydroelectric	Geothermal	Wind	Solar PV	Others
2014	0.9%	62.3%	21.9%	12.9%	0.4%	0.6%	0.0%	0.0%	0.1%	0.8%
2015	1.4%	76.5%	7.3%	12.3%	0.4%	0.7%	0.0%	0.0%	0.1%	1.4%
2020	0.2%	66.6%	18.0%	12.2%	0.4%	0.7%	0.0%	0.0%	0.1%	1.8%
2025	0.1%	59.2%	16.9%	11.3%	0.4%	0.6%	0.0%	0.0%	9.8%	1.7%
2030	0.1%	61.8%	15.9%	10.6%	0.4%	0.6%	0.0%	0.0%	9.2%	1.4%
2035	0.1%	55.7%	14.9%	10.0%	0.4%	0.6%	0.0%	0.0%	16.8%	1.5%
2040	0.1%	54.1%	14.0%	9.5%	0.4%	0.5%	0.0%	0.0%	20.0%	1.4%
MRO Mix	Residual Oil	Natural Gas	Coal	Nuclear	Biomass	Hydroelectric	Geothermal	Wind	Solar PV	Others
2014	0.1%	3.7%	59.2%	12.0%	0.5%	7.2%	0.0%	16.7%	0.0%	0.6%
2015	0.3%	1.9%	62.3%	12.0%	0.3%	5.2%	0.0%	17.7%	0.0%	0.3%
2020	0.2%	3.8%	50.5%	11.3%	0.4%	5.4%	0.0%	27.9%	0.1%	0.3%
2025	0.2%	3.9%	41.3%	11.6%	0.5%	5.6%	0.0%	36.5%	0.1%	0.3%
2030	0.2%	4.6%	38.0%	12.0%	0.6%	5.8%	0.0%	38.4%	0.2%	0.3%
2035	0.2%	5.2%	37.5%	11.9%	0.6%	5.8%	0.0%	38.4%	0.1%	0.3%
2040	0.2%	6.1%	36.0%	11.5%	0.7%	5.8%	0.0%	39.4%	0.1%	0.3%
NPCC Mix	Residual Oil	Natural Gas	Coal	Nuclear	Biomass	Hydroelectric	Geothermal	Wind	Solar PV	Others
2014	1.8%	42.2%	3.8%	32.5%	1.7%	14.2%	0.0%	2.4%	0.2%	1.3%
2015	0.8%	48.8%	2.6%	29.8%	0.6%	13.4%	0.0%	2.2%	0.2%	1.6%
2020	0.3%	46.9%	1.6%	25.9%	0.8%	16.3%	0.0%	6.3%	0.2%	1.6%
2025	0.2%	48.4%	2.3%	24.3%	1.2%	15.3%	0.0%	6.5%	0.2%	1.5%
2030	0.2%	50.4%	2.3%	23.3%	1.2%	14.7%	0.0%	6.2%	0.2%	1.5%
2035	0.1%	50.2%	2.2%	23.5%	1.1%	14.8%	0.0%	6.3%	0.2%	1.5%
2040	0.1%	52.6%	1.4%	22.8%	1.1%	14.4%	0.0%	6.1%	0.2%	1.4%

Table 1. *Continued*

RFC Mix	Residual Oil	Natural Gas	Coal	Nuclear	Biomass	Hydroelectric	Geothermal	Wind	Solar PV	Others
2014	0.6%	15.2%	50.6%	29.5%	0.1%	1.1%	0.0%	2.3%	0.1%	0.6%
2015	0.2%	18.0%	48.8%	28.9%	0.0%	1.1%	0.0%	2.3%	0.1%	0.6%
2020	0.2%	21.4%	47.0%	26.1%	0.2%	1.5%	0.0%	2.9%	0.1%	0.6%
2025	0.2%	28.8%	38.4%	26.8%	0.2%	1.5%	0.0%	3.2%	0.3%	0.6%
2030	0.1%	39.0%	28.9%	26.1%	0.2%	1.5%	0.0%	3.1%	0.3%	0.6%
2035	0.1%	41.0%	27.5%	25.6%	0.2%	1.5%	0.0%	3.1%	0.4%	0.6%
2040	0.1%	45.3%	24.4%	24.5%	0.2%	1.4%	0.0%	3.0%	0.5%	0.6%
SERC Mix	Residual Oil	Natural Gas	Coal	Nuclear	Biomass	Hydroelectric	Geothermal	Wind	Solar PV	Others
2014	0.5%	23.0%	45.0%	27.2%	0.3%	3.3%	0.0%	0.4%	0.1%	0.2%
2015	0.4%	33.2%	33.4%	28.7%	0.2%	3.4%	0.0%	0.4%	0.2%	0.2%
2020	0.2%	26.2%	37.0%	29.7%	0.3%	4.0%	0.0%	0.8%	1.6%	0.2%
2025	0.2%	30.3%	31.7%	29.3%	0.3%	3.8%	0.0%	0.8%	3.5%	0.2%
2030	0.1%	38.0%	24.6%	28.4%	0.3%	3.7%	0.0%	0.8%	4.0%	0.2%
2035	0.1%	38.6%	22.8%	26.9%	0.3%	3.5%	0.0%	0.7%	6.9%	0.1%
2040	0.1%	38.1%	21.7%	25.8%	0.3%	3.4%	0.0%	0.7%	9.8%	0.1%
SPP Mix	Residual Oil	Natural Gas	Coal	Nuclear	Biomass	Hydroelectric	Geothermal	Wind	Solar PV	Others
2014	1.6%	23.2%	55.4%	4.1%	0.0%	1.8%	0.0%	13.7%	0.2%	0.1%
2015	1.7%	29.7%	47.4%	3.8%	0.0%	1.8%	0.0%	15.5%	0.2%	0.1%
2020	0.2%	14.8%	42.8%	3.6%	0.0%	2.1%	0.0%	36.4%	0.2%	0.1%
2025	0.1%	26.5%	34.1%	3.1%	0.0%	1.8%	0.0%	34.1%	0.2%	0.0%
2030	0.1%	29.6%	30.1%	3.2%	0.0%	1.8%	0.0%	35.0%	0.2%	0.1%
2035	0.1%	30.3%	29.3%	3.1%	0.0%	1.8%	0.0%	34.5%	0.8%	0.0%
2040	0.1%	32.0%	26.4%	2.9%	0.5%	1.7%	0.0%	34.0%	2.4%	0.0%
TRE Mix	Residual Oil	Natural Gas	Coal	Nuclear	Biomass	Hydroelectric	Geothermal	Wind	Solar PV	Others
2014	0.0%	41.5%	36.2%	11.6%	0.1%	0.3%	0.0%	10.1%	0.1%	0.2%
2015	0.1%	53.3%	24.4%	11.7%	0.0%	0.2%	0.0%	10.0%	0.1%	0.2%
2020	0.1%	44.3%	31.7%	11.1%	0.0%	0.2%	0.0%	12.0%	0.4%	0.2%
2025	0.1%	41.7%	25.1%	10.5%	0.0%	0.2%	0.0%	19.0%	3.1%	0.3%
2030	0.1%	49.2%	18.2%	10.0%	0.0%	0.2%	0.0%	18.1%	4.0%	0.3%
2035	0.1%	46.7%	17.6%	9.5%	0.2%	0.2%	0.0%	17.2%	8.2%	0.3%
2040	0.1%	51.3%	14.1%	8.8%	0.3%	0.2%	0.0%	16.0%	8.9%	0.3%

Table 1. *Continued*

WECC Mix	Residual Oil	Natural Gas	Coal	Nuclear	Biomass	Hydroelectric	Geothermal	Wind	Solar PV	Others
2014	0.1%	29.4%	28.1%	8.1%	0.6%	22.6%	2.2%	6.6%	2.0%	0.4%
2015	0.2%	29.5%	27.8%	8.5%	0.1%	21.7%	2.4%	6.8%	2.6%	0.5%
2020	0.1%	21.3%	23.1%	8.0%	0.1%	24.3%	2.8%	15.6%	4.2%	0.5%
2025	0.1%	23.0%	18.0%	7.7%	0.3%	23.4%	4.2%	18.4%	4.6%	0.4%
2030	0.1%	23.7%	15.6%	7.3%	0.4%	22.3%	5.1%	17.6%	7.4%	0.5%
2035	0.1%	21.3%	15.3%	7.0%	0.2%	21.4%	6.0%	16.9%	11.3%	0.5%
2040	0.1%	22.3%	13.8%	6.6%	0.4%	20.3%	6.1%	16.2%	13.6%	0.5%
CA Mix	Residual Oil	Natural Gas	Coal	Nuclear	Biomass	Hydroelectric	Geothermal	Wind	Solar PV	Others
2014	0.0%	56.2%	6.9%	9.1%	1.6%	8.4%	4.9%	7.2%	4.7%	1.1%
2015	0.0%	52.4%	4.7%	9.7%	0.4%	13.3%	5.0%	7.1%	6.2%	1.2%
2020	0.0%	38.6%	5.8%	8.5%	0.4%	14.2%	5.7%	16.1%	9.5%	1.3%
2025	0.0%	40.8%	0.1%	8.2%	0.8%	13.6%	8.8%	17.6%	9.1%	1.0%
2030	0.0%	39.0%	0.1%	7.5%	1.0%	12.4%	11.1%	16.1%	11.7%	1.1%
2035	0.0%	34.3%	0.1%	6.9%	0.5%	11.5%	12.3%	14.8%	18.7%	1.0%
2040	0.0%	32.1%	0.1%	6.4%	0.7%	10.7%	12.5%	13.8%	22.8%	0.9%
AK Mix	Residual Oil	Natural Gas	Coal	Nuclear	Biomass	Hydroelectric	Geothermal	Wind	Solar PV	Others
2014	7.4%	54.4%	9.2%	0.0%	1.0%	25.4%	0.0%	2.5%	0.0%	0.0%
2015	7.4%	54.4%	9.2%	0.0%	1.0%	25.4%	0.0%	2.5%	0.0%	0.0%
2020	7.4%	54.4%	9.2%	0.0%	1.0%	25.4%	0.0%	2.5%	0.0%	0.0%
2025	7.4%	54.4%	9.2%	0.0%	1.0%	25.4%	0.0%	2.5%	0.0%	0.0%
2030	7.4%	54.4%	9.2%	0.0%	1.0%	25.4%	0.0%	2.5%	0.0%	0.0%
2035	7.4%	54.4%	9.2%	0.0%	1.0%	25.4%	0.0%	2.5%	0.0%	0.0%
2040	7.4%	54.4%	9.2%	0.0%	1.0%	25.4%	0.0%	2.5%	0.0%	0.0%
HI Mix	Residual Oil	Natural Gas	Coal	Nuclear	Biomass	Hydroelectric	Geothermal	Wind	Solar PV	Others
2014	67.9%	0.0%	14.8%	0.0%	3.3%	0.9%	2.5%	5.7%	0.4%	4.6%
2015	67.9%	0.0%	14.8%	0.0%	3.3%	0.9%	2.5%	5.7%	0.4%	4.6%
2020	67.9%	0.0%	14.8%	0.0%	3.3%	0.9%	2.5%	5.7%	0.4%	4.6%
2025	67.9%	0.0%	14.8%	0.0%	3.3%	0.9%	2.5%	5.7%	0.4%	4.6%
2030	67.9%	0.0%	14.8%	0.0%	3.3%	0.9%	2.5%	5.7%	0.4%	4.6%
2035	67.9%	0.0%	14.8%	0.0%	3.3%	0.9%	2.5%	5.7%	0.4%	4.6%
2040	67.9%	0.0%	14.8%	0.0%	3.3%	0.9%	2.5%	5.7%	0.4%	4.6%

3. Development of Crude Oil Share and Weighted Average Distance

In the GREET model, the sources of crude oil to the U.S. refineries are grouped into seven regions: U.S. domestic, Canada, Mexico, Middle East, Latin America, Africa, others. The largest source of crude to the U.S. refineries is the U.S. domestic crude, which has increased significantly in recent years due to the increased volume of shale oil. The 2015 share of U.S. domestic crude in the total crude inputs to the U.S. refineries can be calculated by the volumes of domestic crude oil production and company level imports provided by EIA (EIA 2016b, EIA 2016c). In 2015, 9.43 million barrels of crude per day is produced in the U.S. (8.96 million barrels/day from the lower 48 states and 0.47 million barrels/day from AK) while 7.35 million barrels of crude per day is imported. Thus, the share of the U.S. domestic crude in 2015 is estimated at 56.2%. For the future years, AEO provides the projected volumes of domestic crude oil production and net imports, which are projected to be 9.38 and 6.97 million barrels per day in 2020, respectively. Thus, the share of U.S. domestic crude is expected to increase to 57.4% in 2020. Note that AEO projects the crude oil volumes produced in the lower 48 states and AK at 8.96 and 0.41 million barrels/day, respectively.

Among the imported crude, Canadian crude oil accounts for the largest share. According to EIA, 3.17 million barrels of Canadian crude oil per day is imported in 2015 (EIA 2016b). Canadian Association of Petroleum Producers (CAPP) project increases in Canadian crude oil import in 2020 to 3.42 million barrels per day. Canadian crude oil can be divided into two different types of crude (namely, Canadian oil sands and conventional oil), and these two types of crude have significantly different energy demand and emissions (e.g., CH_4 emissions from vented, fugitive, and incomplete flaring) (Hao Cai et al. 2014). CAPP also provides the volumes of oil sands received in the U.S. by the Petroleum Administration for Defense Districts (PADDs) in 2015 and projections for 2020 as shown in Table 2. Note that heavy oil imports in Table 2 include a small amount of conventional heavy oil. The ratios of oil sands to total heavy supply are calculated at 87.6% and 93.5% for 2015 and 2020, respectively (CAPP 2016). Taking into account the oil sand shares in heavy oil, the total Canadian oil sands imports are estimated at 1.68 (=0.26+1.62×87.6%) and 2.16 (=0.26+2.03×93.5%) million barrels per day in 2015 and 2020, respectively. Thus, the remaining volume of Canadian crude import is taken into account as conventional oil, which is 1.49 and 1.26 million barrels per day in 2015 and 2020, respectively.

Table 2. The Synthetic Crude Oil and Heavy Crude Oil Receipts by the Petroleum Administration for Defense Districts (PADDs) (CAPP 2016)

(thousand barrels per day)	2015		2020	
	SCO[a]	Heavy	SCO[a]	Heavy
PADD1				
PADD2	225	1,357	220	1,657
PADD4		199		228
PADD5	33	64	44	146
PADD3				
U.S.	258	1,620	264	2,031

[a] Synthetic crude oil;

Similar to the Canadian oil, the 2015 volumes of remaining crude sources, such as Mexico, Middle East, Latin America, Africa and others, were also obtained from EIA's company-level import data (EIA 2016b). However, the projected volumes of these crude sources are not available. Thus, the relative shares of these crude sources in 2020 are assumed to be the same to those of 2015. The resulting crude oil shares in the United States in 2015 and 2020 are presented in Table 3.

Table 3. Crude Oil Share in the U.S. in 2015 and 2020

Regions		2015	2020
U.S. Domestic		56.2%	57.4%
Canada	(Oil Sands)	10.3%	12.9%
	(Conventional Crude)	9.2%	7.5%
Mexico		3.4%	3.1%
Middle East		8.9%	8.1%
Latin America		9.5%	8.7%
Africa		1.7%	1.6%
Others		0.7%	0.7%

In the United States, the ways of importing crude oil are primarily categorized into two – by ocean tankers and pipelines. In order to calculate the weighted average distances for these modes, the company level imports data (EIA 2016b) were used to identify the crude oil sources to each state that imports crude. We assume that crude oil from Canada and Mexico is transported via pipeline while crude from the other sources is transported by ocean tankers. The distance travelled by ocean tankers for each combination of an exporting country and an importing state was assumed to be the shortest distance between major harbors in the exporting country and the importing state, which was obtained from Portworld (S&P Global Platts 2016). For pipeline distances, the method and data are presented in Cai et al. (2015). The weighted average distances are calculated as the sum of multiplication of each distance and the share, divided by the total share. The calculated average distances for ocean tankers and pipelines are presented in Table 4.

Table 4. Weighted Average Distance for Importing Crude Oil

Weighted average distance	(miles)
by ocean tanker of imported off-shore countries	8,373
by pipeline from Canada & Mexico	1,677

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