Vermont Energy Sector: LCA of Upstream GHG Emissions

May 30, 2024

ERG

Project Goal

To support the Climate Action Plan, this work will conduct lifecycle accounting of emissions attributable to the use of energy in Vermont to supplement the state's current GHG Inventory. This analysis primarily covers GHG emissions outside the boundaries of the state that are caused by the use of energy in Vermont, but will be connected to in-state fuel consumption activity and emissions.

Primary Outcomes

- Methodology and Results Report shared with VT
- Workbook with upstream emission factors and upstream emissions results

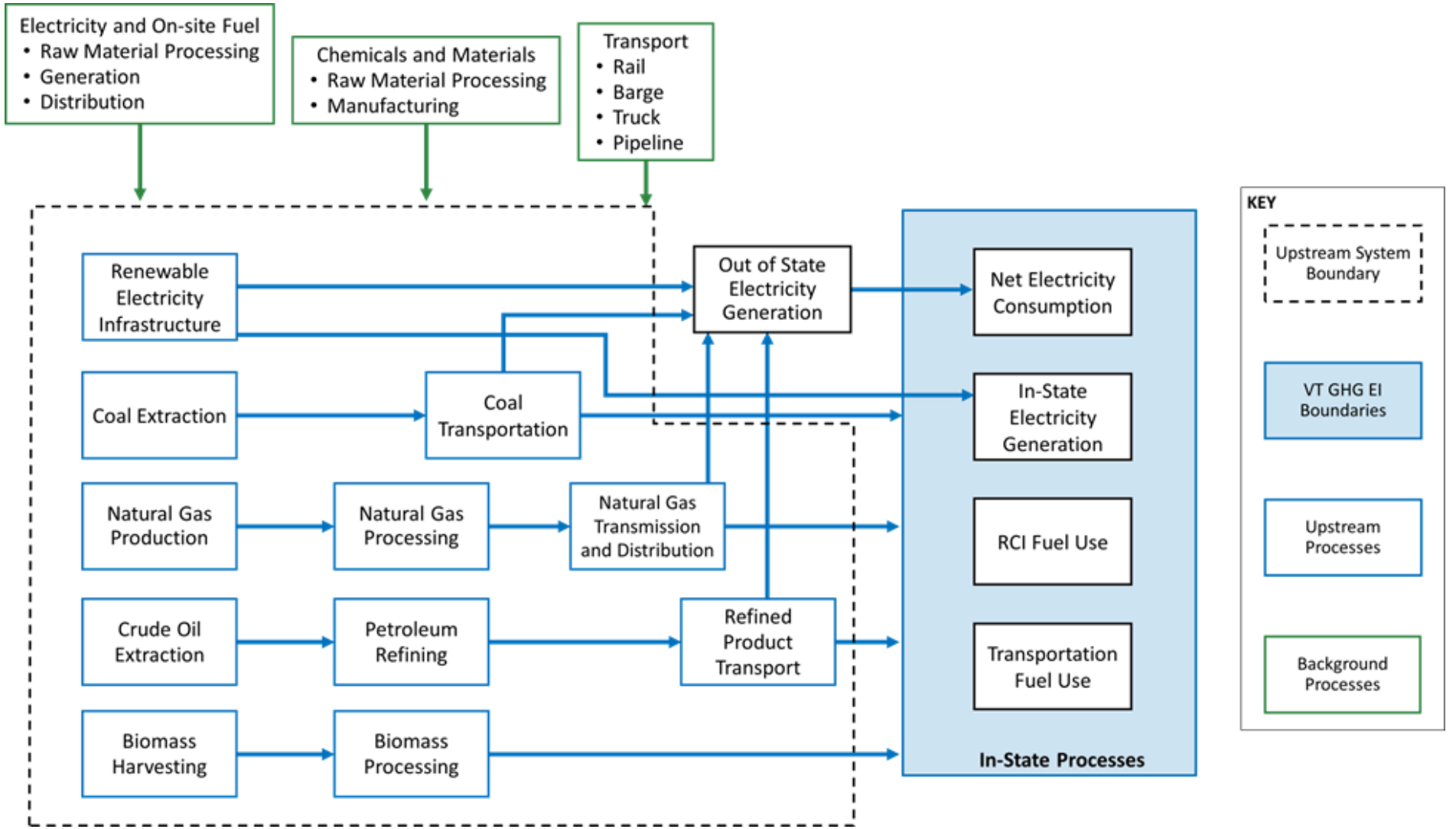
Vermont Project Scope

- Vermont has already modeled emissions associated with in-state consumption of many energy pathways in the Vermont Greenhouse Gas Emissions Inventory and Forecast reports and the modeling completed for the Pathways report.
- ERG's role is to
  1) model *out-of-state* (i.e., upstream) GHG emission factors associated with energy consumption within the state; including
  2) modeling upstream emissions for net electricity consumption; and thereby
  3) estimate total *in-state* and *upstream* emissions totals from total energy consumption in the state

Primary Emissions Model: GREET

- **Greenhouse gases, Regulated Emissions, and Energy use in Technologies** model v2022r1 developed by Argonne National Laboratory
- Highly parameterized life cycle model which includes many of the most common U.S. fuels and energy pathways
- Highly regarded model for U.S. LCA data
- Provides full time series estimates back to 1990
- Where appropriate we configure GREET to reflect conditions specific to Vermont.

Defining the System Boundary



Energy Pathways

Pathway	Model
Natural Gas Products	GREET
Petroleum Products	GREET
Coal	GREET
Wood, Elec.	GREET; Dugan et al. 2020 FPR report
Wood, Heat	GREET; Dugan et al. 2020 FPR report
Biofuels	GREET
Nuclear	GREET
HydroQuebec	Levasseur et al. 2021; Ecoinvent 3.7; GREET
Regional Hydroelectric	Levasseur et al. 2021; Ecoinvent 3.7
Wind (On- and Off-shore)	GREET
RNG, Animal Waste and LFG	GREET

Example: Petroleum Fuels – Crude Extraction

Petroleum to Gasoline, Liquefied Petroleum Gas, Residual Oil, Diesel, and Naphtha			
3) Calculations of Energy Consumption, Water Consumption, and Emissions for Petrole			
	Crude Oil		
	Recovery	Transportation to U.S. Refineries	Storage
Energy efficiency	98.0%		
Loss factor		1.000	1.000
Energy ratio of crude oil feeds to product (mmBtu of crude/mmBtu of fuel throughput)			
Crude oil / SCO	1.0%		
Residual oil	1.0%		
Diesel fuel	15.0%		
Gasoline	2.0%		
Natural gas	61.9%		
Coal	0.0%		
Liquefied petroleum gas			
Electricity	19.0%		
Hydrogen	0.0%		
Pet coke			
Butane			

	Crude Oil		
	Recovery	Transportation to U.S. Refineries	Storage
Total energy	30,480	14,480	0
Fossil fuels	28,792	12,398	0
Coal	2,872	3,541	0
Natural gas	21,748	4,704	0
Petroleum	4,172	4,153	0
Water consumption	20.346	0.918	0.000
Total emissions: grams/mmBtu of fuel throughput			
VOC	1.321	0.259	
CO	6.397	0.993	
NOx	6.746	5.198	
PM10	0.228	0.402	
PM2.5	0.181	0.345	
SOx	0.636	2.654	
BC	0.047	0.048	
OC	0.056	0.130	
CH4: combustion	6.794	1.725	
N2O	0.035	0.021	
CO2	2,747	968	
VOC from bulk terminal	0.702	1.534	
VOC from ref. Station	1,083	CO2 emissions from associated	
CH4: non-combustion	80.000	gas flaring and venting	

Pathways: Emissions Factor Format

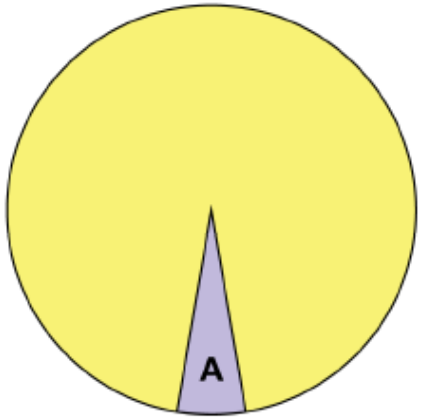
- EFs provided in CO2e, by flow, and by stage

Emission Factor (CO2e)								
Sector	Pathway	Units	2017	2018	2019	2020	2021
Electricity	Coal	g CO2e/MWh	57,812	57,673	57,441	59,931	60,101
Electricity	Hydro Quebec	g CO2e/MWh	19,830	19,830	19,830	19,830	19,830
Electricity	Hydro, Reservoir	g CO2e/MWh	50,793	50,673	50,430	50,445	50,628
Electricity	Hydro, Run-of-River	g CO2e/MWh	2,738	2,738	2,738	2,738	2,738
Electricity	Natural Gas	g CO2e/MWh	83,481	83,443	83,354	93,856	93,931
Electricity	Nuclear	g CO2e/MWh	8,070	7,962	7,611	6,331	6,564
Electricity	Petroleum	g CO2e/MWh	157,864	151,058	144,954	157,354	160,208
Electricity	RNG, Animal Waste	g CO2e/MWh	483,679	483,633	483,591	498,715	498,733
Electricity	RNG, Landfill	g CO2e/MWh	148,210	147,136	143,493	150,435	153,744
Electricity	Wind, Offshore	g CO2e/MWh	13,093	13,053	12,993	12,991	13,031
Electricity	Wind, Onshore	g CO2e/MWh	10,382	10,348	10,291	10,295	10,335
Electricity	Wood Residues	g CO2e/MWh	38,700	38,431	38,172	36,963	37,082
RCI, Transport	Jet/Kerosene	g CO2e/mmBtu	14,206	13,555	12,969	13,006	13,260
RCI	Asphalt	g CO2e/mmBtu	12,614	11,956	11,377	11,439	11,683
RCI	Coal	g CO2e/mmBtu	5,808	5,794	5,770	5,773	5,790
RCI; Residential	Firewood, Commercial	g CO2e/mmBtu	2,700	2,681	2,664	2,593	2,601
RCI; Residential	Firewood, Non-Commercial	g CO2e/mmBtu	406	403	401	401	402
RCI	Heating Oil	g CO2e/mmBtu	15,202	14,546	13,959	14,007	14,261
RCI	Natural Gas	g CO2e/mmBtu	13,742	13,736	13,721	14,473	14,485
RCI	Propane, from Crude	g CO2e/mmBtu	20,747	20,073	19,447	19,520	19,803
RCI	Propane, from NGL	g CO2e/mmBtu	9,312	9,308	9,298	9,993	10,001
RCI	RNG, Animal Waste	g CO2e/mmBtu	48,536	48,531	48,527	48,427	48,429
RCI	RNG, Landfill	g CO2e/mmBtu	20,708	20,558	20,049	19,857	20,294
RCI; Commercial, Industri	Wood Chips	g CO2e/mmBtu	633	625	605	599	616
RCI; Residential	Wood Pellets	g CO2e/mmBtu	28,790	28,674	28,284	28,138	28,471

Counterfactuals in GREET

- Some pathways assign negative emissions credits within LCI calculations, derived from counterfactual scenarios & assumptions, such as:
  - Landfill RNG: avoided flaring emissions
  - Animal Waste RNG: C sequestration in soil via land application of AD residues
- Counterfactuals typically classified as a consequential LCA (CLCA) method
  - Sometimes blended with attributional (ALCA)
  - Further detail in Chapter 3 of 2022 NASEM Low-Carbon Transport Fuels report

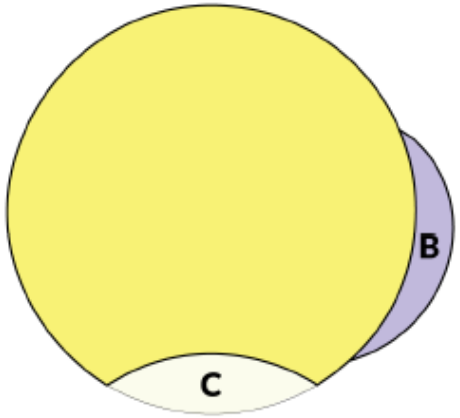
Attributional



Impacts = A

What part of the global environmental burdens should be assigned to the product?

Consequential



Impacts = B - C

What is the change in global environmental burdens resulting from a change in the use or production of a product?

Counterfactuals in GREET

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Disclaimer on RNG tab of GREET1 v2023:
"This pathway uses RNG as a process fuel or feedstock. The LCA results of RNG are subject to further revisions to address technical uncertainties, especially related to counterfactual scenario assumptions for wastes that are used for RNG production."

Impacts = A

What part of the global environmental burdens should be assigned to the product?

Impacts = B - C

What is the change in global environmental burdens resulting from a change in the use or production of a product?

Biogenic C & Temporal Scopes

- GREET1 Woody tab
  - Focus on short-rotation woody crops
  - Stand-level carbon stock accounting
  - Harvest followed by regrowth

- Key LCA Papers:
  - Peñaloza et al. (2019): case study in temporal boundary dilemma
  - Cowie et al. (2021):
    - Stand- vs. landscape-scale assessments (ALCA & CLCA)
    - Critique of “payback period” & “carbon debt” approaches
    - “No-harvest” land use counterfactual (CLCA)
  - Head et al. (2021): integrates CBM-FHWP landscape-level model w/ Dynamic LCA

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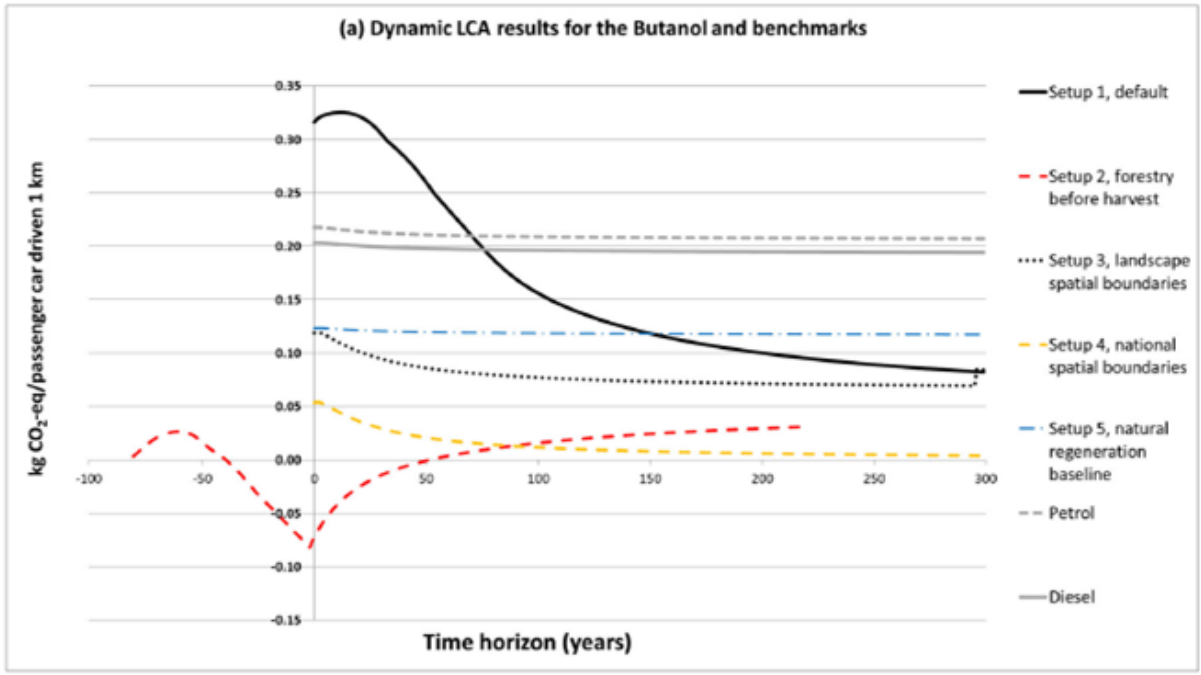

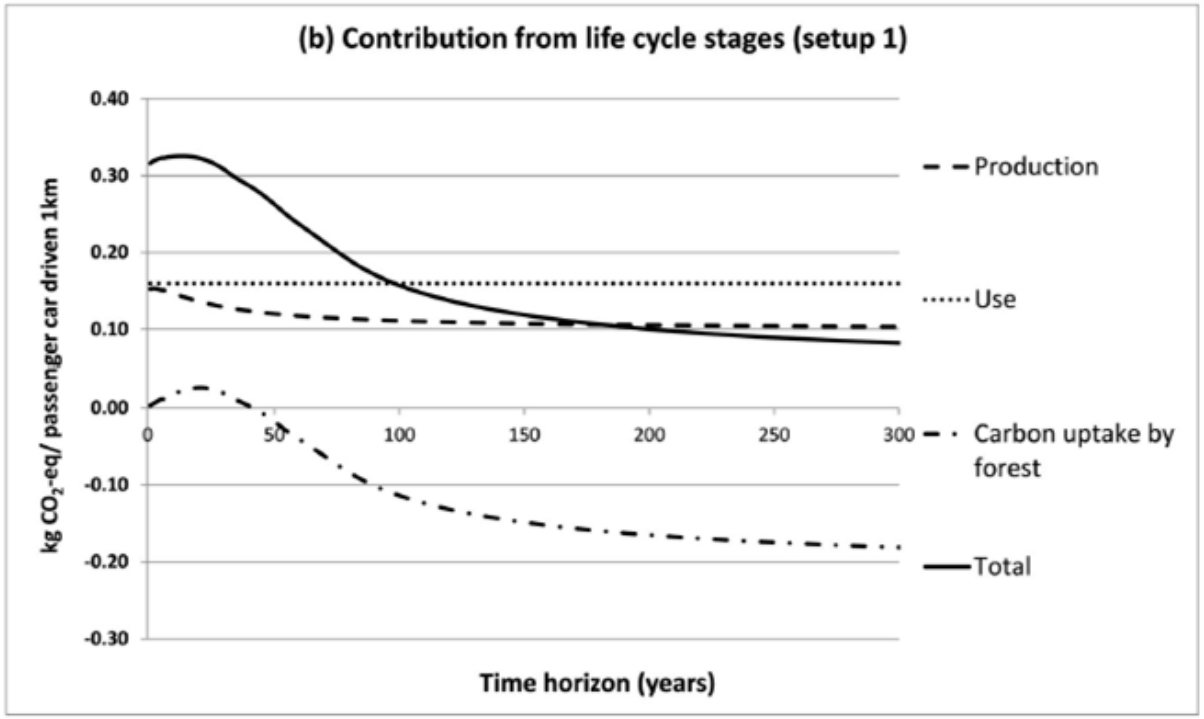

Questions