Vermont Life Cycle Analysis of GHG Emissions

Science and Data Subcommittee Meeting

April 5, 2024

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Agenda

1. Project Status
2. Review Project Scope
3. Review Approach for Calculating Upstream Emissions
4. Energy Sector Results
5. Future Efforts and Discussion

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 gas 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.

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Project Status

- Final report shared with VT
- Workbook with upstream emission factors and total 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

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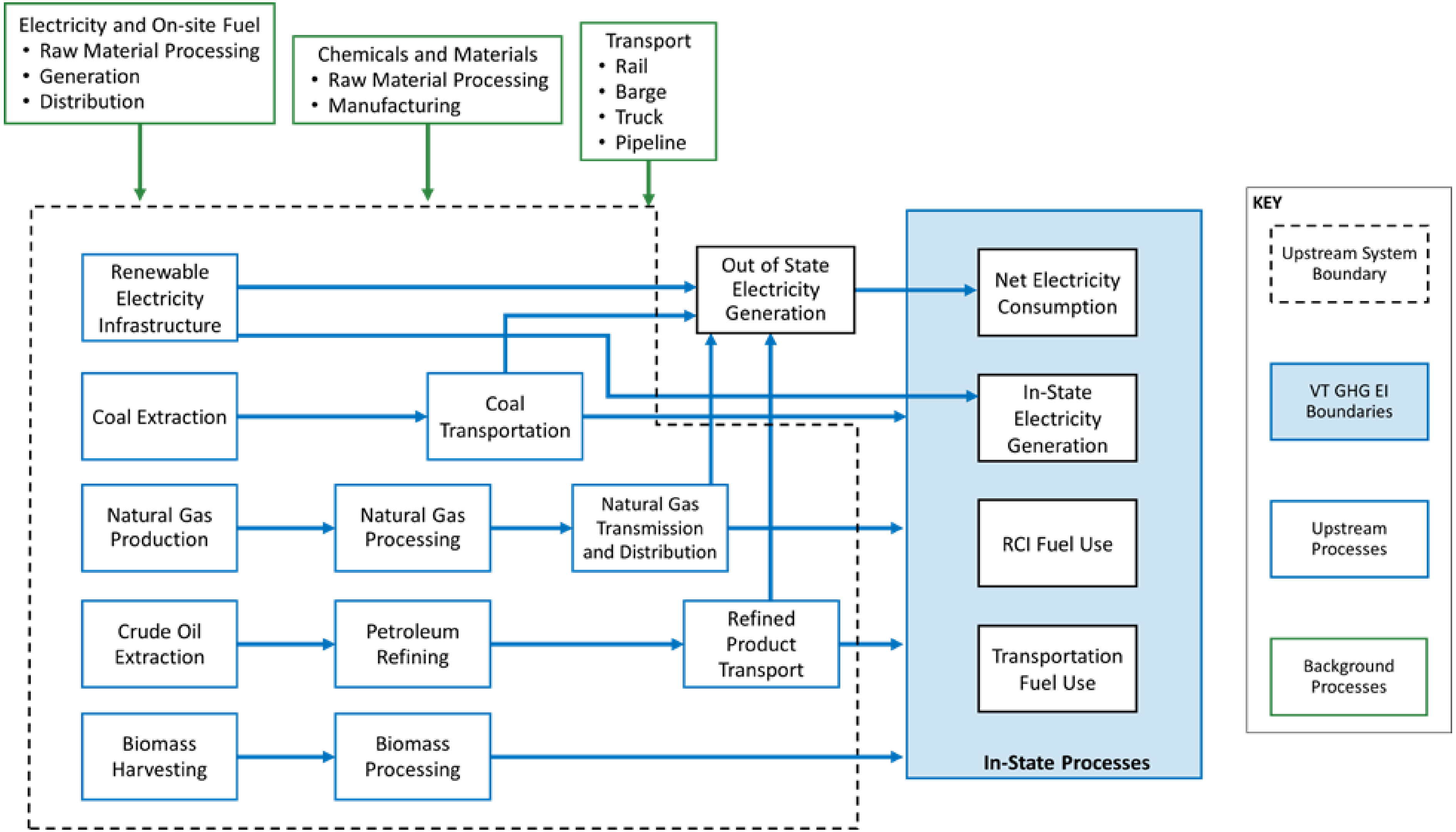
Defining the System Boundary



Energy Pathway Identification

- Resources reviewed to identify energy pathways:
  - Energy Information Administration (EIA) State Energy Data System (SEDS)
  - 2022 VT Comprehensive Energy Plan
  - Initial VT Climate Action Plan, Dec 2021
  - VT GHG Emissions Inventory and Forecast: 1990 – 2017 & Most Recent 2020 Draft

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

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Pathways: Emissions Factor Format

Sector	Sub-Sector Category	Pathway	Stage	Greenhouse Gas	1990	1991		2019	2020
Energy	Residential	Natural Gas	Production	CO_2	E.F.	E.F.		E.F.	E.F.
Energy	Residential	Natural Gas	Production	CH_4	E.F.	E.F.		E.F.	E.F.
Energy	Residential	Natural Gas	Production	N_2O	E.F.	E.F.	…	E.F.	E.F.
Energy	Residential	Natural Gas	Transmission	CO_2	E.F.	E.F.		E.F.	E.F.
Energy	Residential	Natural Gas	Transmission	CH_4	E.F.	E.F.		E.F.	E.F.
Energy	Residential	Natural Gas	Transmission	N_2O	E.F.	E.F.		E.F.	E.F.
…								…	

- Where “E.F.” is an emission factor value
- Stage categories will vary by pathway

Pathways: Emissions Factor Format

- EFs provided in CO_2e, by flow, and by stage

Emission Factor (CO2e)

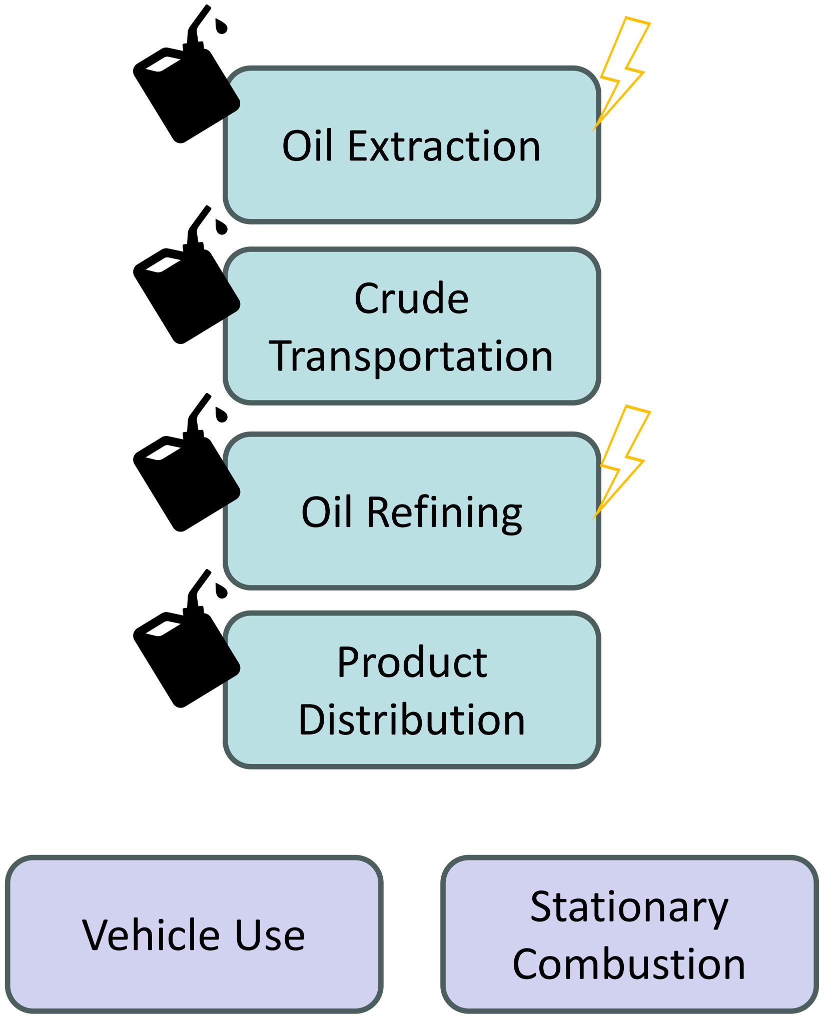
Sector	Pathway	Units	1990	1991	1992	1993	1994
Electricity	Coal	g CO2e/MWh	69,436	69,436	69,436	69,436	69,436
Electricity	Hydro Quebec	g CO2e/MWh	19,830	19,830	19,830	19,830	19,830
Electricity	Hydro, Reservoir	g CO2e/MWh	52,522	52,522	52,522	52,522	52,522
Electricity	Hydro, Run-of-River	g CO2e/MWh	2,738	2,738	2,738	2,738	2,738
Electricity	Natural Gas	g CO2e/MWh	131,018	131,018	131,018	131,018	131,018
Electricity	Nuclear	g CO2e/MWh	43,408	43,408	43,408	43,408	43,408
Electricity	Petroleum	g CO2e/MWh	159,800	159,800	159,800	159,800	159,800
Electricity	RNG, Animal Waste	g CO2e/MWh	535,220	535,220	535,220	535,220	535,220
Electricity	RNG, Landfill	g CO2e/MWh	282,548	282,548	282,548	282,548	282,548
Electricity	Solar PV, Commercial/Utility, Fleet Average	g CO2e/MWh	44,578	44,578	44,578	44,578	44,578
Electricity	Solar PV, Commercial/Utility, Multi cSi	g CO2e/MWh	47,579	47,579	47,579	47,579	47,579
Electricity	Solar PV, Commercial/Utility, Single cSi	g CO2e/MWh	43,998	43,998	43,998	43,998	43,998
Electricity	Solar PV, Residential, Fleet Average	g CO2e/MWh	30,927	30,927	30,927	30,927	30,927
Electricity	Solar PV, Residential, Multi cSi	g CO2e/MWh	32,622	32,622	32,622	32,622	32,622
Electricity	Solar PV, Residential, Single cSi	g CO2e/MWh	30,600	30,600	30,600	30,600	30,600
Electricity	Wind, Offshore	g CO2e/MWh	13,399	13,399	13,399	13,399	13,399
Electricity	Wind, Onshore	g CO2e/MWh	10,756	10,756	10,756	10,756	10,756
Electricity	Wood Residues	g CO2e/MWh	45,880	45,880	45,880	45,880	45,880
RCI, Transport	Jet/Kerosene	g CO2e/mmBtu	13,274	13,274	13,274	13,274	13,274
RCI	Asphalt	g CO2e/mmBtu	11,441	11,441	11,441	11,441	11,441
RCI	Coal	g CO2e/mmBtu	6,195	6,195	6,195	6,195	6,195

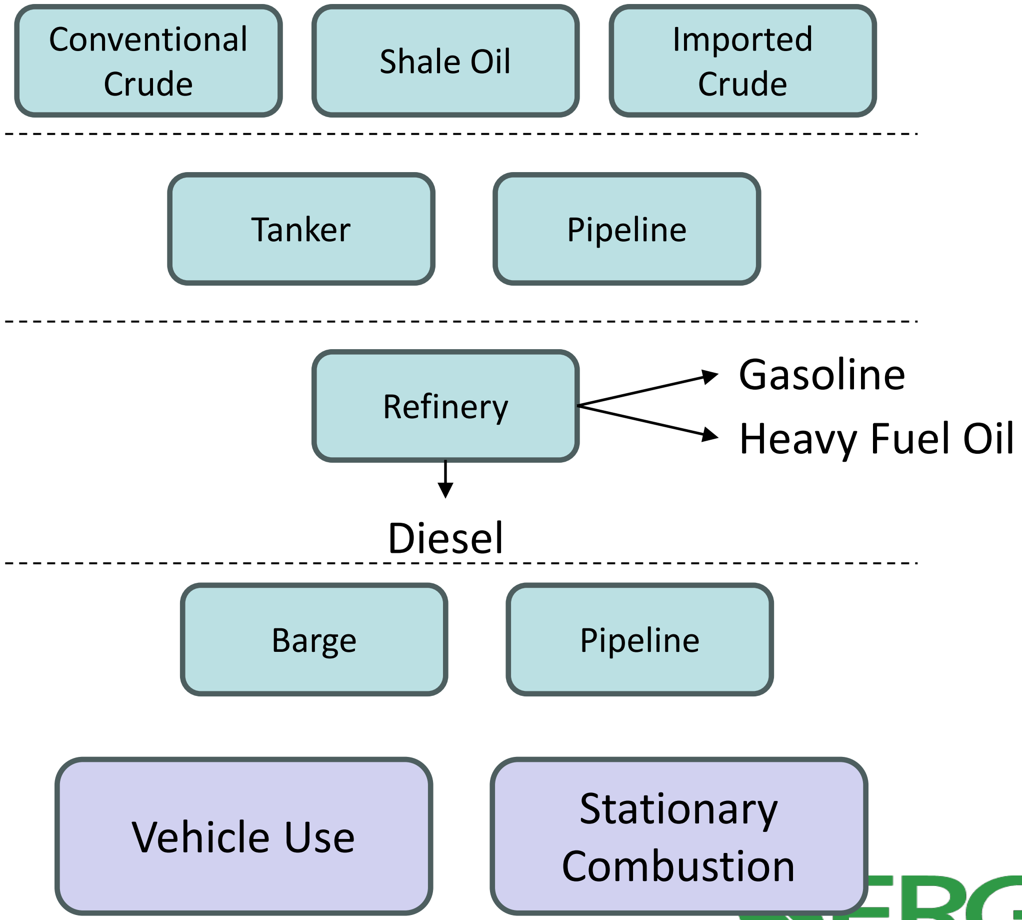
ReadMe | Change Log | Controls | Emissions Summary | Upstream Emissions, total | Upstream Emissions, by flow | EFs, GWP

Primary Emissions Model: GREET

- **Greenhouse gases, Regulated Emissions, and Energy use in Technologies** model v2022 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.

Pathway 1: Petroleum Fuels





Pathway 1: 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	

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Total Upstream Emissions

- Activity data aligned with VT GHG EI, multiplied by EF to calculate total upstream emissions

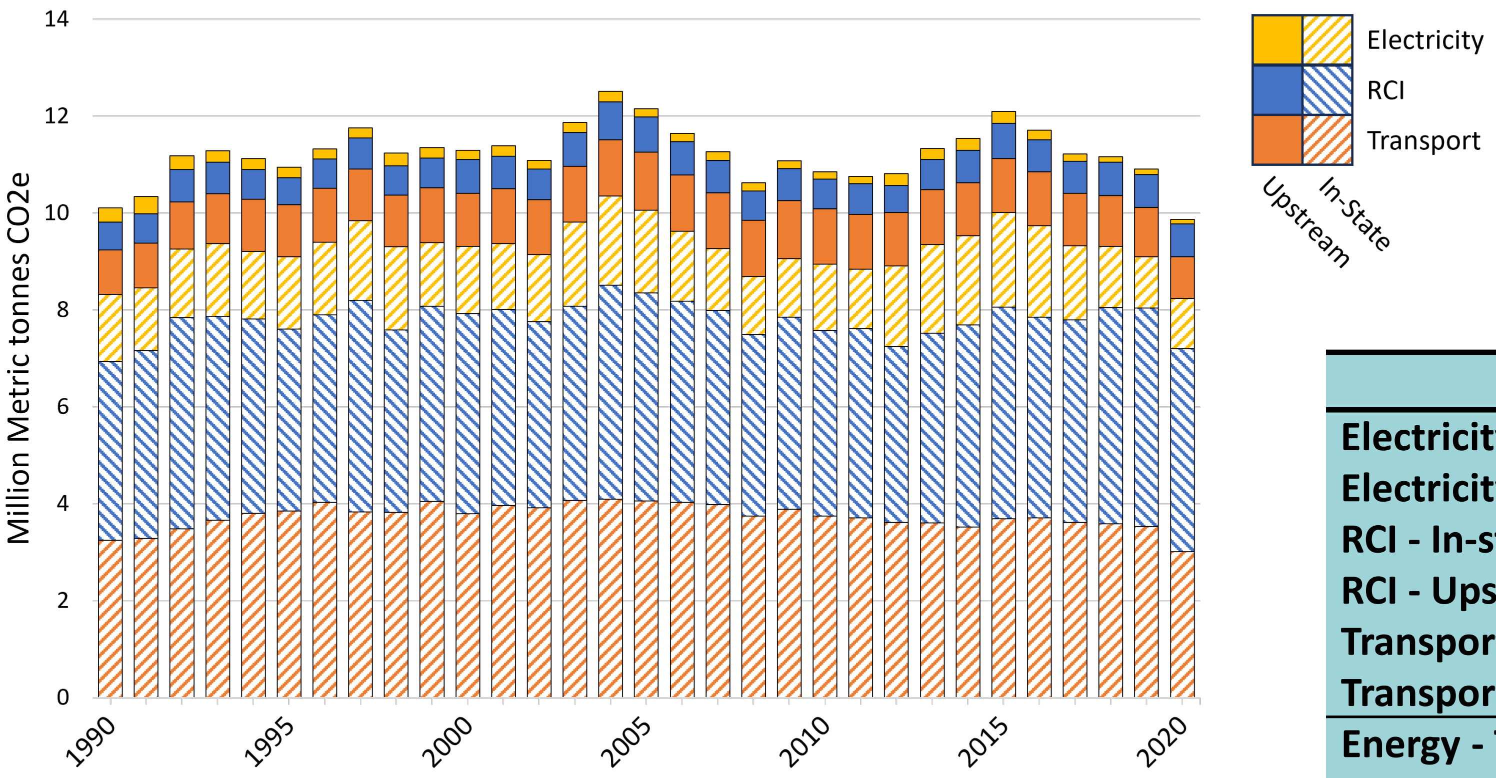
	A	B	C	D	E	F	G	H	I	J	K	L	
1	**Activity Data by Sector and Fuel**												
2		Sector-Fuel	Sector	Sub-Sector	Energy Commodity	Units	1990	1991	1992	1993	1994	1995	19
42		RCI Fuel - Industrial; Distillate Fuel	RCI Fuel	Industrial	Distillate Fuel	MMBtu	3,214,723	3,001,915	3,430,223	3,163,719	2,237,161	1,900,287	1
43		RCI Fuel - Industrial; Kerosene	RCI Fuel	Industrial	Kerosene	MMBtu	97,000	63,000	35,000	46,000	66,000	55,000	
44		RCI Fuel - Industrial; Hydrocarbon Gas Liquids	RCI Fuel	Industrial	Hydrocarbon Gas Liquids	MMBtu	164,741	442,573	442,992	408,117	369,020	403,386	
45		RCI Fuel - Industrial; Lubricants	RCI Fuel	Industrial	Lubricants	MMBtu	86,279	77,197	78,105	79,922	83,554	81,738	
46		RCI Fuel - Industrial; Motor Gasoline	RCI Fuel	Industrial	Motor Gasoline	MMBtu	425,000	463,000	472,000	395,000	438,000	461,000	
47		RCI Fuel - Industrial; Residual Fuel	RCI Fuel	Industrial	Residual Fuel	MMBtu	722,000	820,000	1,053,000	1,900,000	1,230,000	907,000	1
48		RCI Fuel - Industrial; Special Naphthas	RCI Fuel	Industrial	Special Naphthas	MMBtu	197,626	-	-	-	-	-	
49		RCI Fuel - Industrial; Waxes	RCI Fuel	Industrial	Waxes	MMBtu	186,414	-	-	-	-	-	
50		RCI Fuel - Industrial; Fossil Natural Gas	RCI Fuel	Industrial	Fossil Natural Gas	MMBtu	1,845,000	1,696,000	1,950,000	2,041,000	2,015,000	2,150,000	1
51		RCI Fuel - Industrial; RNG, Landfill	RCI Fuel	Industrial	RNG, Landfill	MMBtu	-	-	-	-	-	-	
52		RCI Fuel - Industrial; RNG, Animal Waste	RCI Fuel	Industrial	RNG, Animal Waste	MMBtu	-	-	-	-	-	-	
53		RCI Fuel - Industrial; Wood Chips	RCI Fuel	Industrial	Wood Chips	MMBtu	2,346,542	1,688,575	2,173,818	2,233,858	2,432,040	2,231,185	2
54		Transportation; Blended Motor Gasoline	Transportation		Blended Motor Gasoline	MMBtu	35,451,696	35,933,876	36,442,550	37,826,066	39,831,148	38,586,513	39
55		Transportation; Ethanol	Transportation		Ethanol	MMBtu	-	-	-	-	-	-	
56		Transportation; Fossil Motor Gasoline	Transportation		Fossil Motor Gasoline	MMBtu	35,451,696	35,933,876	36,442,550	37,826,066	39,831,148	38,586,513	39
57		Transportation; Fossil Diesel	Transportation		Fossil Diesel	MMBtu	6,075,000	6,189,000	8,369,000	9,625,000	9,784,000	11,532,000	12
58		Transportation; Bio Diesel	Transportation		Bio Diesel	MMBtu	-	-	-	-	-	-	
59		Transportation; Natural Gas	Transportation		Natural Gas	MMBtu	15,000	15,000	16,000	16,000	18,000	17,000	
60		Transportation; Jet Fuel	Transportation		Jet Fuel	MMBtu	1,020,600	918,540	657,720	703,080	782,460	720,090	
61		Transportation; Aviation Gasoline	Transportation		Aviation Gasoline	MMBtu	75,000	78,000	75,000	61,000	57,000	60,000	
62													

Pause for:

- Questions?
- Public Comment

Results

Energy Sector: Upstream and In-state emissions



With biogenic CO2

	1990	2000	2019	2020
Electricity - In-state	1.39	1.38	1.05	1.04
Electricity - Upstream	0.30	0.21	0.12	0.12
RCI - In-state	3.69	4.13	4.51	4.19
RCI - Upstream	0.58	0.69	0.69	0.67
Transport - In-state	3.25	3.80	3.53	3.01
Transport - Upstream	0.92	1.10	1.02	0.86
Energy - Total	**10.12**	**11.32**	**10.92**	**9.89**
Other* - In-state	1.84	2.30	2.29	2.18
Gross - In-state	10.17	11.61	11.38	10.42
Gross - Upstream	1.79	2.01	1.82	1.65
Total	**11.96**	**13.62**	**13.21**	**12.07**

Units: MMT CO2e (AR5-100yr); includes biogenic CO2

** Other includes the additional sectors captured in the VT GHG EI: Fossil Fuel Industry, Industrial Processes, Waste Management, and Agriculture.*

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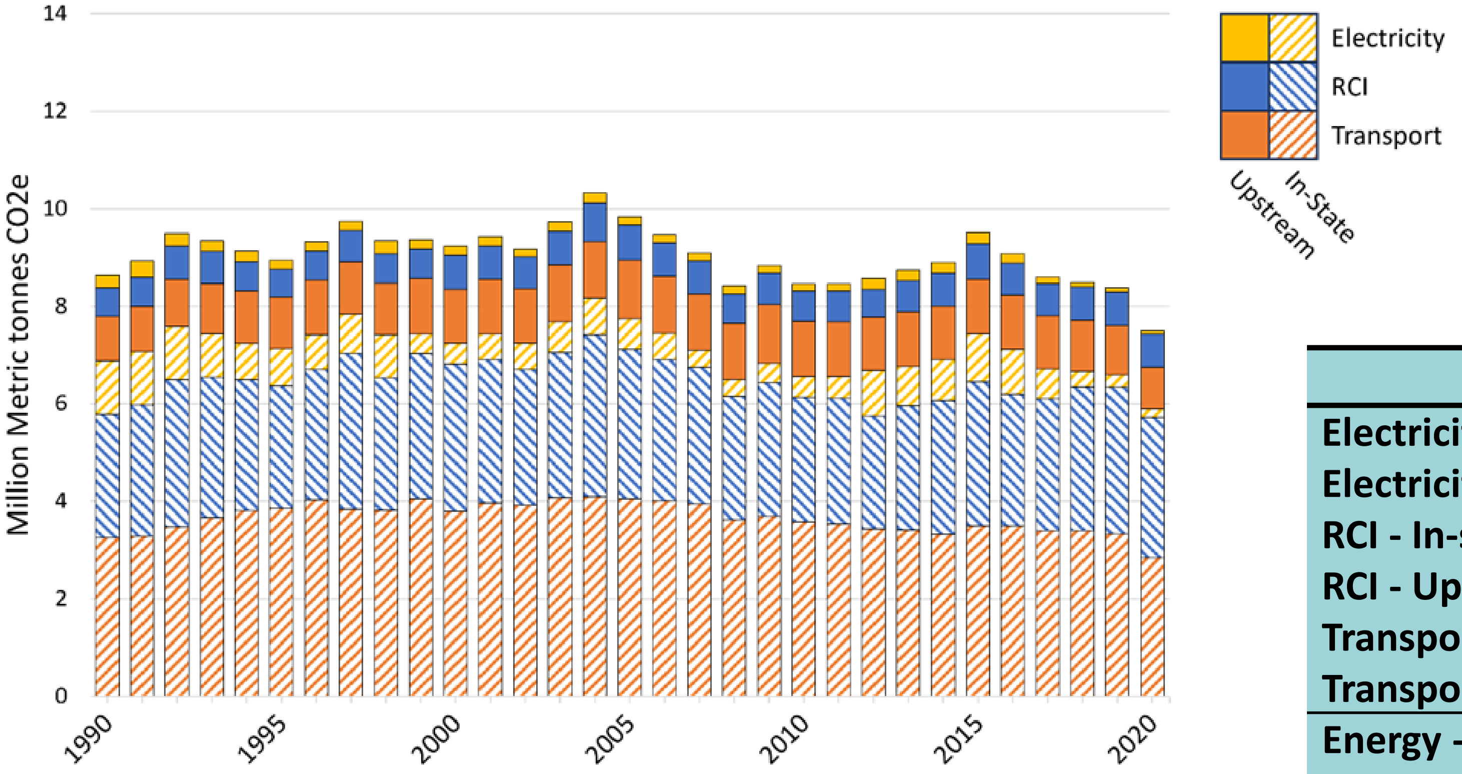
Energy Sector: Upstream and In-state emissions



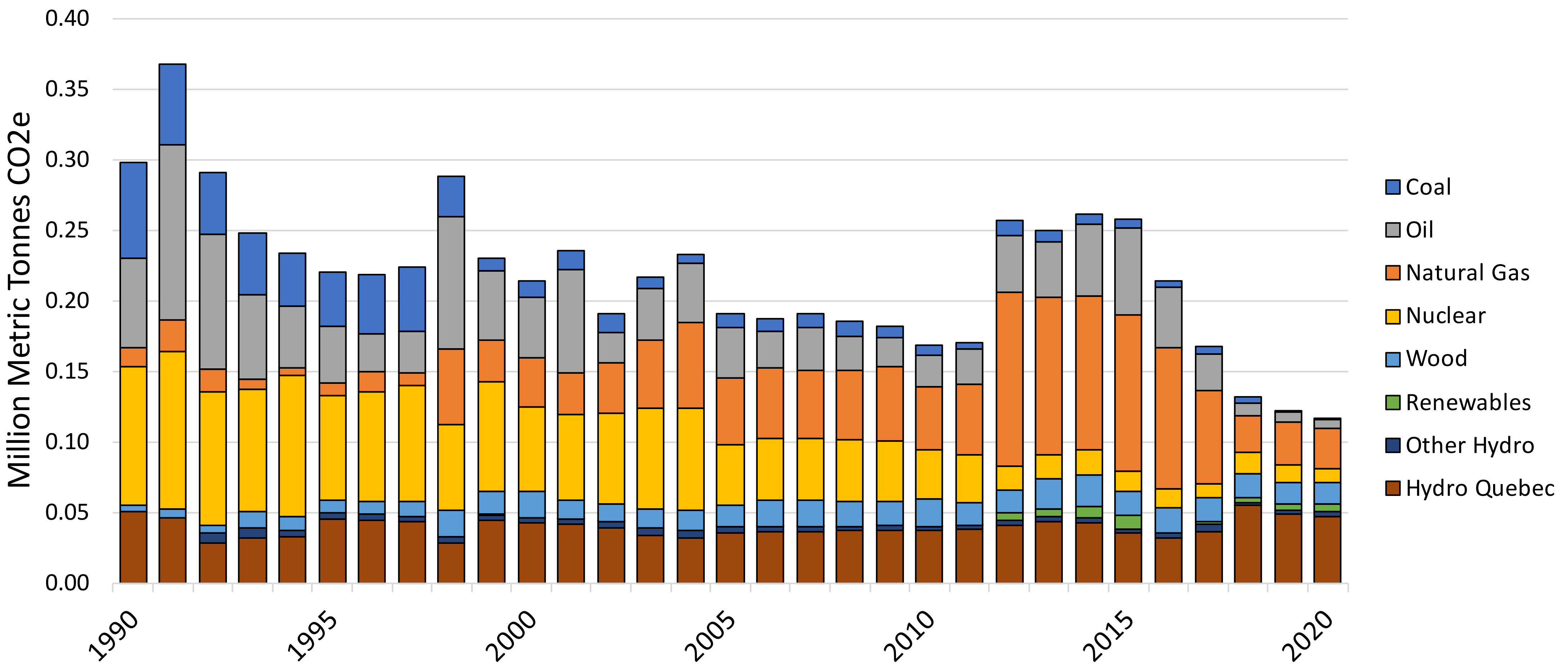
Units: MMT CO2e (AR5-100yr); <u>excludes</u> biogenic CO2

** Other includes the additional sectors captured in the VT GHG EI: Fossil Fuel Industry, Industrial Processes, Waste Management, and Agriculture.*

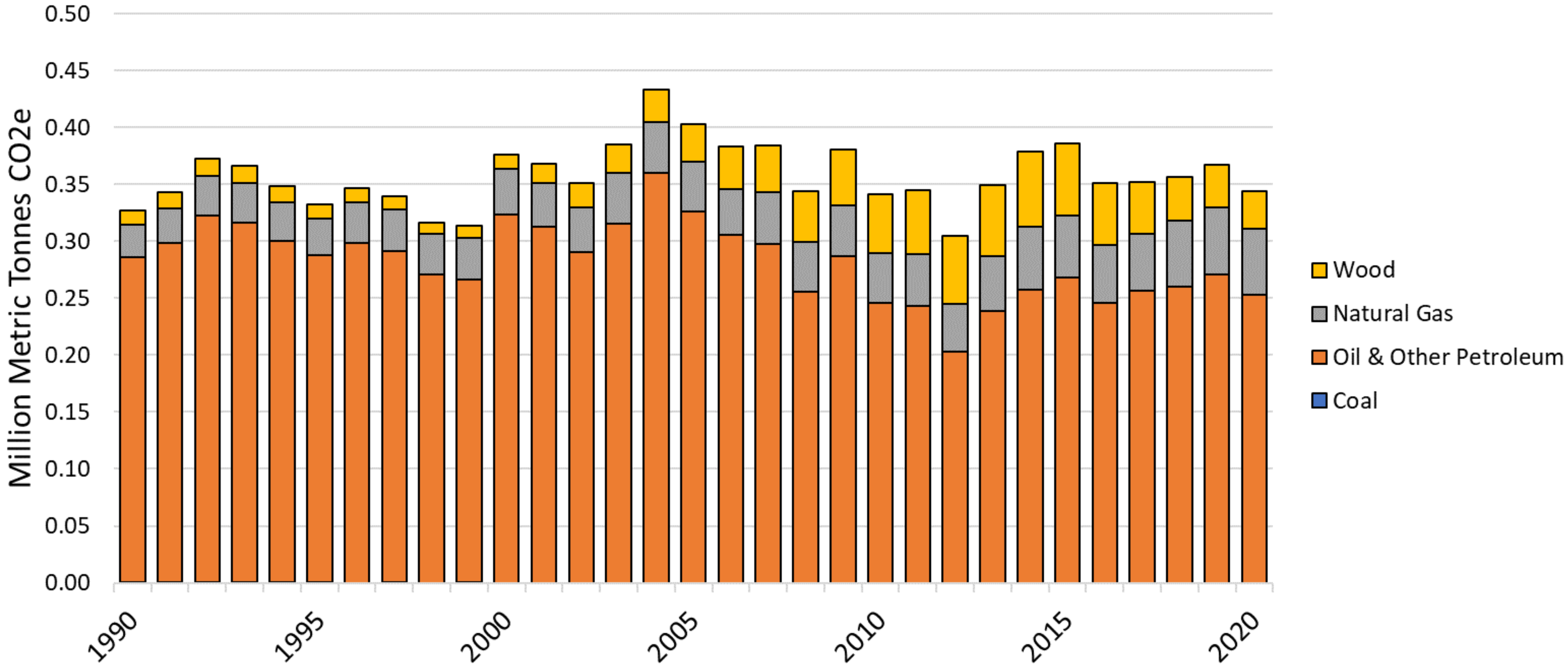
Without biogenic CO2

	1990	2000	2019	2020
Electricity - In-state	1.09	0.43	0.25	0.18
Electricity - Upstream	0.26	0.18	0.09	0.08
RCI - In-state	2.54	3.02	3.00	2.87
RCI - Upstream	0.58	0.69	0.69	0.67
Transport - In-state	3.25	3.80	3.34	2.85
Transport - Upstream	0.92	1.10	1.02	0.86
Energy - Total	**8.64**	**9.23**	**8.38**	**7.51**
Other* - In-state	1.73	2.14	2.20	2.10
Gross - In-state	8.61	9.39	8.79	7.99
Gross - Upstream	1.76	1.97	1.79	1.61
Total	**10.37**	**11.37**	**10.58**	**9.60**

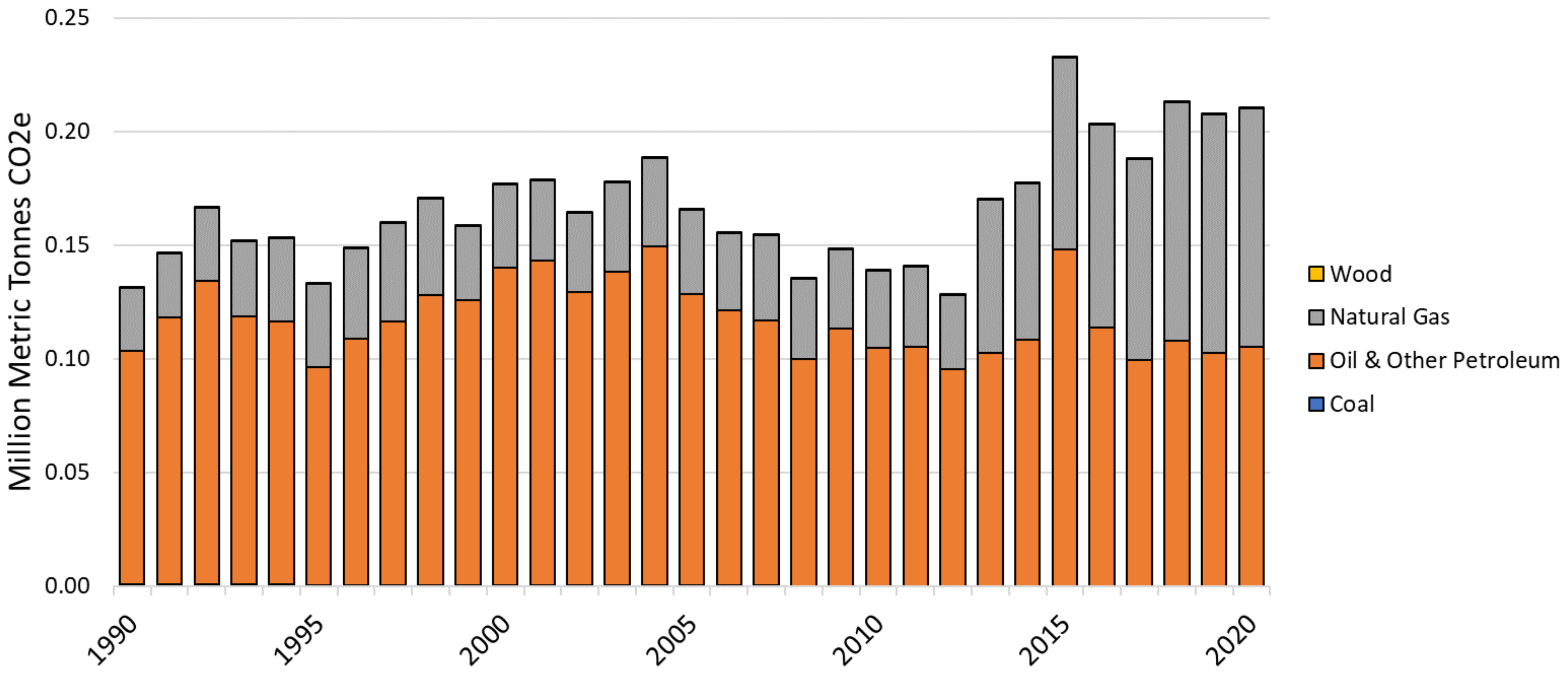
Upstream emissions for Electricity sector



Upstream emissions for Residential sector



Upstream emissions for Commercial sector



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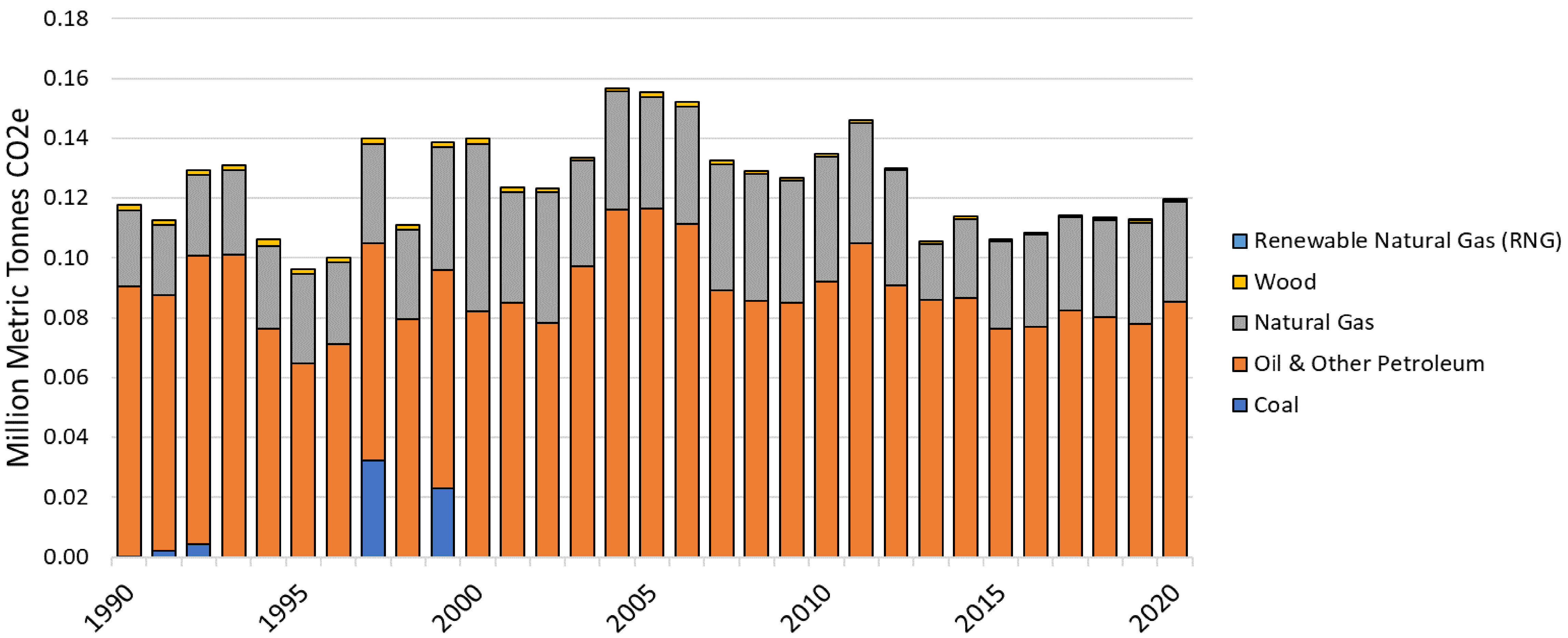
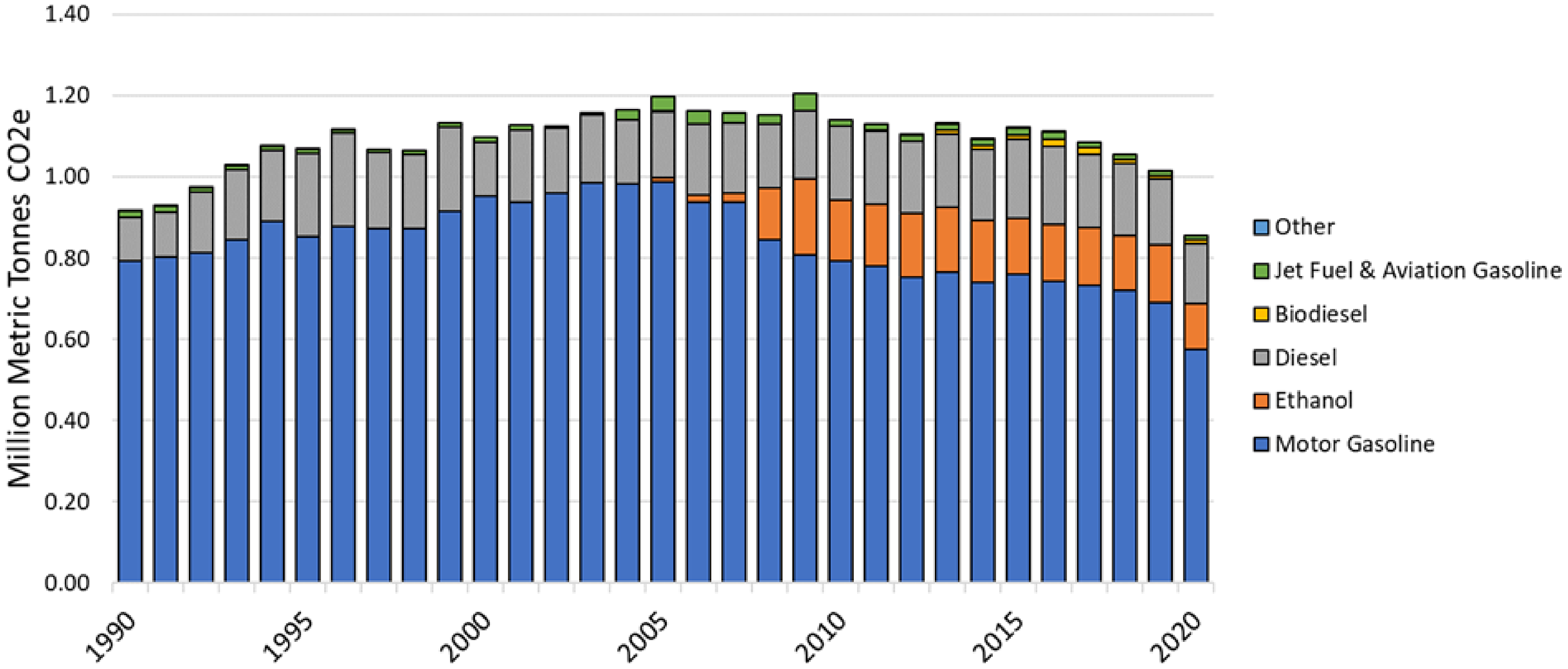
Upstream emissions for Industrial sector



Upstream emissions for Transportation sector



Summary

- Upstream emissions add approximately 20-30% to the GHG impact for the Energy Sector.
- Motor gasoline for transport is the largest single contributor to upstream emissions in 2020.
- Upstream emissions from petroleum products are consistently the highest contributor to upstream emissions within RCI sectors.
- Upstream emissions from hydroelectric power are a small but significant contributor to upstream electricity emissions, especially as the fossil contribution to electricity consumption has decreased.

Future Efforts

- Currently unable to find Traditional Ecological Knowledge (TEK) experts to provide guidance, but will continue to pursue engagement to inform TEK efforts outside of this contract process

- With passage of Affordable Heat Act (S.5), ANR obligated to do a life-cycle analysis annually presenting an ongoing opportunity to learn and adapt our framework and develop additional supplemental analyses

- Potential for multi-attribute analysis that would incorporate other factors outside of GHG emissions and would have the potential to incorporate non (or not easily)-quantifiable considerations surrounding energy pathway choices related to TEK after engagement with TEK experts.

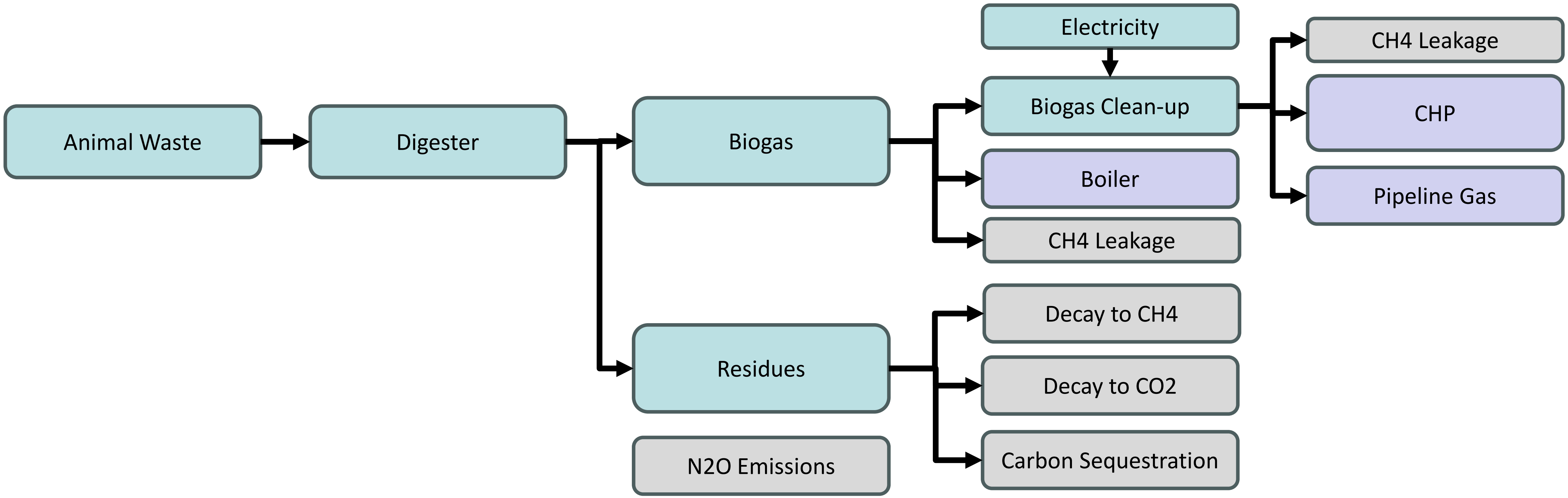
Questions and Public Comment

Appendix

Pathway 2: Renewable Natural Gas (RNG) from Animal Waste

Source: https://vanguardrenewables.com/projects/goodrich-family-farm

Pathway 2: Animal Waste RNG



Pathway 2: Animal Waste RNG