Impacts of Carbon Capture on Life Cycle Inventory of Ammonia and Petroleum Products for Comparison with Thermoelectric Power Generation

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Disclaimer and Attribution

DISCLAIMER

Attribution

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Contents

- **Project Goal: Support LCA of carbon capture at industrial sources**
- **Methods:**
  - Full gate-to-gate LCI
  - Carbon capture model development and validation
- **Preliminary Results**

Project Goal

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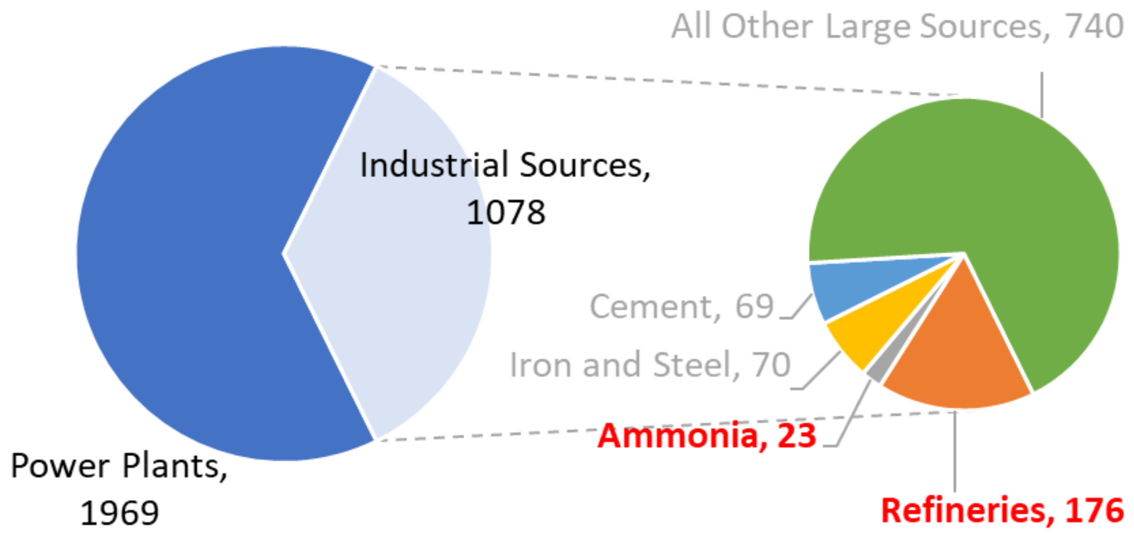
Prepare life cycle inventories suitable for LCA of carbon capture at industrial facilities.

- **Create updated unit processes for a petroleum refinery, ammonia plant, and selected inputs**
  - Transparent, supportive of all TRACI impact categories, based on publicly available data
- **Create variants of the refining and ammonia processes with carbon capture**

Selection of Candidates for Capture

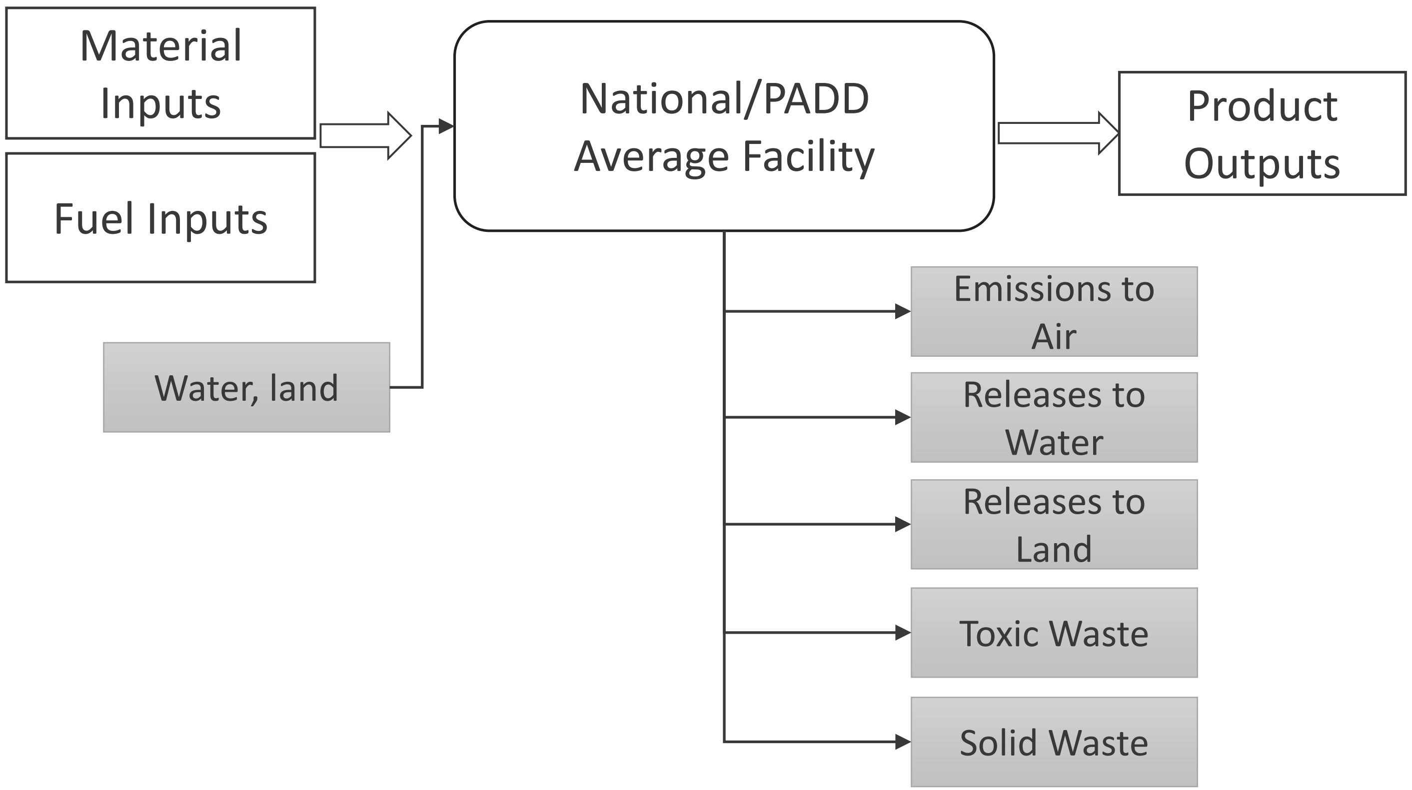
- Capture efficiency dependent on CO_2 concentration in emissions stream
- Considered sectors with large CO2 sources that contribute significantly to U.S. greenhouse gas emissions.
- Ammonia – concentrated CO_2 streams from combustion and SMR processes, significant in fertilizer and chemical supply chains.
- Petroleum refining – large industrial source, significant in chemical and fuel supply chains.



Greenhouse Gas Emissions by Sector (MMT CO2 eq.)

System Boundaries

- **Gate – to – Gate System**
- **Complete inventory**
  - Air Emissions
  - Releases to Water
  - Releases to Land
  - Solid and Toxic Waste
  - Fuel Consumption
  - Material Inputs
- **Reference Flows**
  - Petroleum throughput
  - Ammonia
  - Captured CO_2



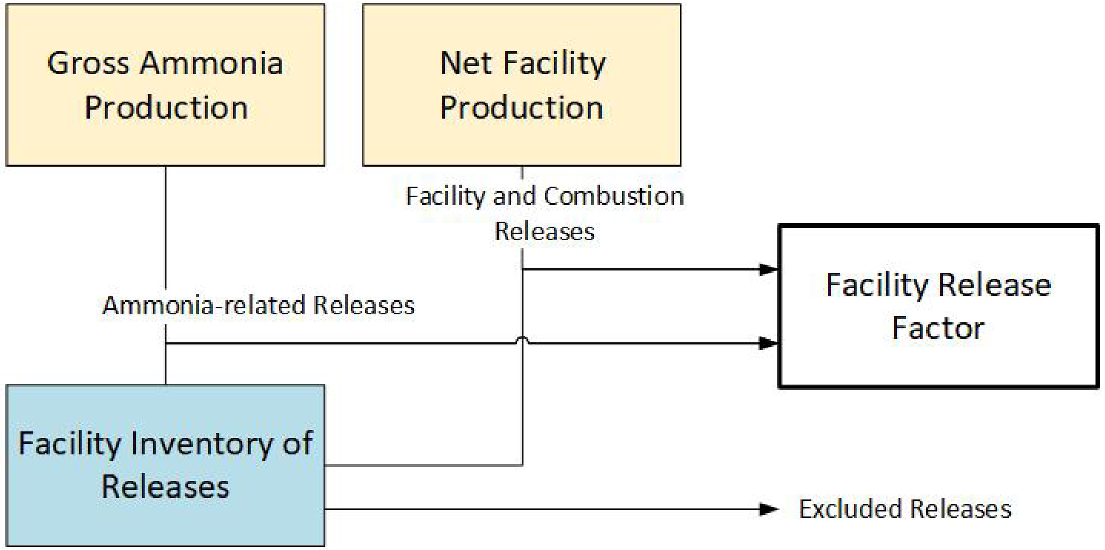
Data Sources

Data source	Provider	Description	Facility Detail?	Year
Environmental Releases:				
National Emissions Inventory	EPA	Comprehensive inventory of point source emissions of criteria and hazardous air pollutants.	Y	2014
Toxics Release Inventory	EPA	Toxic releases to air, water, and land reported by RCRA regulated facilities.	Y	2014
Greenhouse Gas Reporting Program	EPA	Greenhouse gas emissions reported by regulated facilities.	Y	2014
Discharge Monitoring Reports	EPA	Reported and/or estimated effluent amounts and characteristics	Y	2014
Inputs, Intermediate Flows, and Product Outputs:				
Refinery Capacity Report	EIA	Production and throughput capacities reported by U.S. refineries.	Y	2014
Refinery Production	EIA	Refinery production by PADD.	N	2014
Fuels Used by Refineries	EIA	Use of fuels by refineries by PADD.	N	2014
Chemical Data Reporting	EPA	Production of chemicals reported by TSCA regulated facilities.	Y	2012/2016

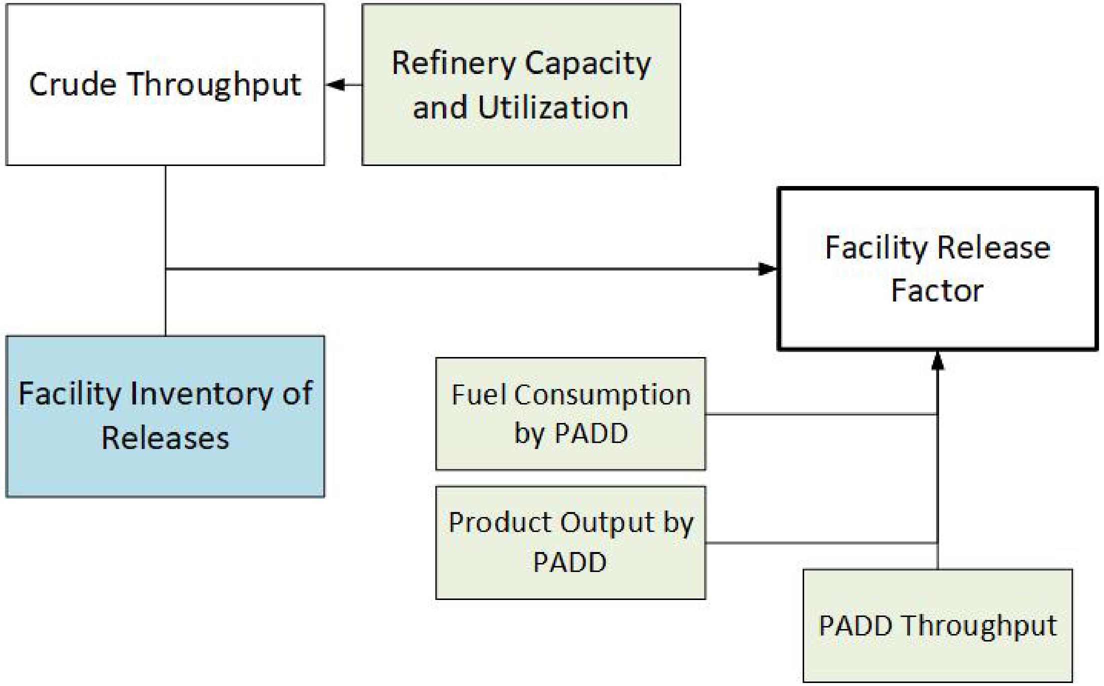
LCI Data Mining (Cashman et al. 2016)

Piecing together sector-relevant data

EIA | NEI, GHGRP, DMR, TRI | CDR



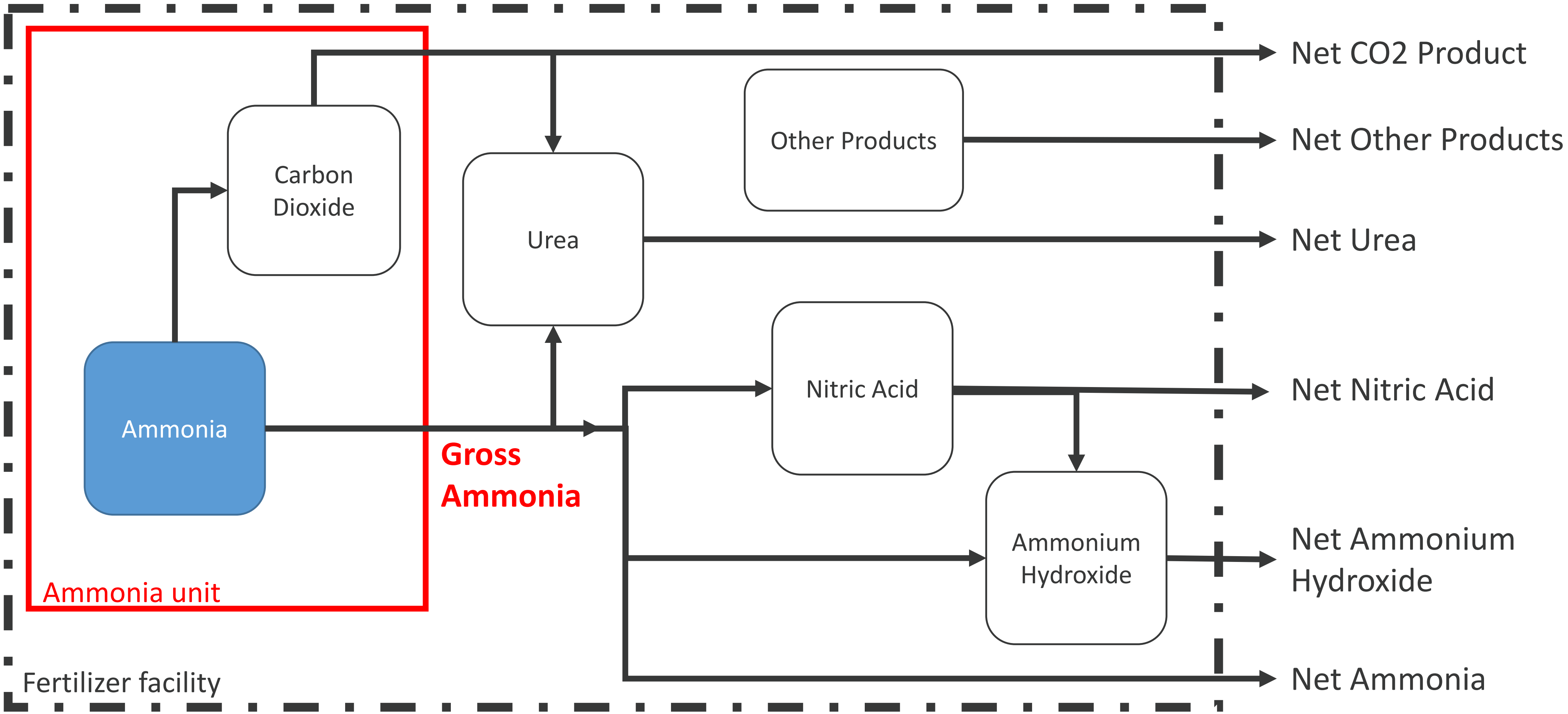
Ammonia Facility



Petroleum Refinery

System Boundaries

Ammonia Facility (1 kg ammonia)

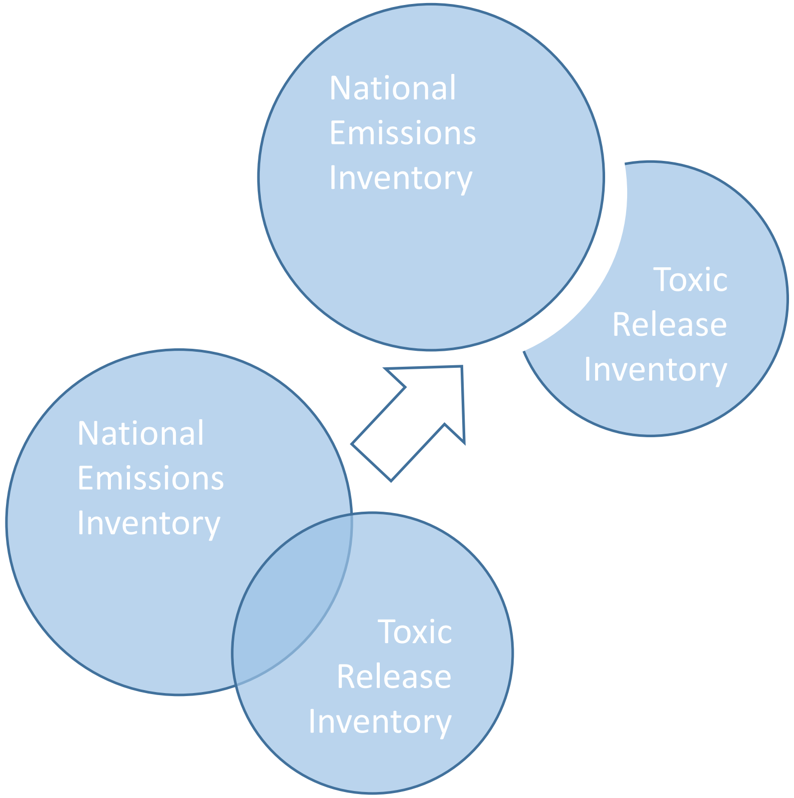


Estimate facility-specific unit processes

1. Assess completeness
2. Facility specific release factors
3. Quality control

Select and relate data across datasets

- Remove duplicate flows within and between datasets
- Estimate petroleum throughput at refineries (EIA)
- Assign emissions to ammonia unit at ammonia facilities (NEI)



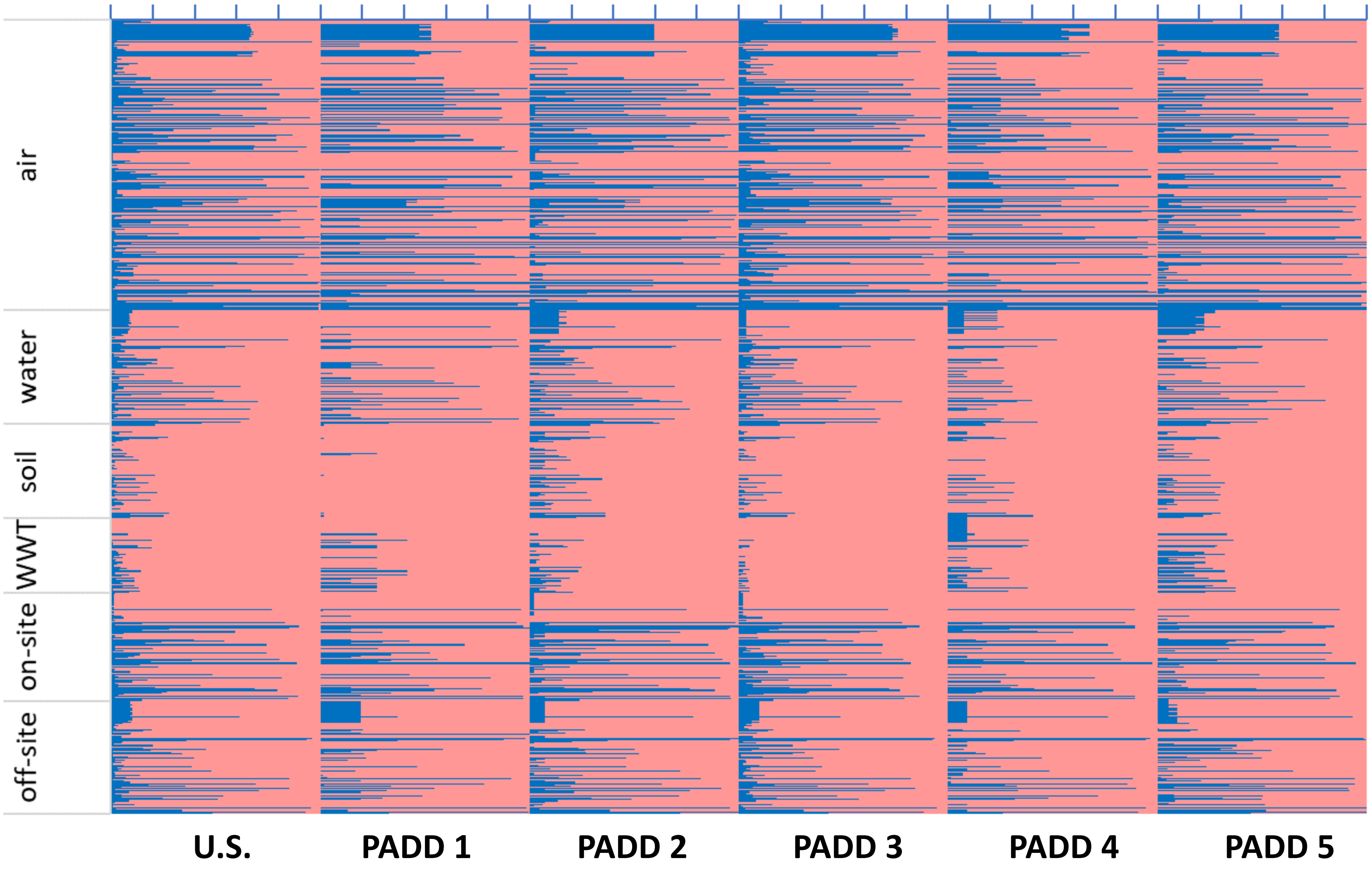
Consistency across facilities

Differences in releases reported

613 total flows

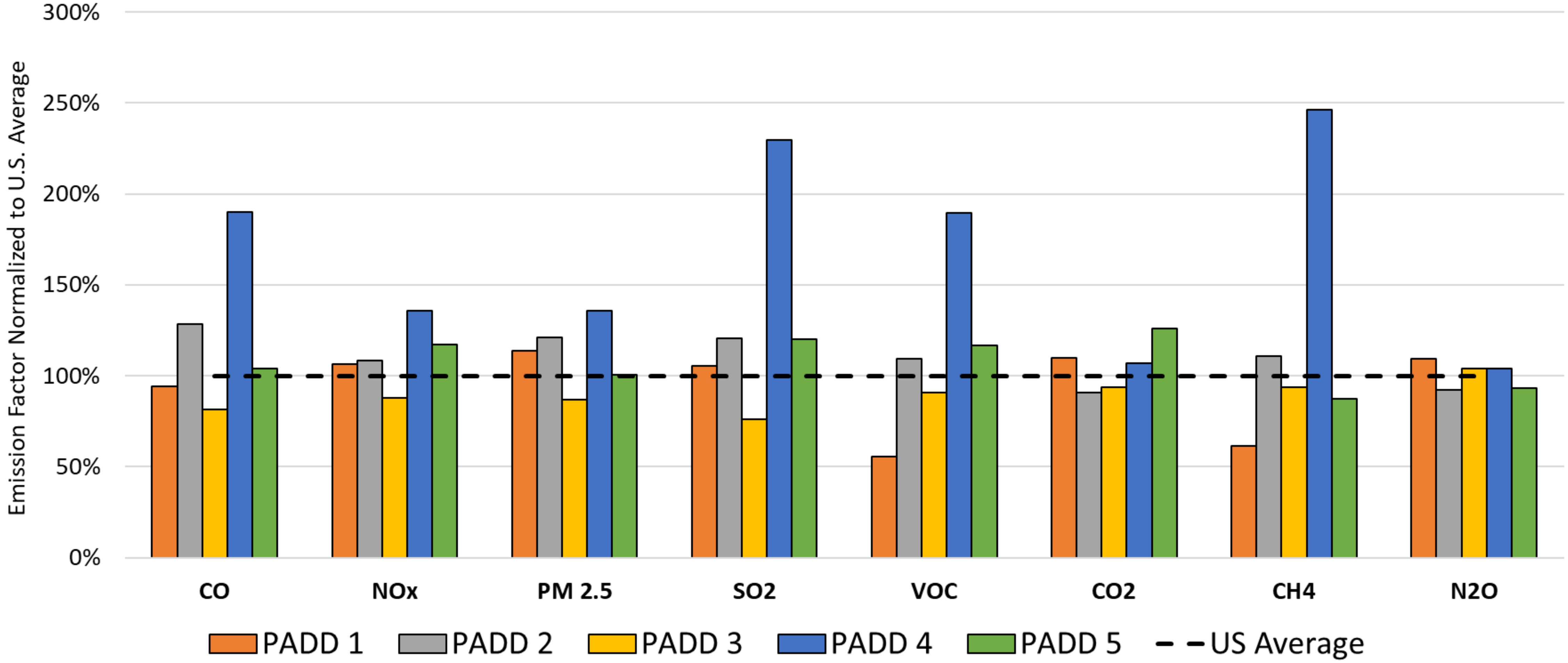
Production weighted averages include only facilities reporting both production and releases

(Sengupta et al. 2015)

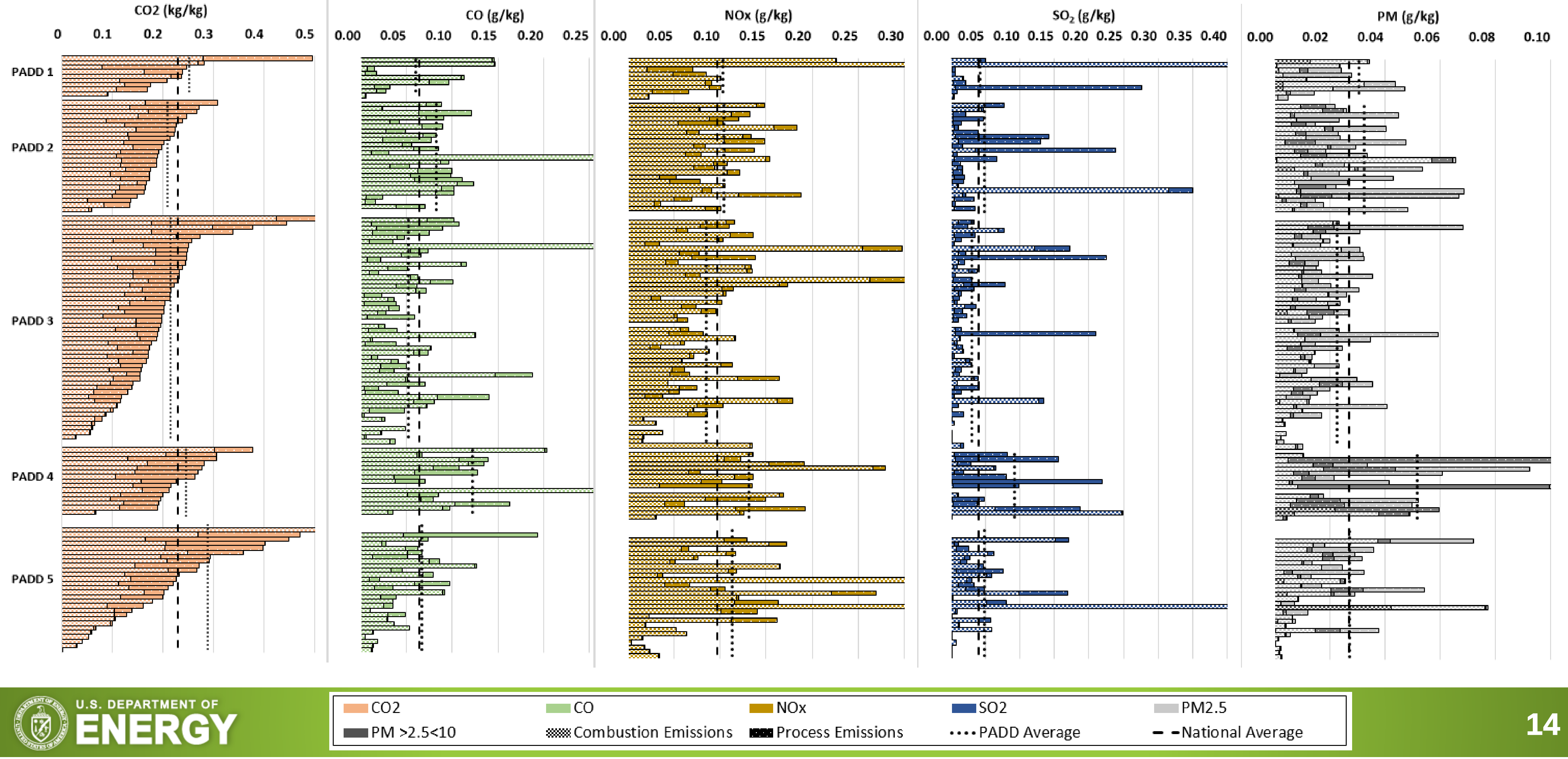


Petroleum Refining EFs by PADD

Production Weighted Average Emission Factors by Petroleum Administration for Defense District (PADD)



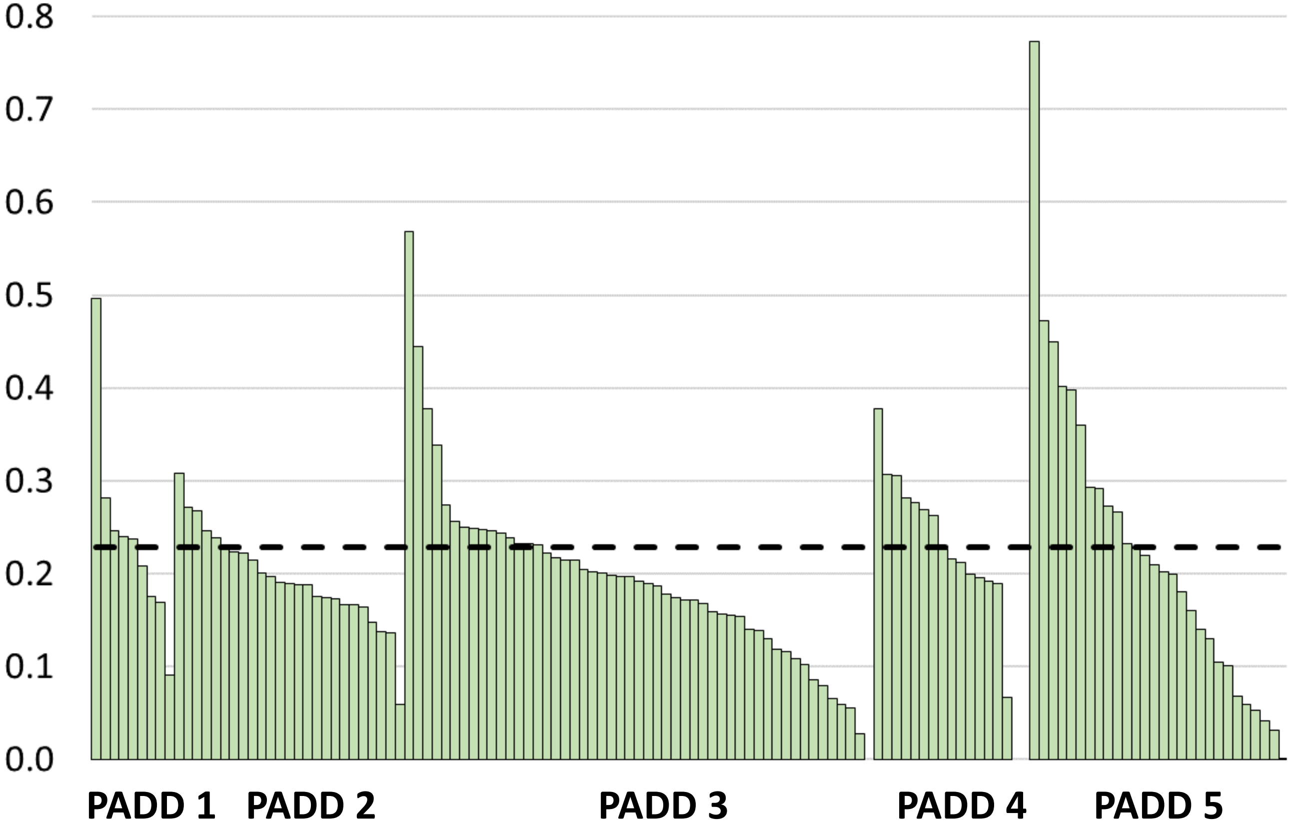
Petroleum Refining EFs by Facility

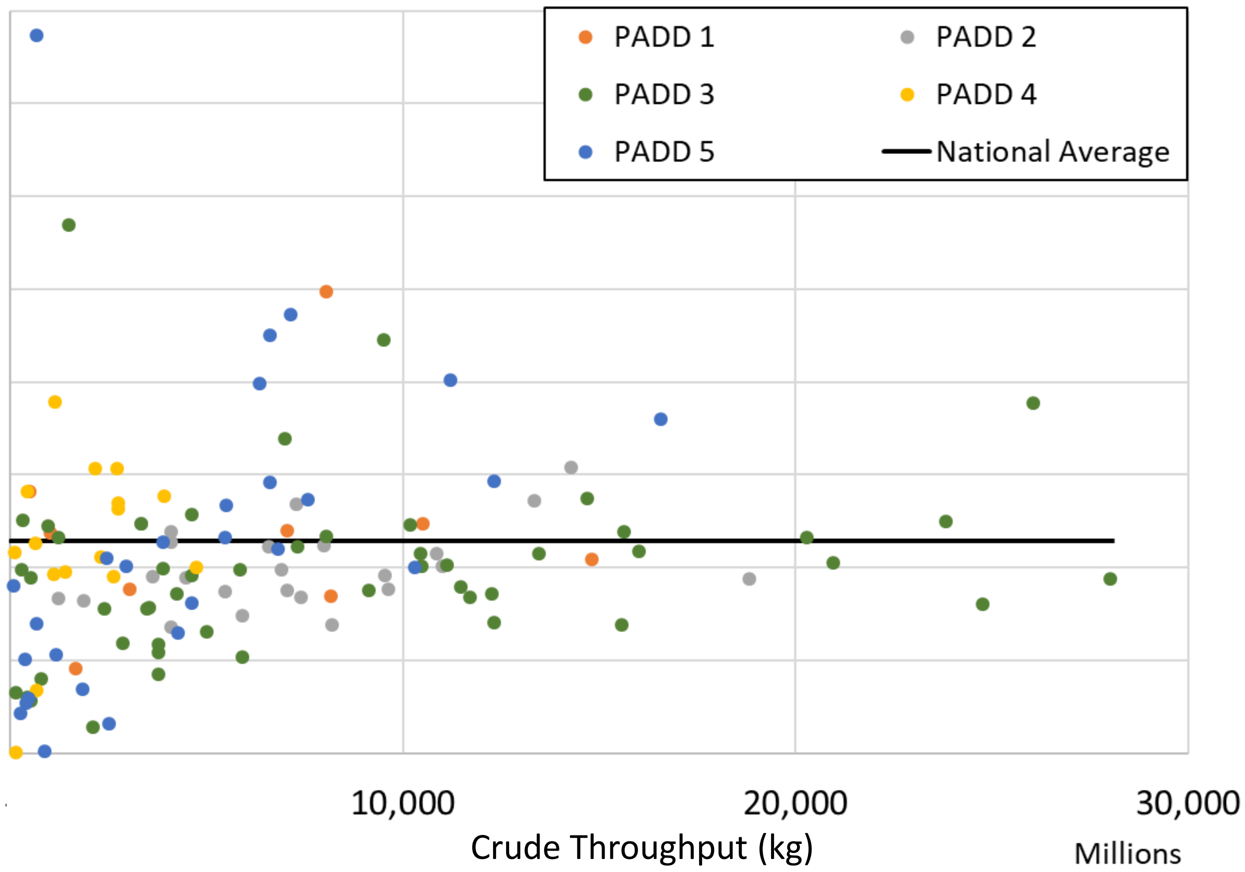


Petroleum Refining EFs by Facility

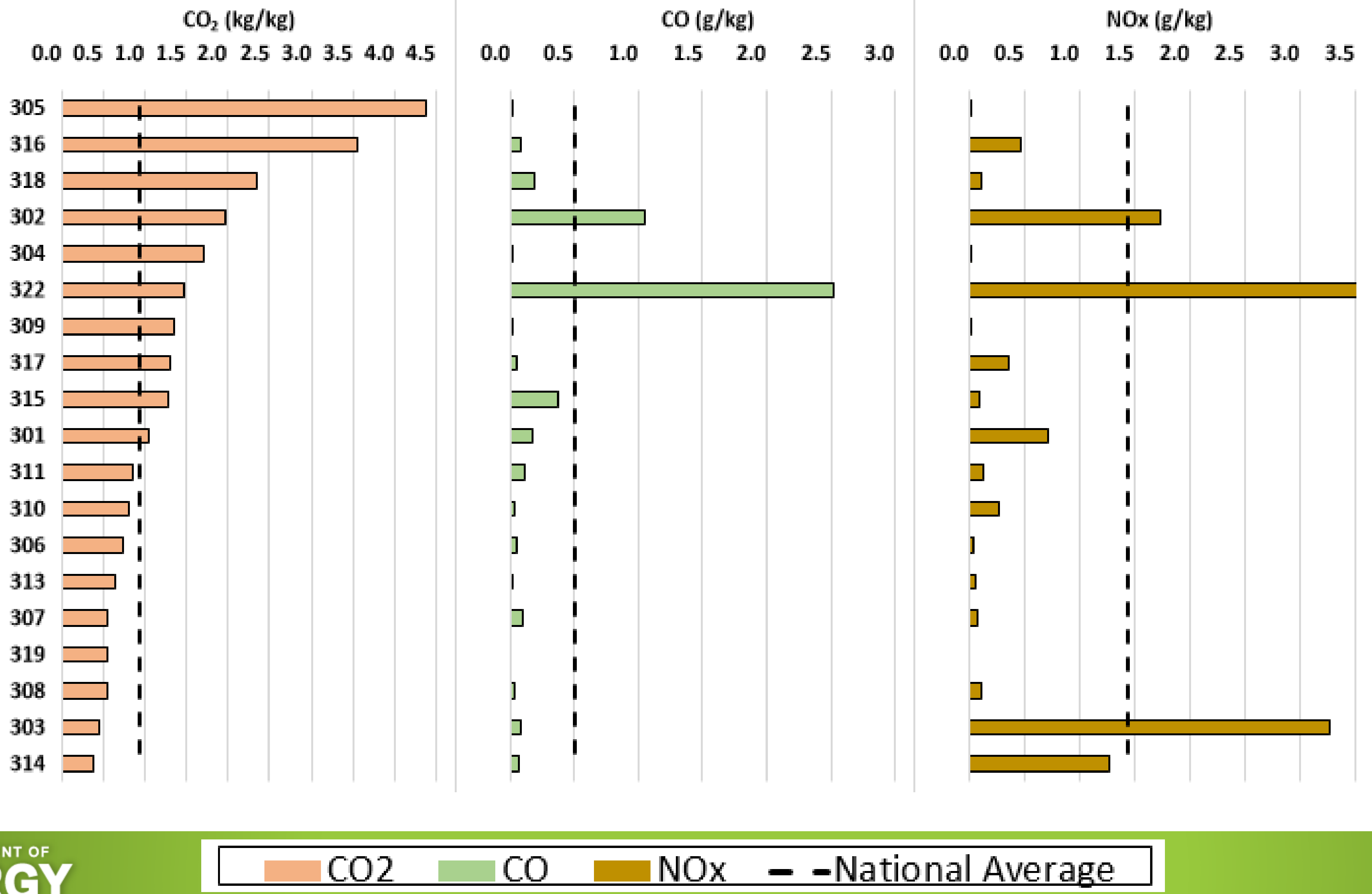
More variation in emission factors for smaller facilities

Carbon dioxide (kg / kg crude)





Ammonia Facility Emission Factors

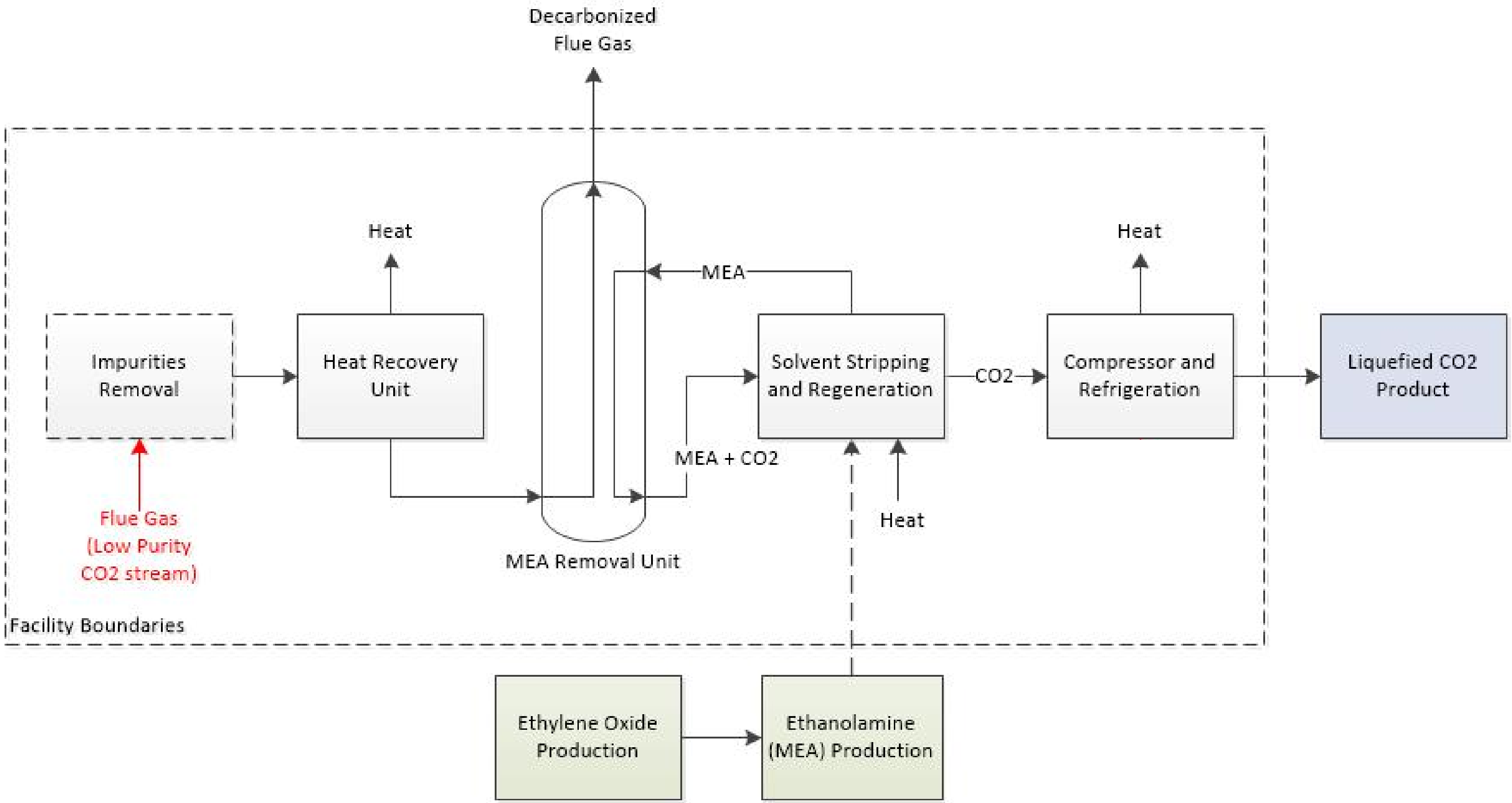


Capture Model Development

Monoethanolamine (MEA) Unit

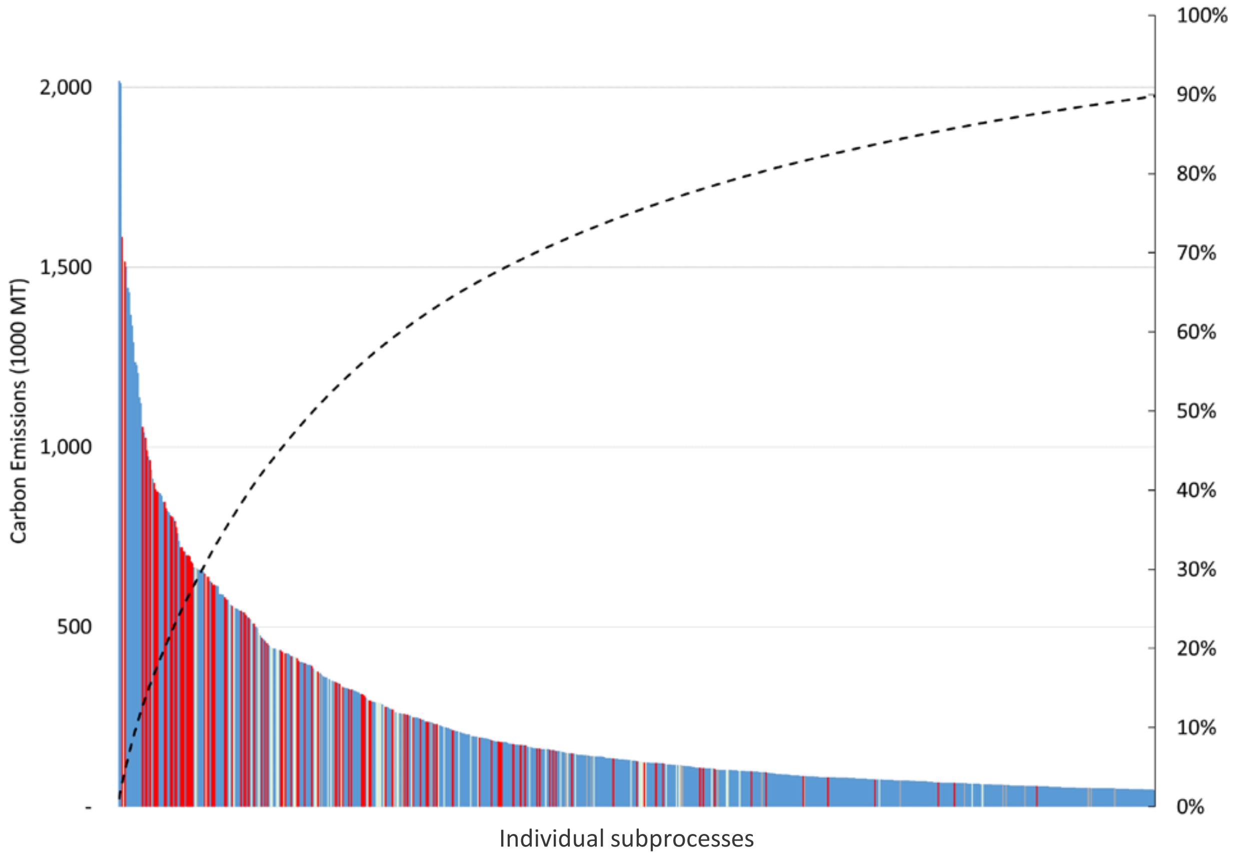
Model Parameters

- Energy consumption
- Emissions from fuel combustion
- Capture of other air emissions
- Releases from capture unit

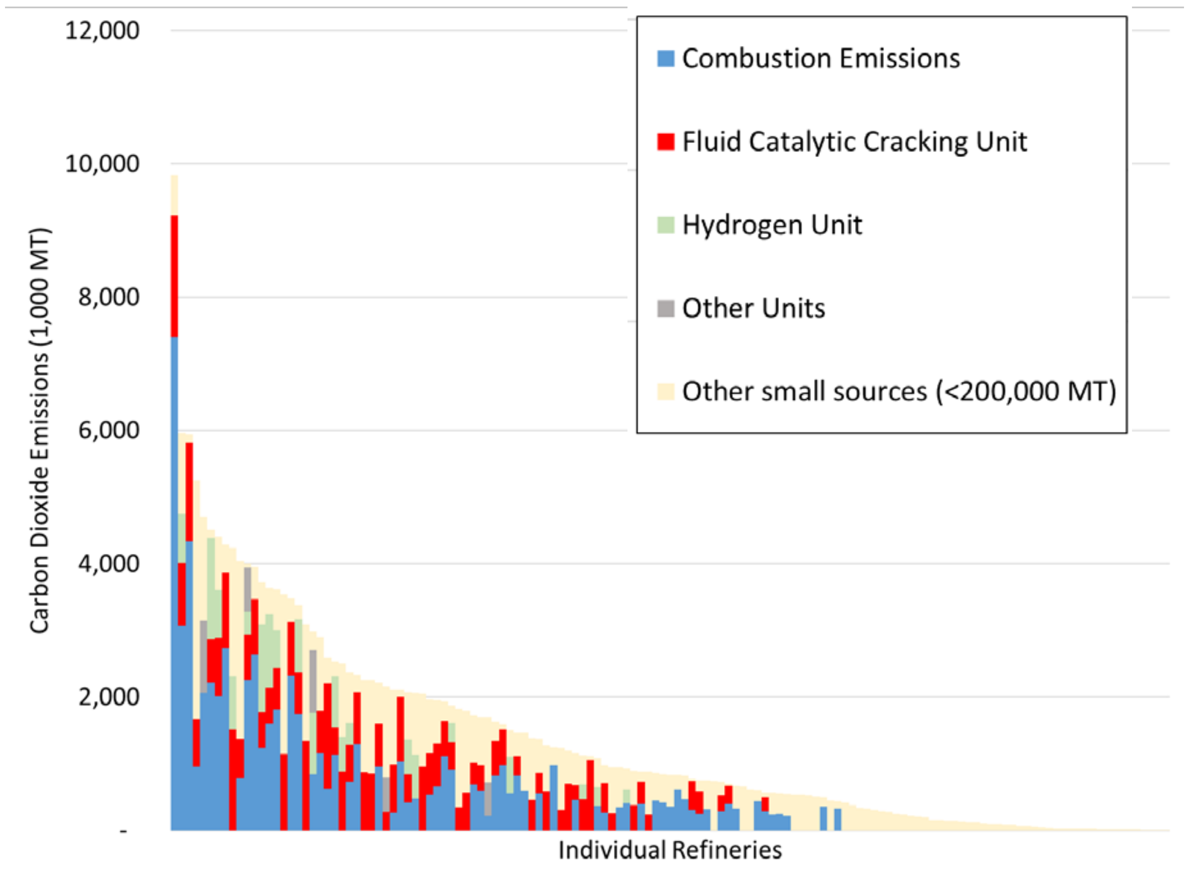


How Much CO_2 is Available for Capture?

Refinery CO_2 Emissions by Subprocess



Refinery CO_2 Emissions by Facility & Subprocess



30% of Refinery CO_2 Available for Capture

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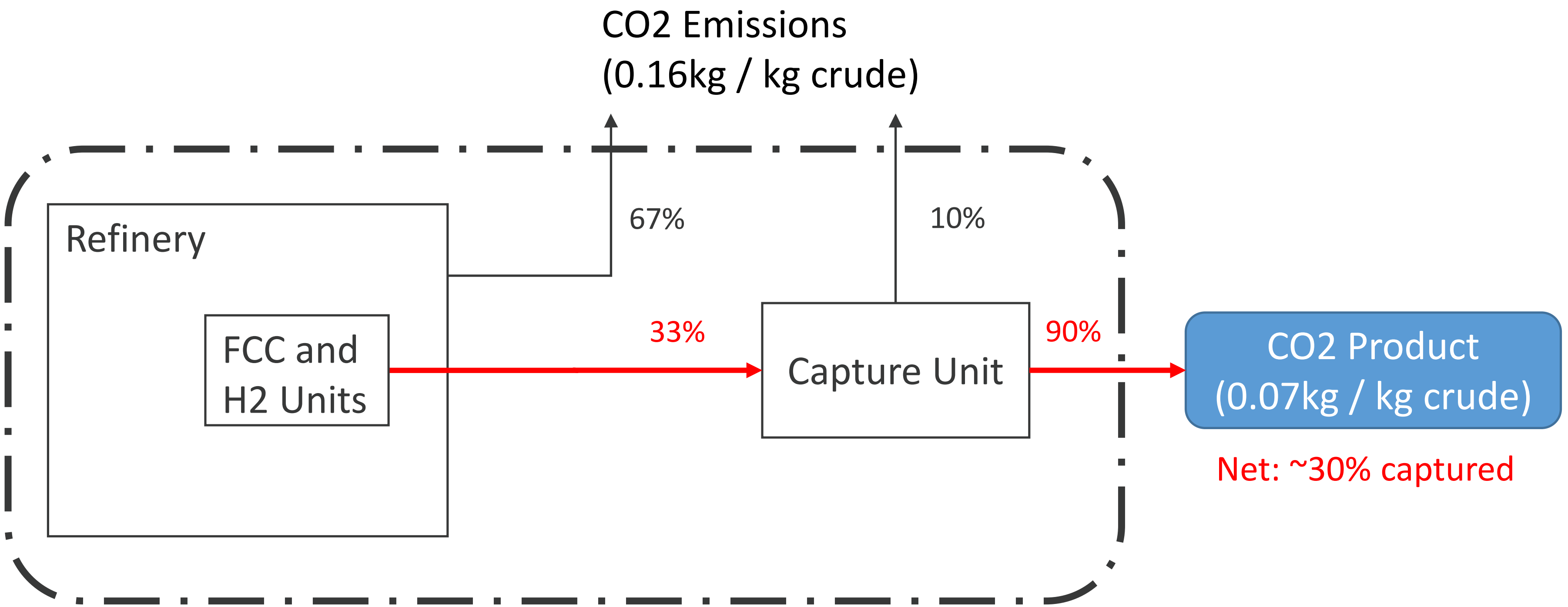
- Capture Unit coverage on emissions from Hydrogen Unit and Fluid Catalytic Cracker



Impacts of Capture on Inventory

Impacts on Flue Gas Emissions

- ↓ SO_2 (enhanced SO_2 removal prior to capture)
- ↓ NO_x (NO_x co-capture)
- ↑ VOCs (solvent degradation products)
- ↑ NH_3 (solvent degradation product)
- ↔ PM (no reduction in PM)

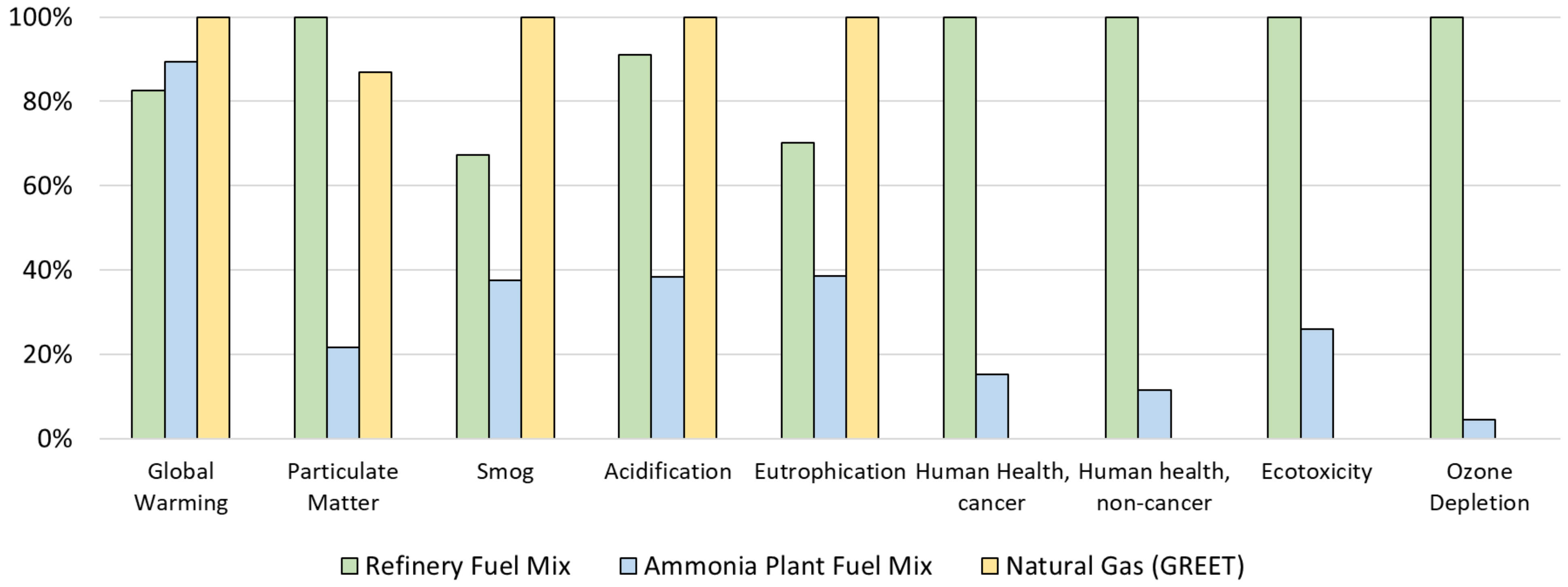
Direct impacts on flue gas from capture

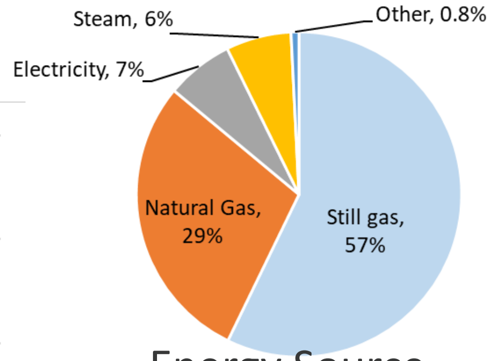
- Uncertainty in magnitude of impact
- Impacts may be negligible in context of overall refinery life cycle

Impacts of Capture on Inventory

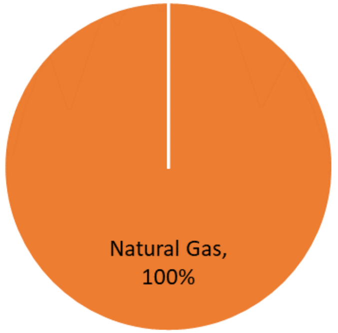
Fuel Combustion Emissions

Facility fuel mix – reflects actual emissions from GHGRP and NEI corresponding to reported fuel mix





Energy Source, Average US Refinery



Energy Source, Average US Ammonia Plant

Impacts of Capture on Inventory

Gate-to-Gate TRACI Impacts, 1 kg Crude with Capture

	Change in Release	Global Warming	Acidification	Particulate Matter	Eutrophication	Ozone Depletion	Smog	Human Health, cancer	Human health, non-cancer	Ecotoxicity
carbon dioxide	(24%)	(23%)	-	-	-	-	-	-	-	-
methane	2%	0.0%	-	-	-	-	0.0%	-	-	-
nitrous oxide	6%	0.0%	-	-	-	-	-	-	-	-
nitrogen oxides	3%	-	4%	0.2%	3%	-	6%	-	-	-
sulfur dioxide	(15%)	-	(5%)	(1%)	-	-	-	-	-	-
ammonia	228%	-	13%	2%	9%	-	-	-	-	-
particulates, < 2.5 um	4%	-	-	3%	-	-	-	-	-	-
particulates, < 10 um, > 2.5 um	1%	-	-	0.0%	-	-	-	-	-	-
carbon monoxide	5%	-	-	0.0%	-	-	0.0%	-	-	-
VOC, volatile organic compounds	1%	-	-	-	-	-	0.1%	-	-	-
acetaldehyde	1055%	-	-	-	-	-	0.1%	0.3%	0.0%	0.0%
ethanolamine	*	-	-	-	-	-	0.1%	-	-	0.0%
acetone	*	-	-	-	-	-	0.0%	-	0.0%	0.0%
All other combustion emissions	n.a.	0.0%	0.0%	-	0.0%	5%	0.0%	3%	2%	0.1%
Total		(23%)	12%	4%	12%	5%	6%	3%	2%	0.2%

Note: *No reported emissions without capture unit

Percent change in impact from U.S. Average Refinery compared to a U.S. average refinery with carbon capture on the Fluid Catalytic Cracker and Hydrogen Units. Negative (green) values indicate a reduction in impact due to the carbon capture unit.

Impacts of Capture on Inventory

Gate-to-Gate TRACI Impacts, 1 kg Ammonia with Capture

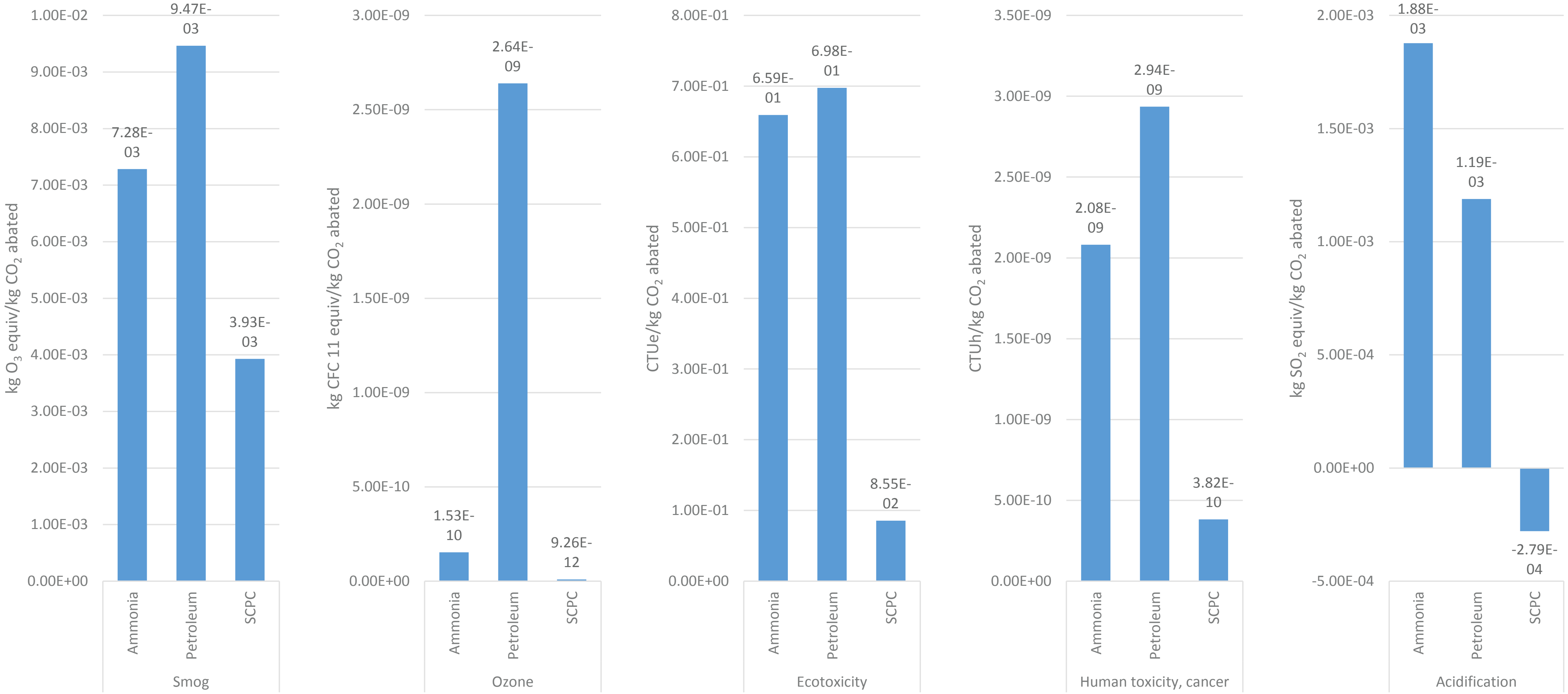
	Change in Release	Global Warming	Acidification	Particulate Matter	Eutrophication	Ozone Depletion	Smog	Human Health, cancer	Human health, non-cancer	Ecotoxicity
carbon dioxide	(45%)	(45%)	-	-	-	-	-	-	-	-
methane	16%	0%	-	-	-	-	0%	-	-	-
nitrous oxide	16%	0%	-	-	-	-	-	-	-	-
nitrogen oxides	(8%)	-	(4%)	(0%)	(1%)	-	(7%)	-	-	-
sulfur dioxide	(15%)	-	(0%)	(0%)	-	-	-	-	-	-
ammonia	14%	-	6%	3%	2%	-	-	-	-	-
particulates, < 2.5 um	1%	-	-	1%	-	-	-	-	-	-
particulates, < 10 um, > 2.5 um	0%	-	-	0%	-	-	-	-	-	-
carbon monoxide	1%	-	-	0%	-	-	0%	-	-	-
VOC, volatile organic compounds	1%	-	-	-	-	-	0%	-	-	-
acetaldehyde	7071%	-	-	-	-	-	0%	1%	0%	0%
ethanolamine	*	-	-	-	-	-	0%	-	-	0%
acetone	*	-	-	-	-	-	0%	-	0%	0%
All other combustion emissions	n.a.	0.0%	0.0%	-	(0.0%)	16.1%	0.0%	1.9%	0.3%	0.0%
Total		(45%)	2%	3%	1%	16%	(7%)	3%	0%	0.0%

**No reported emissions without capture unit*

Percent change in impact from U.S. Average Ammonia Plant compared to a U.S. Average Ammonia Plant with carbon capture. Negative (green) values indicate a reduction in impact due to the carbon capture unit.

Comparative Results

Functional unit is **1kg carbon dioxide abated**. SCPC results from NETL baseline.



Discussion

- **With industrial carbon capture, as CO_2 emissions ⬇ other impacts ⬆**
  - Impacts from increased energy to run capture system, production remains the same
- **Functional unit choice is difficult**
  - Different products make capture difficult to compare
  - Carbon dioxide abated is a consistent unit of comparison but not particularly useful
    - Few decisions will be made on the environmental impacts of added capture
  - More useful might be analysis that includes costs, feasibility, size of the prize
- **Boundaries are not useful in other contexts (full LCA results)**

Discussion

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- **Public data can be used to generate facility specific unit processes**
  - Variation due to differences in refinery configuration, crude assay, fuels, and controls
  - Greater variability for smaller facilities
  - Important to understand co-products at facilities

- **Capture model can incorporate reported data at facilities to better reflect *actual* production releases and fuel mix**

- **Primary drivers of TRACI impacts within the facility gate**
  - Energy used by capture unit and fuel mix
  - Degradation of MEA solvent (i.e. ammonia)

Thank you!

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