Regional Differences in Life-Cycle Greenhouse Gas and Criteria Air Pollutant Emissions of Passenger Cars in the United States

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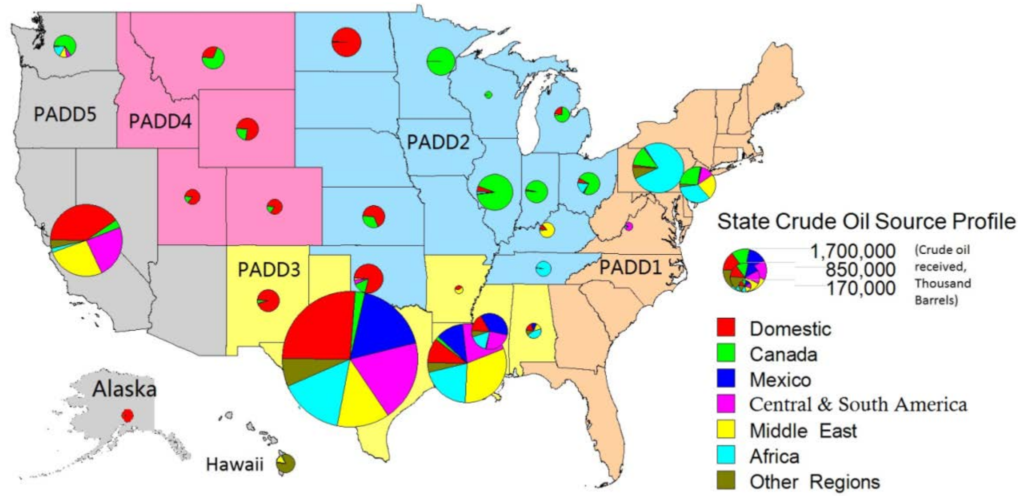
Presentation Outline

- Background and Objectives
- Regional Life-Cycle Analysis (LCA) Boundary
- Methods and Data
- Results
- Conclusions

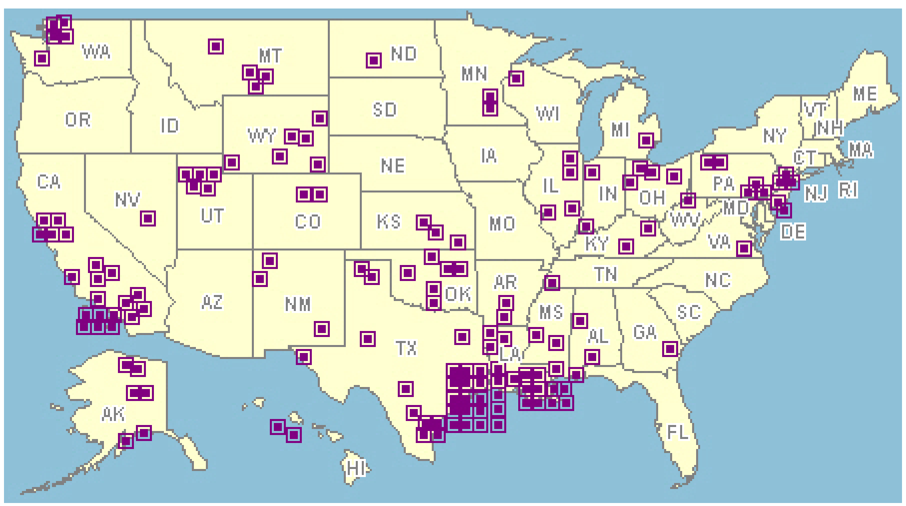
Background

Regional LCA is a step forward towards informing regional policy decision-making

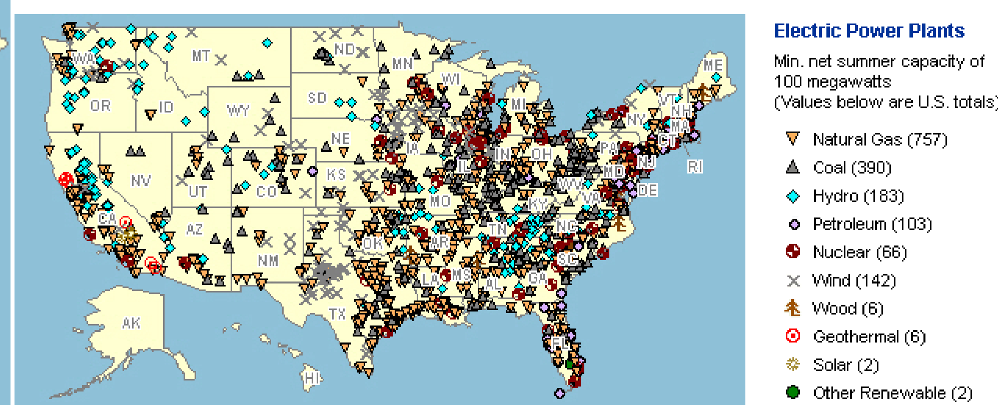
Crude Oil Production



Crude Oil Refineries



Electricity Generation and Supply

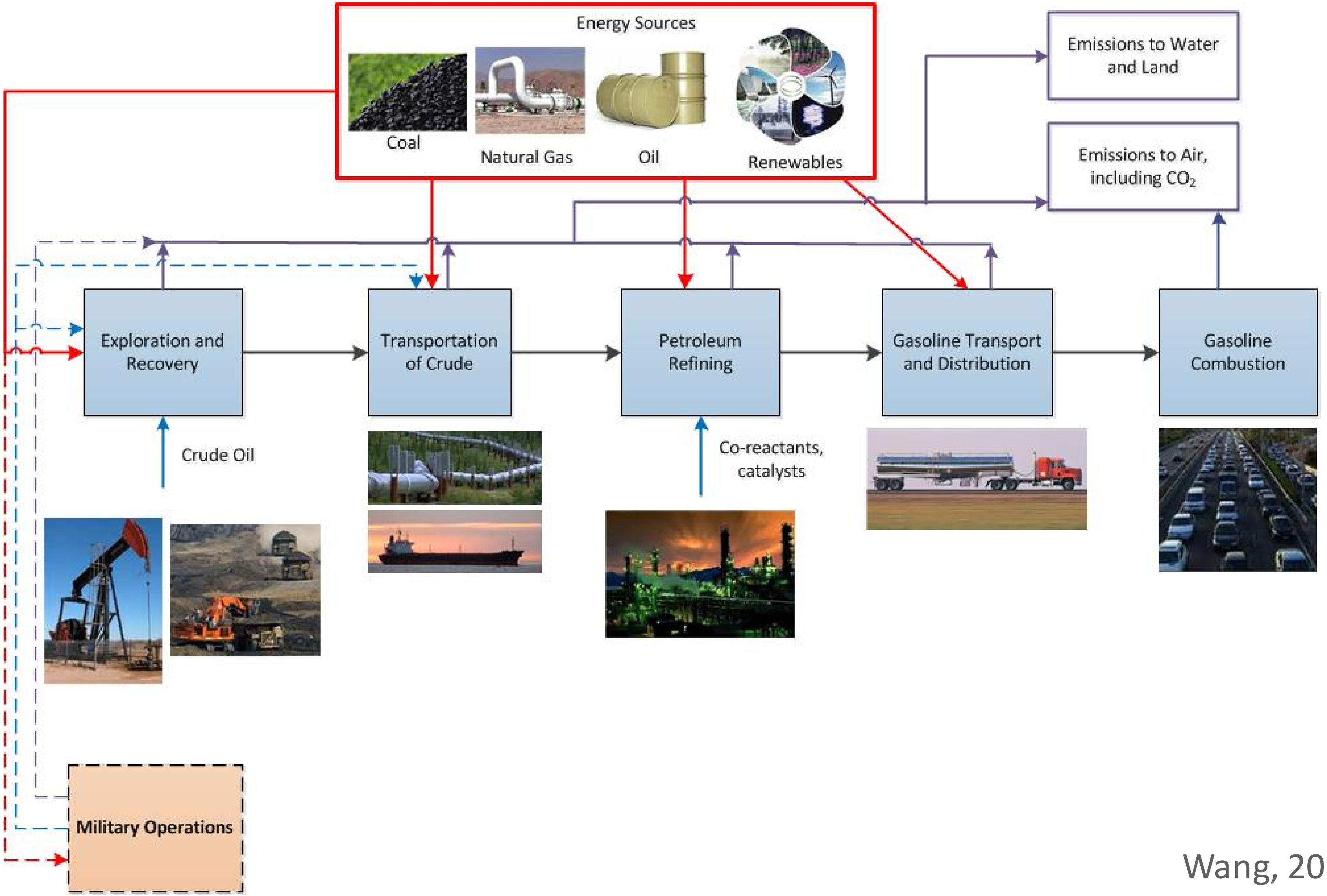


Source: EIA

Objectives

- Expand our efforts from national LCA to regional LCA
- Case study on regional differences in greenhouse gas (GHG) and criteria air pollutant (CAP) emissions of petroleum-based vehicles, which serves as the baseline for regional LCA
- Recognition of the region-specific opportunities for emission reduction via introduction of alternative vehicle/fuel systems

LCA System Boundary For Petroleum Fuels



Wang, 2011

Approach

- Regionalized LCA

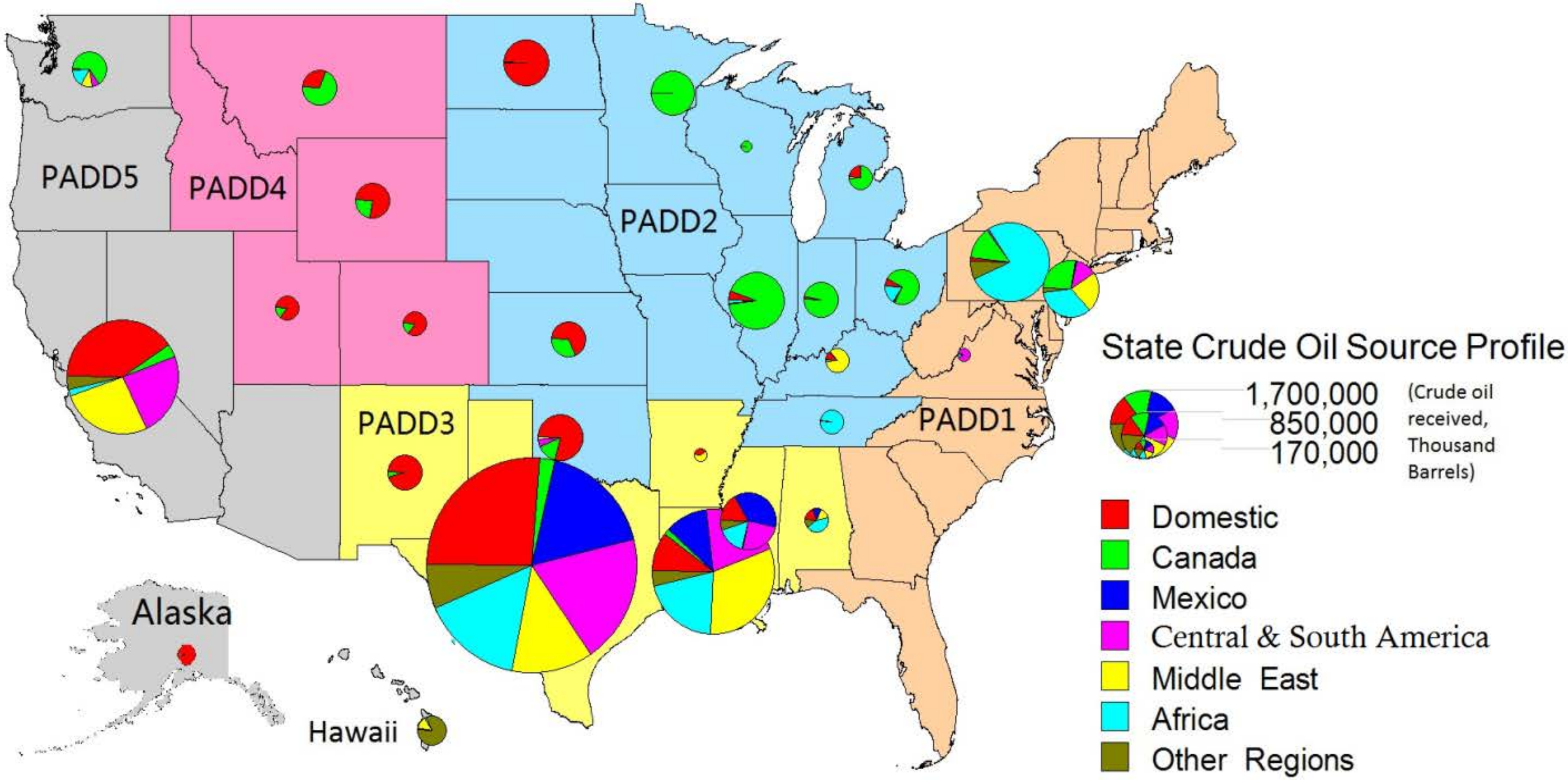
- State-level analysis and PADD region aggregation
- Collection and use of state-level data wherever applicable
- Argonne's GREET LCA model as the analysis tool
- Typical mid-size passenger cars are simulated

- Three sets of LCA emissions are estimated to serve various interests:
  - Analysis of global GHG emissions induced by U.S. regional use of passenger cars
    - GHG Emissions produced both within U.S. and abroad
  - Analysis of regional CAP emissions due to activities at state and PADD levels
    - Regional air quality assessment
  - Urban CAP Emissions
    - Urban air quality issues and health-related impacts

Methods and Data

--Recovery of Crude Oil

- State-level LCA based on state-specific crude oil production source mix



Based on EIA's Company Level Imports data and crude oil production data for 2010

Methods and Data

- **Efficiencies for crude oil recovery by source**

State or region	Representative Crude oil	Efficiency
California	California heavy crude	63.4%[1]
Alaska	Alaska medium crude	98.8%
U.S. Gulf Coast	Gulf Coast medium crude	99.7%
Other U.S. States	Conventional crude	98%[2]
Middle East	Saudi Arabian medium crude	99.9%
	Iraq medium crude	99.8%
Mexico	Mexico heavy crude	98.4%
Central & South America	Venezuela heavy crude	87.9%
Africa	Nigeria light crude	99.8%
Canada	Canada heavy crude	98.2%
	Canadian oil sands, surface mining	94.8%[2]
	Canadian oil sands, in-situ production	84.3%[2]

- [1] 195,089 kWh electricity exported
- [2] From GREET
- Source: **TIAX and MathPro, 2009.**

Methods and Data

- Flaring and venting emissions associated with crude recovery

	Flaring	Venting
	m3/bbl	m3/bbl
United States	1.03	0.35
California Heavy	0.10	0.17
Alaska	6.93	0.068
Gulf of Mexico	0.10	0.60
Canada	2.07	0.18
Mexico	2.61	0.13
Venezuela	3.62	0.28
Iraq	10.42	0.83
Saudi Arabia	0.96	0.0041
Nigeria	16.94	1.72

Source: World Bank, 2011; TIAX and MathPro, 2009

Methods and Data

--Crude Refining Efficiency by Region

		PADD I	PADD II	PADD III	PADD IV	PADD V
Efficiencies (%)		95.0	91.4	91.0	89.8	91.2
Process fuel shares (%)	Residual oil	46.0	39.2	21.6	51.9	24.9
	Natural gas	26.1	26.2	37.1	22.9	37.4
	LPG	0.1	10.5	10.1	3.9	8.0
	Electricity	9.0	5.8	5.2	5.4	3.5
	H_2	18.3	18.4	26.1	16.0	26.2
	Coal	0.5	0.0	0.0	0.0	0.0

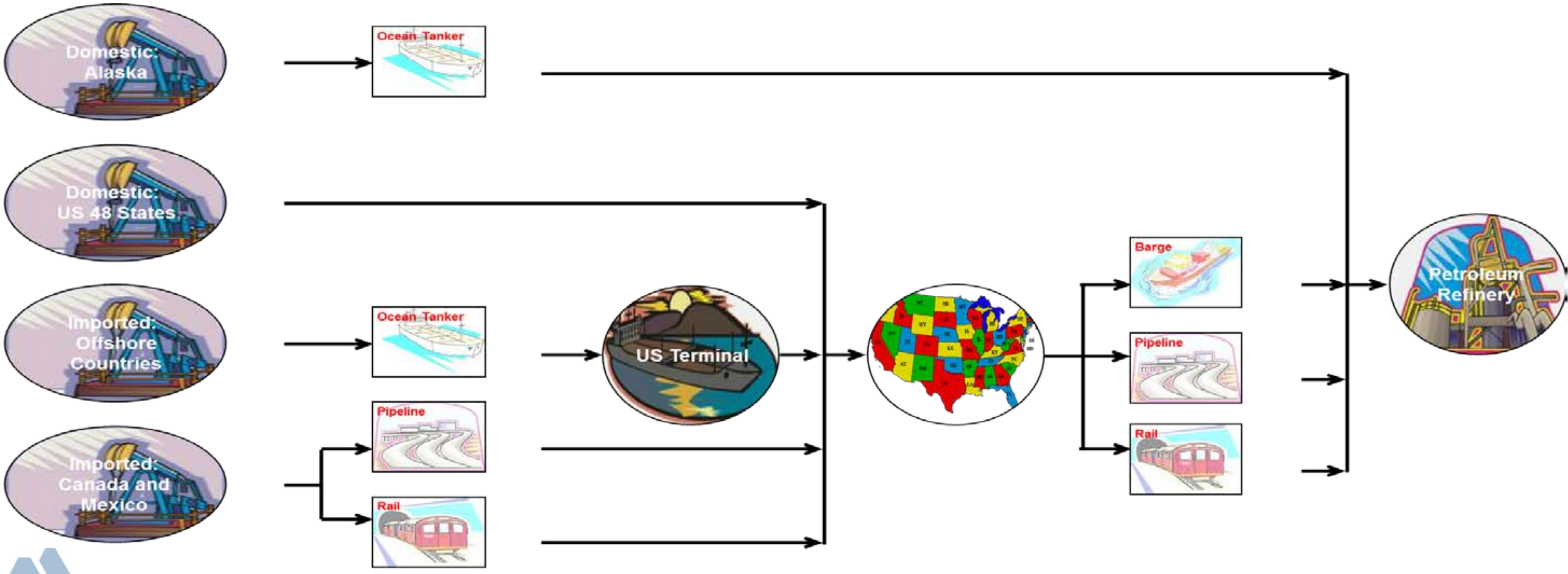
Source: Palou-Rivera et al., 2011

- Emissions calculated based on combustion technologies by process fuels and shares

Methods and Data

--Transportation and Distribution Emissions

- Emissions associated with transportation and distribution
  - Payload energy intensity (Btu/ton-mi)
  - Transportation mode and shares
  - Distance transported (and back haul if applicable)
  - Fuel properties (e.g., C%, S%)
  - Transportation mode emission factors



Methods and Data

--Vehicle's Emissions

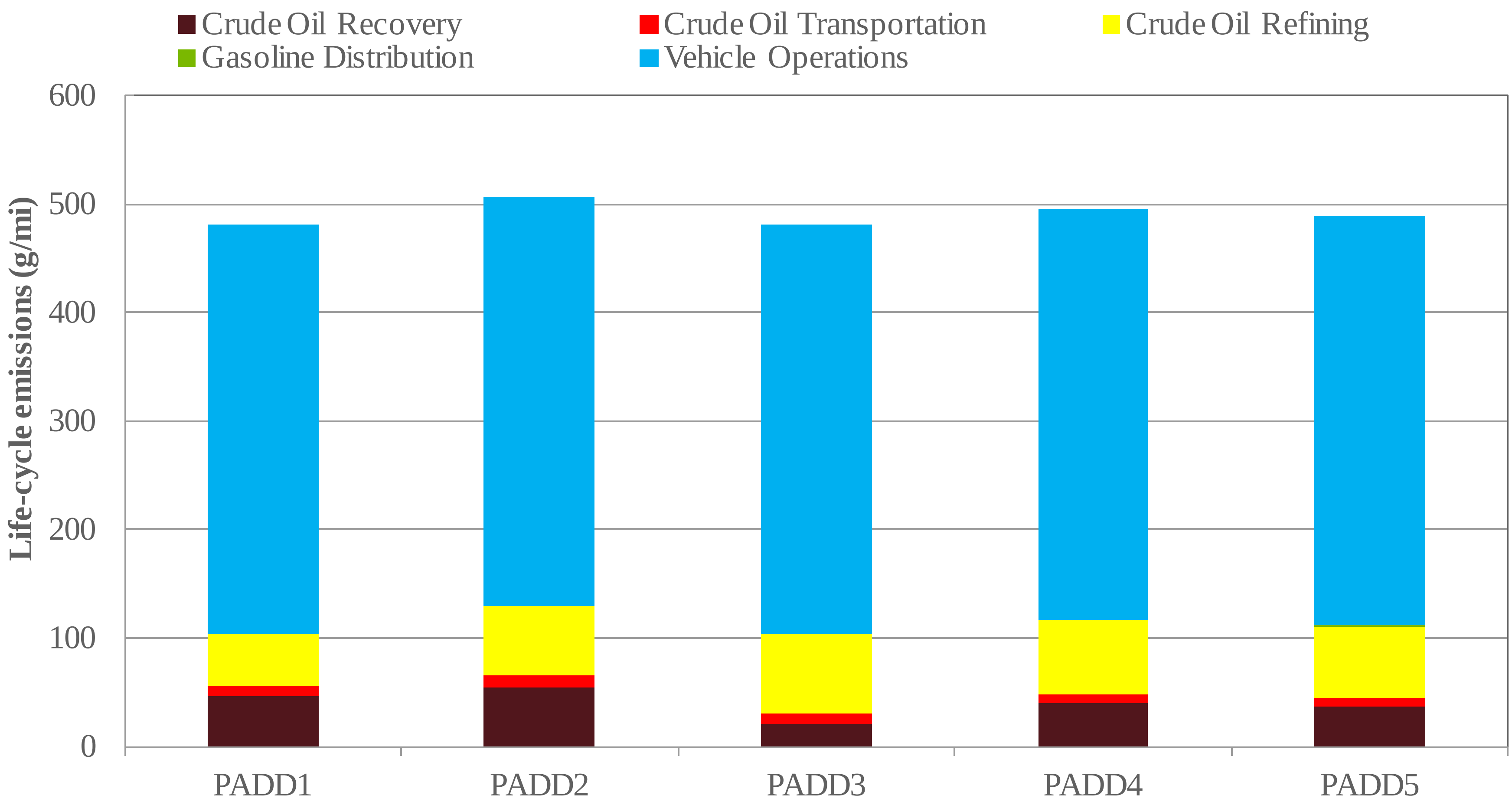
Emissions from vehicle operations

- CAP emissions from MOVES (EPA, 2011)
  - Conventional vehicles
    - ✓ tailpipe CH_4 and N_2O emission factors
    - ✓ tailpipe, evaporative, and brake and tire wear CAP emission factors

- CO_2 and SO_x emissions based on mass balance and fuel properties
  - CO_2 based on carbon mass balance
  - SO_x based on sulfur mass balance

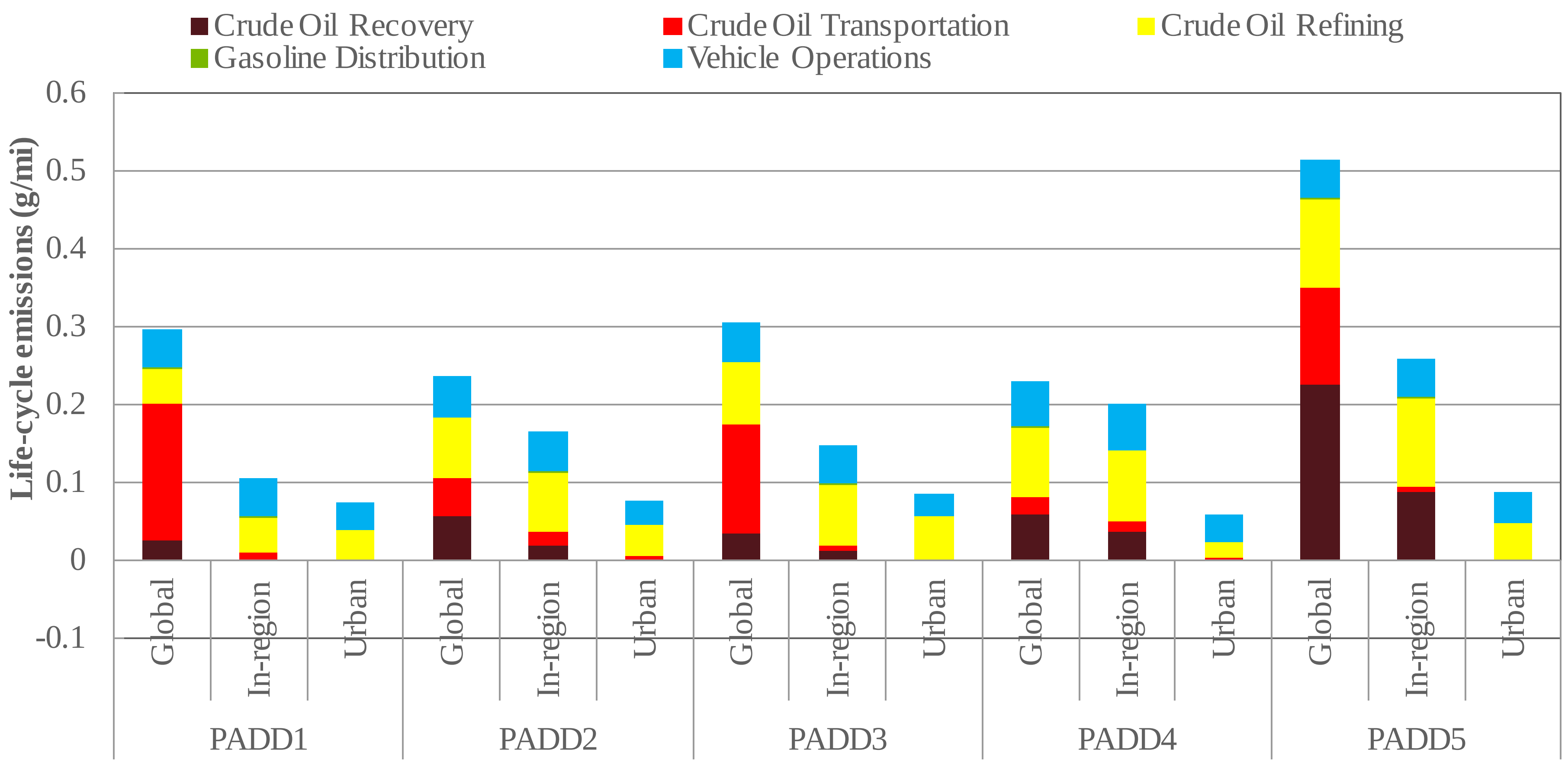
Results

--Global GHG emissions induced by use of gasoline by passenger cars by PADD region



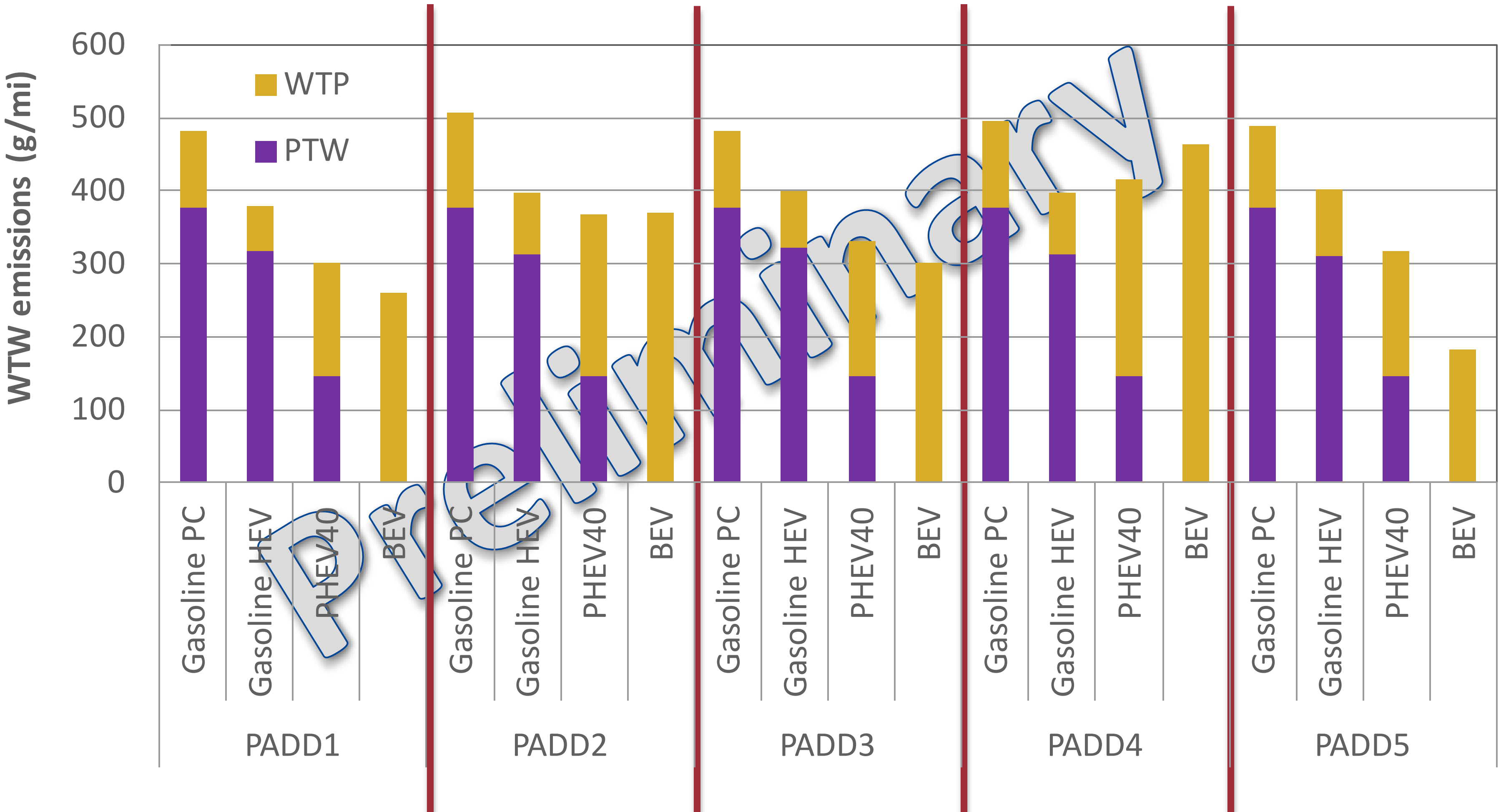
Results (cont.)

--Global, in-region and urban NO_x emissions induced by use of gasoline by PADD region



Results (cont.)

--Global GHG emission reduction potentials by PADD region



PHEV and BEV are assumed to be charged by regional average electricity generation mix

Conclusions

- For conventional gasoline PCs, the differences in **crude oil recovery practices** and in **venting and flaring emissions** by crude source cause regional variability in their WTW **GHG** emissions

- **In-region and urban CAP emissions** vary by PADD region, indicating **varied regional and urban air quality impacts** and **human health effects** from conventional gasoline passenger cars

- PHEVs and BEVs **GHG and CAP emission reduction potentials** differ by region due to the significant variation in **electricity generation mixes for vehicle recharging**

- Introduction of particular alternative vehicle/fuel systems can be targeted to specific regions for increased emission reduction potentials

Thank You

QUESTIONS & COMMENTS?

Back-up Slides

Methods and Data

- State-level LCA is performed using state-specific data on crude oil production, transportation, refining, distribution and vehicle operations
  - State-specific crude oil source profile for both domestic and foreign production of crude oil is explicitly considered
- PADD (Petroleum Administration for Defense Districts)-level LCA is aggregated on the basis of state-level LCA
- Typical mid-size passenger cars (PCs) are simulated by our GREET model

Aggregation Equation:

$$WTW_{PADD_i, plt_j, PC_k} = \sum_m [WF_{m,i,WTP} \times (\mathrm{Rec}_{state_m, plt_j} + Trans_{state_m, plt_j})] + \sum_n [WF_{n,i,WTP} \times (\mathrm{Re}\, f_{state_n, plt_j} + Dist_{state_n, plt_j})] + \sum_o (WF_{o,i,PTW} \times VehOpe_{state_o, plt_j, PC_k})$$

$$WF_{m,i,WTP} = \frac{Quantity_{crude\_oil, state_m, PADD_i}}{\sum_m (Quantity_{crude\_oil, state_m, PADD_i})}$$

Aggregation Weight Factors:

$$WF_{n,i,WTP} = \frac{\mathrm{Re}\, finingCapacity_{state_n, PADD_i}}{\sum_n (\mathrm{Re}\, finingCapacity_{state_n, PADD_i})}$$

$$WF_{o,i,PTW} = \frac{VehiclePopulation_{state_o, PADD_i}}{\sum_o (VehiclePopulation_{state_o, PADD_i})}$$

Crude Recovery

- Combustion of process fuel, venting and flaring emissions during crude oil recovery are quantified:

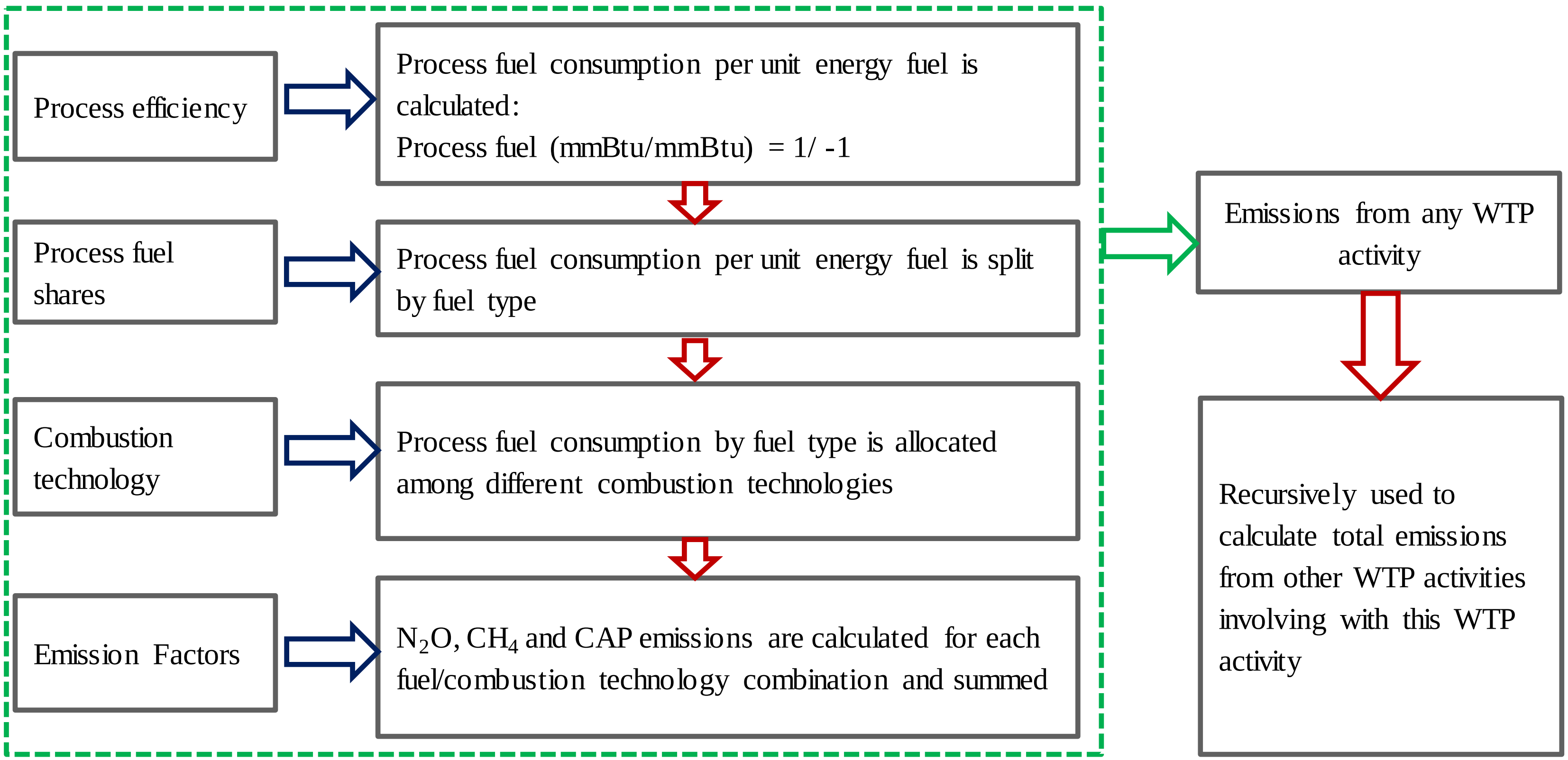
$$Recovery_{state_{m,plt_j}} = \sum_n [Source\,Profile_{m,n} \times (Recovery_{n,plt_j} + Venting_{n,plt_j} + Flaring_{n,plt_j})]$$

Efficiencies and process fuel shares for crude oil recovery by state and region (TIAX and MathPro, 2009)

State or region	Representative Crude oil	Efficiency	Electricity credit (Btu/mmBtu)	Process fuel shares		
				Produced gas	Pipeline NG	Grid electricity
California	California heavy crude	63.40%	195,089[a]	0%	100%	0%
Alaska	Alaska medium crude	98.80%	0	100%	0%	0%
US Gulf Coast	Gulf Coast medium crude	99.70%	0	100%	0%	0%
Middle East	Saudi Arabian medium crude	99.90%	0	94%	0%	6%
	Iraq medium crude	99.80%	0	94%	0%	6%
Mexico	Mexico heavy crude	98.40%	0	4%	95%	1%
Central & South America	Venezuela heavy crude	87.90%	0	65%	35%	0%
Africa	Nigeria light crude	99.80%	0	90%	0%	10%
Canada	Canada heavy crude	98.20%	0	100%	0%	0%

Methods and Data

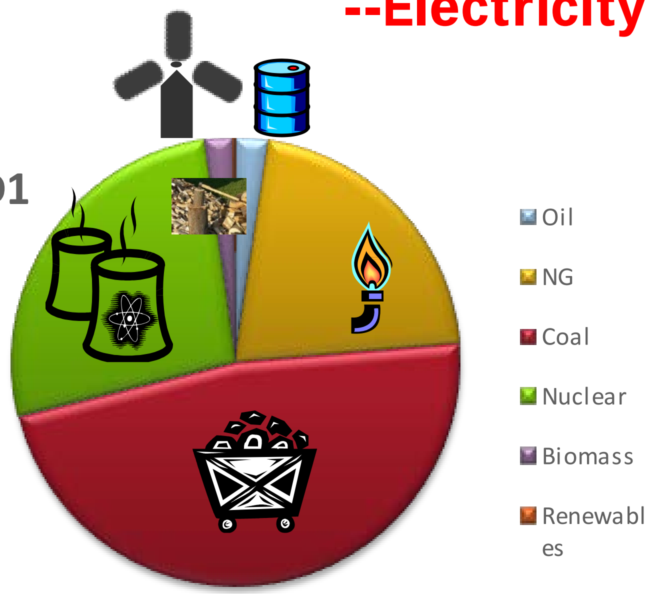
- 40 states produce and/or import crude oil from Canada, Mexico, Central & South America, Middle East, Africa, and other regions of the world in 2010
- Emission profiles for crude oil recovery vary by region due to differences in recovery efficiency and process fuel combustion of various recovery technologies used



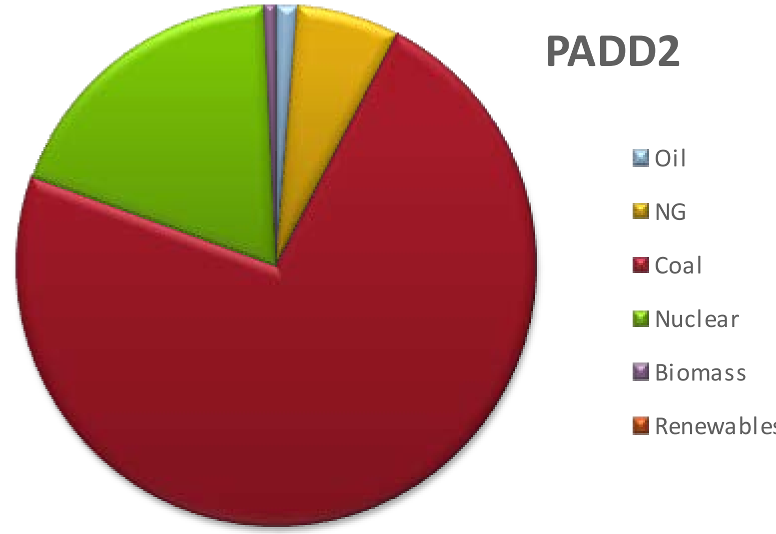
Methods and Data

--Electricity Generation Mixes

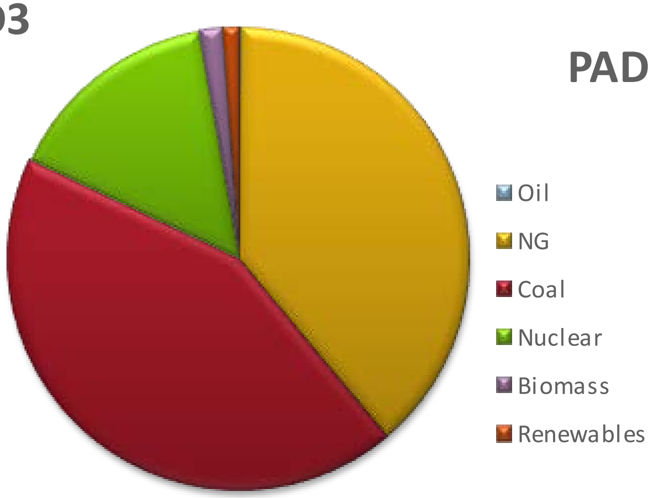
PADD1



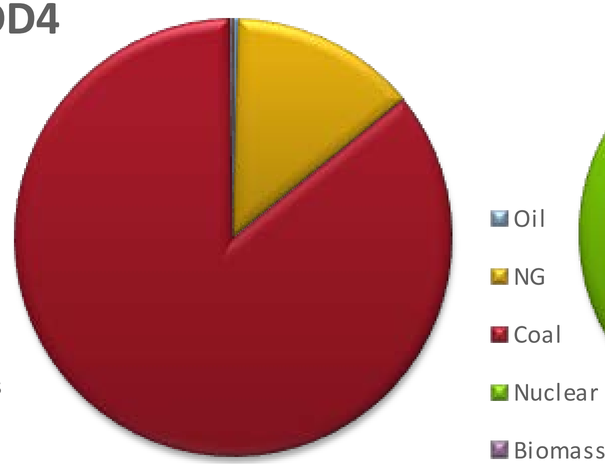
PADD2



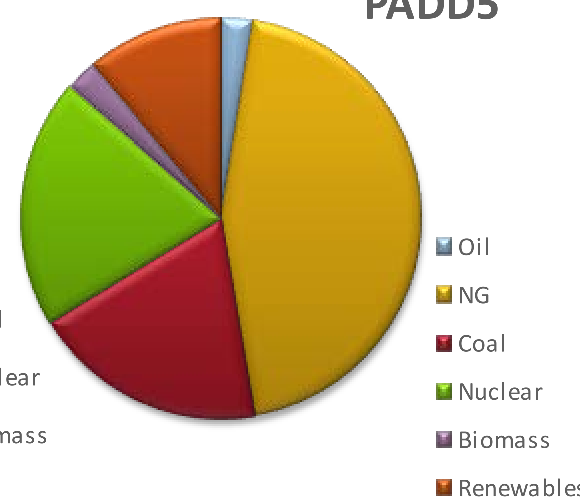
PADD3



PADD4

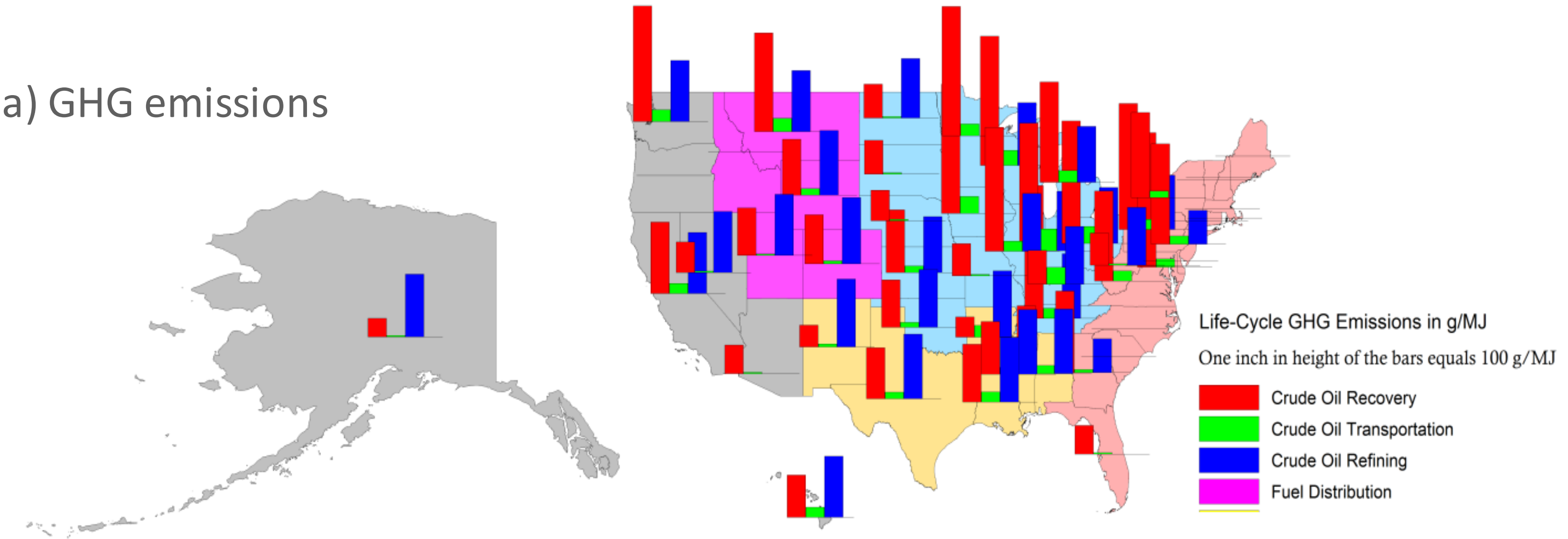


PADD5



State Differences in Life-Cycle GHG Emissions of Conventional Gasoline PCs

(a) GHG emissions



- Noticeable variations in upstream GHG emissions are observed, particularly for the GHG emissions from crude oil recovery, which varied from 3.38 g/MJ in Alaska to 24.7 g/MJ in Maryland;
- The carbon intensity of crude oil recovery in California is about 13.1 g/MJ, which is close to the recent CARB number of 12.1 g/MJ (CARB, 2012);
- Major causes are differences in crude oil recovery technologies for different sources of crude oil, as well as the significant variation in venting and flaring emissions among oil fields around the world.

Global, in-region and urban NO_x emission reduction potentials by PADD region