Quantifying Uncertainty in Life Cycle Assessments of Transportation Fuels

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Outline

- **Introduction**
  - Research Problem and Motivation
  - Literature Review
  - Research Objectives
- **Methodology**
  - Life Cycle Assessments
  - Monte Carlo Simulations
- **Analysis**
  - Scenarios
  - Uncertainty Results
  - Sources of Uncertainty
  - Comparison to Literature
- **Discussion**
  - Key Results
  - Future Work

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Research Problem and Motivation

- Background
  - Fuel Standards from California Air Resource Board (CARB) and European Union (EU)
- Problem
  - Can we confidently compare the well-to-combustion (WTC) emissions of crudes using life cycle assessments (LCA)?
  - Can we compare technology pathways?

Literature Review

- Top-Down Models
  - Use aggregated data
  - GREET, GHOST, and GHGenius
  - GREET includes limited uncertainty analysis

- Bottom-Up Models
  - Use mass and energy balances
  - Jacobs, TIAX, Oil Climate Index (OCI), FUNNEL-GHG

Research Objective

- Determine emission ranges for multiple crudes and determine if LCA can be used to compare their WTC emissions

1. Improve and expand FUNNEL-GHG model
2. Perform a conservative uncertainty analysis
3. Identify key sources of uncertainty
    1. Iteratively improve key distributions
4. Compare the results to the literature

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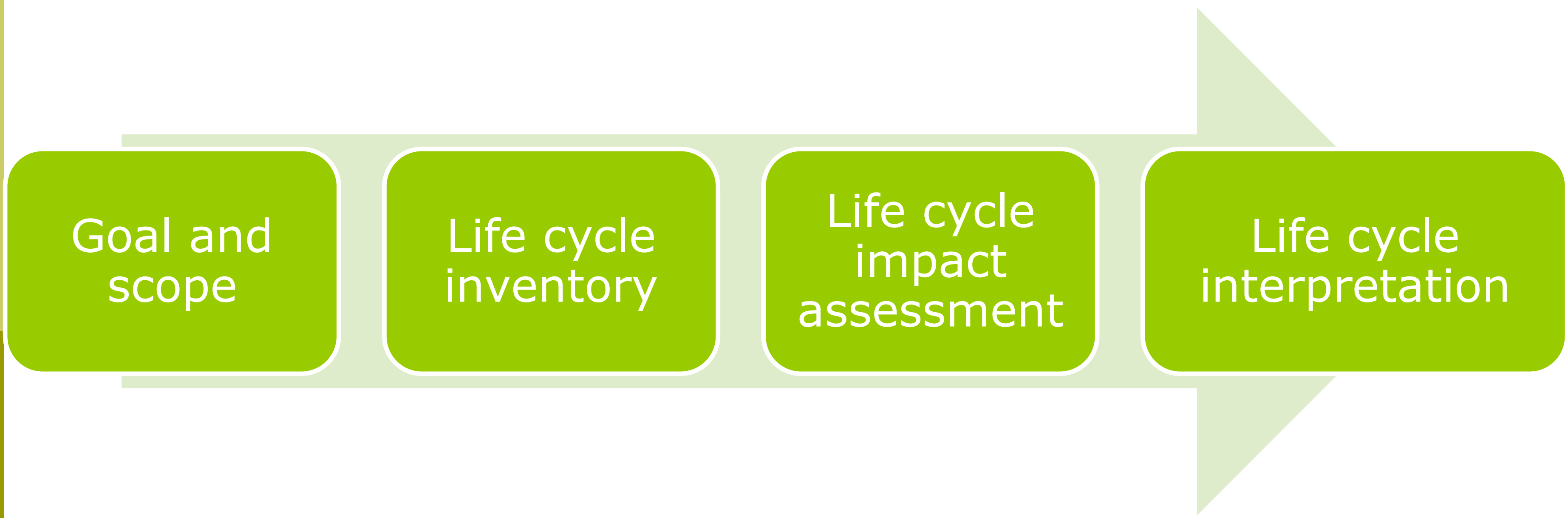
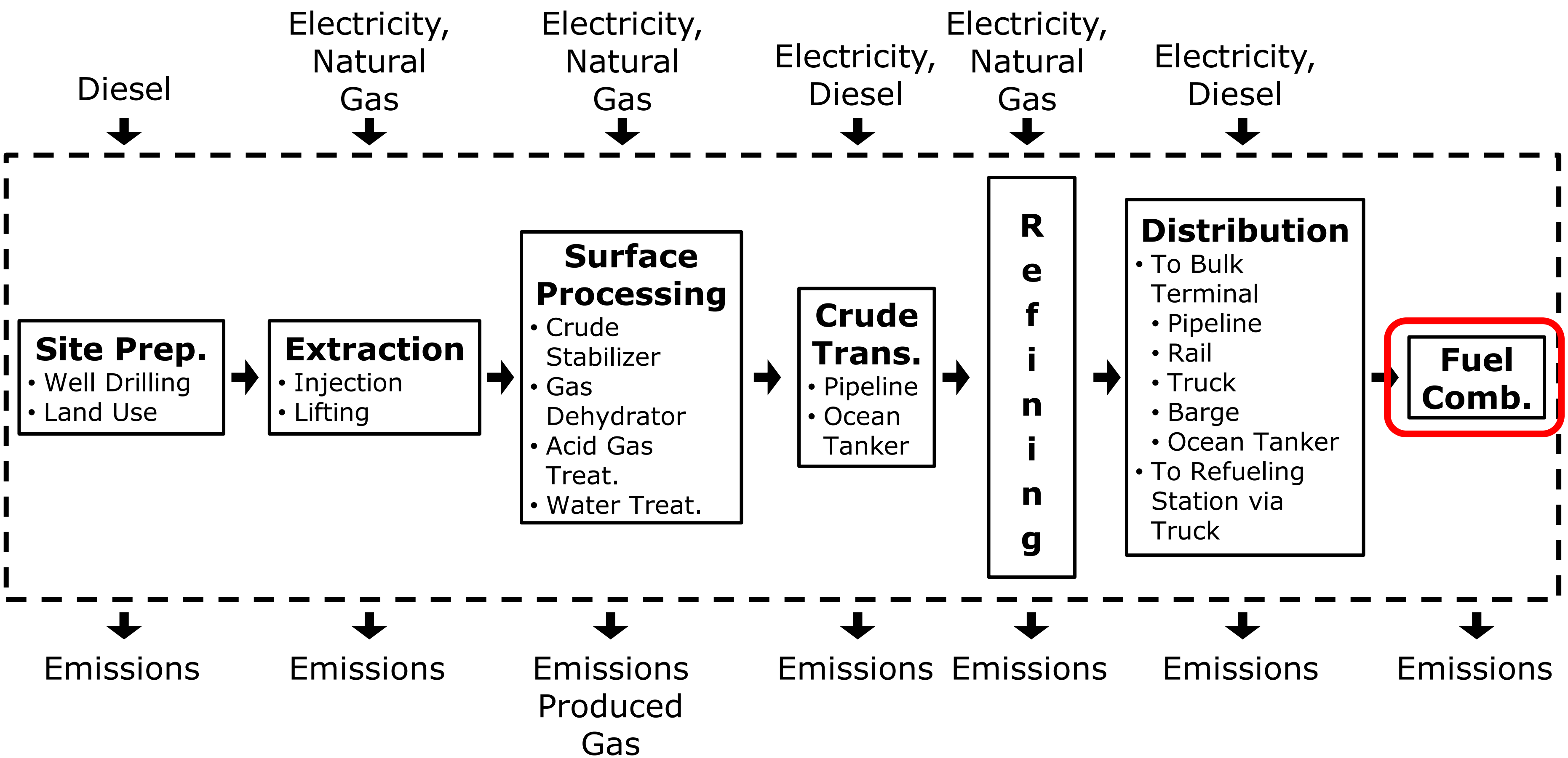
Life Cycle Assessments



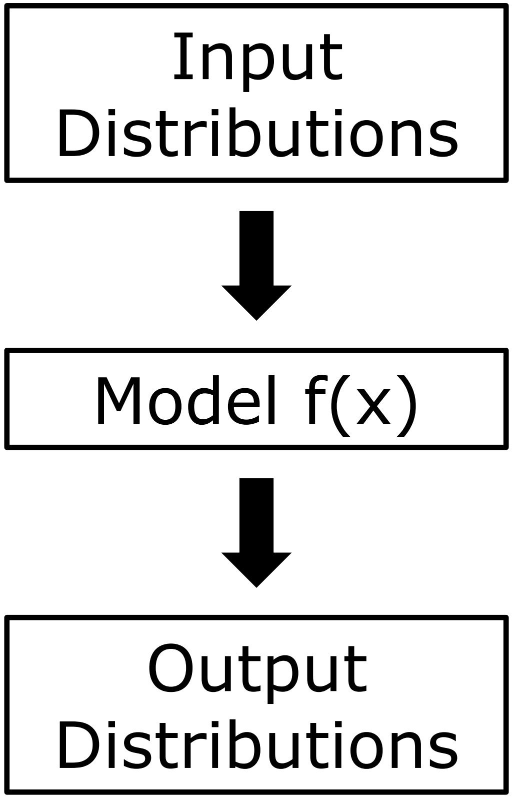
LCA System Boundary



Functional Unit: gCO2eq/MJ

Monte Carlo Simulations

- Data Distributions
  - Triangle
  - Uniform
  - PERT
  - Normal



Monte Carlo: Key Inputs

Emission Factors
- Natural Gas, Marine Fuel, Electricity
- Methane GWP

Unit Efficiencies
- Boilers, Heaters, and Pumps

Surface Preparation
- Well Lifetime Productivity
- Well Depth

Surface Processing
- Crude Specific Heat
- Stabilizer Temps
- Water Treat. Energy Int.
- Ore Separation Water Flow Rate and Temperature
- Upgrading Emissions and Yield

Production
- Inj. Pump Pressure
- Reservoir Pressure
- Compressor Temp and Pressure
- Gas Compressibility Factor
- Compressor Interstage Cooling Efficiency
- Inj. WOR, SOR, GOR
- Prod. WOR, GOR
- N2 Generation Efficiency
- N2 Inj. Volume
- Water and Gas Copulas
- Mining Truck and Shovel
  - Fuel Consumption
  - Cycle Times
  - Rated Payload
  - Availability
- Bitumen Saturation

Crude Transport
- Pipeline Velocities, Capacity
- Tanker Velocity

VFF and Other
- Vented, Flared, and Fugitive Gas Volumes
- Flaring Efficiency
- Gas Methane mol%
- Refinery Yield Factor
- Distribution Transportation Method

Cogeneration
- Natural Gas Consumption
- Electricity/Steam Ratio
- Steam Energy Required
- Steam Capacity
- Electricity Credit

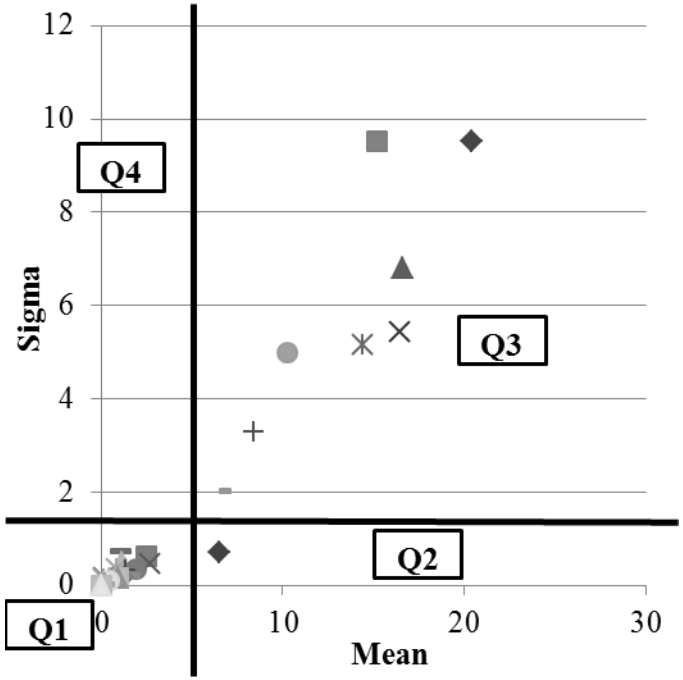
Monte Carlo: Sensitivity Screening

- Output uncertainty = input uncertainty * input sensitivity

- Sensitivity Methods available
  - One at a time (OAT)
  - Morris
  - Sobol
  - MC tornado plots

Monte Carlo: Sensitivity Screening

- Morris Plot



- Sobol Indices
  - Ordered 1-n
  - Total Indices

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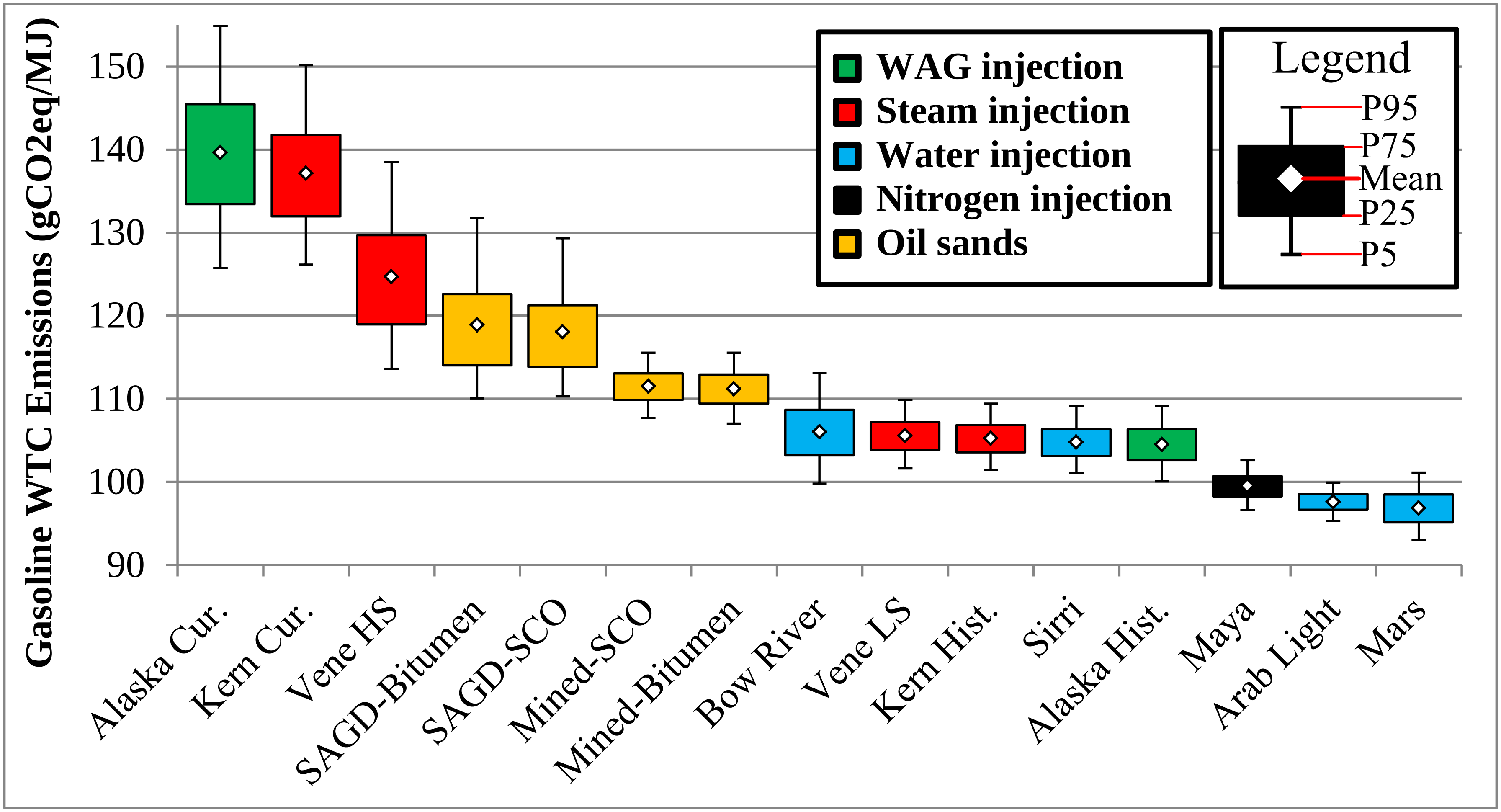
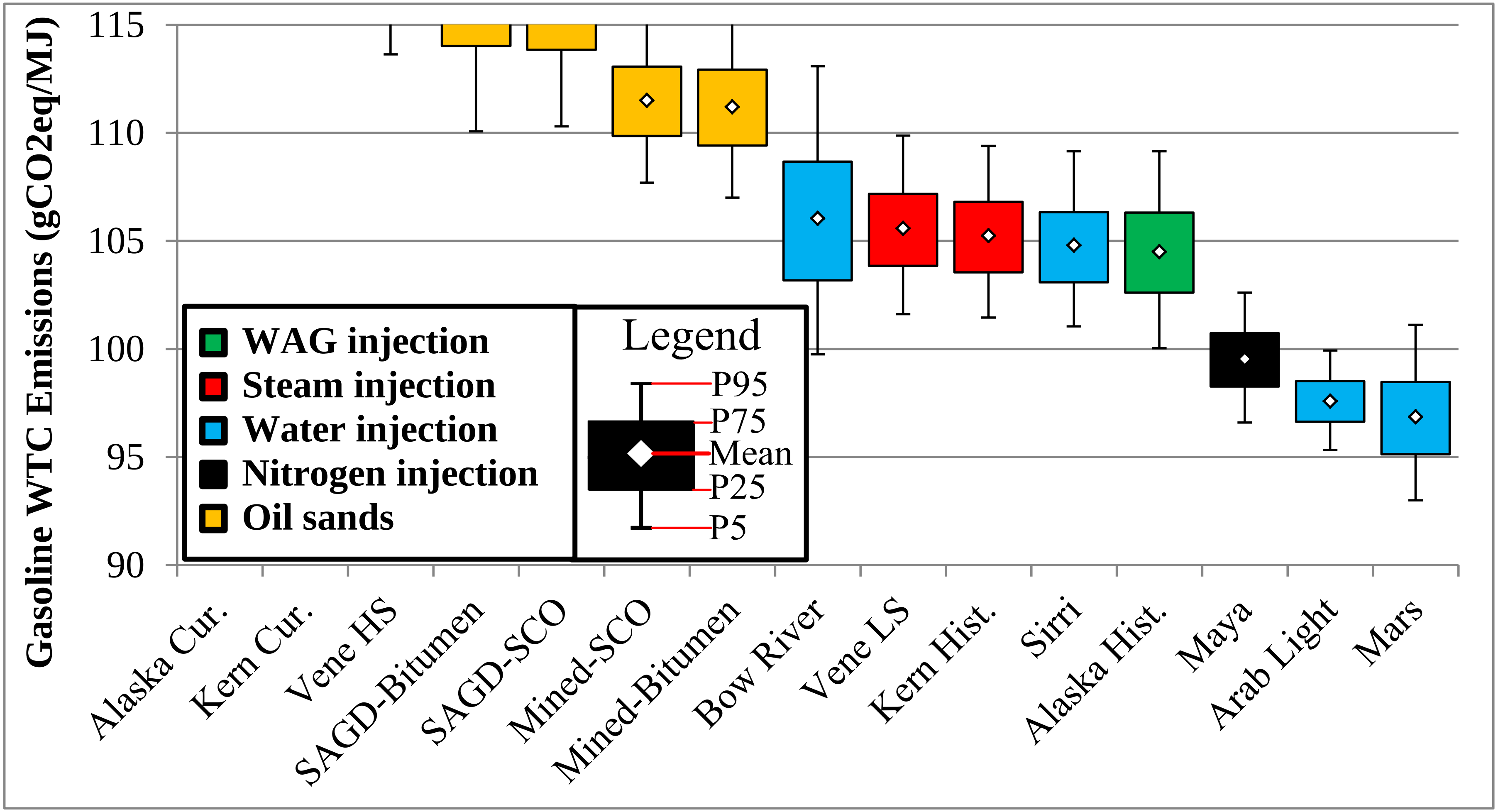
Scenarios

Crude	°API	Extraction Technology	Crude Location	Refinery Location
Maya	22.0	N_2 inj.& gas lift	Mexico	Houston, TX
Mars	31.5	Water inj.	U.S. Gulf Coast	Cushing, OK
Bow River	24.7	Water inj. & pump lift	Canada	Cushing, OK
Alaska	31.9	WAG inj.	Alaska	L.A, CA
Prudhoe Bay	31.9	WAG inj.	Alaska	L.A, CA
Kern	13.0	Steam inj. & pump lift	California	L.A, CA
Vene	11.7	Steam inj.	Venezuela	Houston, TX
Sirri	31.0	Water inj.	Iran	Houston, TX
Arab Light	32.6	Water inj.	Saudi Arabia	Houston, TX
Bitumen	8.2	SAGD & Mining	Alberta	Cushing, OK
SCO	32.8	SAGD & Mining	Alberta	Cushing, OK

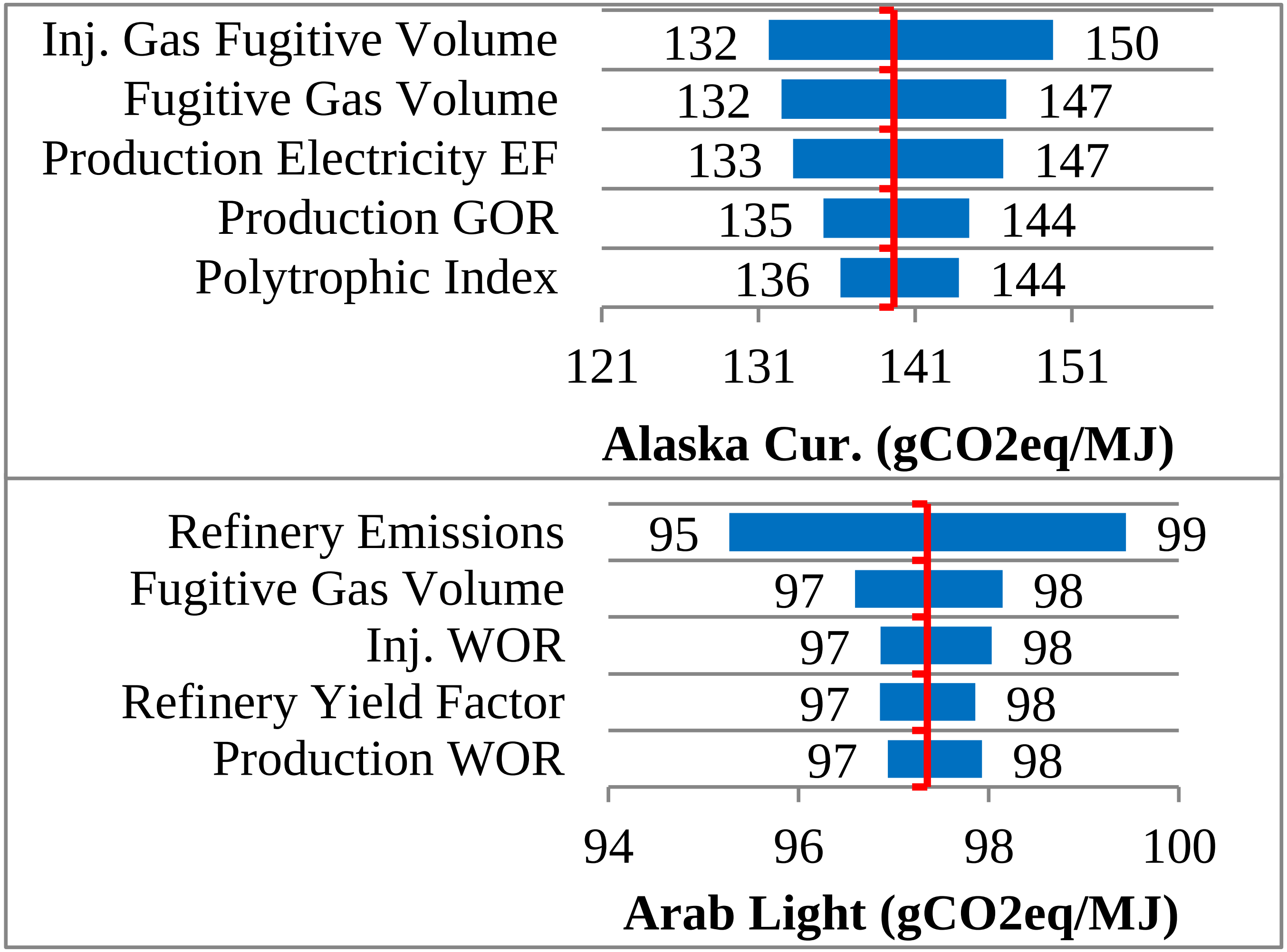
Uncertainty Results



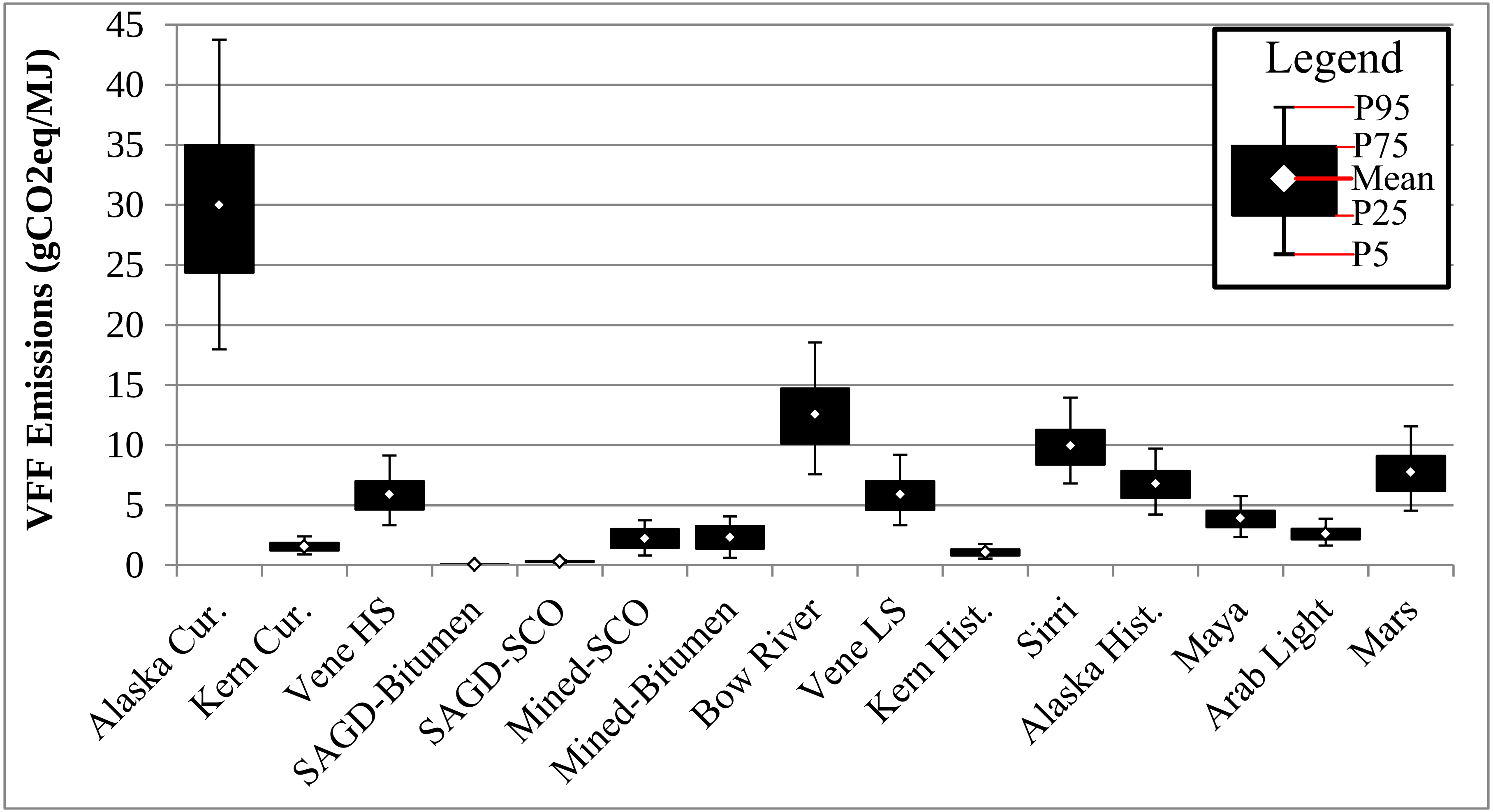
Uncertainty Results



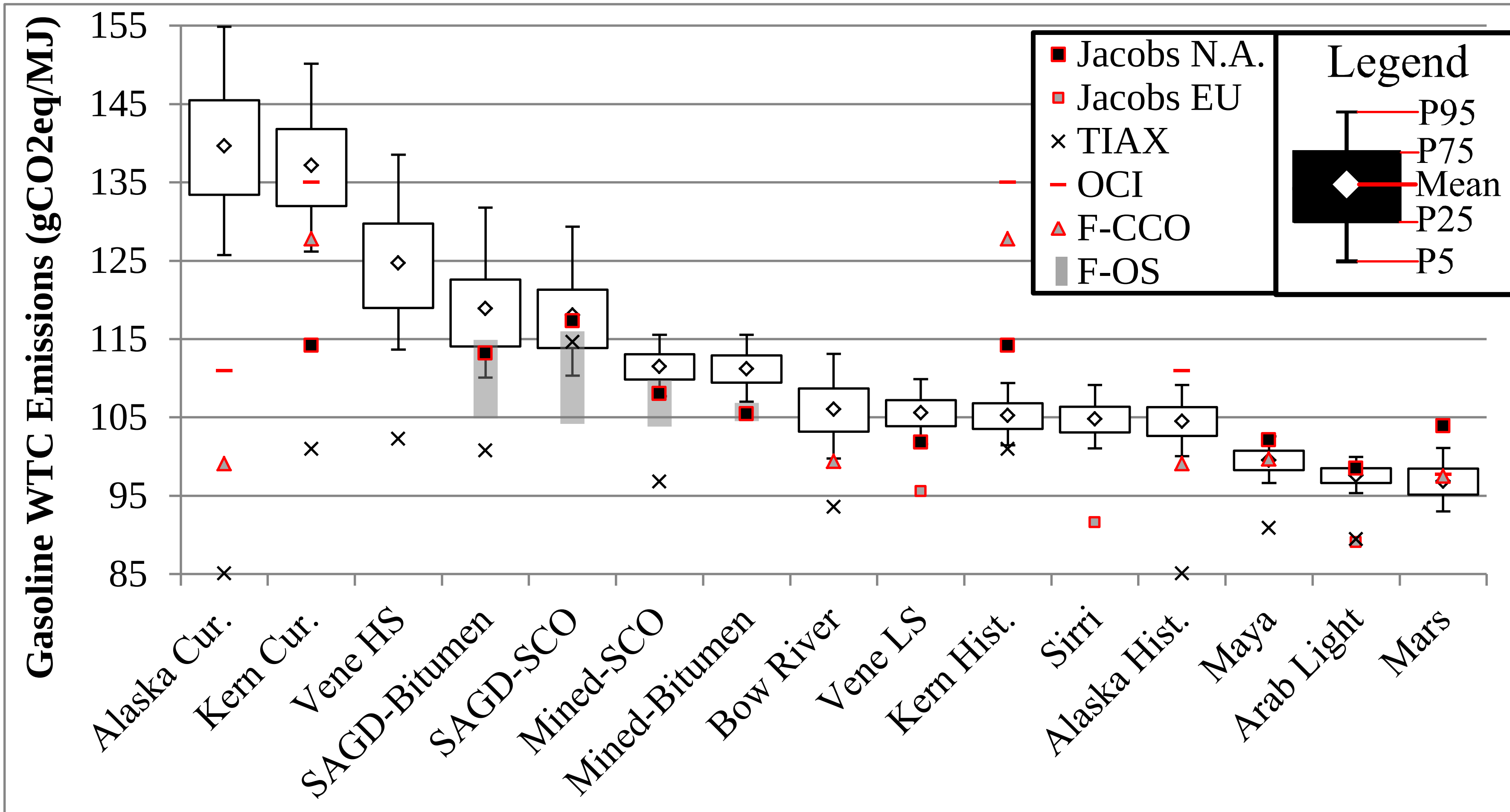
Sources of Uncertainty: WTC



Sources of Uncertainty: VFF



Comparison to the Literature



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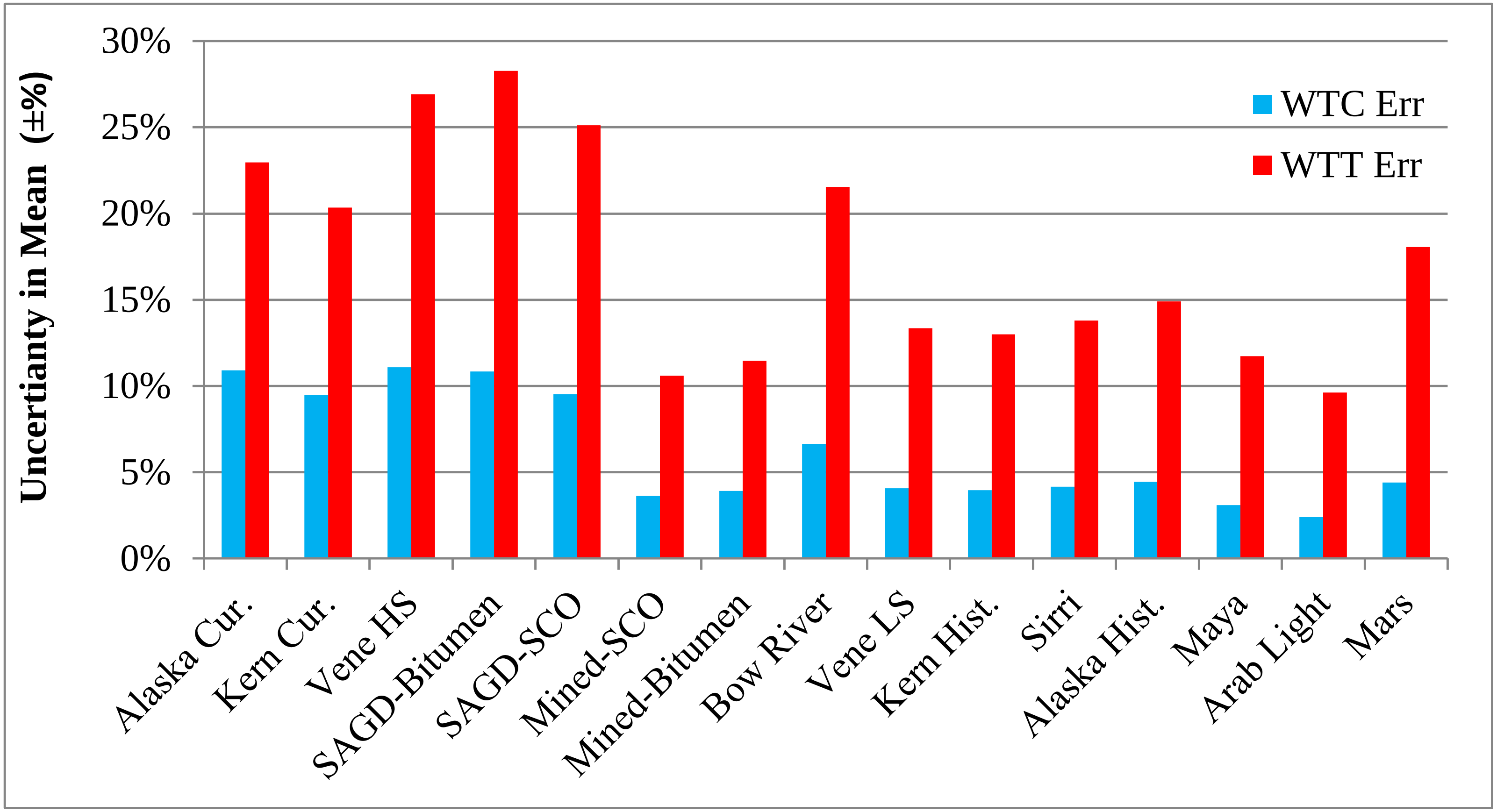
Key Results

- With conservative distributions crudes can be separated into groups

- Largest source of uncertainty is the VFF gas volumes, refinery emissions, and injection/production GORs and WORs

Discussion:

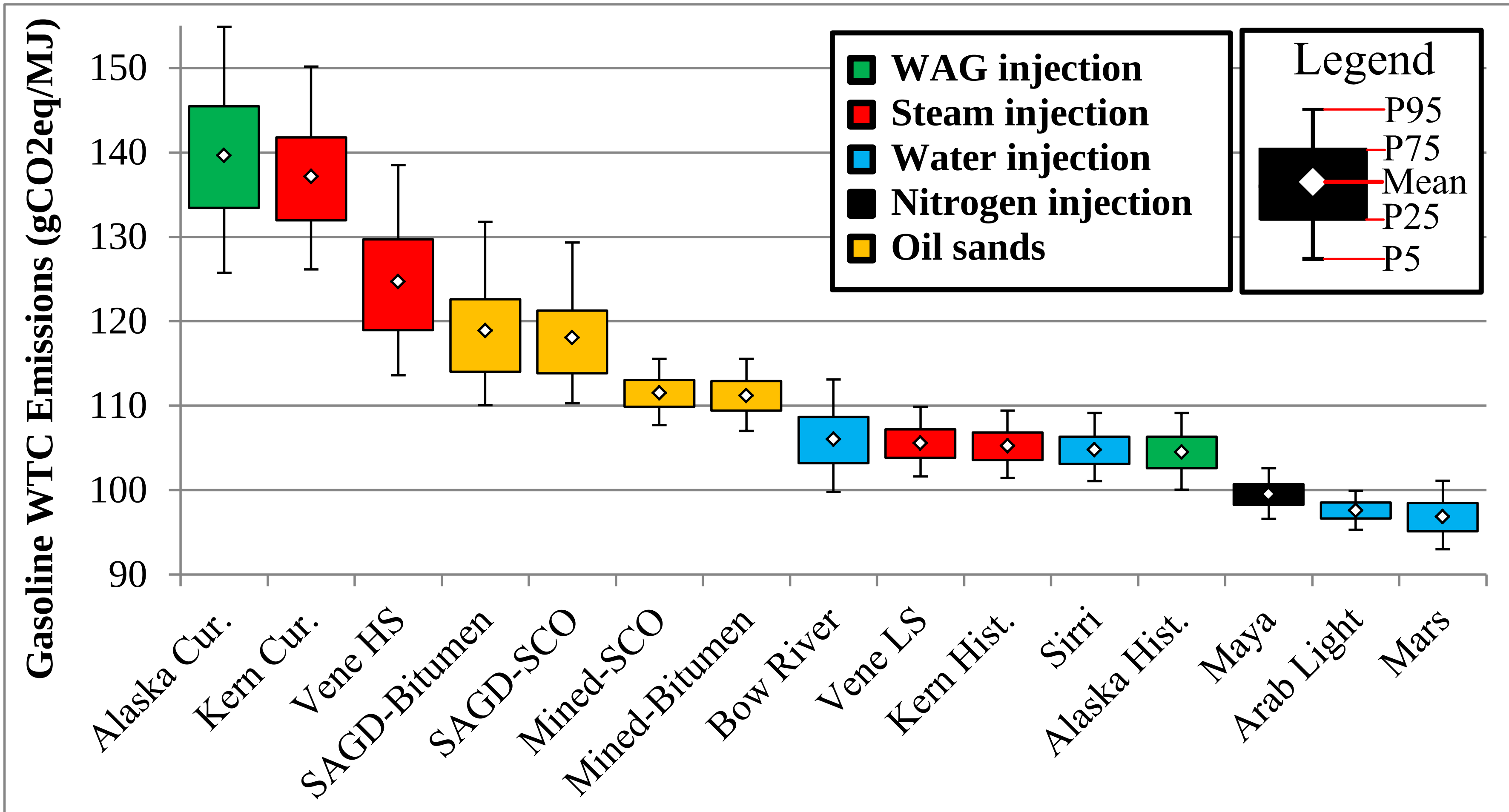
Key Results: Magnitude of Uncertainty



Future Work

- Include different refinery configurations and examine crude blends
- Gather data from industry to improve input distribution accuracy
- Examine by-product fates
- Look at correlations between crudes

Uncertainty Results



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- **Inputs and comments:** Cenovus Energy Inc., Suncor Energy Inc., Alberta Innovates (Clean Energy and Bio Divisions)

Published Work

- FUNNEL-GHG-CCO Model
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  - G. Di Lullo, H. Zhang, and A. Kumar, "Evaluation of uncertainty in the well-to-tank and combustion greenhouse gas emissions of various transportation fuels," Applied Energy, vol. 184, no. pp. 413-426, Dec. 15 2016. [Online]. Available: 10.1016/j.apenergy.2016.10.027.
  - G. Di Lullo, H. Zhang, and A. Kumar, "Uncertainty in well-to-tank with combustion greenhouse gas emissions of transportation fuels derived from North American crudes," Energy, vol. 128, no. pp. 475-486, 6/1/ 2017. [Online]. Available: http://doi.org/10.1016/j.energy.2017.04.040.

Thank You/Questions

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