2017 DOE Hydrogen and Fuel Cells Program
Annual Merit Review

Life-Cycle Analysis of Air Pollutants Emission for Refinery and Hydrogen Production from SMR

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Overview

Timeline

- Start: FY 2017
- End: Determined by DOE
- % complete (FY17): 60%

Barriers to Address

- ❑ Inconsistent data, assumptions, and guidelines
- ❑ Insufficient suite of models and tools
- Emission data are only available for specific years (2011 and 2014)
- Confidential business information

Budget

- Funding for FY17: $200K

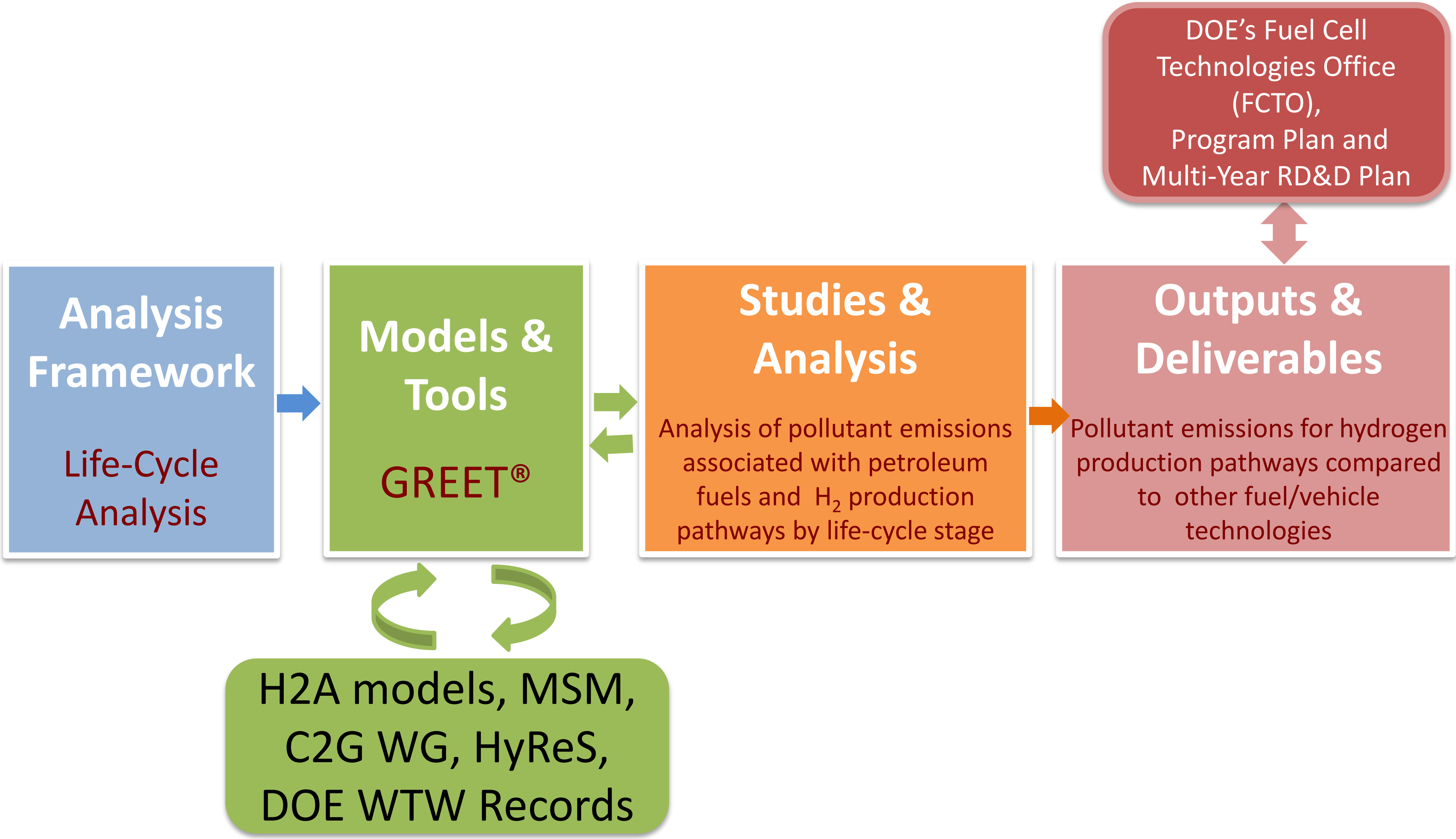
Partners/Collaborators

- Eastern Research Group (ERG)
- Jacobs Consultancy
- PNNL
- Other industry stakeholders

Relevance/Impact

- Reducing air pollutant emissions from transportation is a target for major cities in the U.S.
  - Zero emissions vehicle (ZEV) regulations in California and NE states
  - Vehicle electrification, including fuel cell electric vehicles, provides significant potential for reducing air pollutant emissions
- Fuel cell electric vehicles (FCEVs) have zero tailpipe emissions
  - Hydrogen is mostly produced from steam methane reforming (SMR)
  - Upstream emissions with hydrogen production, delivery and compression may negate emissions benefits of FCEVs
  - Accurate air pollutant emissions is needed for baseline petroleum fuels and H_2
  - LCA provides a consistent platform for evaluating and comparing air pollutant emissions along the production pathways of transportation fuels (including H_2)
- Hydrogen is also essential for processing, refining and upgrading of petroleum and biofuels
  - Understanding emissions associated with hydrogen production is key for evaluating life cycle emissions of other fuels

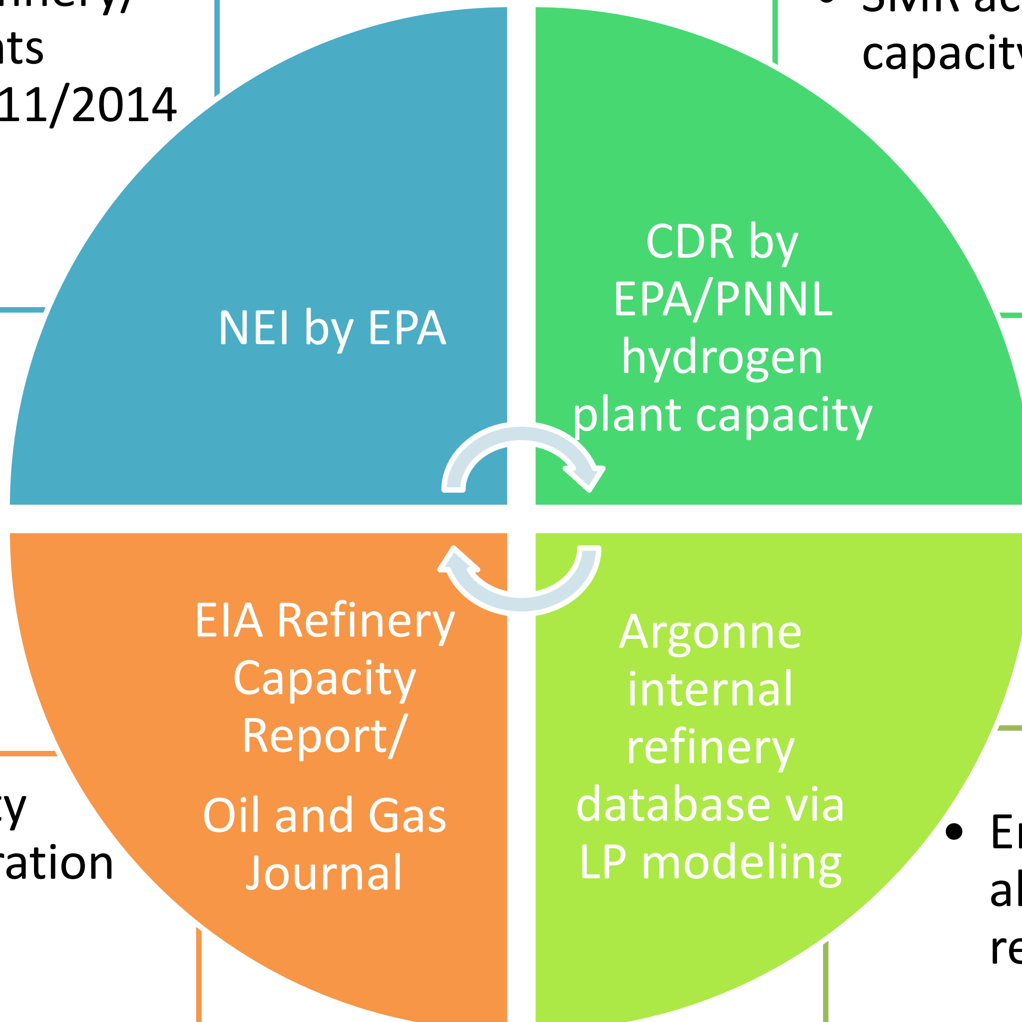
LCA of air pollutant emissions for petroleum fuels and hydrogen production pathways – Relevance



Acquire refinery and SMR air emissions and production data – Approach

- Individual Refinery/ SMR pollutants emissions 2011/2014

- SMR actual production/ capacity



- Refinery facility capacity/ operation data

- Emissions allocation to refinery products

Part I: U.S. Refinery Air Pollutants Emission

Connect refinery air emissions inventory to refinery products – Approach

Facility

- Match individual refinery for process emission from NEI at unit level and utility/auxiliary emission

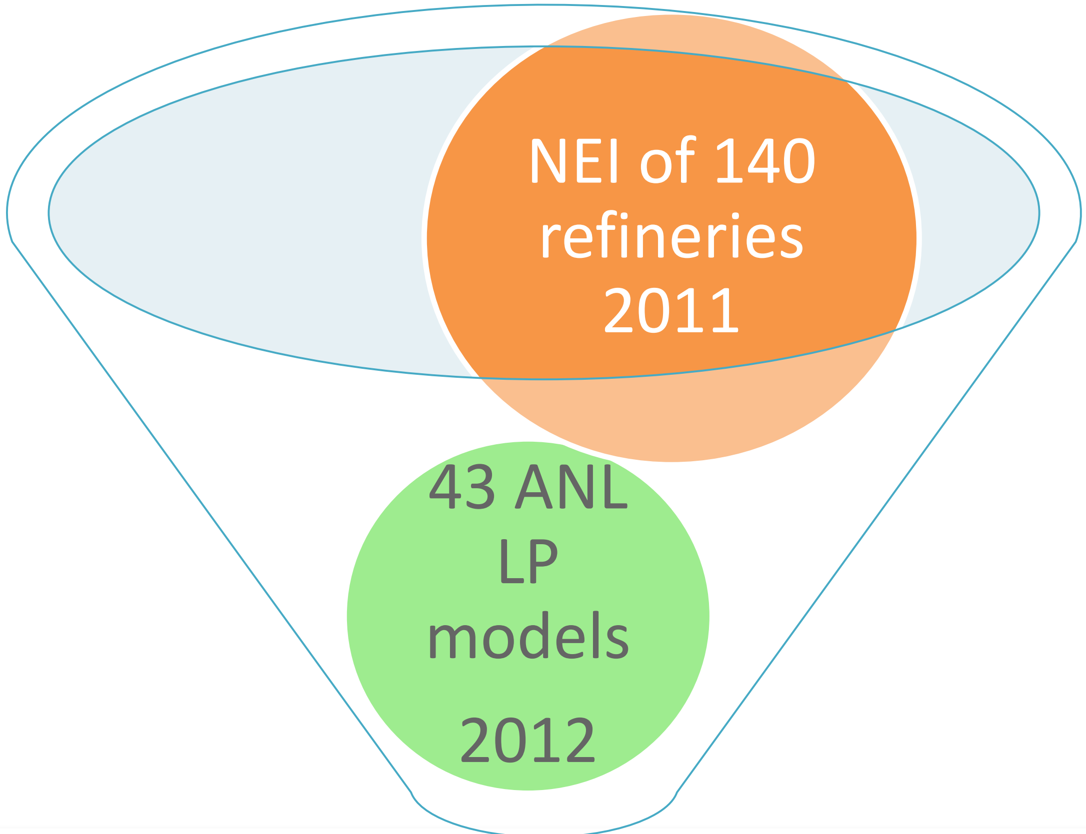
Unit

- Guided by LP modeling flow schemes, allocate utility/auxiliary emissions to individual process units

Product

- Guided by LP modeling flow schemes and product pools, allocate unit emissions to individual refinery products

Connect refinery air emissions inventory to refinery operation – Approach

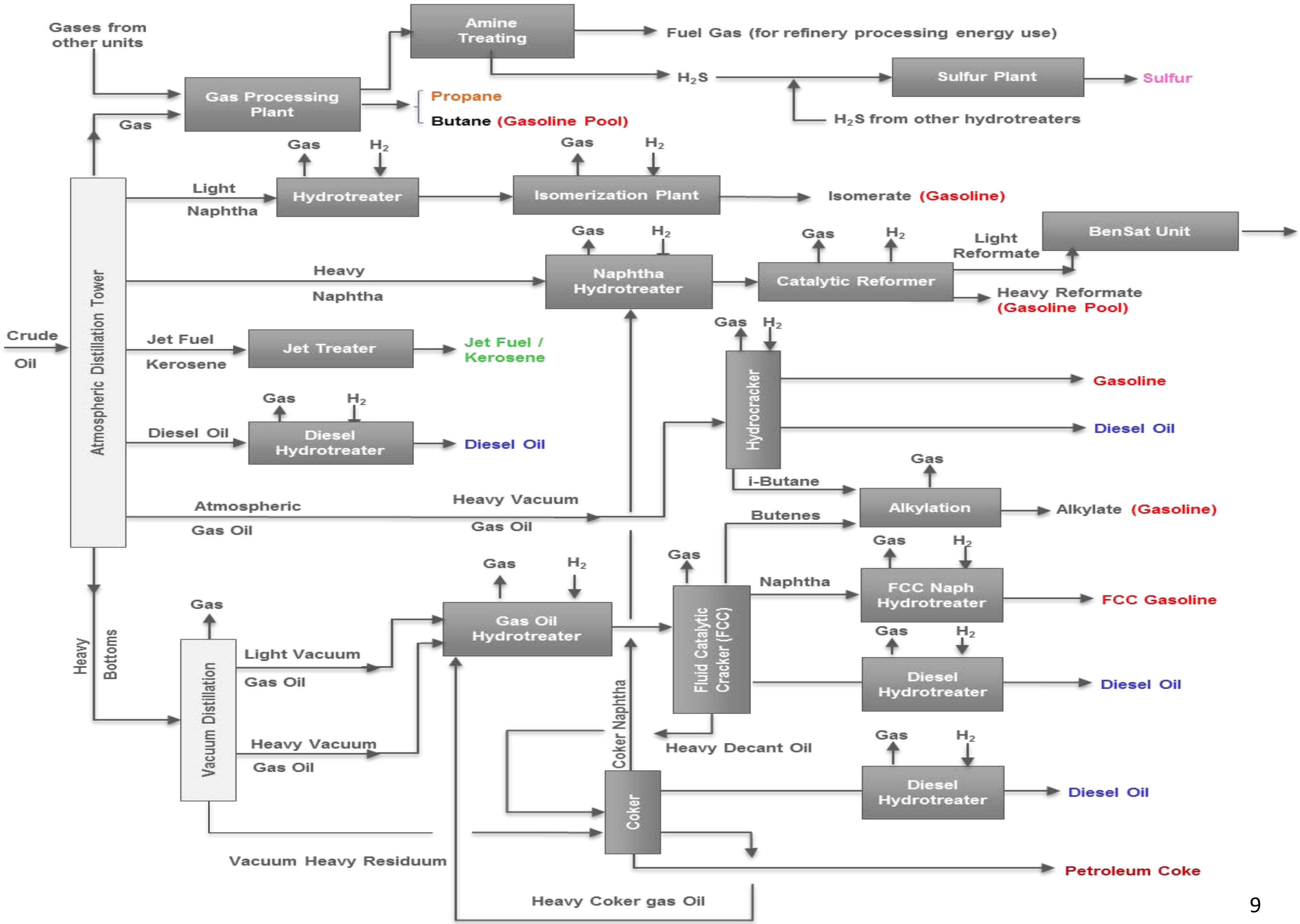


<u>Extra filter</u>: minimal refinery operation change from 2011 to 2012 to ensure consistency

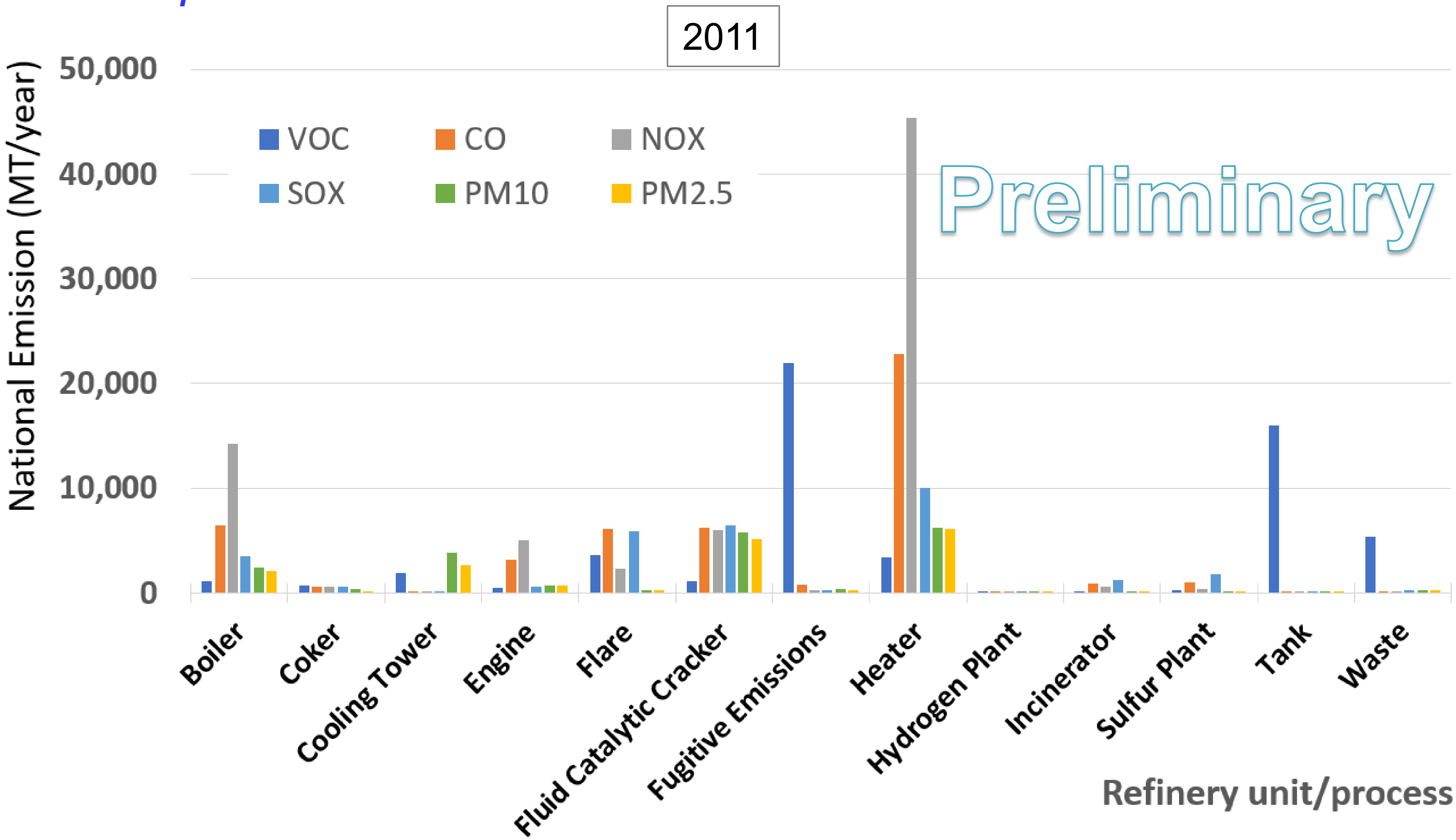
<u>Evaluated 11 refineries with 2011 emissions data</u>:

Seven non CA refineries (PADD 2,3,5) and four CA refineries

Develop refinery flow scheme via LP modeling – Approach

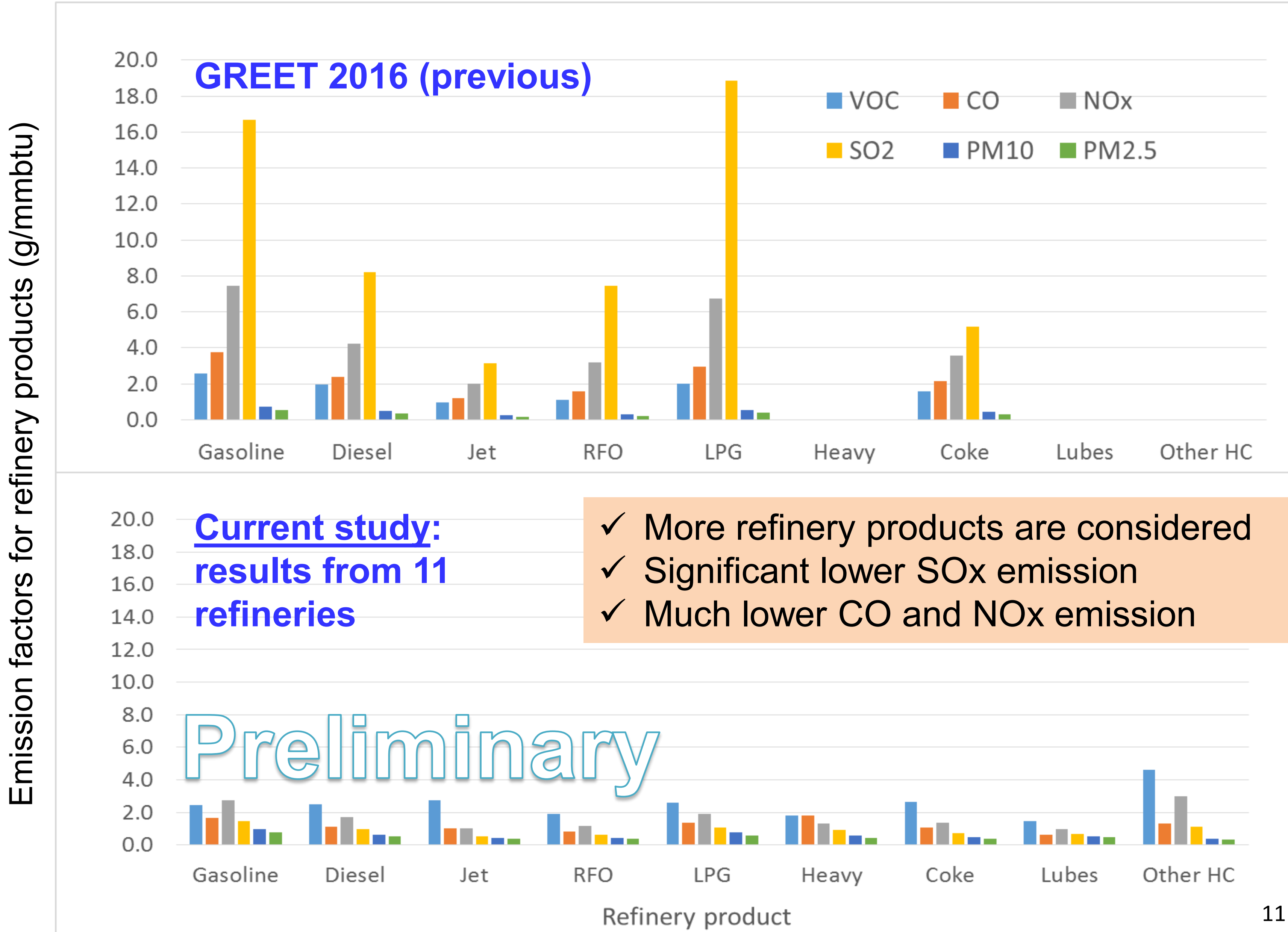


Refinery National Emission Inventory at Process Unit Level – Accomplishment



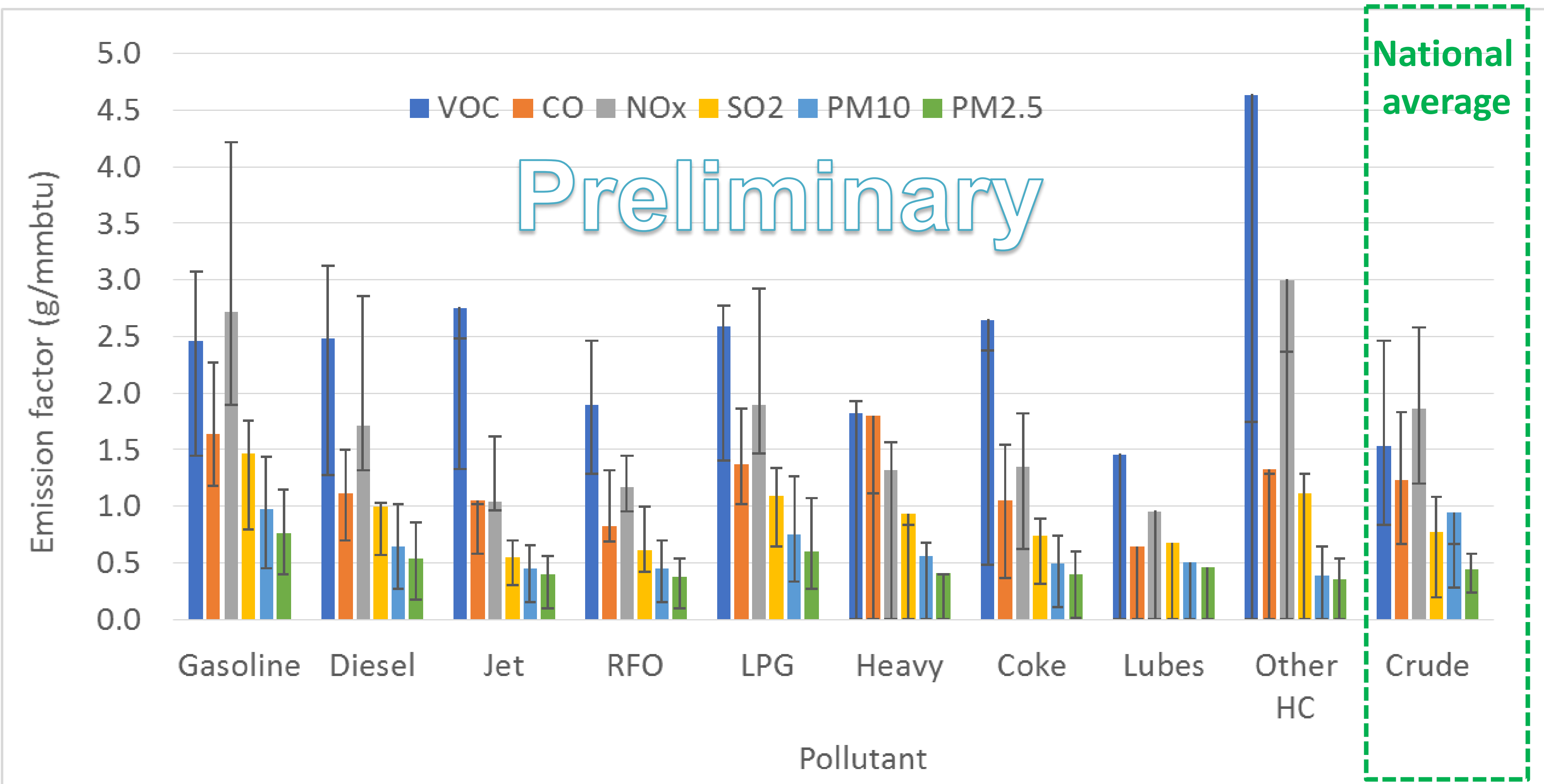
- Most pollutant air emissions are mainly sourced from combustion via heater, boiler, FCC, flare, and engine
- VOC is mainly sourced from fugitive emission, tank and waste

Refinery emissions allocated to products – Accomplishment



- ✓ More refinery products are considered
- ✓ Significant lower SOx emission
- ✓ Much lower CO and NOx emission

Large variation of emissions between refineries – Accomplishment



- The product emission factors are based on 11 refineries (capacity weighted)
- The average emission factors per unit crude input is calculated on a national level (>120 refineries)
- The error bars indicate **1 quartiles and 3 quartiles by facility**

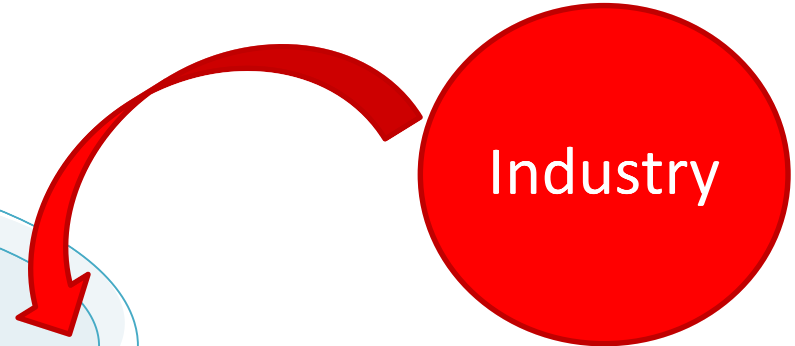
Part II: Standalone SMR

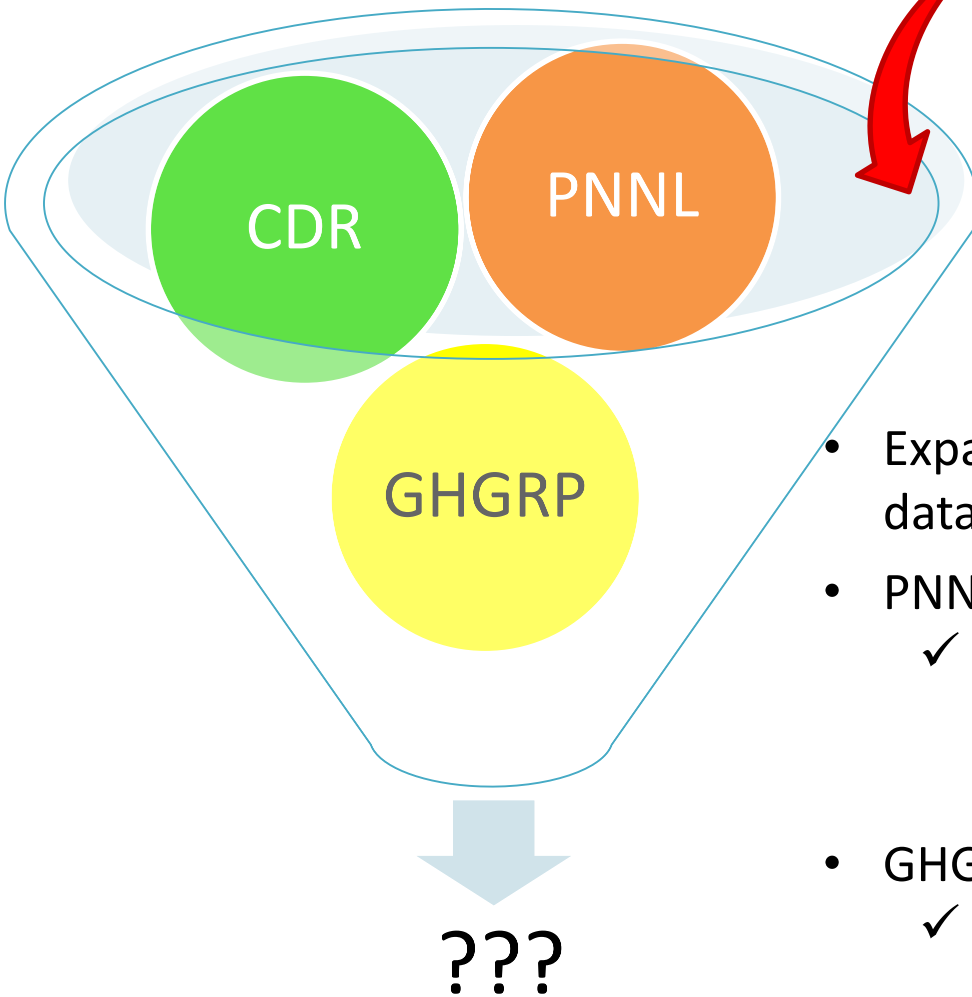
Pollutants Emission

Acquire SMR emissions and production data – Approach

- SMR can be within refinery fenceline or standalone
- After initial reviews: only standalone SMR were investigated as the former do not have a consistent system boundary
- For standalone SMR, no allocation is needed, all facility emissions are accounted for H_2 production
  - ✓ 2014 emissions data
  - ✓ Combustion and non-combustion emissions
- Limited overlap of facilities reporting both emissions and productions
- Verified via communication with industry

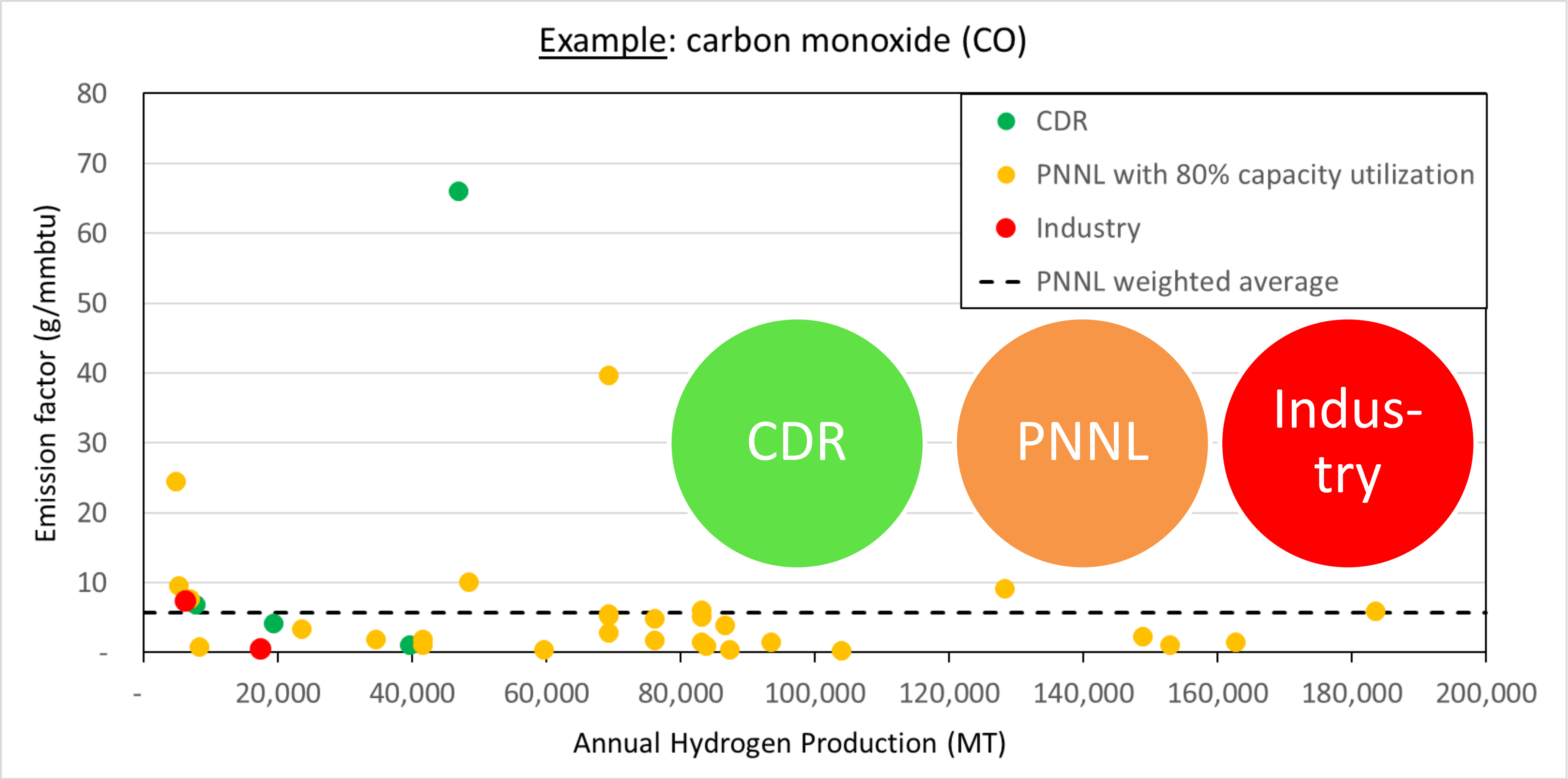
Standalone SMR H_2 production data pooling – Approach





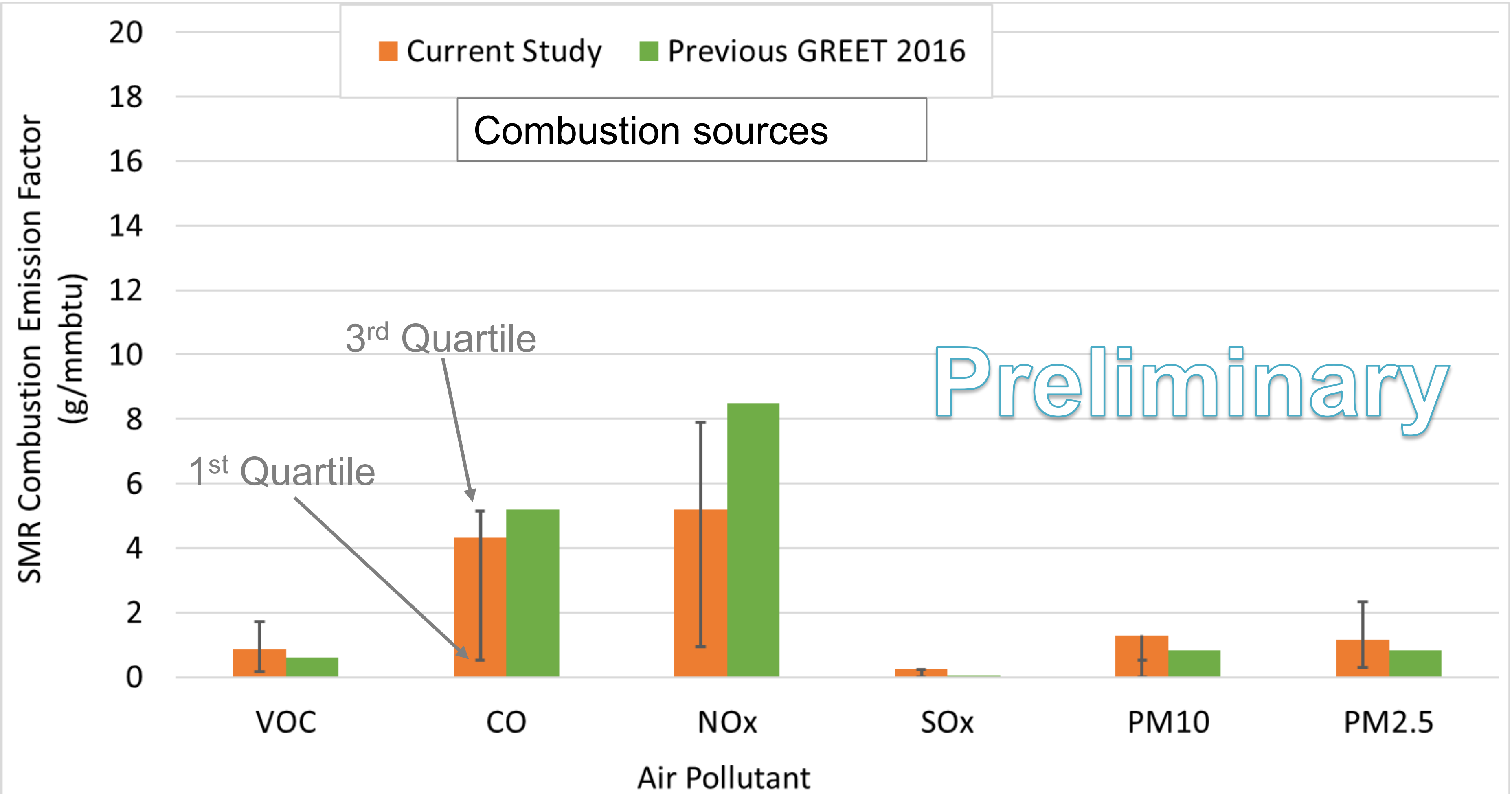
- Expanded the pool of hydrogen production data beyond CDR
- PNNL reports SMR capacity
  - ✓ assumed a conservative 80% utilization rate (consistent with petroleum refining capacity utilization in 2014)
- GHGRP reports CO_2 emission
  - ✓ assumed a conservative energy conversion ratio to derive H_2 production
- Vet against industry data

Examining SMR emission factors from various data pools – Approach/Accomplishment



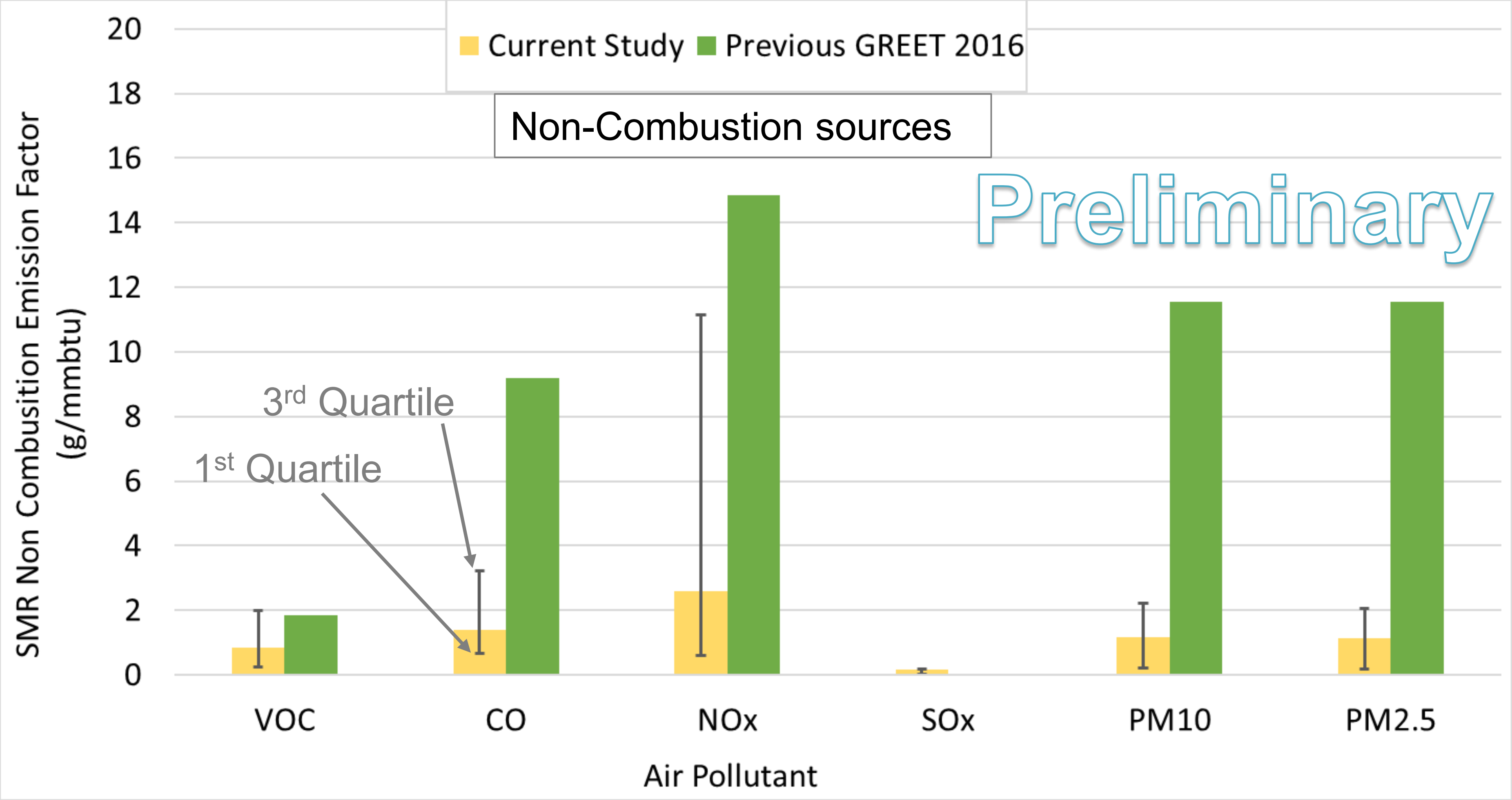
- Smaller SMR plants have apparent higher emission factor
- Used the CDR derived emission factors (EF) and industry input as **metrics** to evaluate the results from the PNNL data
- The significant scattering and divergence of GHGRP derived EFs (relative to CDR derived EFs) led to the GHGRP EF pool rejection

Develop SMR emission factors (combustion) – Accomplishments



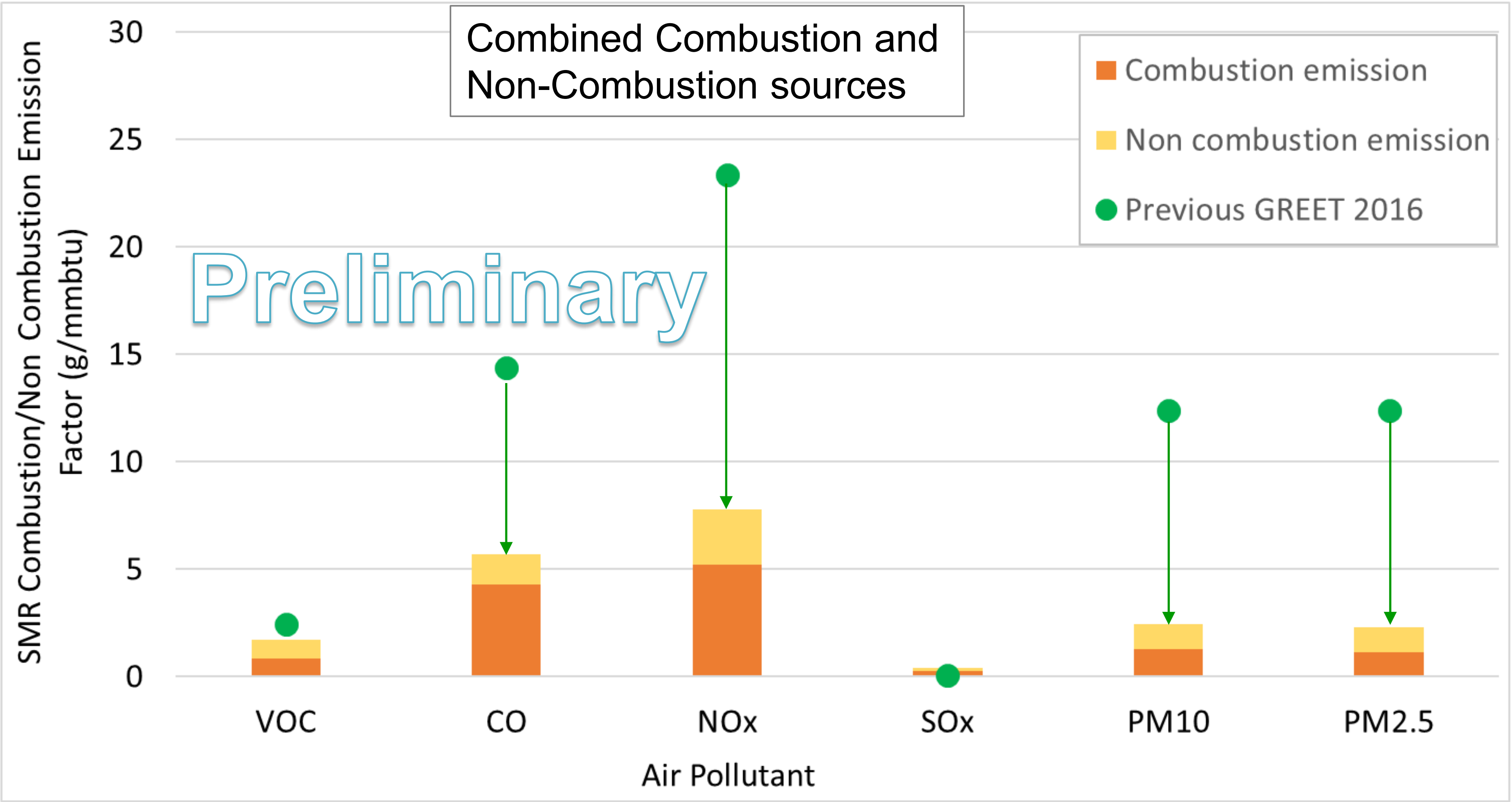
- Similar to refinery facilities, the SMR emissions are mainly sourced from combustion sources, heater, boiler, engine, flare
- Previous GREET 2016 combustion related emission factors are within the variation range from the present study

Develop SMR emission factors (non-combustion) – Accomplishments



- The non combustion sources include hydrogen plant, cooling water, fugitive emission, and other (based on SCC code)
- The weighed average of non-combustion emission factors are smaller compared to previous GREET 2016 values

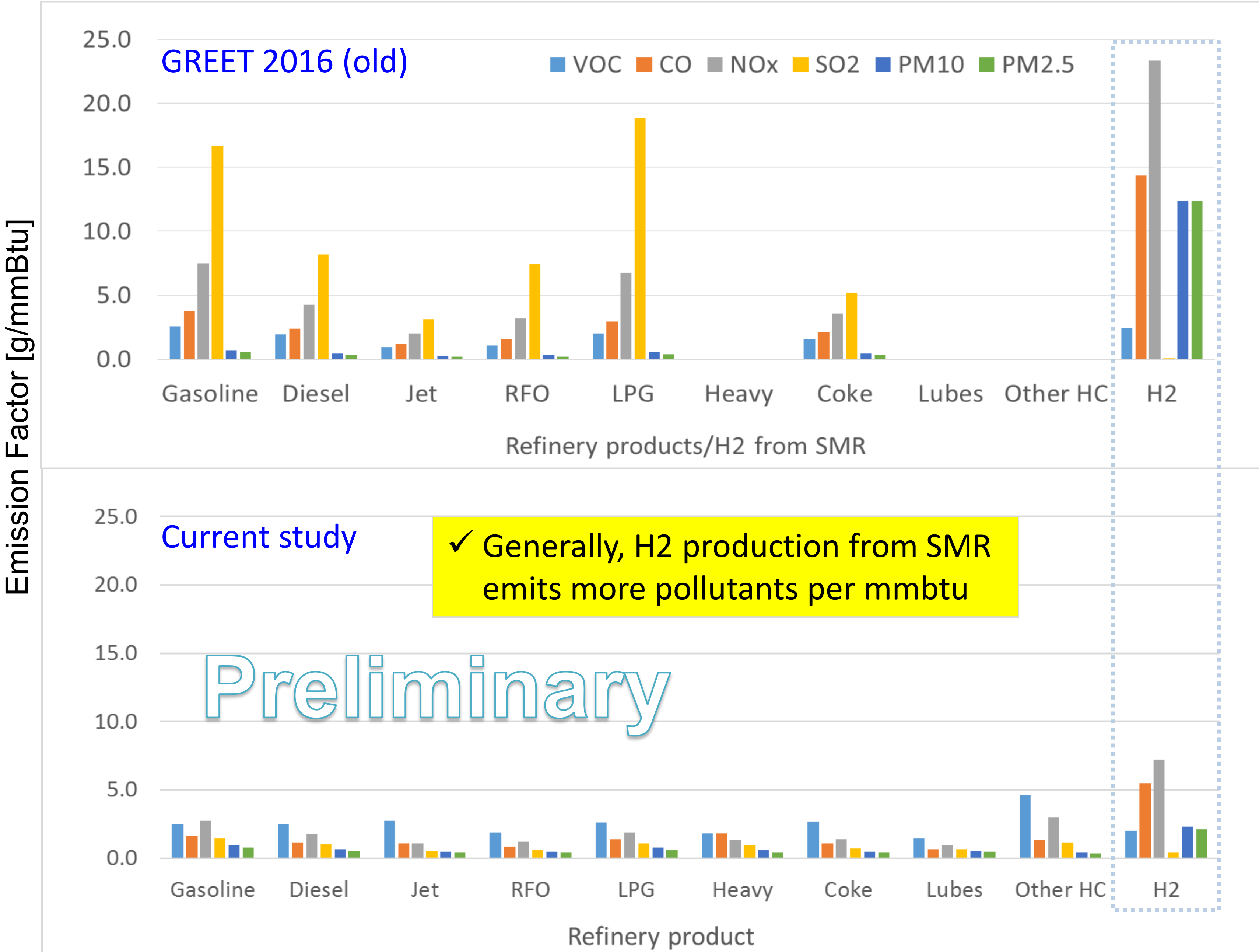
Total SMR emission factors – Accomplishments



- Considering a <u>larger emissions data pool</u>, the weighed average SMR emission factors are much smaller compared to previous GREET 2016 values
  - ✓ Mainly due to updates of non-combustion emissions

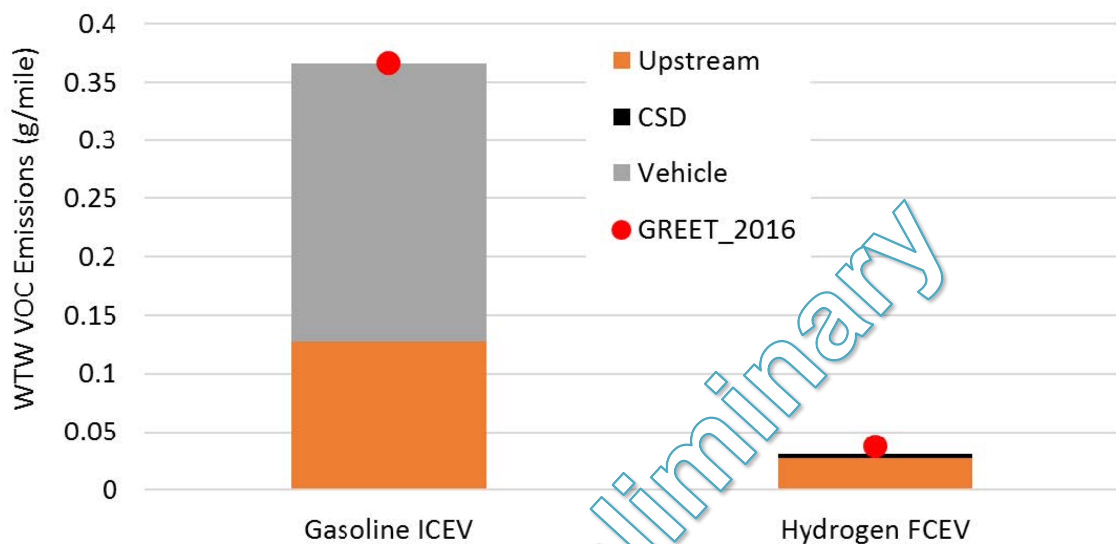
Part III: Petroleum Fuels vs. SMR Hydrogen in Light-Duty Vehicle Applications

Refinery fuels and SMR H_2 emission factors – Accomplishments



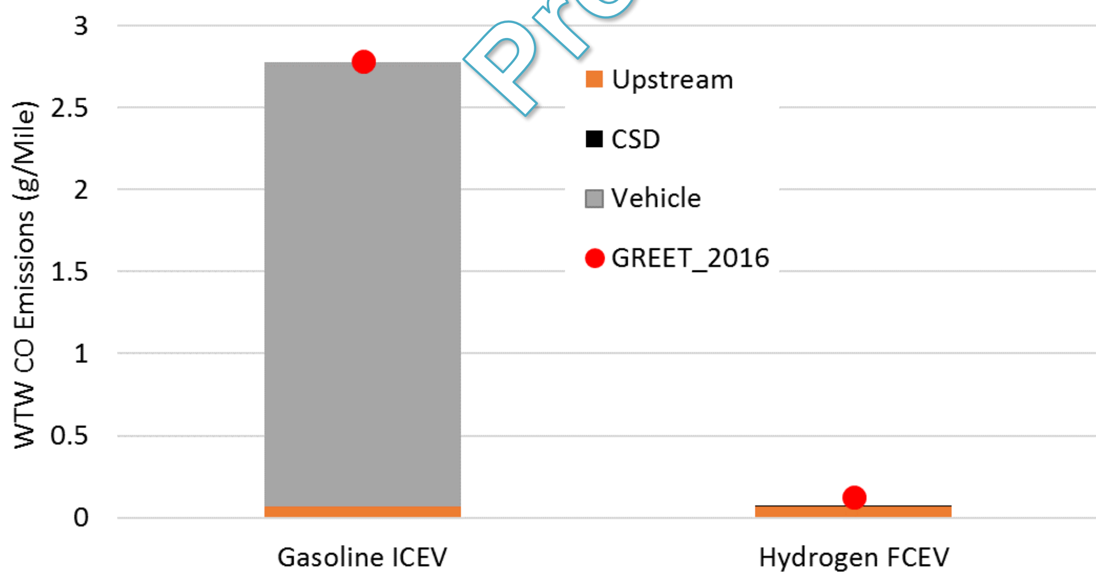
Well-to-wheels (WTW) VOC and CO emissions of FCEV are much lower compared gasoline ICEV – Accomplishments

<u>VOC</u>



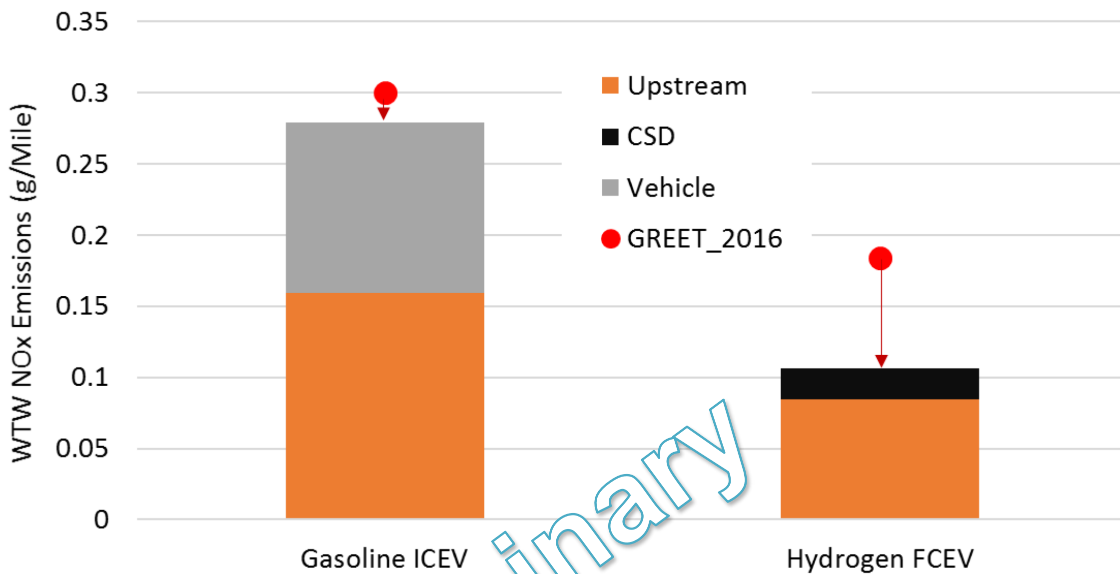
<u>Fuel Economy</u>:
Gasoline ICEV→ 26 mpg
H_2 FCEV → 55 mpgge

<u>CO</u>



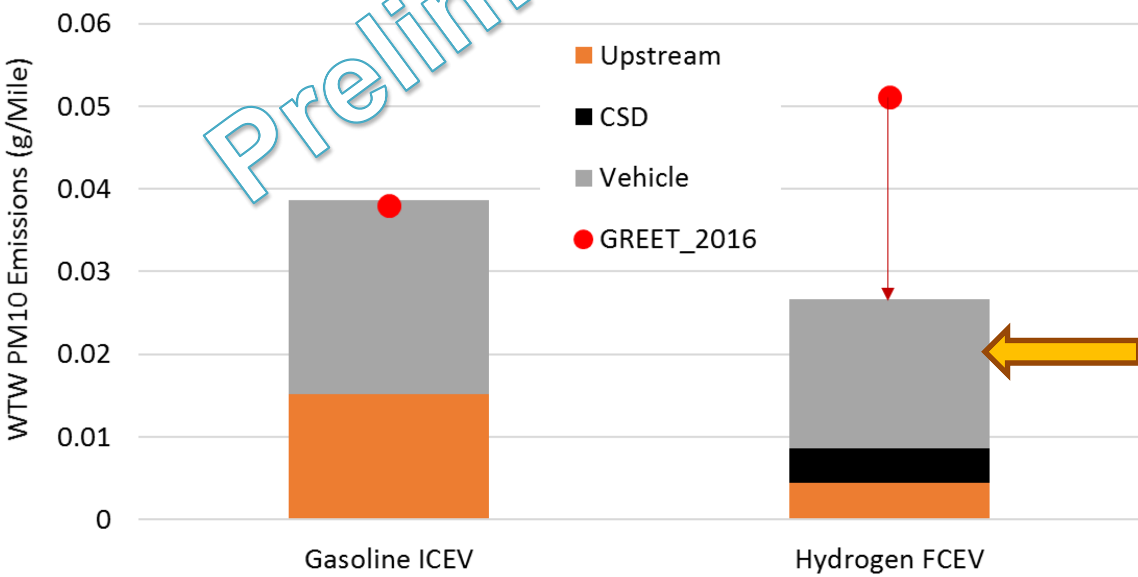
Well-to-wheels (WTW) NOx and PM10 emissions of FCEV are much lower compared to gasoline ICEV – Accomplishments

NOx



Fuel Economy:
Gasoline ICEV→ 26 mpg
H_2 FCEV → 55 mpgge

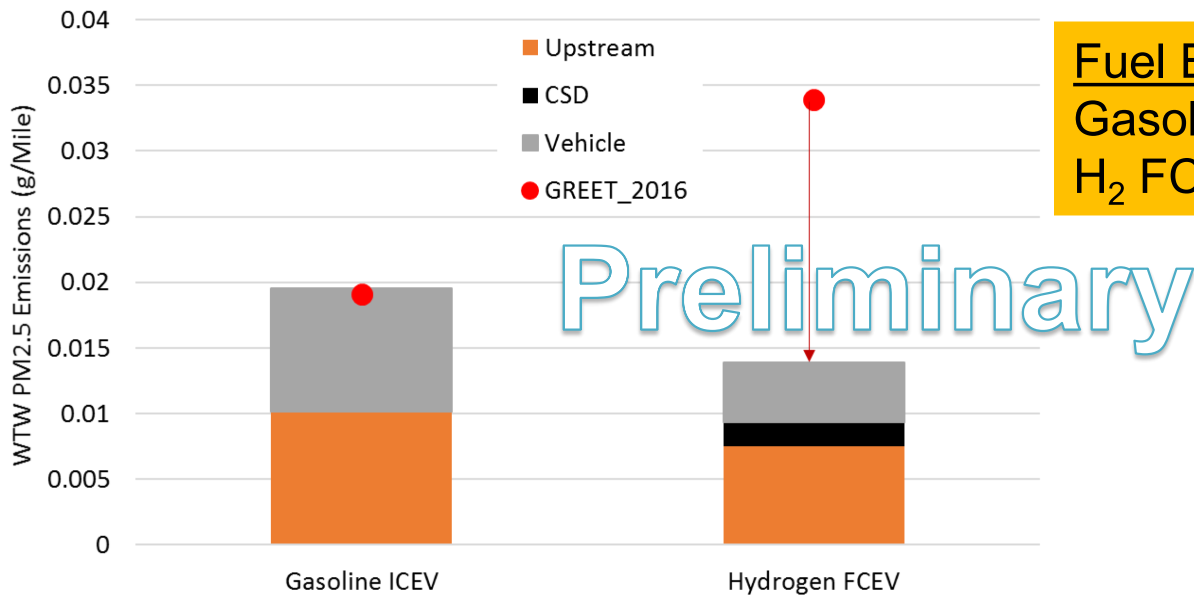
PM10



PM emissions for FCEV are from brake and tire wear

Well-to-wheels (WTW) SOx emissions of FCEV are higher compared to gasoline ICEV – Accomplishments

PM2.5



<u>Fuel Economy</u>:
Gasoline ICEV→ 26 mpg
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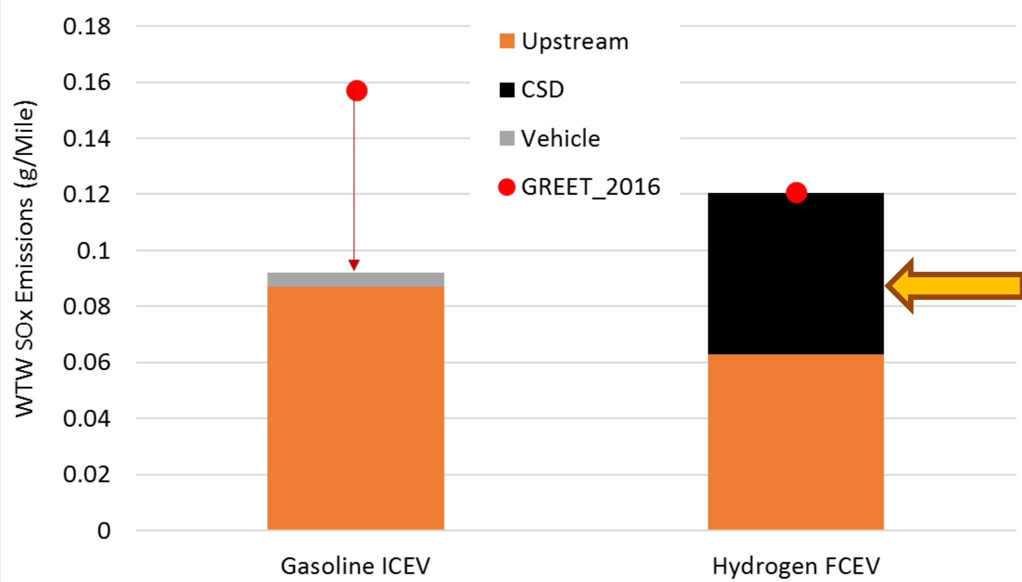
SOx



SOx emissions from electricity generation for H_2 CSD at refueling stations
✓will likely reduce over time with retirement of coal power plants

Summary – Accomplishment

- ✓ Collected emissions inventory data of individual refineries and for individual refining process units
- ✓ Mapped refinery process unit data into individual process units using flow schemes and unit energy intensities from LP modeling
- ✓ Allocated unit level emissions into various refinery product pools
- ✓ Quantified regional differences and variability for emissions associated with each refinery product
- ✓ Collected emissions inventory data and developed combustion and non-combustion related emission factors in standalone SMR plants
- ✓ Considering the larger emissions data pools, the weighed average emission factors for refinery products and SMR hydrogen are smaller compared to previous GREET 2016 values
- ✓ Updated GREET with new emission factors for refinery and SMR products
- ✓ Compared WTW emissions of hydrogen FCEVs vs. baseline gasoline ICEVs
  - ➢ Much lower WTW air pollutant emissions (except SOx) for FCEVs compared to gasoline ICEVs
  - ➢ WTW SOx emissions for SMR hydrogen is impacted by electricity use for CSD

Collaborations and Acknowledgments

- ERG Consultancy pooled U.S. refinery/SMR emissions inventory and production capacity
- Jacobs Consultancy provided refinery configurations and energy and yields at the process unit level
- PNNL provided nameplate capacity for SMR plants
- Industry stake holders verified SMR emissions information

Future Work

- Continue to match individual refinery unit operation and emissions using 2014 emissions dataset
  - improve product-specific emissions estimate with a larger sample of emissions inventory data
- Expand sample of SMR emission factors with annual production estimates and considering combined 2011/2014 emissions data
- Correlate emission factors with SMR plant capacity
- Reconcile and refine different air emission evaluation methods with respect to system boundary and allocation (e.g. tank emission, fugitives)
- Assess variability of air emissions by region (regional analysis)
- Expand analysis from inventory level to impact assessment by region
  - ✓ Assess benefits of hydrogen FCEVs on air quality in different regions
- Update public GREET model with revised emission factors and publish air emission results in peer reviewed article

Project Summary

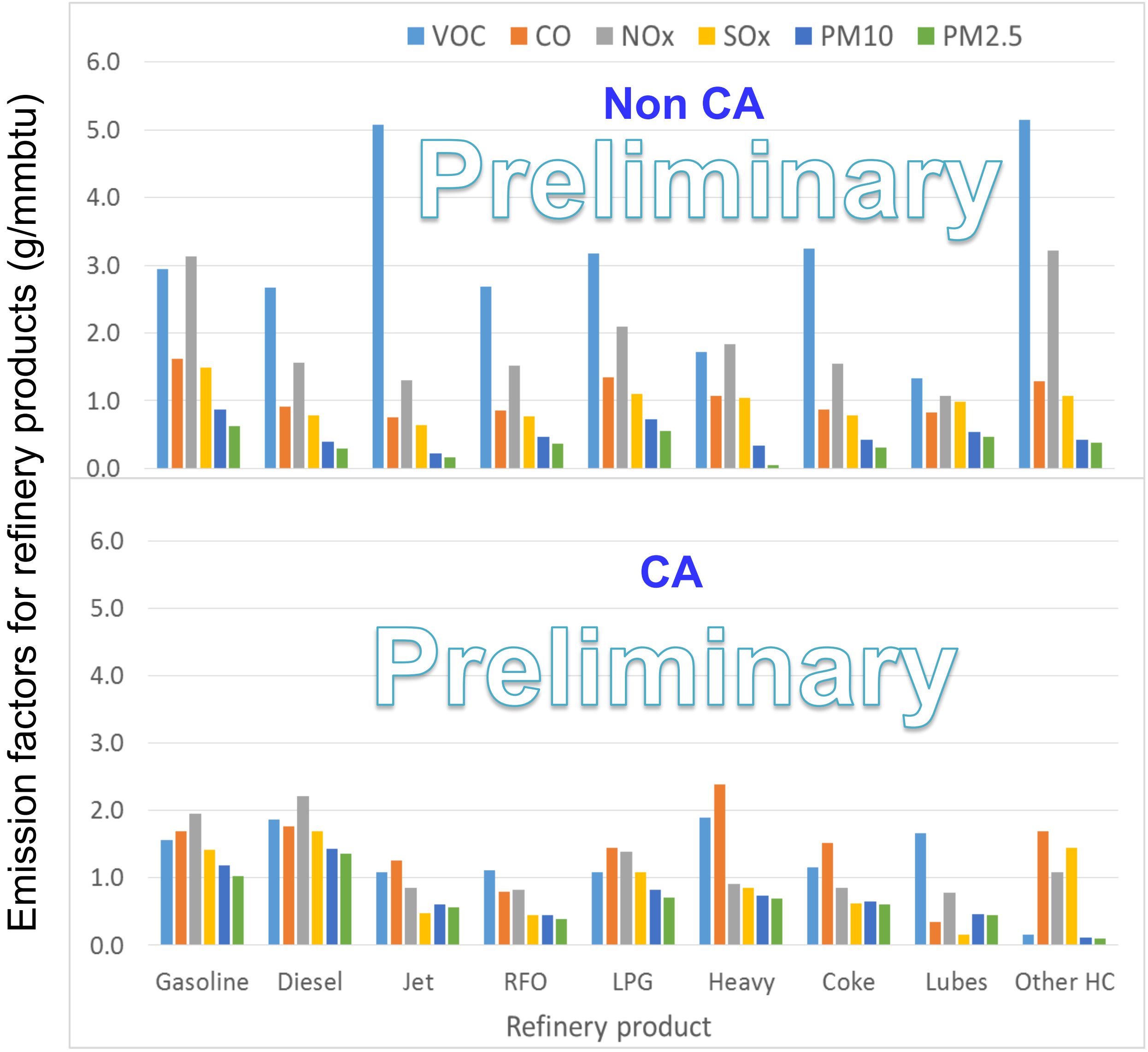
- **Relevance:**
  - Reducing air pollutant emissions from transportation is a target for major cities in the U.S.
  - Vehicle electrification provides significant potential for reducing air pollutant emissions
  - Accurate air pollutant emissions is needed for baseline petroleum fuels and H2
  - LCA provides a consistent platform for evaluating and comparing air pollutant emissions along the production pathways of transportation fuels (including H2)
- **Approach:** Acquire emissions inventory and production data for petroleum refineries and SMR hydrogen plants. Allocate emissions to individual refinery products using flow schemes from LP modeling.
- **Collaborations**: Worked with ERG, Jacobs Consultancy and PNNL to acquire high quality emissions inventory and refinery/SMR operation data. Communicated with industry to verify emissions data.
- **Technical accomplishments and progress:**
  - Allocated refinery pollutant emissions into various refinery product pools
  - Quantified regional differences and variability for emissions associated with each refinery product
  - Developed combustion and non-combustion related emission factors in standalone SMR plants
  - Considering the larger emissions data pools, the weighed average emission factors for refinery products and SMR hydrogen are smaller compared to previous GREET 2016 values
  - Lower WTW air pollutant emissions (except SOx) for FCEVs compared to gasoline ICEVs
- **Future Work:**
  - Expand emissions inventory sample by considering 2014 refinery and SMR operation and emissions
  - Assess variability of air emissions by region (regional analysis)
  - Expand analysis from inventory level to impact assessment by region
    - Assess benefits of hydrogen FCEVs on air quality in different regions
  - Update public GREET model with revised emission factors and publish air emission results in peer reviewed article

Acronyms

- C2G WG: Cradle-to-Grave Work Group
- CA: California
- CDR: chemical data reporting
- CO: Carbon Monoxide
- CSD: Compression, Storage, and Dispensing
- EF: Emission Factor
- EIA: Energy Information Administration
- EPA: Environmental Protection Agency
- FCC: Fluid Catalytic Cracking
- FCEV: Fuel Cell Electric Vehicle
- FCTO: Fuel Cells Technologies Office
- FY: Fiscal Year
- GHG : Greenhouse Gases
- GHGRP: Green house gas reporting program
- GREET: Greenhouse gases, Regulated Emissions, and Energy use in Transportation
- H_2: Hydrogen
- H2A: Hydrogen Analysis
- ICEV: Internal Combustion Engine Vehicle
- LCA: Life-Cycle Analysis
- LP: Linear Programming
- LPG: Liquefied Petroleum Gas
- mpg: miles per gallon
- mpgge: miles per gallon of gasoline equivalent
- MSM: Maco-Systems Model
- NE: North Eastern
- NEI: national emission inventory
- NOx: Nitrogen Oxides
- PM10: Particulate Matter less than 10 micron
- PM2.5: Particulate Matter less than 2.5 micron
- PNNL: Pacific northwest national laboratory
- RD&D: Research, Development, and Demonstration
- RefCap: refinery capacity report
- SCC: Standard Classification Code
- SMR: Steam Methane Reforming
- SOx: Sulfur Oxides
- VOC: Voatile Organic Compound
- WTW: Well-To-Wheels
- ZEV: Zero Emissions Vehicle

Technical Backup Slides

Refinery regional emissions difference – Accomplishment



Non-CA: higher in VOC, NOx

CA: higher in CO, PM10 andPM2.5