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Developing an Approach for the Life Cycle Analysis of Conventional Petroleum Fuels: Outlook to 2040 – Crude Extraction and Transport

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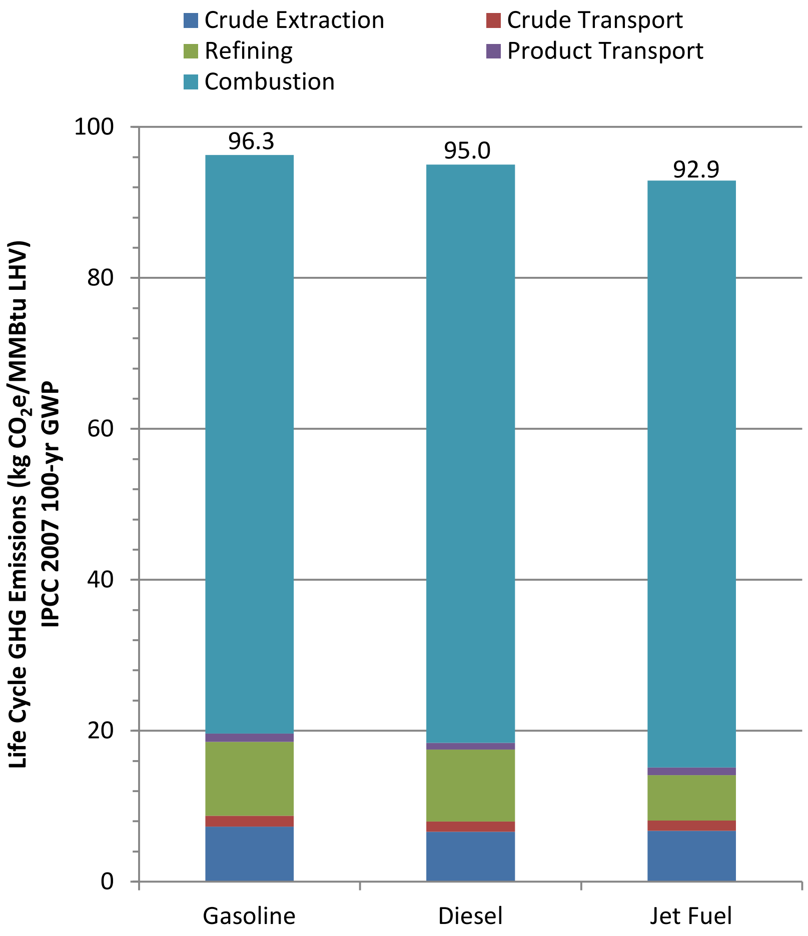
NETL Petroleum LCA published in 2008 set the baseline for fuel consumed in the U.S.

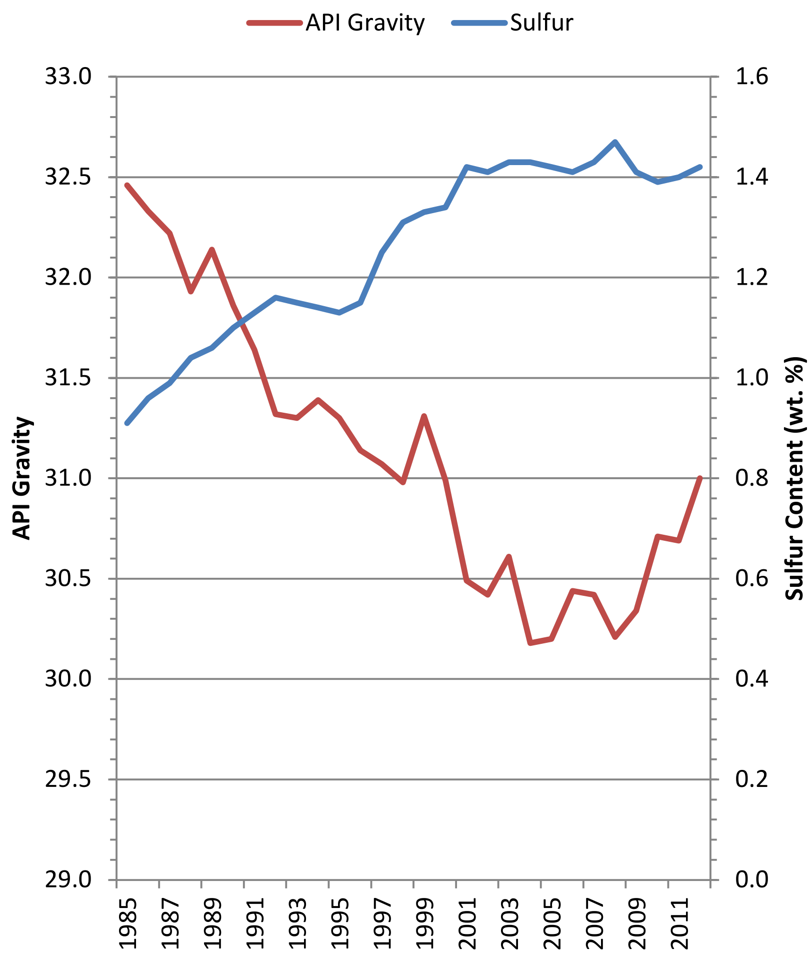
- **Published in 2008; representative of year 2005**
- **Policy Applications**
  - Energy Independence and Security Act Section 526
  - Renewable Fuels Standards
- **Data:**
  - Crude extraction profiles based on PE International data
  - Refining impacts based on EIA data; allocation at unit process level
- **Well-to-Tank: 16.3 – 20.4% of total LC emissions**



NETL. (2008). *Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels.* (DOE/NETL-2009/1346). Pittsburgh, PA: National Energy Technology Laboratory

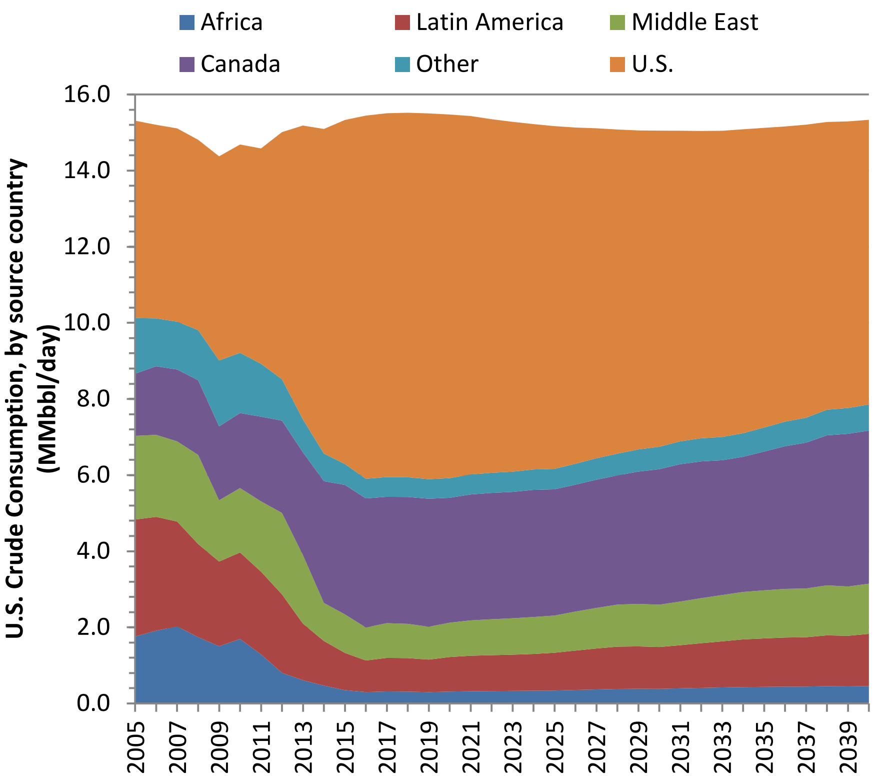
Crude extraction and refining have changed significantly since the 2008 NETL Baseline

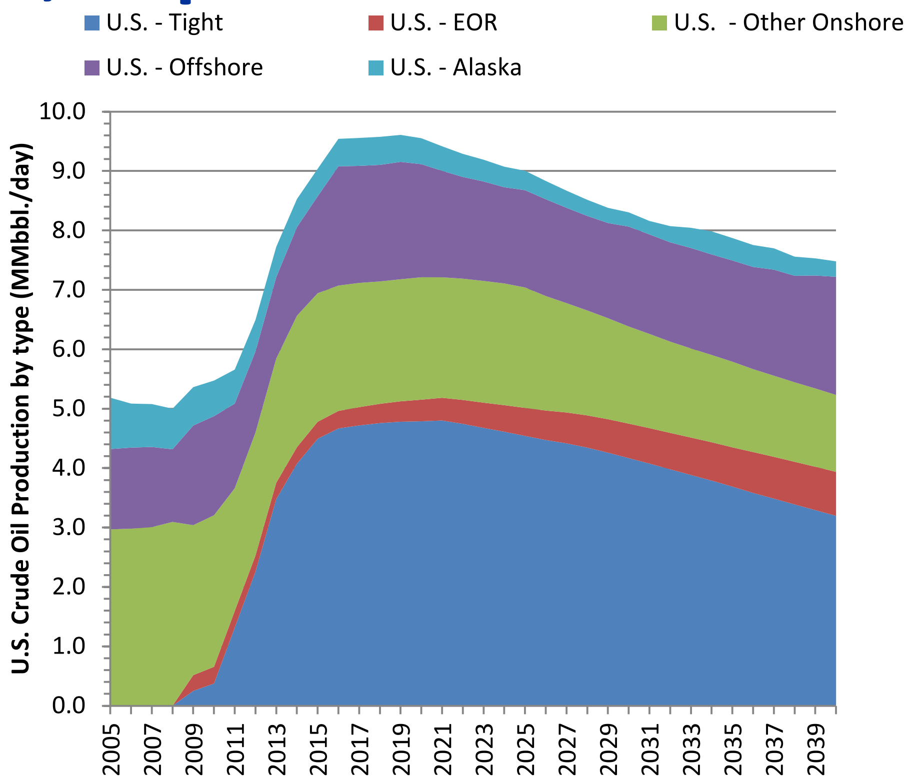
- **Known changes to crude oil mix (source, extraction method, and quality)**
- **Transition to ultra low sulfur diesel, increasing refinery hydrogen demand**
- **Research Goals:**
  - Establish an updated baseline
  - Evaluate to understand uncertainty in long-term comparisons of alternative fuels projects to the petroleum baseline
  - Utilize a transparent and flexible modeling approach



EIA. (2013). *Petroleum & Other Liquids Data.* US Department of Energy Retrieved January 2, 2014, from http://www.eia.gov/petroleum/data.cfm

Domestic crude production increases due to the tight oil boom; imports decline





- U.S. domestic share peaks at 62% in 2016
- Daily crude consumption is flat throughout
- Canadian imports increase (shift towards oil sands); all other imports drop off

- Tight oil accounts for 50% of U.S. domestic production by 2015
- EOR share of production doubles over the forecast period

EIA. (2013). *AEO 2014 Interactive Table Viewer.* US Department of Energy Retrieved January 2, 2014, from http://www.eia.gov/oiaf/aeo/tablebrowser/
EIA. (2013). *Petroleum & Other Liquids Data.* US Department of Energy Retrieved January 2, 2014, from http://www.eia.gov/petroleum/data.cfm
Canadian Association of Petroleum Producers. (2013). *Crude Oil Forecast, Markets & Transportation*. (2013-0013). Alberta, Canada: CAPP

Modeling Environmental Impacts: Cradle-to-Gate Crude Extraction Tools

OPGEE
Primary, secondary, tertiary extraction (steam)

GHOST
Canadian Oil Sands (surface mining and in situ extraction)

NETL CO_2-EOR
Enhanced oil recovery using injected CO_2

Modeling Environmental Impacts: Cradle-to-Gate Crude Extraction Tools

- **OPGEE - Oil Production Greenhouse Gas Emissions Estimator**
  - Used to model U.S. (non-EOR) and international production (except CA Oil Sands)
  - Engineering based model that accounts for seven main stages of operation:
    - (1) Exploration, (2) Drilling and Development, (3) Production and Extraction, (4) Separation and Surface Processing, (5) Maintenance and Workovers, (6) Waste Treatment and Disposal, (7) Crude Product Transport
  - Key parameters:
    - Water-Oil Ratio (WOR)
    - Flaring Rate
    - API
    - Steam-Oil Ratio (SOR)
    - Gas-Oil Ratio (GOR)
    - Depth
    - Production Rate

El-Houjeiri, H. M., Brandt, A. R., & Duffy, J. E. (2013). Open-Source LCA Tool for Estimating Greenhouse Gas Emissions from Crude Oil Production Using Field Characteristics. *Environmental Science & Technology,* 47(11), 5998-6006. doi: 10.1021/es304570m

Modeling Environmental Impacts: Cradle-to-Gate Crude Extraction Tools

- **GHOST – GreenHouse gas emissions of current Oil Sands Technologies**
  - Process-based model
  - Based on information from technical experts and confidential operating data collected from the industry
  - Model includes three primary bitumen recovery and extraction technologies (SAGD, surface mining, and CSS) and two upgrading technologies (delayed coking and hydrocracking)
  - Key parameters:
    - Extraction method
    - Steam-Oil Ratio (SOR)
    - Product type – Dilbit, Synbit, Syncrude
    - Flare/vent rate
    - Cogen/no cogen

Charpentier, A. D., Kofoworola, O., Bergerson, J. A., & MacLean, H. L. (2011). Life Cycle Greenhouse Gas Emissions of Current Oil Sands Technologies: GHOST Model Development and Illustrative Application. *Environmental Science & Technology*, 45(21), 9393-9404. doi: 10.1021/es103912m
Bergerson, J. A., Kofoworola, O., Charpentier, A. D., Sleep, S., & MacLean, H. L. (2012). Life Cycle Greenhouse Gas Emissions of Current Oil Sands Technologies: Surface Mining and In Situ Applications. *Environmental Science & Technology*, 46(14), 7865-7874. doi: 10.1021/es300718h

Modeling Environmental Impacts: Cradle-to-Gate Crude Extraction Tools

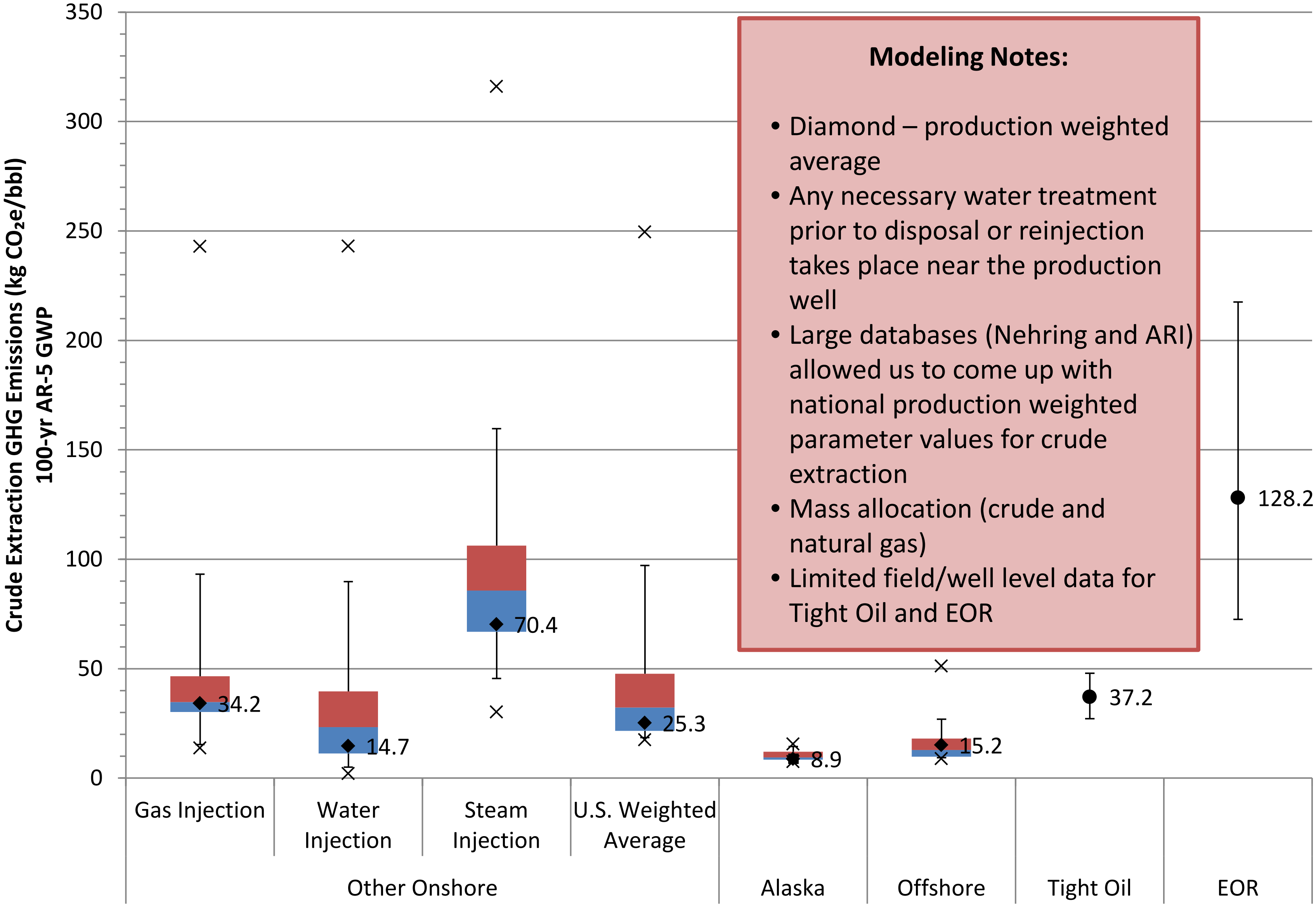
- **NETL CO_2 – Enhanced Oil Recovery Model**
  - Injection of CO_2 to improve the recoverability of crude oil by reducing viscosity, swelling crude oil, and lowering interfacial tension
  - Based on reservoir and fluid calculations from DOE PROPHET model
  - WAG (water-alternating gas) injection scheme
  - Options for surface gas processing: refrigeration/fractionation, Ryan-Holmes, membrane
  - Does not include the impacts for the source of the carbon dioxide (this analysis assumes the source is a natural dome)
  - Key parameters:
    - Injection pressure
    - Formation leakage
    - Crude recovery (bbl/tonne CO_2 sequestered)

NETL. (2013). *Gate-to-Gate Life Cycle Inventory and Model of CO_2-Enhanced Oil Recovery*. (DOE/NETL-2013/1599). Pittsburgh, PA: National Energy Technology Laboratory

Tuning the model parameters is key to representing the desired areas/methods of extraction

- **Nehring database (proprietary)**
  - Select information on significant reservoirs in the US
  - Depth, API, GOR, initial pressure, annual oil & gas production, and secondary/tertiary recovery methods
  - Over 7,000 entries representing 76% of all U.S. crude production in 2007
- **ARI database (proprietary)**
  - WOR, reservoir pressure decline
- **North Dakota Oil and Gas Division for Bakken Shale**
  - Flare rate, GOR, WOR, production, EUR
- **NETL models and Oil and Gas Journal for CO_2-EOR**
  - Permian Basin
  - Injection pressure, crude recovery ratio
  - NGL recovery methods

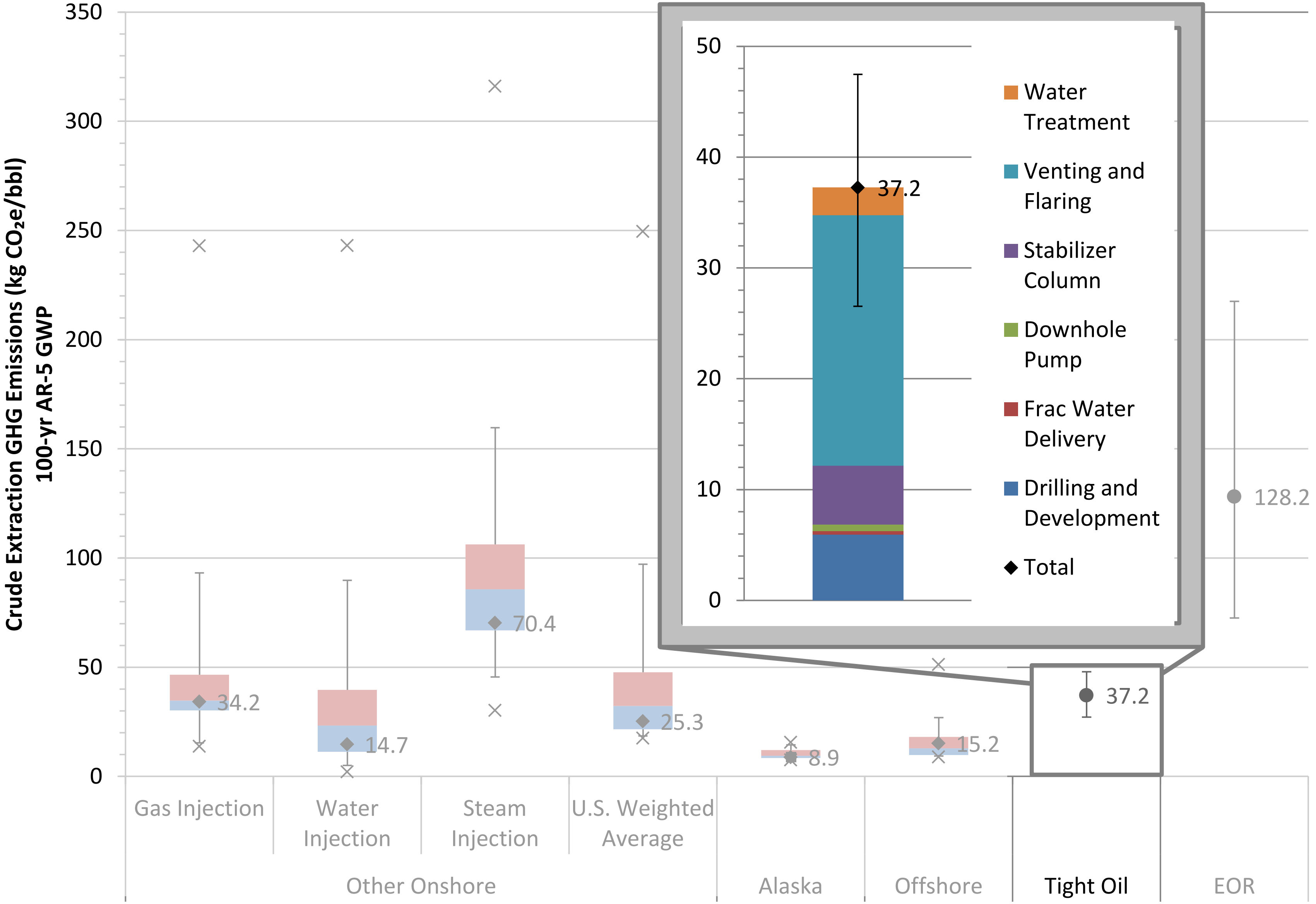
U.S. Crude Extraction GHG Results



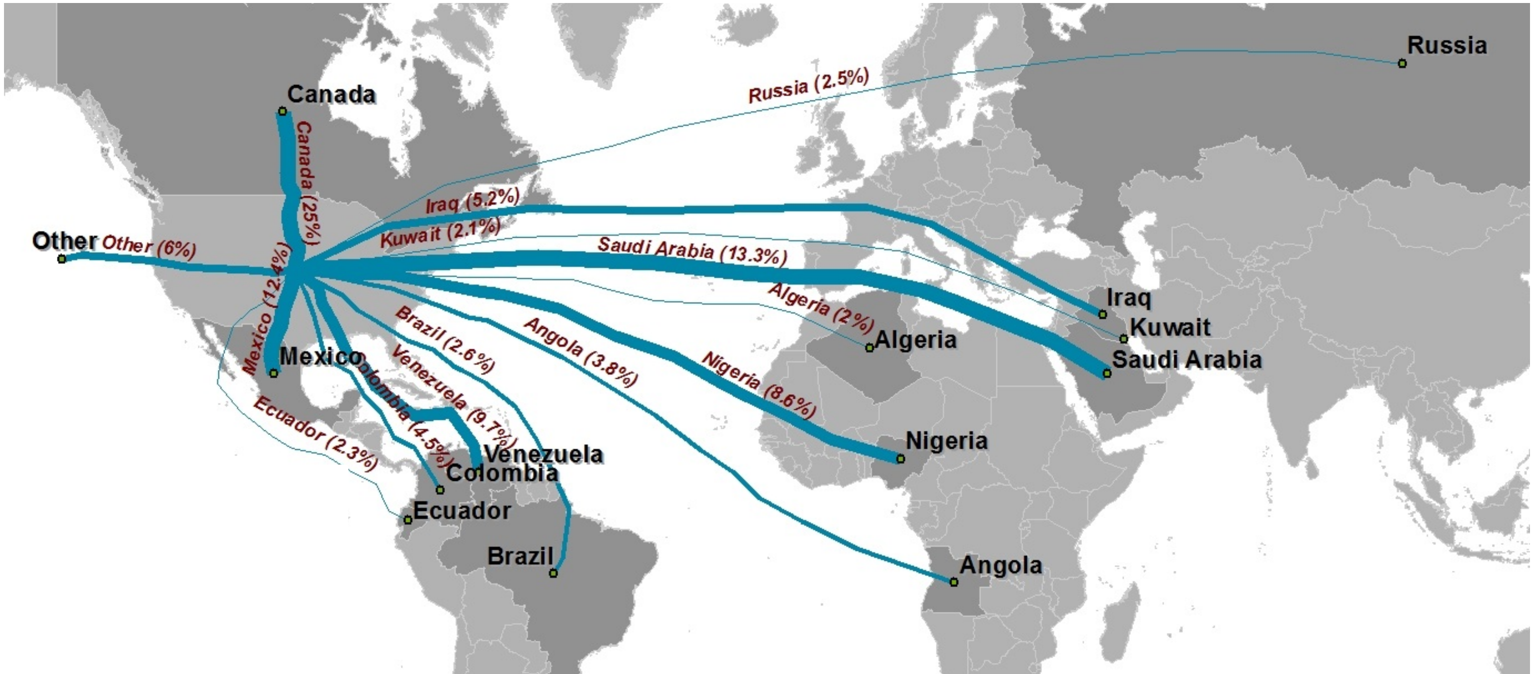
Modeling Notes:

- Diamond – production weighted average
- Any necessary water treatment prior to disposal or reinjection takes place near the production well
- Large databases (Nehring and ARI) allowed us to come up with national production weighted parameter values for crude extraction
- Mass allocation (crude and natural gas)
- Limited field/well level data for Tight Oil and EOR

U.S. Crude Extraction GHG Results



Characterizing foreign crude is much more difficult because of a lack of transparent data



- Limited information available for the key parameters for foreign crude extraction
- Apply data used previously in other studies, where available for parameters like API, depth, GOR, reservoir pressure[1,2]
- Use U.S. average extraction as defaults for countries where no other data is available
- Focus on venting/flaring fraction, which has been shown to be a large differentiator in extraction emissions between foreign crudes

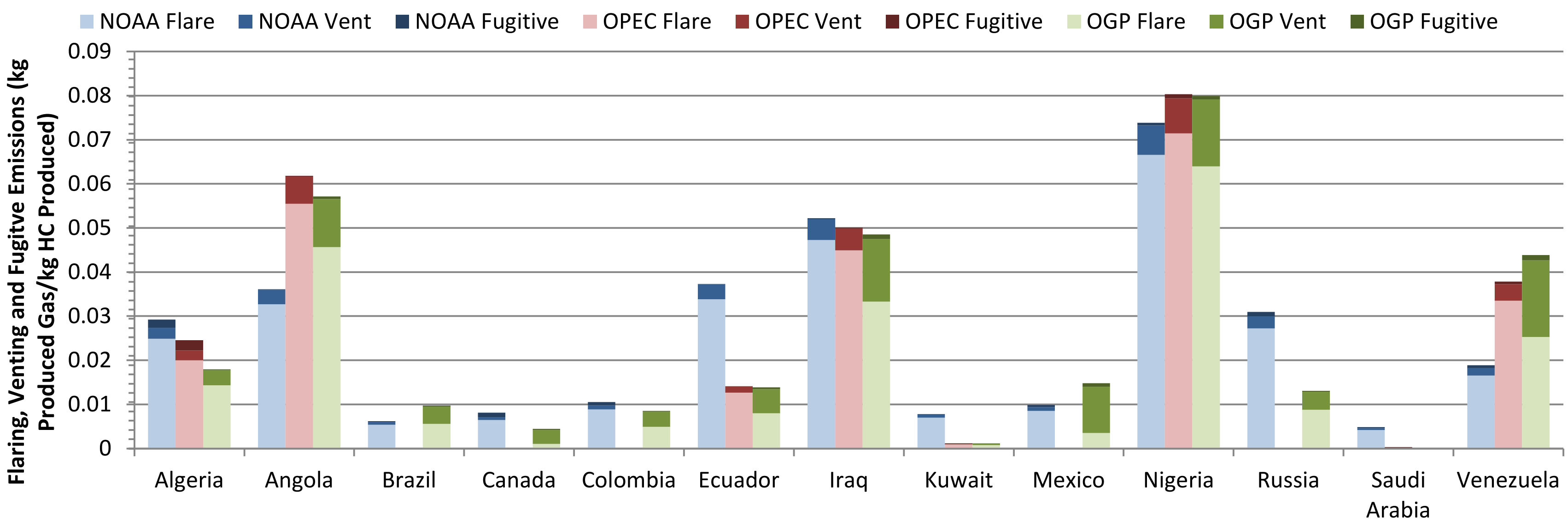
[1]Consultancy. (2012). *EU Pathway Study: Life Cycle Assessment of Crude Oils in a European Context.* Calgary: Alberta Petroleum Marketing Commission
[2]ICCT. (2014). *Upstream Emissions of Fossil Fuel Feedstocks for Transport Fuels Consumed in the European Union.* Washington, DC. The International Council on Clean Transportation

Flaring and venting data for international crude production are sparse and inconsistent

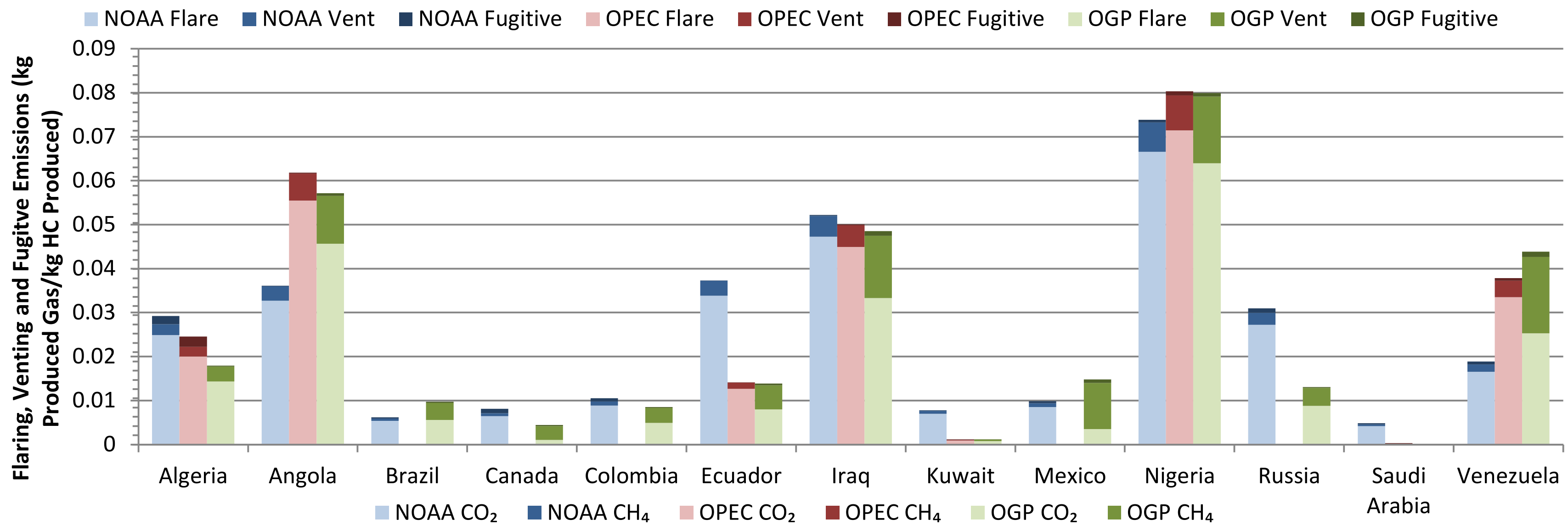
Data Source	Method	Geographic Coverage	Advantages	Limitations
NOAA[1]`	Satellite Data	Worldwide (individual country level)	Geographic coverage; independent analysis	No information on vented fraction
OPEC[2]	Reported data from member countries	Limited to OPEC countries (Algeria, Angola, Ecuador, Iraq, Kuwait, Nigeria, Saudi Arabia, Venezuela)	Only source to report country-specific data	Geographic coverage; no information on vented fraction
OGP[3]	Reported data from member companies operating around the world	Continental/Regional (North America, South America, Europe, Africa, Middle East, Former Soviet Union, Asia/Australia)	Only source that reports vented data in addition to flared gas	Accounts for only 32% of worldwide production; regional representativeness is uneven (Europe 100%; FSU 9%)

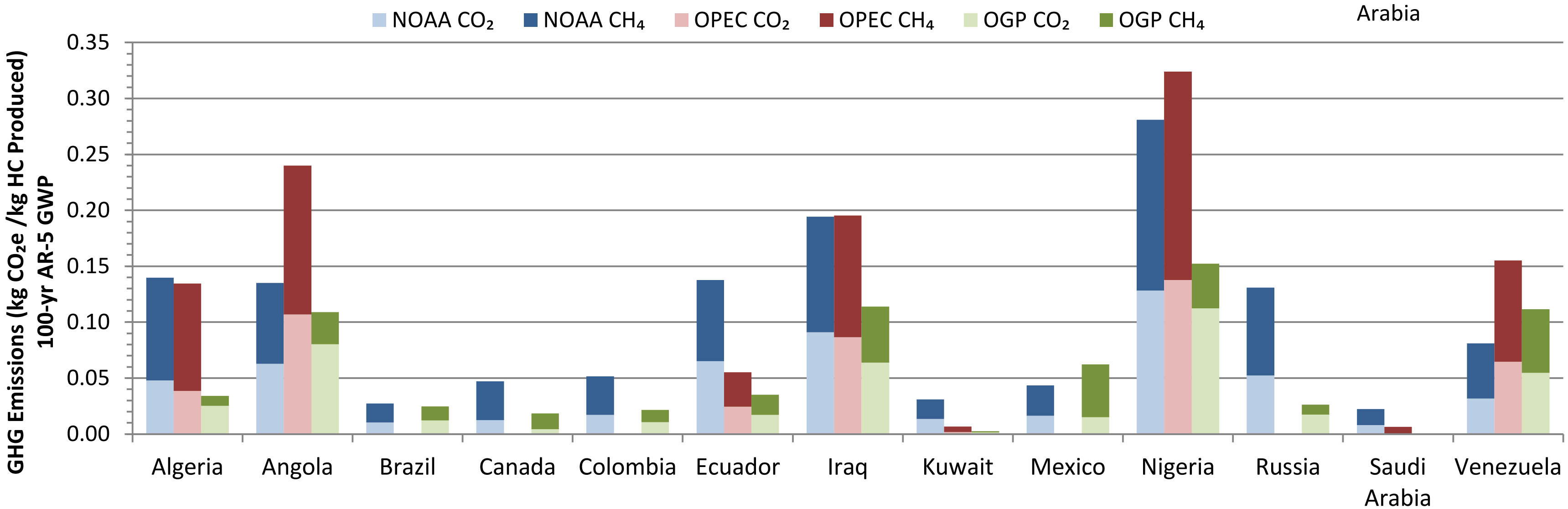
[1]NOAA. (2011). Global Gas Flaring Estimates Retrieved Septmber 30, 2014, from http://ngdc.noaa.gov/eog/interest/gas_flares.html
[2]OPEC. (2013). *Annual Statistical Bulletin*. Vienna, Austria: Organization of the Petroleum Exporting Countries
[3]OGP. (2012). *Environmental performance indicators*. London, England: International Association of Oil & Gas Producers

Sources provide a reasonable match on the amount of gas…



Sources provide a reasonable match on the amount of gas, but compositions drive GWP





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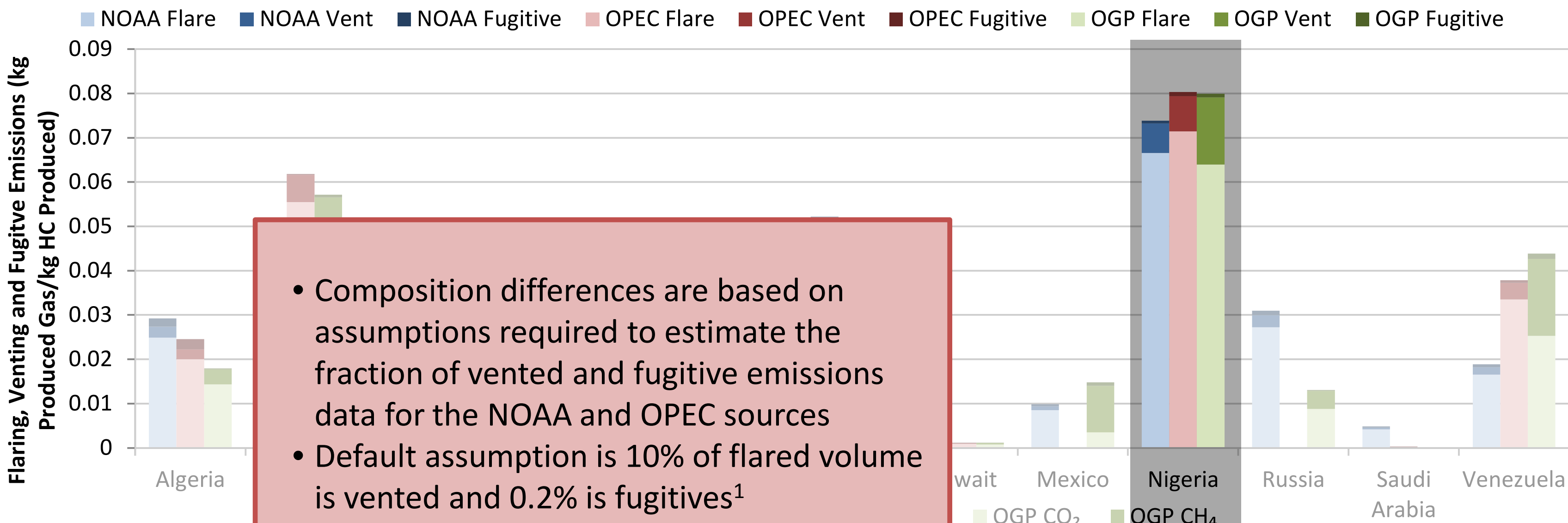

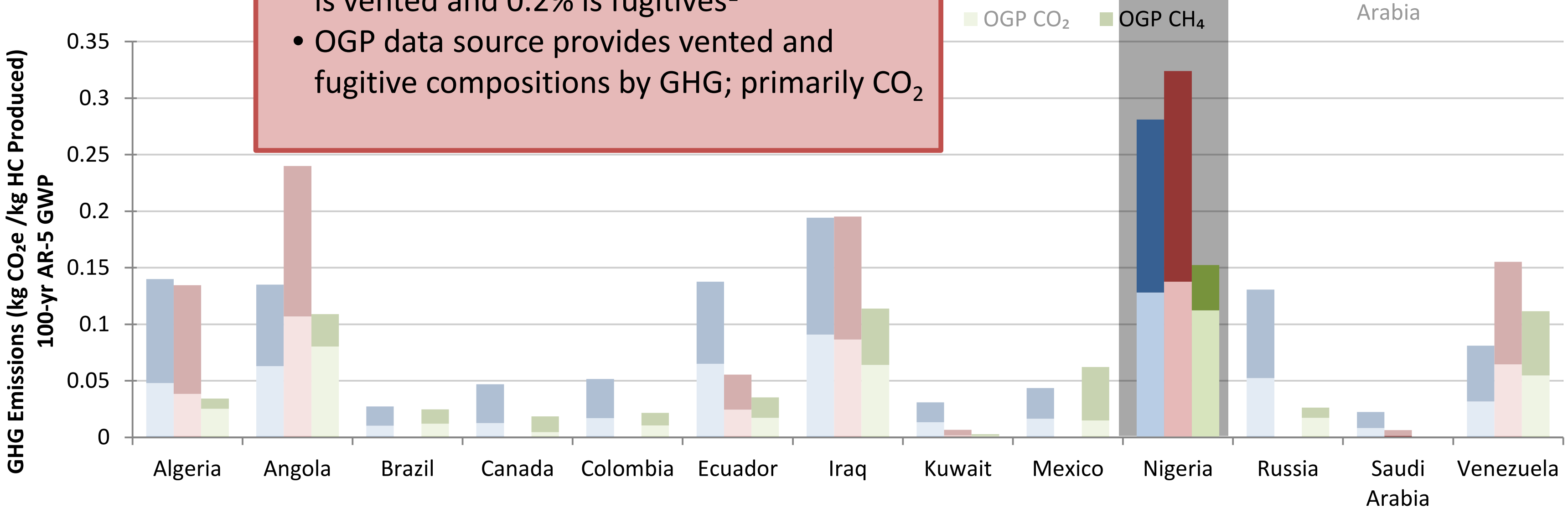

- Composition differences are based on assumptions required to estimate the fraction of vented and fugitive emissions data for the NOAA and OPEC sources
- Default assumption is 10% of flared volume is vented and 0.2% is fugitives[1]
- OGP data source provides vented and fugitive compositions by GHG; primarily CO_2

[1]Jacobs Consultancy. (2012). *EU Pathway Study: Life Cycle Assessment of Crude Oils in a European Context*. Calgary: Alberta Petroleum Marketing Commission

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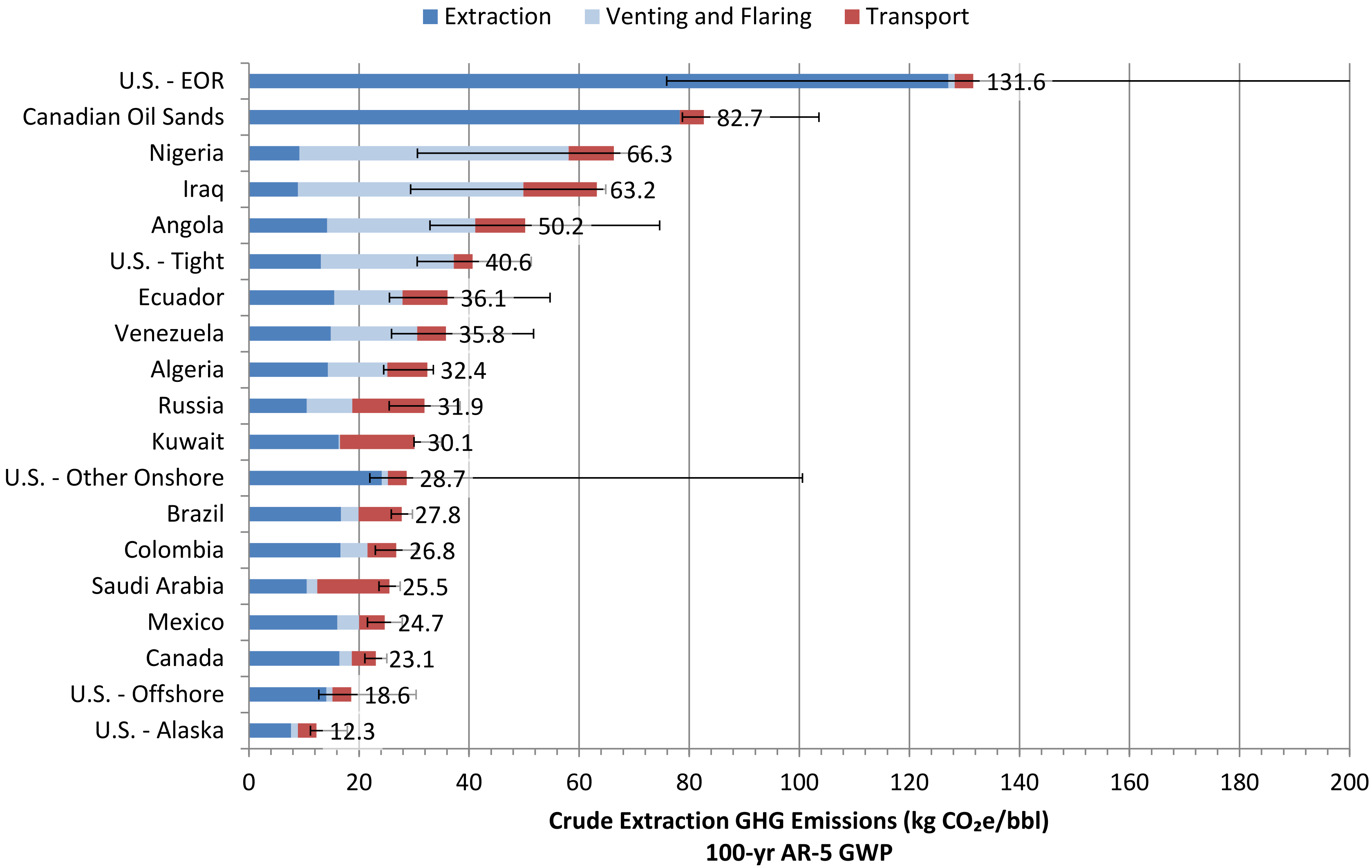
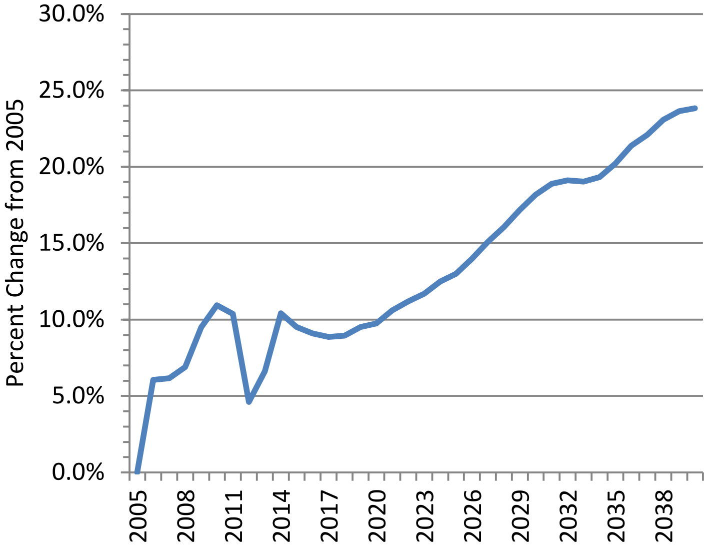
Cradle-to-Gate comparison of extracted and delivered crudes consumed in the U.S.



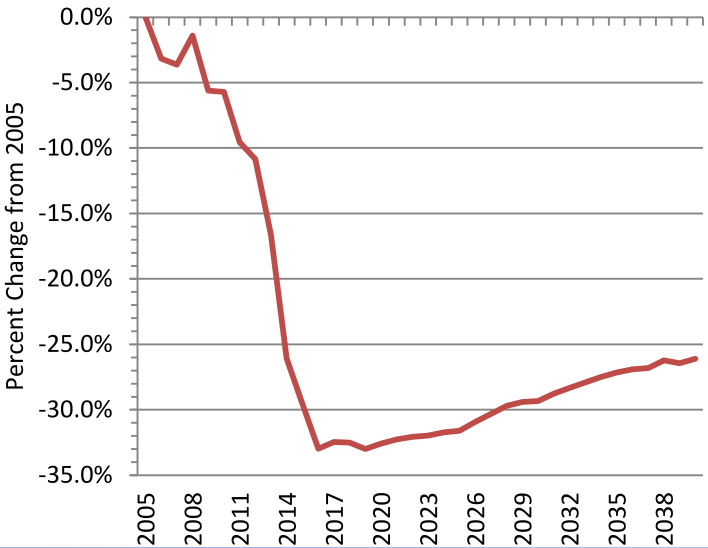
Projected U.S. crude mix has increased GHG emissions as unconventional sources develop

Crude Extraction



- GHG intensity of extraction increases over time as more shale oil, EOR crude, and Canadian oil sands become part of the mix
- EOR share of production doubles over the forecast period (GHG-intensive)
- Behavior in 2012-2013 timeframe is due to a drop in Nigerian crude (high CH_4) and then an increase in tight and oil sands production

Crude Transport



- As crude oil imports decrease, GHG emissions from crude transport decrease
- Majority of imports come from Canada
- As domestic production drops off after peak in 2020, imports from other countries increase, changing the direction of the plot

Next Steps

- **Model finished product refining utilizing PRELIM model**
  - Crudes quality is highly variable (API, sulfur, etc.)
  - Sensitive to more crude characteristics (e.g. cut points)
  - Multiple configurations
- **Update transport assumptions**
- **Updated NETL Petro Baseline Report**
- **Analysis of crude changes out to 2040**
  - Consider how to appropriately model uncertainty related to technology and quality changes

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