Well-to-Wheels (WTW) Analysis of High Octane Fuels

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Motivation for HOF WTW: Addressing Tradeoff Between Vehicle Efficiency Gain and HOF Production Penalty

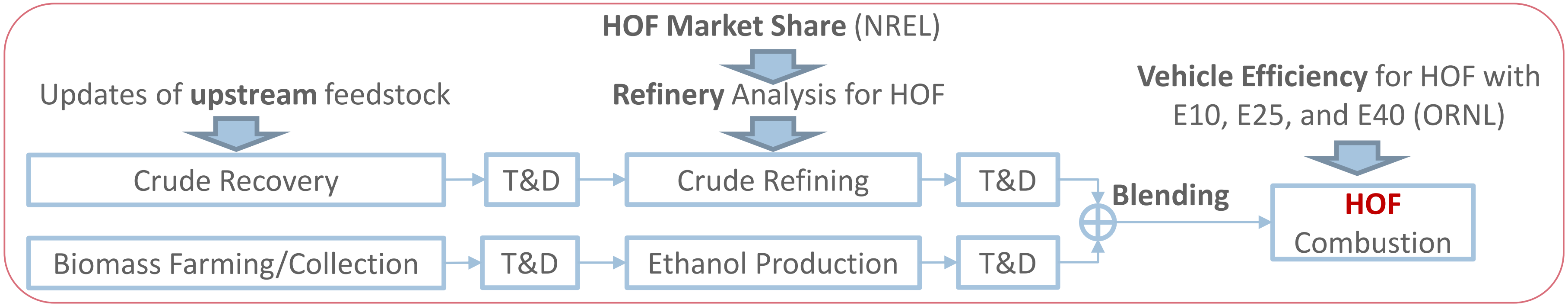
Reference	RON	Efficiency Gain (%)		Comment
		Engine	Vehicle	
Nakata et al. (2007)	**100**	7.4		Constant load, Compression ratio = 13
Leone et al. (2014)	**102**		**5.5–8.8**	Compression ratio = 13
Hirshfeld et al. (2014)			**6–9**	Compression ratio =13
Speth et al. (2014)	**98**		**3.0–4.5**	
This study	**100**		**5**	We considered **10%** for E40 as a sensitivity case

Scope of HOF WTW:

- Petroleum refinery linear programming (LP) modeling of producing HOF with different ethanol blending levels
  - ✓ Analyze refinery challenges to meet RON and RVP requirements
- WTW analysis of HOF-fueled vehicles with refinery efficiency and vehicle efficiency

WTW Approach

- Petroleum refinery LP modeling for PADDs 2 and 3 (with Jacobs Consultancy)
  - Key fuel spec constraints: RON and Reid Vapor Pressure (RVP)
  - **HOF market share** is a key parameter for refinery LP modeling (from vehicle choice models by NREL)
  - **No new capital investment assumed for refineries**
  - **Gasoline export** is allowed with discount after the US gasoline demands are met
- Crude recovery and ethanol production
  - Canadian oil sands, and cellulosic and corn ethanol production were updated
- Vehicle efficiency gains
  - Baseline regular gasoline (E10, RON 92) fuel economy: 23.6 mpg
  - Two assumptions for HOF MPGGE relative to regular E10:
    - **Uniform 5% MPGGE gain** based on 100 RON for E10, E25, and E40 (RON is the driver)
    - **Fuel parity** gain assumption: **10% gain** for HOF E40

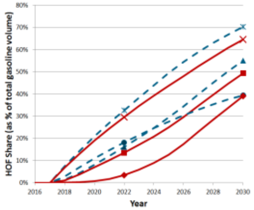


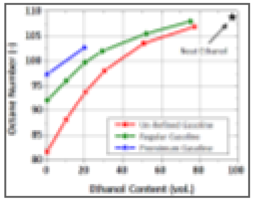
WTW System Boundary

Detailed Refinery LP Modeling Needed for Reliable WTW

Crude Slate

Product Slate

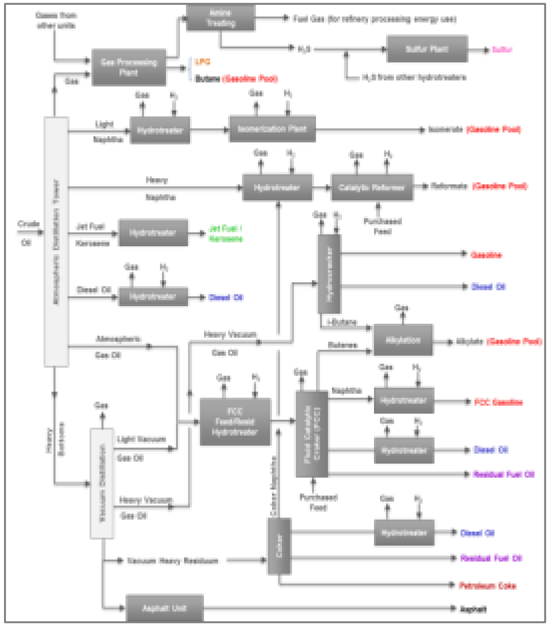




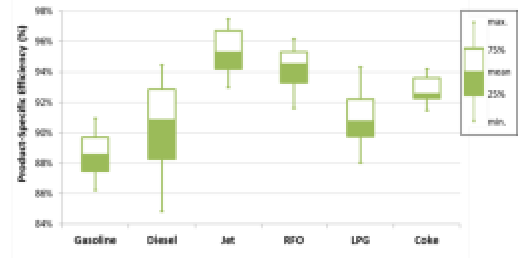
Fuel Specifications
(RON, RVP)

Economic
factors

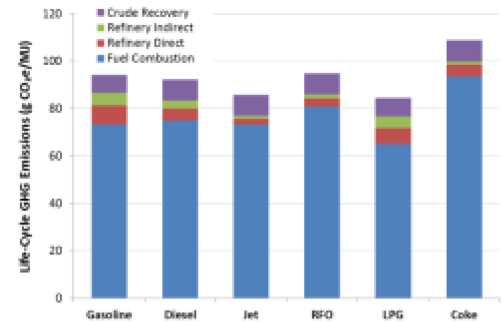
Refinery LP Modeling



Refining Efficiency

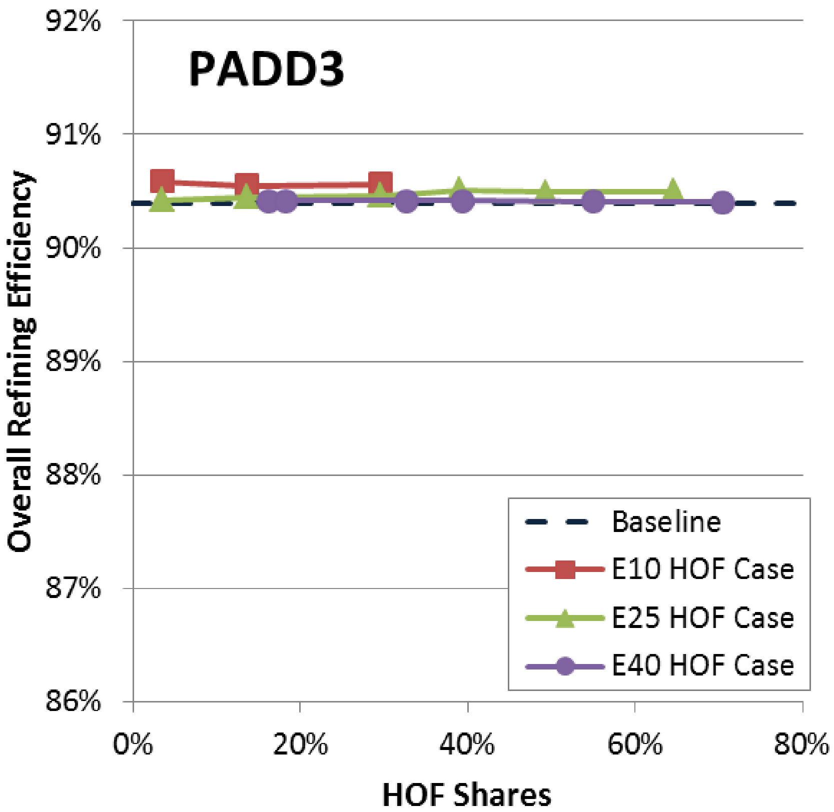


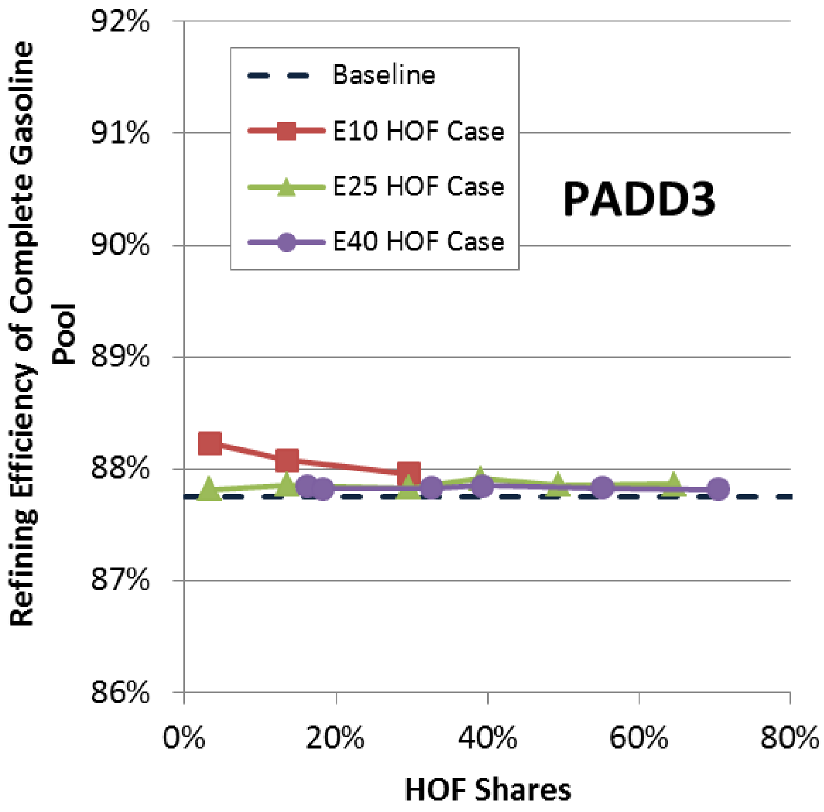
Life-Cycle Analysis



- ❑ Reliable modeling of complex refinery industry
- ❑ Detailed modeling results of refining process units, intermediate products flow rates, utility consumptions, etc.
  - ✓ To evaluate the energy and emissions burden of individual refinery products

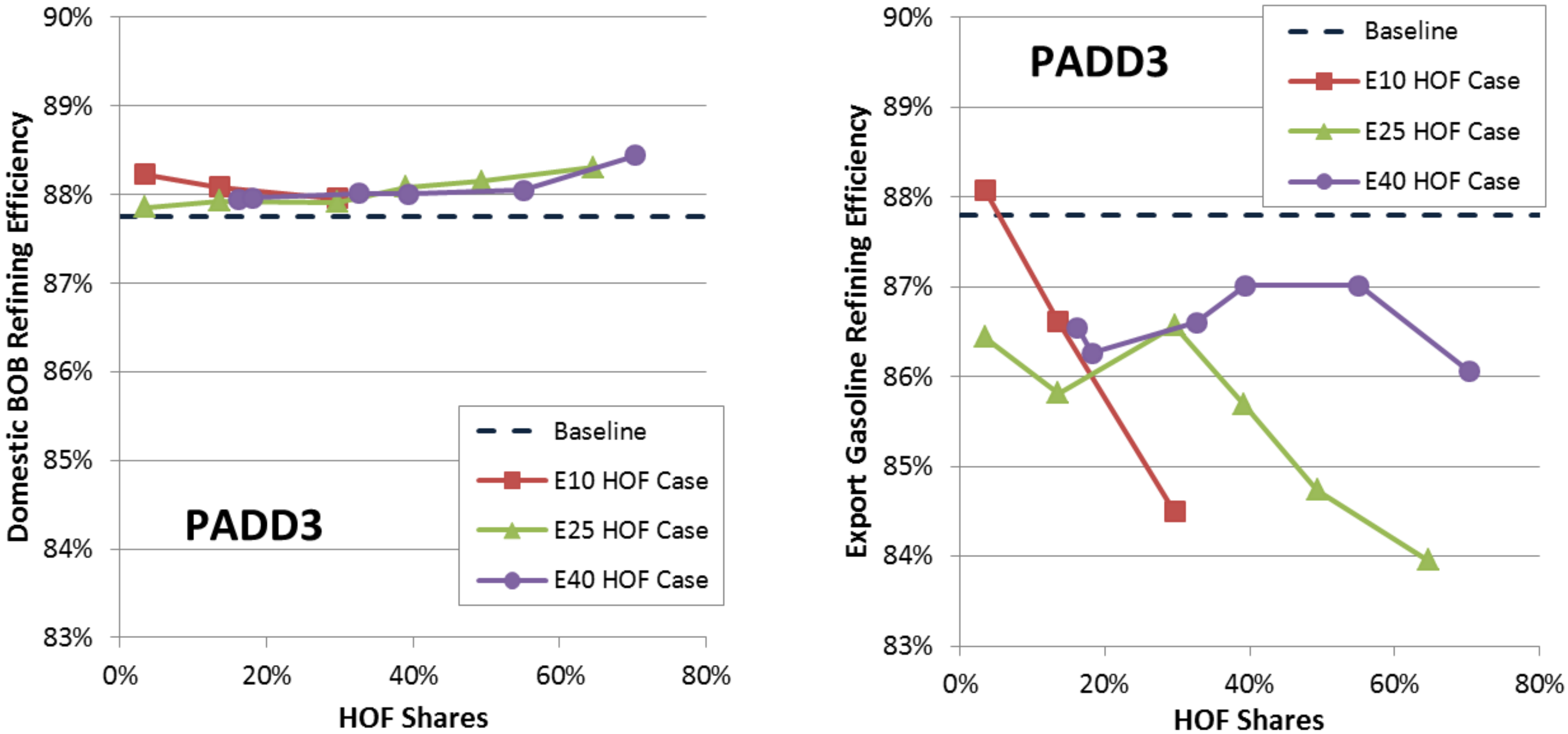
Overall Refinery and Gasoline Blendstock Energy Efficiencies Are Subject to Small Changes with EtOH Blending Level and HOF Share





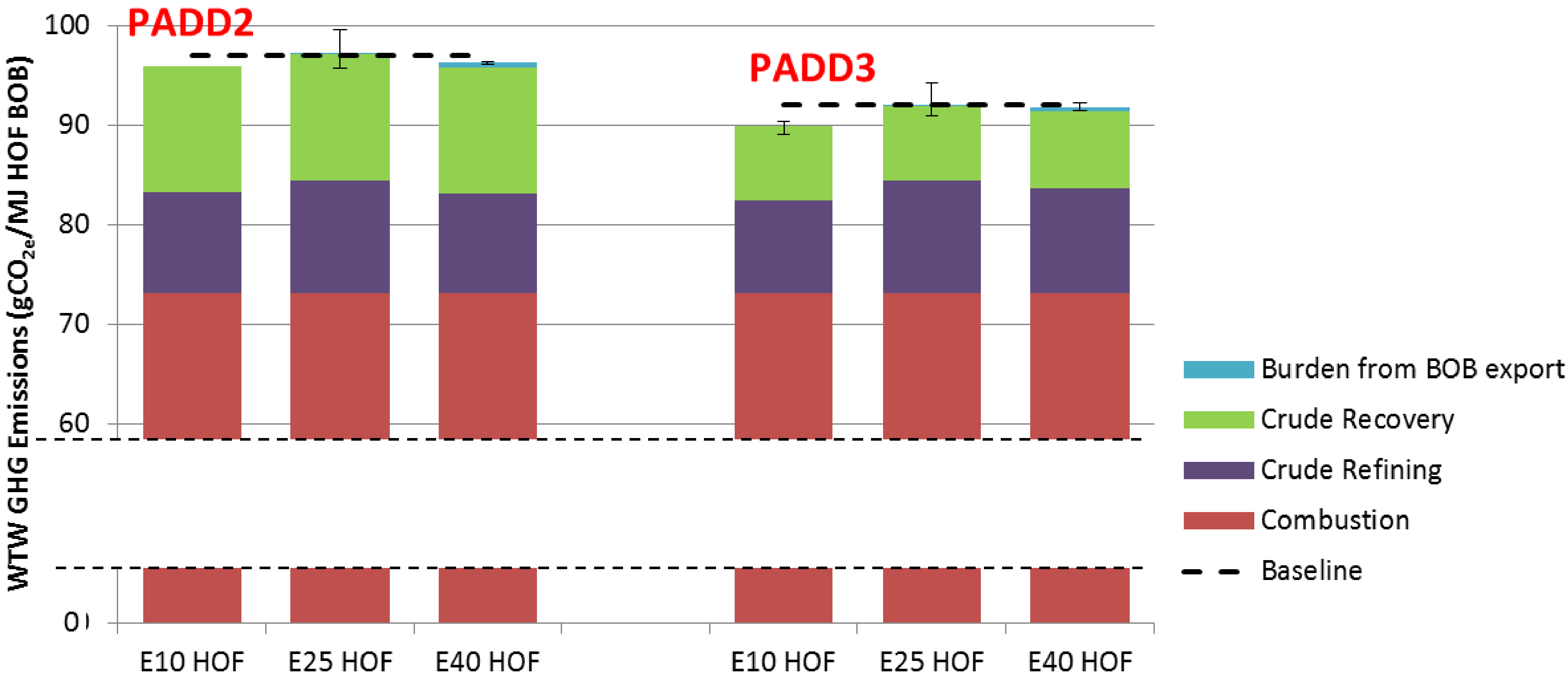
- BOB: Blendstock for Oxygenate Blending; BOB + Ethanol = Finished Gasoline
- E10 HOF is feasible only up to ~25% of gasoline market share
  - A result of **no new capital investment assumption**
- PADD2 shows similar trends, though with overall lower efficiency

Refining Energy Efficiencies Vary Between Domestic Blendstock and Exported Gasoline



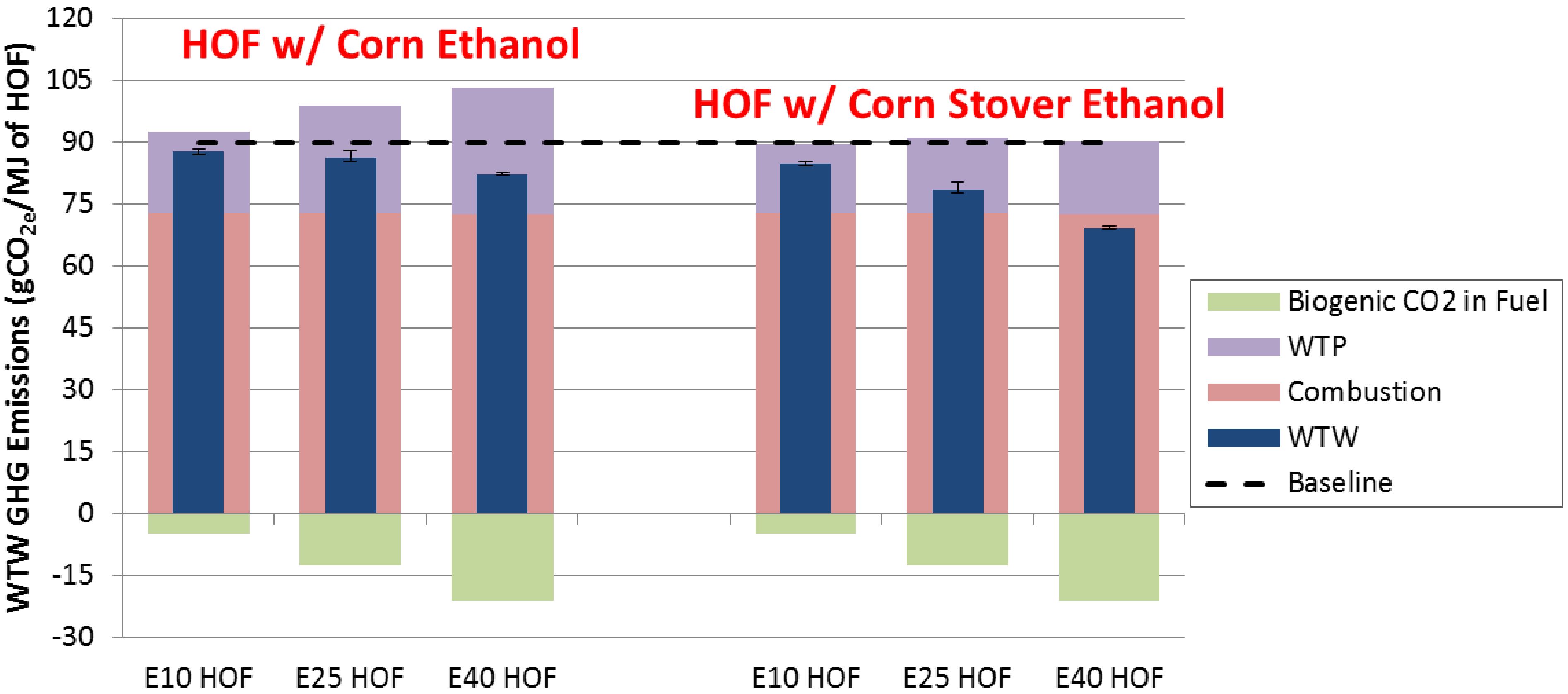
- Domestic BOB efficiency has little change
- Possible spill over of energy penalty from domestic BOB to export gasoline pool
  - Up to 4% drops in export gasoline refining efficiency from the baseline (non-HOF) case
  - Up to 2.5 g CO2e/MJ increases in export gasoline's GHG emissions from the baseline
- But combined change is small with allocated to HOF (<1 gCO_2e/MJ HOF)

HOF Blendstock: GHG Emission Variation of HOF Blendstock Component Is Small



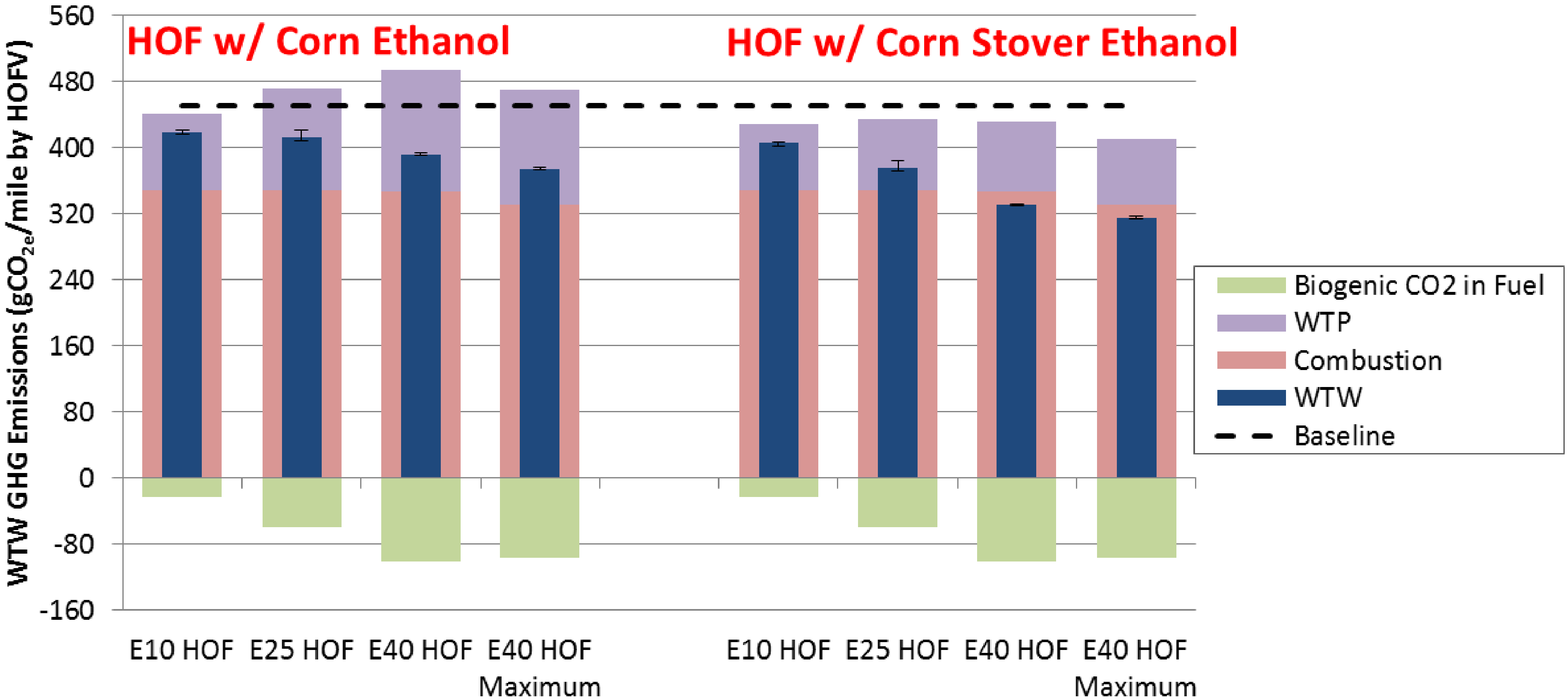
- Larger WTW GHG emissions in PADD2 is due to a larger share of GHG-intensive oil sands
- Adjustment for the spill over is 0.2 gCO_2e/MJ of HOF on average (up to 0.8 gCO_2e)
- Baseline BOB is Business-As-Usual
  - Market shares of different gasoline types: 92% of regular E10 and 8% of premium E10

Finished HOF: Higher Ethanol Blending Level Contributes to Lower WTW GHG Emissions of HOF (per unit of energy results, PADD3)



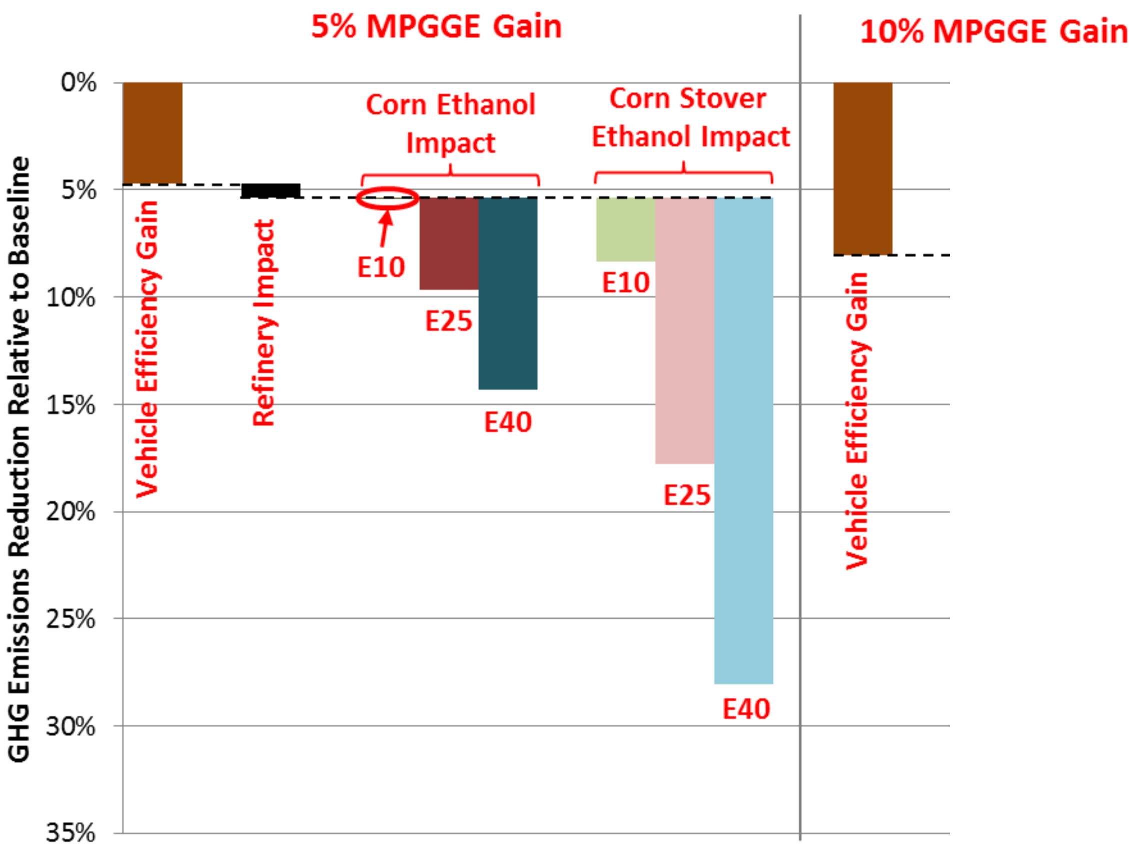
- Corn stover ethanol is used as a surrogate for cellulosic ethanol

Vehicle Fuel Economy Gains Provide Additional WTW GHG Emissions Reductions (per mile results, PADD3)



- E10, E25 and E40 HOF → 5% MPGGE gain (volumetric fuel parity at E25)
- E40 HOF Maximum → 10% MPGGE gain (volumetric fuel parity at E40)

Cellulosic E25 and E40 HOF Can Reduce GHG Emissions by Up to 17% and 31% Relative to Baseline Gasoline, Respectively (based on per mile results)



- GHG reduction w/ vehicle efficiency gain: 5% with 5% MPGGE gain, 9% with 10% MPGGE gain
- Refinery GHG Impact: <1% (small)
- Ethanol Blending GHG Impact
  - Corn Ethanol: 0% for E10, 4% for E25, 9% for E40
  - Corn Stover Ethanol: 3% for E10, 12% for E25, 23% for E40

WTW Conclusions

- Vehicle efficiency gains and ethanol blending are the two dominant factors for WTW GHG emissions reduction
- Impacts of HOF production on refinery GHG emissions is relatively small
- Ethanol can be a major enabler in producing HOF with significant vehicle efficiency gains and a large reduction in WTW GHG emissions

Summary

- Ethanol blended at 25 to 40% provides high octane number and fuel/air charge cooling
  - E25 to E40 can be used in over 17M FFVs currently deployed
- HOF enables production of more efficient, optimized vehicles
- Biofuel production and vehicle adoption models suggest potential HOF consumption of up to 30 billion gallons ethanol in 2035
- WTW GHG emission reductions range from 9-18% for corn ethanol HOF and 17-31% for cellulosic ethanol HOF
- There are challenges to introduction of ethanol HOF
  - Underground storage tanks are likely compatible
  - Fuel dispensing equipment will require upgrading
  - Challenges of developing supply and demand in concert

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