Petroleum and Natural Gas Life-Cycle Analysis: Issues, Results, and Case Simulation:

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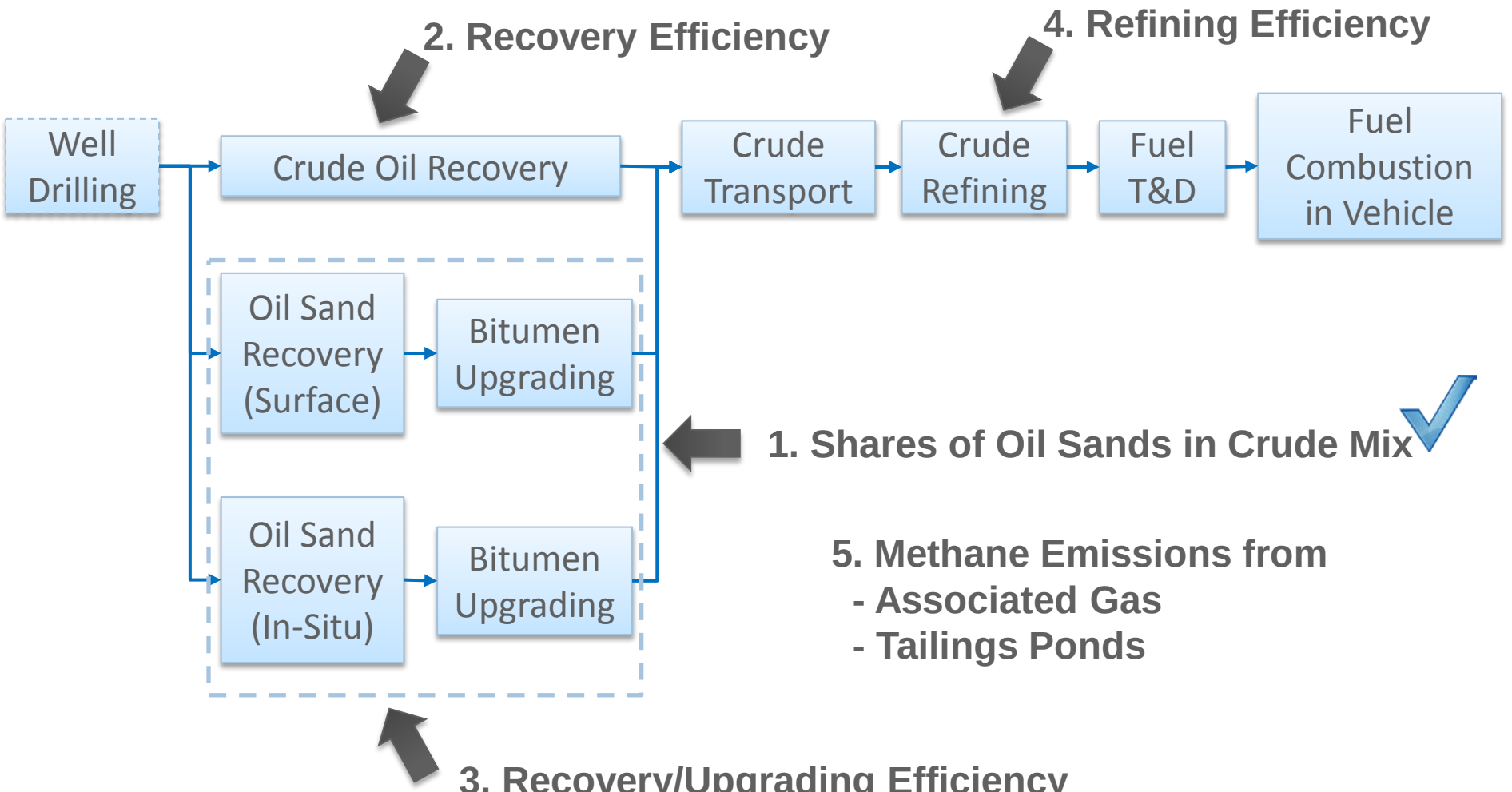
Supporting Documents for Petroleum and Natural Gas Pathways : Journal Article, Technical Report and Technical Memo

1. Burnham, A., J. Han, C. E. Clark, M. Wang, J. B. Dunn, and I. Palou-Rivera. “Life-Cycle Greenhouse Gas Emissions of Shale Gas, Natural Gas, Coal, and Petroleum.” *Environmental Science Technology* 46, no. 2 (2011): 619-627. http://pubs.acs.org/doi/abs/10.1021/es201942m

2. Han, J., M. Mintz, M. Wang. *Waste-to-Wheel Analysis of Anaerobic-Digestion-Based Renewable Natural Gas Pathways with the GREET Model*. Argonne, IL: Argonne National Laboratory, 2011 http://greet.es.anl.gov/publication-waste-to-wheel-analysis

3. Palou-Rivera, I., J. Han and M. Wang. *Updated Estimation of Energy Efficiencies of U.S. Petroleum Refineries*. Argonne, IL: Argonne National Laboratory, 2011. http://greet.es.anl.gov/publication-petroleum

System Boundary and Key Parameters of Petroleum Pathways



System Boundary and Key Parameters of Natural Gas Pathways

- Share of conventional and shale gas in the U.S. NG mix
- Methane emissions from
  - Well completion and workover
  - Liquid unloading
  - Well equipment
  - NG transmission and distribution
- NG recovery efficiency
- NG processing efficiency

Significant Uncertainty in Methane Emissions

Key Parameters on per-well-basis
Uncontrolled methane emissions from well completion, workover and liquid unloading

÷ Estimated ultimate recovery (EUR)

× Occurrence during well lifetime

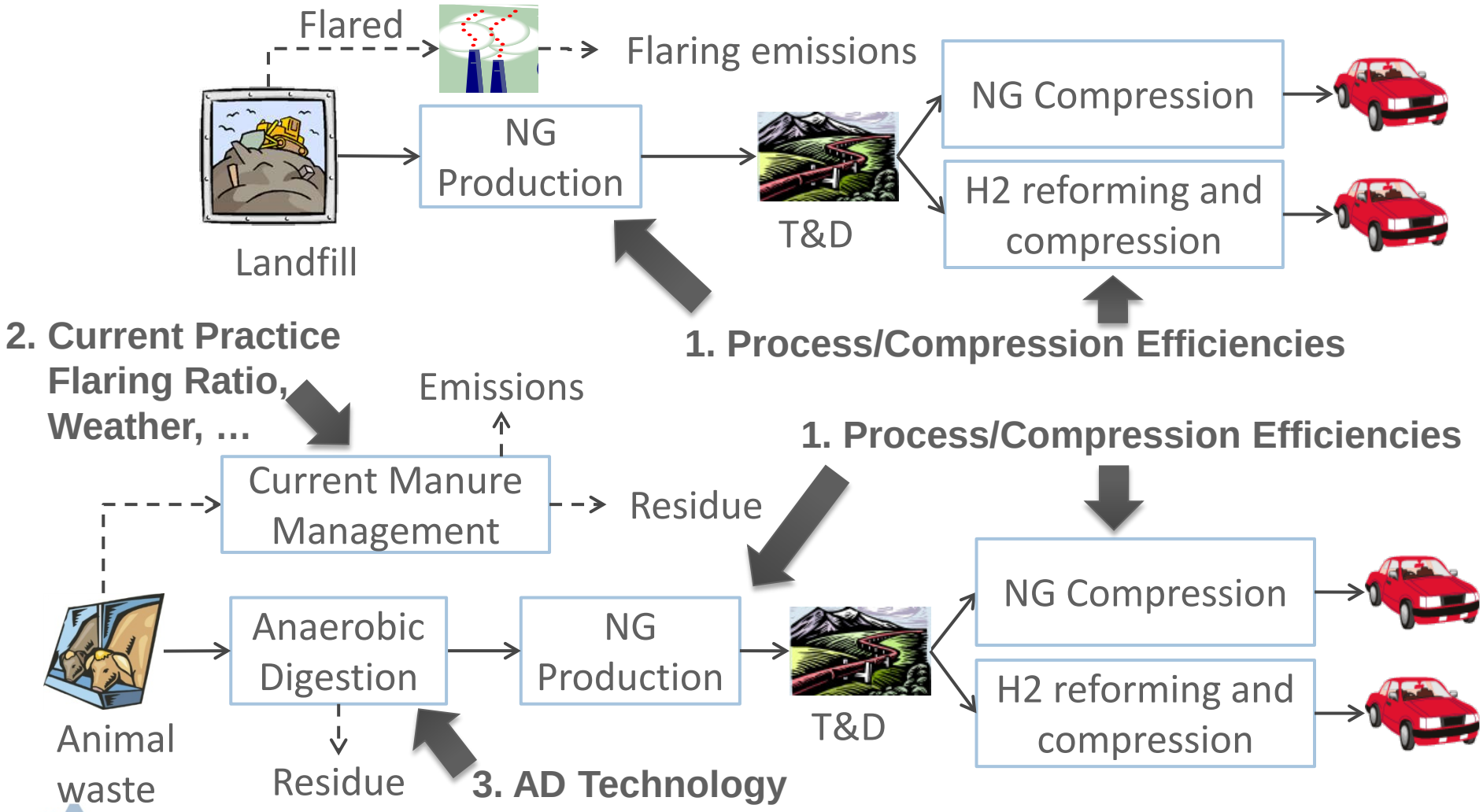
× % of vented CH_4 after recovery and flaring

=

Key Parameters on per-mmBtu-basis
Controlled methane emissions from well completion, workover and liquid unloading

Argonne has Examined Renewable Natural Gas From Landfills and Anaerobic Digesters

(RNG-based CNG and gaseous H_2 shown as example)



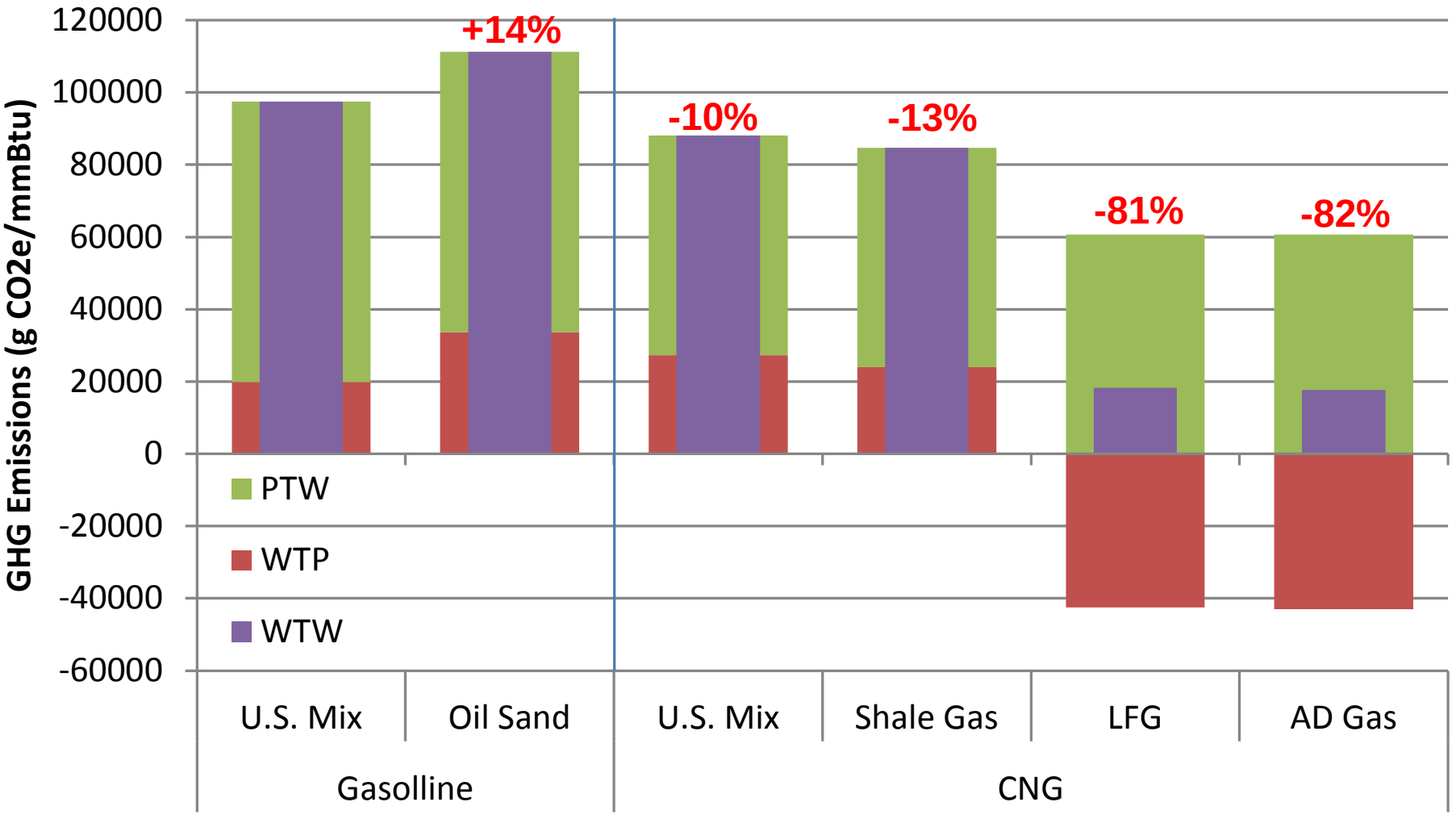
Demo

Case No.	Fuel	Share of Oil Sands Products in Crude Oil Blend	NG Feedstock[a]	Share of Shale Gas in Natural Gas Supply	Share of LFG for RNG
1	U.S. average gasoline and NG	9.4%	1	22.6%	100%
2	Gasoline from oil sands	**100.0%**	1	22.6%	100%
3	Shale gas	9.4%	1	**100%**	100%
4	Landfill Gas	9.4%	**4**	22.6%	100%
5	AD Gas	9.4%	**4**	22.6%	**0%**

Default

[a] 1:North America Natural Gas; 4: Renewable Natural Gas

Demo Results



Reduction in GHG emissions relative to gasoline