Value of LCA and its Applicability to Natural Gas Analysis

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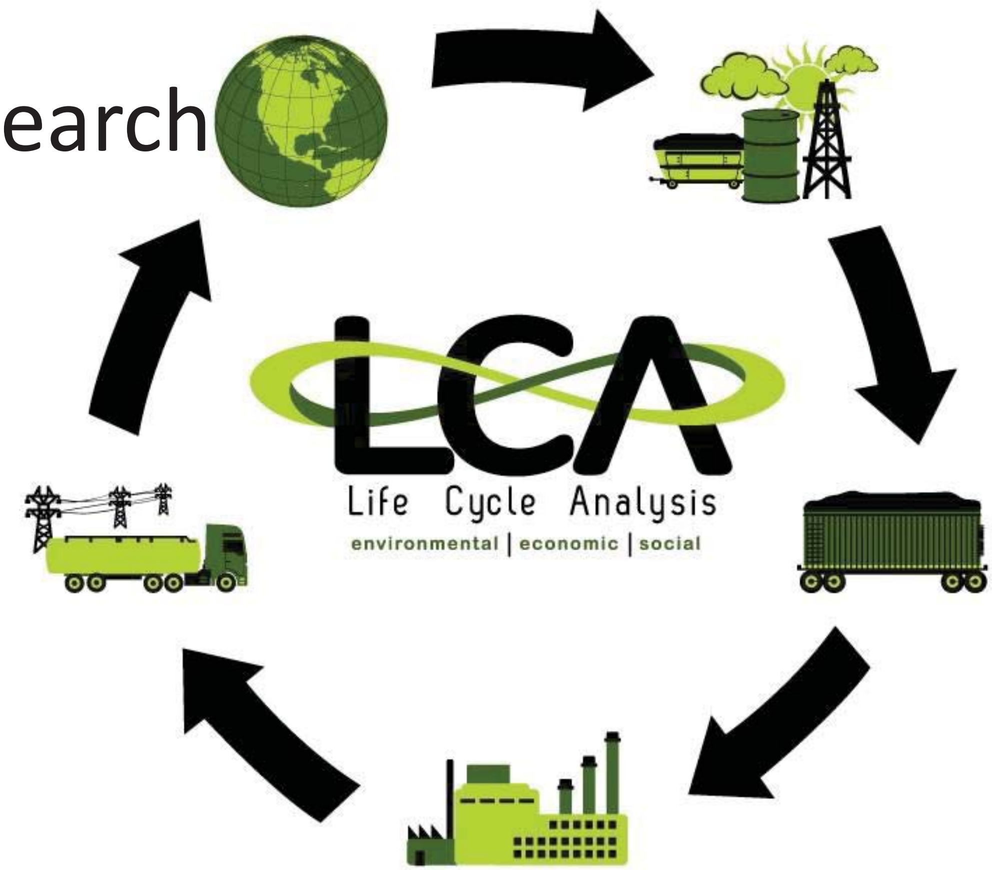
Agenda

- Value of an LCA perspective
- Upstream natural gas
- Current natural gas research

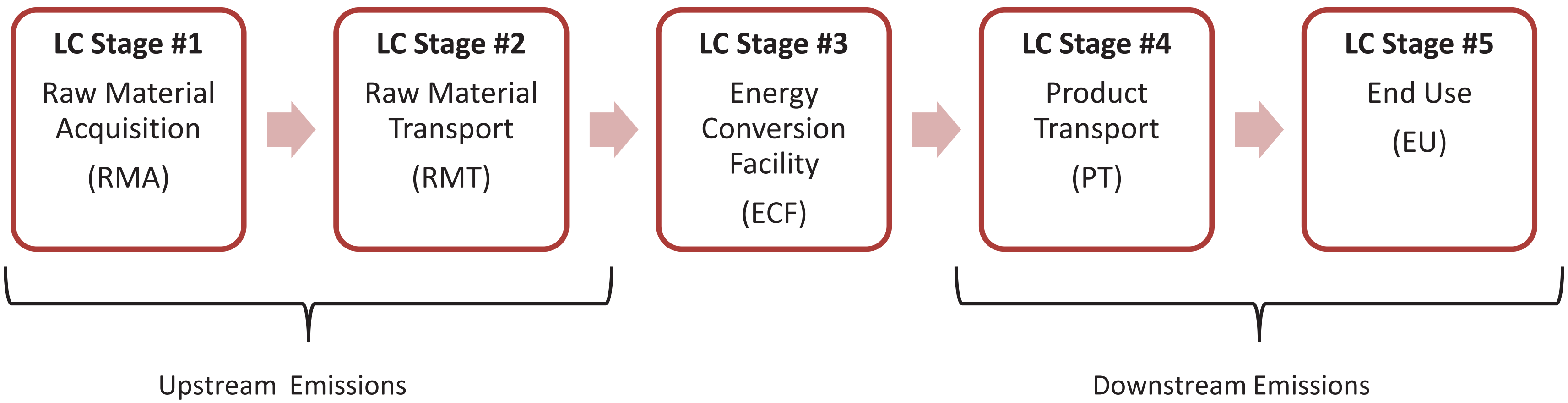


LCA is well suited for energy analysis

- Draws a more complete picture than one focused solely on stack or tailpipe emissions
- Allows direct comparison of dramatically different options
- Includes methods for evaluating a wide variety of burdens

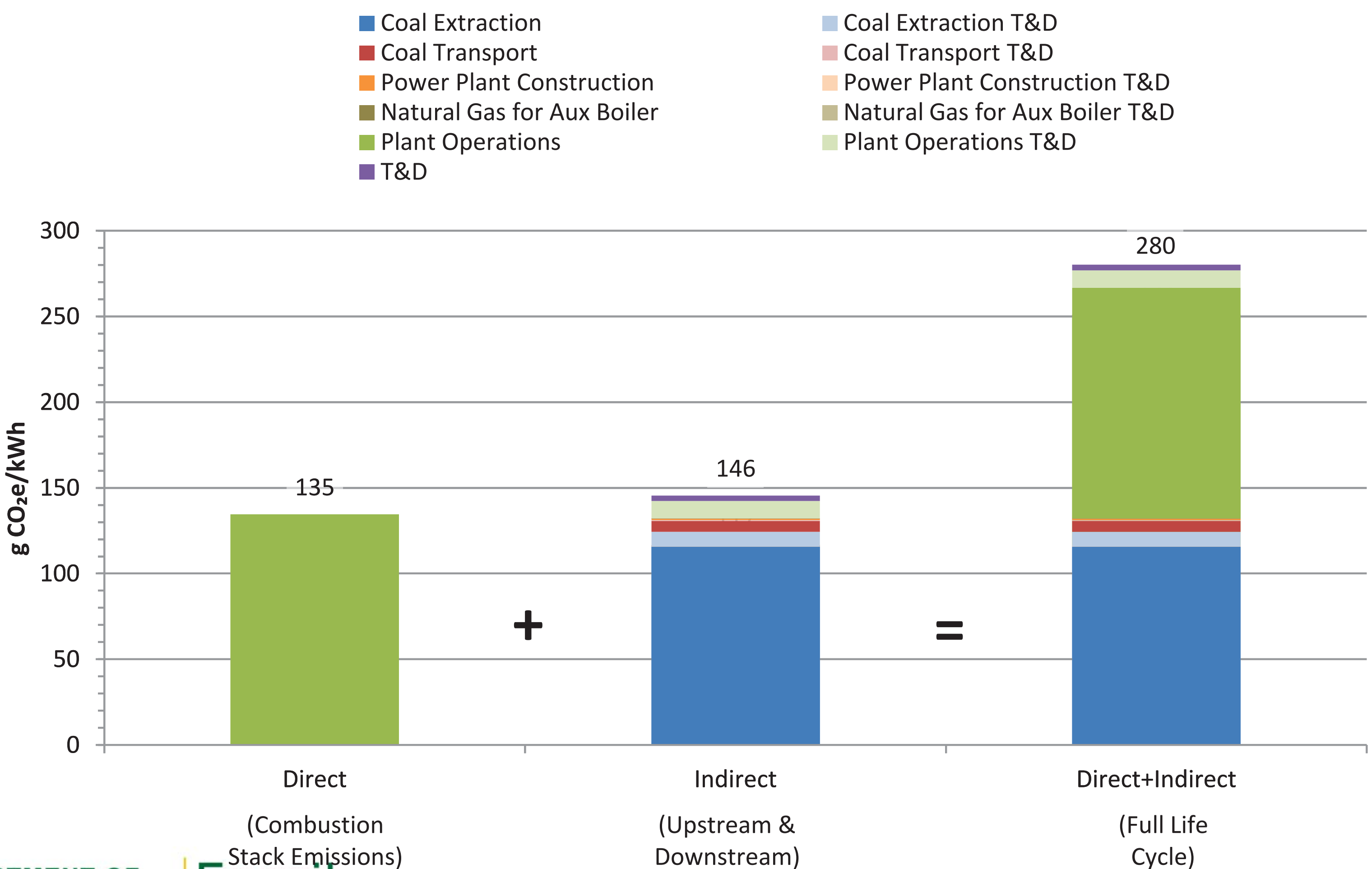
NETL approaches each LCA systematically to ensure comparability and transparency

- **Compilation and evaluation of the inputs, outputs, and potential environmental impacts of a product or service throughout its life cycle, from raw material acquisition to final disposal**



- **Ability to compare different options depends on functional unit (denominator)**
  - 1 kWh of electricity delivered to the end user
  - 1 MJ of fuel combusted

LCA shows the importance of each portion of the life cycle



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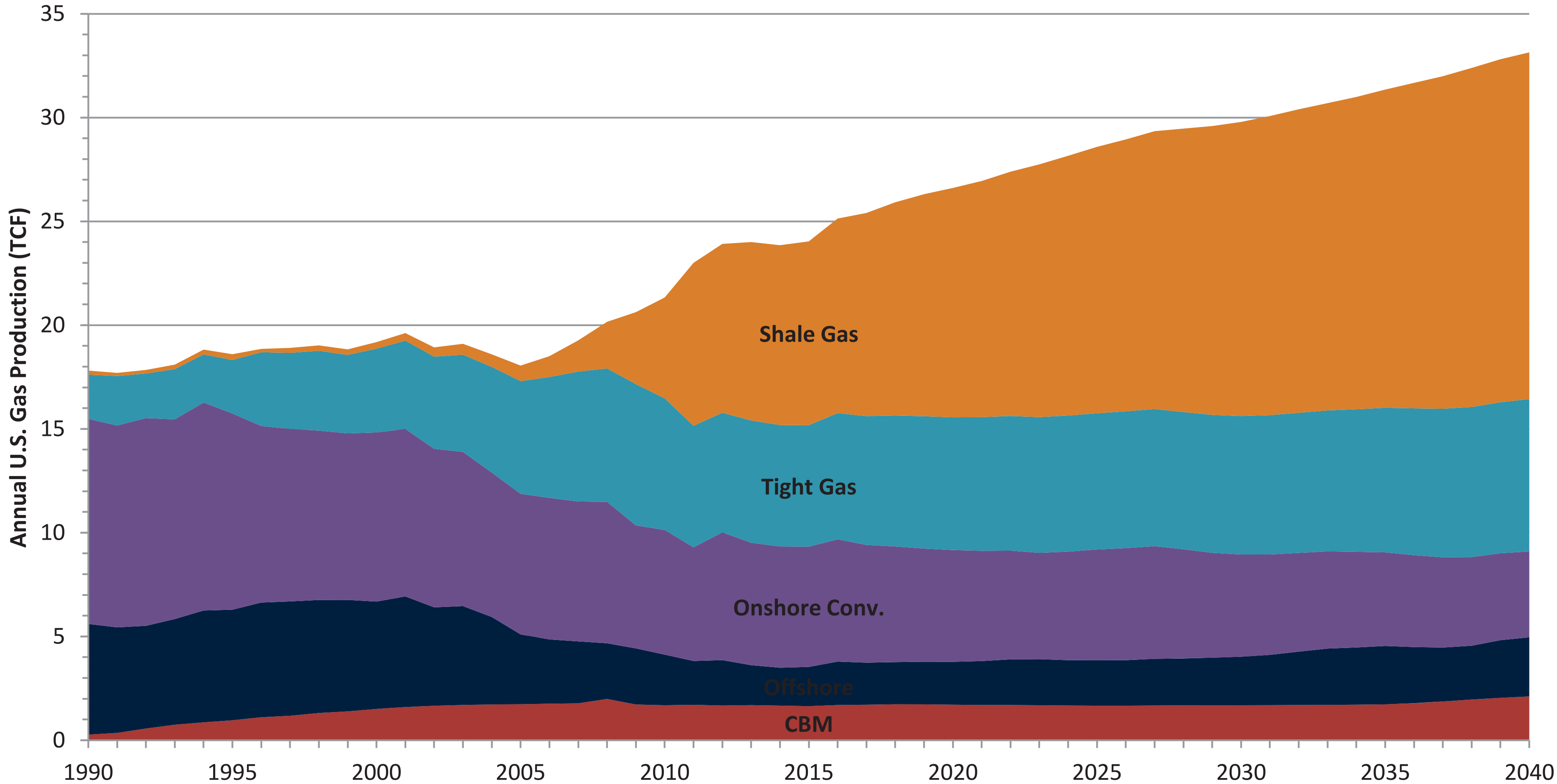
LCA answers are sensitive to the question asked

- How does a given technology compare to other options?
  - Narrow boundaries and attributional results
  - Example: Life cycle emissions from 1 MWh of electricity from NGCC vs. SCPC power
- How will a given policy affect an entire system?
  - Broad boundaries and consequential results
  - Example: Changes to global energy supply and associated GHG emissions if U.S. exports liquefied natural gas (LNG)

Potential trade-off between usefulness and uncertainty

The more complete the picture, the more uncertain it becomes

Unconventional sources of natural gas are changing the resource profile of the U.S. natural gas supply

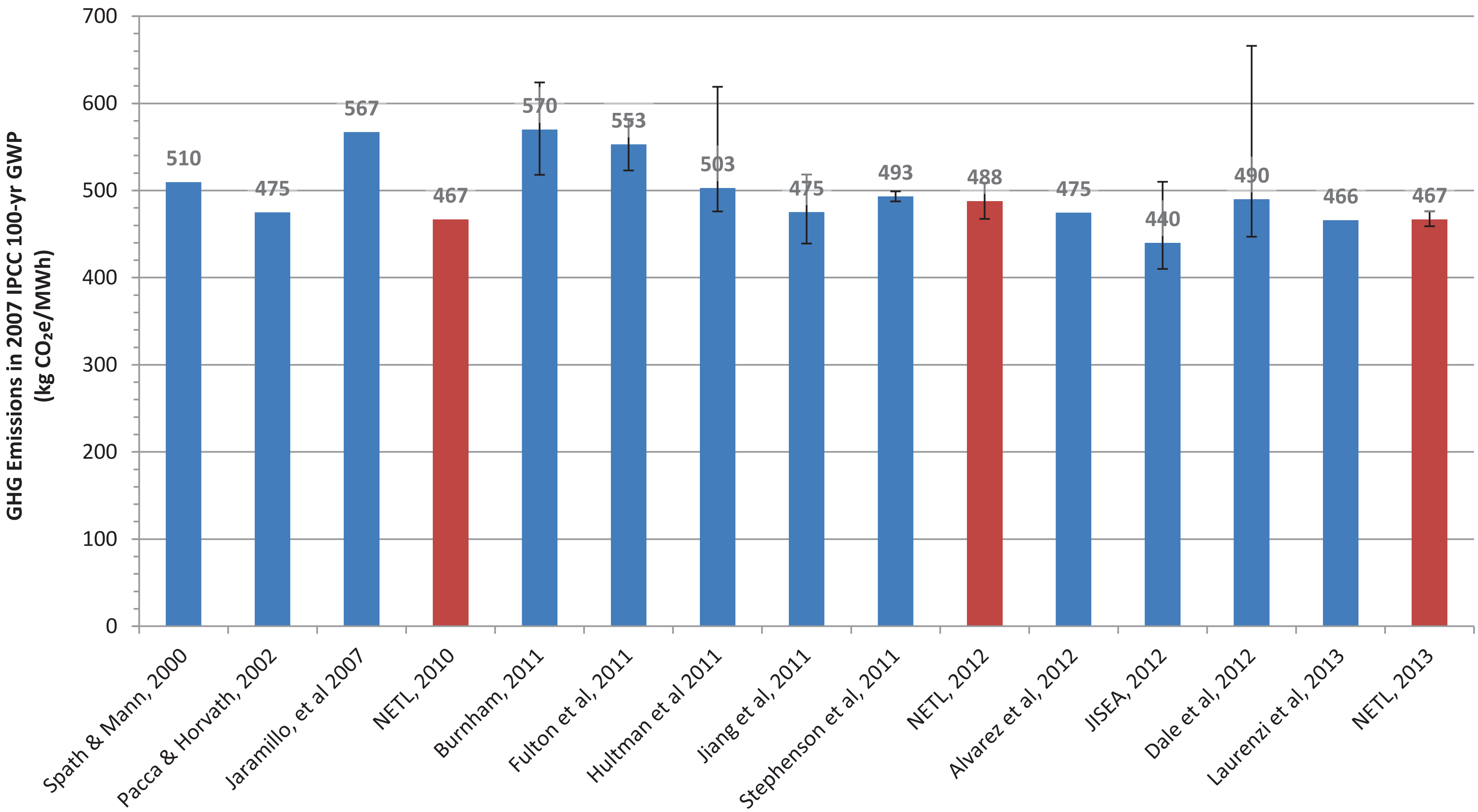


- Total U.S. natural gas consumption was 26 Tcf in 2012 and is projected to grow to 32 Tcf by 2040[1]
- Unconventional sources of natural gas are a growing share of U.S. production
- LCA is well suited to analyze the effect of shale gas growth on the environmental profile of natural gas systems

- [1] EIA. (2014). Annual Energy Outlook 2014. U.S. Department of Energy, Energy Information Administration. DOE/EIA-0383(2014).
- Retrieved June 6, 2014 from http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf

Life Cycle of Natural Gas through Power

Comparison of Published Results



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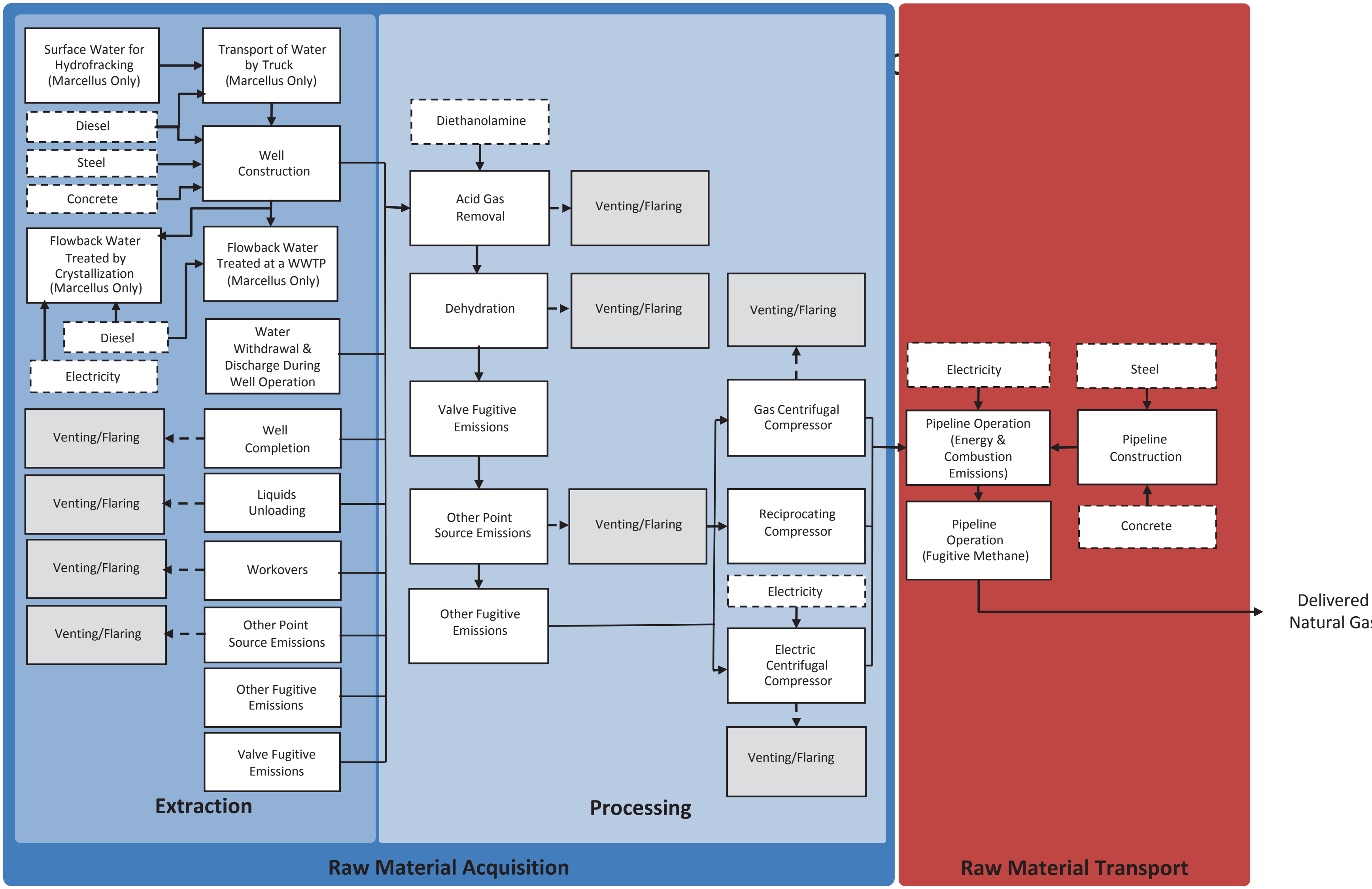
Our upstream natural gas model is an important component of our power LCAs



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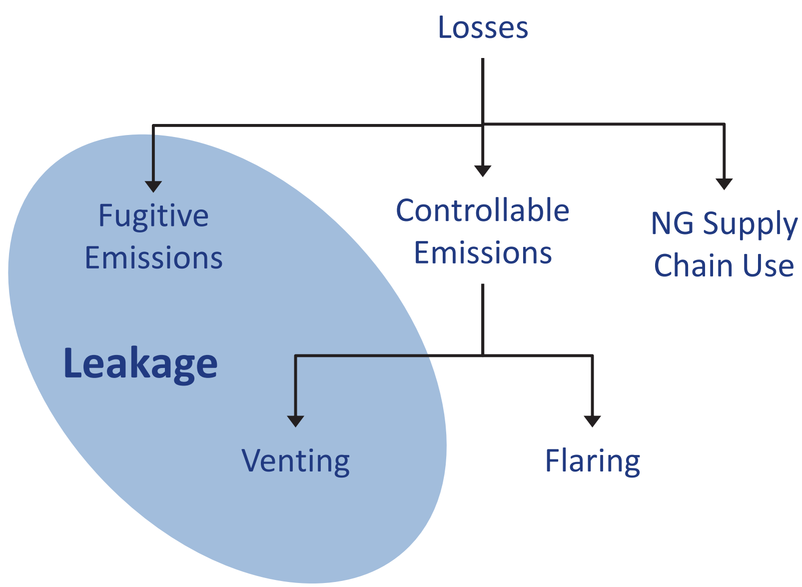
Parameters allow flexibility, which allows scenario, uncertainty, and sensitivity analysis

Property (Units)		Onshore	Associated	Offshore	Tight Gas	Barnett Shale	Marcellus Shale	CBM
Natural Gas Source								
Contribution to 2010 U.S. Domestic Supply		22%	6.6%	12%	27%	21%	2.5%	9.4%
Average Production Rate (Mcf /day)	low	46	85	1,960	77	192	201	73
	expected	66	121	2,800	110	274	297	105
	high	86	157	3,641	143	356	450	136
Expected EUR (Estimated Ultimate Recovery) (BCF)		0.72	1.32	30.7	1.20	3.00	3.25	1.15
Natural Gas Extraction Well								
Flaring Rate (%)		51% (41 - 61%)			15% (12 - 18%)			
Well Completion (Mcf natural gas/episode)		47			3,600	9,000	9,000	49.6
Well Workover (Mcf natural gas/episode)		3.1			3,600	9,000	9,000	49.6
Lifetime Well Workovers (Episodes/well)		1.1			0.3			
Liquid Unloading (Mcf natural gas/episode)		3.57	n/a	3.57	n/a	n/a	n/a	n/a
Lifetime Liquid Unloadings (Episodes/well)		930	n/a	930	n/a	n/a	n/a	n/a
Valve Emissions, Fugitive (lb CH_4/Mcf natural gas)		0.11		0.0001	0.11			
Other Sources, Point Source (lb CH_4/Mcf natural gas)		0.003		0.002	0.003			
Other Sources, Fugitive (lb CH_4/Mcf natural gas)		0.043		0.01	0.043			

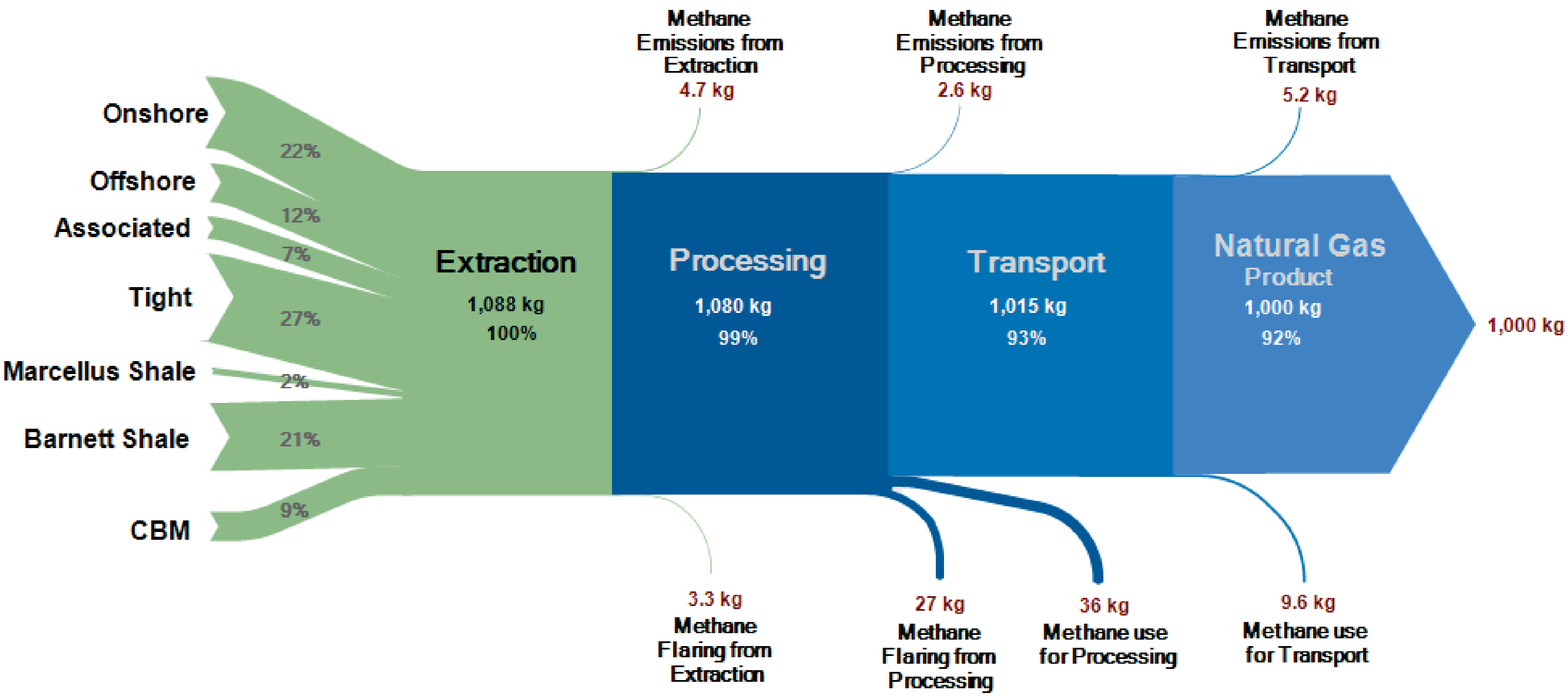
- Parameters include expected values and uncertainty/variability ranges
- Similar level of parameterization is used for processing and pipeline transmission

Our model accounts for natural gas lost as fugitives, through environmental controls, and as upstream fuel

- **Fugitive Emissions**
  - Cannot be practically recovered by control technologies
  - Examples: pneumatic or flange leaks
- **Controllable Emissions**
  - Can be reduced by using capture equipment
  - *Venting* releases CH_4 and *flaring* converts CH_4 to CO_2
  - Examples: flowback emissions or venting from acid gas removal
- **Natural Gas Use**
  - Natural gas is used as a fuel in processing and transmission equipment
  - CO_2 emissions result from fuel combustion
  - Examples: processing reboilers or gas-powered compressors



We can model the overall properties of a mix of gas sources



- NETL's ***cradle-to-delivered*** leakage rate is 1.2%
- NETL's ***extraction*** leakage rate is 0.44%, which is close to leakage rates measured by EDF and University of Texas[1]

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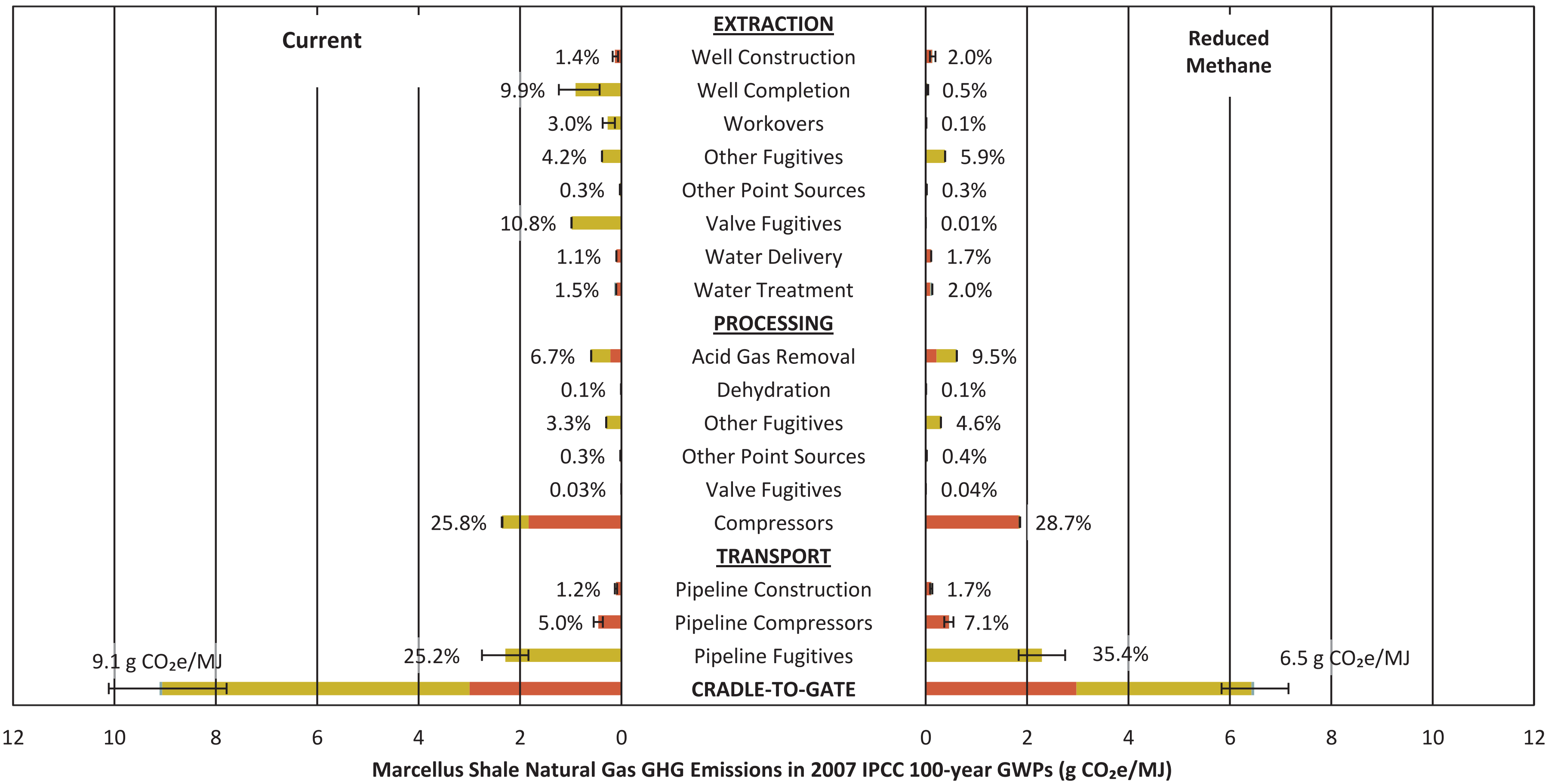
We can zero in on dynamics of specific scenarios



- Our *reduced methane* scenario is based on NSPS rules and uses best practices to reduce completion, valve, and compressor emissions at extraction and processing.
- Best practices for natural gas extraction and processing can reduce GHG emissions from new or modified Marcellus Shale wells by 29%.

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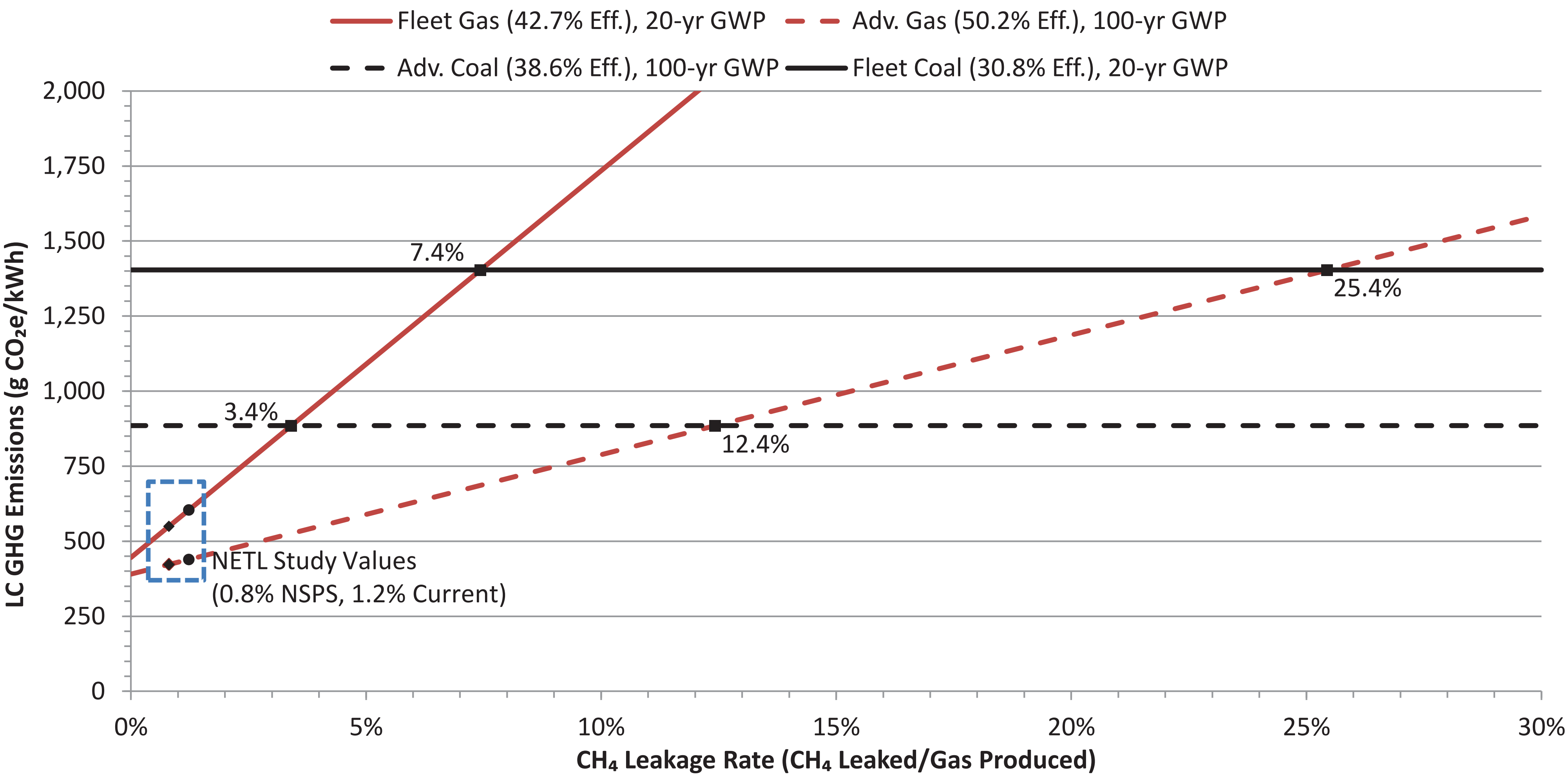
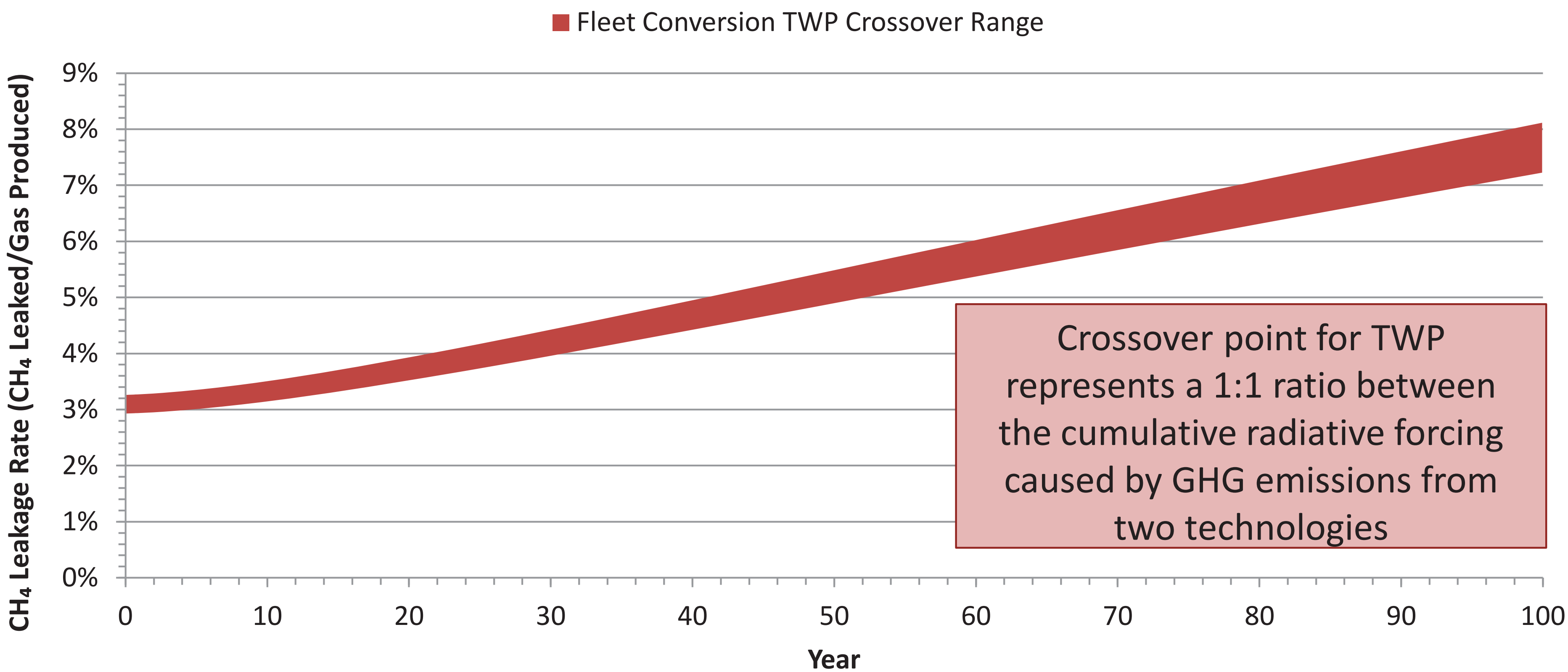
We can calculate results across a performance range



- Intersections of natural gas and coal are breakeven points
- This is a bounding analysis that accounts for extremes
- Our calculated leakage rates are well below the breakeven leakage rates

We can reconcile our results with other authors and validate alternative methods



- Alvarez[1] uses technology warming potential (TWP) to compare climate impacts
- Applying TWP to NETL's natural gas model yields results similar to Alvarez's results
- If the leakage rate is 3% or less, natural gas power will always have a lower cumulative radiative forcing than coal power

[1] Alvarez et al. "Greater focus needed on methane leakage from natural gas infrastructure." Proceedings of the National Academy of Sciences (2012)

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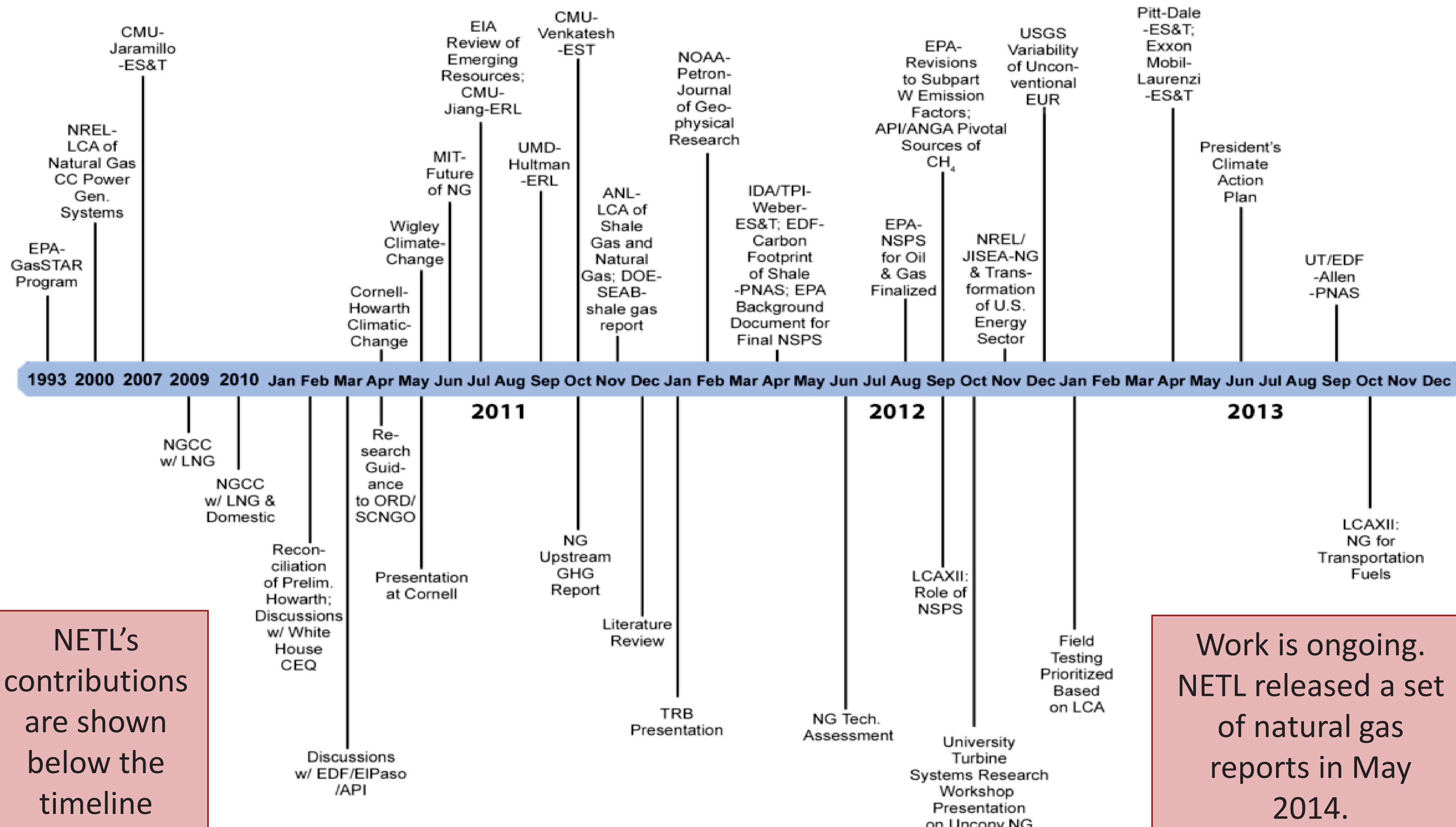
Our model has been a key part of the NG discussion



NETL's contributions are shown below the timeline

Work is ongoing. NETL released a set of natural gas reports in May 2014.

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Top 10 research and data collection needs

1. Regional variation in gas composition
2. Estimated ultimate recovery (EUR)
3. NSPS implementation
4. Pipeline compressor leakage and efficiency
5. Completion and workover emissions
6. Workover frequency
7. Flaring rates
8. Fugitive emissions at extraction
9. Non-GHG emissions (VOCs) from extraction
10. Water use for hydrofracking

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