Estimating the GHG Footprint of Large-scale, Interconnected Energy Systems

Timothy J. Skone, PE

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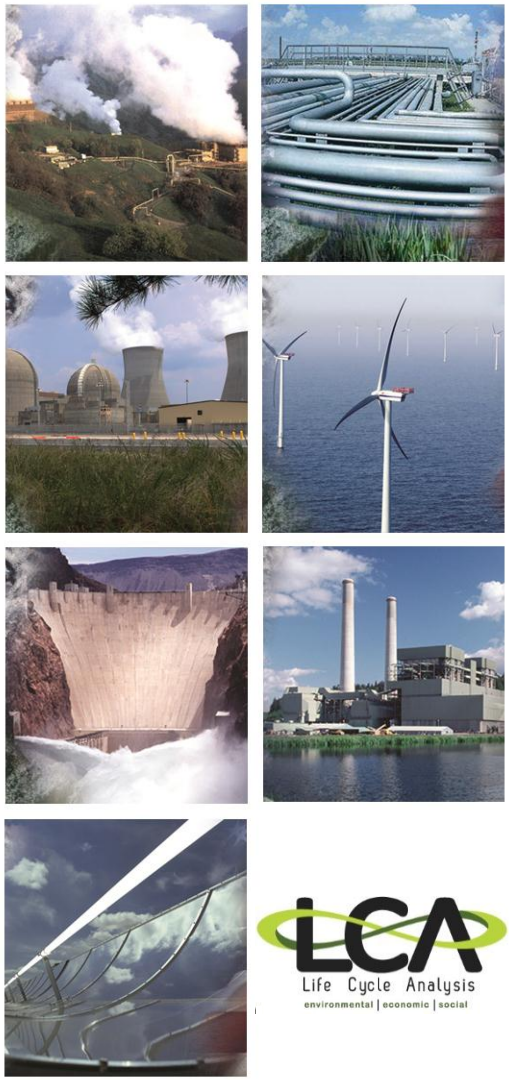
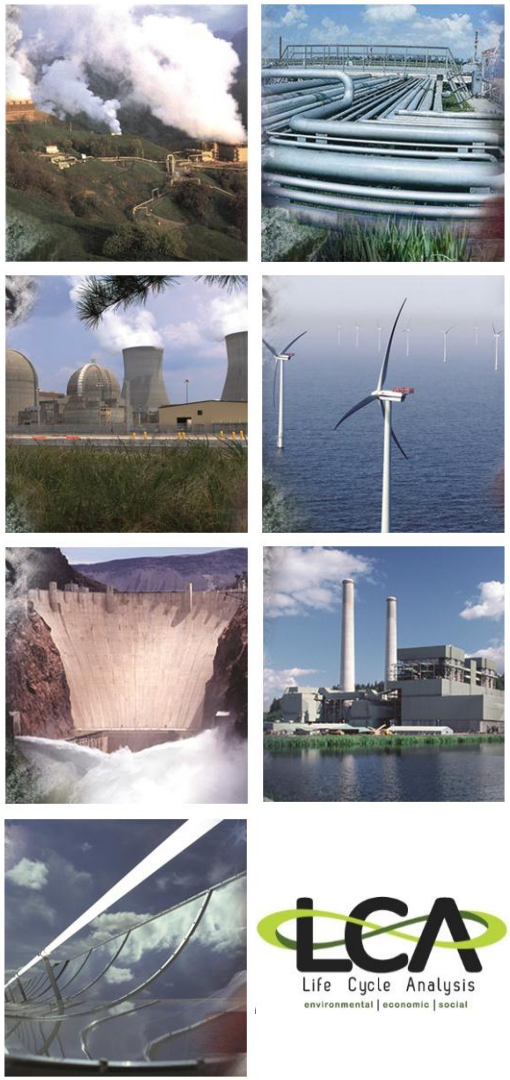
LCA is well suited for energy analysis

- Draws a more complete picture than one focused solely on stack or tailpipe emissions
- Allows direct comparison of dramatically different options based on function or service
- Includes methods for evaluating a wide variety of emissions and impacts on a common basis
- Brings clarity to results through systematic definition of goals and boundaries



LCA answers are sensitive to the question asked

- **Purpose of the analysis**
  - Comparing two technology options
  - Evaluating impact of a policy on entire system
- **Boundaries and function considered**
  - Coal: production of feedstock vs. delivered electricity
  - Natural gas: all annual domestic or marginal shale only
- **Metrics evaluated**
  - Greenhouses gases: 20 or 100 year GWPs, inclusion of timing and feedback effects
  - Economic, environmental, and human health metric results may favor different options; and relative importance of each may differ among technologies



Potential trade-off between usefulness and uncertainty

The more complete the picture, the more uncertain it becomes

Life cycle results depend on whether you're studying *attributes* or *consequences*

	Attributional	Consequential
Purpose	*Regulatory compliance, Corporate footprint*	*Policy implications*
Goal	What are the environmental burdens of a particular product?	How does new system change the world around it?
Functional unit	Single product	Multiple products (within a defined world)
Boundaries	Truncated (to isolate burdens of a single product)	Expanded (to include indirect effects)
Uncertainty	Methods for isolating a single product can arbitrarily shift burdens between systems	Extent to which system alters the world around it

Both types of analyses – attributional and consequential – are valid LCA approaches; context of a study must be known before determining which one is appropriate

Handling co-products in large-scale energy systems leads inevitably to consequential LCA

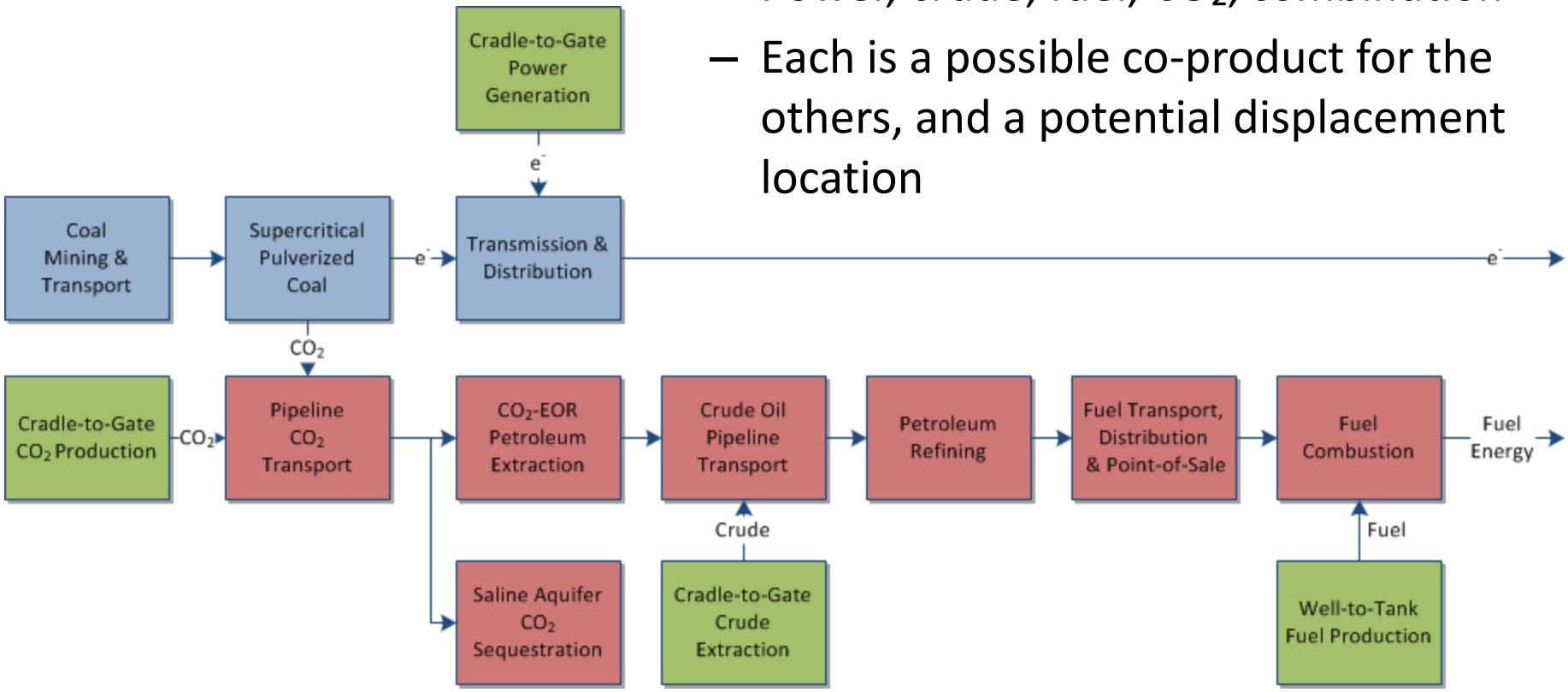
- **Began by exploring options for dealing with power, fuel and CO_2 from:**
  - Alternative fuel plants (CTL, CBTL, GTL)
  - Advanced fossil power with carbon capture connected to CO_2-Enhanced Oil Recovery

- **Historically LCAs we have done had a single dominating product: either fuel *or* power**
  - Linking captured power systems to EOR required a broader approach to managing co-products

Full System: Advanced coal power with CO_2 capture, sent to EOR or aquifer

Possible functional units:

- Power, crude, fuel, CO_2, *combination*
- Each is a possible co-product for the others, and a potential displacement location

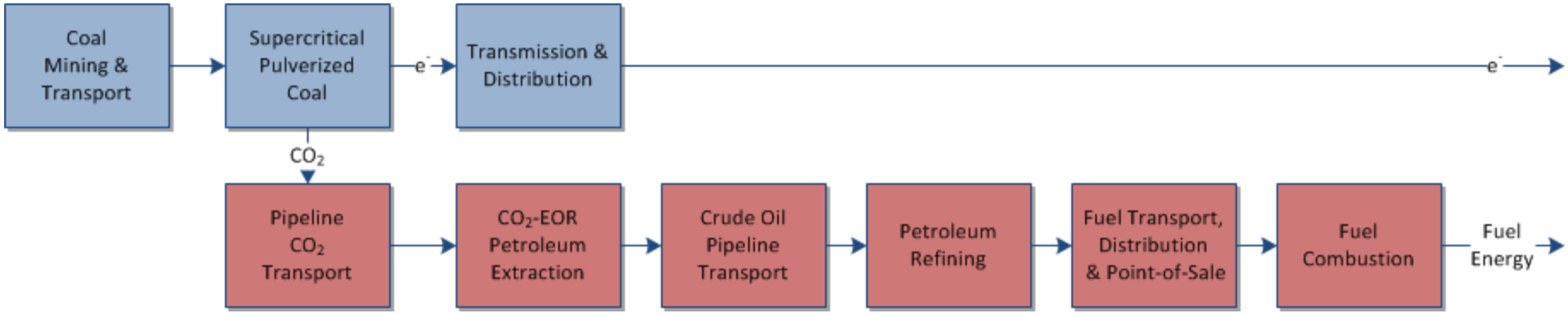


Captured CO_2 sent to Enhanced Oil Recovery

2 products, perform co-product allocation

- **Electricity has no mass or volume, entities are economically independent, so *energy* only physical basis for allocation**

- **Issue: 1 MJ of electricity ≠ 1 MJ of fuel, combusted**
  - Could choose an end use for each and measure exergy, but this ignores all other possible end uses and the differences in end use efficiency



If end uses (and associated efficiencies) are not explicitly chosen, an implicit choice has been made:

1 MJ electricity = 1 MJ fuel, combusted

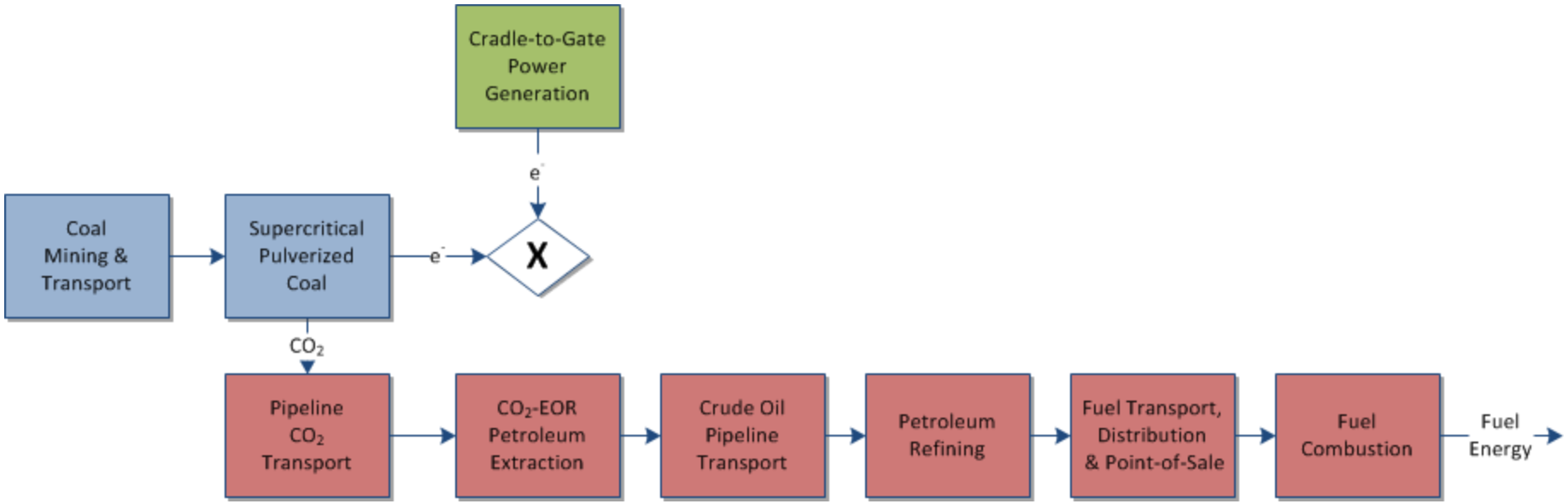
With allocation options ruled out, system expansion becomes best option

- **For large-scale energy systems displacement calculations need to be handled systematically**
- **Any displacement credit has three components**
  1. Location in the system the displacement occurs
     (end use, finished product, feedstock)
  2. Which option gets displaced
     (highest marginal cost, average, highest GHG)
  3. What percent of it gets displaced
     (all, none, other)

Functional unit of 1 MJ diesel fuel from EOR

Need to displace the power production

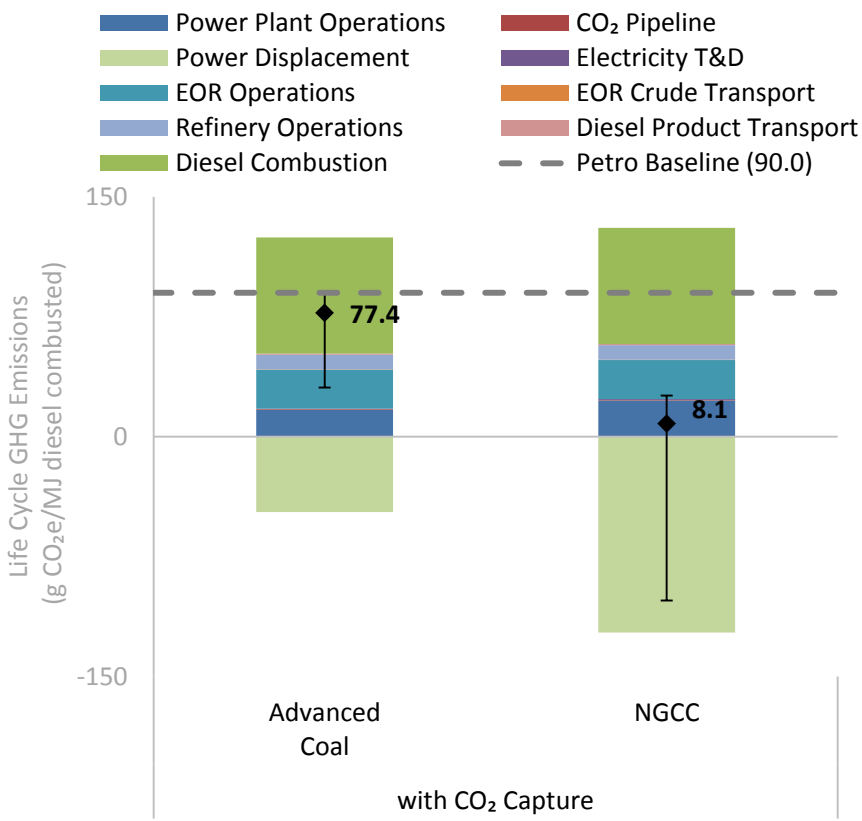
- **Assume that demand is relatively inelastic w.r.t. changes in supply**
- **Could displace anything from wind at 15 g/kWh to retiring coal at 1,300 g/kWh**
- **Narrowing the range of this displacement credit requires careful thought about the long-run marginal change to the grid induced by new power generated, and testing of the range's impact on conclusions being made in the study**

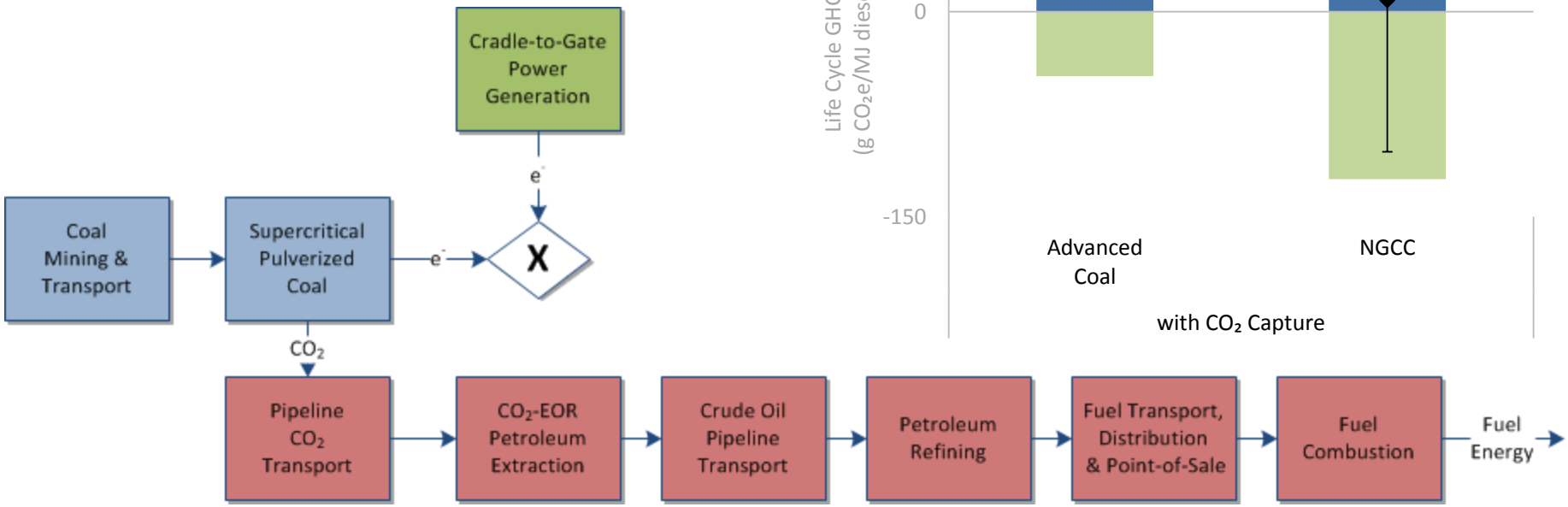


Functional unit of 1 MJ diesel fuel from EOR

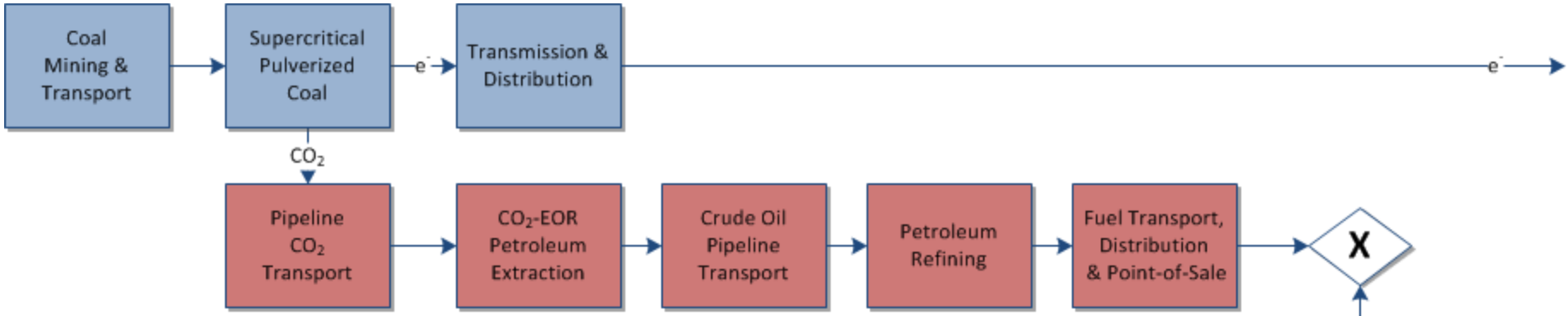
Need to displace the power production

- **Location is easy (green box), but is this advanced fossil plant with carbon capture displacing a retiring coal plant? Renewables or nuclear with similar price point? The grid? Is it 100% displacement or some fraction?**
- **We argue for 100% of the grid, with fleet coal and wind as the Hi/Lo choices**

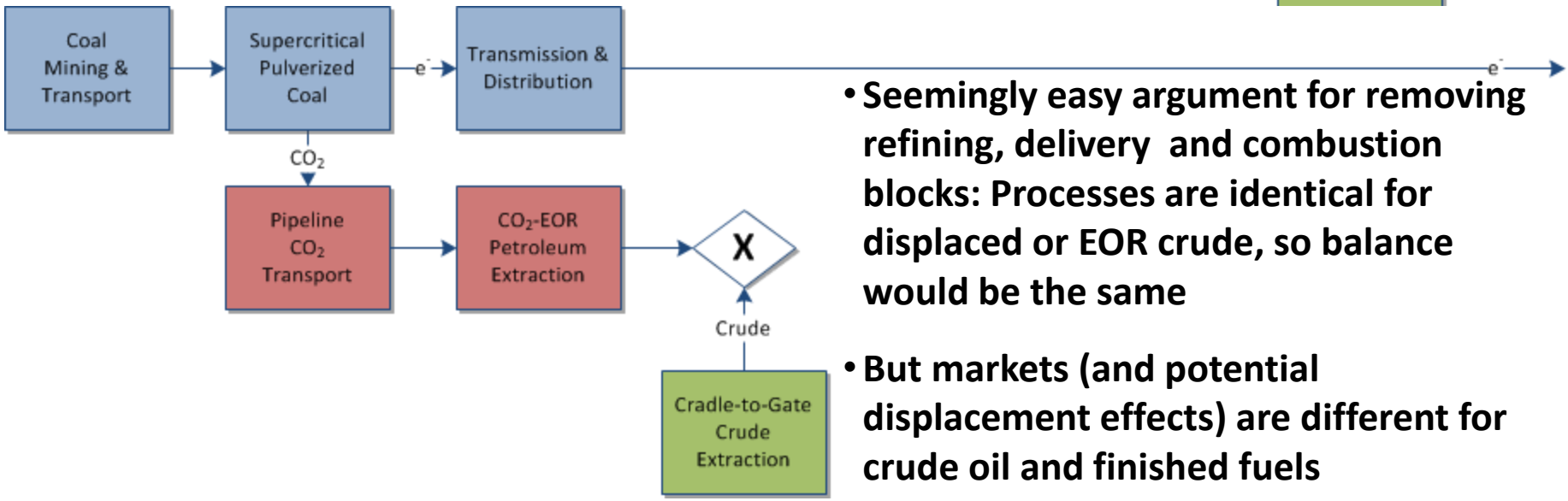




Similar exercise, but now power is the functional unit



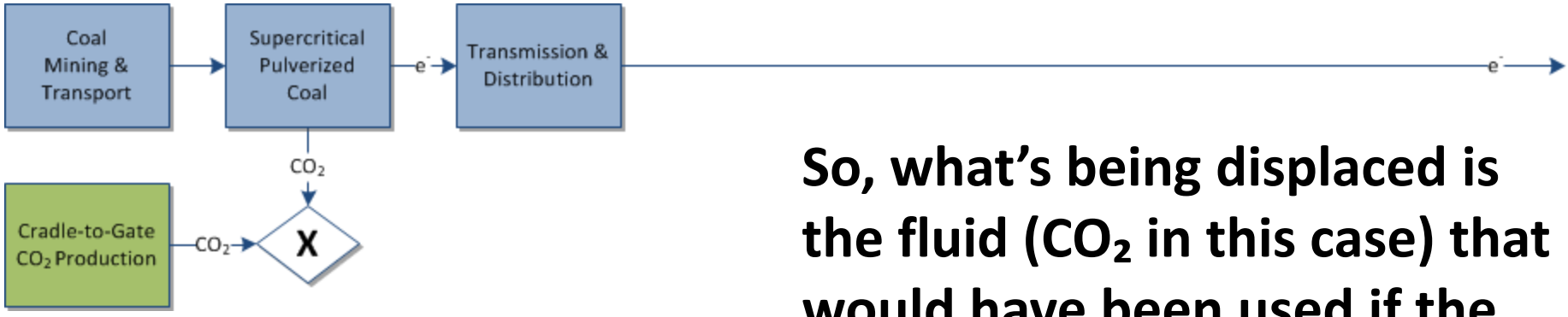
Most obvious option is to produce fuel from EOR crude, and then displace that production with a conventional or imported alternative



- **Seemingly easy argument for removing refining, delivery and combustion blocks: Processes are identical for displaced or EOR crude, so balance would be the same**
- **But markets (and potential displacement effects) are different for crude oil and finished fuels**

Case for removing the EOR block entirely

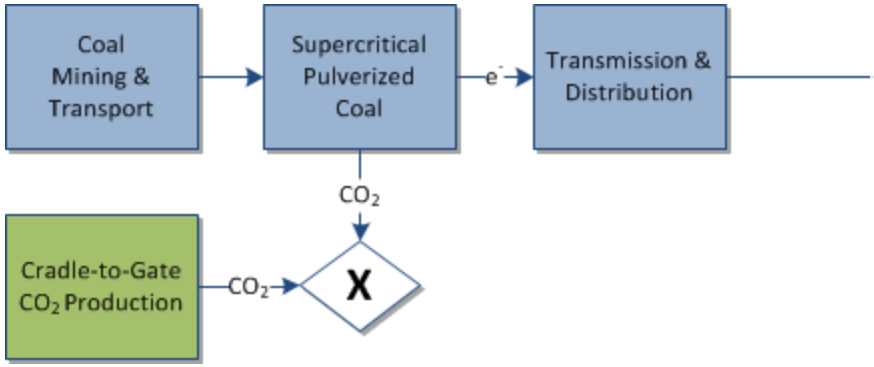
- **Argument for displacing here hinges on an existential case rather than an economic one:**
  - Domestic EOR crude production will happen regardless of the existence of this power plant
  - At $150/bbl world crude price, and no source of anthropogenic CO_2, EOR operators will find a way to get crude out; at $40/bbl, even free CO_2 won't be enough to make tertiary recovery attractive

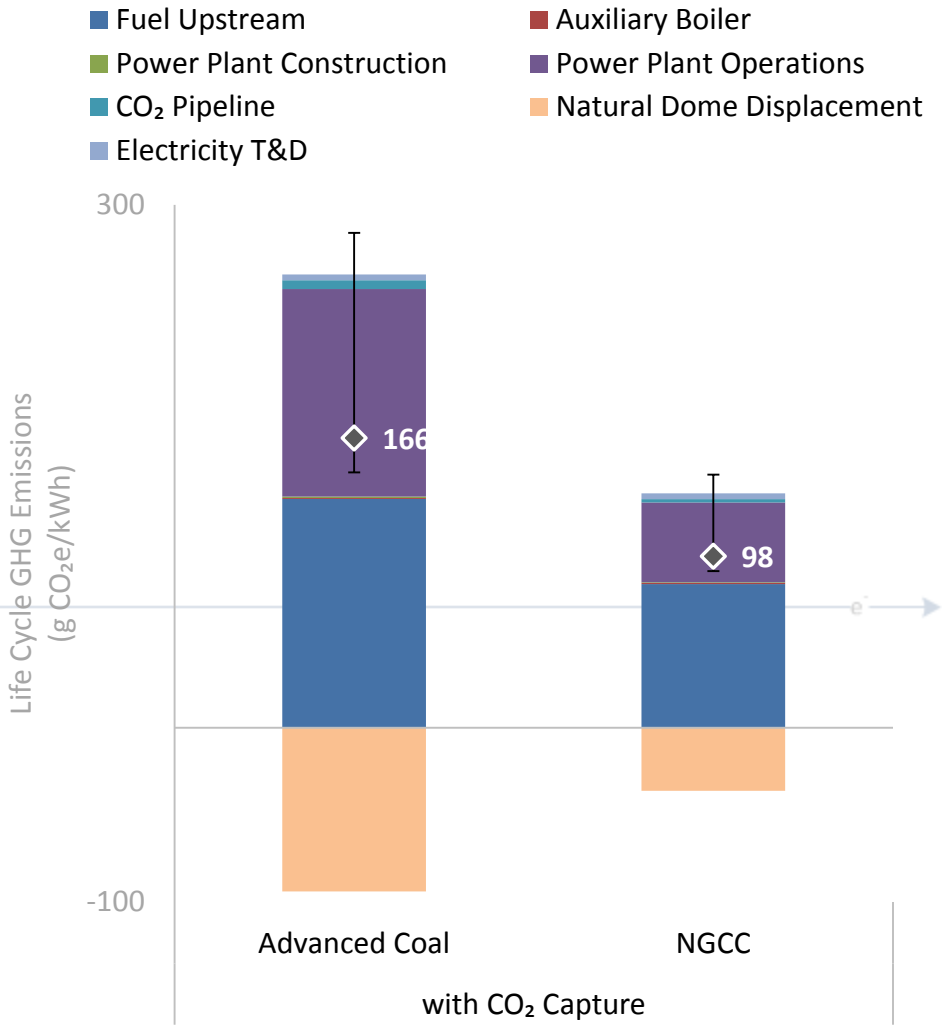


So, what's being displaced is the fluid (CO_2 in this case) that would have been used if the power plant didn't exist

Apply displacement with natural dome CO_2

- **Advanced coal with carbon capture likely exists in a world where generators would take just about any price – or even pay – to get rid of CO_2**
- **Strong case for displacement of natural dome CO_2 production, which we vary between 0 and 100%**



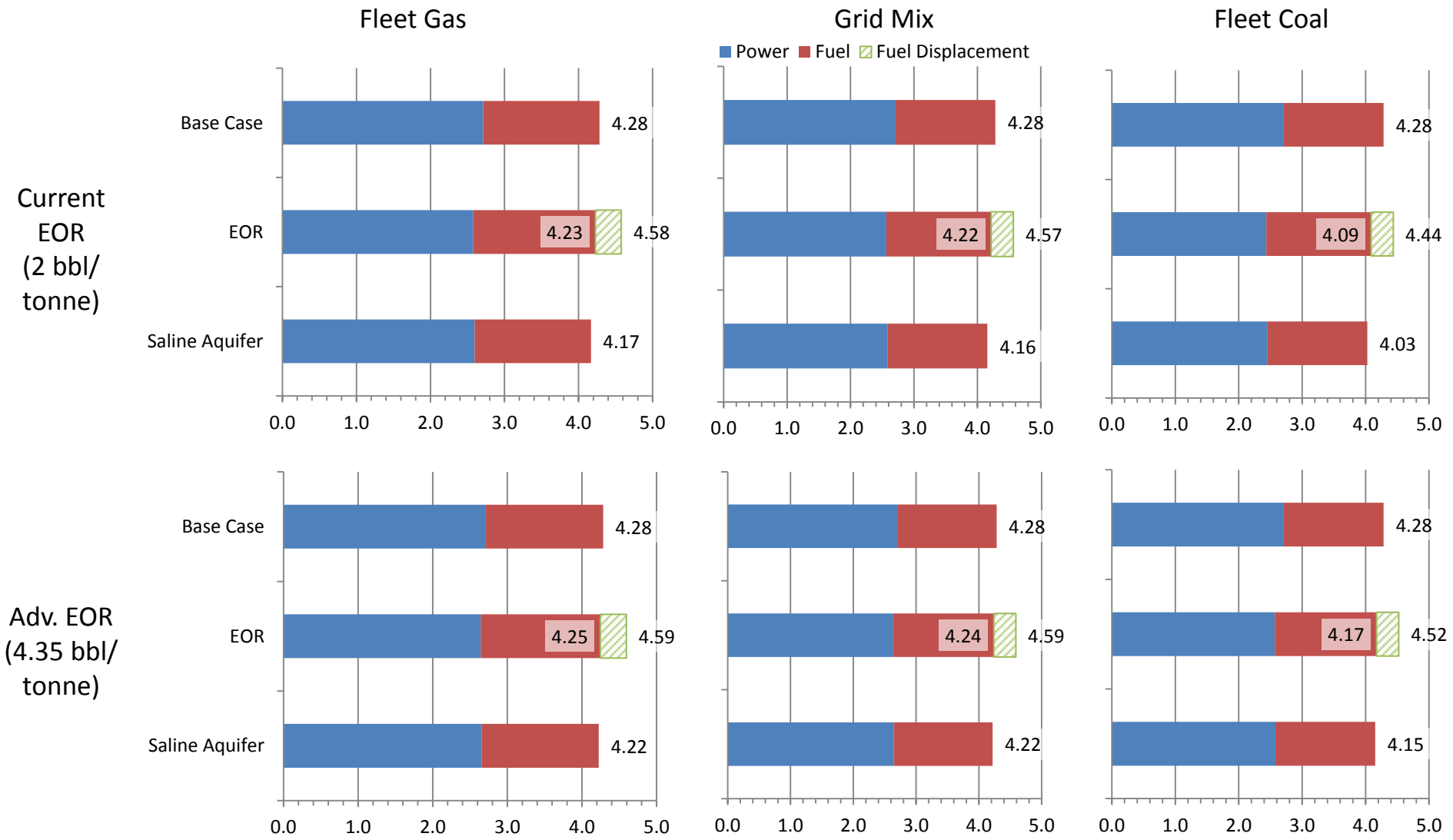


Change the purpose of our LCA – and now consider a consequential approach

- **No co-product management – system boundary includes all products produced**
- **In practice, looks like scenario comparison to a business-as-usual (BAU) case**
  - We've taken to referring to it as a "worlds" view, as in, "what would the world look like before and after"
- **Good for comparing a scenario against a baseline**
- **Uncertainty transferred from values of displacement to the definition of the BAU**
  - More critical than the question what the world looks like is *which portion of the world the new system will replace*

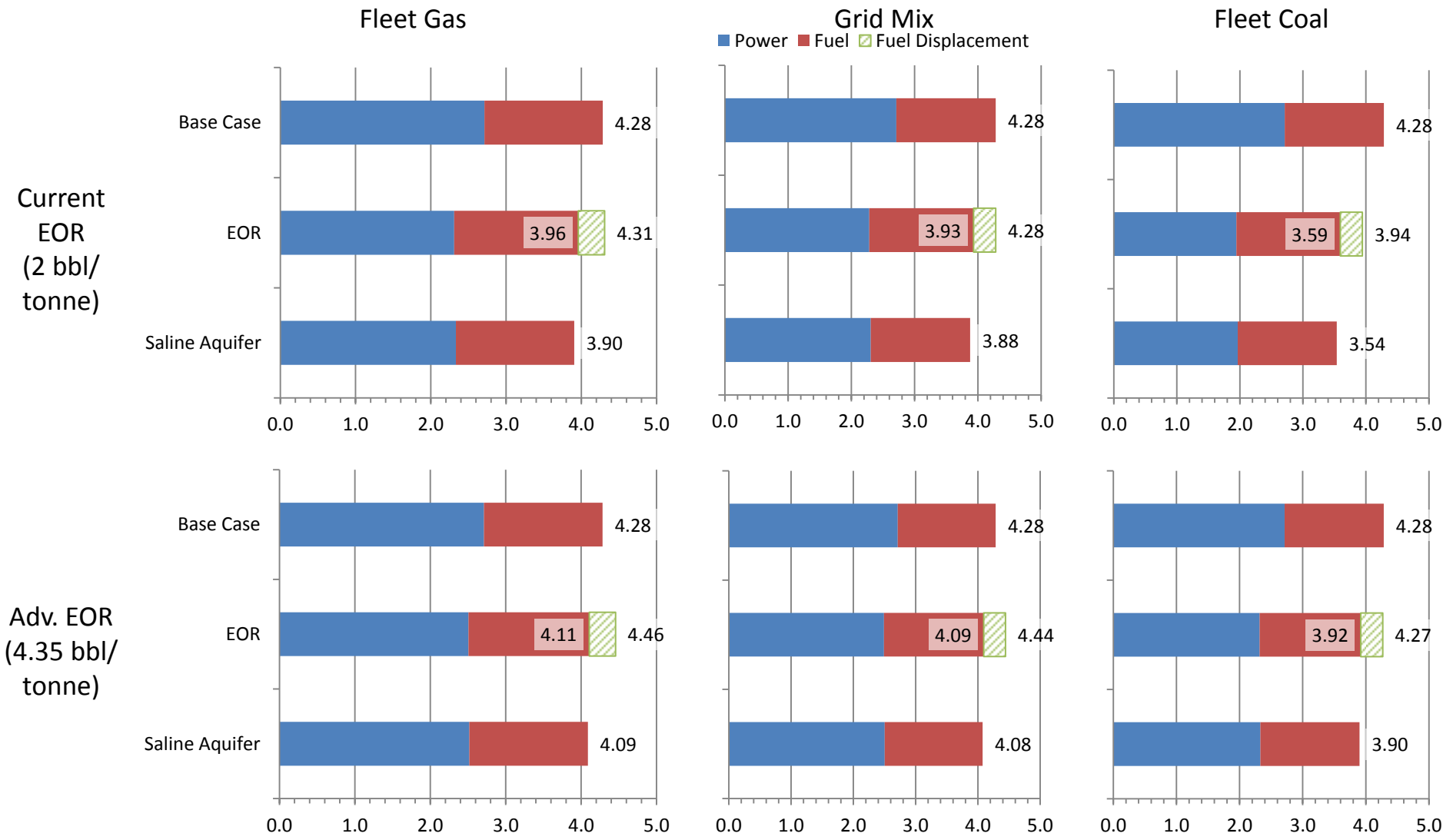
Annual US GHG Emissions for SCPC EOR Scenarios

Annual Greenhouse Gas Emissions for the U.S. for Power and Fuel (billion metric tonnes CO_2e)



Annual US GHG Emissions for NGCC EOR Scenarios

Annual Greenhouse Gas Emissions for the U.S. for Power and Fuel (billion metric tonnes CO_2e)



Creating useful – or understanding existing – LCA results requires well-defined questions

- **What was the purpose of the analysis?**
  - Comparing two technology options
  - Evaluating impact of a policy on entire system
- **What function do the systems provide?**
  - Coal: production of feedstock vs. delivered electricity
  - Natural gas: all annual domestic or marginal shale only
- **What metrics are of interest?**
  - Greenhouses gases: 20- or 100-year GWPs, inclusion of timing and feedback effects
  - Economic, environmental, and human health metric results may favor different options; relative importance of each may differ among technologies

With LCA – as with any analysis – the more complete the picture, the more uncertain it becomes

Contact Us

Timothy J. Skone, P.E.

Senior Environmental Engineer • Strategic Energy Analysis and Planning Division • (412) 386-4495 • *timothy.skone@netl.doe.gov*

Joe Marriott, Ph.D.

Lead Associate • Booz Allen Hamilton • (412) 386-7557 • *marriott_joe@bah.com*

James Littlefield

Associate • Booz Allen Hamilton • (412) 386-7560 • *littlefield_james@bah.com*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LCA@netl.doe.gov


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