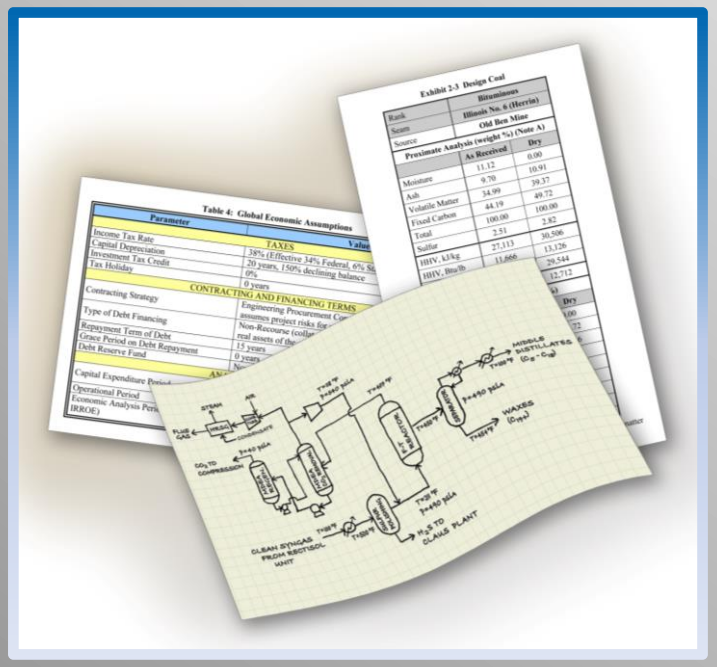

NETL Studies on the Economic Feasibility of CO_2 Capture Retrofits for the U.S. Power Plant Fleet

Kristin Gerdes

Office of Program Performance and Benefits

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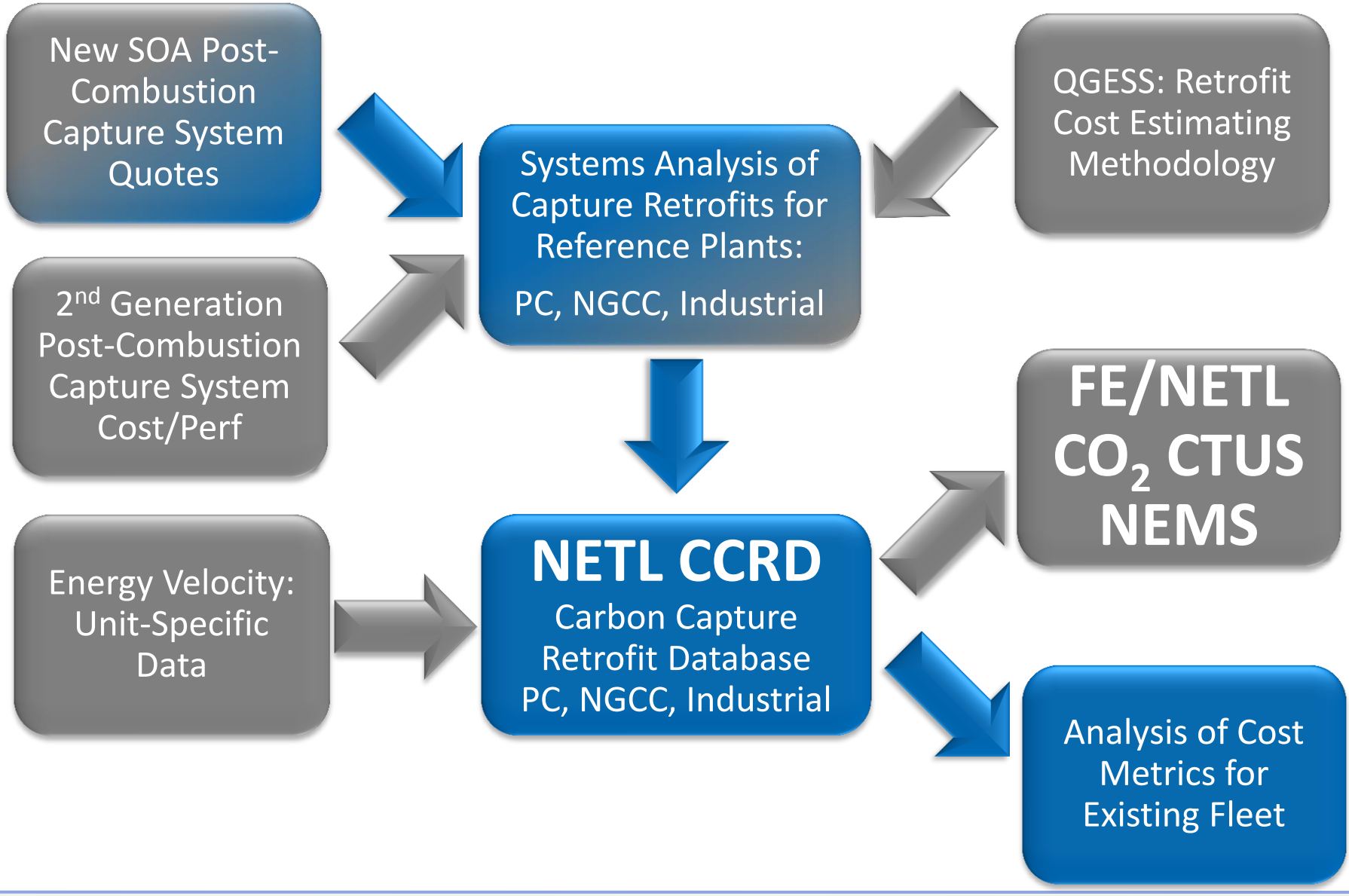
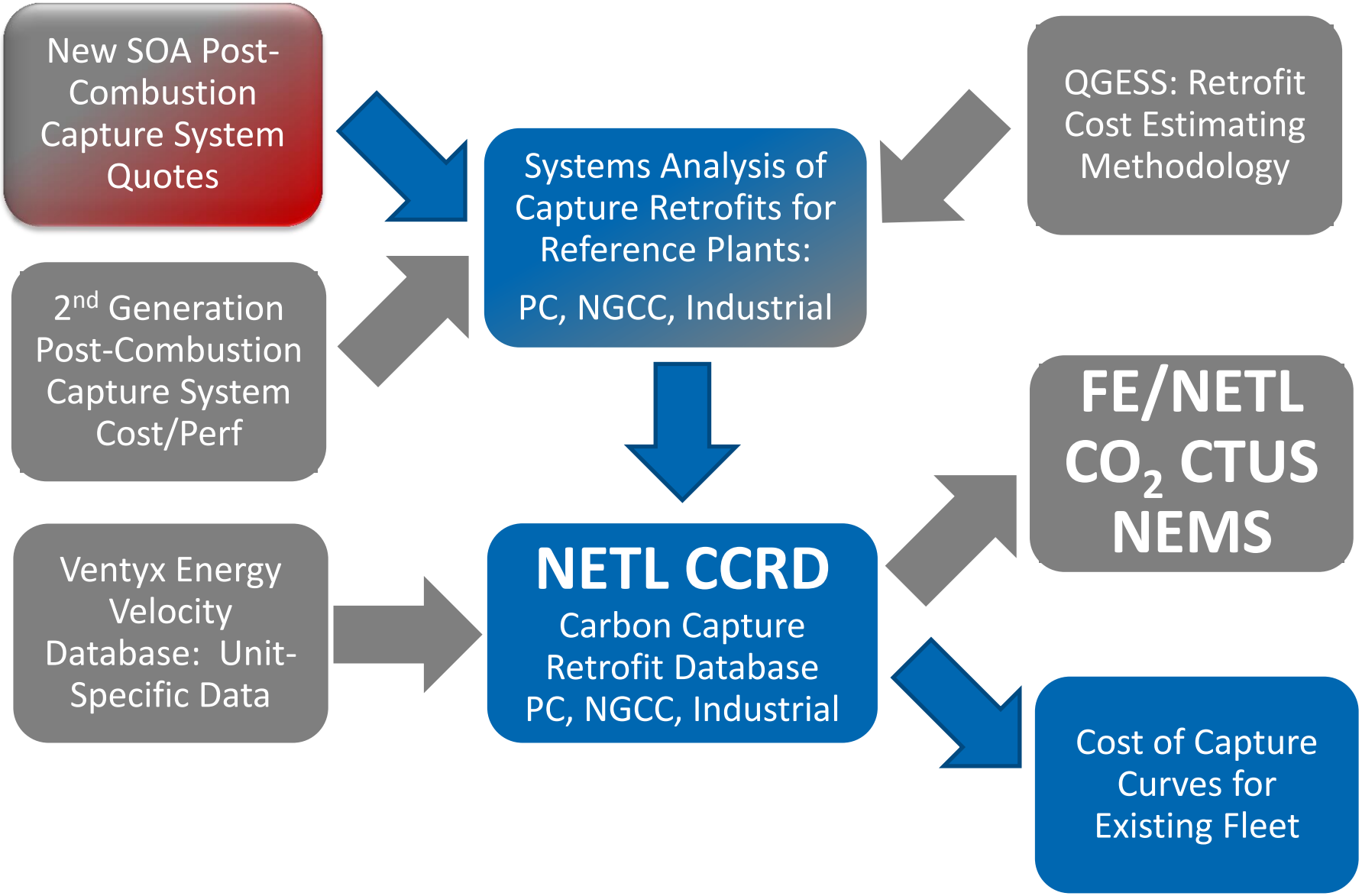
- **Worley-Parsons**
- **OnLocation**

NETL Carbon Capture Retrofit Analyses



NETL Carbon Capture Retrofit Analyses

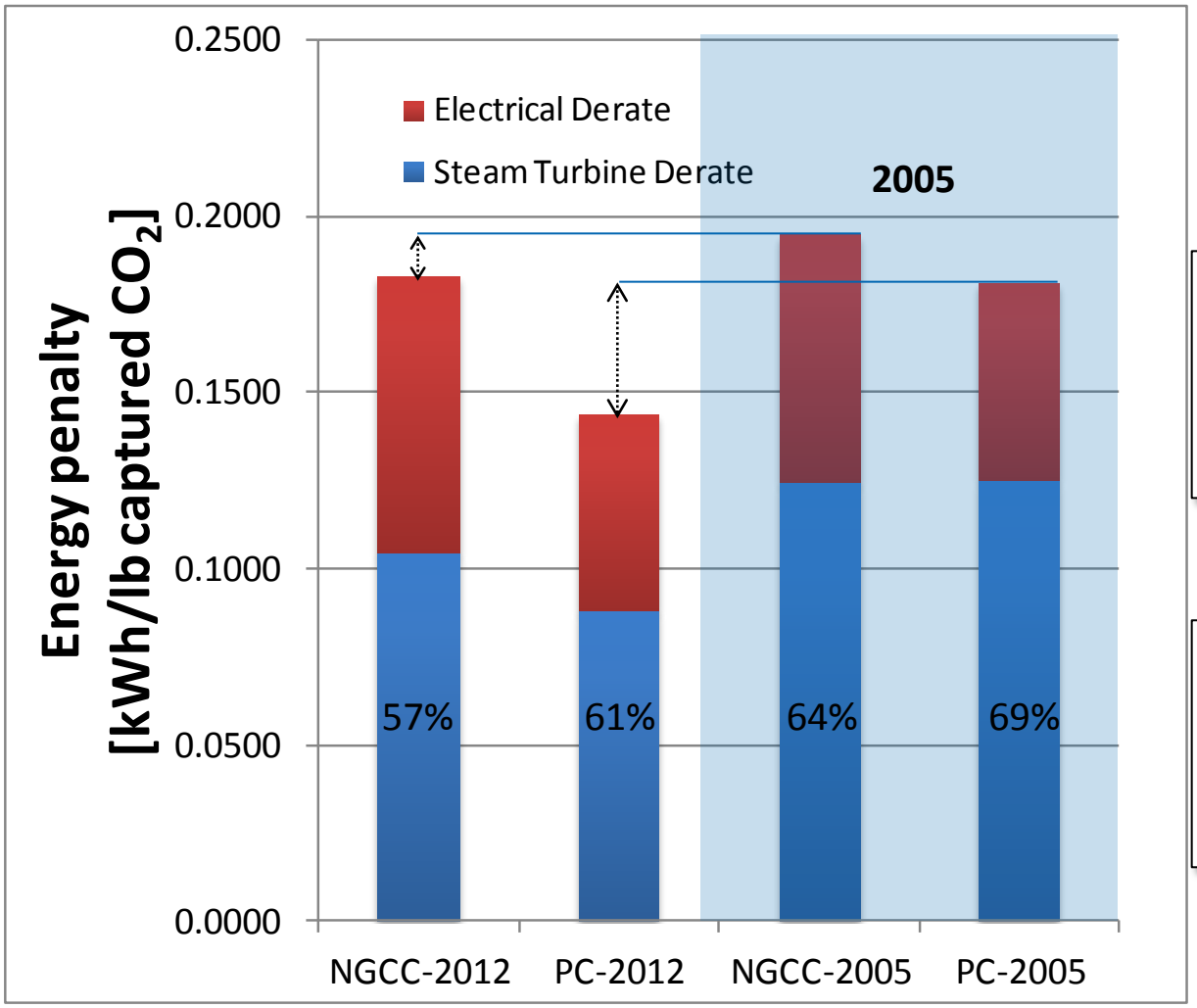


Baseline Retrofit Capture Technology Update

PC Plants	Technology/Quote Vintage	
Metric	2005 Amine	***2012 Amine***
Net Energy Penalty [kWhnet/lb CO_2 Captured]	0.181 **(+26%)**	***0.144***
Reference Capital Cost [$/tpd CO_2 Capt. @ full load]	$55,400 **(-17%)**	***$66,400***
Incremental Fixed O&M [$/tpd CO_2 Capt. @ full load]	$1,828 **(-5%)**	***$1,926***
Incremental Variable O&M [$/tpd CO_2 Capt. @ full load]	$2.59 **(-50%)**	***$5.13***
CO_2 Capture Basis [tpd]	11,216	***11,216***

- **For greenfield plant, COE impact is minor while cost of capture is slightly higher for new quote due to its higher efficiency**

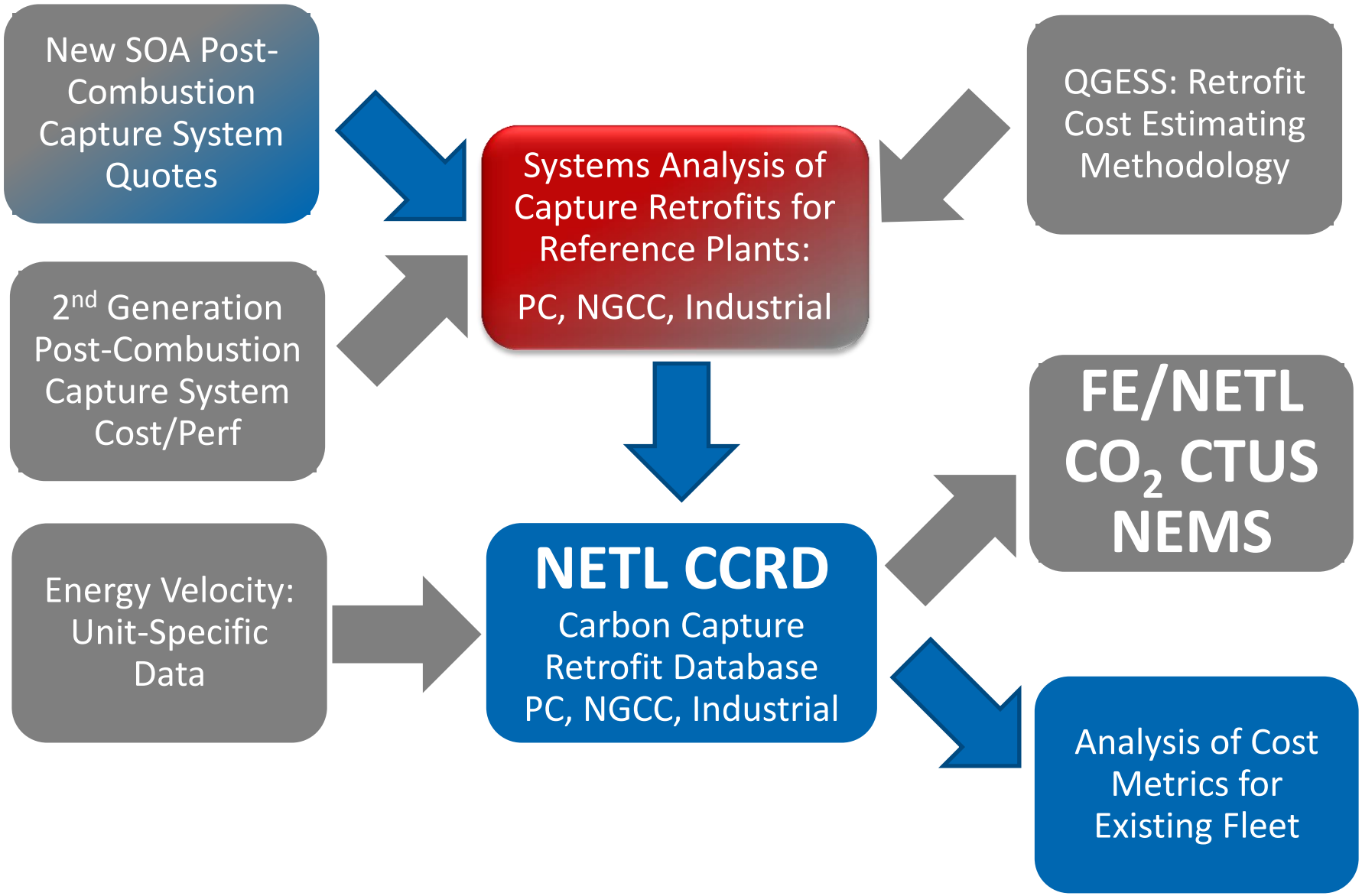
Net Derate Contributions



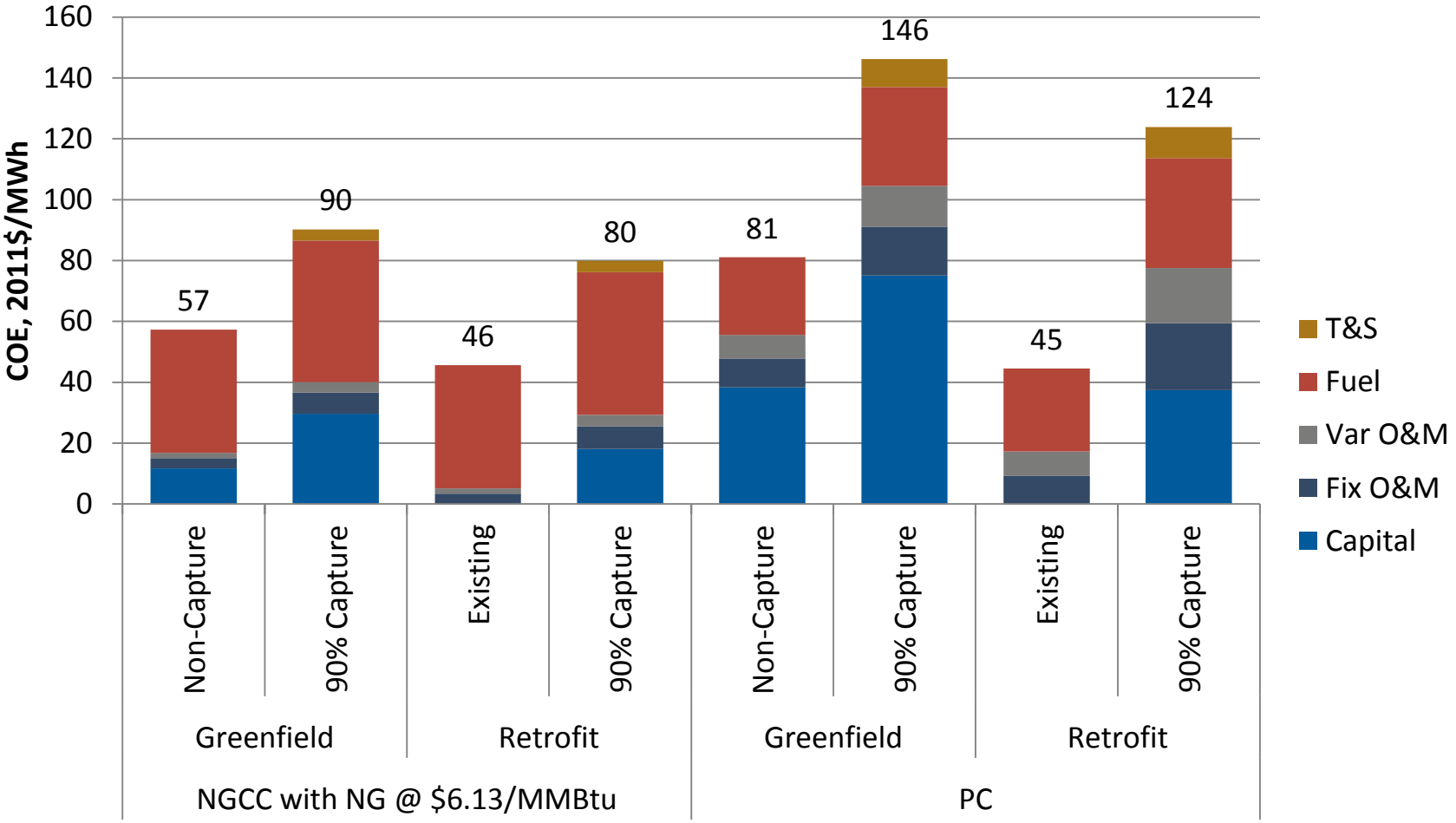
PC: ~30% reduction in regeneration energy penalty

NGCC: ~15% reduction in regeneration energy penalty

NETL Carbon Capture Retrofit Analyses



Reference Capture Plants: *Cost of Electricity*



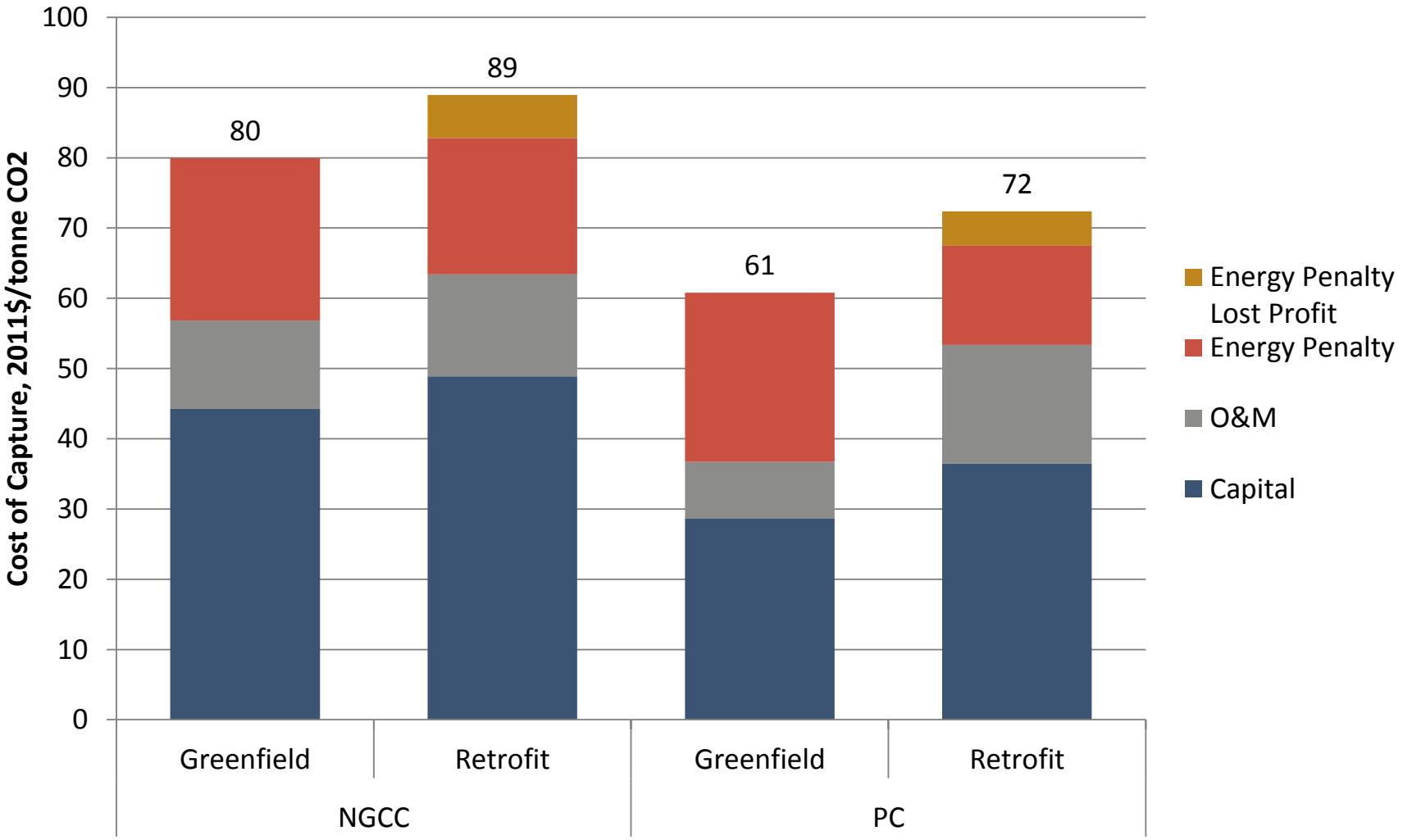
Cost of Capture for CCS Retrofits

- **Cost Retrofitting with CCS economically incentivized via sale of CO_2 if:**

Annualized Capital and Incremental O&M Costs for Retrofit + Annual Revenues Foregone Due to Lost Generation (Derate) ≤ Annual Revenues from Sale of Captured CO_2

- **When normalized by CO_2 captured, the above becomes:**
  - Cost of capture
  - Minimum CO_2 plant gate price for which CCS retrofits are incentivized

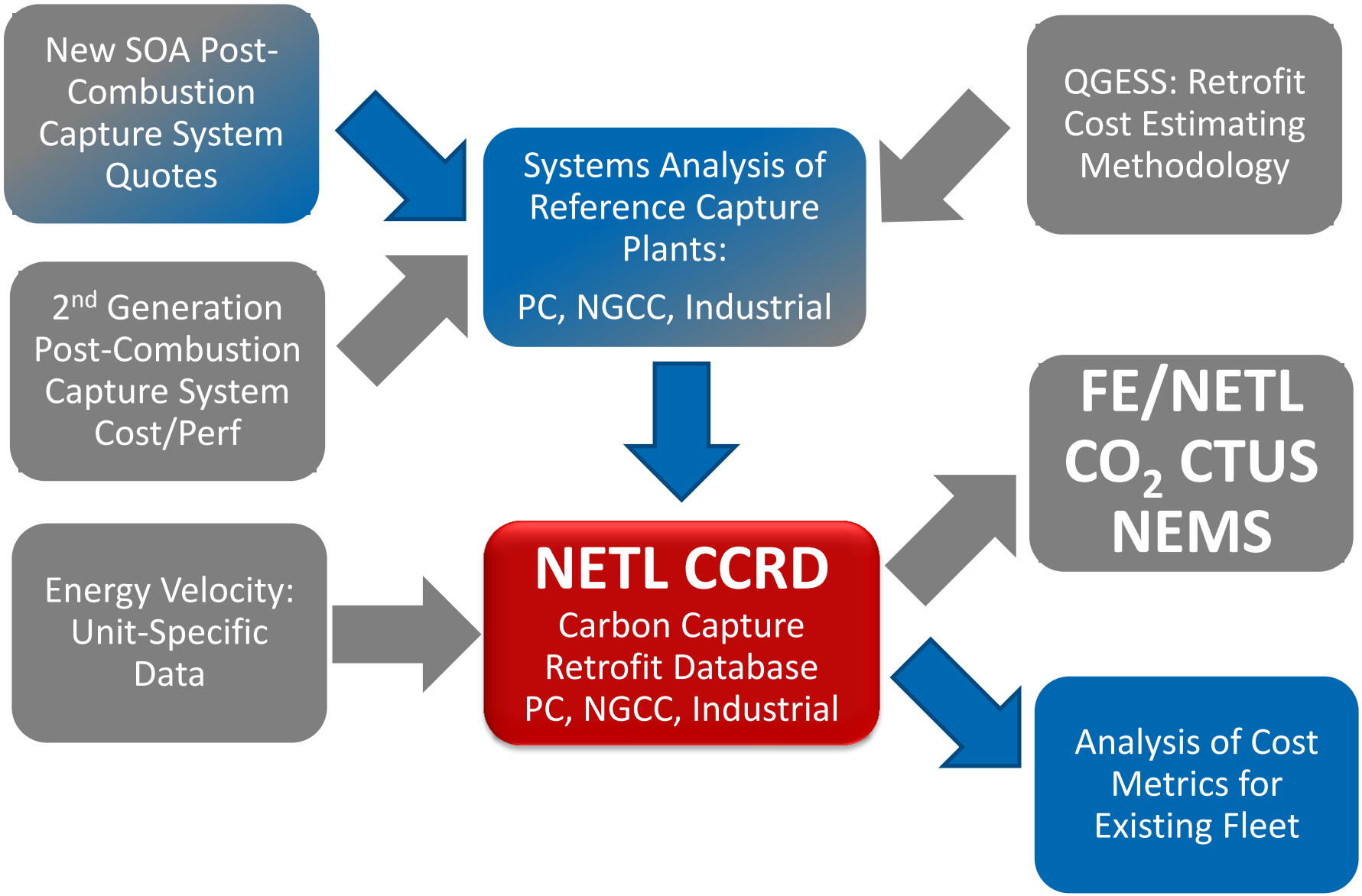
Reference Capture Plants: *Cost of Capture*



NG Price = $6.13/MMBtu
Market Power Price = $60/MWh

DRAFT Results

NETL Carbon Capture Retrofit Analyses



NETL CCRD

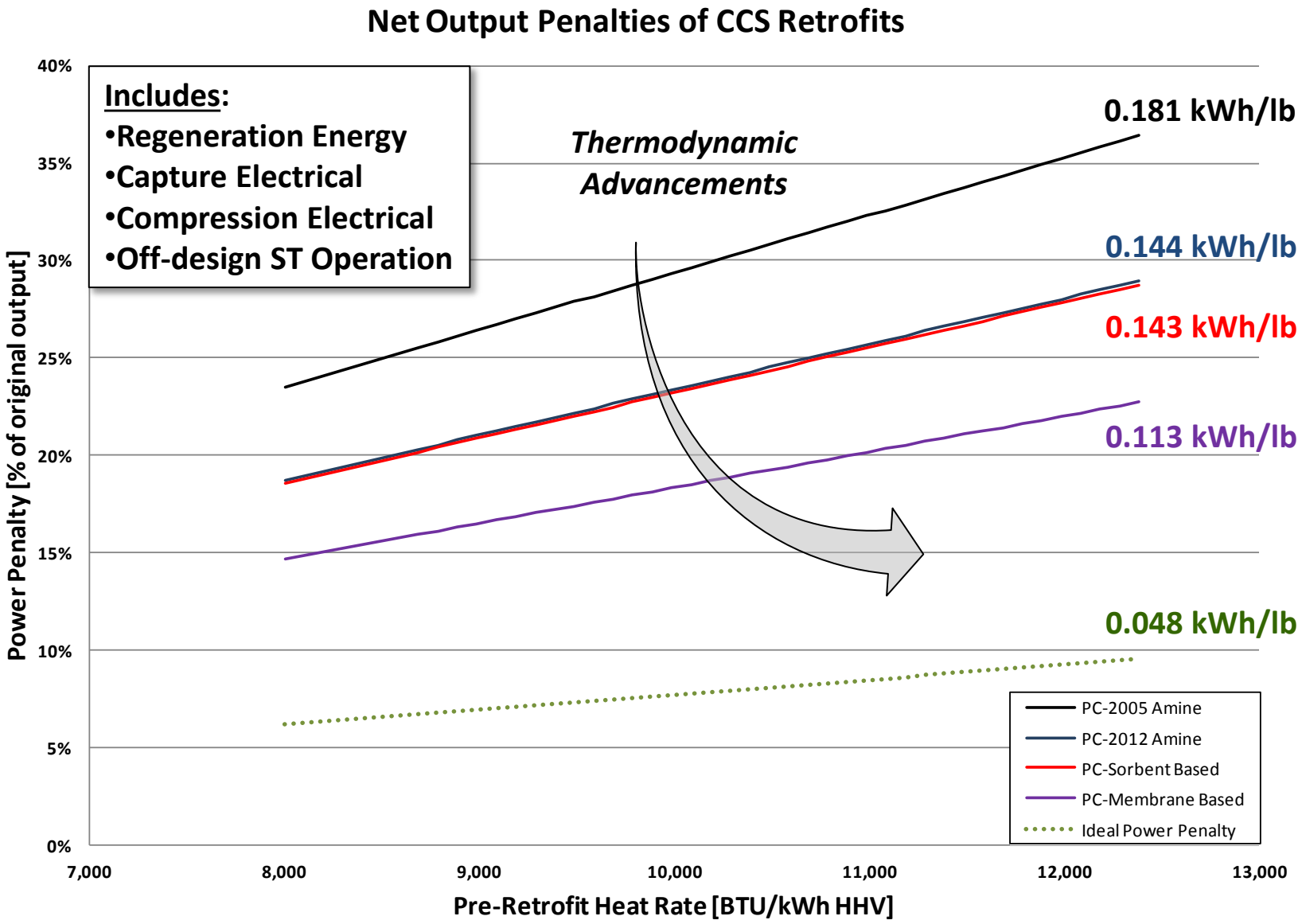
- **Carbon Capture Retrofit Database (CCRD)**
  - Existing pulverized coal fleet
  - Existing NGCC fleet
  - Industrial sources
    - Ammonia
    - Cement
    - Ethanol
    - Refinery hydrogen
    - Natural gas processing

NETL CCRD

PC and NGCC

- **Data on 1,355 individual PC units (324 GW) and 601 (216 GW) NGCC units**
  - Key information: Unit ID, Nameplate Capacity, Heatrate, CO_2 Emissions, Capacity Factor, Base Plant O&M Costs
- **Cost and performance parameters**
  - Retrofit capital costs, incremental O&M costs and scaling approach
  - Derate (in kWh/lb CO_2 captured)
  - Can be modified to reflect impact of R&D
- **Calculation of cost of capture, incremental COE, etc.**
- **Sensitivities to economic life, capacity factor, etc.**
- **Filter by plant size, age, etc.**

Net Derate Projections*



**As evaluated on baseline existing plant. Does not include balance of plant improvements*

Incentivizing CCS Retrofits with EOR Revenues

- **Retrofitting with CCS economically incentivized via sale of CO_2 if:**

Annualized Capital and Incremental O&M Costs for Retrofit + Annual Revenues Foregone Due to Lost Generation (Derate) ≤ Annual Revenues from Sale of Captured CO_2

  - When normalized by CO_2 captured, the above becomes the cost of capture or the minimum CO_2 plant gate price for which CCS retrofits are incentivized

- **NETL Carbon Capture Retrofits Database (CCRD) provides retrofit assessments for entire fleet**

NETL Retrofit Studies: Incremental cost and derate of retrofits for example plants

AEO/NEMS: Projected electricity price *(to estimate lost revenues)*

Ventyx Energy Velocity: Unit-specific data

$ per lb CO_2

kWh lost per lb CO_2

$ per Mwh

Output, CO_2 emissions, heat rate, etc.

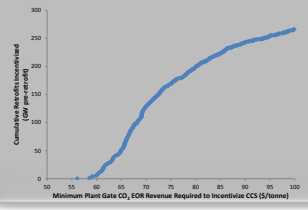
NETL CCRD

PC, NGCC, Industrial Sources

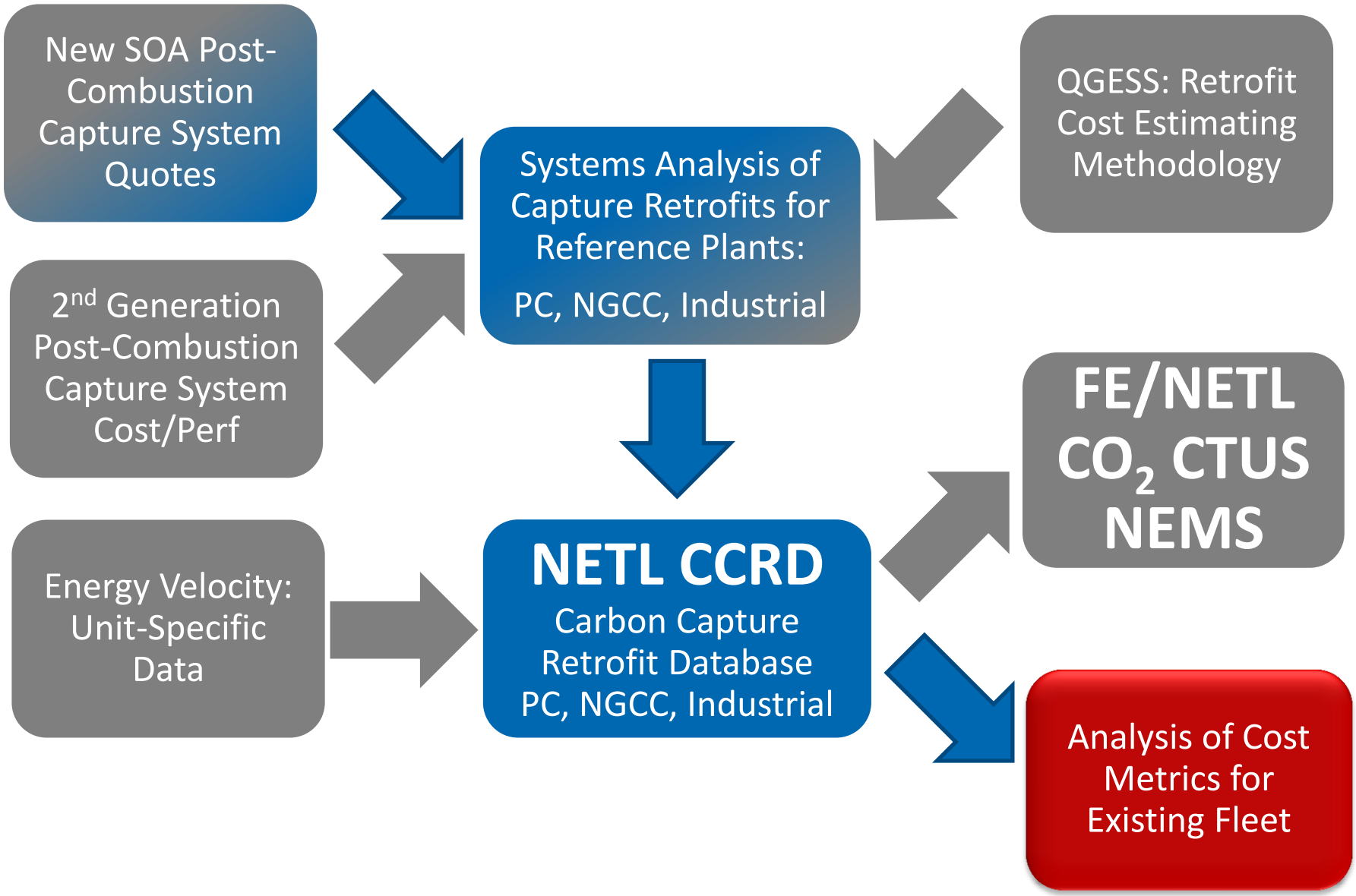
Scales retrofit costs and calculates derates and lost revenues for units in entire fleet

CO_2 Supply Curves:

Minimum CO_2 plant gate price for which CCS retrofits are incentivized for each unit in the fleet

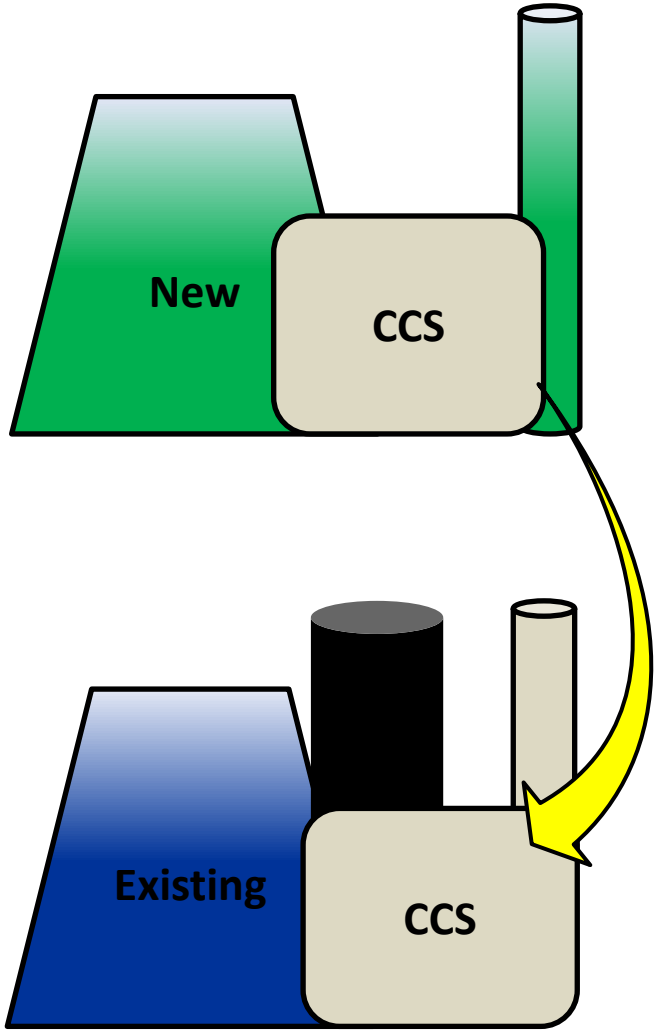


NETL Carbon Capture Retrofit Analyses

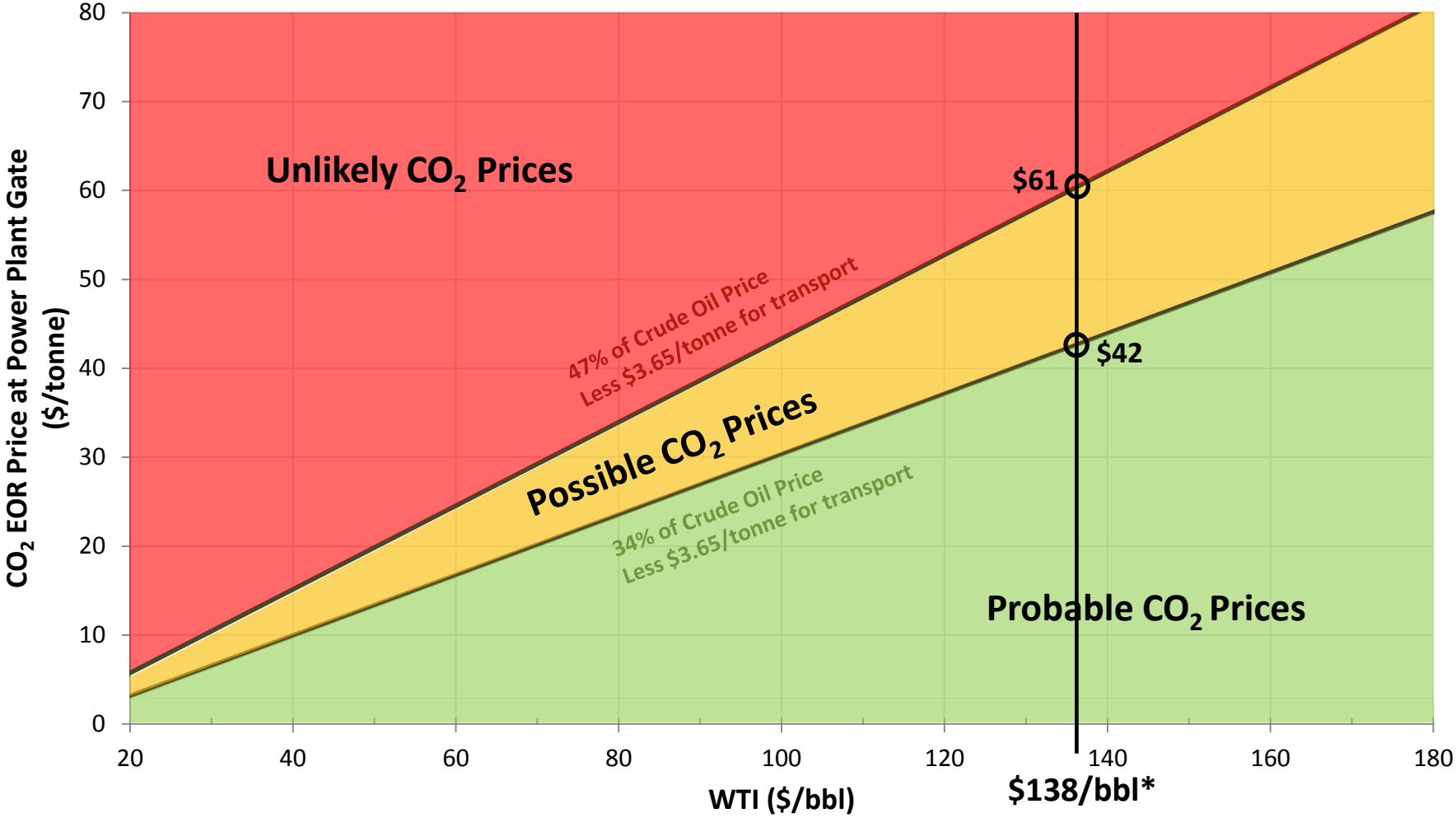


Analysis of CCS Retrofits of Existing PC Fleet

1. **Estimate cost and performance for state-of-the-art retrofit for <u>baseline existing plant</u>**
2. **Identify system that meets 2nd Generation goal of $40/tonne for <u>baseline greenfield plant</u>**
   - Conceptual, 550MW greenfield installation
   - Includes benefits of A-USC Steam cycle
3. **Apply same 2nd Generation capture technology to <u>baseline existing plant</u>**
   - Retain existing limitations such as fixed steam cycle, non-capture heat rate, etc. and exclude advanced technologies that could improve the base plant (e.g., AUSC materials)
4. **Extrapolate SOA and 2nd Gen performance and cost to existing power plant fleet**
5. **Assess market competitiveness for entire fleet – *<u>incentivizing CCS with CO_2 sales</u>***



2030 Oil Prices May Support EOR CO_2 Prices that are Equal to or Above CO_2 Capture Costs

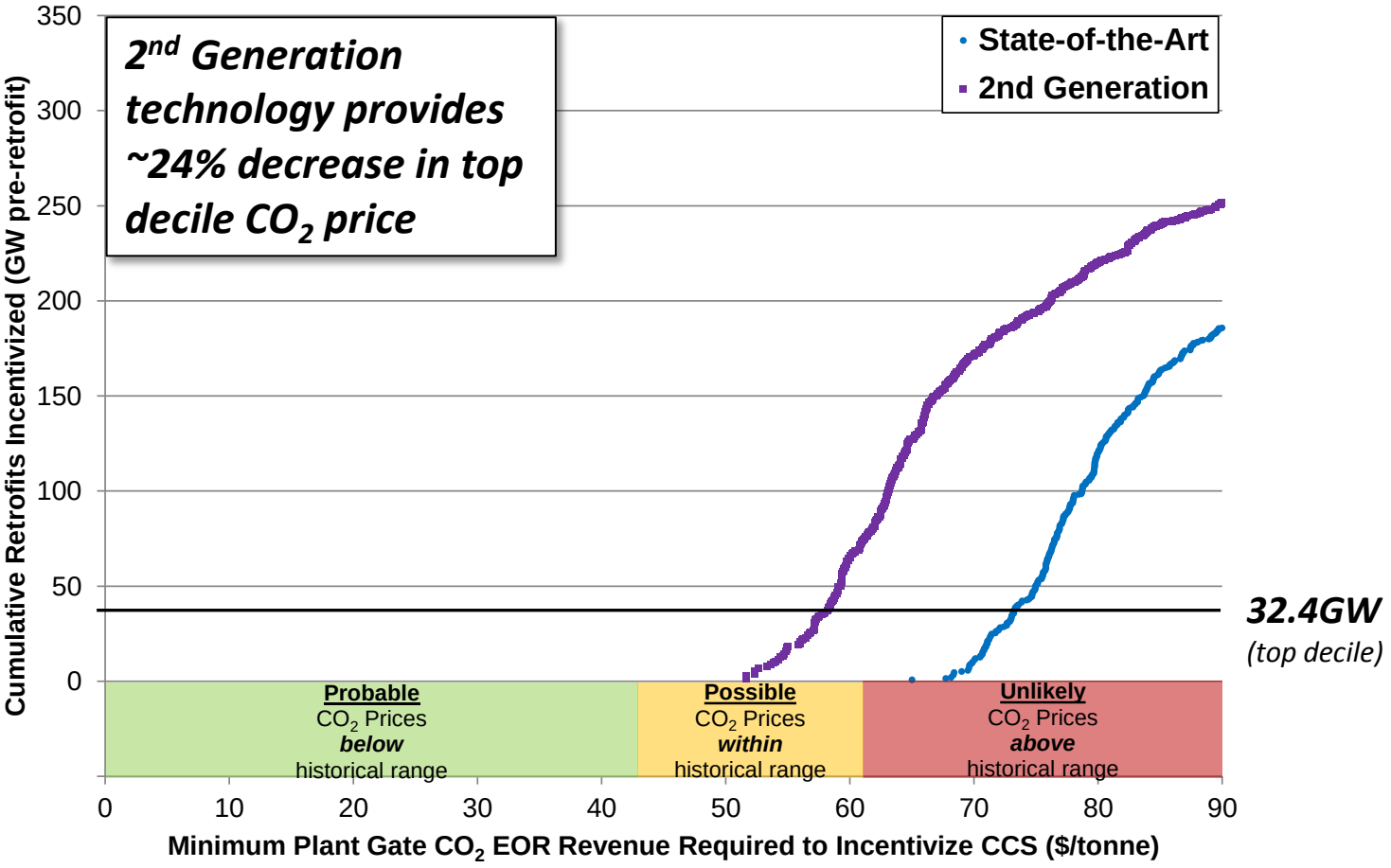


From 2008 to mid-2011, the average annual new contract price for CO_2 ($/MSCF) at the Denver City, Texas "hub", varied between 1.8% and 2.5% of the average annual WTI Crude oil price ($/bbl) in the corresponding years. Expressed in $/tonne, this is 34% to 47% (at standard conditions of 60 °F and 14.7 psia). (The non-averaged contract prices ($/MSCF) varied between 1.4 and 3.3% of the oil price between 2008 and mid-2011.) Source: Chaparral Energy "US CO2 & CO2 EOR Developments" Panel Discussion at CO_2 Carbon Management Workshop December 06, 2011. Estimated 100 km pipeline transport cost of $3.65/tonne is subtracted to convert the historical "hub" price to an estimated power plant gate price.

*NEMS Projection

Minimum Plant Gate CO_2 EOR Revenue to Incentivize CCS – Year 2030

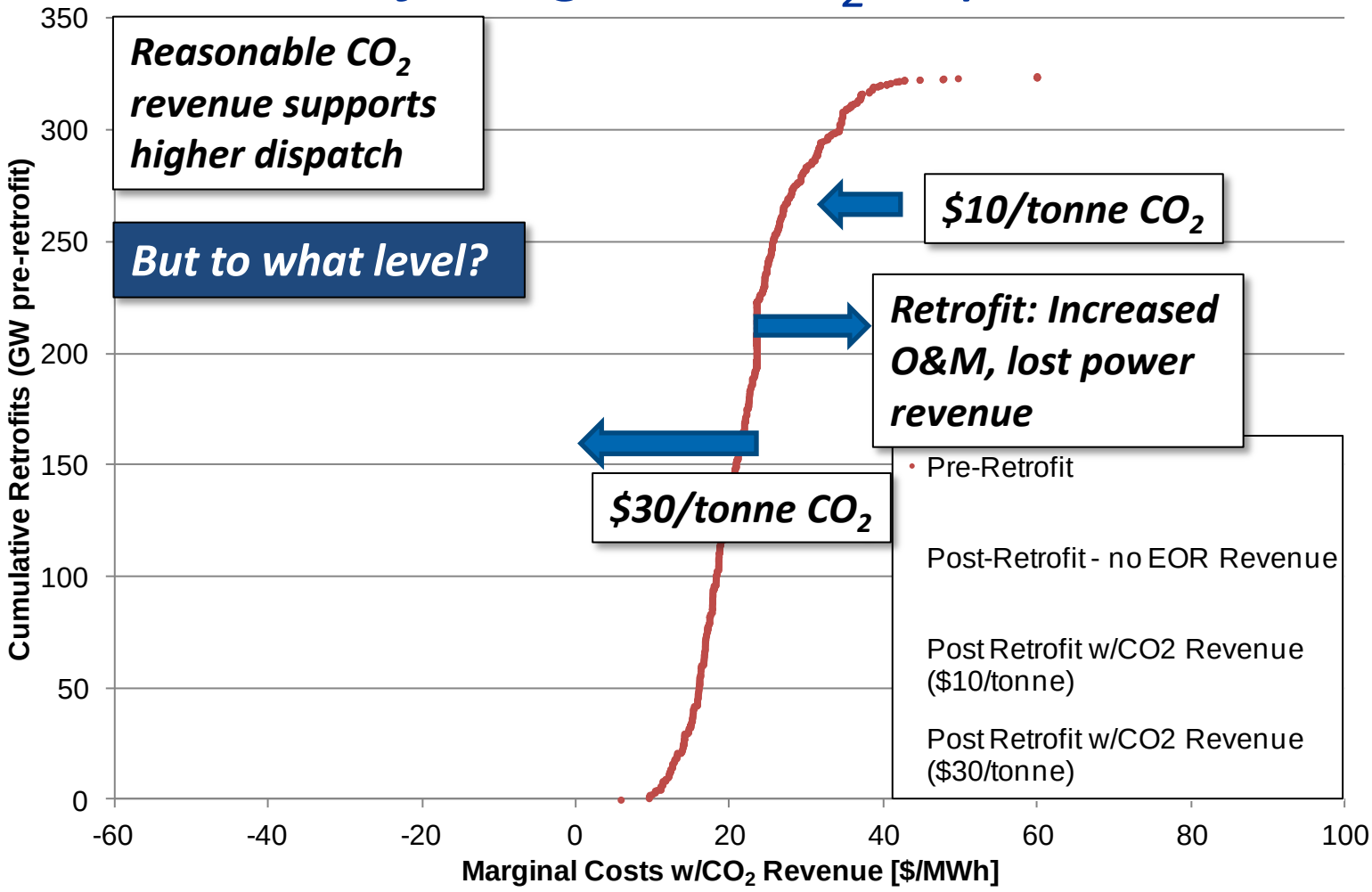
- *Same CF pre- and post-retrofit*
- *30-yr economic life*
- *$75/MWh* power price*
- *$138/bbl oil**



**NEMS Projections. Capital costs reflect ~15% premium due to increase in oil prices.*

Incremental Marginal Cost Trends

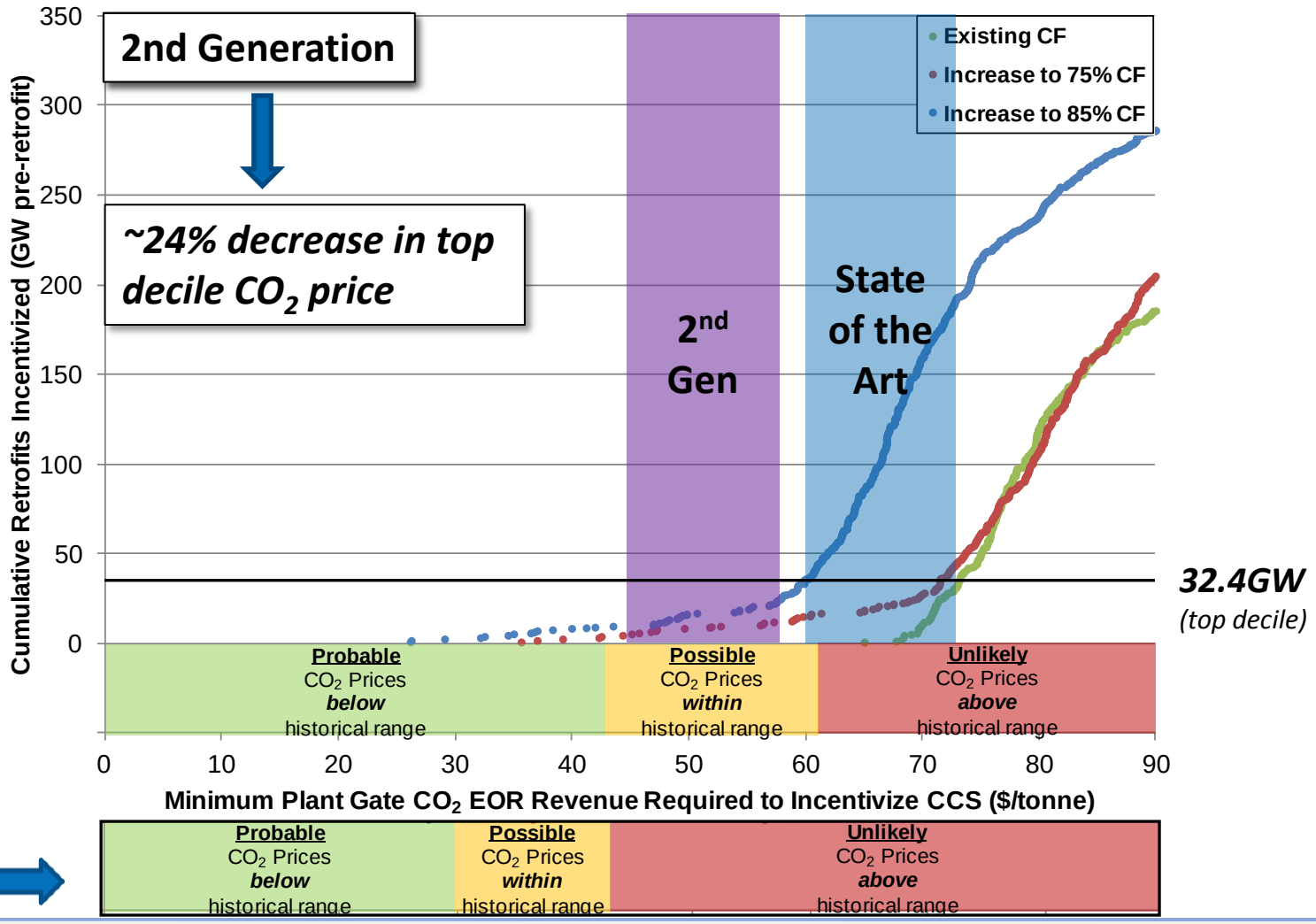
Retrofitting SOA CO_2 Capture



Effect of Dispatch - 2030

Capacity Factor Parameter Sensitivity

- ***30-yr life***
- ***$75/MWh* power price***
- ***$138/bbl oil****

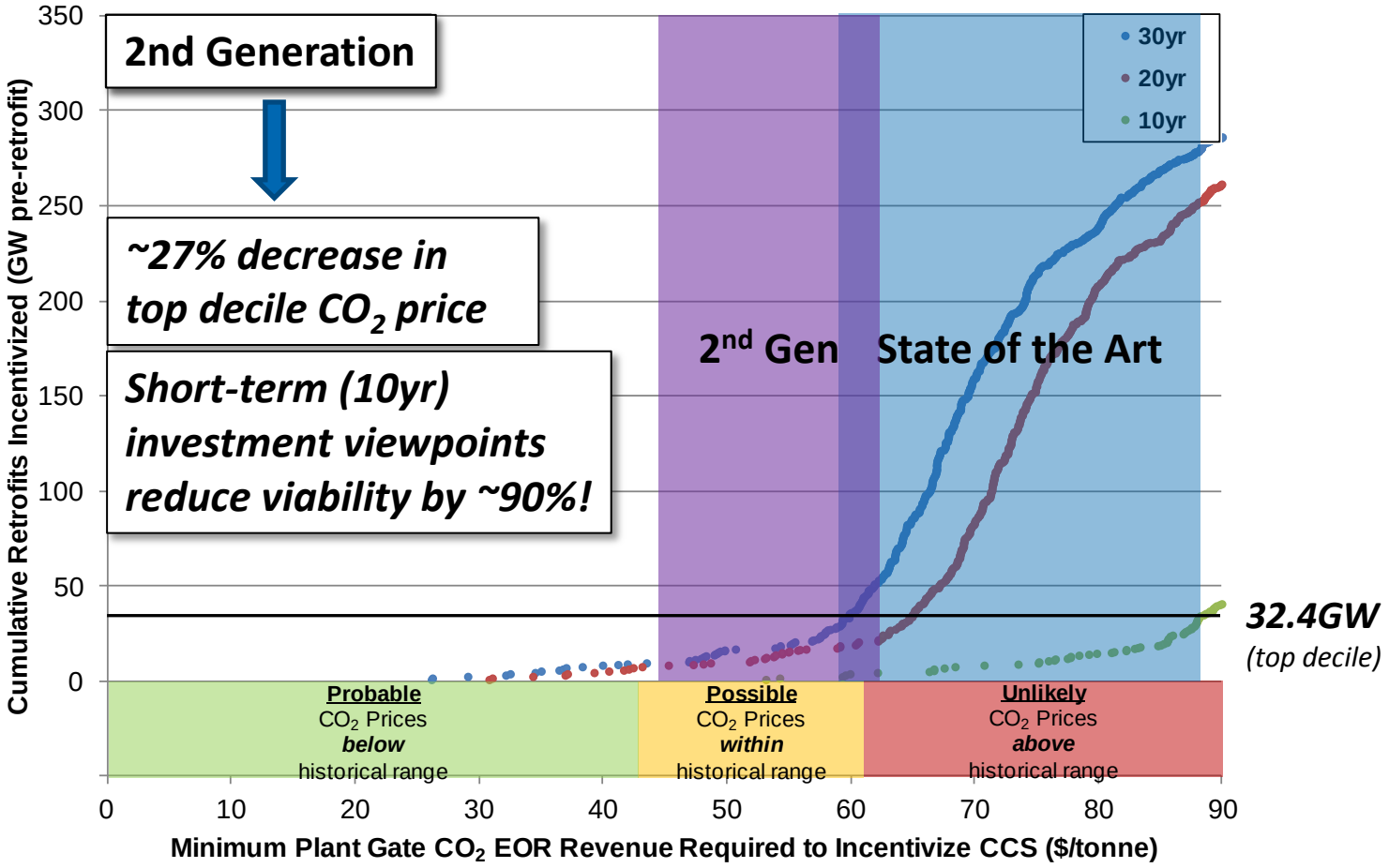


Note shift from EOR revenues @ $100/bbl

**NEMS Projections. Capital costs reflect ~15% premium due to increase in oil prices.*

Effect of Economic Life - 2030

- *85% CF*
- *$75/MWh power price*
- *$138/bbl oil*



Conclusions

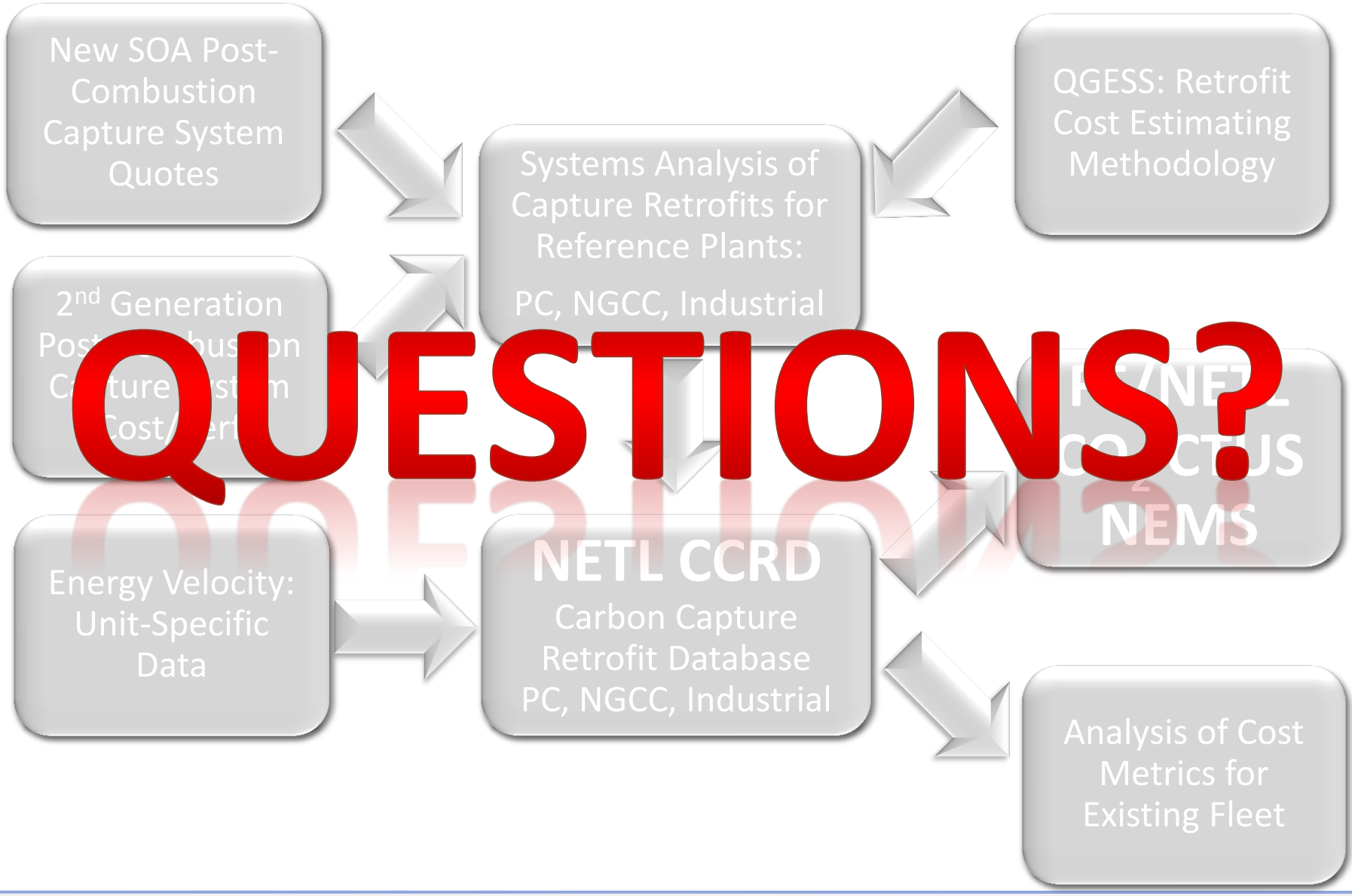
Compared cost of CO_2 retrofits to minimum CO_2 price in EOR market

- **Even with EOR revenues, SOA technology unlikely to promote significant retrofits**
- **2nd gen improvements reduce cost of capture by ~25% and significantly increase potential of deployment**
  - CO_2 contract price relationship to price of WTI crude
- **EOR market while limited in size, is an excellent transition step for proving out carbon capture and reducing risk for future installations**
- **Still need help for "slam dunk" EOR scenario**
  - Need CO_2 capture R&D success!
  - Dispatch is essential – and likely achievable
  - Regulatory drivers encouraging CO_2 capture should also support a long-term (30yr) investment viewpoint

Limitations and Next Steps

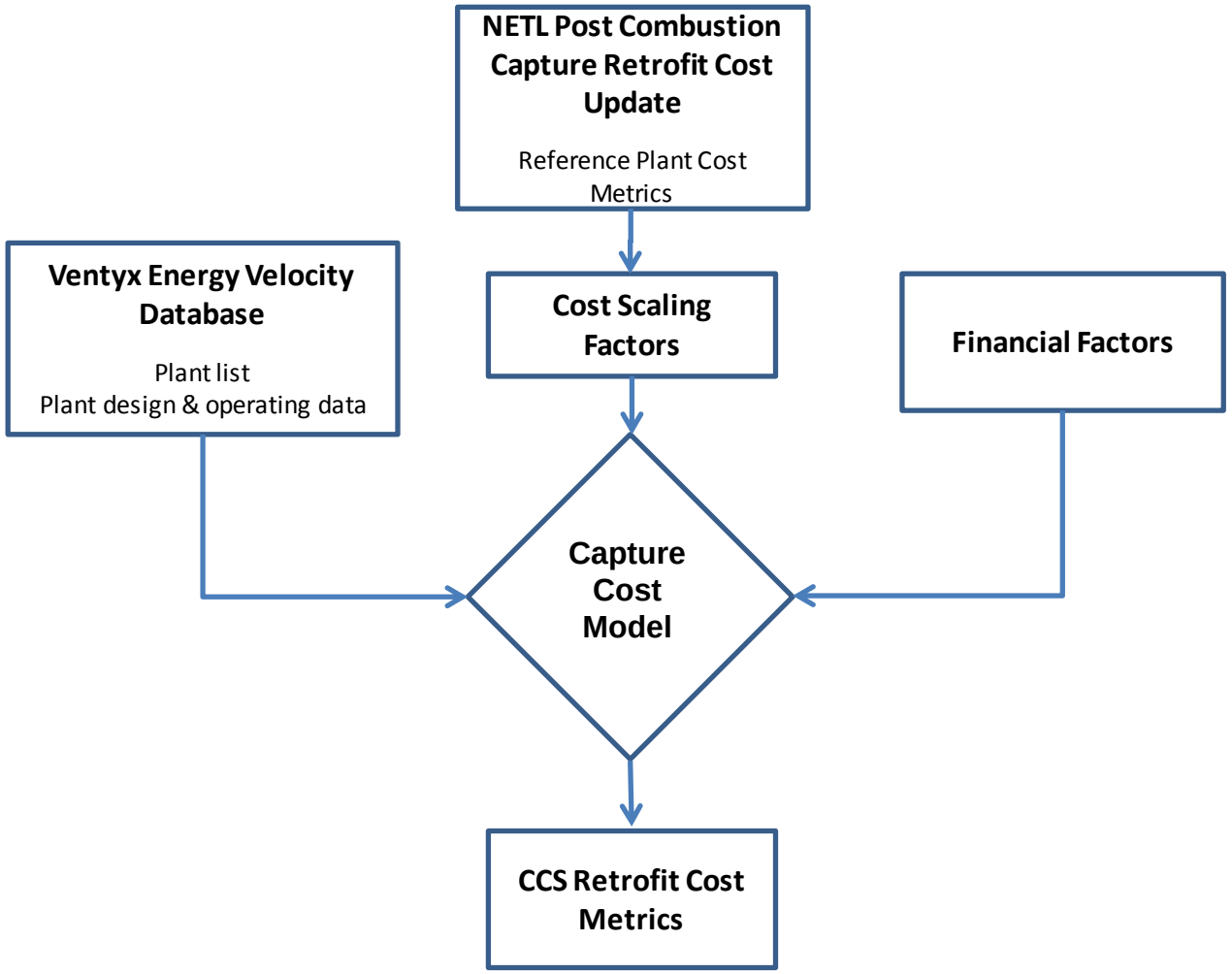
- **Limitations of analysis**
  - Uncertainty in crude oil and CO_2 price projections
  - Plant locations relative to EOR opportunities
  - Capability of EOR sites to take entire stream
- **Next Steps**
  - FE/NETL CTUS model integrates with NEMS
  - Links CO_2 sources and sinks
  - Detailed transport and storage/EOR cost models
  - Evaluate combinations of CO_2 emissions price and CO_2 revenues

NETL Carbon Capture Retrofit Analyses



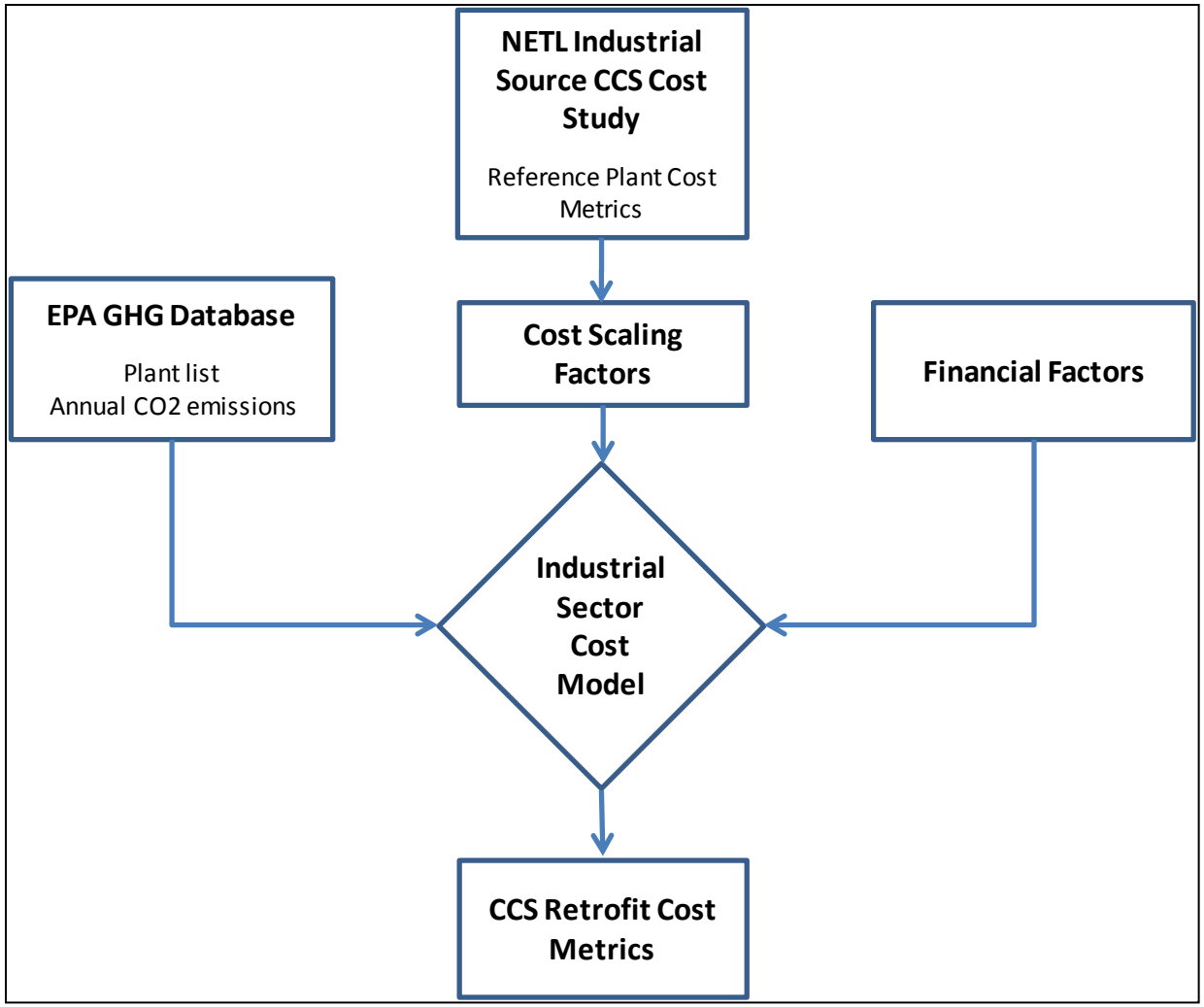
NETL CCRD

PC and NGCC

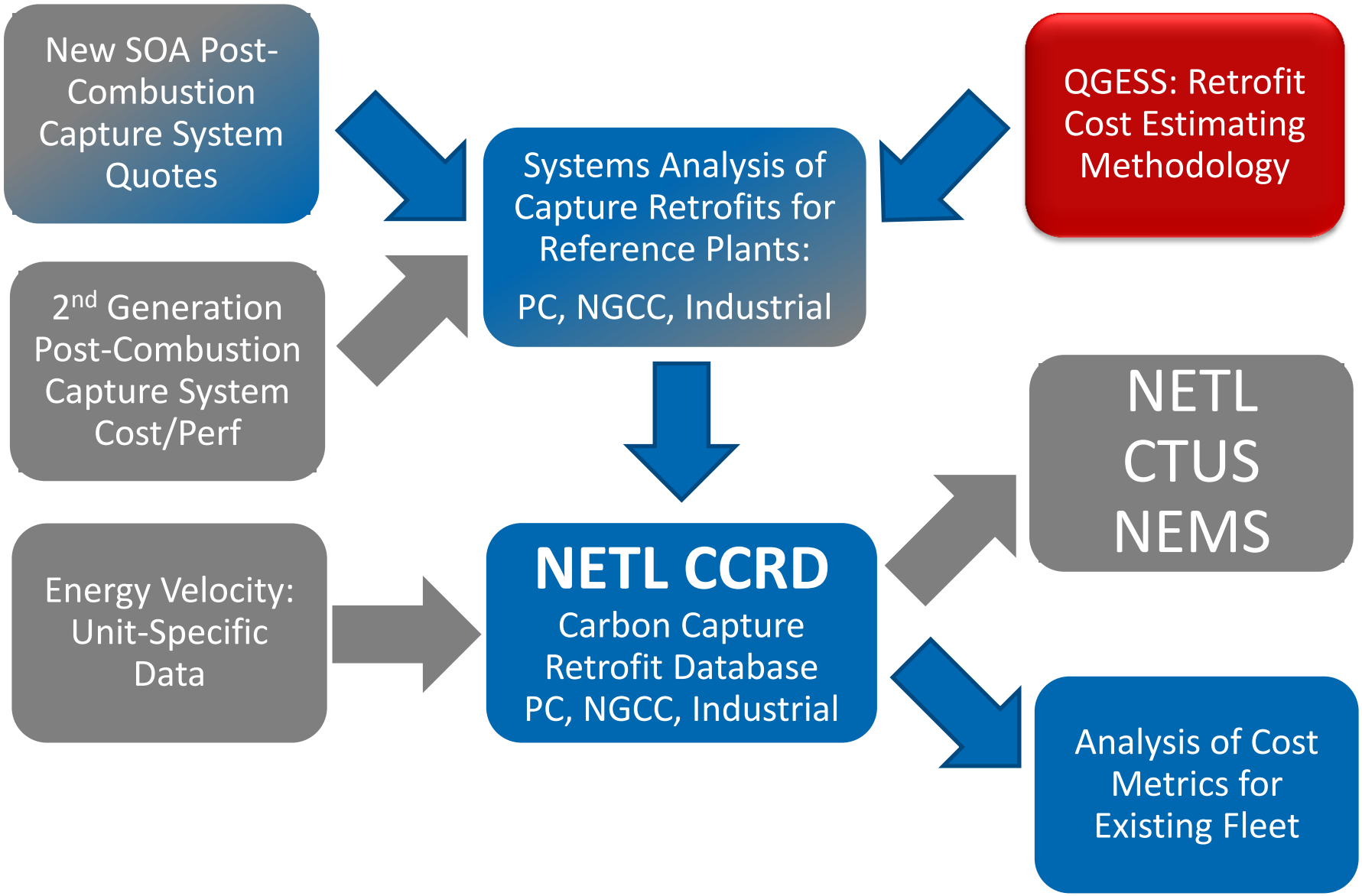


NETL CCRD

Industrial Sources



NETL Carbon Capture Retrofit Analyses



QGESS: Retrofit Cost Estimating Methodology

- **Capture equipment costs scaled from greenfield study costs**
- **Add equipment specific to retrofit:**
  - Eg. Steam turbine modifications and letdown turbine
- **Add retrofit difficulty factors to capital cost equipment subaccounts**
  - Equipment and material scope adjustments
    - Accounts for minor differences in equipment specifications, layout, duct routing, and items where additional complexity is likely to be encountered
    - Range from 1.00 to 1.25 within each subaccount
  - Labor productivity adjustments
    - Productivity losses associated with working on an existing operating plant site in potentially highly congested areas, and with modifications and tie in to existing equipment and/or systems
    - Range from 1.00 to 1.30 within each subaccount
  - **Typical impact of retrofit difficulty factor on total plant cost is +10%**

Posted on NETL QGESS page:
http://www.netl.doe.gov/energy-analyses/quality_guidelines.html