Utilizing systems analysis to inform carbon capture technology development

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NATIONAL ENERGY TECHNOLOGY LABORATORY

U.S. DEPARTMENT OF ENERGY

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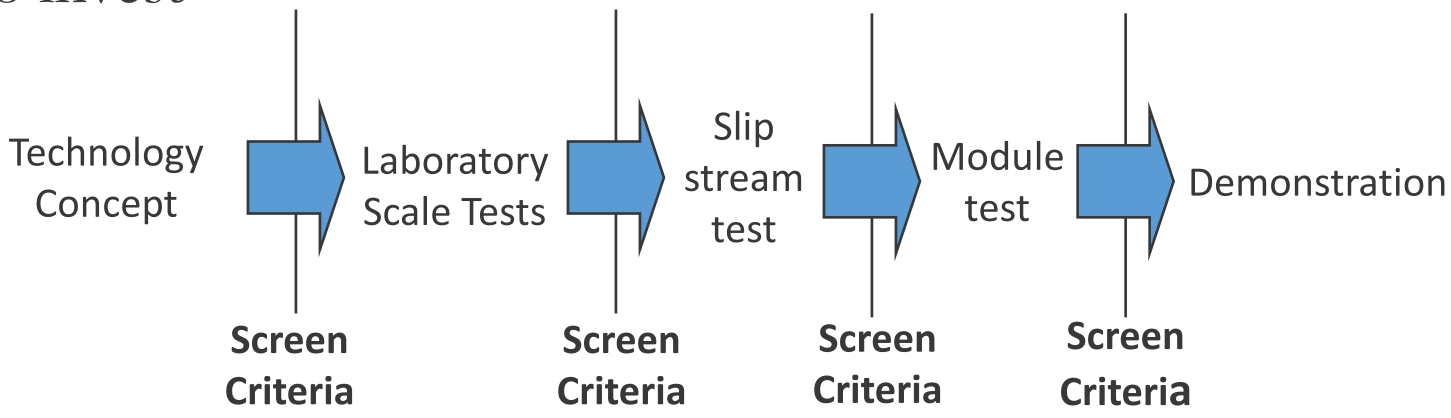
Illustrating the role of systems analysis

- **Boundaries for the systems analysis**
  - Technology Focus: Economic carbon management
  - Technology State: Pre-commercial
  - Application: Fossil electric power generation
- **Question for systems analysis**
  - What are the priority data needs
  - What scale to invest



Supporting technology development

Develop Reference Plant Incorporating Innovative Technology

- Review and assess innovative technology test data and concepts
- Model innovative technology
- Model integrated system using Baseline plant data and assumptions

Baseline Report – PC Capture Plant

- Bituminous coal
- 550 MW greenfield plant
- Midwestern U.S. ISO conditions
- Base load
- Amine-absorbent CO_2 capture
- Plant performance and cost

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Innovative Carbon Management Technology Studies Include

- PC post-combustion capture
- IGCC pre-combustion capture
- Chemical looping technologies
- Supercritical CO_2 cycles
- Solid oxide fuel cells

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Design and Operating Parameter Sensitivity Studies

- Determine effect of parameters on performance and cost

Results

- Inform basis for establishing technology goals
- Inform priorities for technology development

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Methodology to Assess Development Status of Post-Combustion CO_2 Separation Technologies*

- Provides metric that quantifies performance and cost gaps relative to a desired COE goal

* solvents, sorbents, adsorbents, membranes, phase change separation technologies

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Adapt Analysis for Alternative Applications

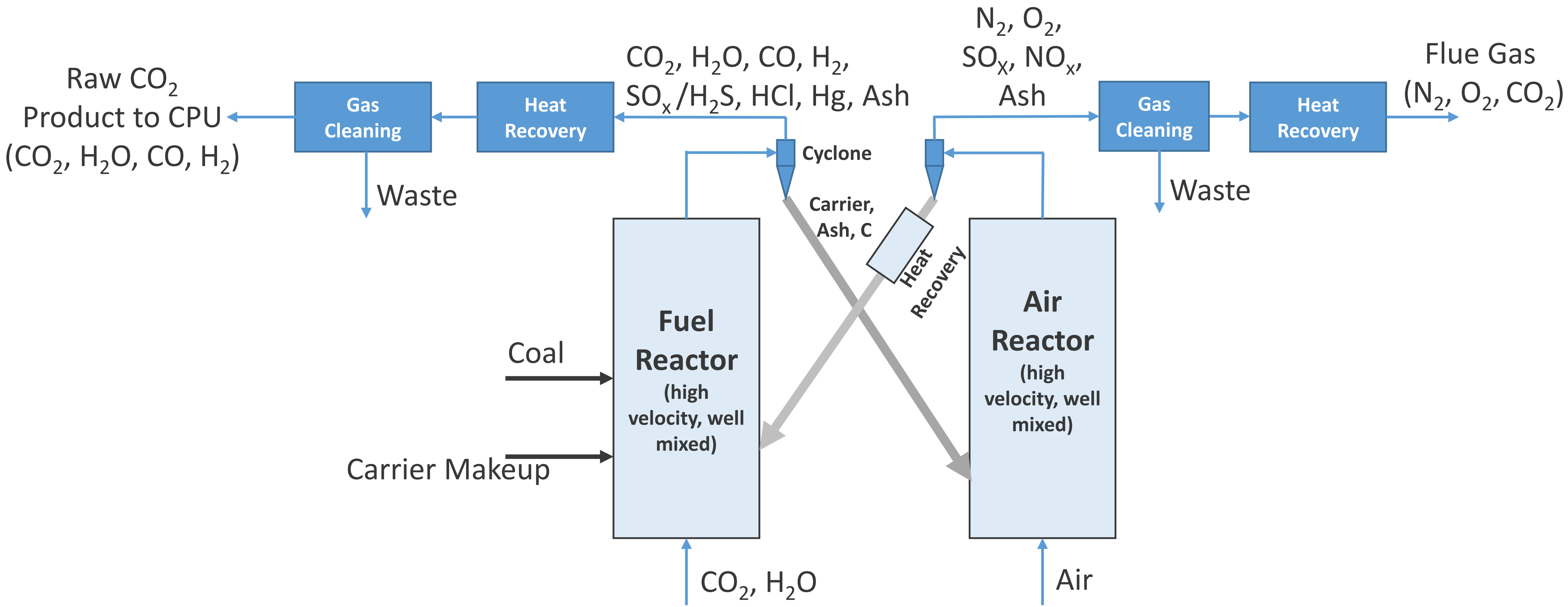
- New plant, retrofit
- Baseload, cyclic operation
- Plant scale
- Water constraints
- Alternative system boundaries

* solvents, sorbents, adsorbents, membranes, phase change separation technologies

Chemical Looping Combustion (CLC)

- **Chemical Looping Combustion Concepts**
  - Combustion, chemical looping with oxygen uncoupling (CLOU)
  - Candidate Oxygen carriers: Ni, Mn, Cu, Fe, Ca
  - Fuel options: coal, natural gas, syngas, biomass, petcoke
  - Atmospheric and pressurized
- **International studies: U.S., Sweden, Korea, Spain, China, UK, Canada**
- **Experimental testing**
  - Multiple international academic testing limited to bench scale up to 150 kWt
  - 3 MWt GE-Alstom CFB facility

Chemical Looping Combustion Circulating Fluid Bed Concept



Source: NETL

Utilizing systems analysis to inform CLC development priorities

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Chemical Looping Combustion (CLC) Reference Plant

- Review and assess CLC test data and concepts
- Model chemical looping process
- Model integrated system using Baseline plant data and assumptions

Baseline Report – PC Capture Plant

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- Performance and cost data base

CLC Reference Plant – Design and Operating Parameter Sensitivity Studies

- Oxygen carrier: conversion/circulation rate
- Oxygen carrier makeup
- Oxygen carrier makeup cost
- Fuel reactor carbon gasification conversion
- Component costs (e.g., char separator)
- Use of CO_2 purification unit (CPU)
- Fuel and air reactor temperatures
- Fuel and air reactor gas velocities
- Air reactor outlet gas oxygen content

Process Model Simulation and Sensitivity Case Study Results

- Inform basis for establishing technology goals
- Inform priorities for technology development

CLC CFB Reference Plant Performance and Cost

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Oxygen carrier type	Fe_2O_3	$CaSO_4$	BBR Case 12
Plant Capacity (MW)	550	550	550
Plant Efficiency (%, HHV)	32.8	31.9	28.4
Carbon Capture Efficiency (%)	95.8	85.9	90
CO_2 Product Purity (mole% CO_2)	99.0	99.95	100
Total Plant Cost ($/kW)	2,631	2,975	3,563
Cost of Electricity ($/kWh) first-year w/o T&S	126.4	117.5	137.3

CLC CFB Reference Plant Capital Cost

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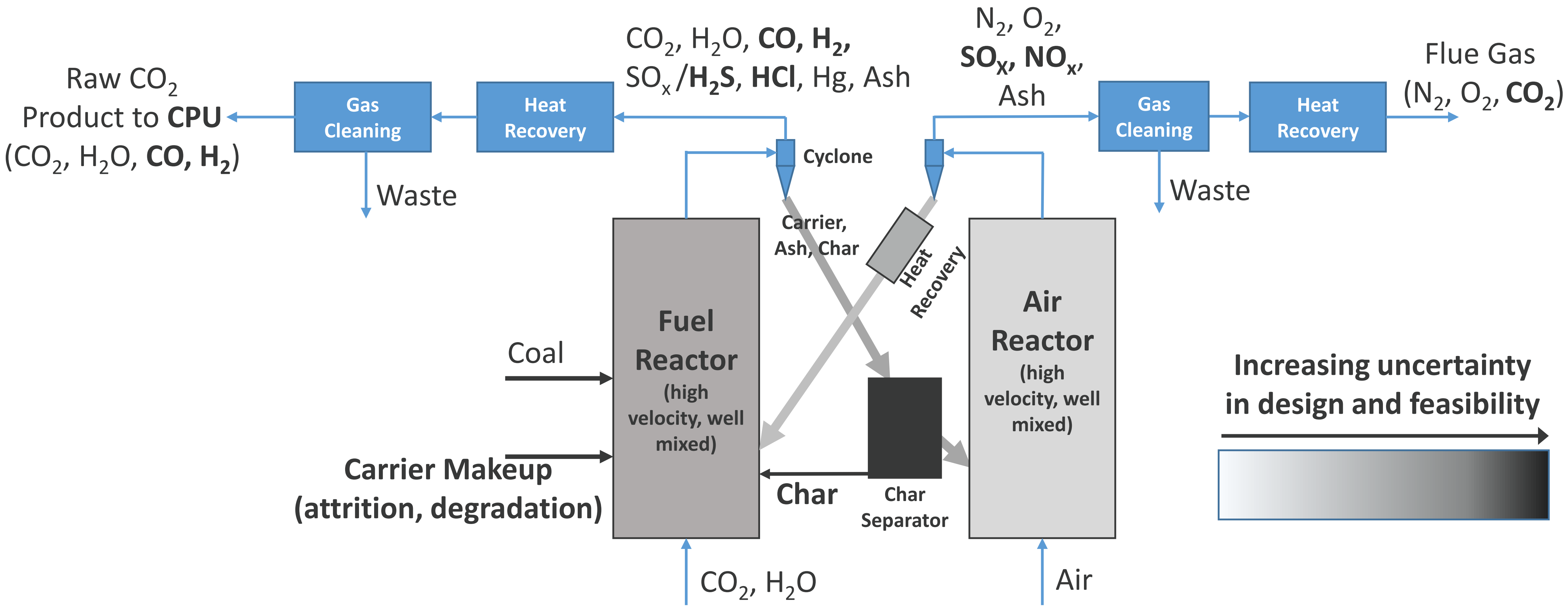
Oxygen carrier type	Fe_2O_3	$CaSO_4$	BBR Case 12
Plant Efficiency (%, HHV)	32.8	31.9	28.4
Total Plant Cost ($/kW)	2,631	2,975	3,563
CLC System Cost* (%)	25.3	23.4	
CPU Cost (%)	5.7	12.2	
Reducer Reactor Cost (% of CLC System Cost)	< 2	< 2	

* **Chemical Looping Combustion System Components**: reducer reactor, cyclones, piping; oxidizer reactor, cyclones, piping; char-carrier separator; HRSGs; FD/ID fans

Systems analysis messages for CFB concept development



Source: NETL

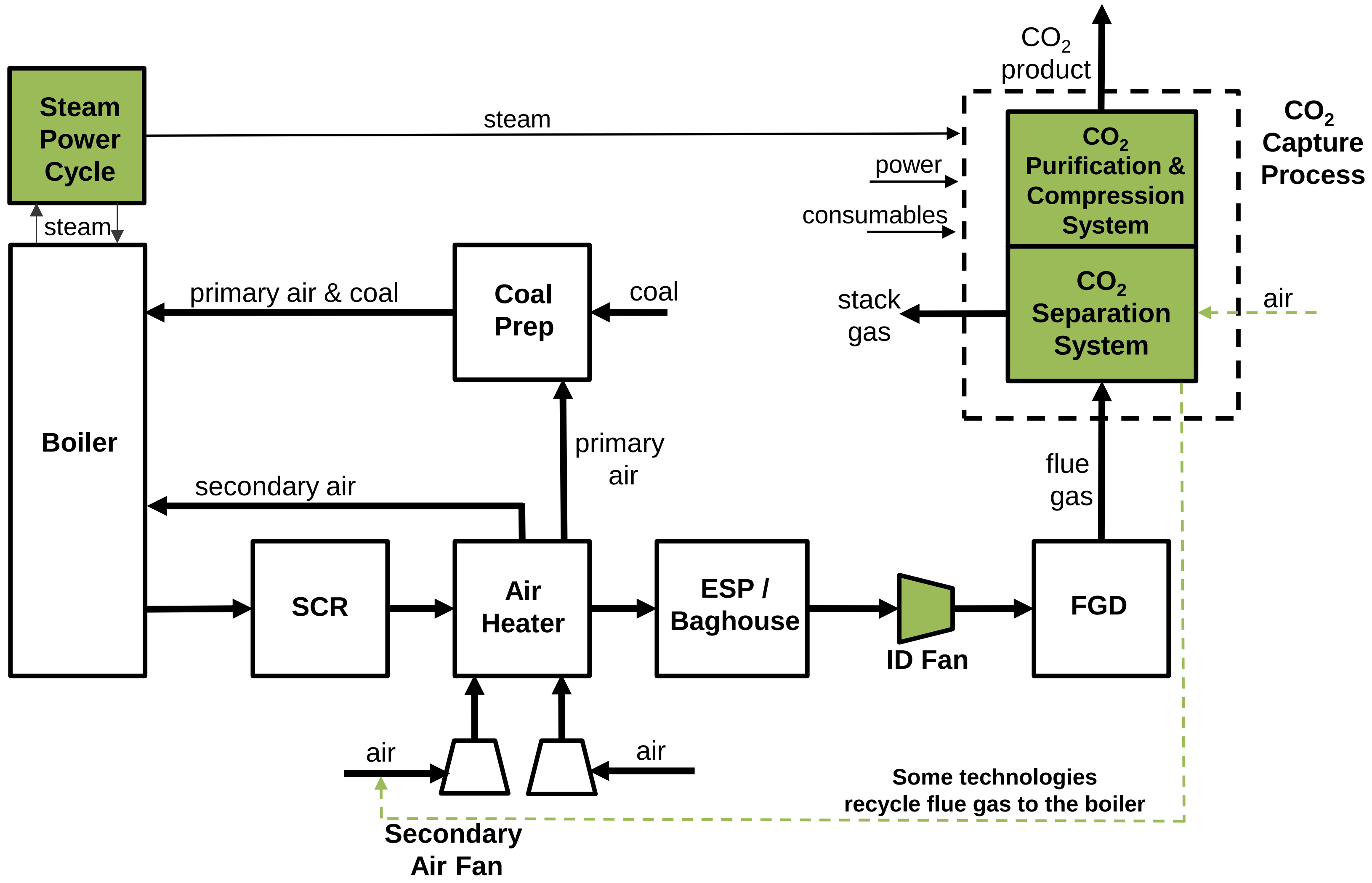
CLC Assessment Results Perspective

- The assessment is founded on the premise that the CLC power plant operability and availability are comparable to that of the conventional PC power plant and do not limit the technology's ultimate feasibility – experimental basis is required to support this premise
- The "reference-case" process simulations show the possibility that CLC could provide significant performance and cost advantages over conventional PC power plants using conventional, amine-based CO_2 capture technology
- The fuel reactor is the key developmental component in the CLC power plant
- Steady-state test data is required that is representative of the integrated CLC reactors, or of individual CLC reactors, suitable for scale-up to commercial capacity

CLC Assessment Results Perspective (cont'd)

- Oxygen carrier cost and life are key parameters for achieving a low cost system
- The cost of the fuel reactor will represent only a small portion of the CLC power plant total cost and its development focus should be on achieving acceptable operability and reliability, and not on compact vessel design
- Carrier/char separation is required for circulating bed concepts: separation performance, reliable and within cost constraints
- The CO_2 specification is an important parameter and affects system cost
- The analyses provide understanding of risk: the combined effects of a few of the uncertain sensitivity parameters can result in the technology not being competitive; balance-of-plant equipment (e.g., heat recovery, gas cleaning) specifications, conceptual designs, and cost estimates are required

Representation of Post-Combustion Capture



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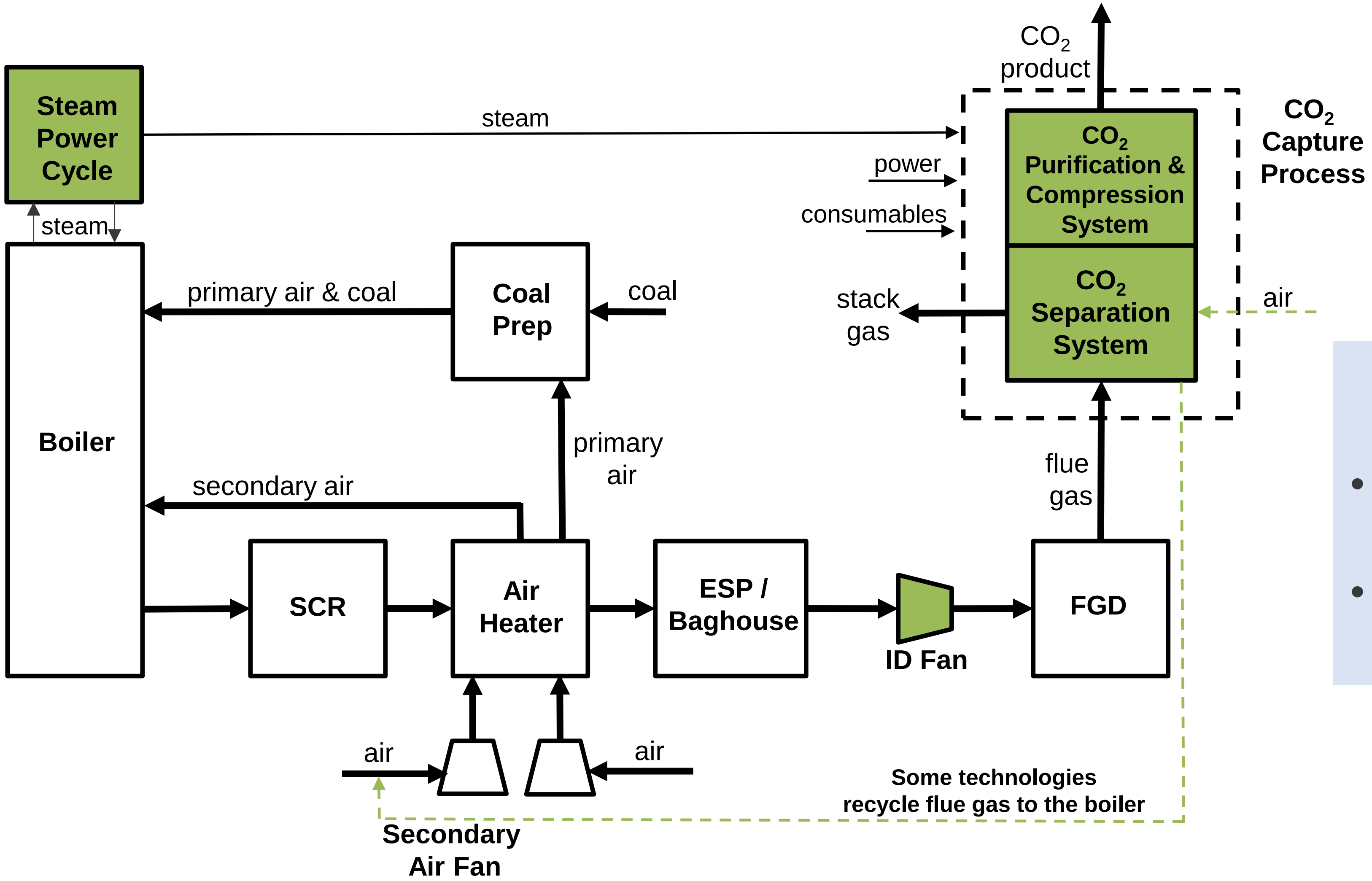

Membrane Option

- Eliminates interface with steam cycle
- No circulating medium

Utilizing systems analysis to inform membrane development priorities

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Post-Combustion Membrane Capture Reference Plant

- Review and assess membrane test data and concepts
- Model membrane process
- Model integrated system using Baseline plant data and assumptions

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Membrane Design and Operating Parameter Sensitivity Studies

- CO_2 permeance
- Gas constituents selectivity (CO_2, N_2, O_2, H_2O, SO_2)
- Membrane thickness
- Membrane module design and performance (capacity, pressure drop, mass transfer)
- Membrane flow configuration (counter-current, cross-flow, co-current)
- Process configuration (flue gas pressure, single flue gas membrane, staged)
- Membrane cost and life

Process Model Simulation and Sensitivity Case Study Results

- Inform basis for establishing technology goals
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Membrane Guidance Illustrations

- Membrane-based CO_2 capture has the potential to provide performance and cost benefits over conventional, solvent-based technologies if specific membrane characteristics can be achieved
- Water vapor must be considered in membrane process modeling efforts due to its high permeability and tendency to be condensed between process stages – typically not included as a gas stream test constituent
- For a low-pressure, single flue gas membrane configuration, research focused on advanced, high-selectivity (>50 to 200) membranes is not a priority, since there is limited benefit in COE reduction
- Membrane-based CO_2 capture processes that apply flue gas pressurization are not a priority, since there is limited cost advantage over low-pressure processes
- All membrane-based CO_2 capture processes will require raw CO_2-stream purification (use of a CPU rather than conventional CO_2 compression) to meet CO_2 product gas purity specifications, with the O_2 specification being the most stringent

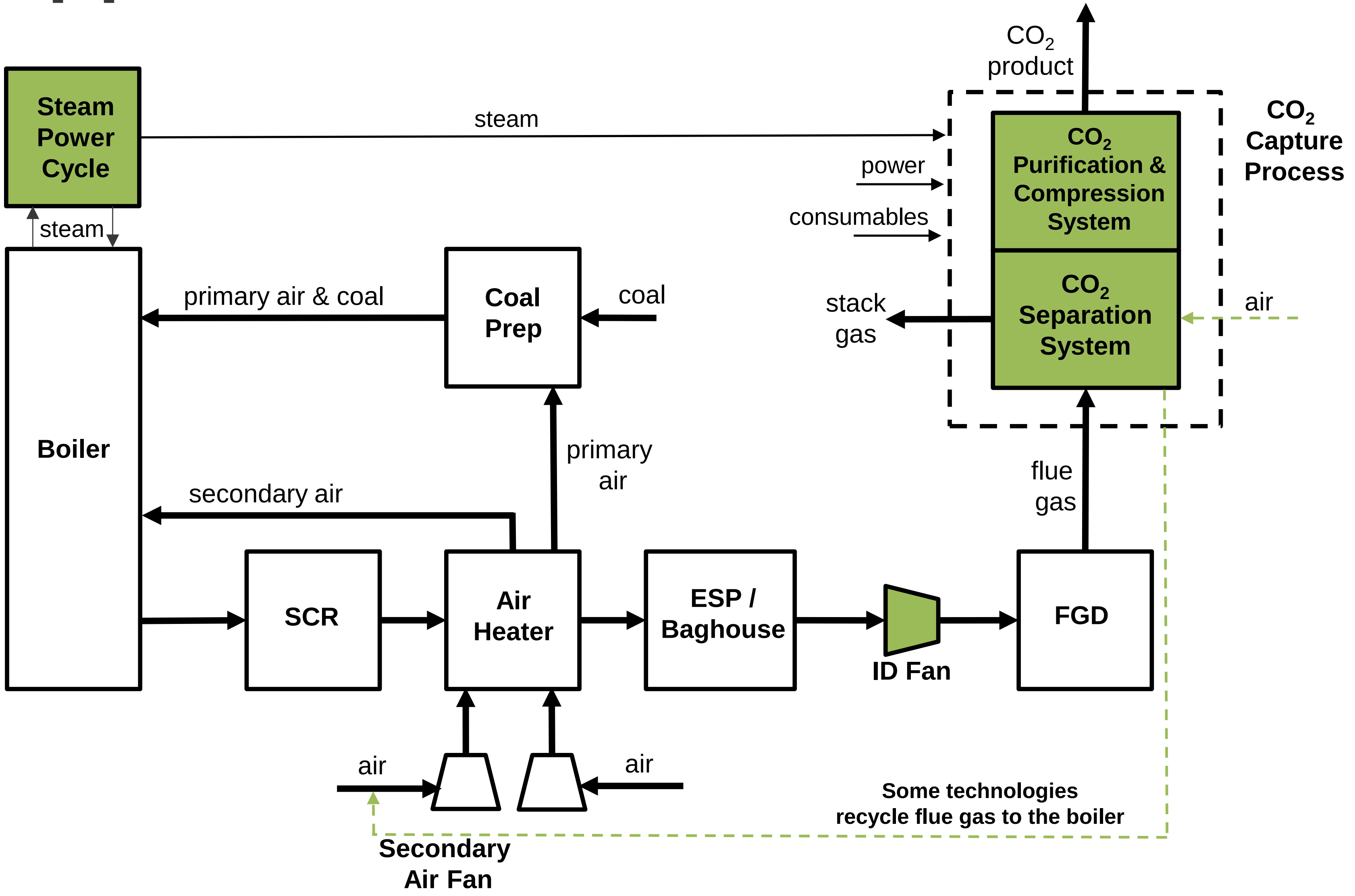
Assess the status of technology development with respect to performance and cost metrics*

Objectives:

- Identify the minimal requisite parameters that should be measured by a technology developer through laboratory investigations to effectively support post-combustion CO_2 capture system studies
  - ✓Applicable for systems analysis: pre-screening, screening, commercial techno-economic analysis (TEA)
- Create a tool to test new experimental results and updated equipment performance and cost estimates
  - ✓Applicable for post-combustion capture technologies: solvents, sorbents, adsorbents, membranes, phase change

* T. Fout, R. Stevens, D. Miller, R. Newby, D. Keairns, M. Matuszewski, D. Bhattacharyya; Guidelines for parameter measurements in laboratory-scale post-combustion research efforts, Proceedings of the 2016 NETL CO_2 Capture Technology Meeting, August 8, 2016 (www.netl.doe.gov/events/conference-proceedings)

Approach



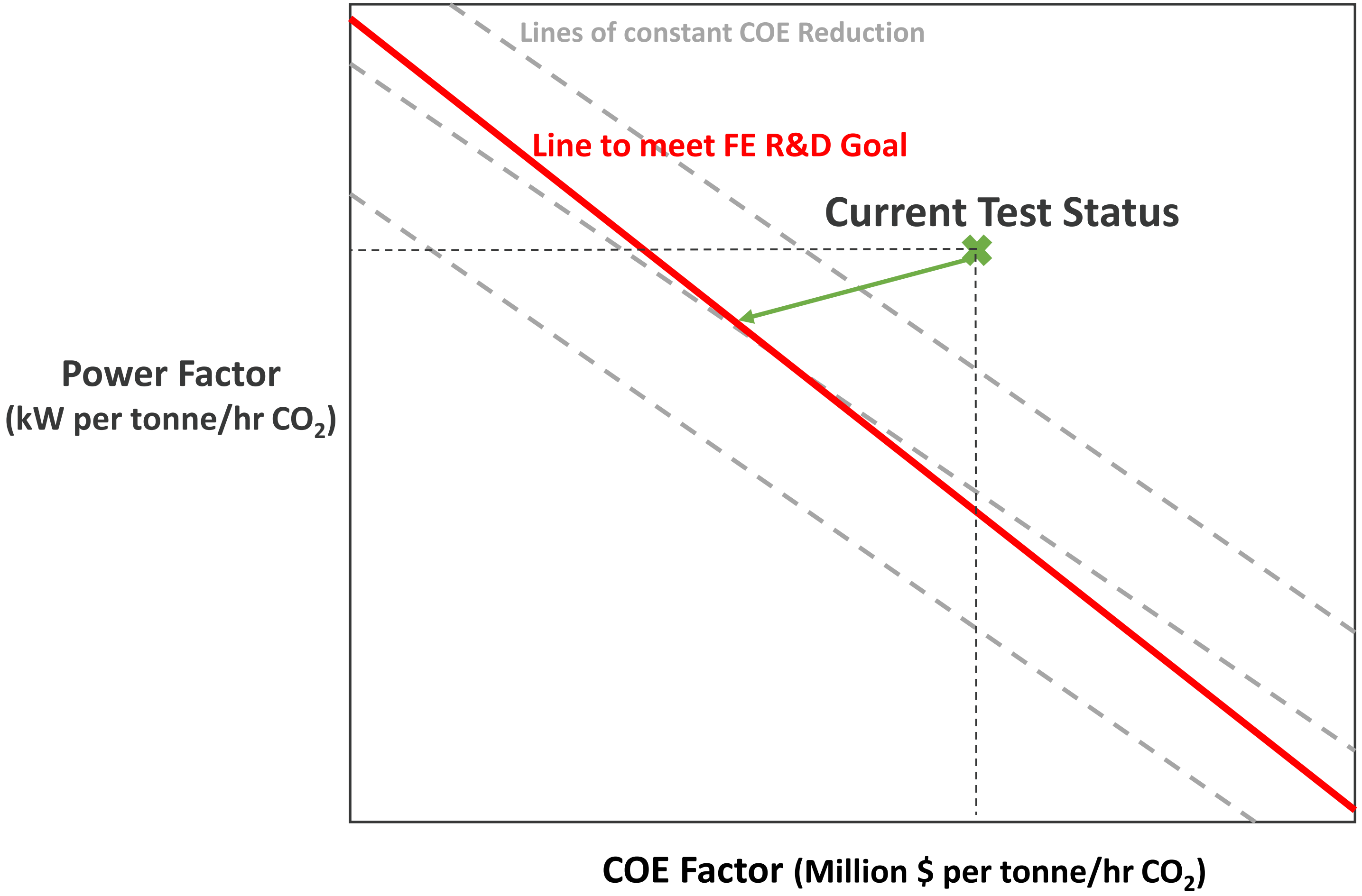
Develop two parameters that characterize the capture system economic potential

- Power consumption impact
- COE impact

Characteristic Parameters

- **Power Factor: Total CO_2 capture process power-impact on reference plant/(tonne/hr CO_2), dependent on:**
    1. CO_2 separation system auxiliary power
    2. CO_2 separation system heating duty and heating temperature
    3. CO_2 separation system cooling water duty
    4. Raw CO_2 gas composition and pressure
- **COE Factor: Total CO_2 capture process cost-impact on reference plant/(tonne/hr CO_2), dependent on:**
    1. CO_2 separation system materials consumption rates and materials replacement prices
    2. CO_2 separation system capital investment for process equipment

Methodology Plot



The acceptable Power Factor and COE Factor ranges can be translated into the range of test parameter goals for the technology

Concluding Message

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- **Important tasks for development of innovative carbon management technology development include:**
  - Understand the application system boundaries, needs, and constraints
  - Utilize systems analysis to inform the priority process design, operation, and cost parameters that affect system performance and cost
  - Focus development on obtaining data to address the priority parameters
  - Implement testing at the appropriate scale to obtain relevant data
- **An approach and methodology has been developed and implemented to guide development of innovative carbon management technology**