Systems Analysis: Process Assumptions and Data Gaps

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NETL CO_2 Capture Technology Project Review Meeting
Pittsburgh, PA, August 21-25, 2017

U.S. DEPARTMENT OF ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY

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KeyLogic Systems, Inc.'s contributions to this work were funded by the National Energy Technology Laboratory under the Mission Execution and Strategic Analysis contract (DE-FE0025912) for support services.

Total Eclipse of the Sun

Presentation Objectives

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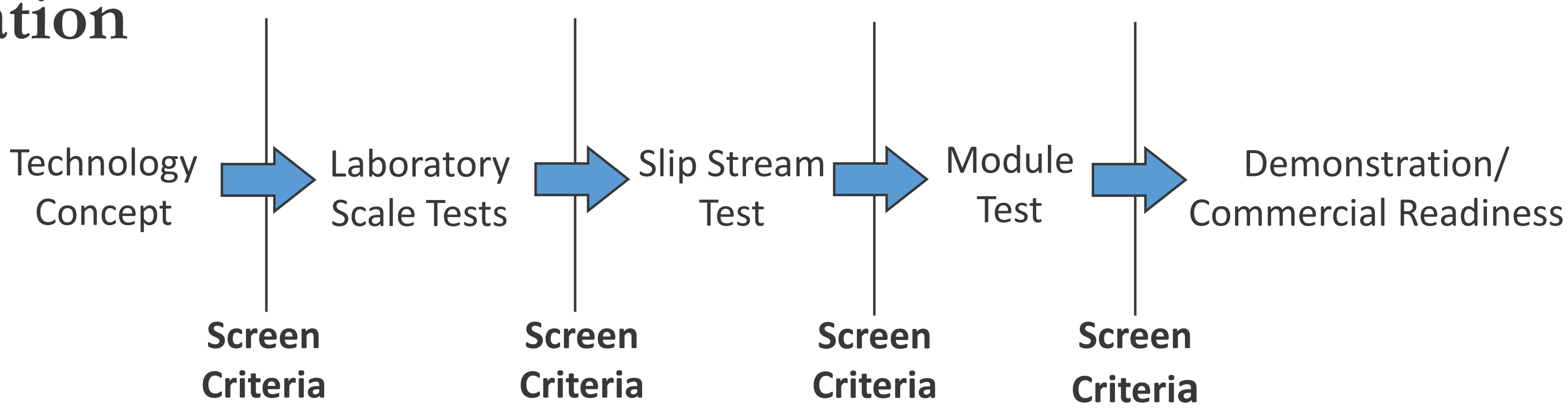
- Typical technology development pathways includes transitions from discovery, to development, to system testing, with the ultimate goal of commercialization



- Techno-economic analysis (TEA) is a key tool for aiding in screening of technologies to progress through R&D stages
- Utilizing TEA to inform technology development
- Common TEA pitfalls

Concluding Messages

- **The examples presented consider specific instances that NETL has observed in our systems analysis, but the broader message is that:**
  - Plant integration points require sufficient characterization early in the development process
    - Considerations, such as the quality of heat recovered within the plant, or the impacts on balance of plant equipment performance, may not be critical items for the capture system itself, but will play a part in overall systems analysis results
  - The basis for system costs should be consistent with the reference plant, and should be grounded in vendor/EPC firm methodologies where possible
    - The relative importance and impact of individual costs (e.g., reagent cost, developmental equipment cost) should be understood

Supporting Technology Development

Develop Reference Plant Incorporating Advanced Post-combustion Technology

- Review and assess advanced technology test data and concepts
- Model advanced technology
- Model integrated system using Baseline Report plant data and assumptions
- Follow QGESS documents

Baseline Report – PC Capture Plant[1]

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

[1] Cost and Performance Baseline for Fossil Energy Plants, Volume 1a: Bituminous Coal (PC) and Natural Gas to Electricity

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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 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

Example 1 - Utilizing systems analysis to inform membrane development priorities

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

Baseline Report – PC Capture Plant

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

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
- Inform priorities for technology development

Example 1 - Membrane Guidance Illustrations

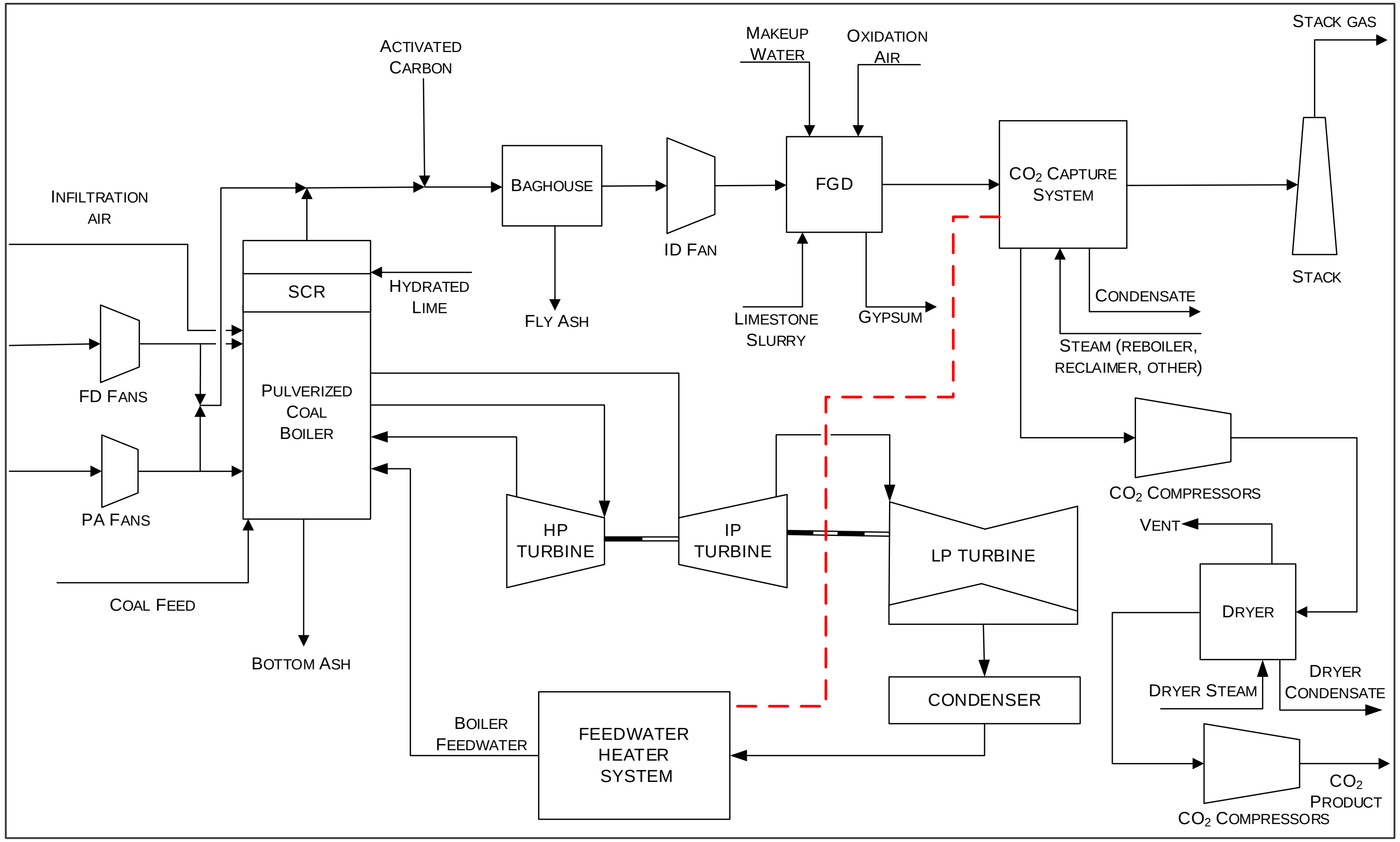
- Membrane-based CO_2 capture has the potential to provide performance and cost benefits over state-of-the-art, solvent-based technologies if specific membrane characteristics can be achieved
- Water vapor must be considered in membrane process modeling efforts due to its high permeability and tendency 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
- All membrane-based CO_2 capture processes will require a CO_2 purification unit (CPU) to meet CO_2 product gas purity specifications, with the O_2 specification being the most stringent

Systems Analysis – Potential Pitfalls

- **NETL systems analysis stages:**
  - At an early pre-screening stage to project performance and inform development (gaps/goals)
  - At a lab-scale/pilot screening stage to assess critical data and re-confirm/update performance projections
  - At a commercial scale with techno-economic analysis (TEA) to characterize current state-of-the-art and provide a baseline for comparison
- **The following examples highlight process and cost considerations that are often overlooked at early stages of development, and that often require significant assumptions or sensitivity analysis to fully characterize**

Example 2 – Heat Integration

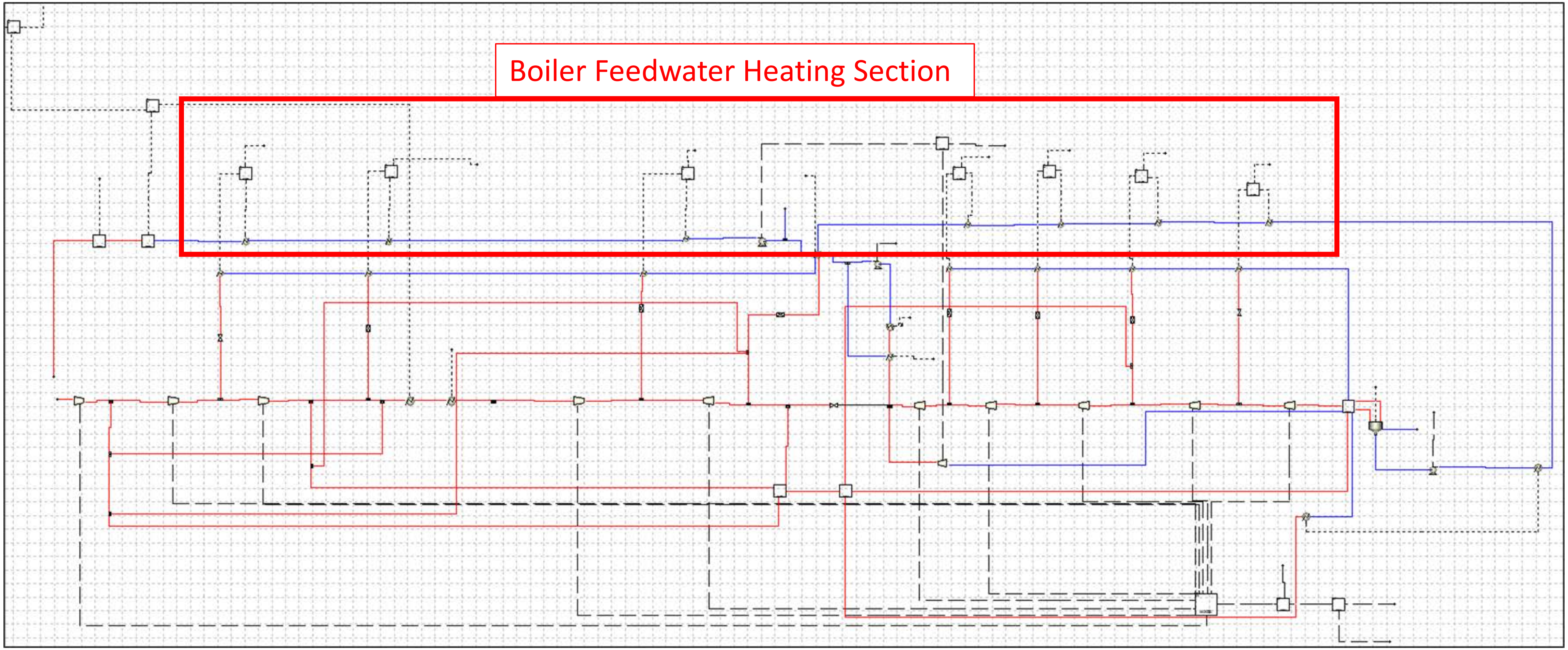
- **Variation in capture concepts (solvent, sorbent, membrane) necessitate varying system configurations, which can present opportunity for heat recovery within the PC plant**
  - Demand for flue gas compression to provide driving force for CO_2 separation imparts auxiliary load, but can provide heat for recovery



Example 2 – Heat Integration

- **In this scenario, the amount and quality of heat available for recovery is unknown**
  - Flue gas compression is required and the discharge pressure to facilitate CO_2 capture has been defined by lab testing; the auxiliary load of the total system has been approximated, but the number of compression stages and more importantly, the extent of intercooling performed in the flue gas compressor, is not defined
  - Overall plant efficiency is reported
- **From a systems analysis perspective, the system is under specified and the potential number of solutions is large**
- **Rather than fill in all the data gaps with specific assumptions, determine performance, and compare with that reported, our first step is to identify the level of heat recovery required to obtain the stated plant efficiency**

Example 2 – Heat Integration



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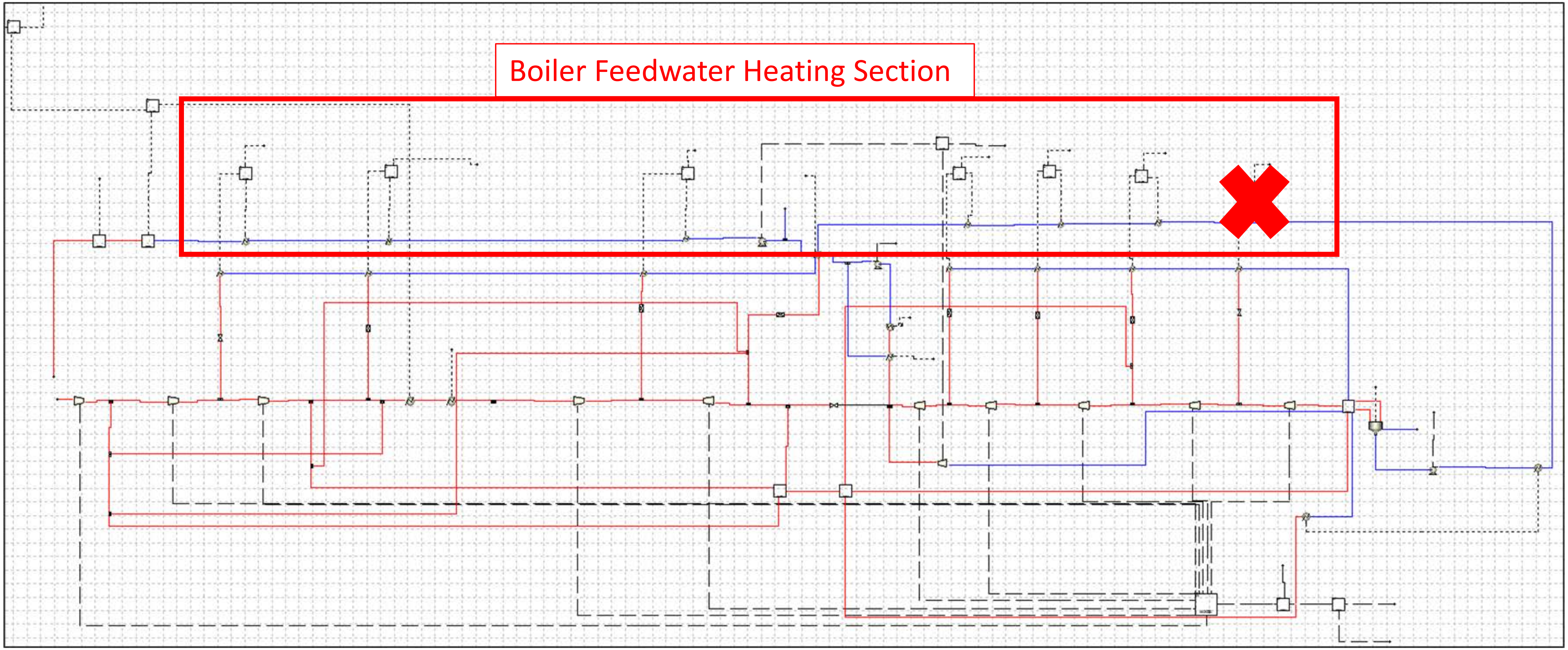

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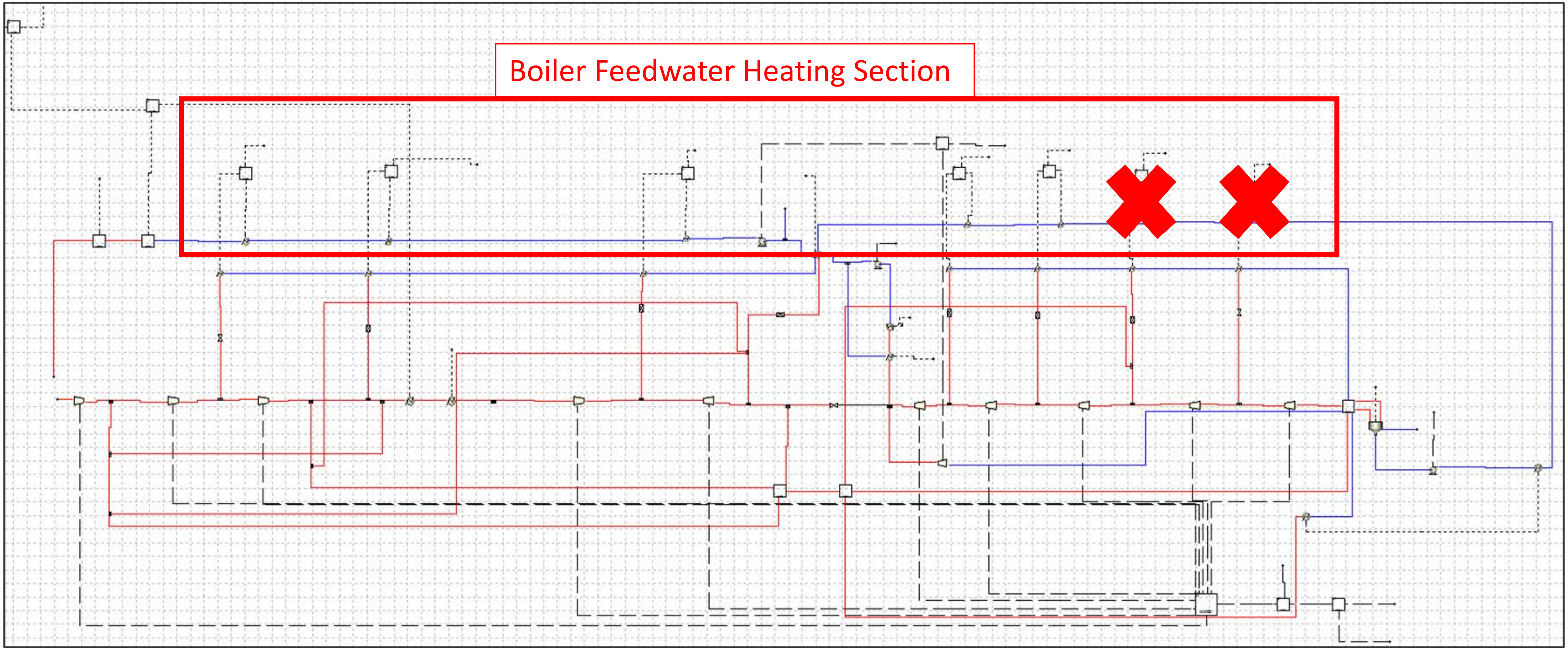

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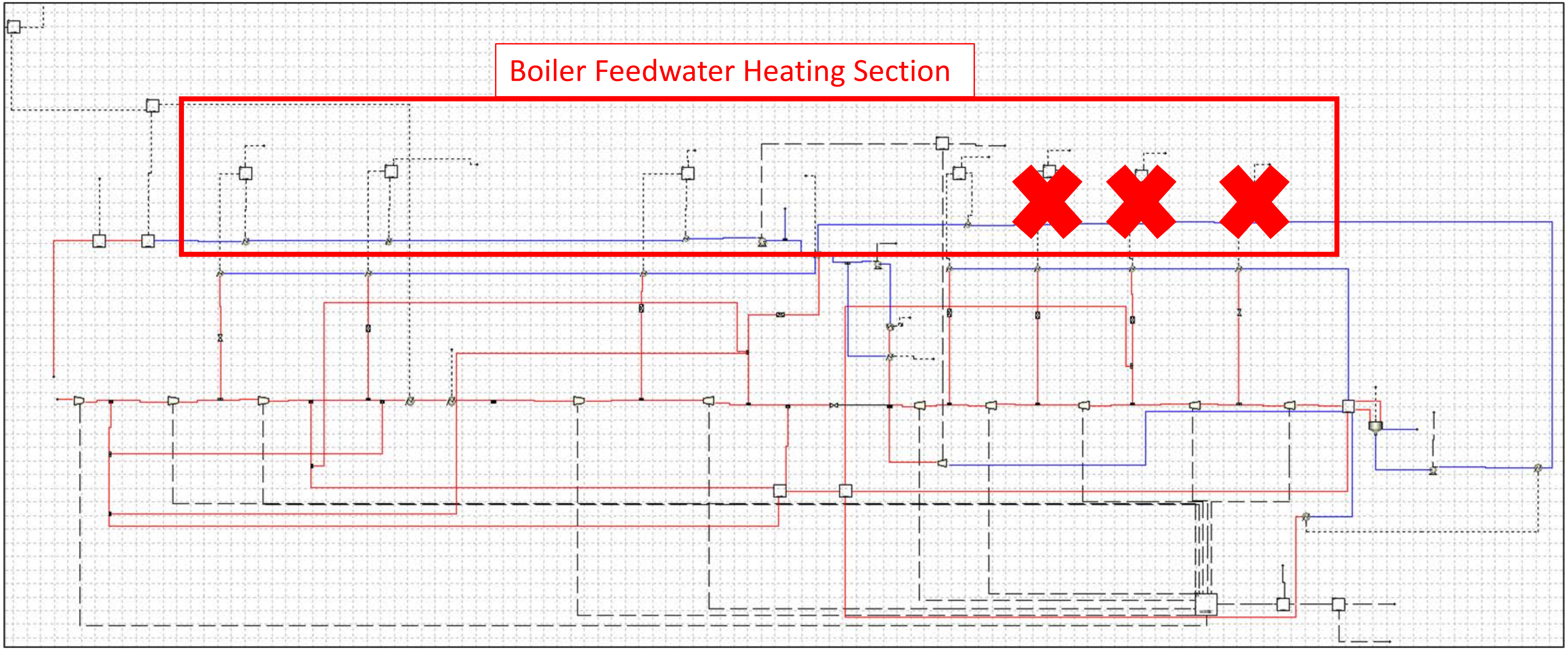

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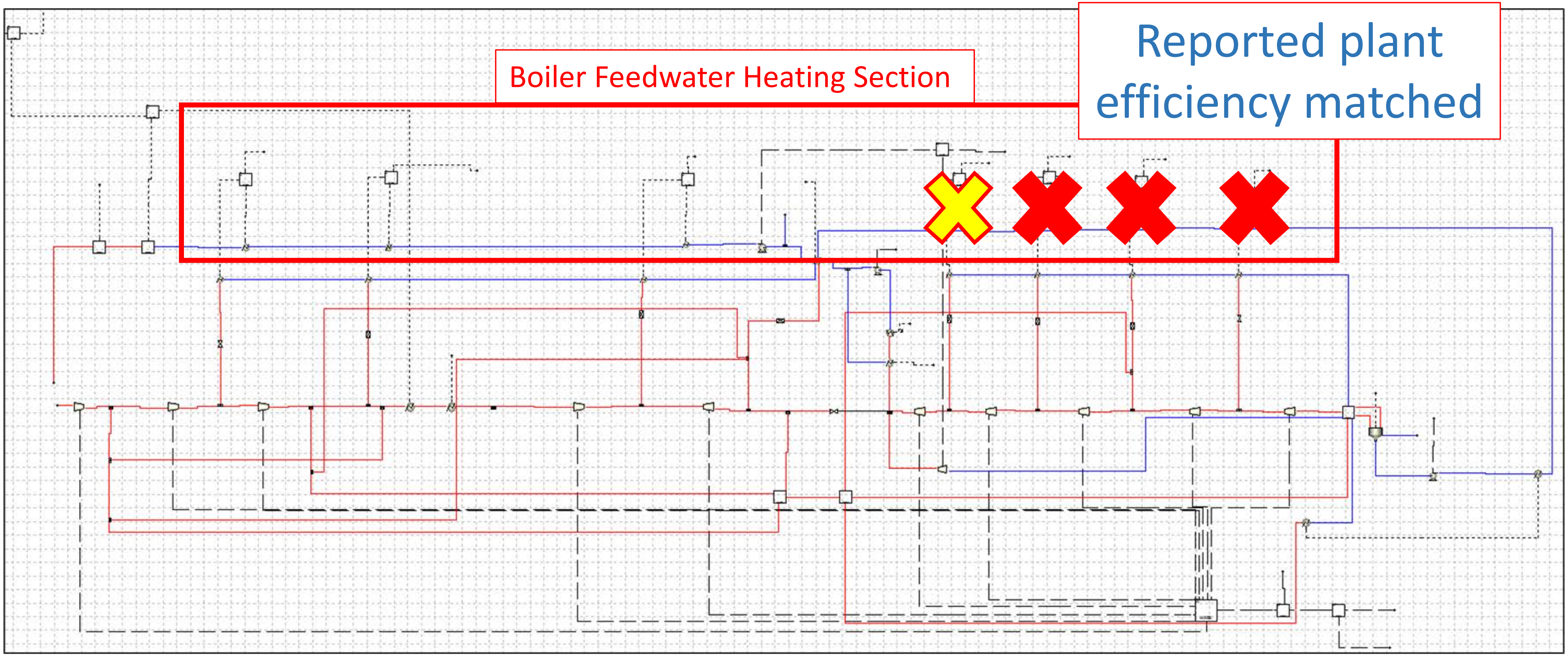


Example 2 – Heat Integration

- **How much heat is required to be recovered such that the plant efficiency is matched?**
  - What are the temperature(s) of the boiler feed water heaters that must be satisfied with heat recovery, rather than steam extraction?
- **Once determined, a series of sensitivities examining compression of the flue gas are conducted**
  - If considering no compressor intercooling, how much heat is available, and at what quality? Does this satisfy our requirements to match plant efficiency?
    - Applying assumptions for approach temperature, pressure drop, etc.
  - Auxiliary load – does the identified amount of intercooling, and the resulting power requirement for the compressor, match the reported auxiliary load of the system/compressor?
    - In cases where a total capture system auxiliary load is reported (e.g., not itemized by equipment), assessment of whether the compressor auxiliary load is reasonable is largely based on engineering judgement

Example 2 – Heat Integration

- **If a match between compressor auxiliary load, heat recovery, and plant efficiency can be projected, then the system concept is considered viable**
- **However, if the compressor auxiliary load is higher than capture system's reported auxiliary, while meeting heat recovery and plant efficiency benchmarks, then the system concept is not viable for the plant efficiency reported and should be revised**
- **In the second case, the scenarios evaluated are used to inform performance targets**
  - For example, if a specific amount of heat is available for recovery at a specific quality, then the plant efficiency can be projected

Example 3 – Capital and O&M Cost

- **The Bituminous Baseline reference cases capital cost estimates are constructed by an EPC firm, and are consistent with AACE Class 4 cost estimates (i.e., a feasibility study) with an uncertainty band of -15%/+30%**
  - Up to 15% of project engineering completed
- **The intent is to represent the cost for the next commercial offering of the technology**
  - Costs reported for plants without capture represent nth-of-a-kind (NOAK)
  - Costs reported for plants with capture use the same estimation methodology as non-capture, but do not necessarily reflect the cost premiums associated with initial, complex integration of new technology in commercial application
- **When assessing a developing technology's potential, as compared to the current state-of-the-art (SOA), a consistent cost estimation basis is key**

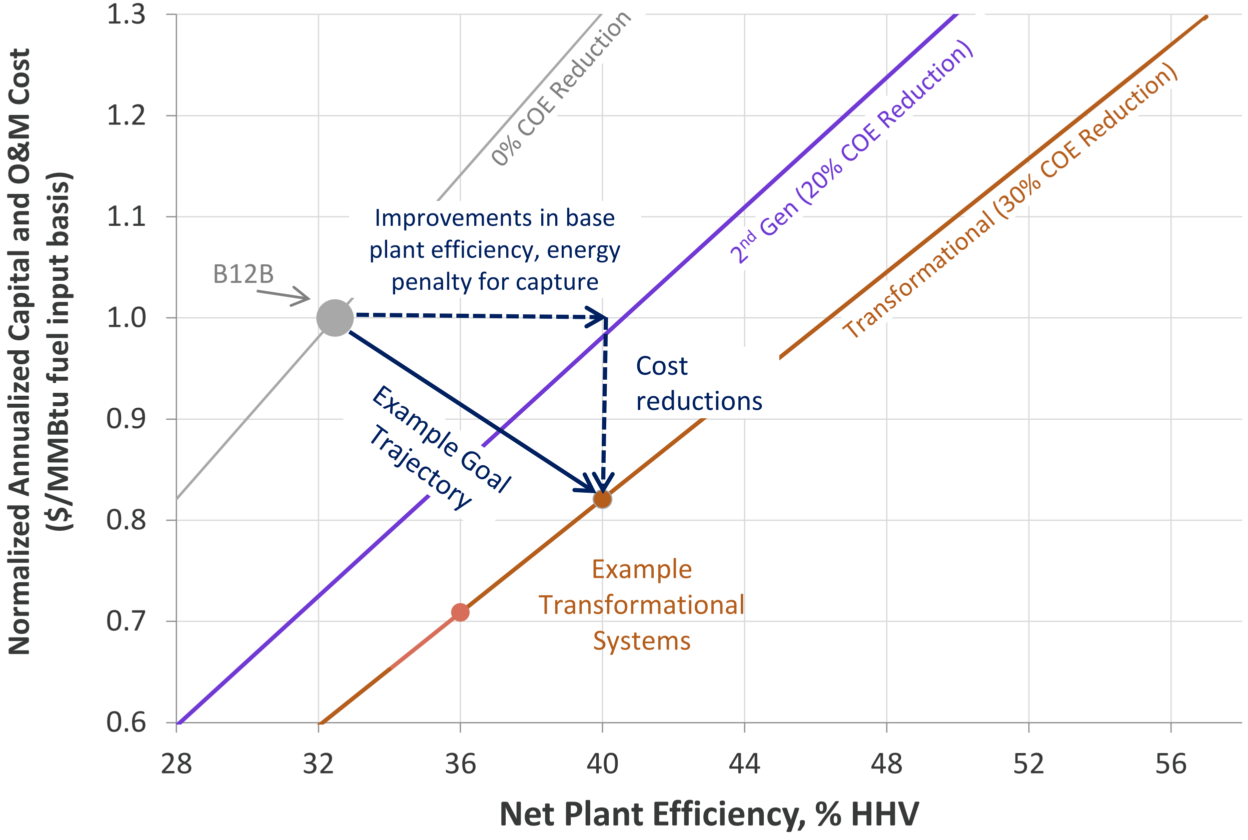
AACE International. *Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries; TCM Framework 7.3 – Cost Estimating and Budgeting.* s.l. : AACE International, 2005. Recommended Practice No. 18R-97.

Example 3 – Capital and O&M Cost

- **At the lab-scale/pilot-scale level of development estimation of a technology's capital and operating costs often lack sufficient detail due to:**
  - Level of system development
  - Developmental equipment required for the capture system concept
  - Developmental material required to handle operating conditions
  - The cost estimation method/reference employed
  - Other secondary cost assumptions (labor costs, contingencies, financing, etc.)
  - Data gaps in solvent degradation mechanisms over extended operational periods

Example 3 – Capital and O&M Cost

- **Multiple pathways to assessing capital cost:**
  - Versus the SOA:
    - Use the reference SOA capital cost ($/kW) to isolate the impact of changes in plant efficiency on COE
    - Are claims of advancement based solely on cost reduction, efficiency gain, or a combination?
  - Versus program goals:
    - To achieve a target COE result, vary capture system capital cost and determine the percent reduction from the SOA reference
    - Determine the necessary percent reduction, and assess if feasible given the stated technology advances (e.g., solvent properties reduce circulation rate, and thus, equipment sizing)

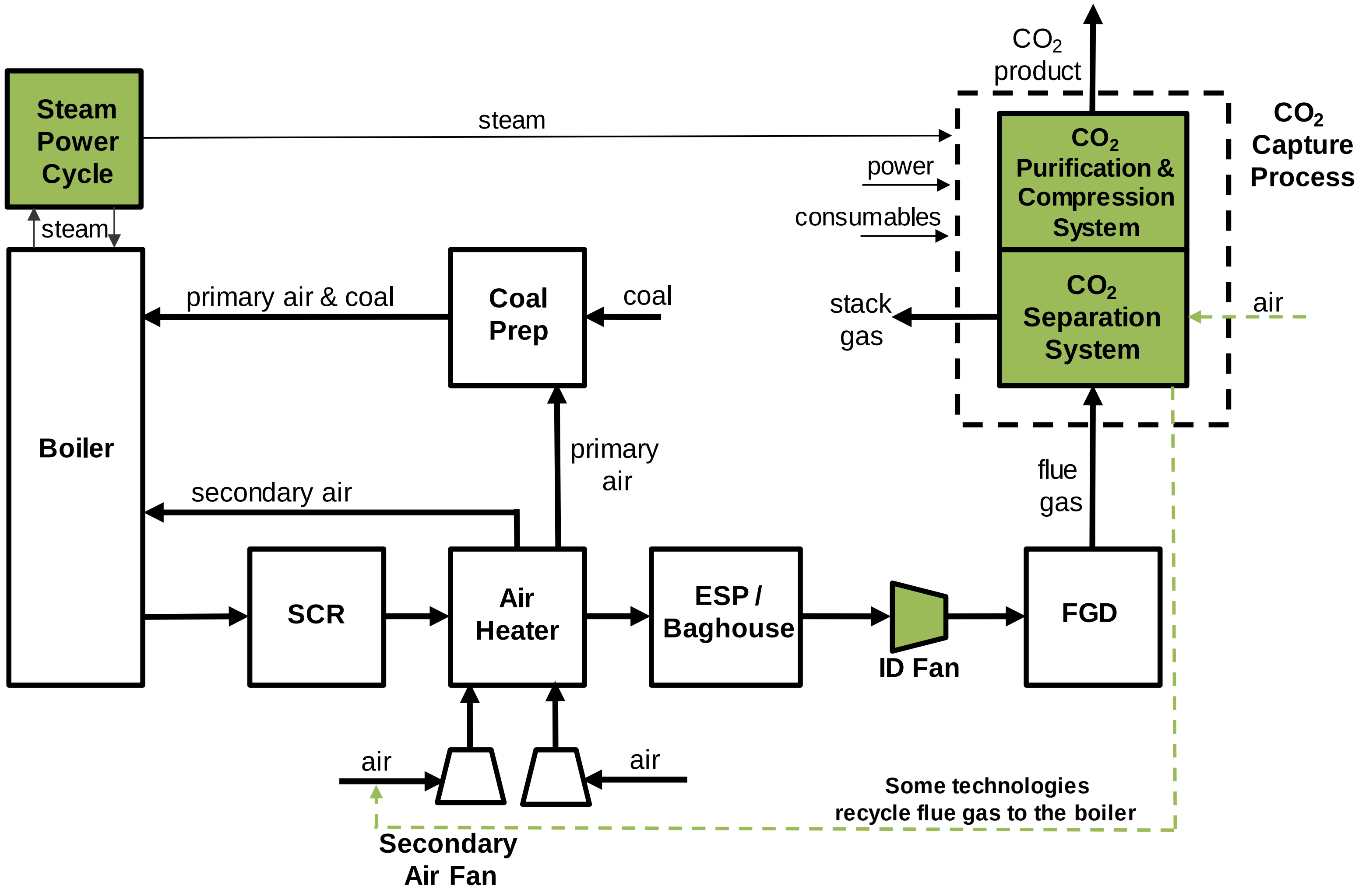


Example 3 – Capital and O&M Cost

- **Adjust equipment costs based on a reference technology**
  - Requires method to estimate equipment cost
  - Calibrate against vendor quotes when possible
- **Utilize available commercial cost estimating software**
  - Verify that cost scope is consistent with the reference estimate
  - Adjust for equipment size limitations
- **Determine solvent cost basis and relative impact**
  - Limited basis at early stages of development
  - For conditions in the Fossil Energy Baselines, overall costs are insensitive to changes in solvent cost
  - Solvent cost reduction curves can be employed, accounting for manufacturing advances, level of deployment, and other factors

Example 4 – Plant Integration/Cost Impact

- Capture system concepts that consider recycle of CO_2-depleted flue gas to the boiler as combustion air offer another example of process considerations that may be overlooked
  - Represent the combination of plant integration and capital cost considerations



Example 4 – Plant Integration/Cost Impact

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- **For technologies considering recycle of flue gas to the boiler, the performance and cost impacts of increased CO_2 concentration and decreased O_2 concentration on the separation medium are well characterized and understood**
- **However, impacts on the performance of the boiler are often not considered or assumed to be negligible, particularly at the lab/pilot scale level of development**
  - Similarly, cost impacts, whether related to additional capital to compensate for operational issues, or simply due to derate, are also overlooked

Concluding Message

- **The examples presented consider specific instances that NETL has observed in our systems analysis, but the broader message is that:**
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Key references

- **NETL Quality Guidelines for Energy System Studies**
  - https://www.netl.doe.gov/research/energy-analysis/quality-guidelines
- **NETL Baseline Studies for Fossil Energy Plants**
  - https://www.netl.doe.gov/research/energy-analysis/baseline-studies

Questions?

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