Overview of CCS plant flexibility modelling

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Workshop on operating flexibility of power plants with CCS
Imperial College London
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Outline

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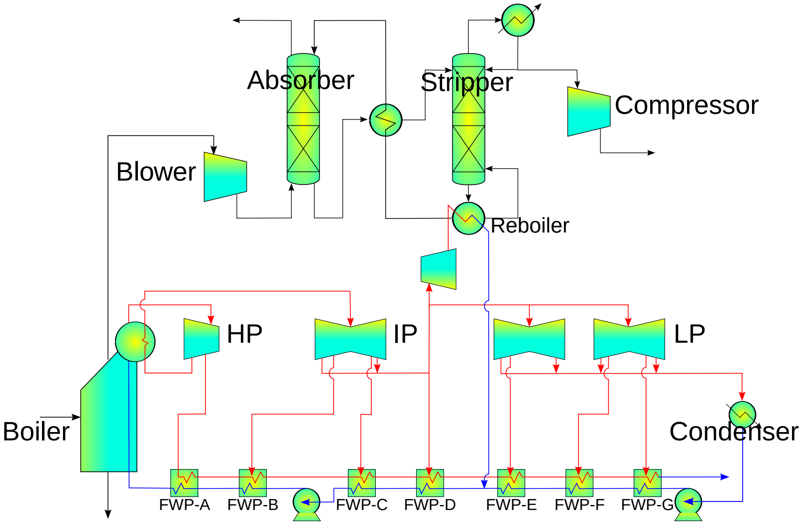
Novel process concept to be evaluated.



Cost of CO_2 avoided oft-used performance metric.

Cost of CO_2 avoided

$$CCA = \frac{(CoE)_{cap} - (CoE)_{ref}}{(CEI)_{ref} - (CEI)_{cap}}$$

where *Cost of Electricity* can be expressed as:

$$CoE = \frac{\left(\begin{array}{c}\text{annualized}\\ \text{capital cost}\end{array}\right) + FOM}{\text{annual energy output}} + VOM_e + \left(\begin{array}{c}\text{fuel cost per}\\ \text{unit energy}\end{array}\right)$$

- Need a method to predict unit utilization:
  - *annual energy output*
  - *fuel cost per unit energy*
  - CO_2 *emissions intensity*
- Need to assess benefit of operating flexibility

Process modelling + electricity system simulation.

Three-step process:

1. Modelling and simulation of generating unit with CCS
2. Simulation of electricity system
3. Analysis of results

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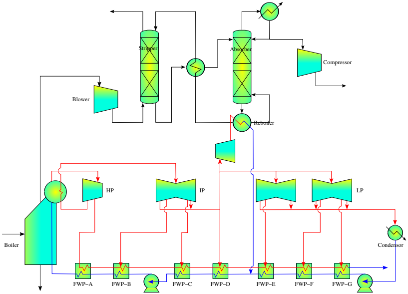
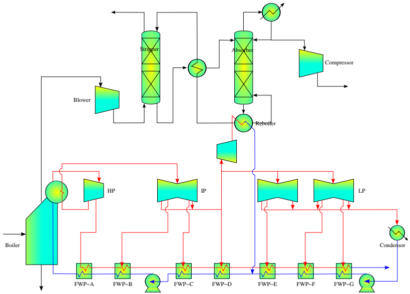
Develop process model of generating unit with CCS.



Example workflow:

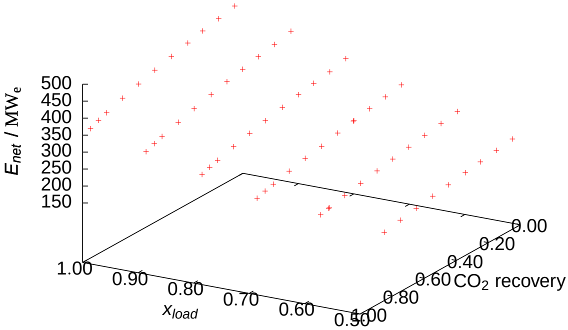
1. develop model of boiler and steam cycle from heat design balance at 50%, 75%, and 100% load
2. design PCC process to recover 85% of CO_2 at nominal load
3. integrate PCC process and generating unit models
4. characterize part-load performance of integrated unit

Objective is to find Pareto frontier of integrated unit.



- interested in the relationship between:
  1. heat input to boiler ($\dot{q}$)
  2. CO_2 recovery (x_{CO_2})
  3. net unit power output (E_{net})
- $E_{net} = f\left(\dot{q}, x_{CO_2}, \ldots\right)$
- only interested in the ‘best’ performance (*i.e.*, Pareto frontier)
- Find E^*_{net} for feasible combinations of $\dot{q}$ and x_{CO_2}.

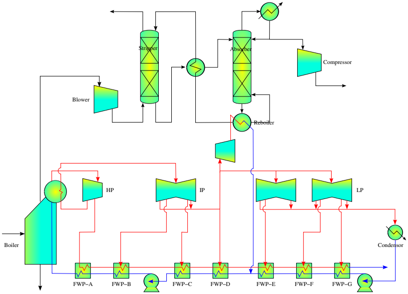
Pareto frontier for generating unit with CCS.



Developed model describing Pareto frontier using linear regression:

$$\dot{q} = f\left(E^*_{net}, x_{CO_2}\right)$$

Summary of data requirements for novel process.



- Key unit parameters:
  - incremental heat rate
  - minimum and maximum power output
  - start-up heat input
  - ramp rates
  - minimum up- and downtimes
  - fuel cost
- Initial assumption is that CO_2 capture process dynamics are fast.

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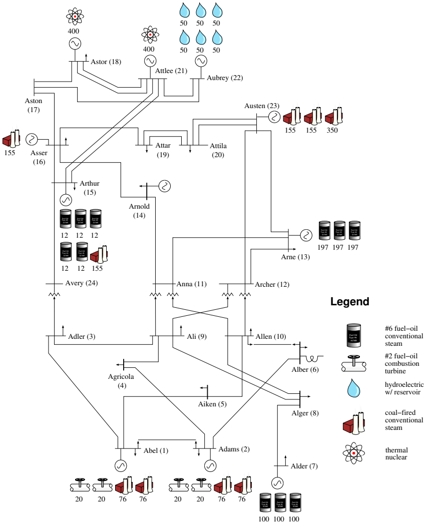
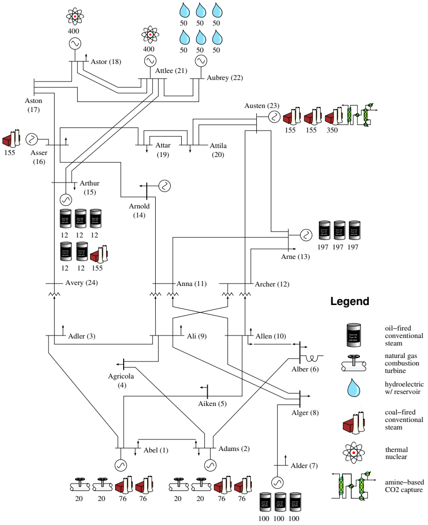
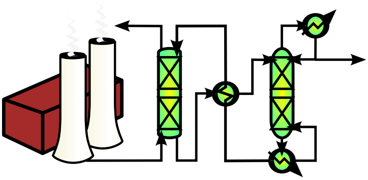
Analysis is electricity system-specific.



- Grigg et al. The IEEE Reliability Test System — 1996, *IEEE Transactions on Power Systems*, 14(3):1010–1021, August 1999.
- Example workflow:
  1. Incorporate novel process into electricity system.
  2. Simulate system operation.
  3. Analyze simulation results.

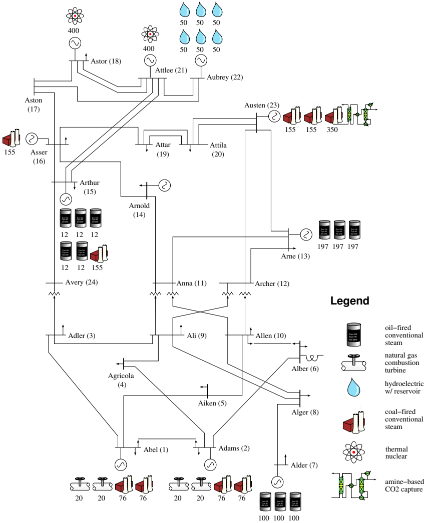
Novel process added to electricity system.

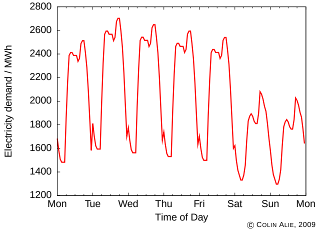




- MEA (monoethanolamine)-based PCC (Post-Combustion Capture) added to 500 MW$_e$ coal-fired unit at Austen
- plant load and CO_2 recovery are flexible

Electricity system operation simulated.





For each time period, select units that will satisfy:

- demand
- reserve requirement
- physical constraints on equipment

such that overall benefit is maximized.

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Cost of CO_2 avoided estimate is easily had.

Cost of CO_2 avoided

$$CCA = \frac{(CoE)_{cap} - (CoE)_{ref}}{(CEI)_{ref} - (CEI)_{cap}}$$

where *Cost of Electricity* can be expressed as:

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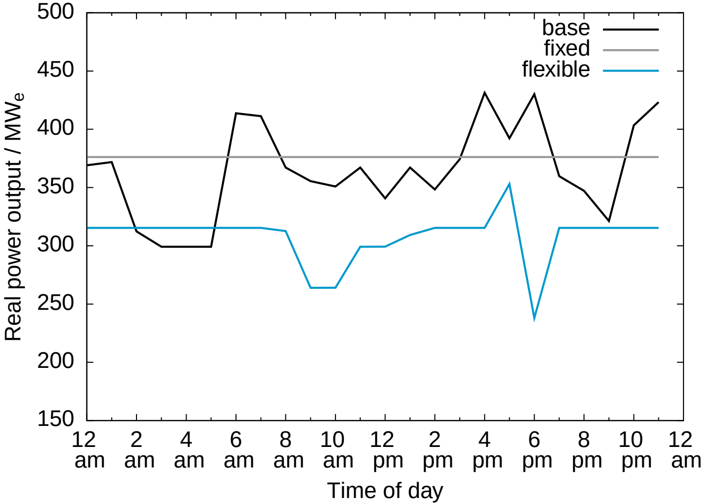
Simulation directly provides:

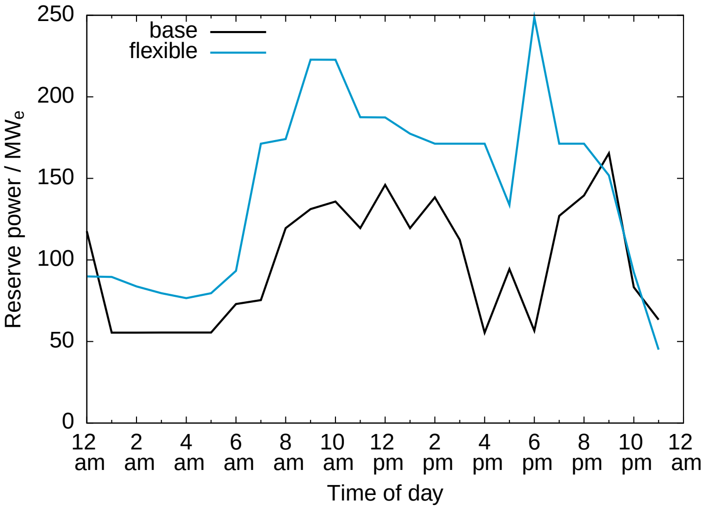
- *Cost of Electricity*
- CO_2 *Emissions Intensity*

so estimate of *Cost of* CO_2 *Avoided* is readily obtained, if desired.

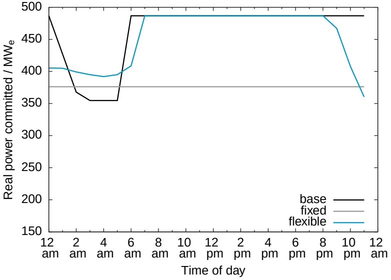
At $40/tonne, flexible case delivers least power.



Flexible case commits more to reserve markets.



Overall utilization similar: base vs flexible.



- Utilization is similar between base case and flexible case.
- However, flexible case has better economics as costs are lower
- Cost of CO_2 avoided wouldn't reflect this

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Summary and future work

- Able to quantify benefits from operating flexibility.
- Operating flexibility shifted capacity from energy market to reserve markets.
- Assessment of dynamic performance needs to be included!
- Sensitivity analysis.

Acknowledgements

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