Carbon Capture and Storage Developments

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AGENDA

- Who is the CCS Knowledge Centre
- The Boundary Dam 3 CCS Facility
- Combined Heat and Power Integrated Carbon Capture and Compression at the Lehigh Edmonton Cement Manufacturing Facility
- Carbon Capture and Compression on 360 MW NGCC Study

INTERNATIONAL CCS KNOWLEDGE CENTRE

WE TAKE CLIMATE ACTION SERIOUSLY

- We are a non-profit organization dedicated to advancing large-scale CCS projects as a critical means of managing greenhouse gas emissions and achieving the world's ambitious climate goals.

- We provide independent, expert advice throughout the lifecycle of CCS projects, based on real-world experience and the latest knowledge from projects around the globe.

REDUCING RISK
IMPROVING PROJECT OUTCOMES

WE ARE UNIQUE IN THE CCS SPACE:

- **Trusted advisors** for planning, design, construction, start-up and operation of CCS facilities to **reduce risk** based on unique real-world experience.
- technical experience from the Boundary Dam 3 CCS Facility, and ongoing **feasibility & FEED studies** on CCS across **all industries**.
- Actively **engage** with financiers, policy makers, decision makers, and business partners.

BOUNDARY DAM 3 CCS FACILITY

INTERNATIONAL
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LEHIGH EDMONTON CEMENT FACILITY INTEGRATED CCS

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CCS ON CEMENT: LEHIGH EDMONTON CCS FEASIBILITY STUDY - RESULTS

- Amine Post Combustion Capture selected
- CO_2 capture of 95%.
- Heat Integration is not possible to the same extent as a coal power plant
    - Dedicated steam boiler is required
    - Supplemental energy from waste heat was studied, but was not economical in this case
    - Steam driven compressor reduced costs

Global CO_2 emissions reductions in the cement sector by mitigation strategy 2019-2070

Lehigh Hanson Edmonton Cement Plant

CCS ON CEMENT: LEHIGH EDMONTON CCS FEASIBILITY

CHP FOR LEHIGH FEASIBILITY STUDY

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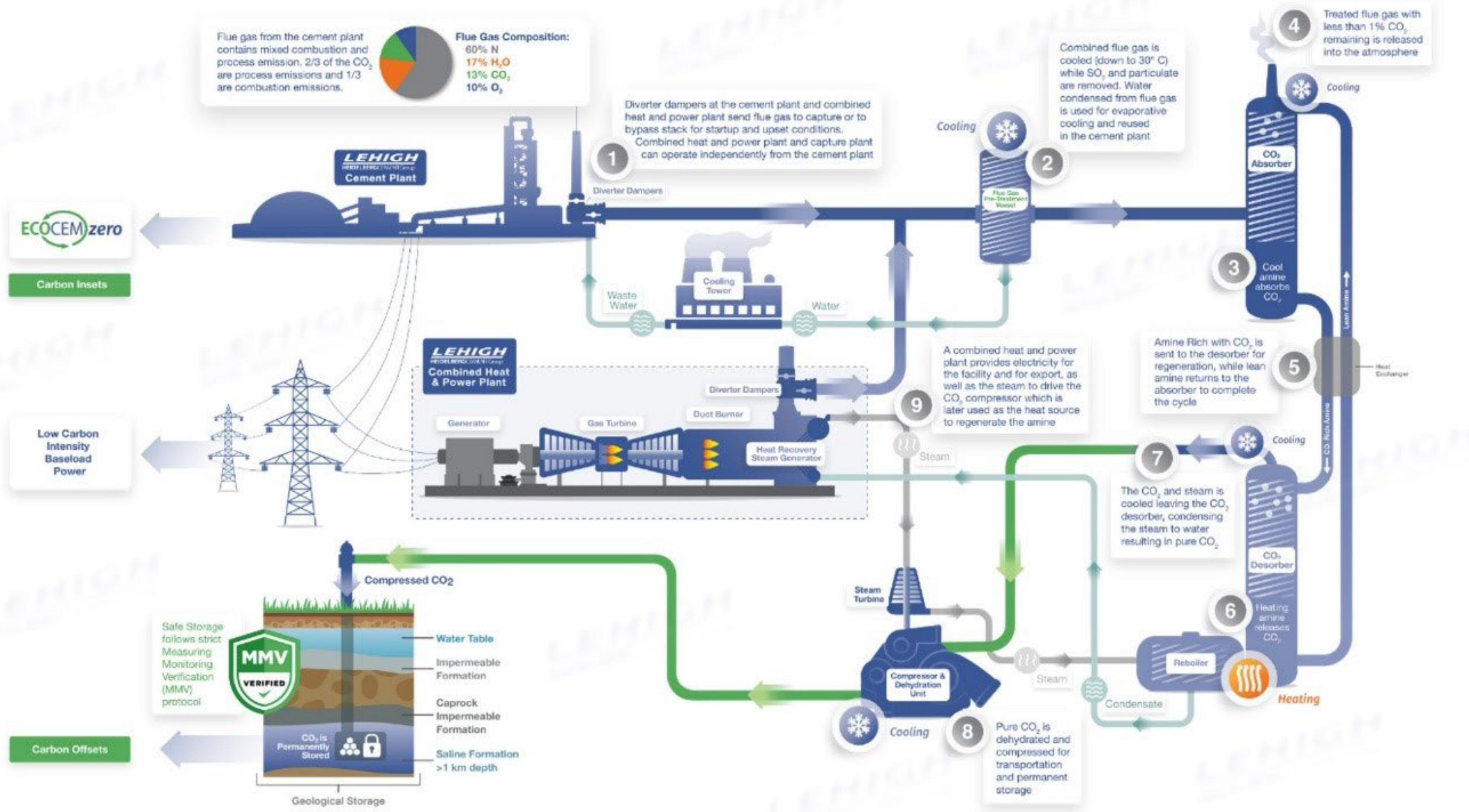
Adding CHP to industrial facilities at same time as CCS is installed, creates opportunity for relatively low cost near zero emissions electricity generation.



DESIGN CRITERIA / CONSIDERATIONS

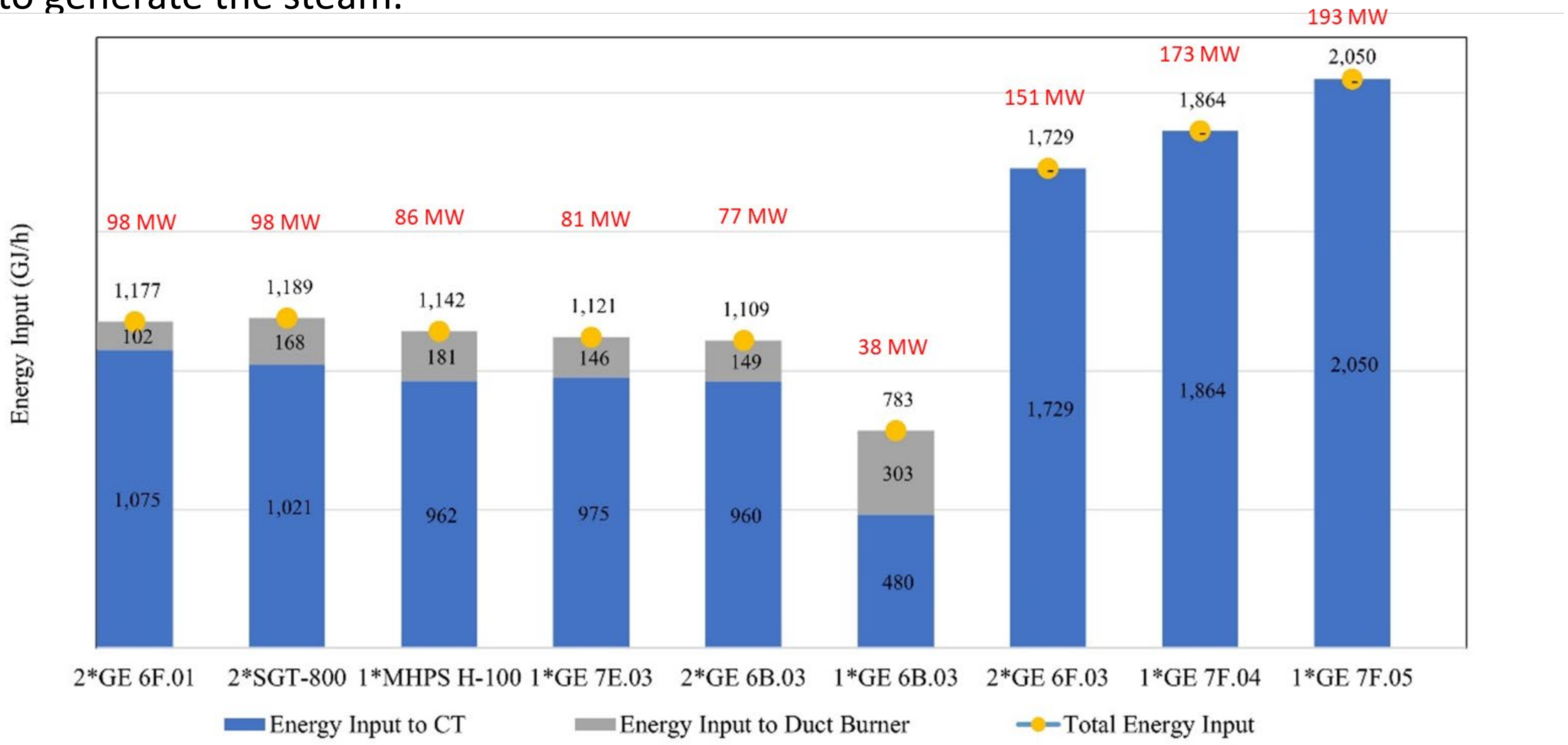
The two modes of operation of the CCS facility and the CHP plant were applied in the design as follows:

Design Mode: The CHP must be capable of providing sufficient steam to the capture plant for capturing and compressing CO_2 emitted from the cement kiln and the CHP plant.

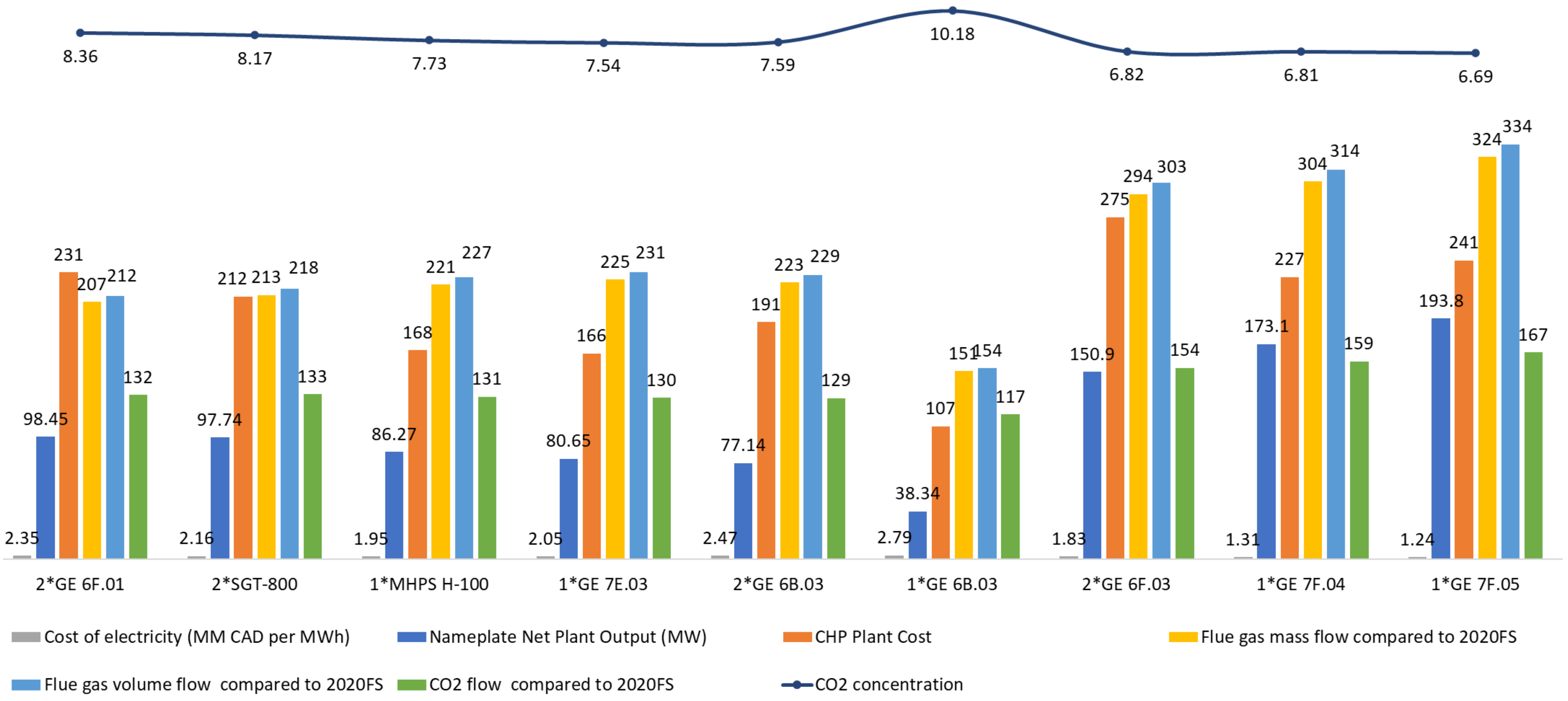
Electrical or Power Production Mode: The CHP must be capable of providing sufficient steam to the capture plant for capturing and compressing CO_2 generated from the CHP plant only. The intention of this mode is to allow the start-up and operation of the capture plant to be independent of the kiln.

SUMMARY OF ENERGY CONSUMPTION FOR EACH CHP OPTION

For the small CT cases where the heat recovery steam generator (HRSG) does not provide sufficient steam required by the capture plant to capture CO_2, a duct firing system is installed, and additional fuel is consumed to generate the steam.

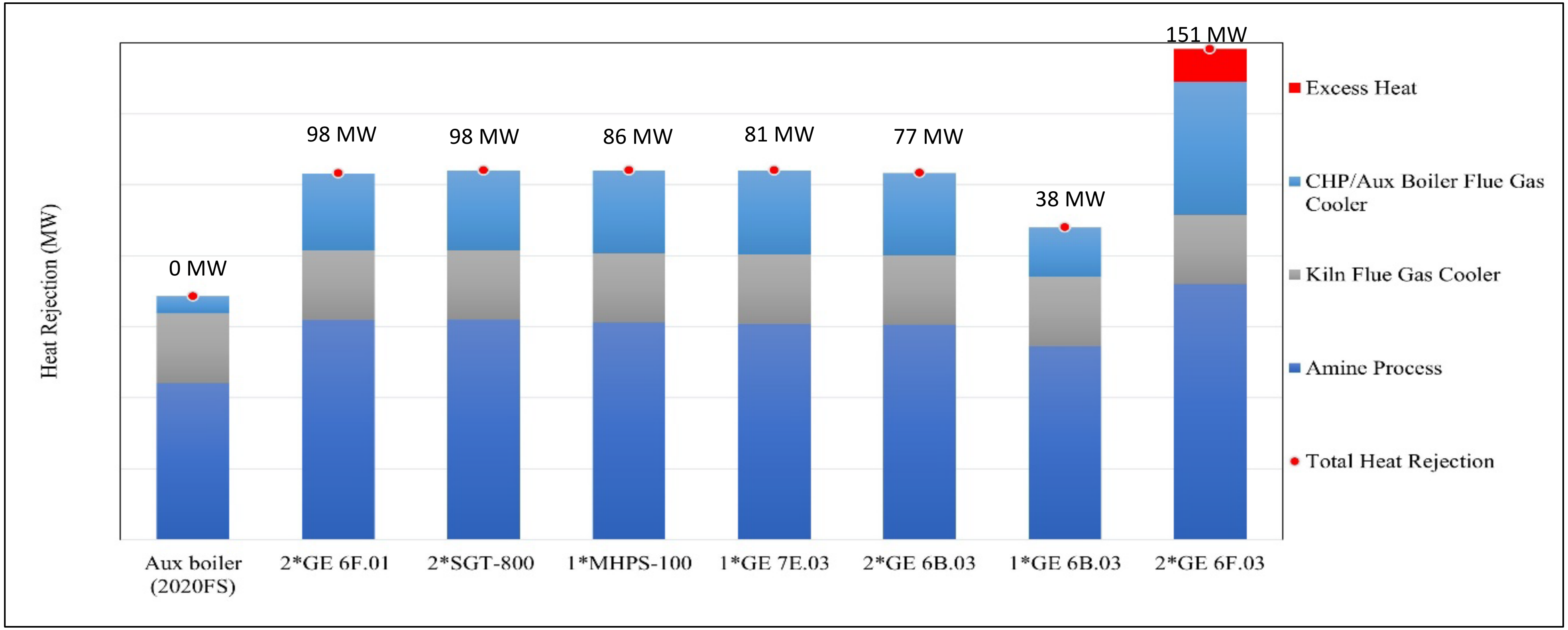


SUMMARY OF THE IMPACT OF THE CHP PLANT ON THE CO_2 CAPTURE PLANT SIZE



The bigger CHP plant, which provides higher electricity output and promises to provide revenue from the power sale to the project, results in higher flue gas flow and CO_2 flow and requires a bigger CCS plant. The CO_2 concentration in the flue gas is more diluted, which may impact regeneration energy requirements.

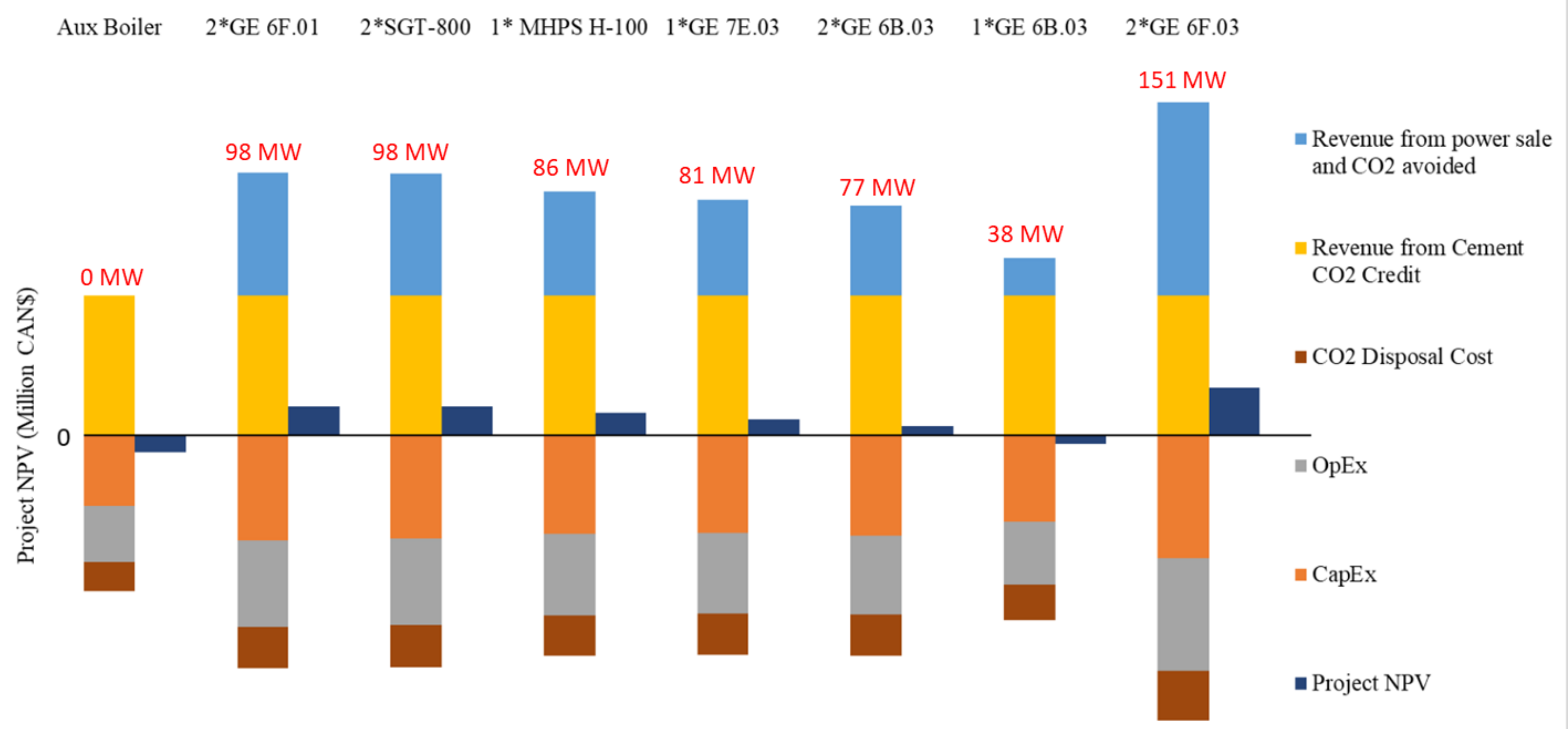
HEAT REJECTION LOAD FOR DESIGN CASES



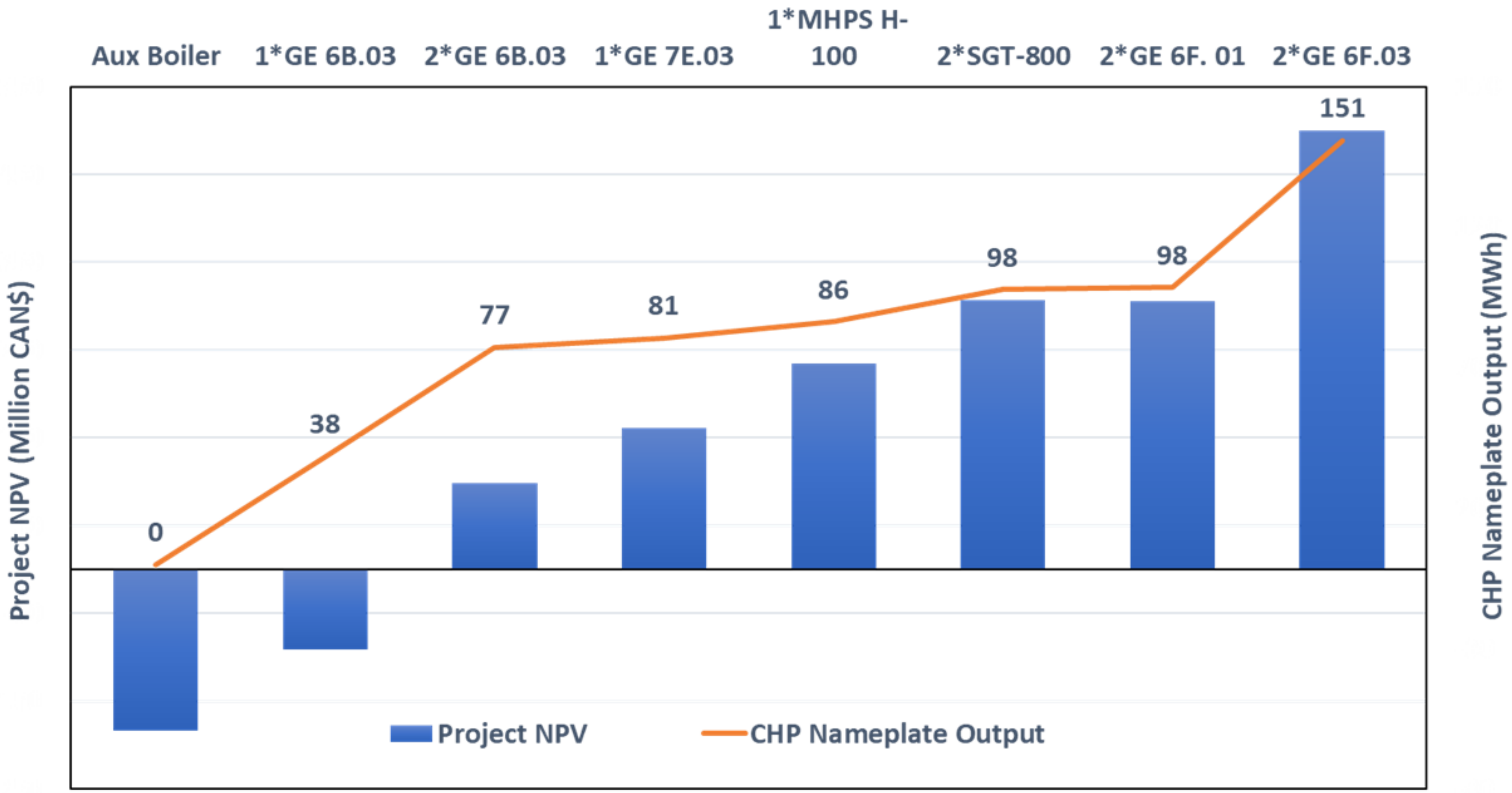
The heat rejection for the design cases used for heat rejection plant capital cost estimates and power consumption. It is obviously seen that the largest gas turbine case (2*GE 6F.03) produces excess steam or heat, more than required by the capture plant, which is continuously condensed in the dump condenser and leads to higher heat rejection load than other cases.

PROJECT NPV OF AUXILIARY AND CHP CASES

- A cost model that includes capital and operational cost estimates for 30 years of operation of the CHP and CCS plants.
- Bigger CHP plant results in higher CapEX and OpEx but provides higher project NPV due to the significant profit from power sales and emission credits from clean electricity.
- A big CHP plant, like the 2*GE 6F.03, produces excess steam beyond what is required by the capture plant.



PROJECT NPV OF AUXILIARY AND CHP CASES



- ❑ will take advantage of the economics of scale to provide incrementally low-cost carbon capture for electrical supplies and the related Scope 2 emissions,
- ❑ increase the utilization of the plant by running in power mode when the process is down,
- ❑ will provide more consistent operation of the plant that will reduce the number of start-ups.

CARBON CAPTURE AND COMPRESSION ON NATURAL GAS COMBINED CYCLE (NGCC)

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INTRODUCTION

Natural gas combined-cycle (NGCC) with carbon capture and storage (CCS) is a promising technology for reducing carbon dioxide (CO_2) emissions in the electricity sector.

However, the high cost and efficiency penalties associated with CCS may limit the role of NGCC-CCS in achieving stringent greenhouse gas (GHG) reduction goals. ***Careful heat and power integration can minimize the energy penalties and significantly improve the economics.***

The Knowledge Centre has recently completed a screening study of heat integration for NGCC with CCS.

MODELING OF NGCC WITH THERMOFLOW

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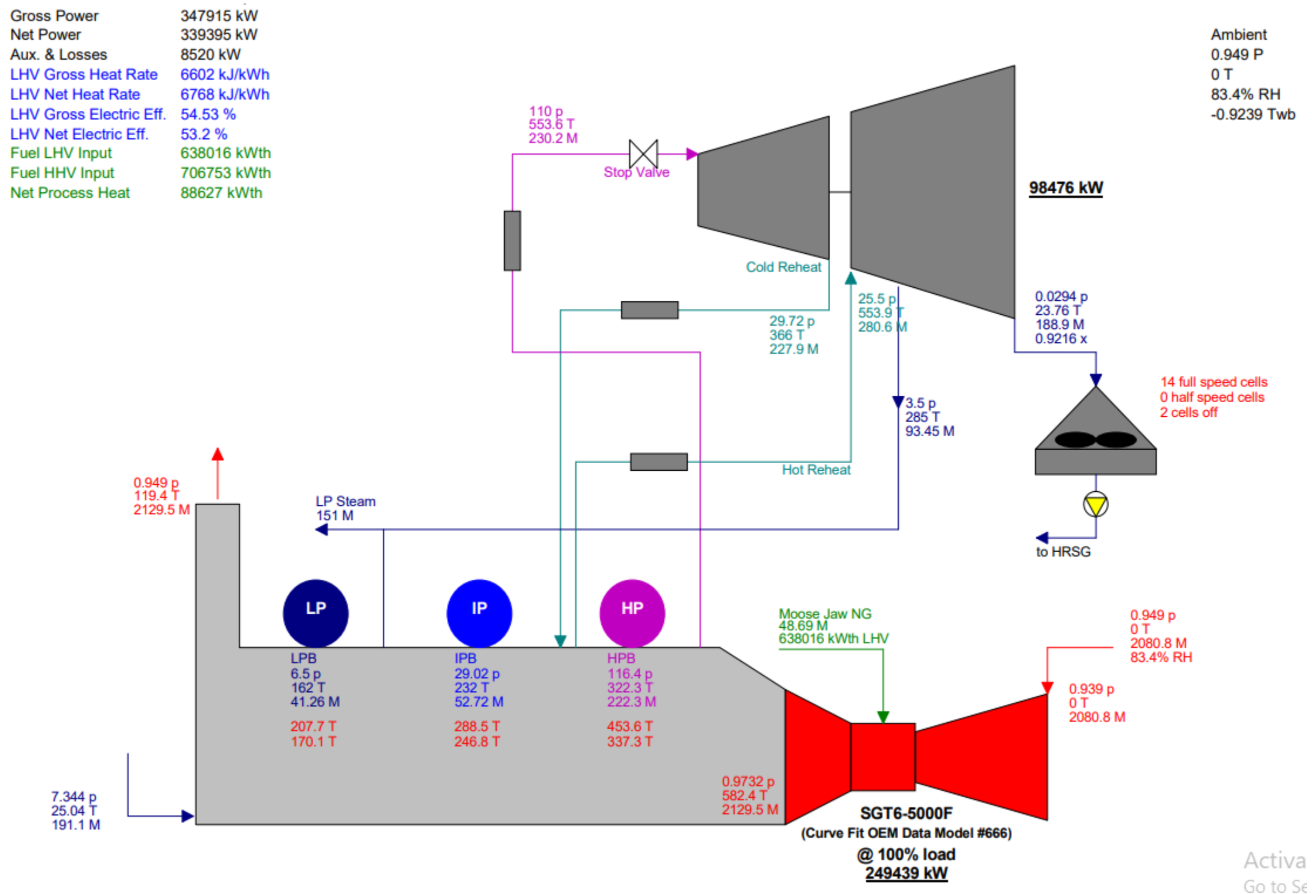


Thermodynamic simulations and cost estimates of the CHP were performed using Thermoflow software, a thermal engineering software application for the power and cogeneration industry.

STEAM SOURCES/ EXTRACTION CONFIGURATION

Several options for heat integration between the CCS plant and the NGCC power plant were investigated.

New Build

- ❑ Optimized Steam Turbine with IP-LP Extraction
- ❑ Main Steam with duct firing

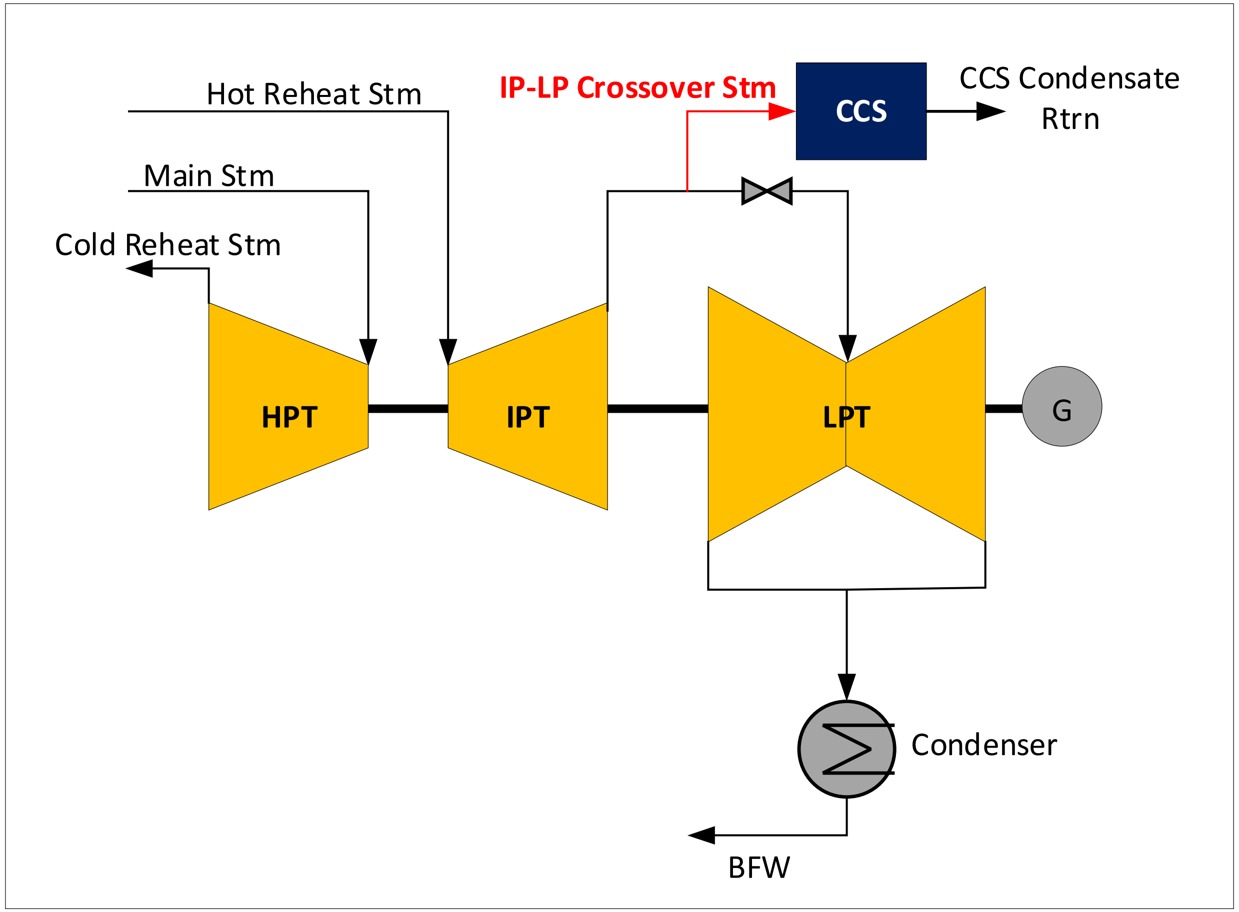
Retrofit NGCC

- ❑ Addition of Auxiliary Boiler
- ❑ IP-LP Crossover
- ❑ Main Steam w/wo back pressure turbine
- ❑ Hot Reheat w/wo back pressure turbine
- ❑ Cold Reheat w/wo back pressure turbine

STEAM SOURCES/ EXTRACTION CONFIGURATION

Greenfield Optimized Steam Turbine with IP-LP Extraction

- ❑ The steam will be withdrawn from IP-LP crossover. The turbines and HRSG are optimized to provide steam to the CCS plant.
- ❑ Suitable for a greenfield plant.



STEAM SOURCES/ EXTRACTION CONFIGURATION

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Main Steam with duct firing

- This option assumed a duct burner installed downstream of the gas turbine exhaust.

Addition of Auxiliary Boiler for CCS Steam Supply

- This option will not require modifications to the existing power plant or steam cycle as the steam supply to the CCS plant will be produced in an additional auxiliary boiler. The additional flue gas from the boiler will be routed to the CCS plant.
- Can be added to both greenfield and existing plants.

STEAM SOURCES/ EXTRACTION CONFIGURATION

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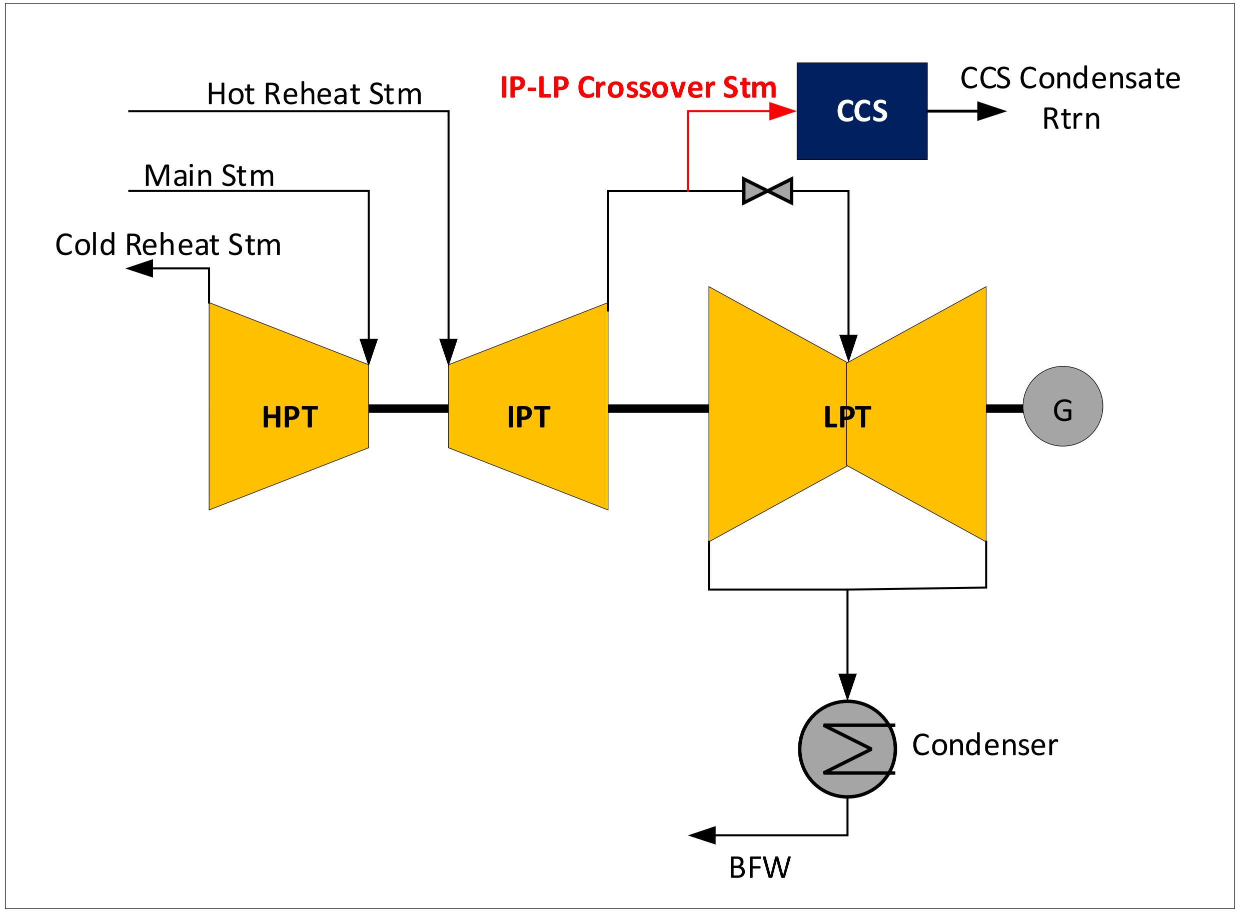
Retrofit Existing NGCC: IP-LP Crossover

- The steam will be withdrawn from IP-LP crossover. If the steam turbine are not optimized to provide the steam condition required by the CCS plant, the extracted steam will be throttling before entering the capture process.
- Some NGCC plants are equipped with compact steam turbines. This leads to the challenge in accessing of IP-LP Crossover steam. To extract steam from IP-LP crossover, steam turbine modification or replacement may be required.



STEAM SOURCES/ EXTRACTION CONFIGURATION

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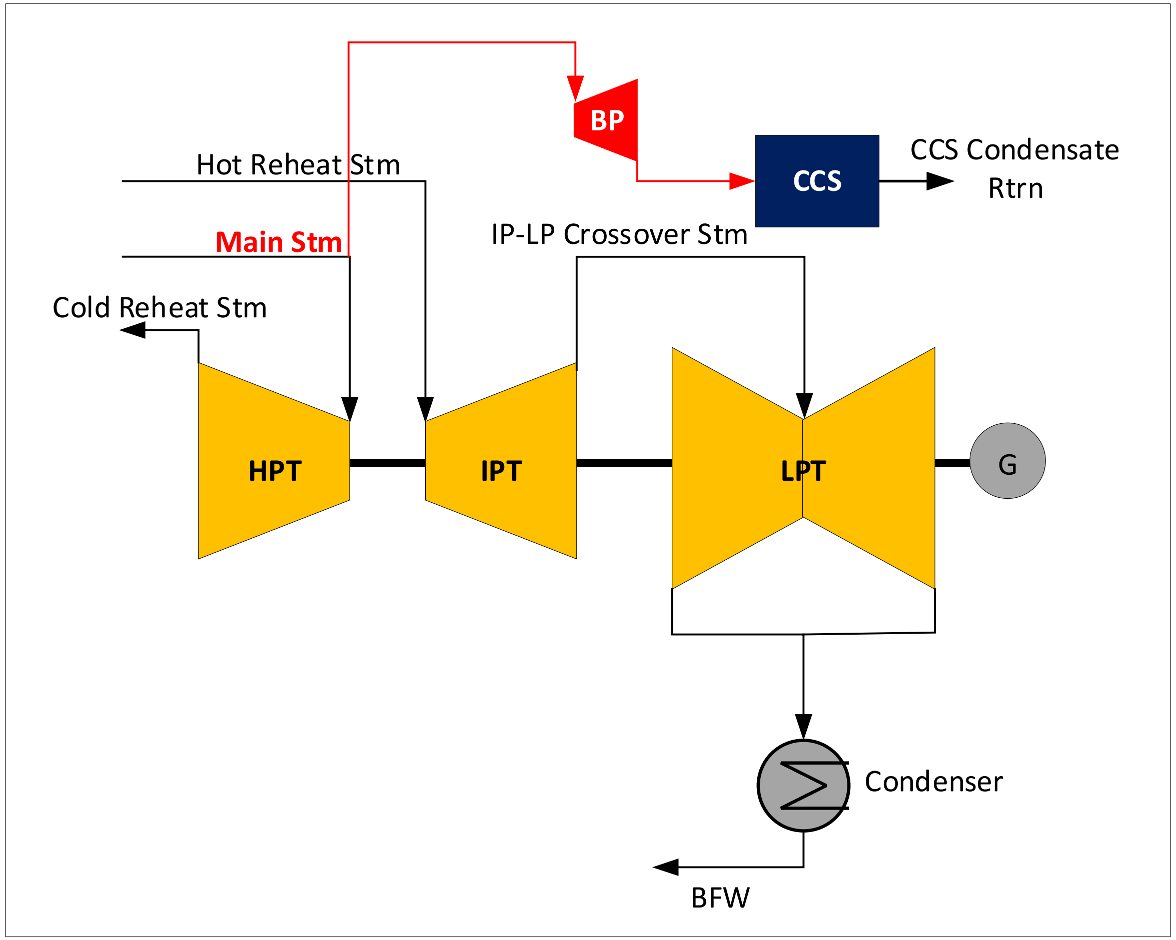
Main Steam w/wo back pressure turbine

- This option withdraws high-energy steam from the main steam. Two scenarios were investigated:
  - (a) feeding to an attemperator prior supply to the CCS plant using reboiler condensate return
  - (b) feeding it to a backpressure turbine prior to use in the capture facility/ A backpressure turbine generates additional electricity before sending the steam to the capture process, reducing losses in gross output for the power plant.
- May require a change to HRSG surface area.



STEAM SOURCES/ EXTRACTION CONFIGURATION

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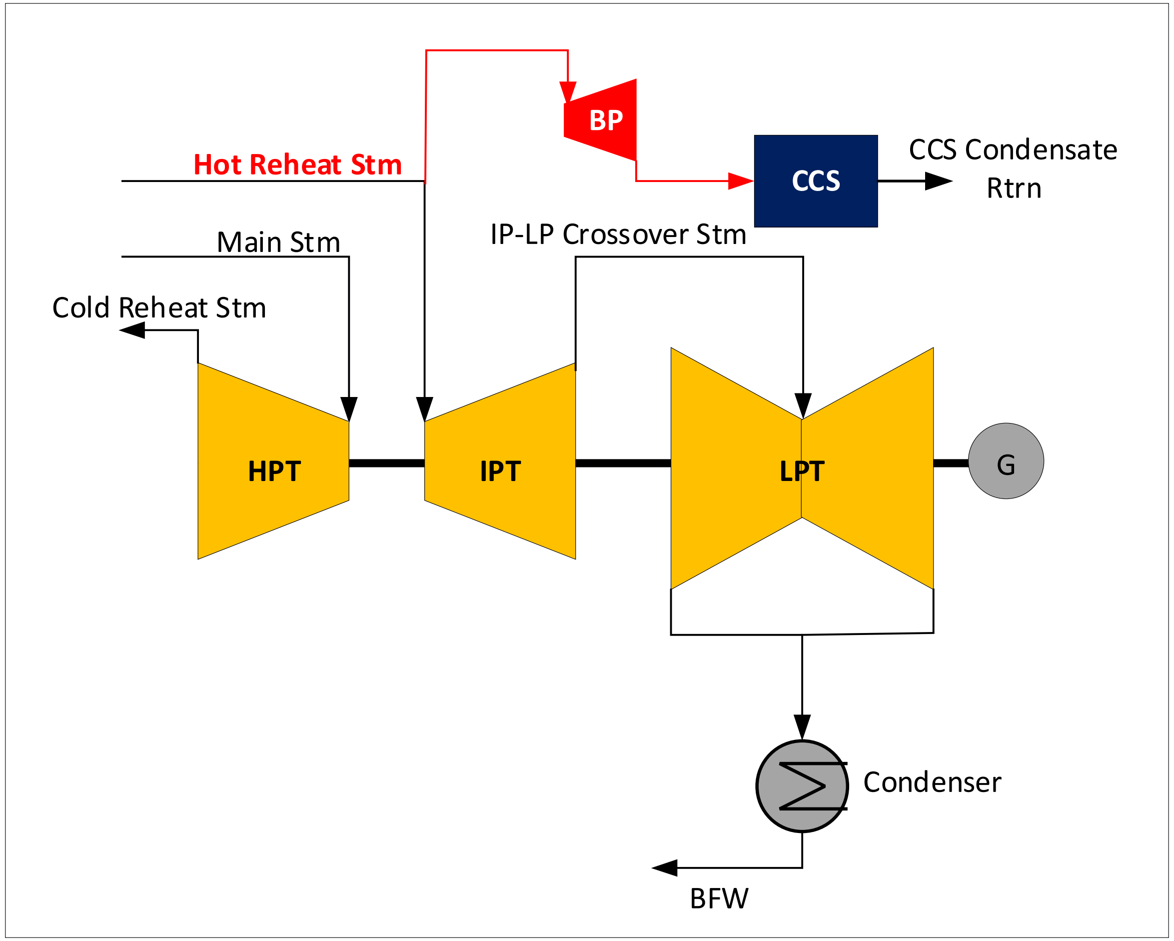
Hot Reheat w/wo back pressure turbine

- This option withdraws steam from the hot reheat. Configurations both with and without installation of a back pressure turbine were investigated.
- The steam withdrawal can alter the thrust loading and pressure ratios in the HP turbine, unless the inlet to the IP turbine is throttled.
- It might result in changes to the cold reheat temperature, which could require adjusting the relative distribution of heat transfer surface in the HRSG.



STEAM SOURCES/ EXTRACTION CONFIGURATION

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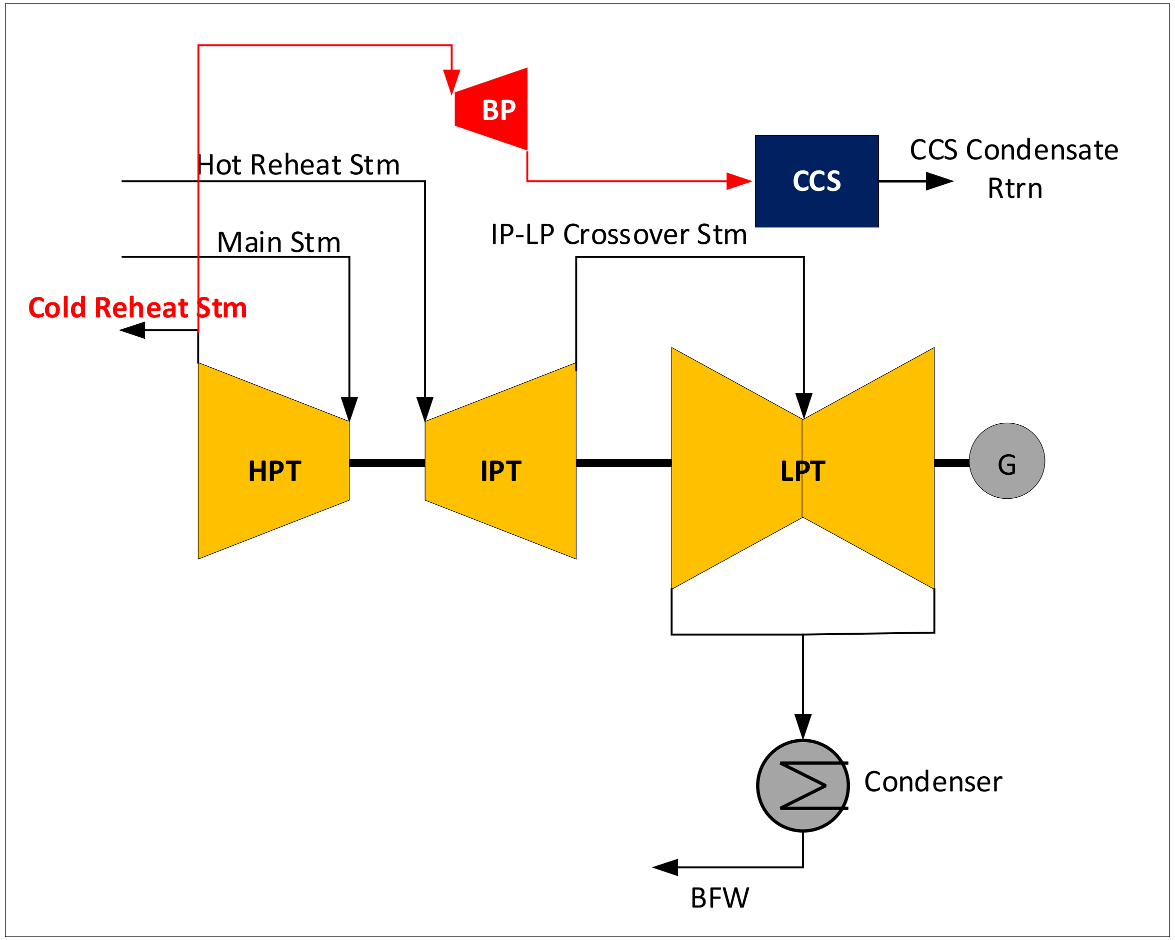
Cold Reheat w/wo back pressure turbine

- This option withdraws steam from the cold reheat. Both with and without installation of a back pressure turbine are investigated.
- The steam withdrawal can alter the thrust loading and pressure ratios in the HP turbine, unless the inlet to the IP turbine is throttled.
- Taking steam from the cold reheat can reduce the steam flow through the reheater. This may require changes to the reheater surface area.



PERFORMANCE SUMMARY - ANNUAL AVERAGE

Comparison of Change in Gross MW Output with CCS for each Heat Integration Option

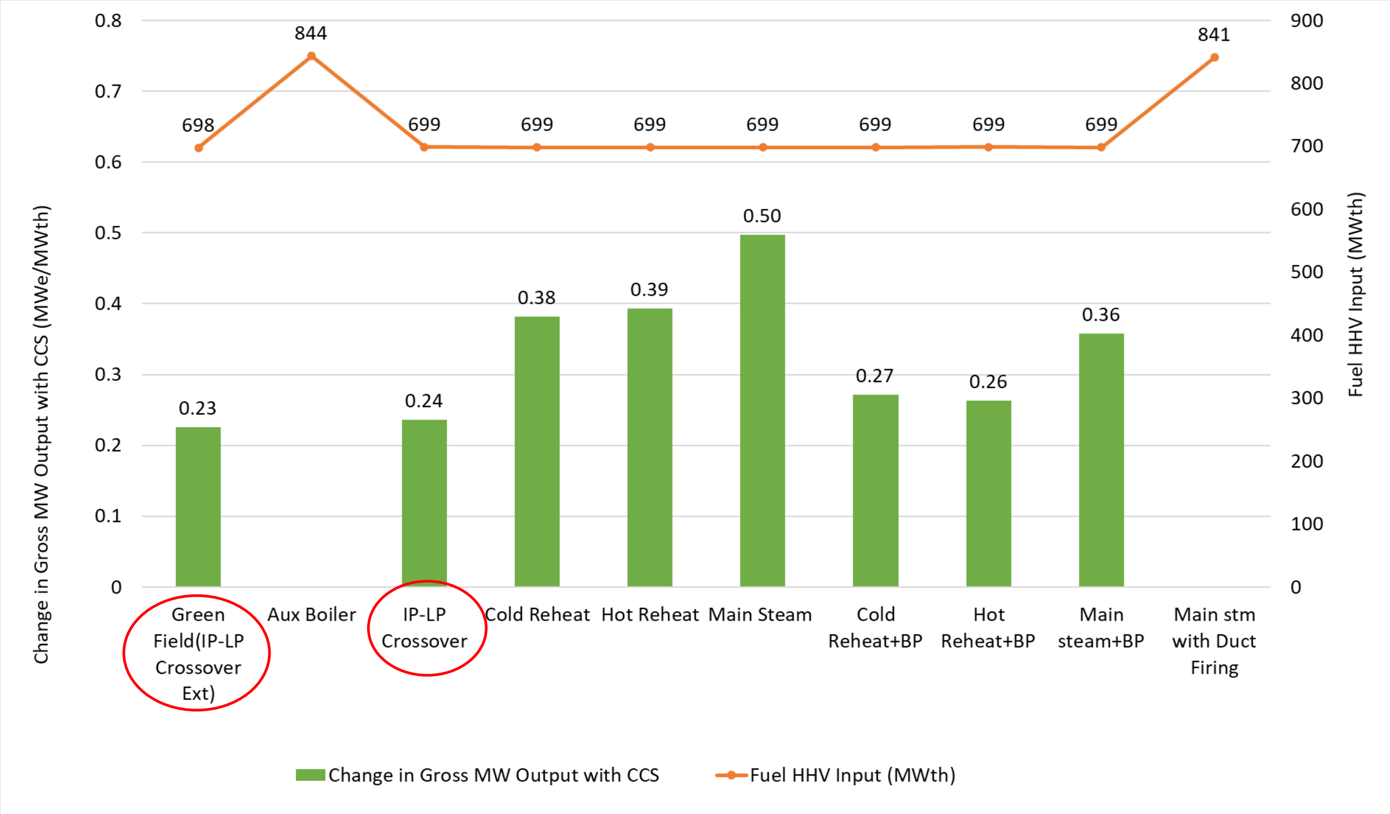
Installation of an auxiliary boiler or duct firing does not have an impact on the gross output. It provides flexible and less impact to the power plant. However,

- ❑ Increase in fuel consumption.
- ❑ Increase in CCS plant size.
- ❑ The duct firing temperature is limited by the material in the HRSG.
- ❑ Taking steam from the main steam will reduce the reheat flow relative to other flows in HRSG and this will need to be considered in the arrangement of HRSG surface areas.

PERFORMANCE SUMMARY - ANNUAL AVERAGE

INTERNATIONAL CCS KNOWLEDGE CENTRE

Comparison of Change in Gross MW Output with CCS for each Heat Integration Option



- IP-LP extraction for both Greenfield with optimized turbine and existing plant show the smallest impact on cycle efficiency.
- The extraction from this location has no impact on LP operation other than reducing the flow; similar to reducing load condition.

Not available if plants are equipped with compact steam turbines!

PERFORMANCE SUMMARY - ANNUAL AVERAGE

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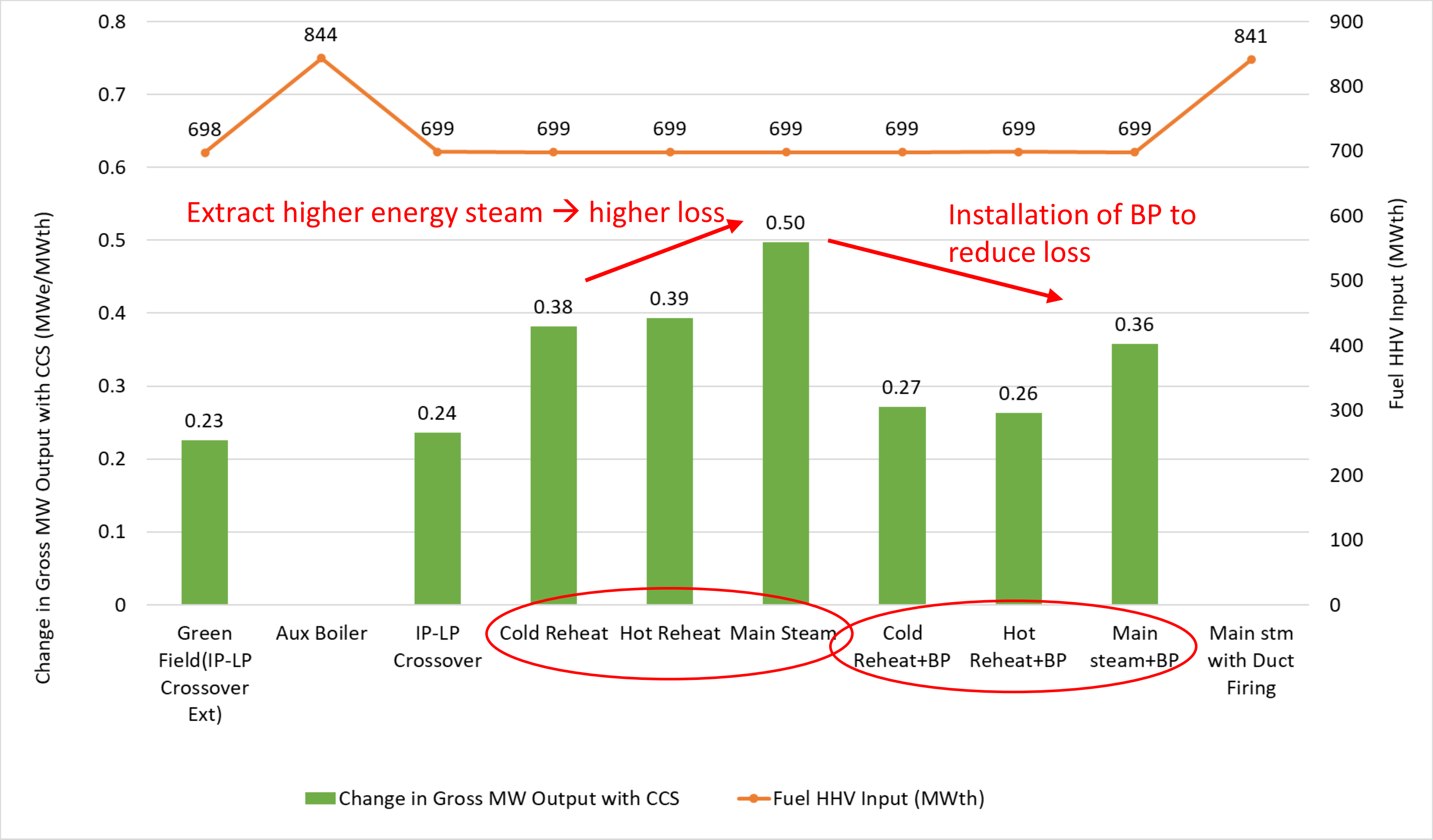
Comparison of Change in Gross MW Output with CCS for each Heat Integration Option



- The remaining options will be to extract higher energy steam from Cold reheat steam, Hot reheat steam, and Main steam which results in a higher loss.

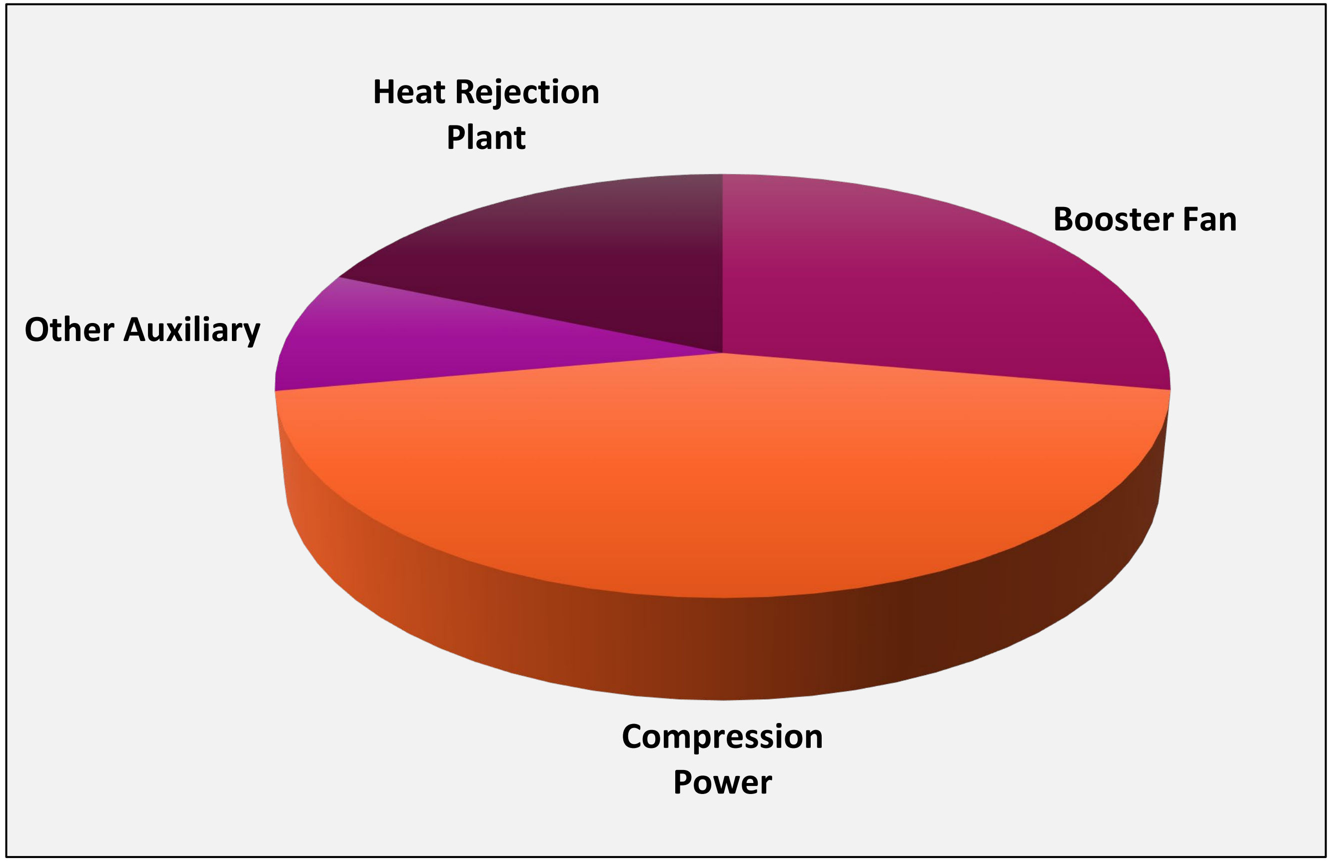
Or

- install an additional back pressure turbine to improve the thermal efficiency of the steam cycle. **A back pressure turbine would result in additional complexity to the plant.**

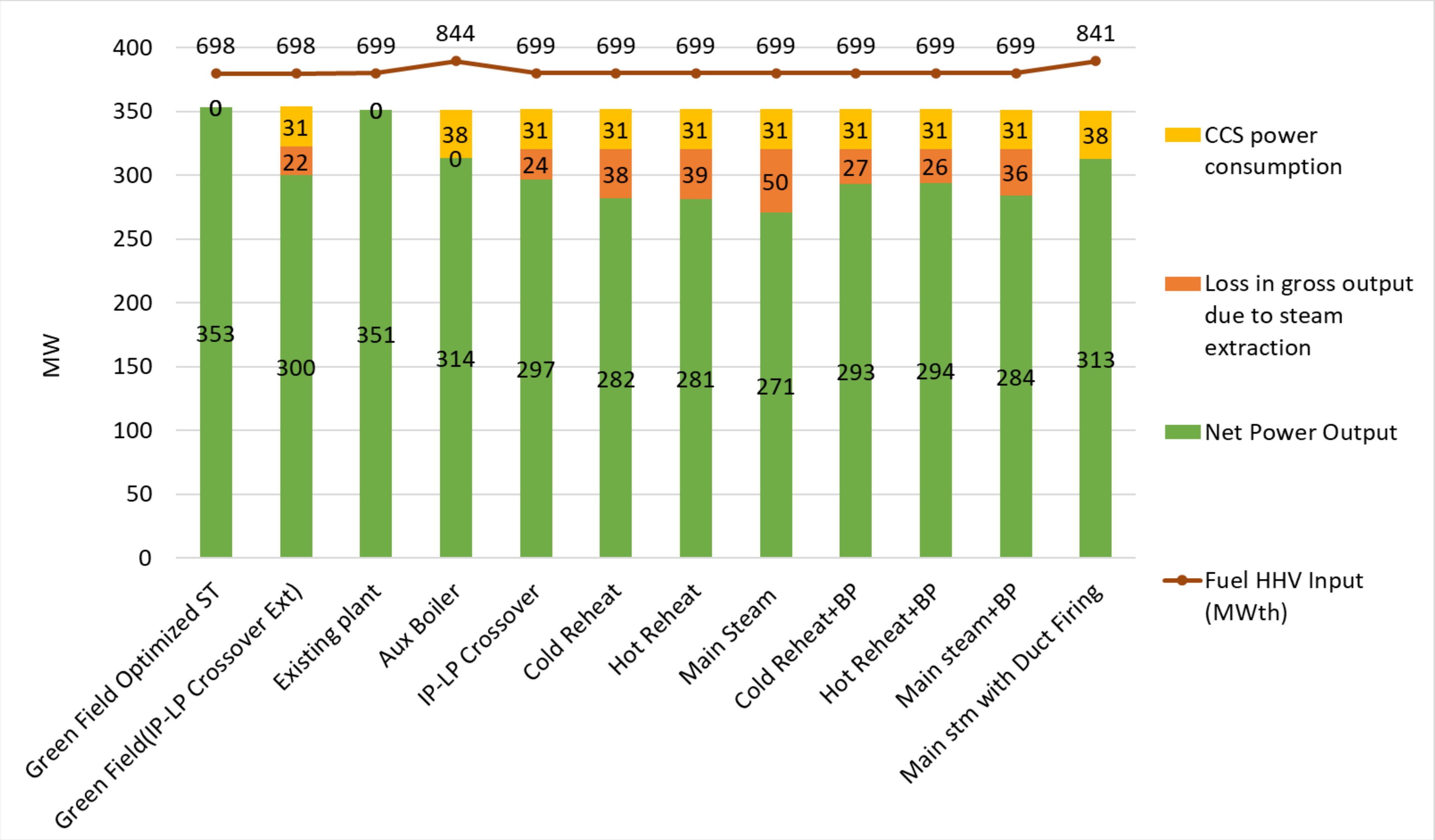
CCS POWER CONSUMPTION

The addition of a CO_2 capture plant and BOP systems to the NGCC 360 MW plant requires significant electrical power for:

- ❑ CO_2 compression and dehydration
- ❑ the booster fan operation to deliver flue gas flow to the capture plant
- ❑ Operation of heat rejection plant
- ❑ auxiliary equipment



PERFORMANCE SUMMARY - ANNUAL AVERAGE



CO_2 EMISSION INTENSITY AND POTENTIAL FOR OVER CAPTURE AT PARTIAL LOAD

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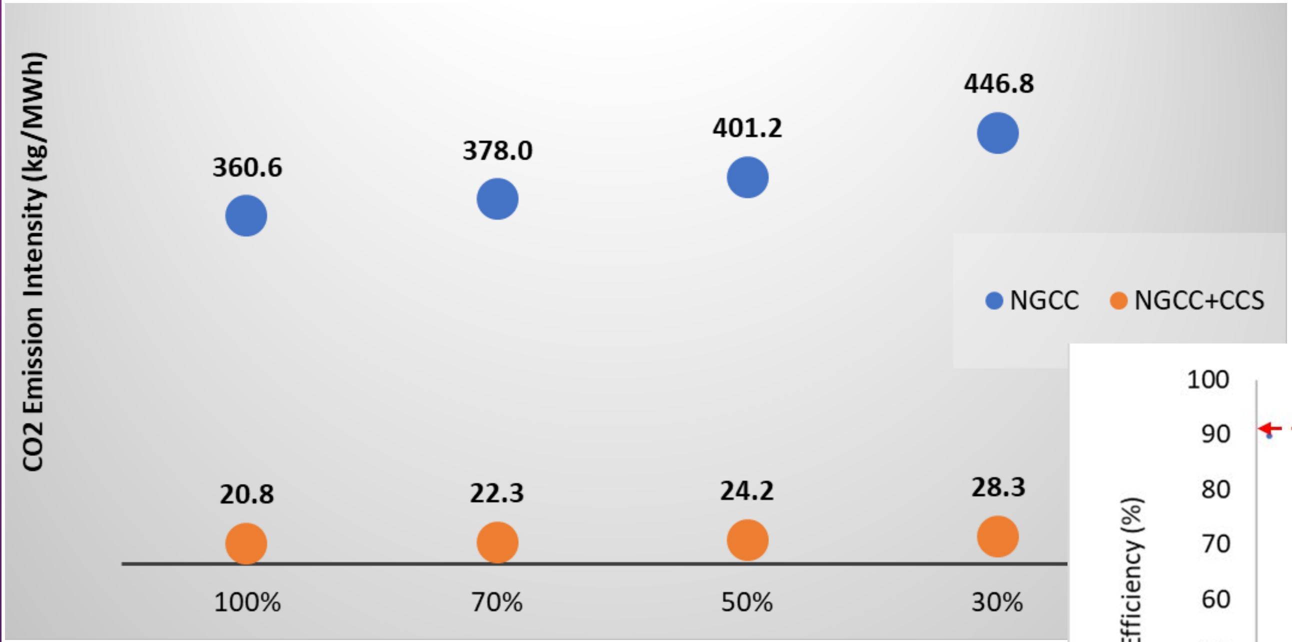
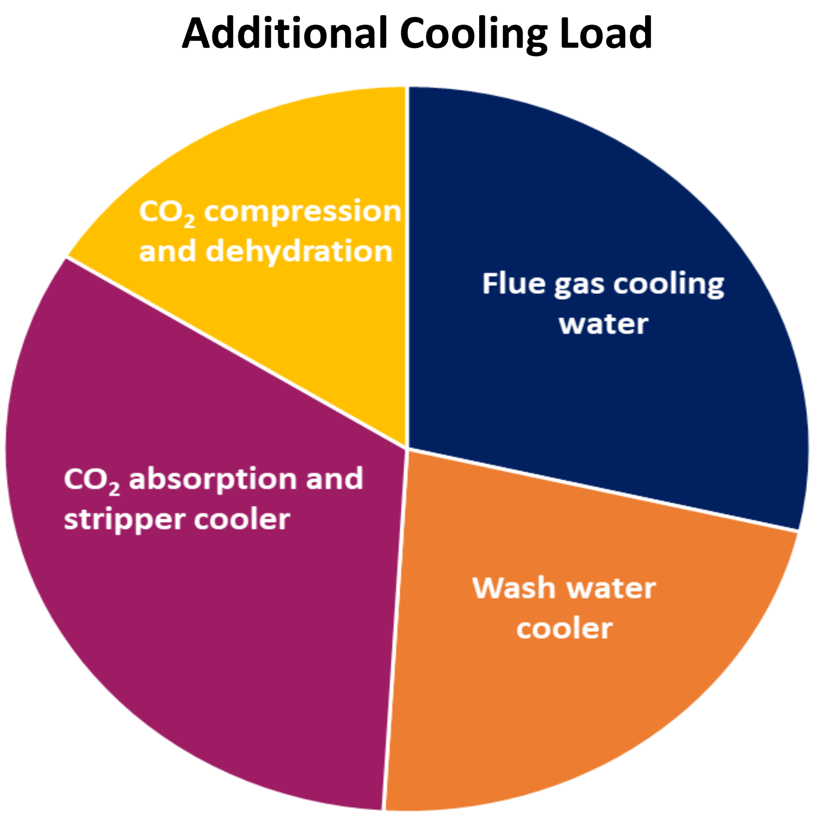
CO_2 Emission Intensity of 360 NGCC with and with CCS



Plant data - CO_2 Capture rate at BD3 ICCS

HEAT REJECTION



The addition of CCS will result in an increase in heat rejection load due to the additional flue gas to be cooled before entering the capture plant, and heat rejection within the amine and compression processes.

EFFECT OF DESIGN TEMPERATURES OF THE HEAT REJECTION PLANT

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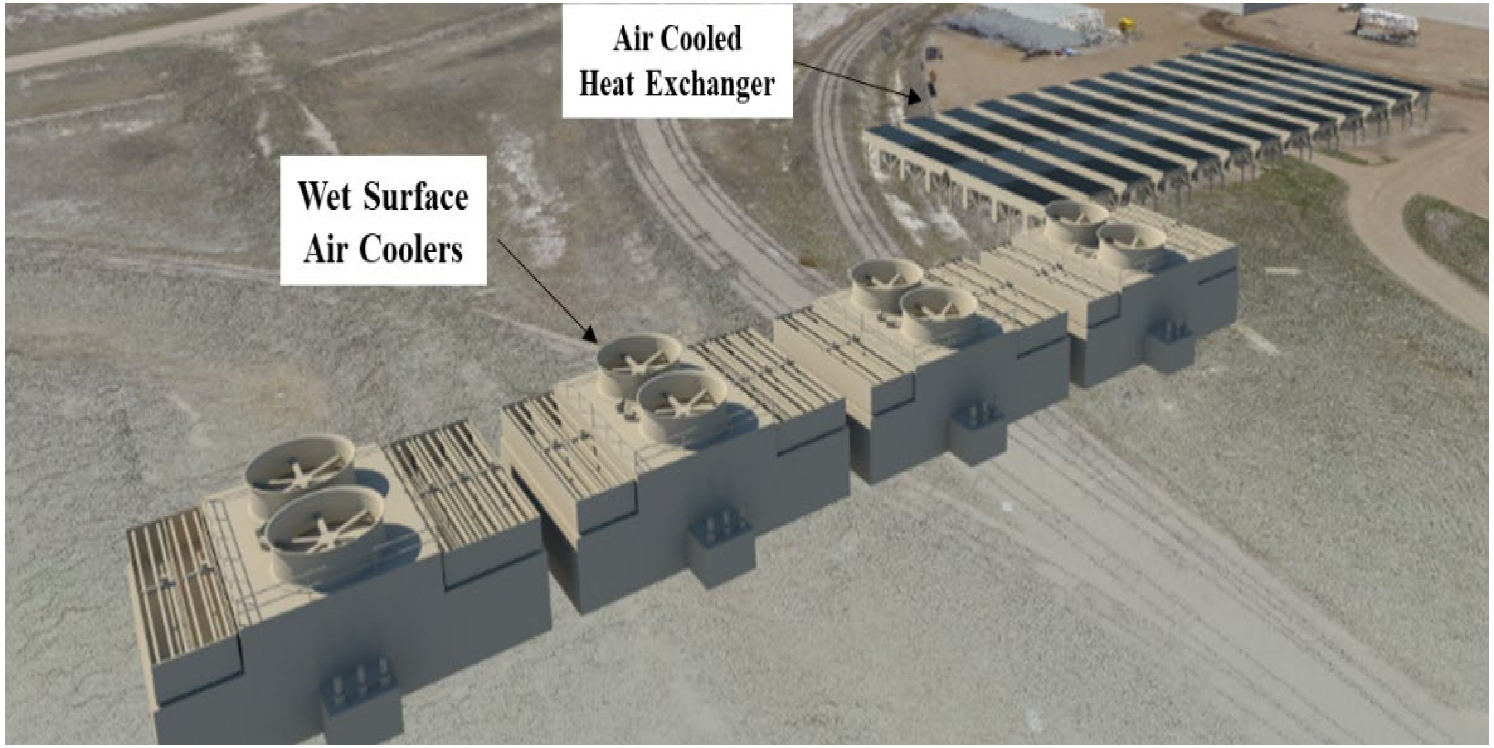
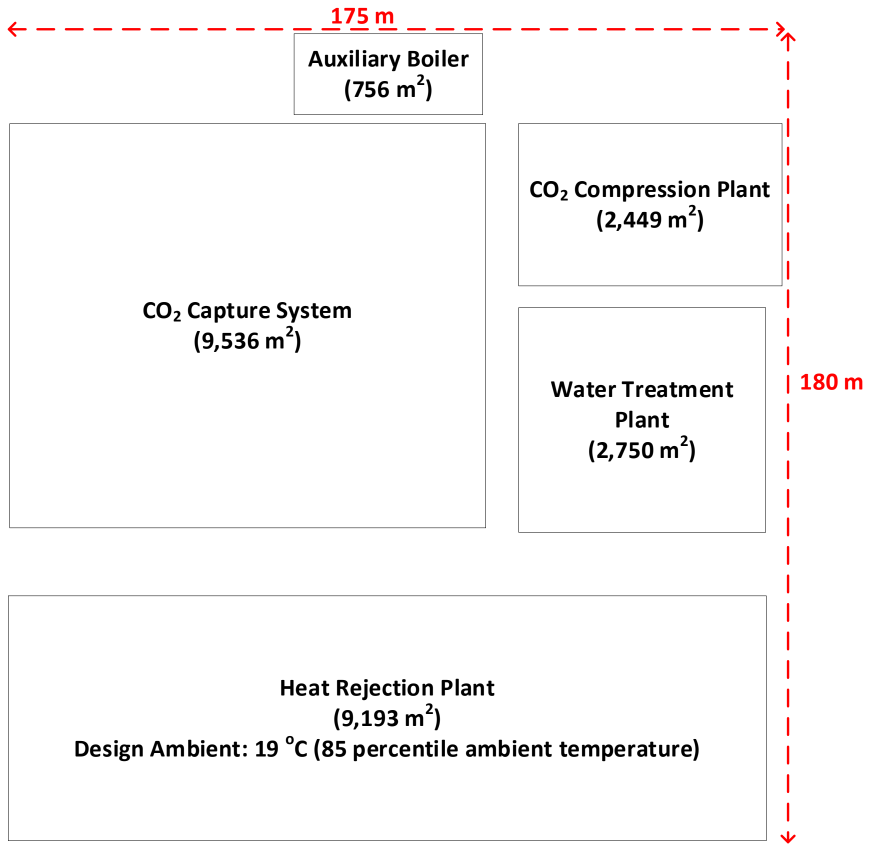
- Capture facility performance is affected by heat rejection performance.
- Increased ambient temperatures constrain heat rejection performance. Results in limitations to the extent of cooling supplied to the capture facility.



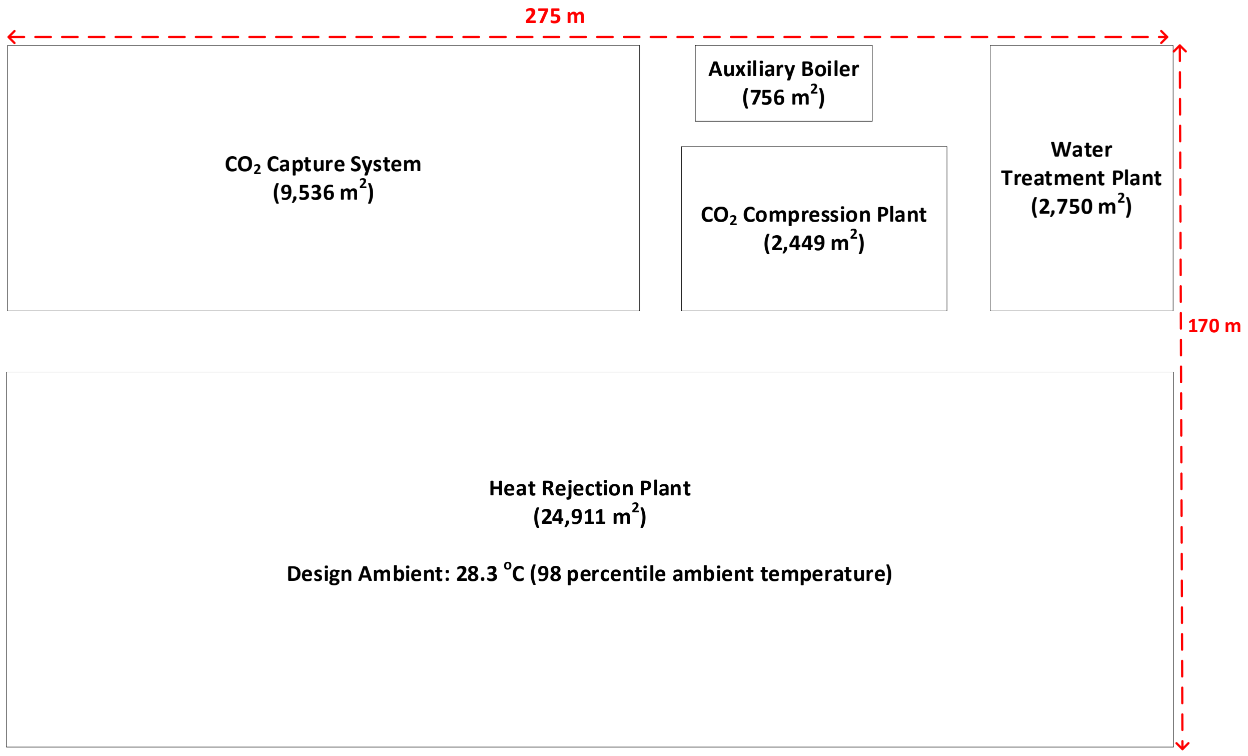
However, we can't design the heat rejection plant for the hottest day!

IMPACT OF HEAT REJECTION PLANT DESIGN ON THE CCS PLANT SITE LAYOUT

Designed Based on 85 Percentile Ambient Temperature (19˚C)



Designed Based on 98 Percentile Ambient Temperature (28.3˚C)



SUMMARY

The most efficient way to integrate NGCC with CCS is to make the plant capture ready. This can minimize the energy penalties and significantly improve the economics of projects.

Ensure that:

- ❑ the heat integration between NGCC and CCS plant is optimized
    - If possible, ensure IP-LP crossover steam can be accessed.
    - the steam turbine can be optimized to provide steam conditions needed by CCS – no throttling of steam required.
- ❑ there is sufficient space for the future CCS and other balance of the plant installation

SUMMARY

In the case of retrofitting existing NGCC plants with CCS, heat integration can be more challenging especially when the low-energy steam at IP-LP cannot be extracted. The preferred options can be:

- ❑ Installation of a backpressure turbine to generate additional electricity before sending the steam to the capture process, reducing losses in gross output for the power plant.
- ❑ Installation of an auxiliary boiler to generate steam supply to the capture plant. This will impact the capture plant size.

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