

# Optimal design and operations of a flexible oxyfuel natural gas plant

SCCS Annual Meeting 2018

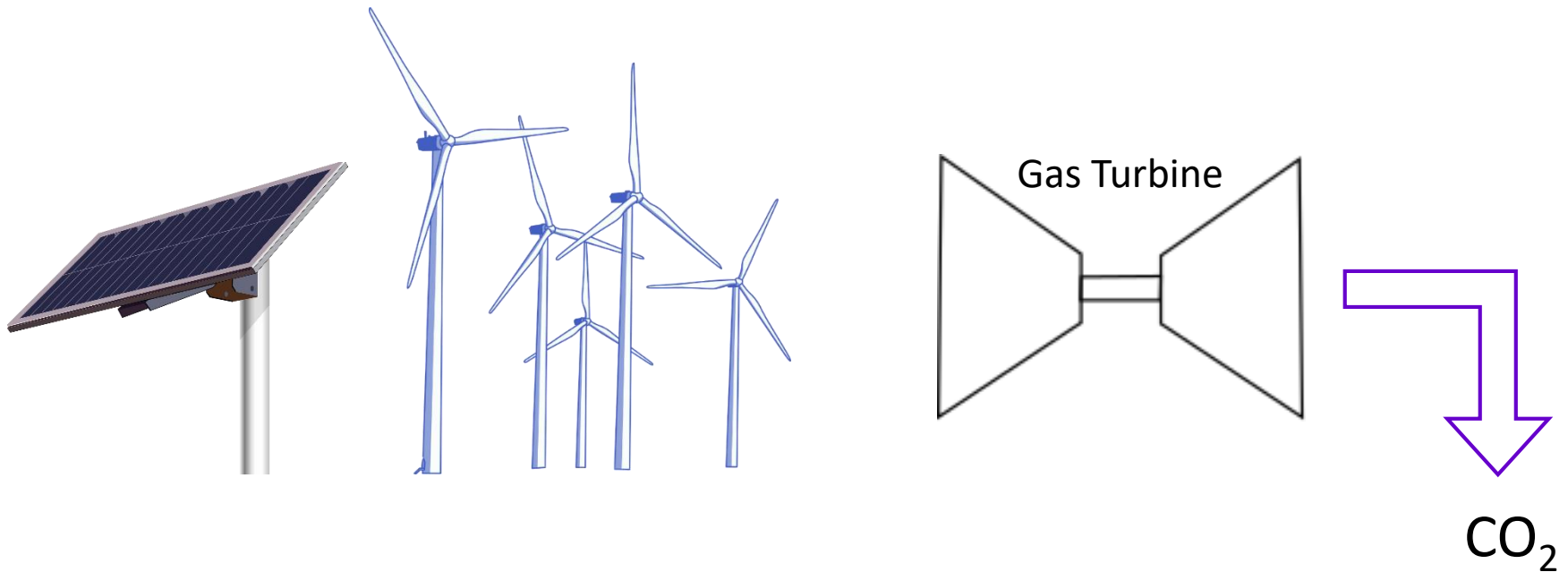
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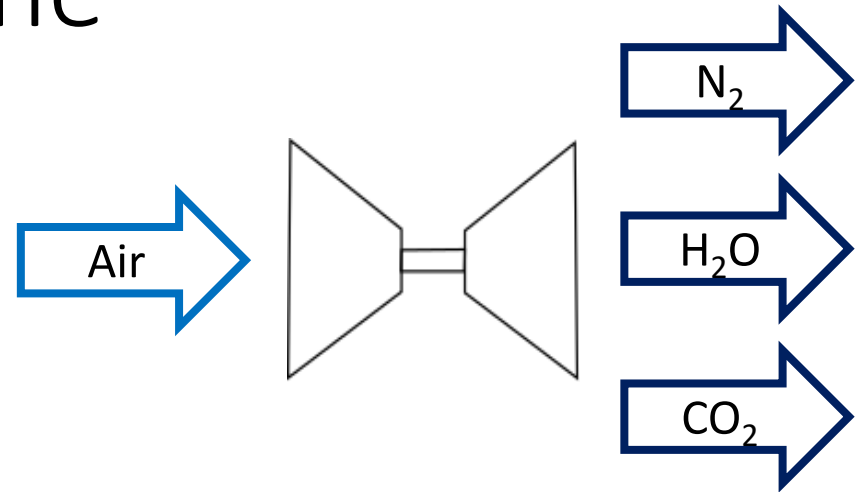
# Motivation

Gas turbines provide flexibility today. How can we **optimally design** and **operate** zero-emission gas turbines for a low carbon emission future?

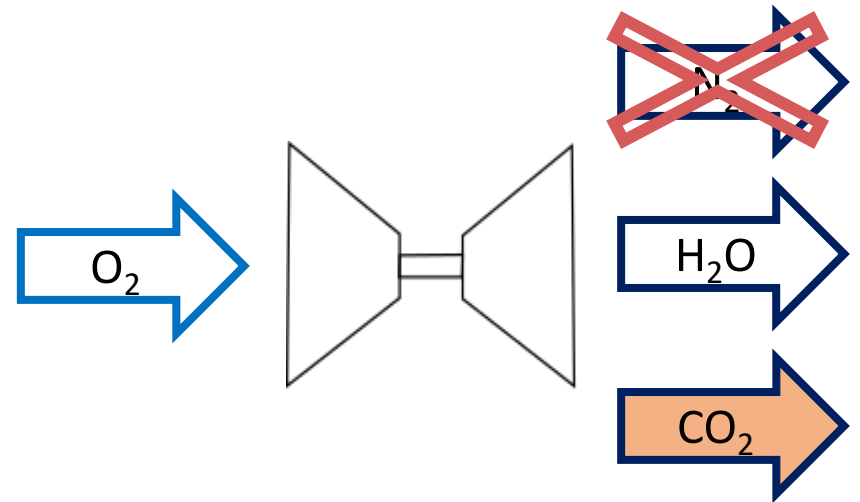


# Oxyfuel Gas Turbine

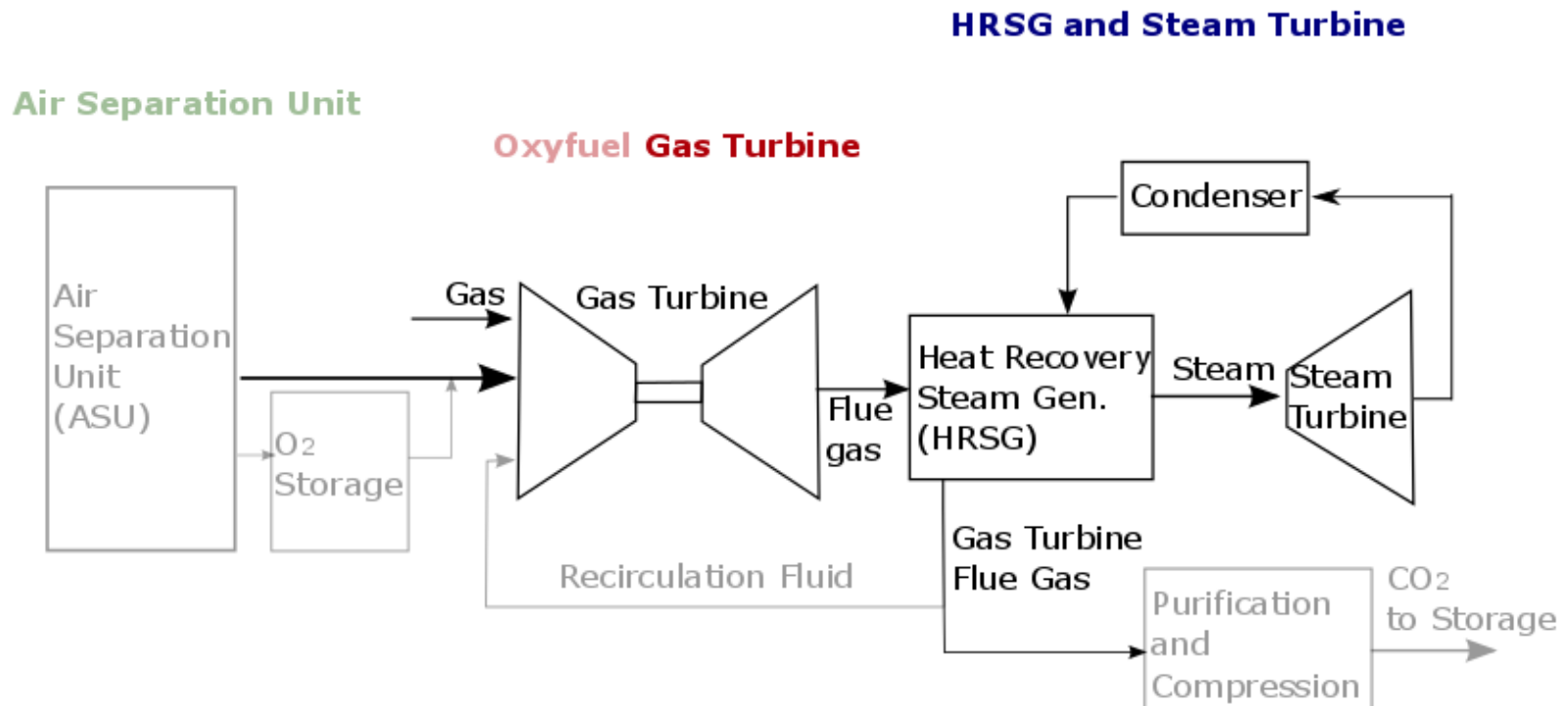
Conventional gas turbine



Oxyfuel gas turbine

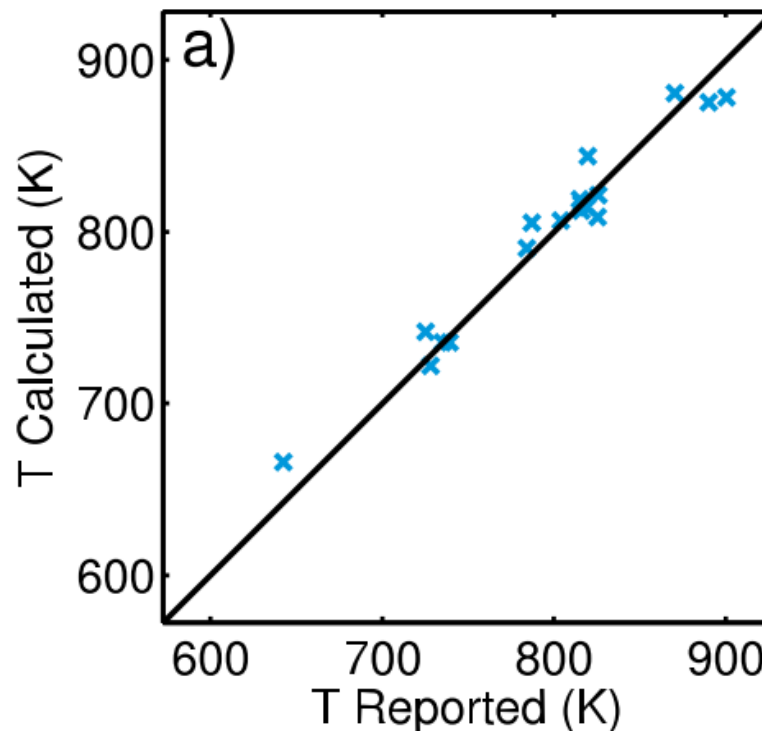


# Semi-Closed Oxyfuel-Combustion Combined Cycle (SCOC-CC)



# Gas Turbine Full Load Model

- Mass and energy balances
- Full load model validated with 18 gas turbines from [GTWH]

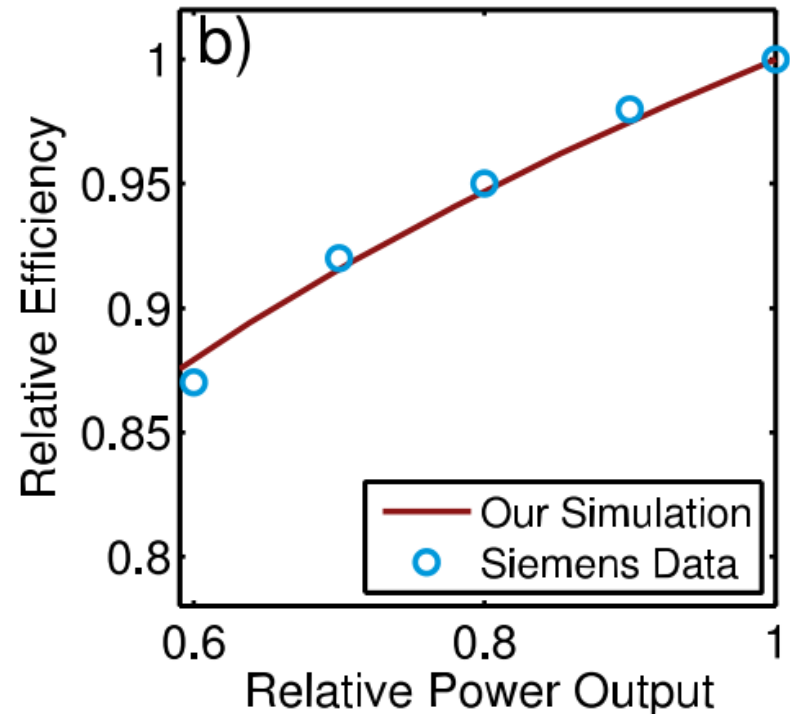


# Gas Turbine Part Load Model

- Assume choked flow at turbine inlet:

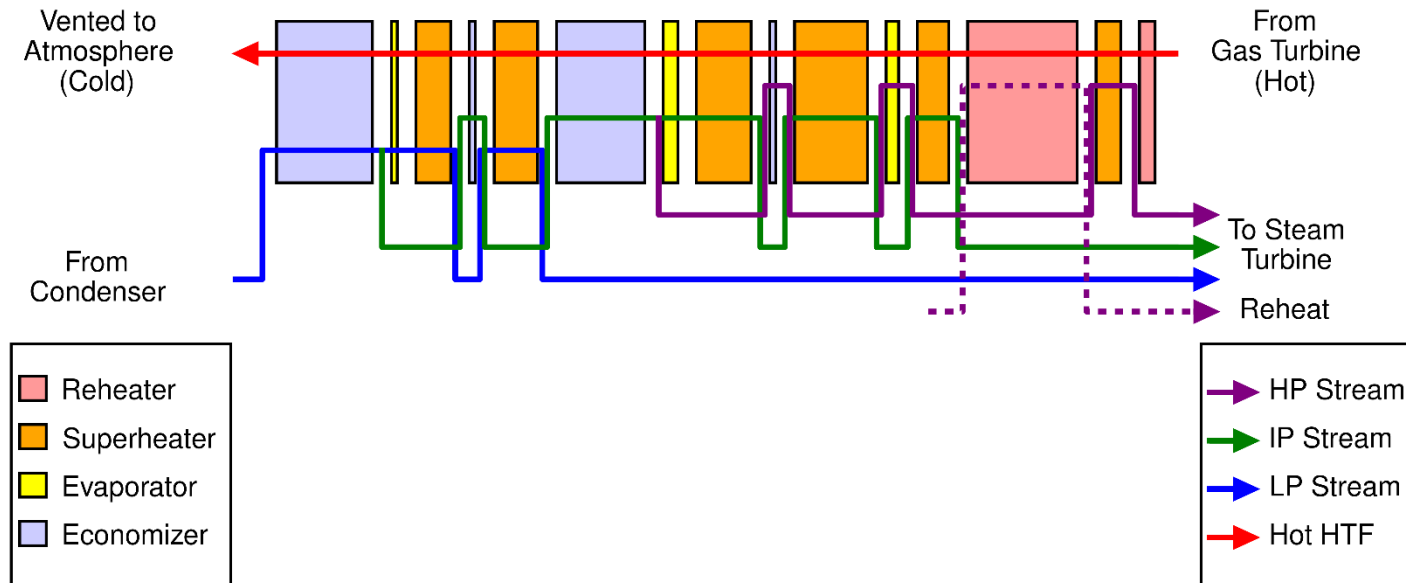
$$\dot{m}_{red} = \frac{\dot{m}_{GT,in} \sqrt{T_{GT,in}}}{P_{GT,in}} = const.$$

- Model validated with data from Jansen et al.

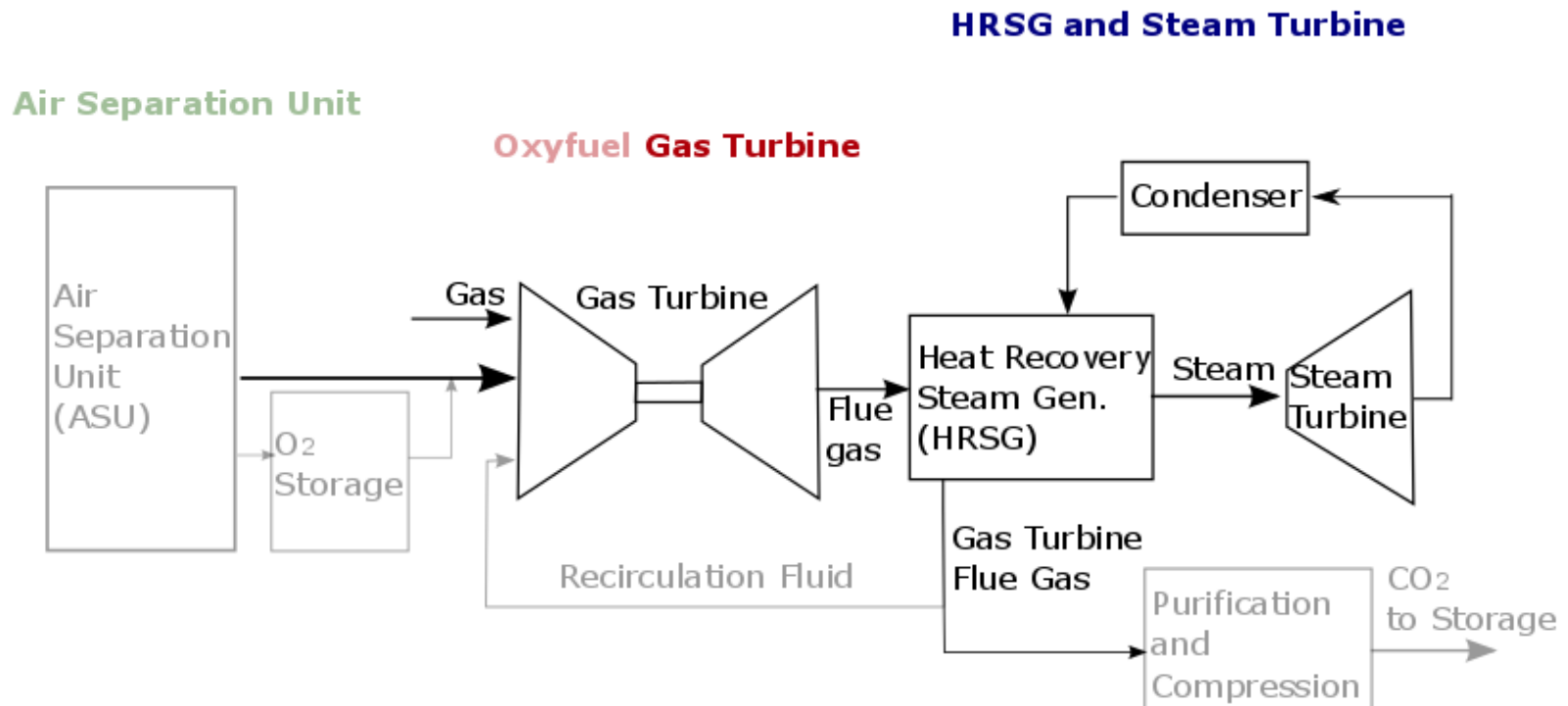


# Heat Recovery Steam Generator

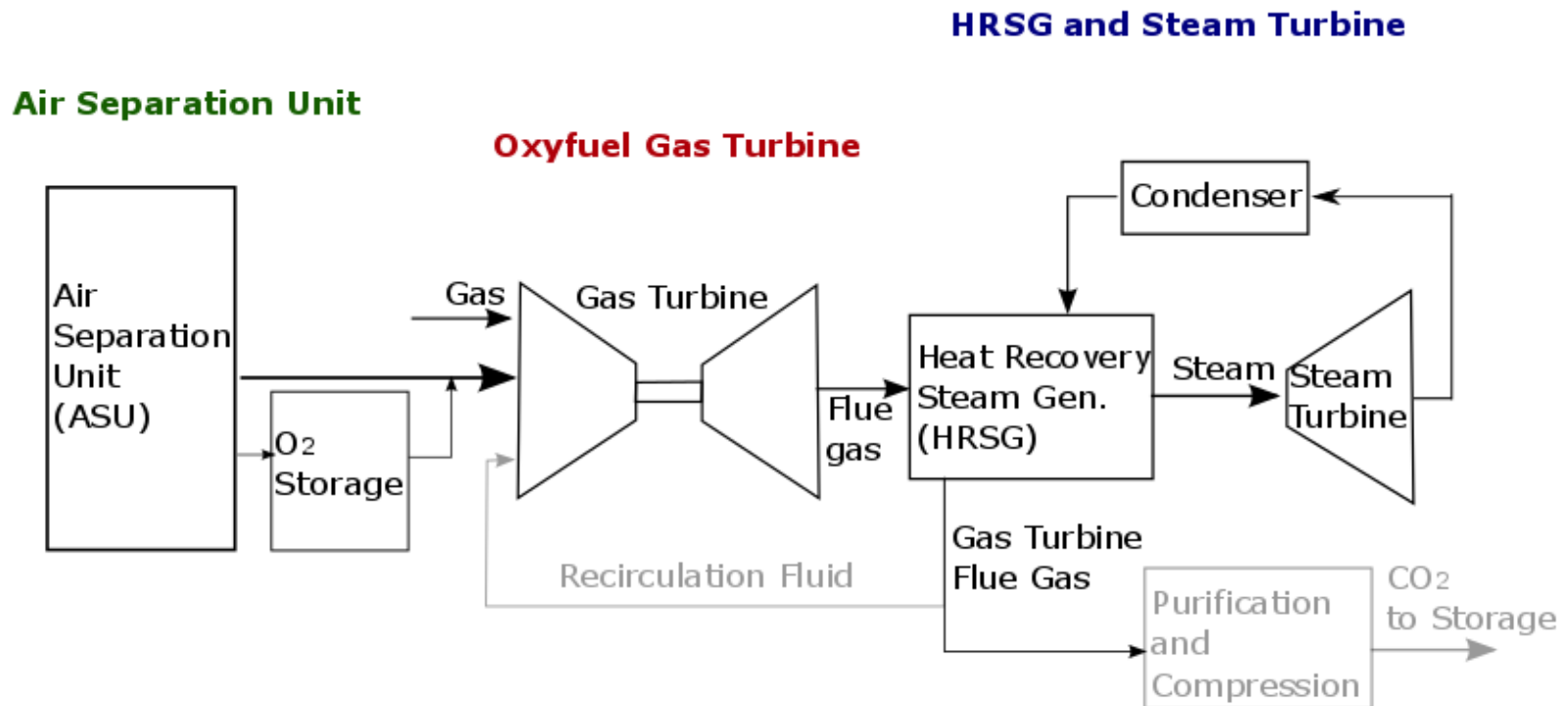
- Heat Recovery Steam Generator (HRSG) and Steam turbine model developed by Kang et al. and Brodrick et al.



# Semi-Closed Oxyfuel-Combustion Combined Cycle (SCOC-CC)

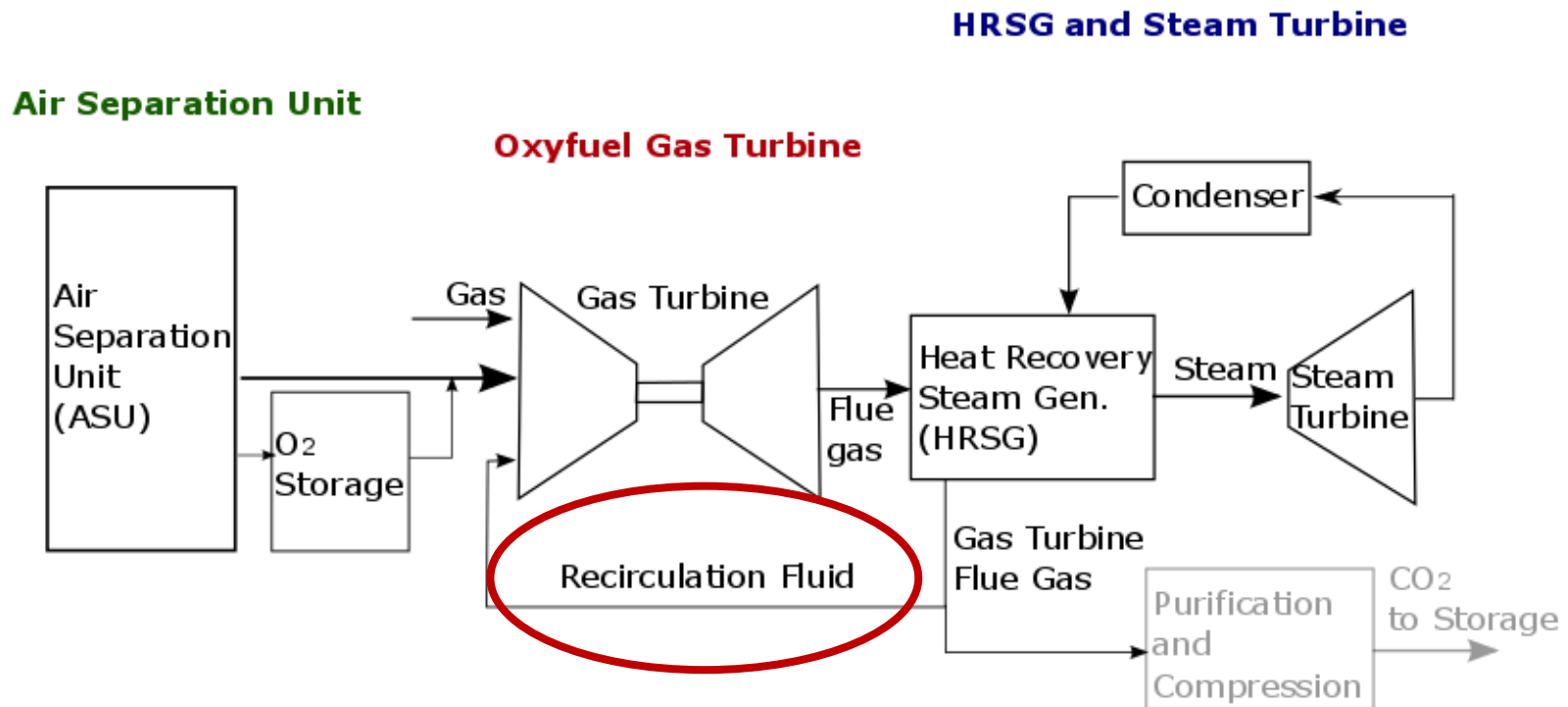


# Semi-Closed Oxyfuel-Combustion Combined Cycle (SCOC-CC)



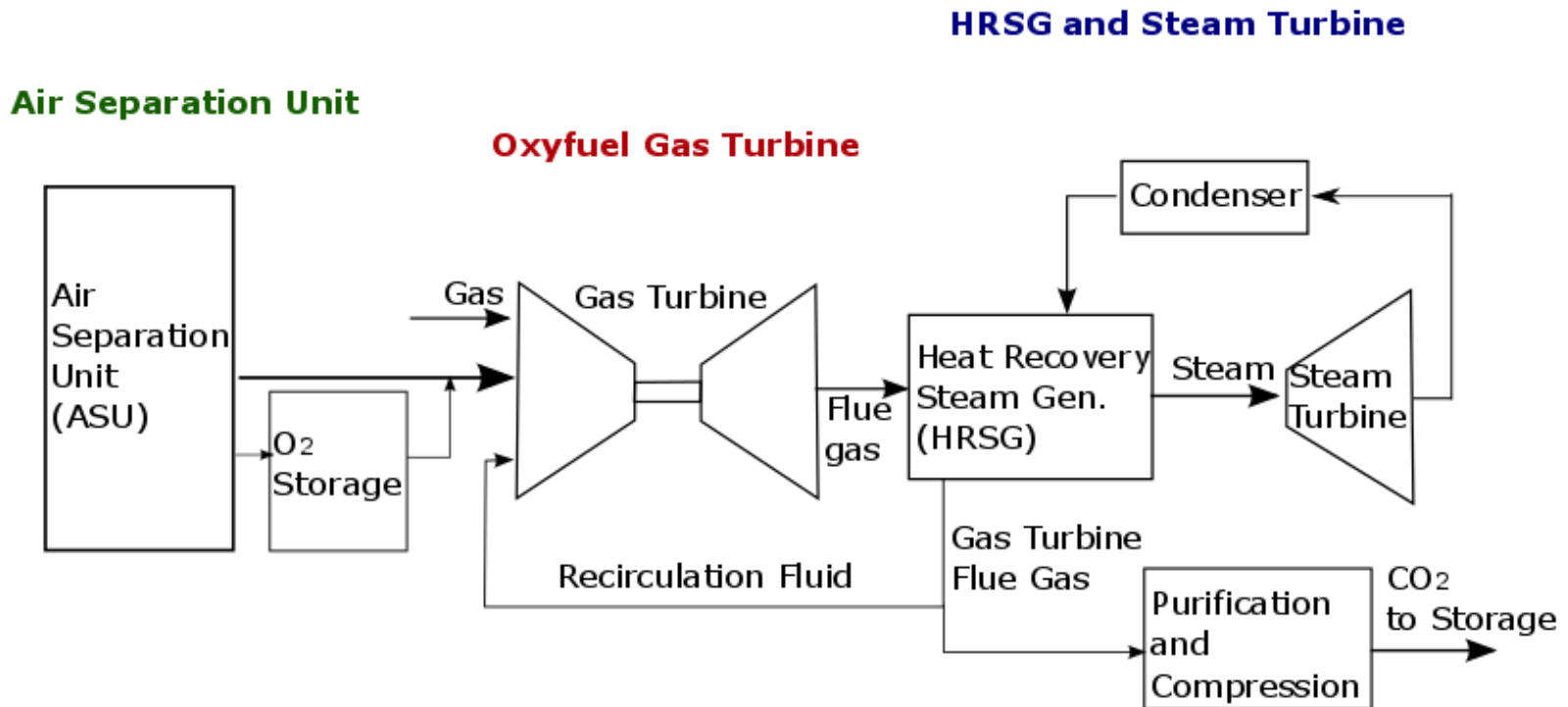
- Air Separation Unit and Oxygen Storage based on empirical data from [Linde2015]

# Semi-Closed Oxyfuel-Combustion Combined Cycle (SCOC-CC)

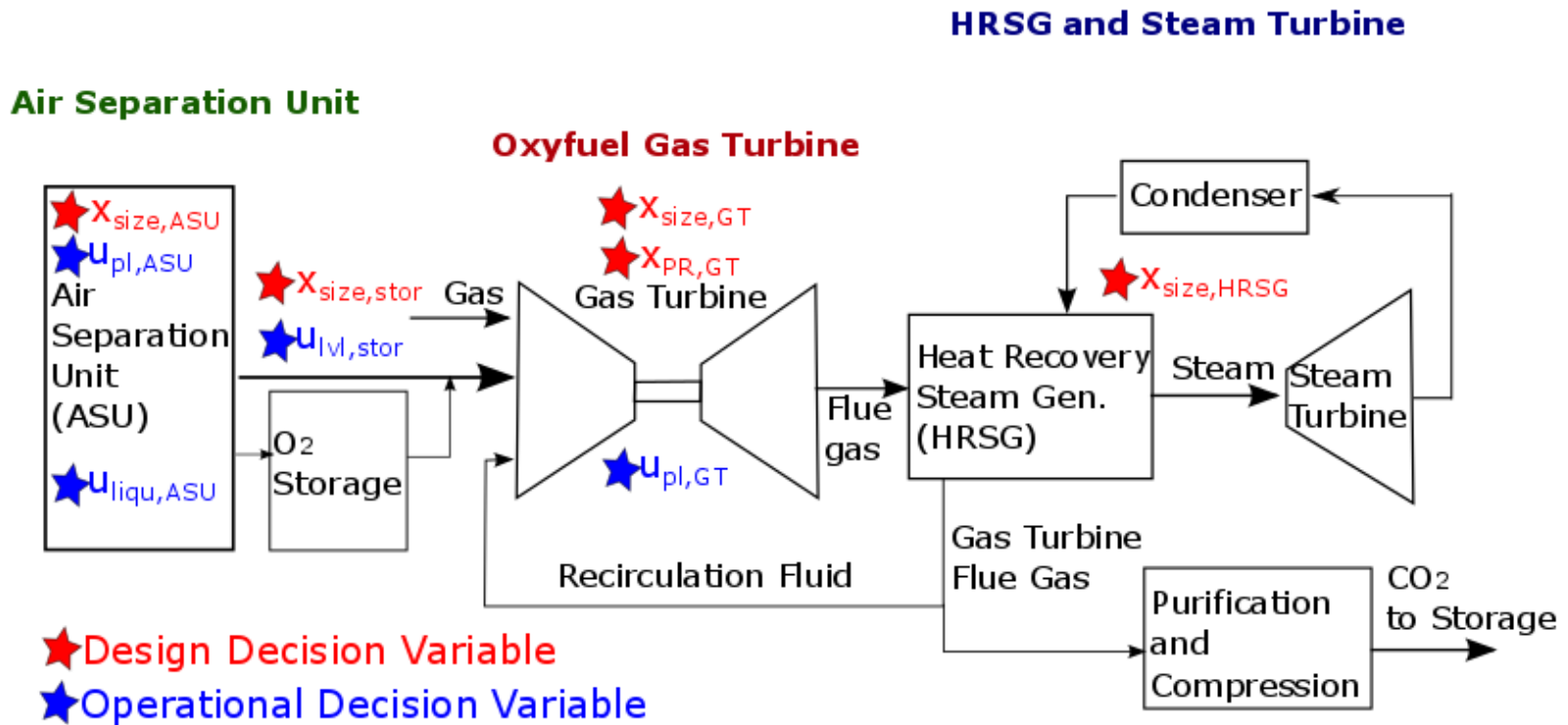


- Recirculation Fluid: 88.5% CO<sub>2</sub>, 2% H<sub>2</sub>O, 3% N<sub>2</sub>, 6.5% Ar (all vol%)

# Semi-Closed Oxyfuel-Combustion Combined Cycle (SCOC-CC)



# Semi-Closed Oxyfuel-Combustion Combined Cycle (SCOC-CC)



- Build a 400 MW gross power output SCOC-CC

# Optimization Formulation – NLP

- Maximize Net Present Value (NPV)

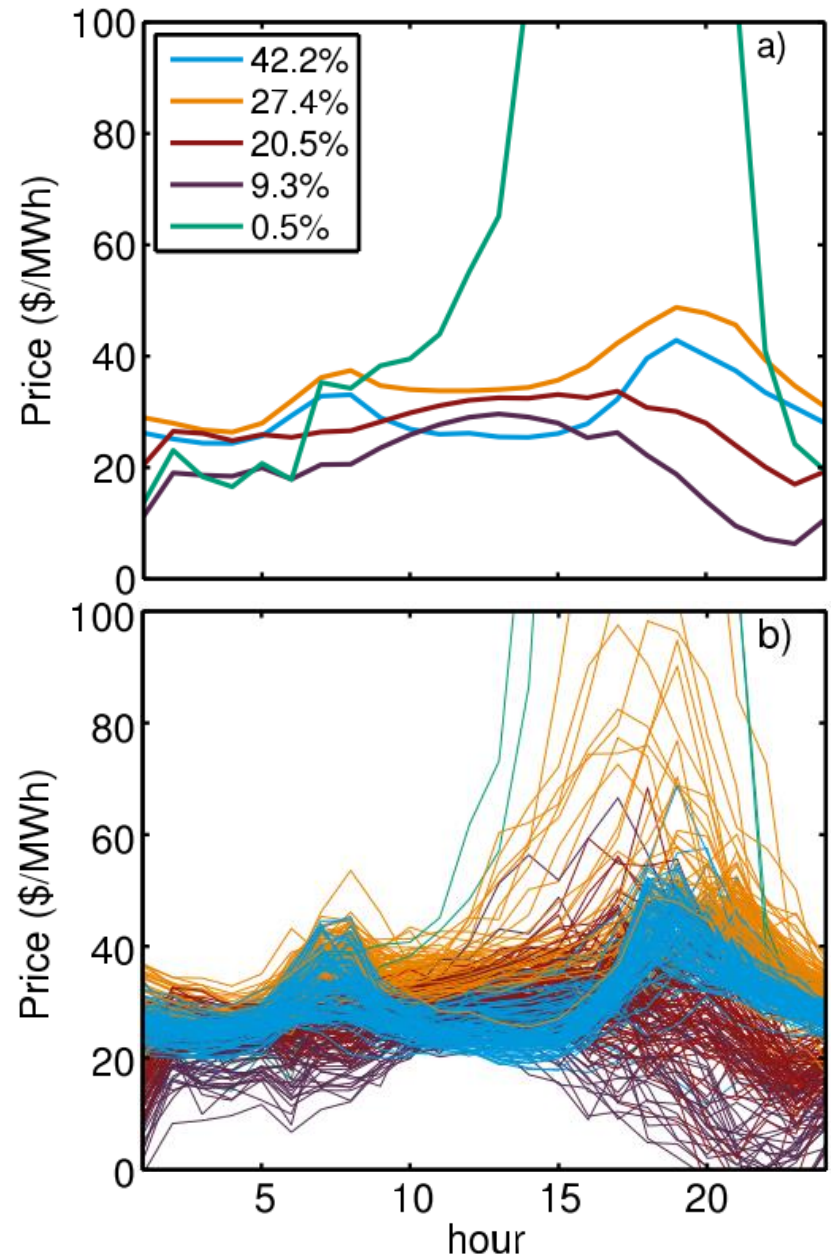
# Optimization Formulation – NLP

- Maximize Net Present Value (NPV)
- Two optimization loops: design (MIDACO) and operations (SNOPT)

$$\begin{aligned} & \max_{\mathbf{x} \in X, \mathbf{u} \in U} \text{NPV}(\mathbf{x}, \mathbf{u}) \\ & = \max_{\mathbf{x} \in X} \left( -C(\mathbf{x}) + \underbrace{\max_{\mathbf{u} \in U} \left( \sum_{\tau=1}^{N_{years}} \frac{P(\mathbf{x}, \mathbf{u})}{(1+r)^\tau} \right)}_{\text{s.t. } h_{op}(\mathbf{x}, \mathbf{u}) \leq 0} \right) \\ & \quad \underbrace{\hspace{10em}}_{\text{s.t. } h_{des}(\mathbf{x}) \leq 0, h_{op}(\mathbf{x}, \mathbf{u}) \leq 0} \end{aligned}$$

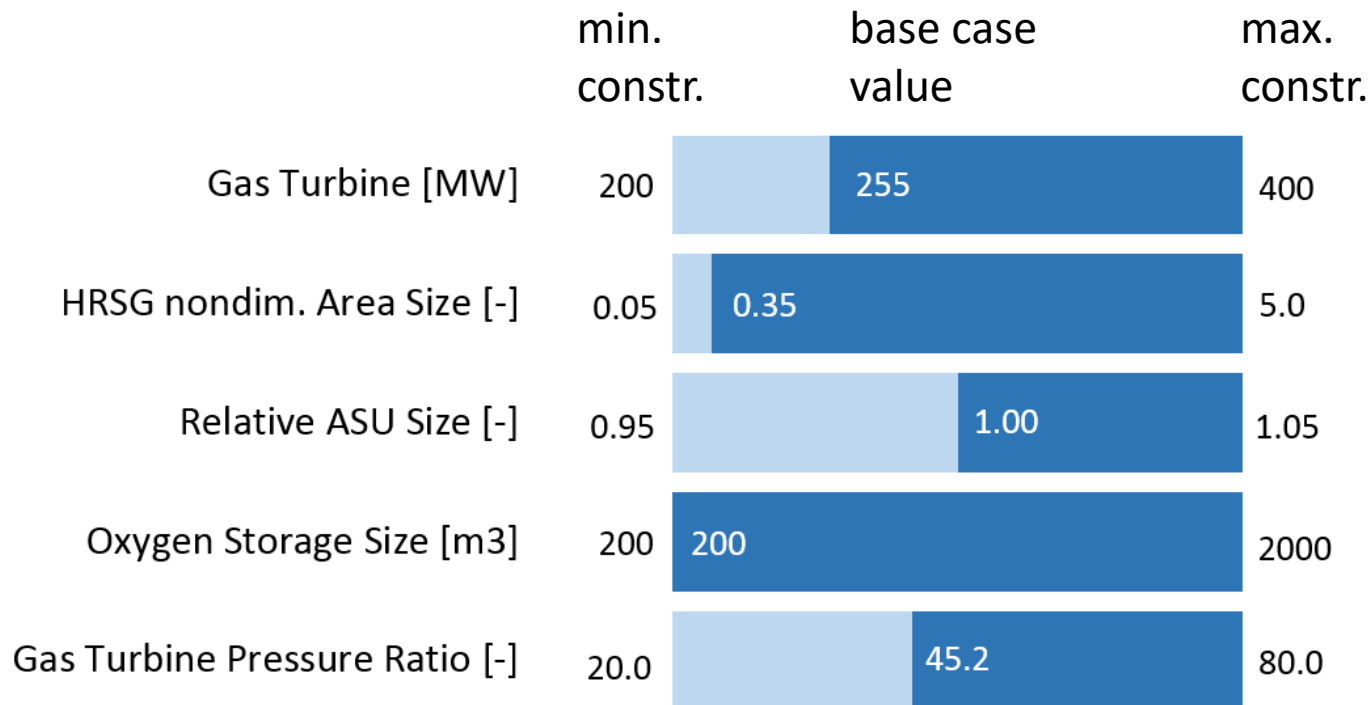
# Generating Representative Days

- Function evaluations are too expensive to run 365 days
- Use *k-means clustering*
- $k=5$  representative days

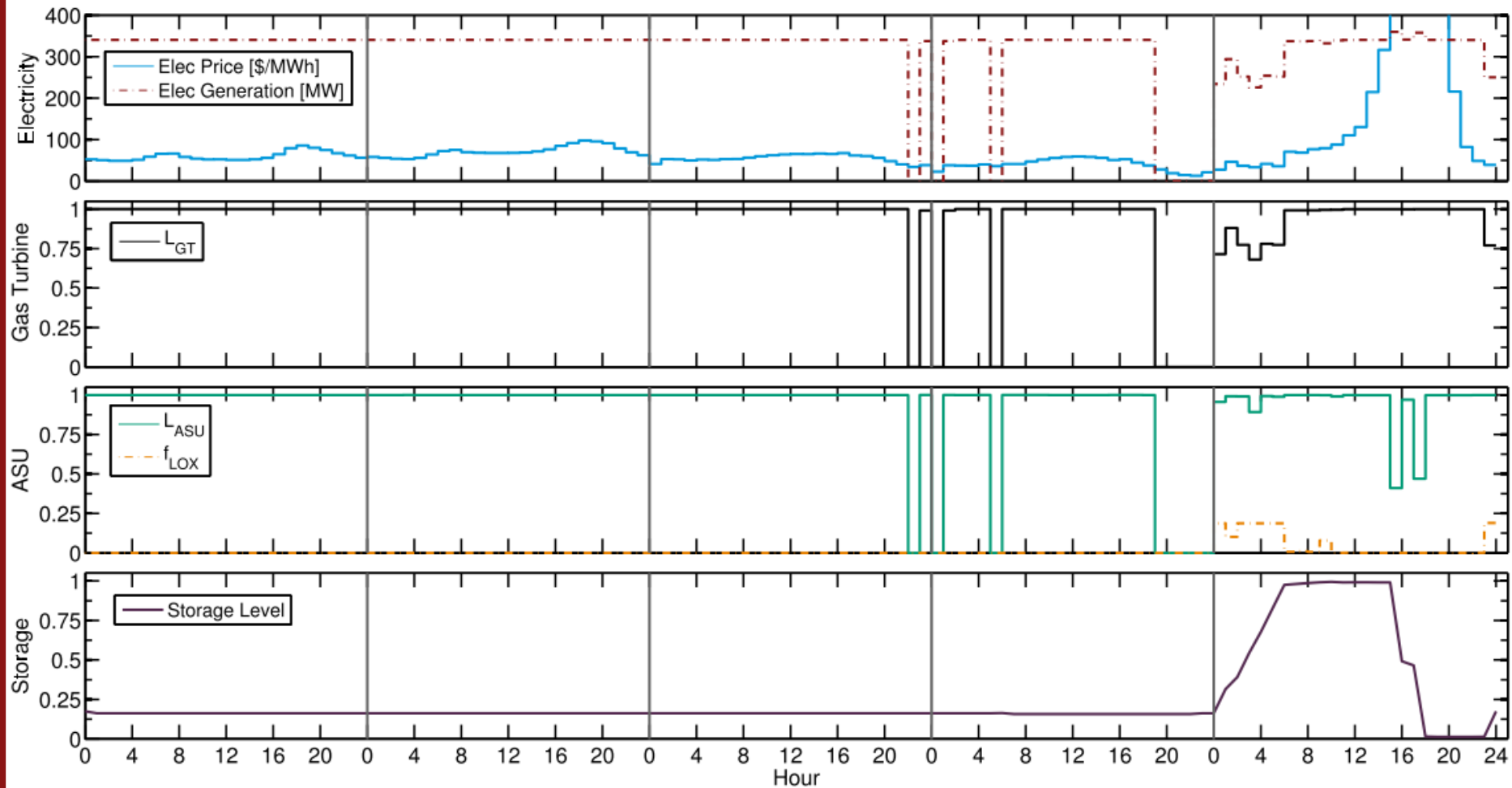


# Base Case

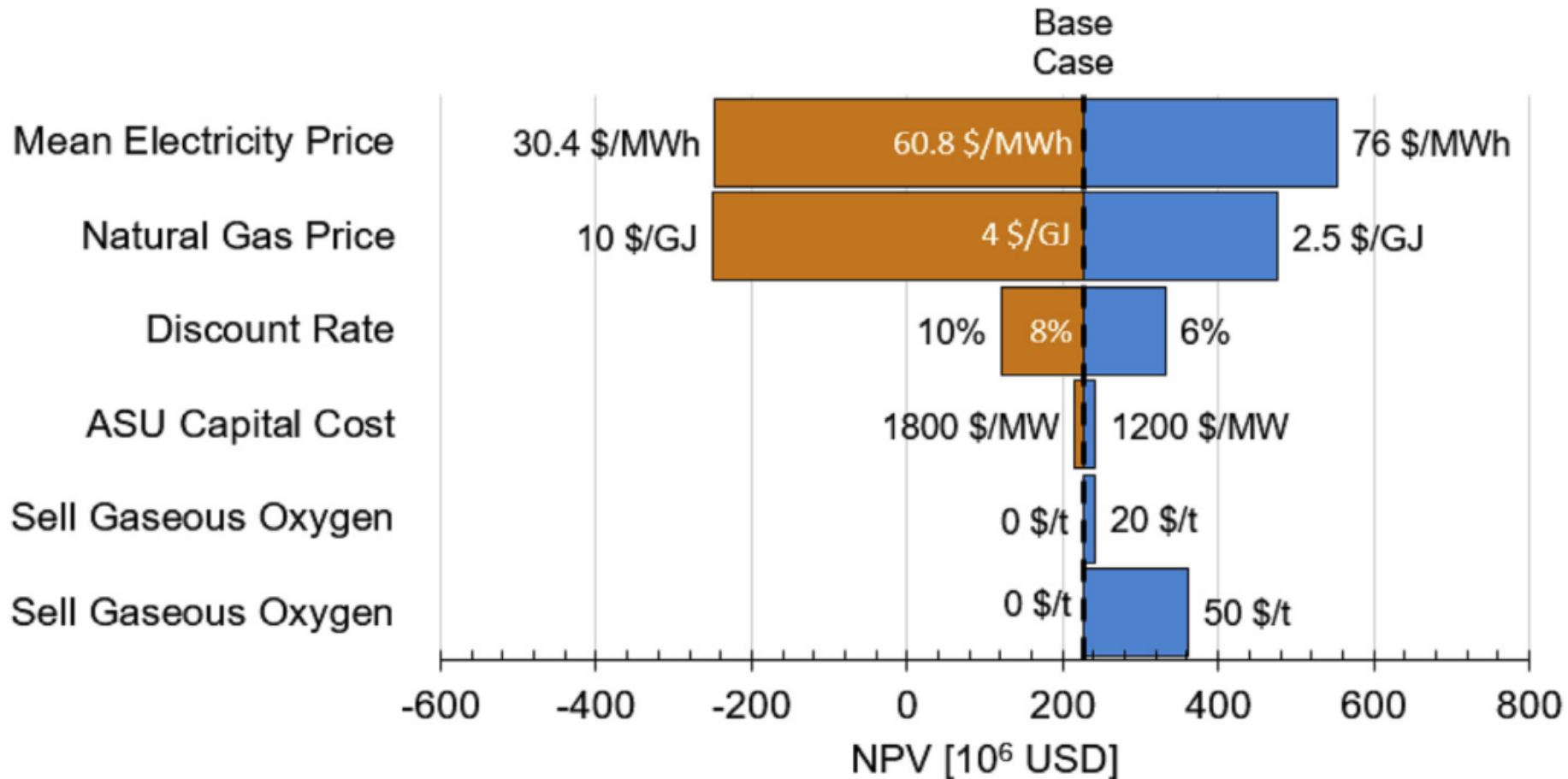
- Build 400 MW gross power output capacity
- Electricity price two times California 2015
- Net Present Value: 220.6 Million USD



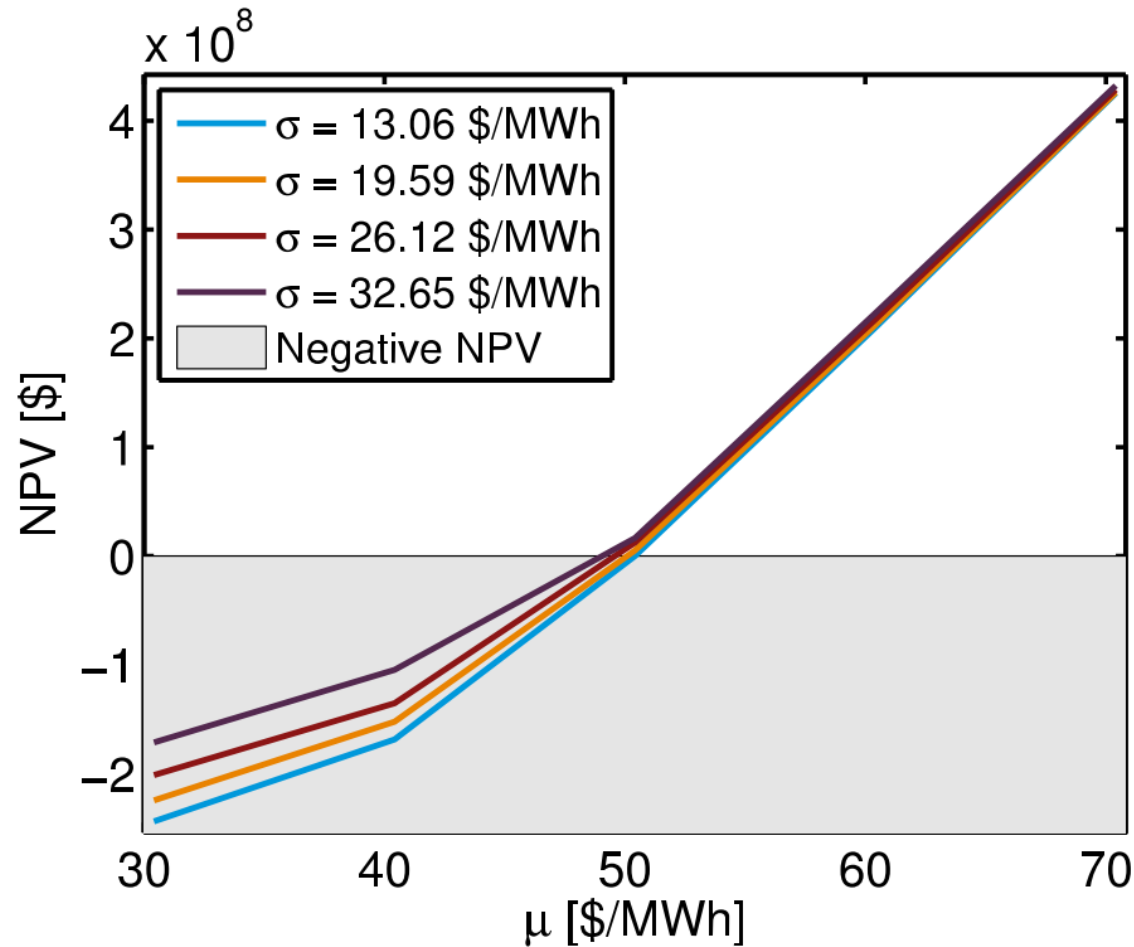
# Base Case – Operating Profile



# NPV Sensitivity Analysis



# Sensitivity to electricity price changes



# Conclusion

- **Optimal design** and **operation** of a semi-closed oxy-combustion combined cycle power plant
- Overall system profitability depends mostly on external economic parameters
- Value of storage in this system is low
- Electricity price variability does not strongly impact system design and profitability

# Thank you

Financial support from the Wells Family Stanford Graduate Fellowship is greatly appreciated.

## References:

[P1] <https://pixabay.com/en/blue-electricity-pale-turbine-wind-1294725/>

[P2] <https://pixabay.com/en/solar-panel-photovoltaic-solar-cells-303455/>

[GTWH] Farmer, R., deBiasi, B., Isles, J., Jaeger, H., Cornett, M., & Janson, J. (2013). *Gas Turbine World Handbook*. (R. Farmer, Ed.) (Vol. 30)

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