Performance Evaluation of Hydrogen Oxyfuel Steam Cycles

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Context and motivation

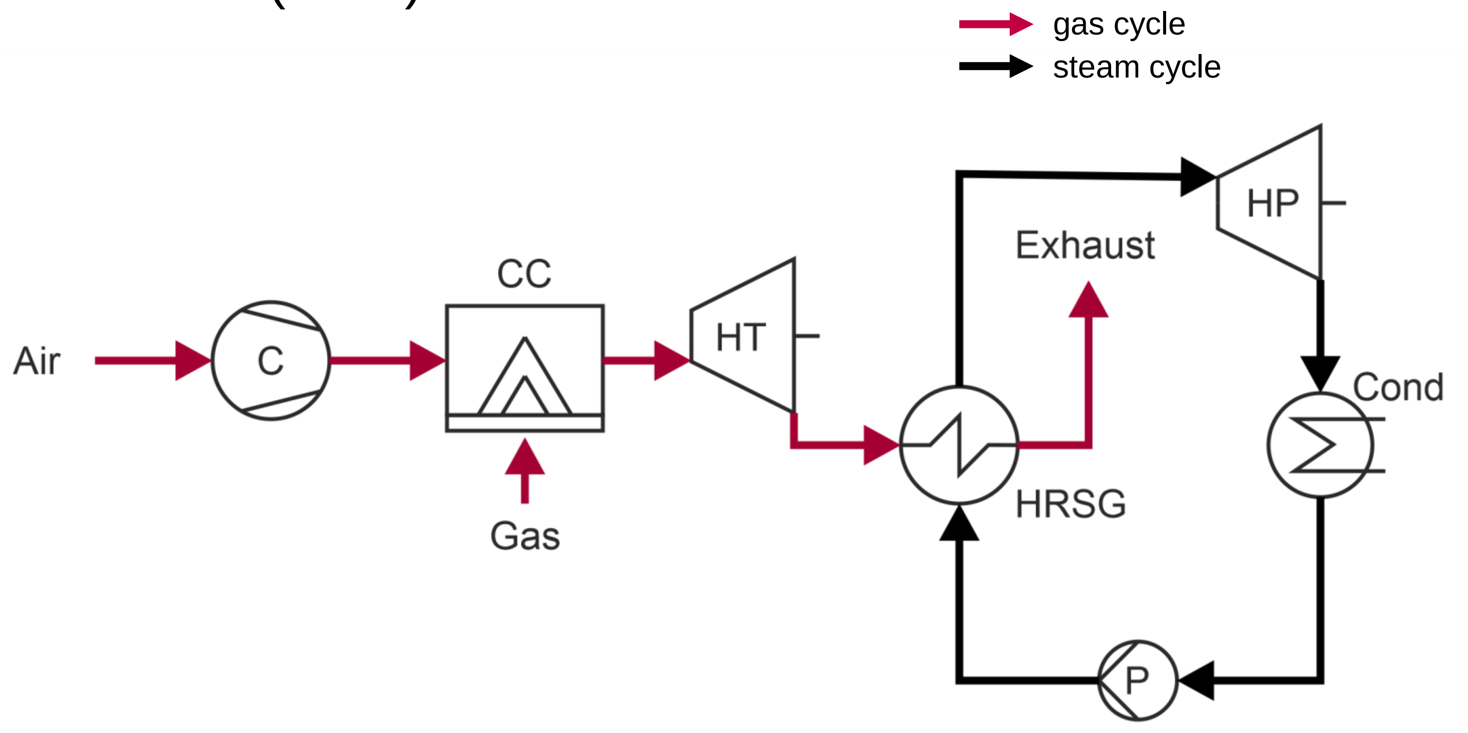
- Energy transition towards renewable production
- Highly fluctuating
- Necessity to store energy: green hydrogen
- Challenges: production, storage, transport and
- Reconversion to electricity
  - Efficient: high thermal efficiency
  - Large scale (500 MW)
  - Without emissions

➡ **Hydrogen oxyfuel cycles**

working fluid + $2H_2 + O_2 = 2H_2O$ + working fluid

Basic principle of a hydrogen oxyfuel process in steam

- „Combining gas turbine philosophy with steam plant practice“ Jericha et al. (1995) [1]



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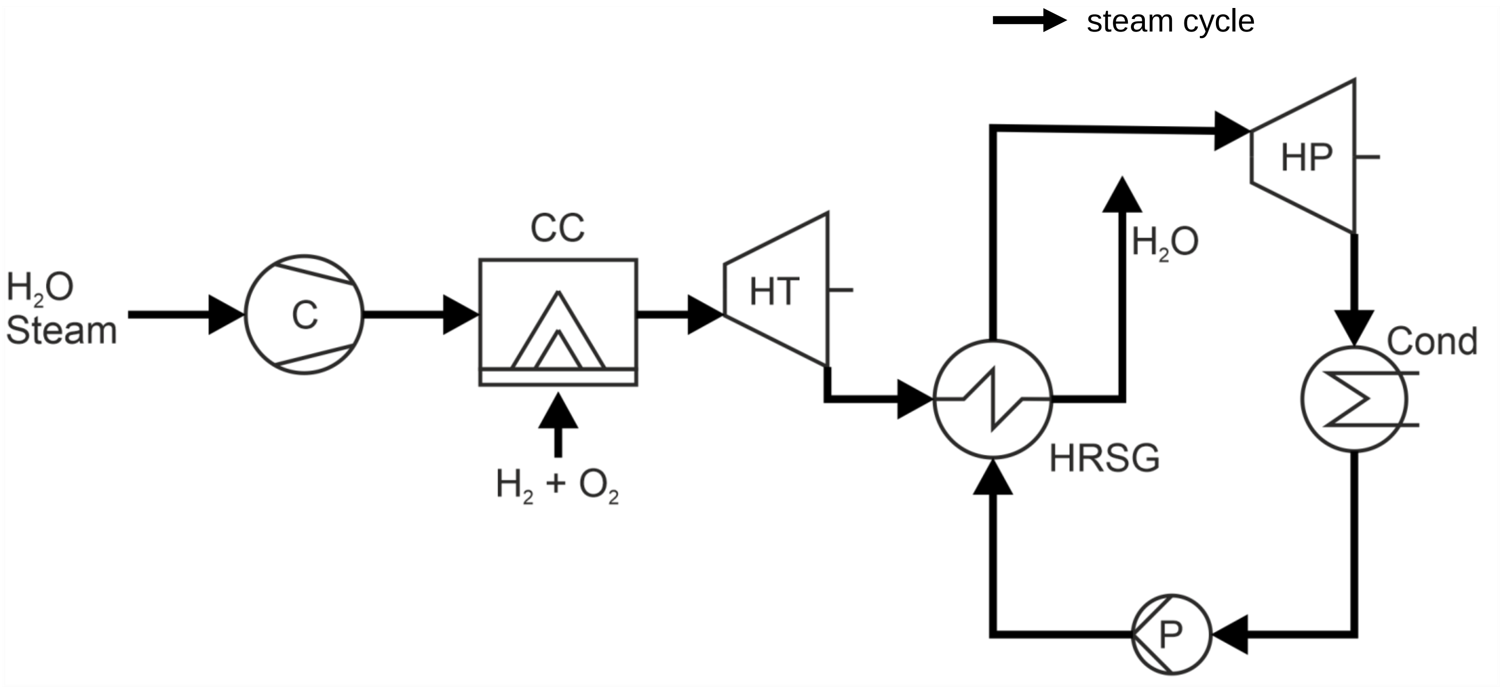

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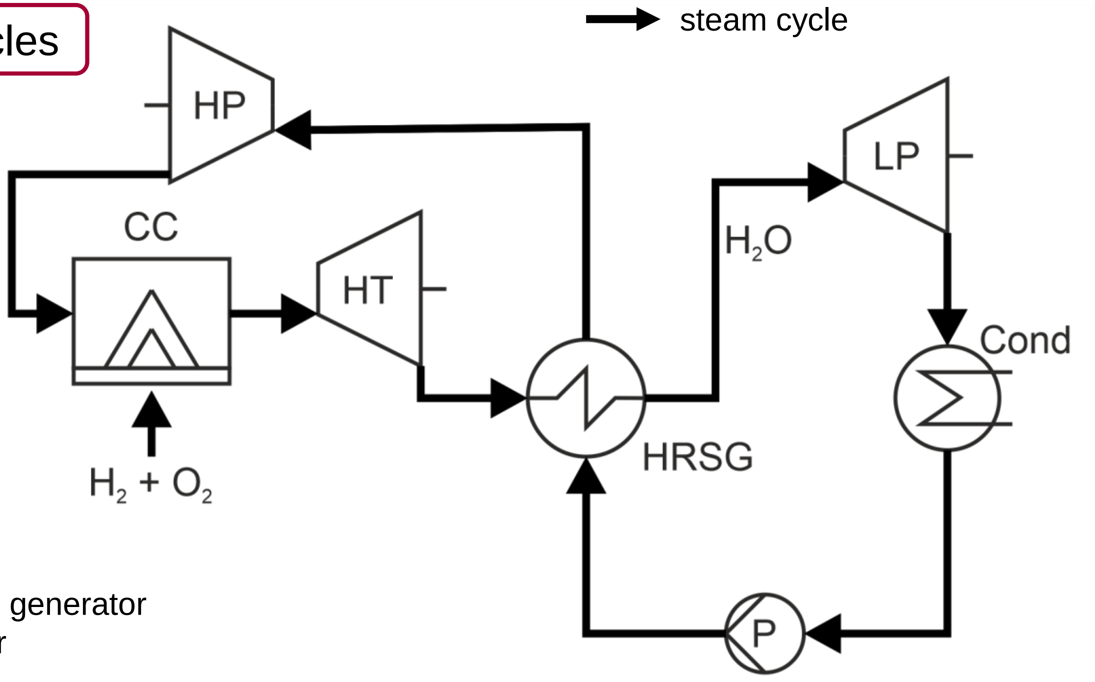
Fully condensing cycles



HRSG: heat recovery steam generator
CC: combustion chamber
HP: high pressure
HT: high temperature
P: pump
LP: low pressure

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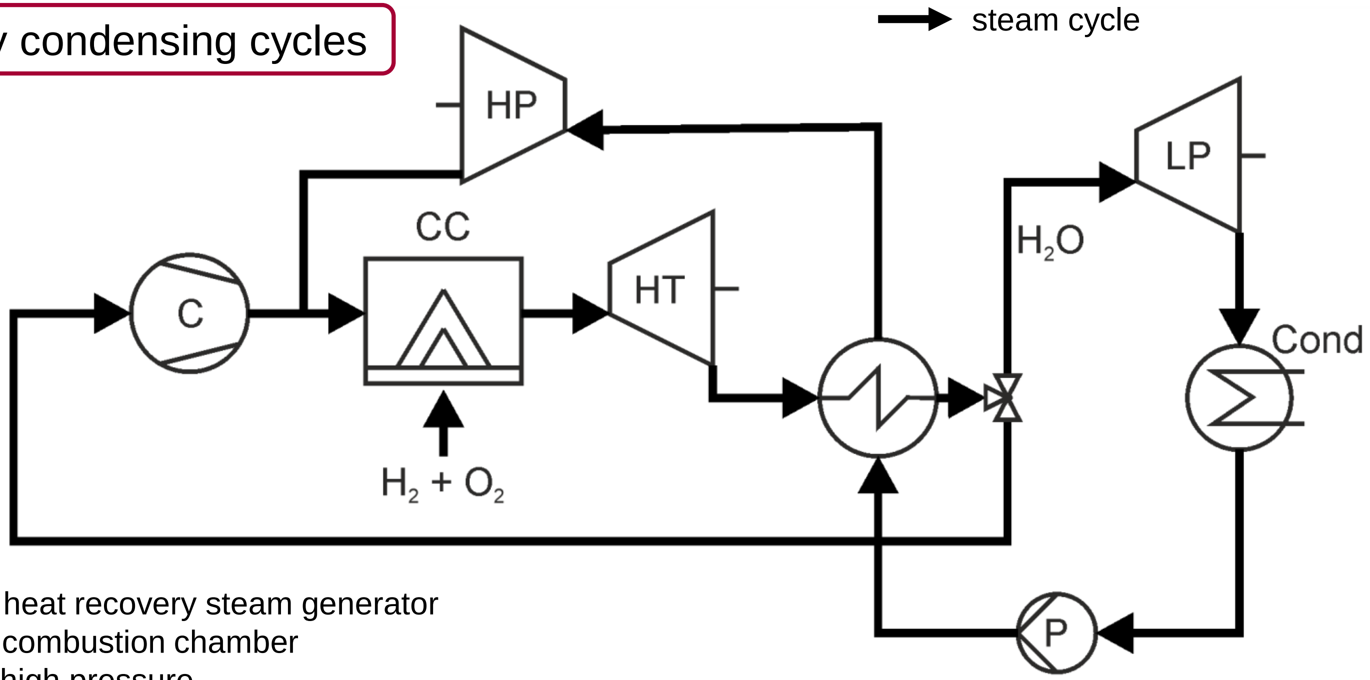
Partly condensing cycles



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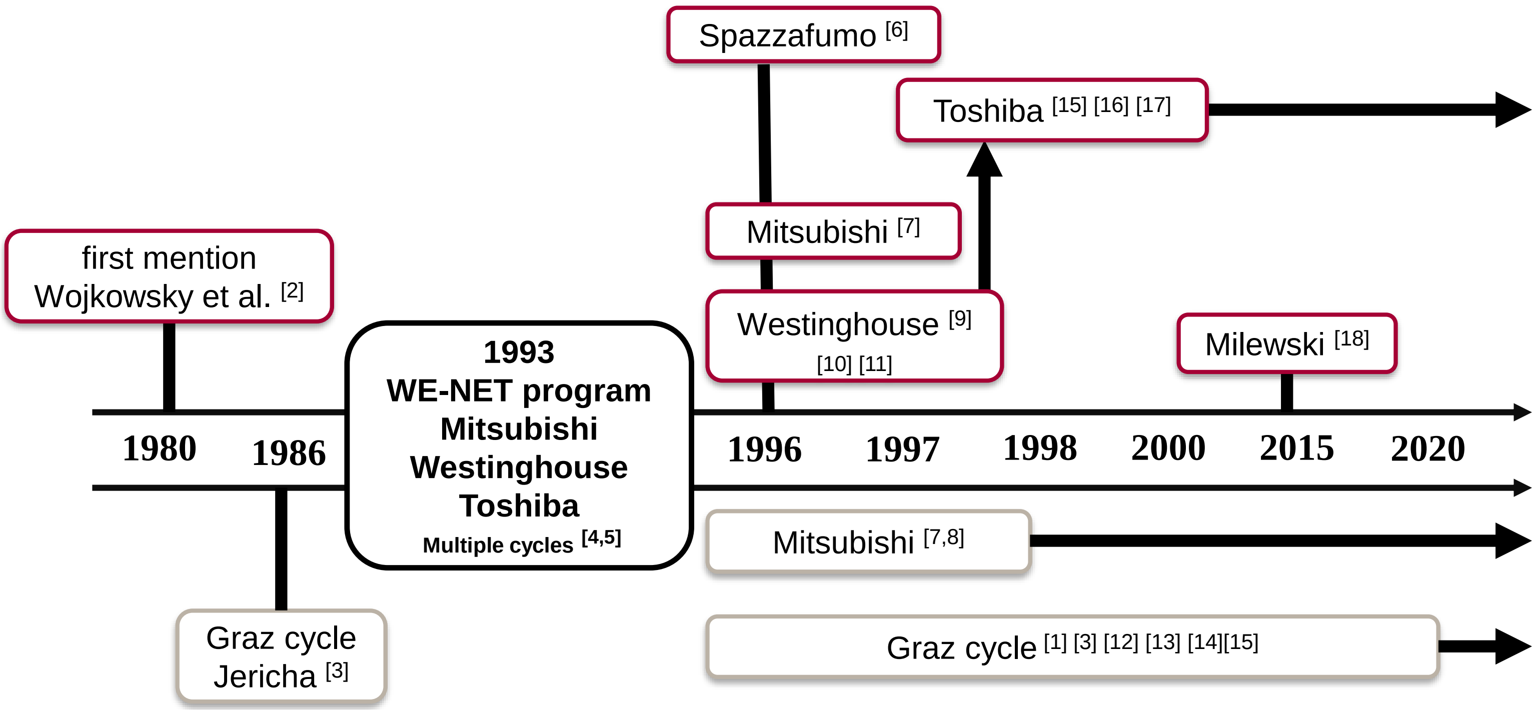
History and evolution of the hydrogen oxyfuel steam cycles

Fully condensing cycles



Partly condensing cycles

History and evolution of the hydrogen oxyfuel steam cycles

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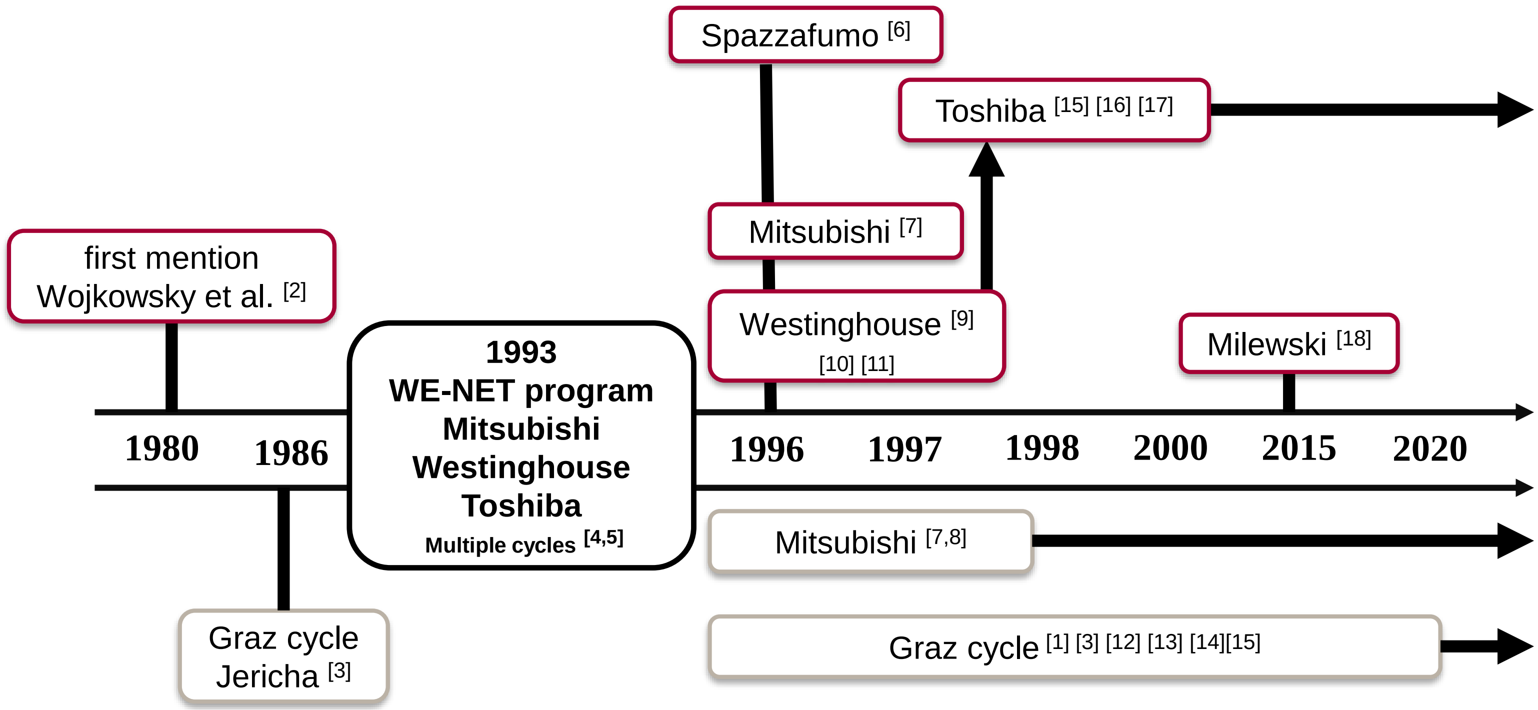
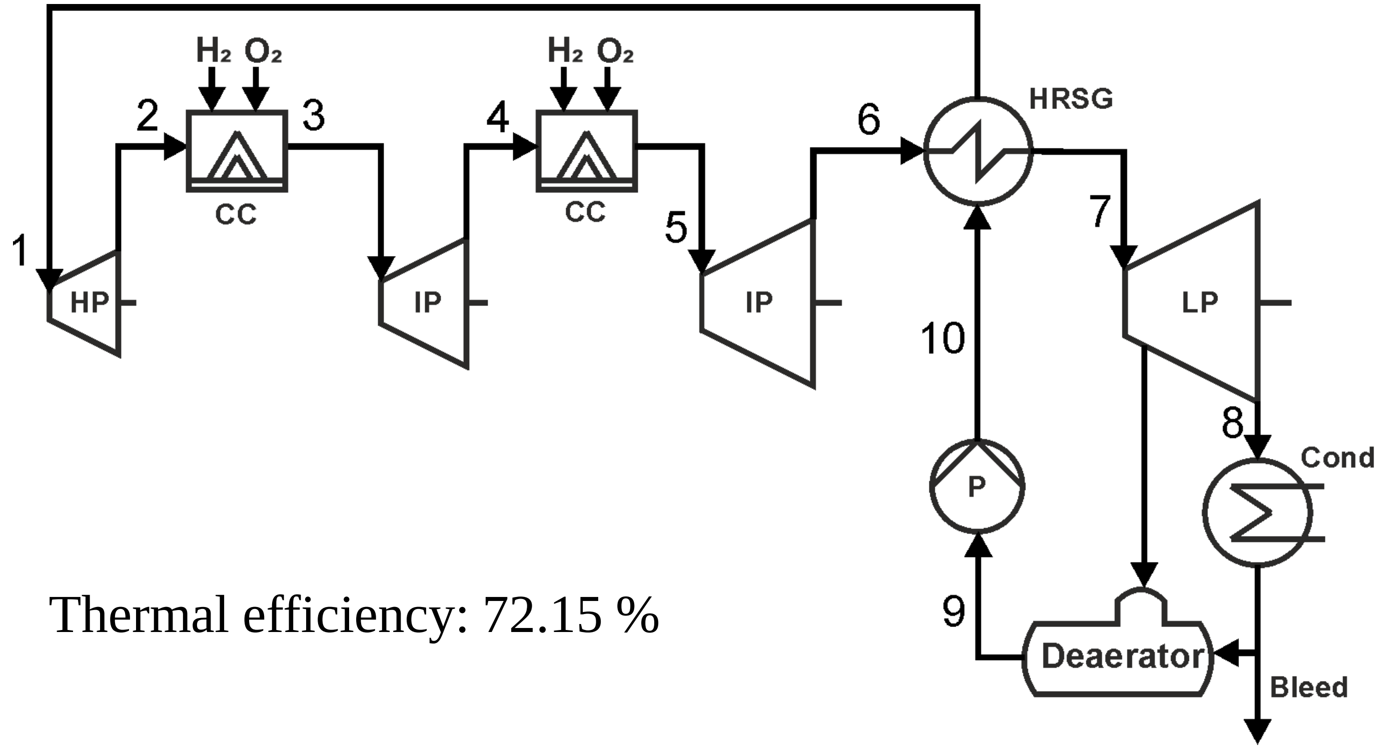


Partly condensing cycles

To this date:
no cycle has been built

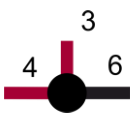
Fully condensing cycle: Toshiba principle

- Extraction of unburned H_2 and O_2
- Low complexity
- Very high thermal stress in HRSG
- Depending on high TIT

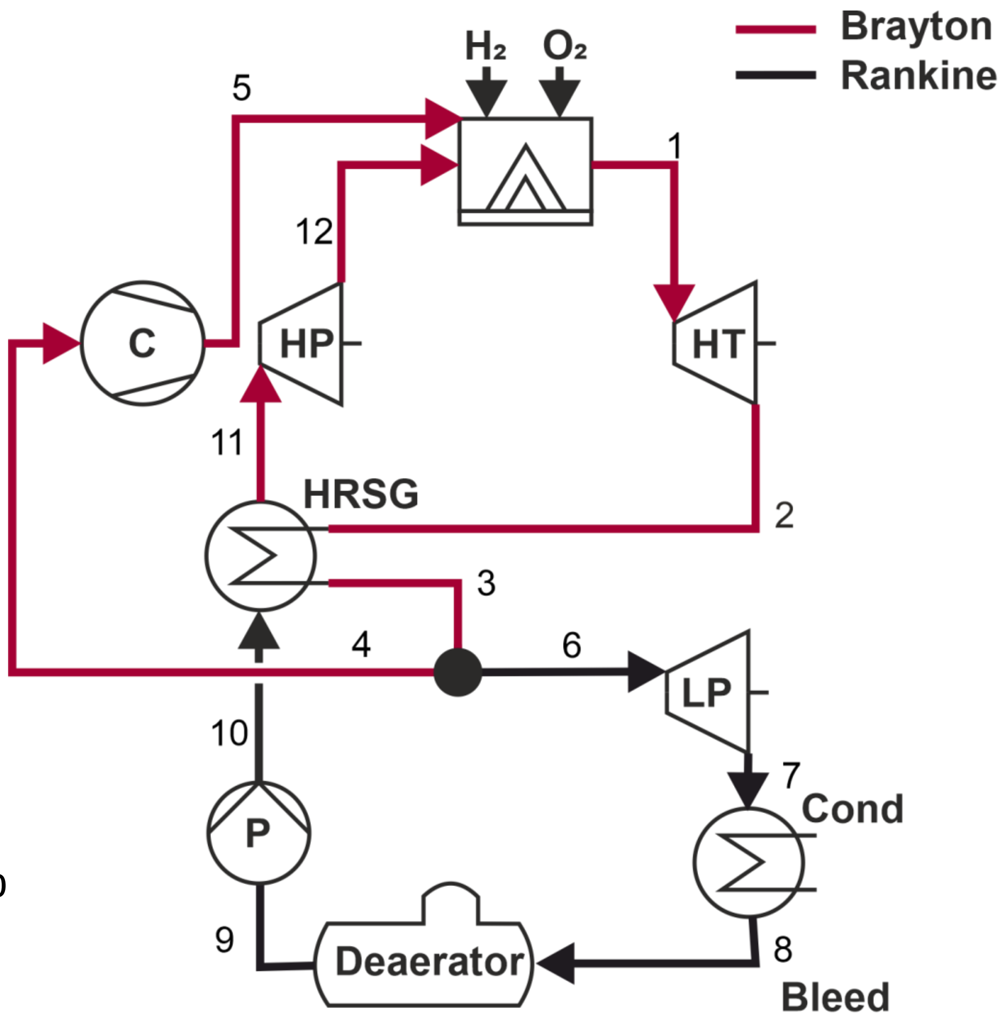


Thermal efficiency: 72.15 %

Partly condensing cycle: Graz principle

- Splitting point (3) 

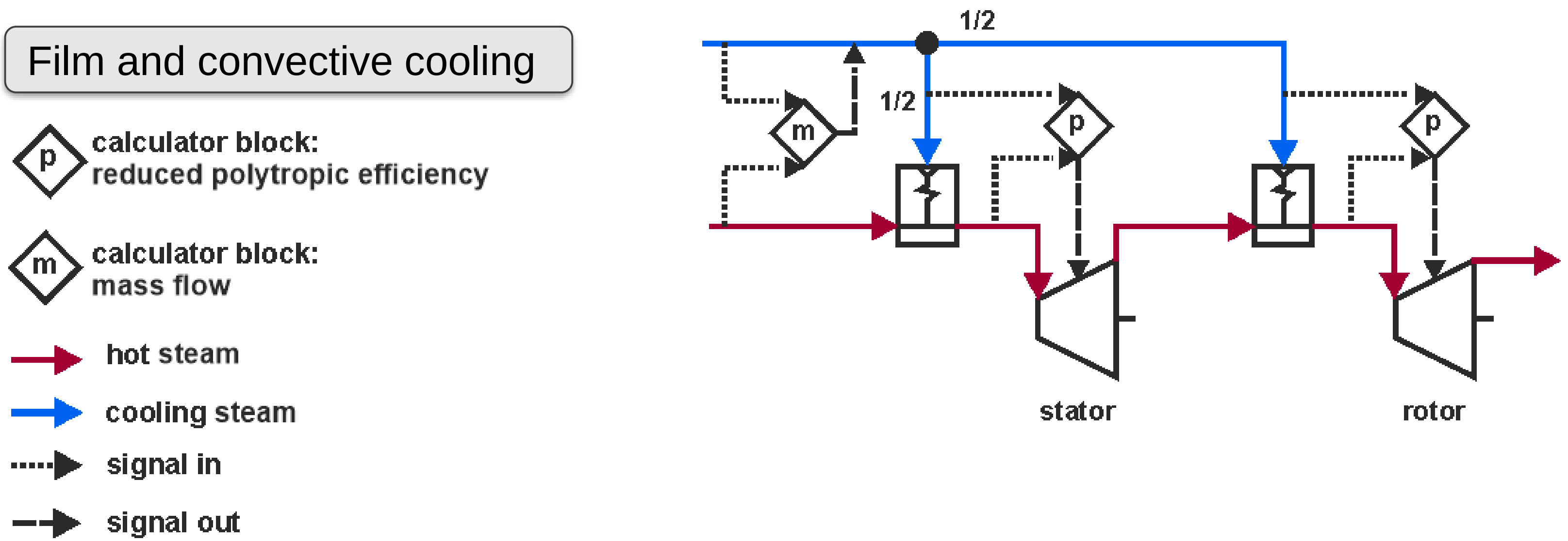
  - Crucial
  - Grants flexibility
- Two most relevant cycles
  - Mitsubishi
  - Graz



- Highly flexible
- High complexity
- Thermal efficiency: 70.35 %

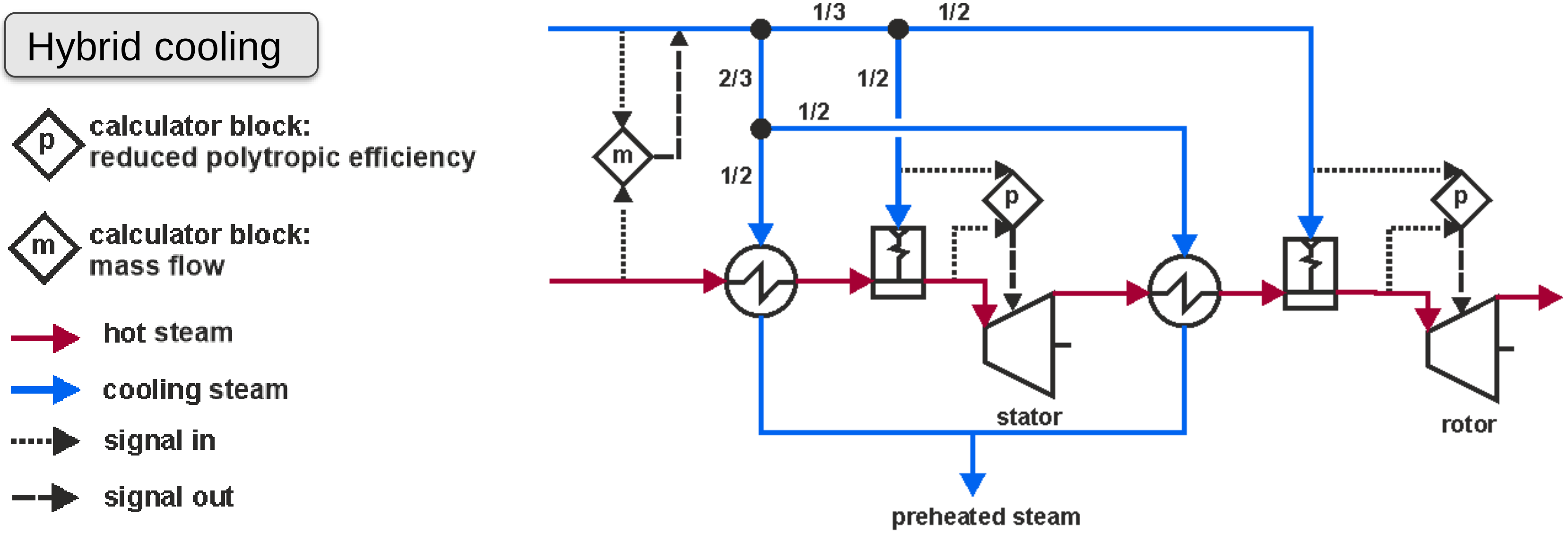
High temperature turbine cooling

Film and convective cooling



- Simplified model required
- Cooling and expansion treated independently:
  1. Calculation of cooling mass flow
  2. Mixing with the main steam
  3. Expansion with reduced polytropic efficiency

High temperature turbine cooling



- Simplified model required
- Cooling and expansion treated independently:
  1. Calculation of cooling mass flow
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Selected cycles and model validation

- Selection criteria:
  - Turbomachinery limits
  - Thermal efficiency
  - Complexity
- Selected cycles:
  - Toshiba
  - Graz
  - Mitsubishi

- Validation with **parameters from original** description and **adopted cooling** technology:
  - Toshiba: hybrid cooling
  - Graz: film and convective cooling
  - Mitsubishi: none

Results of the validation: cycle thermal efficiencies			
Cycles	Original	Own model	Relative error
Toshiba	72.15 %	70.90 %	-1.73 %
Graz	70.35 %	70.89 %	0.77 %
Mitsubishi	73.52 %	74 %	0.62 %

Researching and defining modelling parameters

- Cycles in the literature calculated with different parameters
  - ➡ Not comparable
- High parameters assuming fast technological progress
  - ➡ Too optimistic
  - ➡ Not up to date
- Research and redefinition of uniform and presently achievable parameters

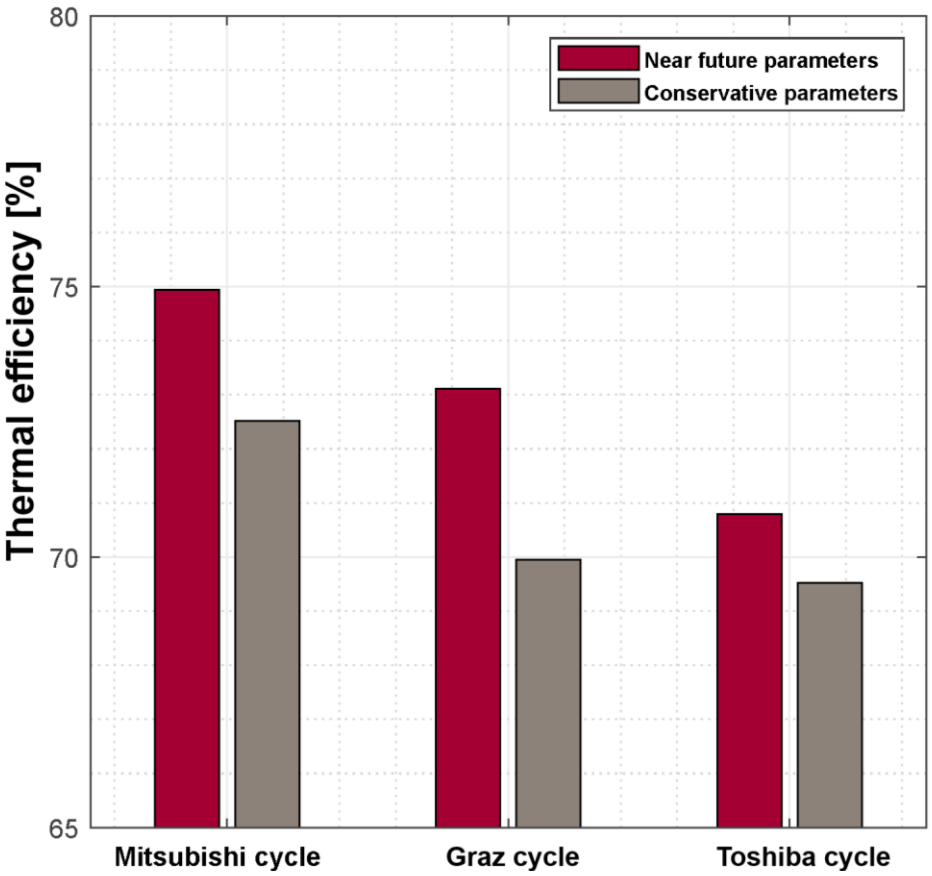
Main cycle parameters	Unit	Near future/ optimistic	Present/ conservative
HTT inlet temperature	[°C]	1700	**1600**
HPT inlet temperature	[°C]	720	**620**
HPT inlet pressure	[bar]	310	**250**
condenser pressure	[mbar]	35	**50**
LP Turbine wetness	[%]	**10 to 12**	
compressor pressure ratio	[-]	42	**32**
H2 und O2 temperature	[°C]	**15**	

Results of the performance analysis

- Highest efficiencies:
  - Mitsubishi
  - Graz
  - Toshiba

- Highest increase in thermal efficiency:
  - Graz
  - Mitsubishi
  - Toshiba

Calculated thermal efficiencies



Conclusions

- Hydrogen oxyfuel steam power plants as a solution for reconversion of green hydrogen to electricity
- Cycles can be categorized in **fully** and **partly** condensing cycles
- Selection of the most likely regarding technical **limitations**, **complexity** and **efficiency**
- Results of the performance analysis:
  - Efficiencies > 70 % achievable
  - Fully condensing cycles
    - Lower complexity
    - Safer regarding extraction of unburned H_2 and O_2
  - Partly condensing cycles
    - Highest efficiencies with **75 %** for the **Mitsubishi** cycle
    - High flexibility regarding TIT

Outlook

- Start-up analysis
- Steam generation and availability
- Optimization of the Toshiba cycle through reheating
- Water and hydrogen storage capacity demand
- Research on:
  - Gas turbine design suited for steam as a working fluid
  - Heat Recovery Steam Generator material
  - Creep resistant material
  - Hydrogen detection in steam
  - Combustion chambers for stoichiometric combustion in steam
- Research at the LSM in Hamburg: **designing and building a prototype cycle at a small scale**

Thank you for your attention.

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