CO_2 power cycle development – tools and applications

Petter Nekså

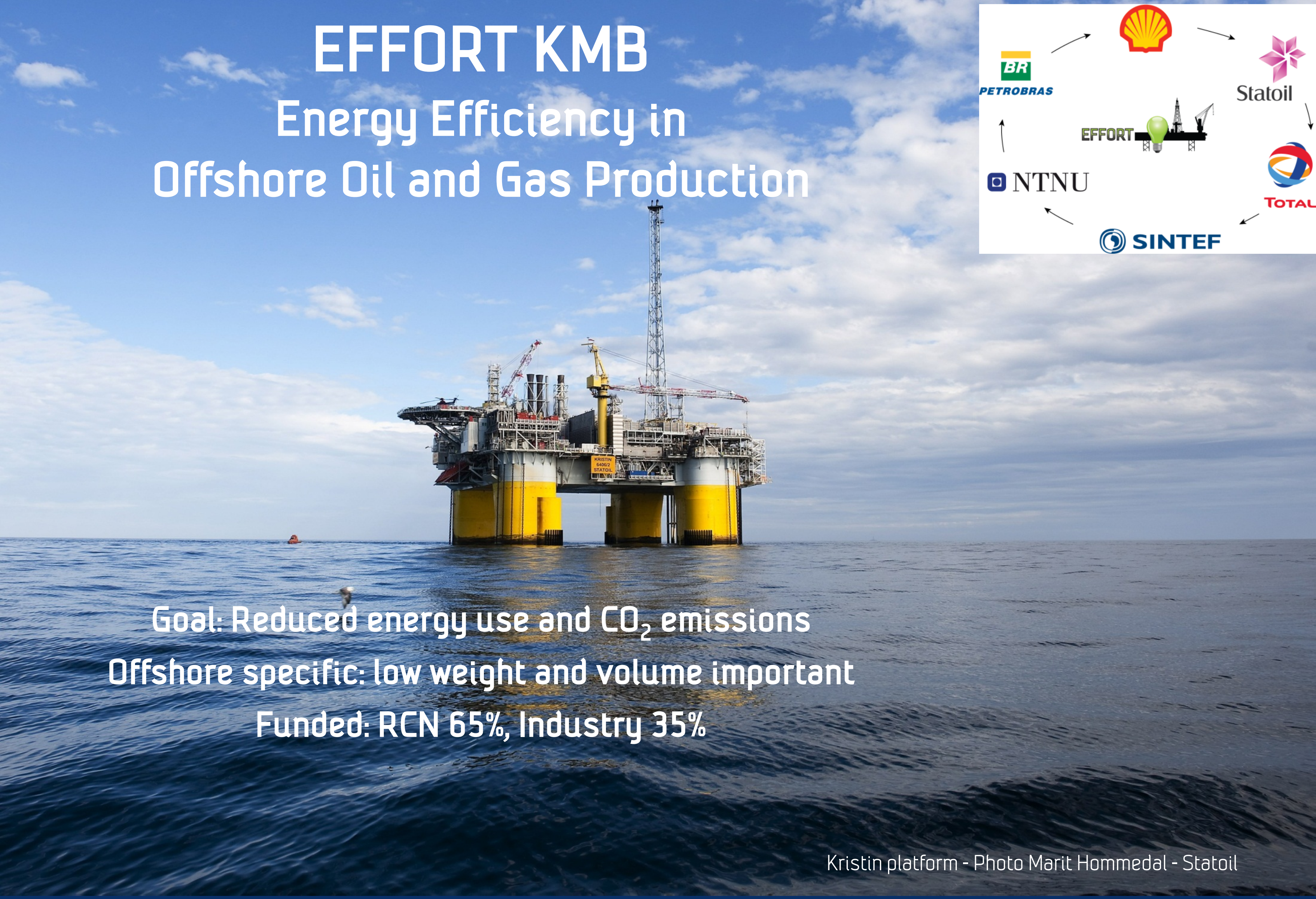
Chief Scientist SINTEF Energy Research

Adjunct Professor at NTNU, Dept of Energy and process engineering

Visiting Fellow at Doshisha University, Energy Conversion Research Center

EFFORT KMB

Energy Efficiency in Offshore Oil and Gas Production



Goal: Reduced energy use and CO_2 emissions

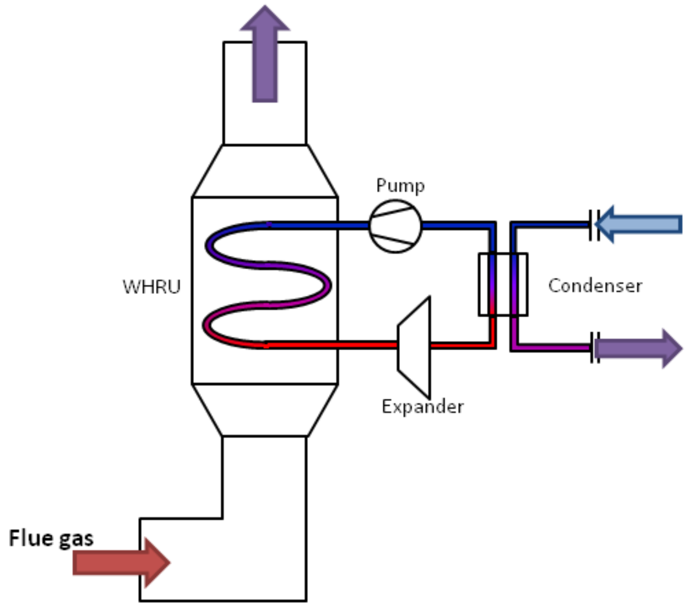
Offshore specific: low weight and volume important

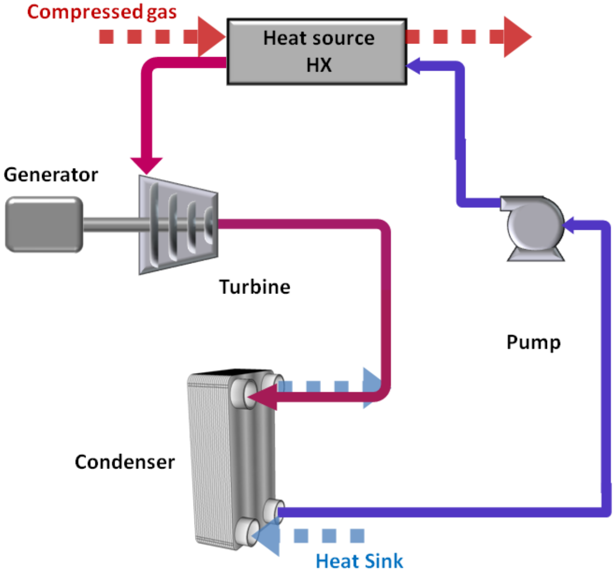
Funded: RCN 65%, Industry 35%

Kristin platform - Photo Marit Hommedal - Statoil

EFFORT project example:

Power Production from Surplus Heat Sources





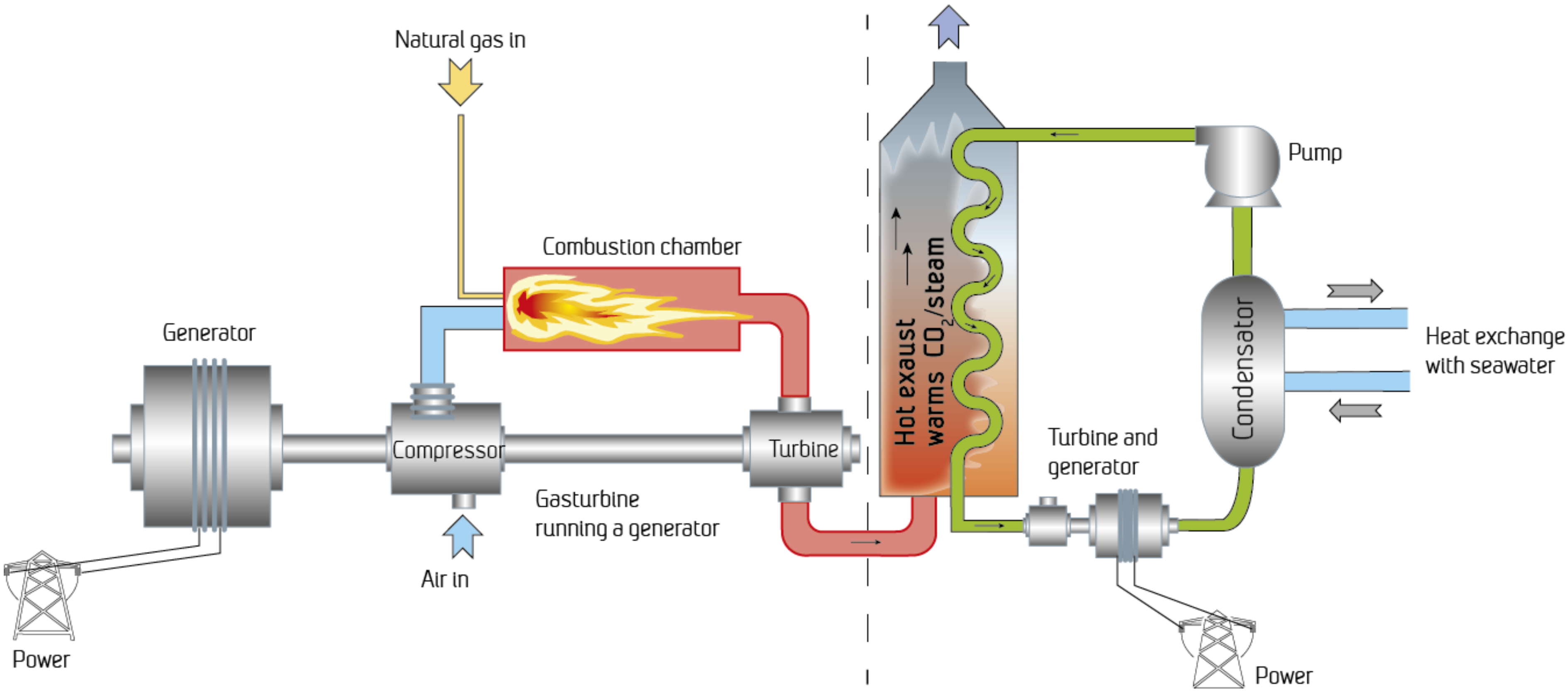
High temperature gas turbine exhaust gas (550'C)

- Compact bottoming Rankine Cycles
  - Transcritical CO_2
  - Steam, once though boilers
  - Hydrocarbons

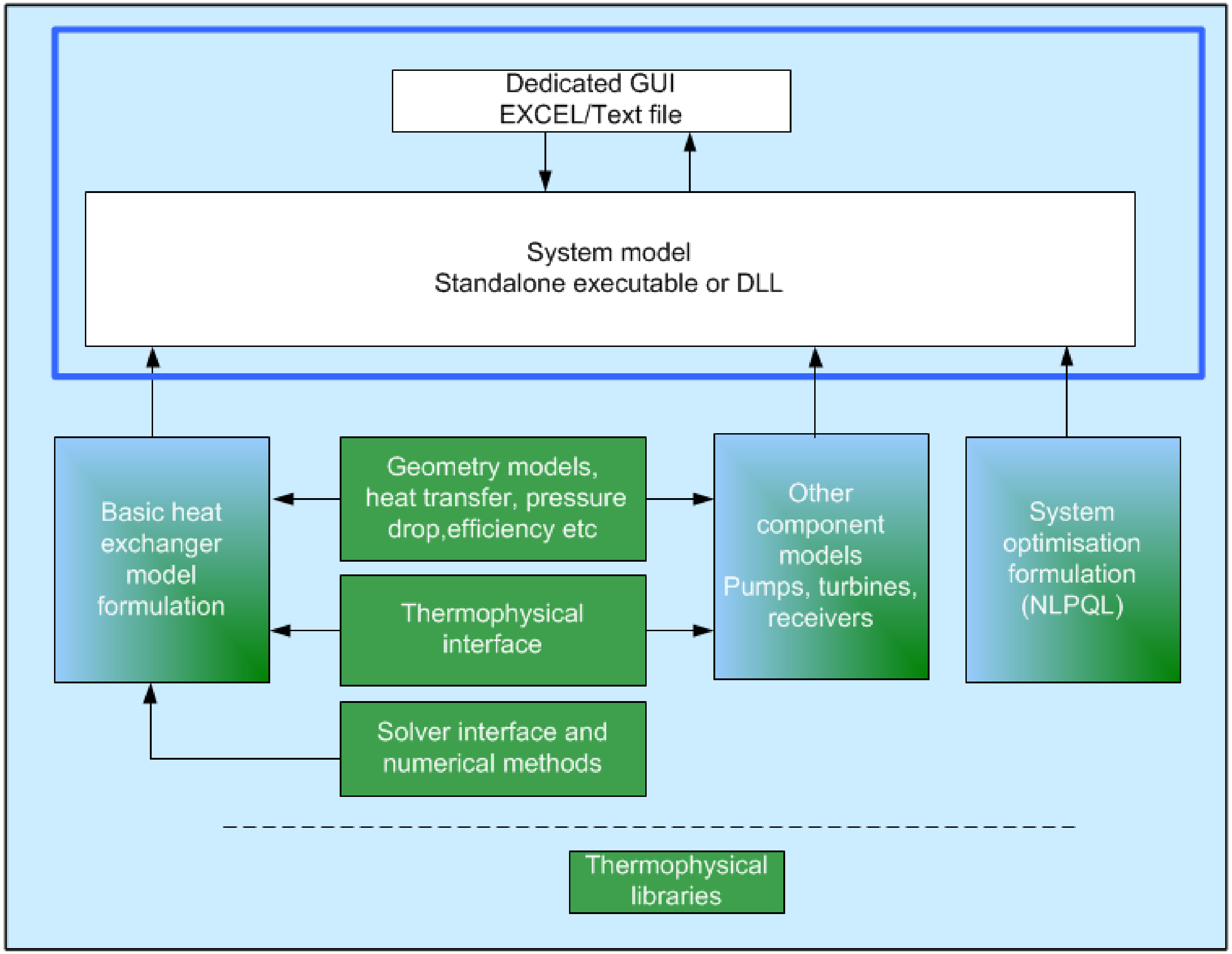
Low temperature compressed gas (150'C)

- High pressure -> compact HX
- Rankine Cycle
  - Subcritical hydrocarbon
  - Transcritical CO_2 or hydrocarbon

Application 2: CO_2 bottoming cycle for a Gas Turbine (GT)

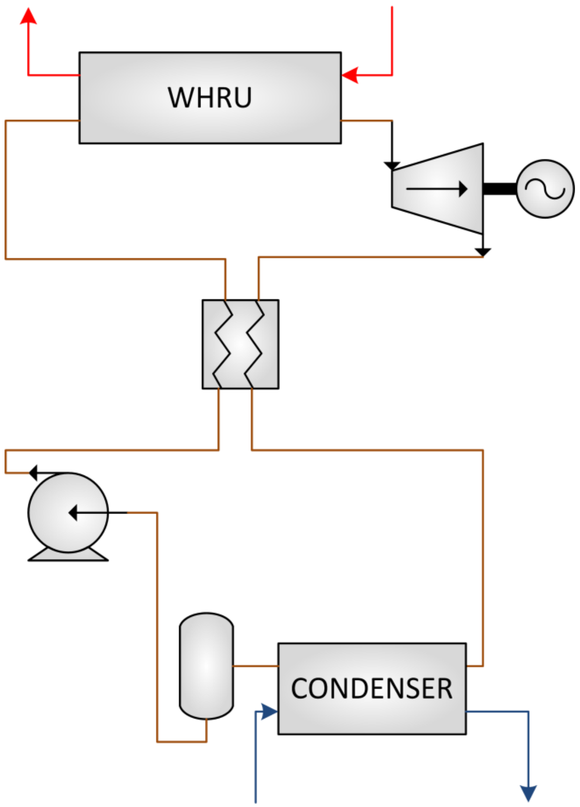


Simulation tool

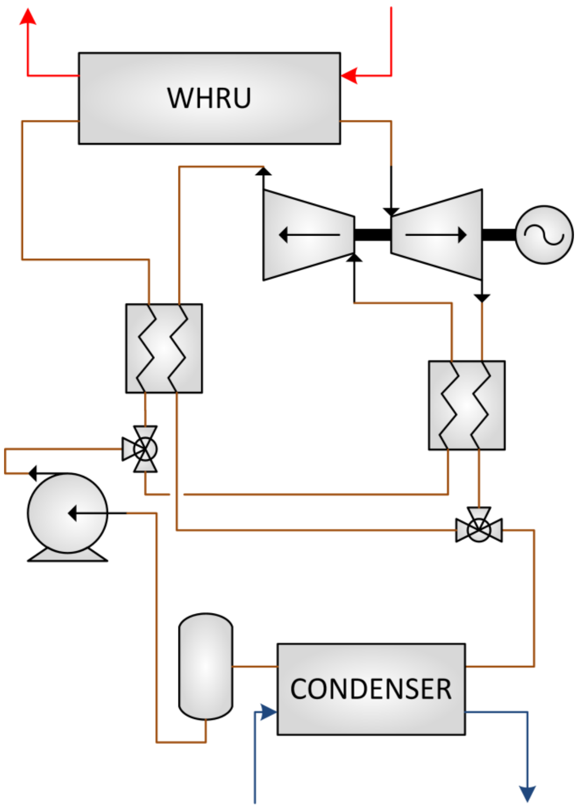


Off – design simulations

Two layouts are chosen based on HYSYS evaluation and inspiration from patents



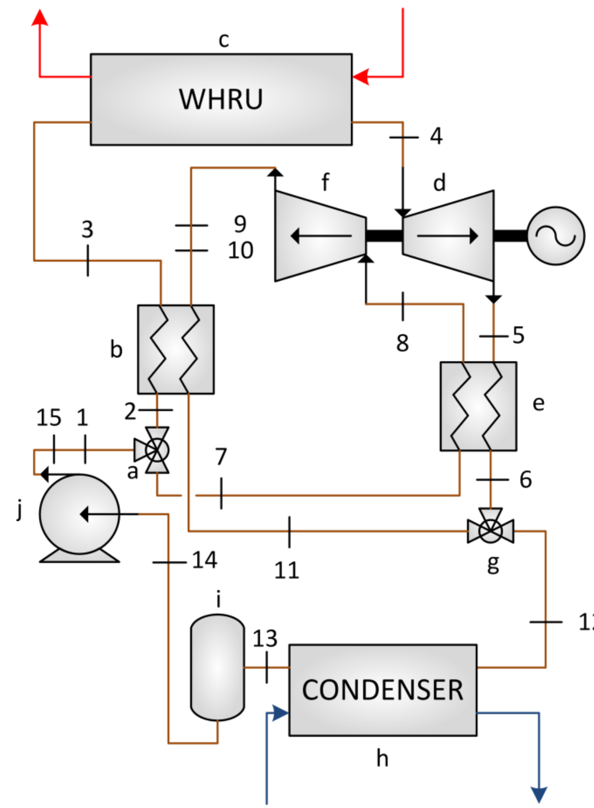
Single stage



Dual stage

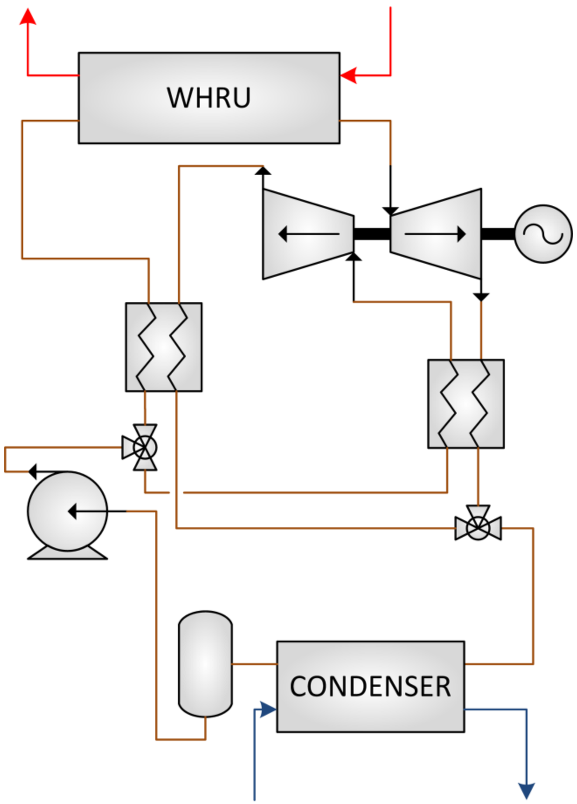
Model description

- FLEXHX heat exchangers
  - Tube and fin WHRU
  - Compact heat exchanger recuperators
  - Plate / plate and shell condenser
- Isentropic efficiency based turbomachinery
  - Improved models to be included when available
- Low pressure receiver
  - Balances the system and stabilizes integration
- NLPQL – constrained optimization problem solver
  - System constrained variables
  - "Free" optimization variables



Boundary conditions, assumptions and design considerations

Ambient	
Temperature [°C]	15
Pressure [bar]	1.013
Relative humidity [%]	60
Cooling water temperature [°C]	10
Gas Turbine	
Model type	GE LM2500+G4 DLE
Fuel	Methane
Inlet pressure drop [bar]	0.010
Bottoming Cycle	
WHRU UA* [kW/K]	400
Recuperator 1 UA* [kW/K]	1000
Recuperator 2 UA* [kW/K]	250
Max pump outlet pressure [bar]	200
Condensation temperature *[°C]	20
Cooling water temperature increase [K]	10
Pump efficiency [%]	80
Expander efficiency [%]	85
Motor/generator efficiency [%]	95



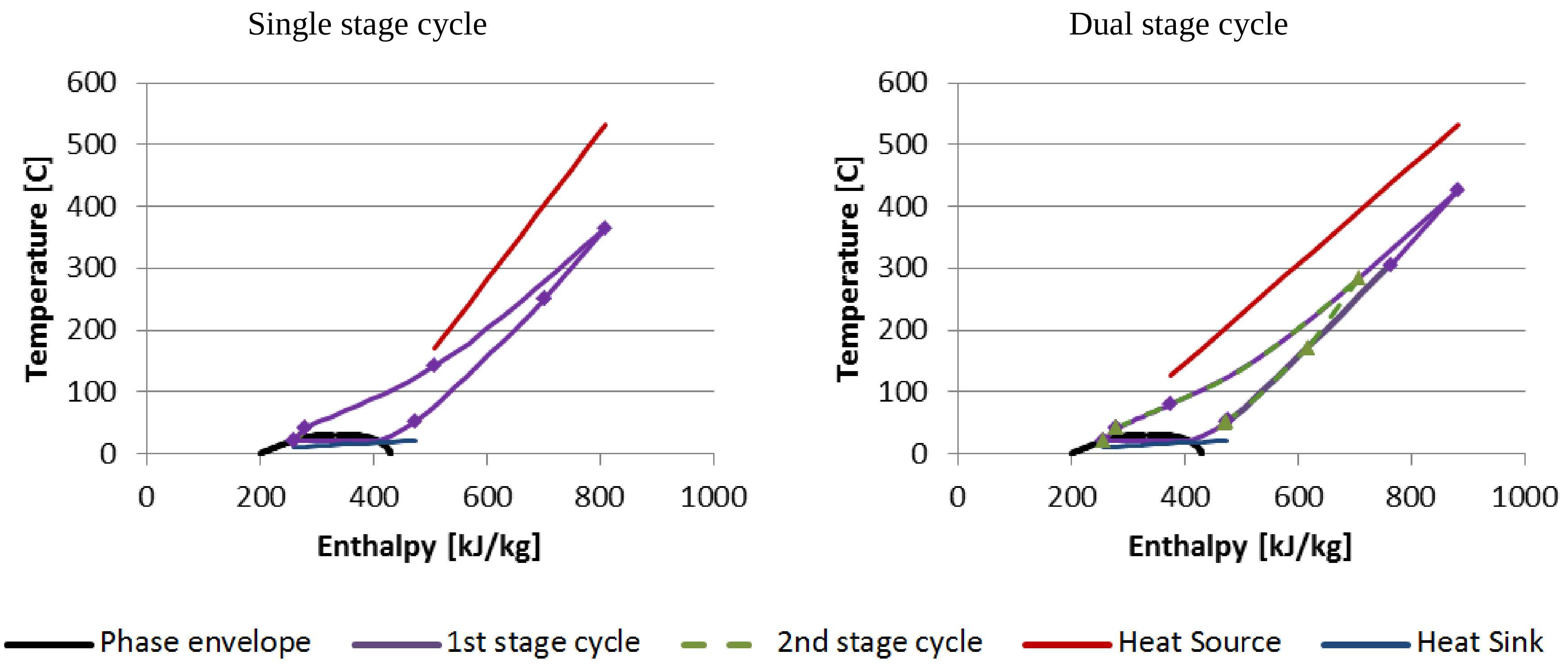
**Only at design, and will change at off-design*

Design point – Main results

Plan type	Simple cycle	Combined cycle single stage	Combined cycle dual stage
Gas Turbine	GE LM2500+G4	GE LM2500+G4	GE LM2500+G4
Net plant power output [MWe]	**32.2**	**41.1**	**42.0**
GT gross power output [MWe]	32.5	32.1	32.1
CO_2 turbine shaft power [MW]	-	13.0	14.2
CO_2 pump shaft power [MW]	-	2.7	2.9
CO_2 BC gross power output [MWe]	-	9.5	10.4
Plant efficiency [%]	**38.6**	**48.9**	**50.0**
Exhaust mass flow [kg/s]	89.9	89.9	89.9
Exhaust Temperature after WHRU [°C]	528	170	126

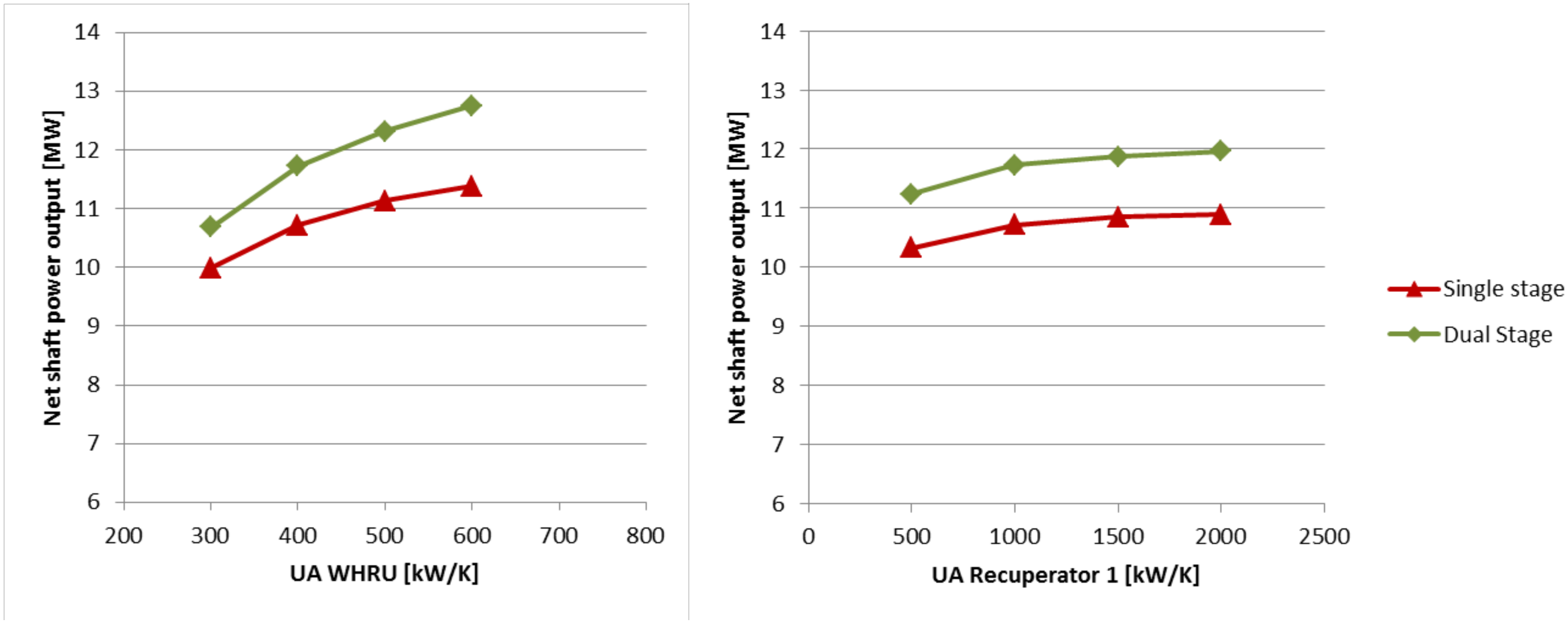
- 28-30 % increase in net power output
- 10-11.5 %-points increase in total efficiency
- About 1 MWe difference between single and dual stage

Design point – Cycle comparison



Design point – Cycle comparison

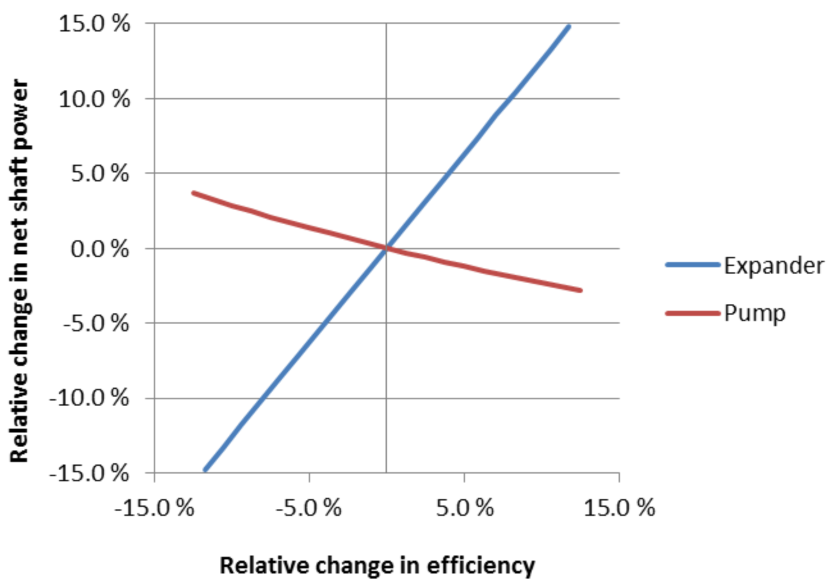
- The difference between the cycles will increase with increased WHRU size
  - Comparison performed with perfect counterflow heat exchangers



HYSYS evaluation of effect of heat exchanger size

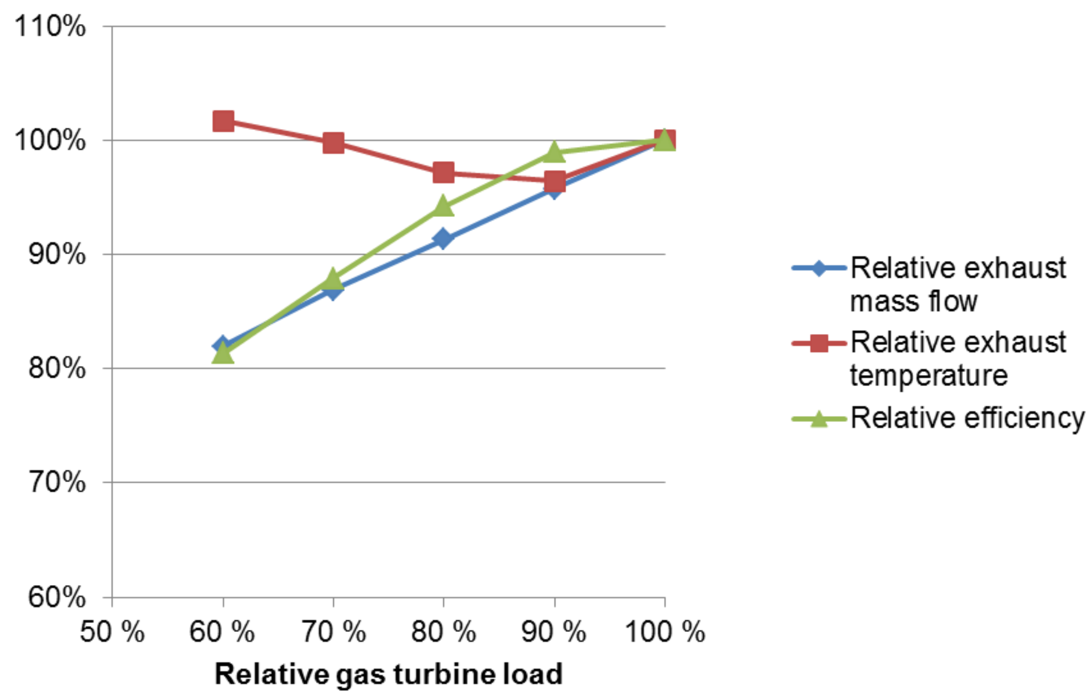
Influence of CO_2 turbomachinery efficiency

- Very limited information on CO_2 turbomachinery
  - Core technology for vendors
- High power density makes different challenges compared to conventional expanders
- Compared to steam, the pump efficiency important
- 5 % change in pump efficiency yields 1.3 % change in net shaft power output
- 5 % change in expander efficiency yields 6.3 % change in net shaft power output



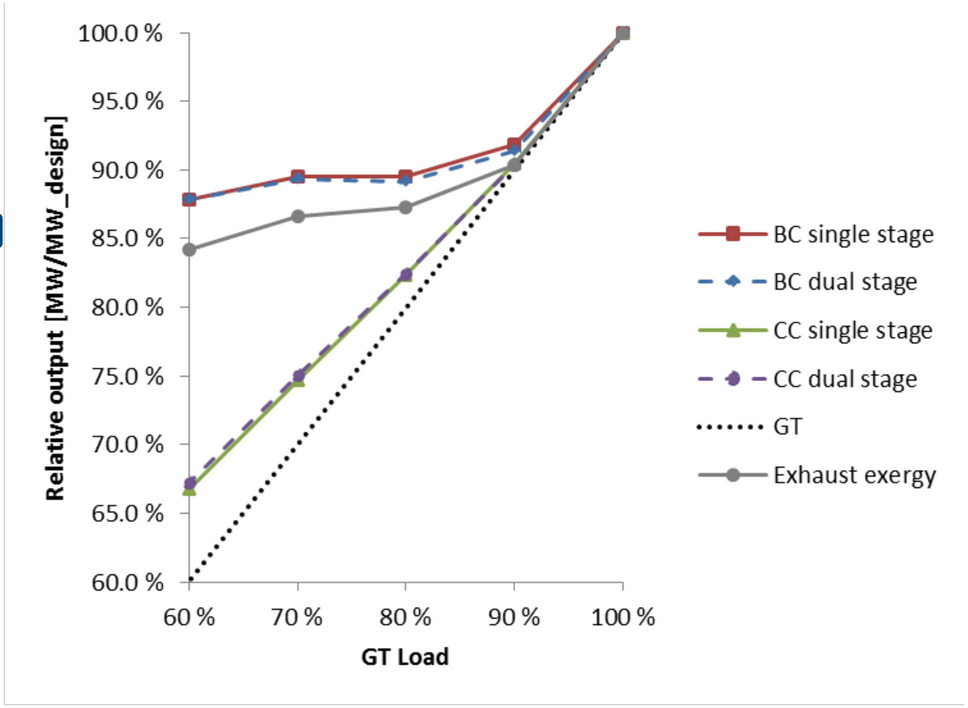
Off-design – Gas turbine

- Linear reduction in exhaust flow rate
- Increased exhaust temperature below 90 % load
  - Due to DLE fuel staging
- Rapid drop in efficiency below 90 % load



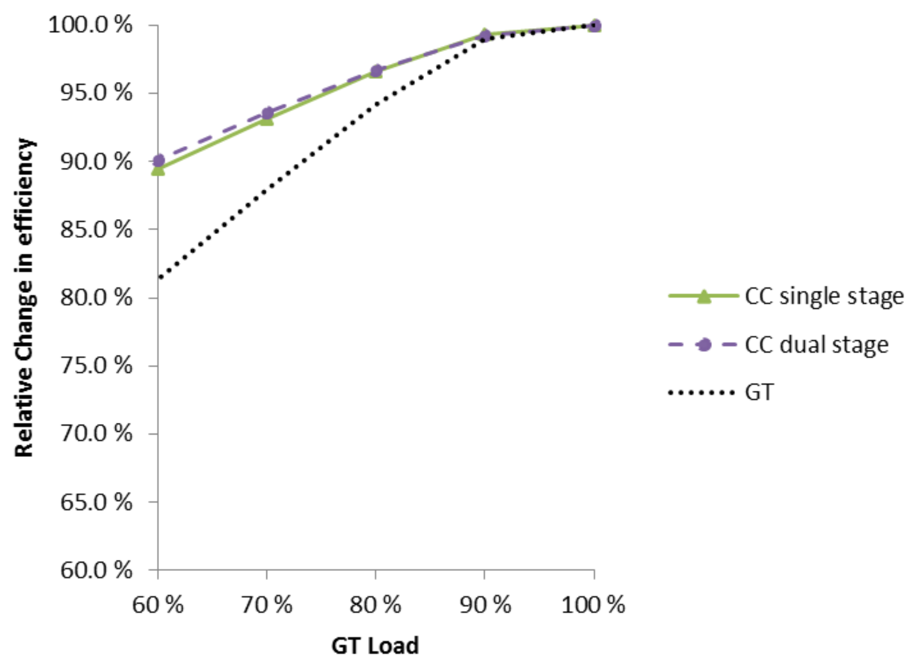
Off-design – Bottoming cycle

- Similar relative performance of the two cycles
- Increased exergy efficiency
  - Increased heat exchanger efficiency
  - Reduced pressure drop due to reduced flow rates
- Flattens total performance curves



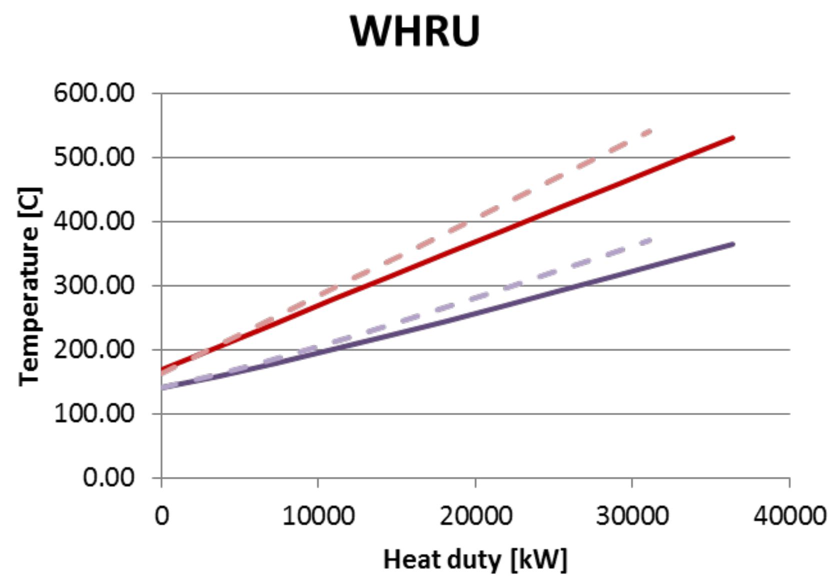
Off-design – Bottoming cycle

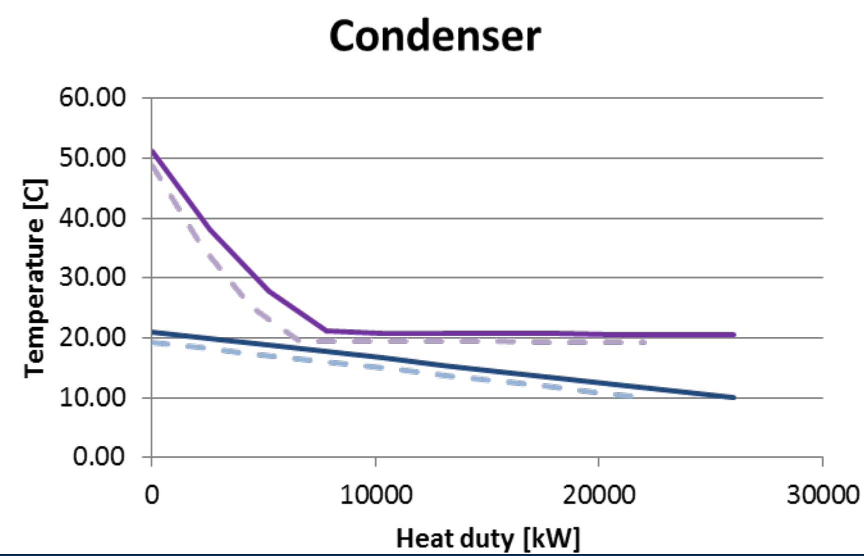
- Similar relative performance of the two cycles
- Increased exergy efficiency
  - Increased heat exchanger efficiency
  - Reduced pressure drop due to reduced flow rates
- Flattens total performance curves



Off-design – Heat exchangers

- 100 % vs 60 % GT load
- WHRU and recuperator
  - $Q = UA\overline{\Delta T}$
  - Area is constant
  - Reduced flow rate → reduced heat transfer coefficient (U) and duty (Q)
  - Temperature difference ≈ constant
- Condenser
  - Water flow is constant
  - Reduced temperature difference
  - Reduced condensation pressure





Summary Application: CO_2 bottoming cycle offshore

Inclusion of **bottoming cycles** to gas turbines on offshore oil and gas installations could be an attractive solution for **improved energy efficiency and reduced emissions**. The results show that utilisation of **CO_2** as working fluid in the bottoming cycles could be a **viable alternative to steam**.

The results show **8 and 16 % lower power output respectively for a dual- and single stage CO_2 cycle compared to compact steam bottoming cycles reported in literature**. Taking into account the probable positive characteristics with respect to volume, weight, cost, which are important advantages especially for off-shore applications, the results are highly interesting.

It is further shown that the **output can be increased if the heat exchanger sizes are increased or the efficiency of the turbomachinery is improved**. However, only a techno-economical optimisation may show if this is desirable.

A further aspect is the **advantageous off-design characteristics** with the proposed control strategy. **Gas turbine part load condition of 60% still maintains about 85% net power output from the CO_2 bottoming cycle, resulting in 67 % net plant output**. Also the efficiency is kept higher at lower load, with 45 % net plant efficiency at 60 % GT load, compared to 31 % for only the gas turbine.

The **CO_2 bottoming cycle technology is not fully commercially available yet**, and compared to steam cycles much less mature. **Important development is however on-going** and the technology is already demonstrated at scale, and full scale pilots are planned. This will give important information in verifying the results achieved through modelling and simulation.

Thank you for your attention!

Petter.Neksa@sintef.no

The presentation was made with input from presentations of the project EFFORT with input from Trond Andresen, Marit Mazetti and Petter Nekså

Acknowledgement
The EFFORT project, performed under the strategic Norwegian research program PETROMAKS. The authors acknowledge the partners: Statoil, TOTAL E&P Norway, Shell Technology Norway, PETROBRAS, and the Research Council of Norway (203310/S60) for their support.