LOW-TEMP WASTE HEAT RECOVERY

POWERING A SUSTAINABLE FUTURE

Per Askebjer
Senior Scientist
System Architect



CLIMEON for Västerbergslagens Ingeniörsklubb

Climeon



Climeon statistics

- Started 2011
- Global market

- 35 employees
- 8 nationalities

- Company language: English

Agenda

- Climeon – few words about why we do what we do
- Quick walk through of the technology
- Applications and integration –
  What is important for our customer
- The technology in some detail
- Questions and discussion



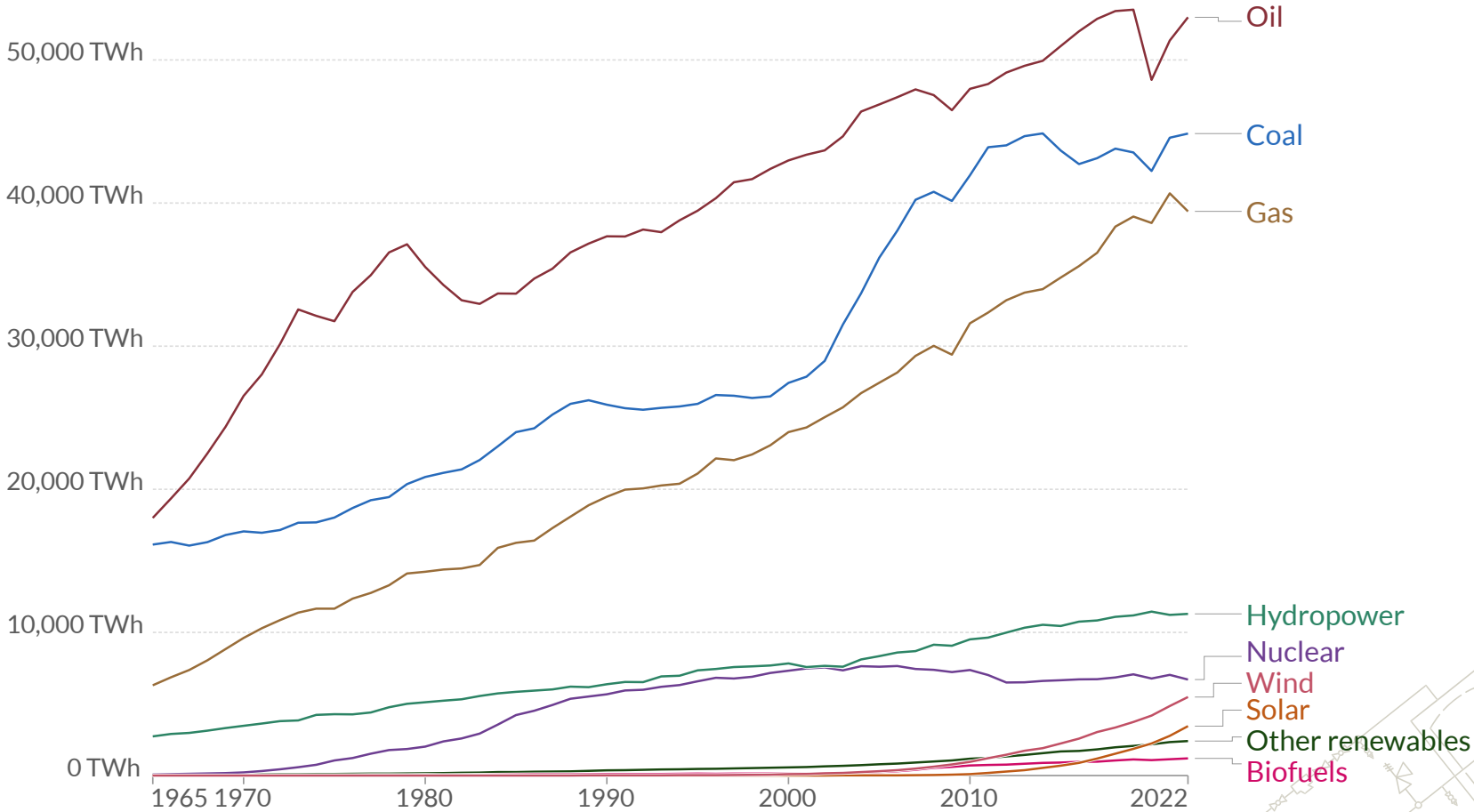
CLIMEON for Västerbergslagens Ingeniörsklubb

Energy accounts for more than three quarters of GHG (Green House Gases) emissions globally

Primary energy consumption by source, World

Primary energy[1] is measured in terawatt-hours[2], using the substitution method[3].

Our World in Data



Data source: Energy Institute - Statistical Review of World Energy (2023)

OurWorldInData.org/energy | CC BY

CLIMEON MISSION:
REDUCE CO_2 EMISSIONS BY SAVING ENERGY

CLIMEON

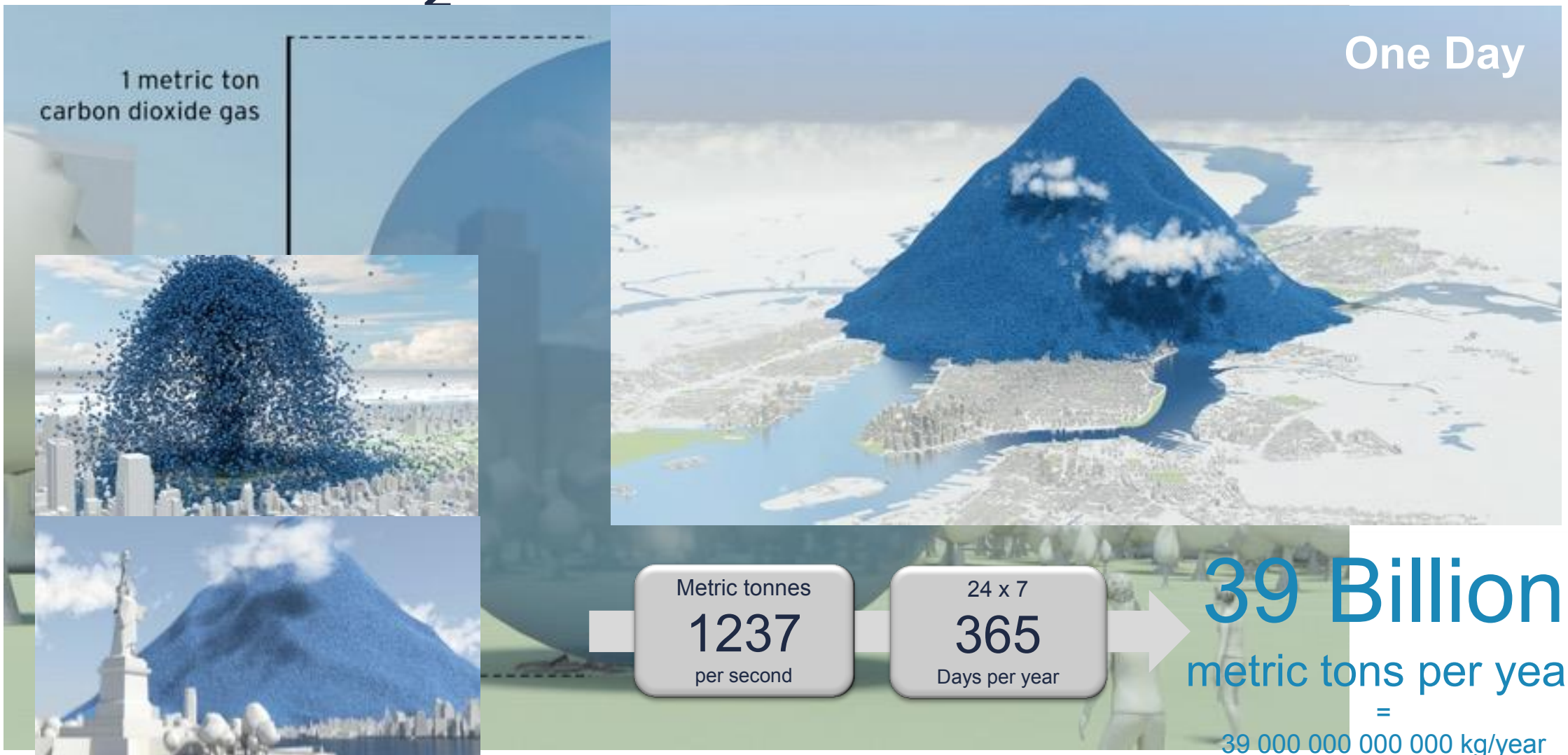
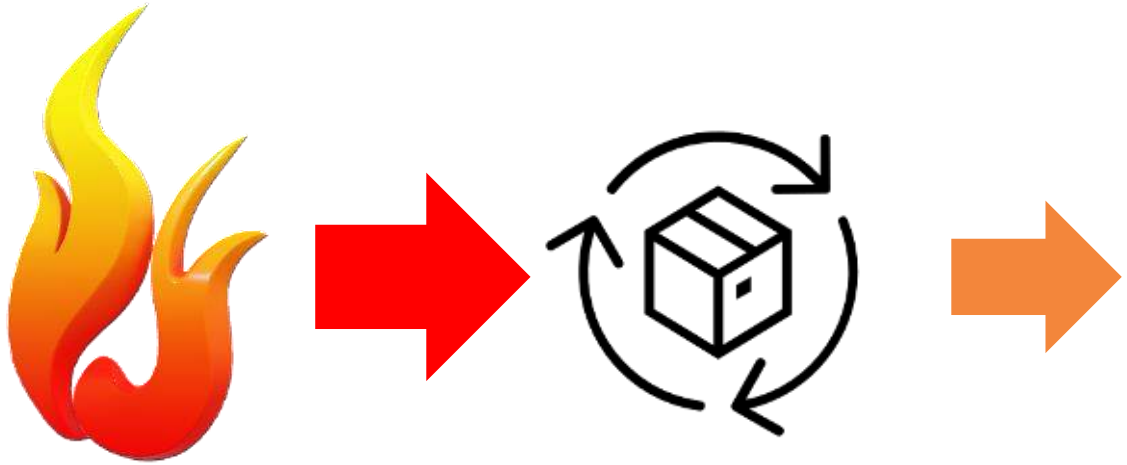


Image source: Carbon Visuals

Industrial processes produce lots of waste heat



Heat Process

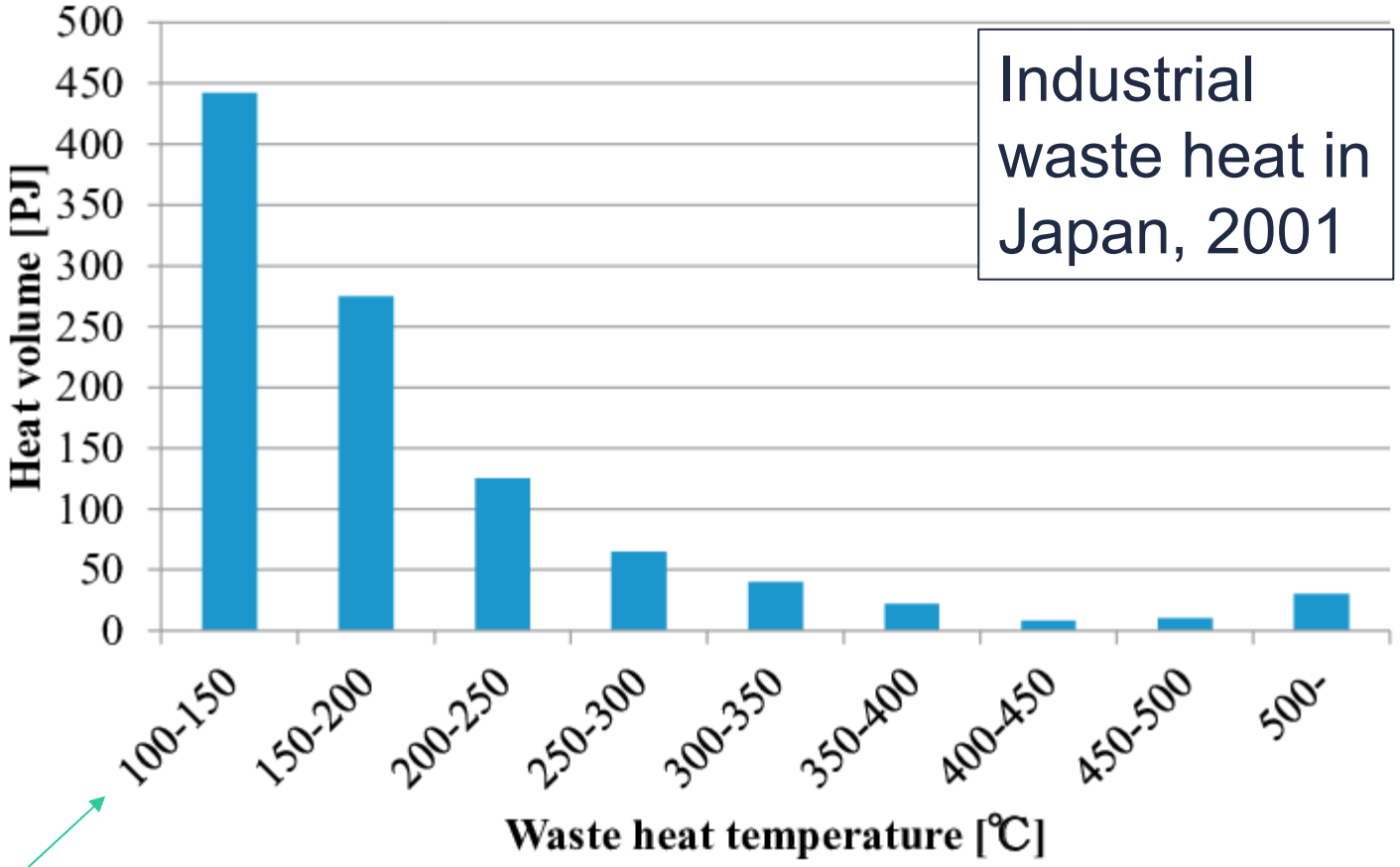


Waste heat

Waste heat everywhere:

- Concrete, Steal, Glass, Plastic… manufacturing
- Food processing
- Combustion engines (Ships, Gensets…)
- …
- **60-70% of all power produced ends up as waste heat!**

Waste Heat is more Abundant at Low Temperatures



Question:
How to harvest low temperature waste heat?

Climeon target

Source: The Energy Conservation Center Japan, Survey research on the energy system of the factories ; 2001, p.34-39 (in Japanese).







HEAT POWER











CLIMEON

MARITIME MARKET

FUEL SAVINGS

DECARBONIZATION

IMO requires an emissions reduction of GHG by **40%** between 2008 and 2030 and by **70%** by 2050.

EU's Emissions Trading Scheme (ETS) expands to include the shipping industry.





What is important for the customer?

ROI

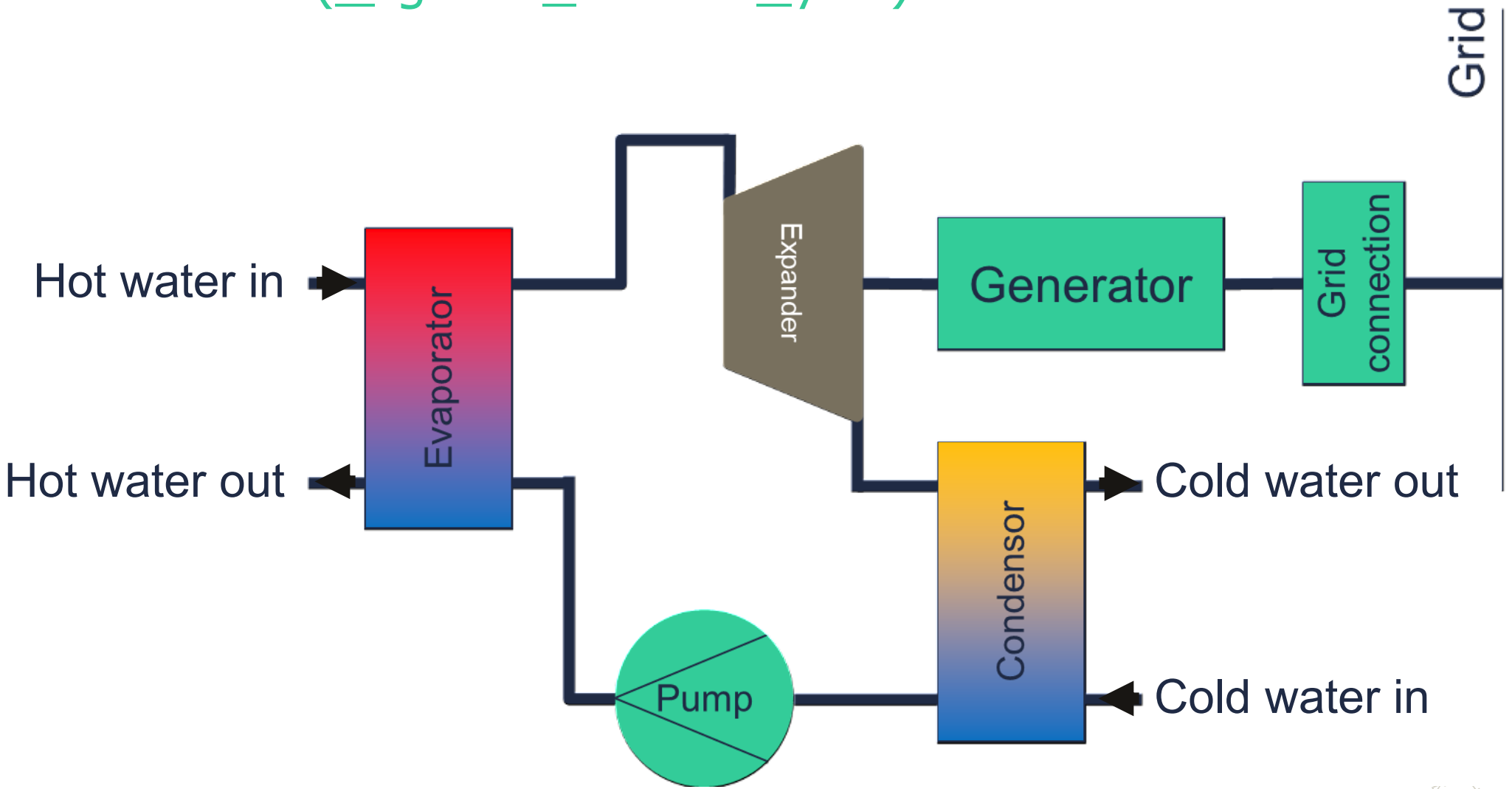
ROI

ROI

ROI

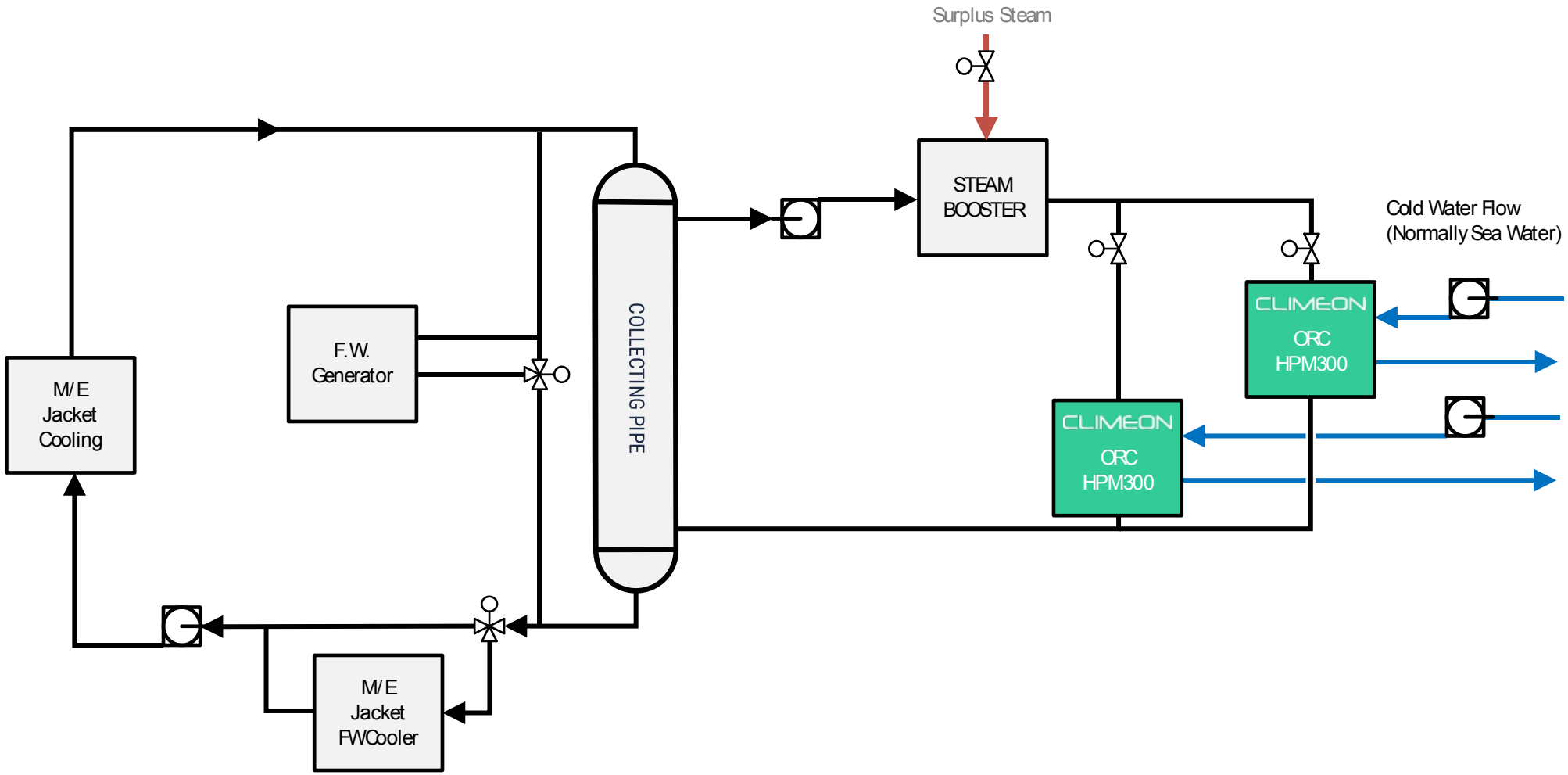
RIO = Return of investment

Generic ORC (Organic Rankine Cycle)



Example of a maritime installation
2-Stroke Jacket Cooling

Jacket cooling circuit - Jacket Heat + Surplus Steam: Concept



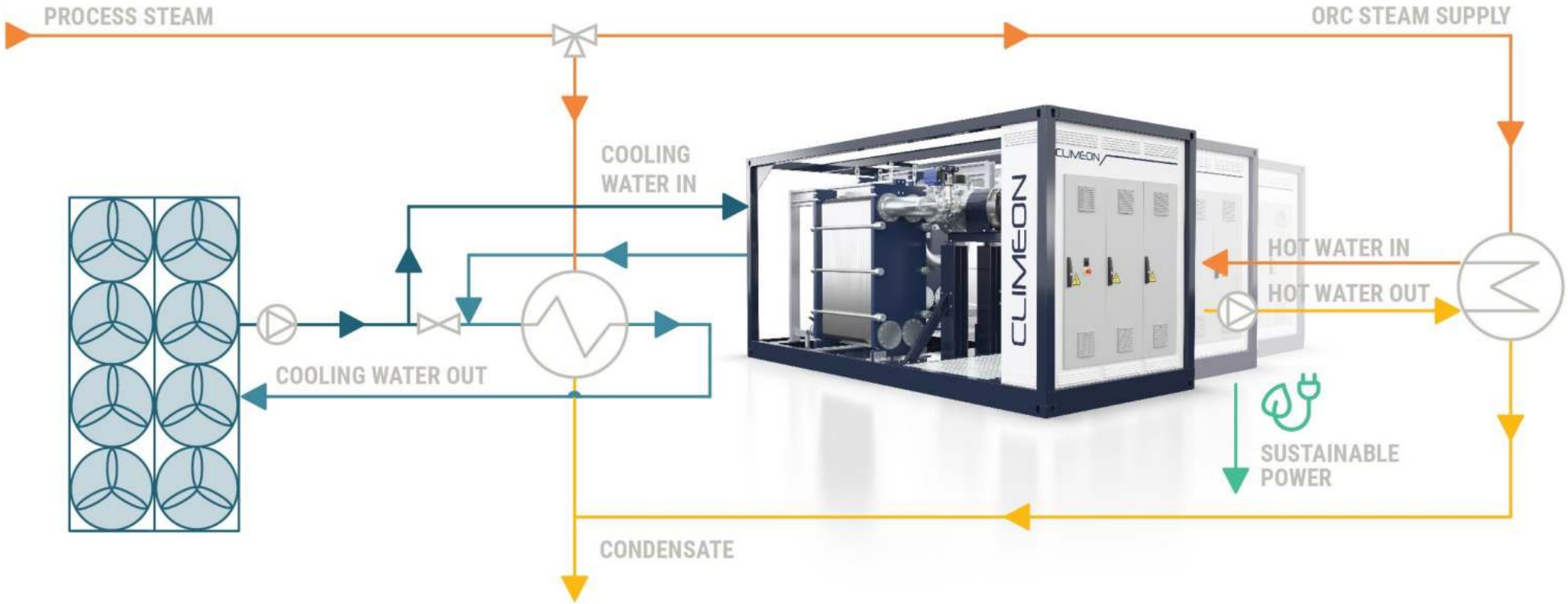


CLIMEON

Example ORC Integration:

Industrial Process Steam

With pre-existing steam condenser





CLIMEON

Example ORC Integration:

Industrial Process Cooling Water

Hot water temps above 105 °C



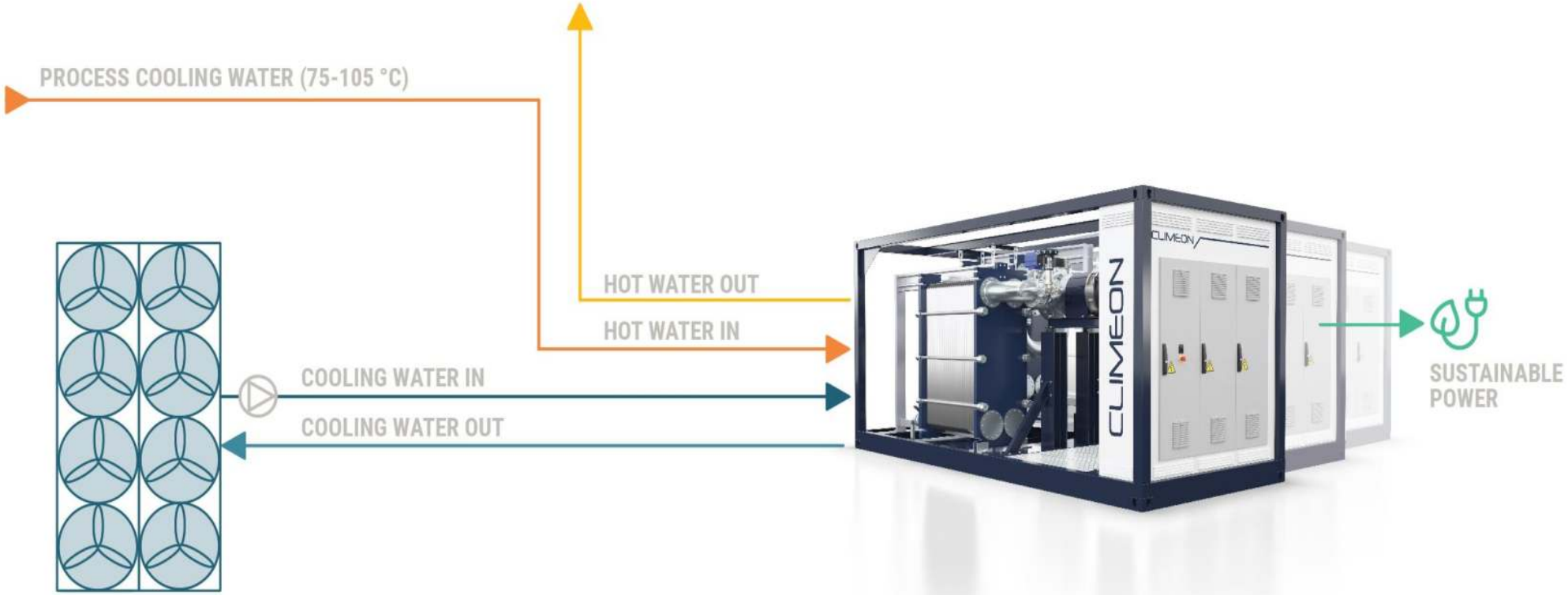


CLIMEON

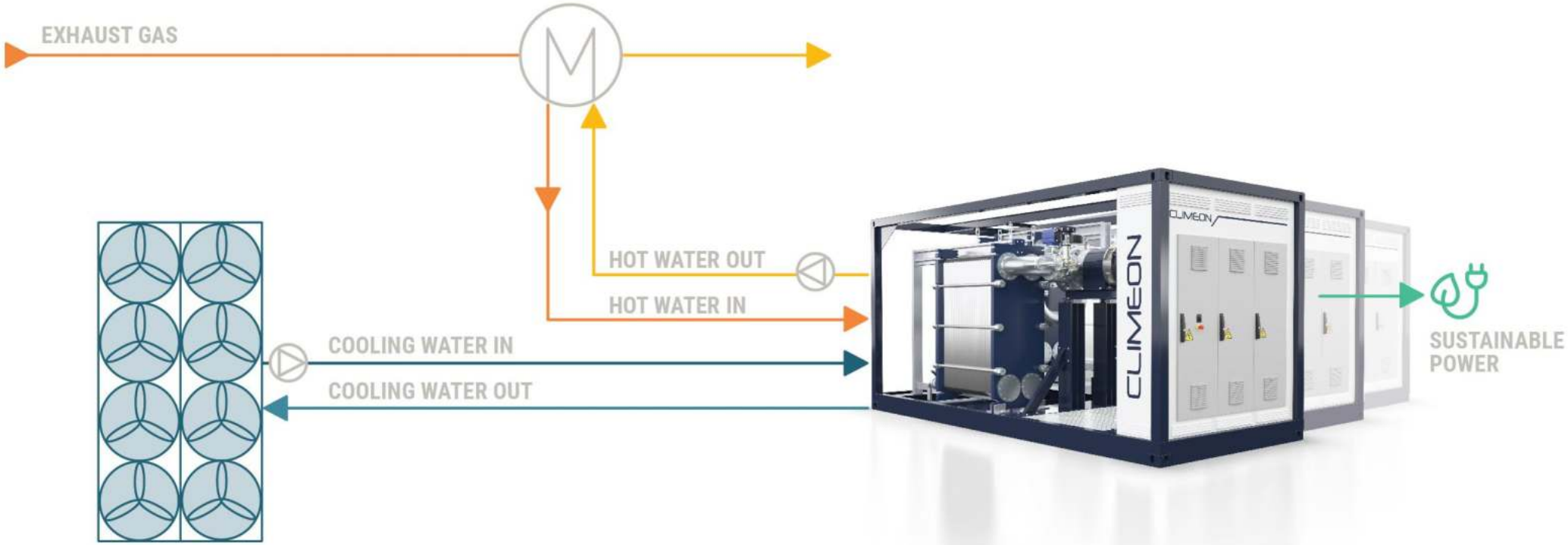
Example ORC Integration:

Industrial Process Cooling Water

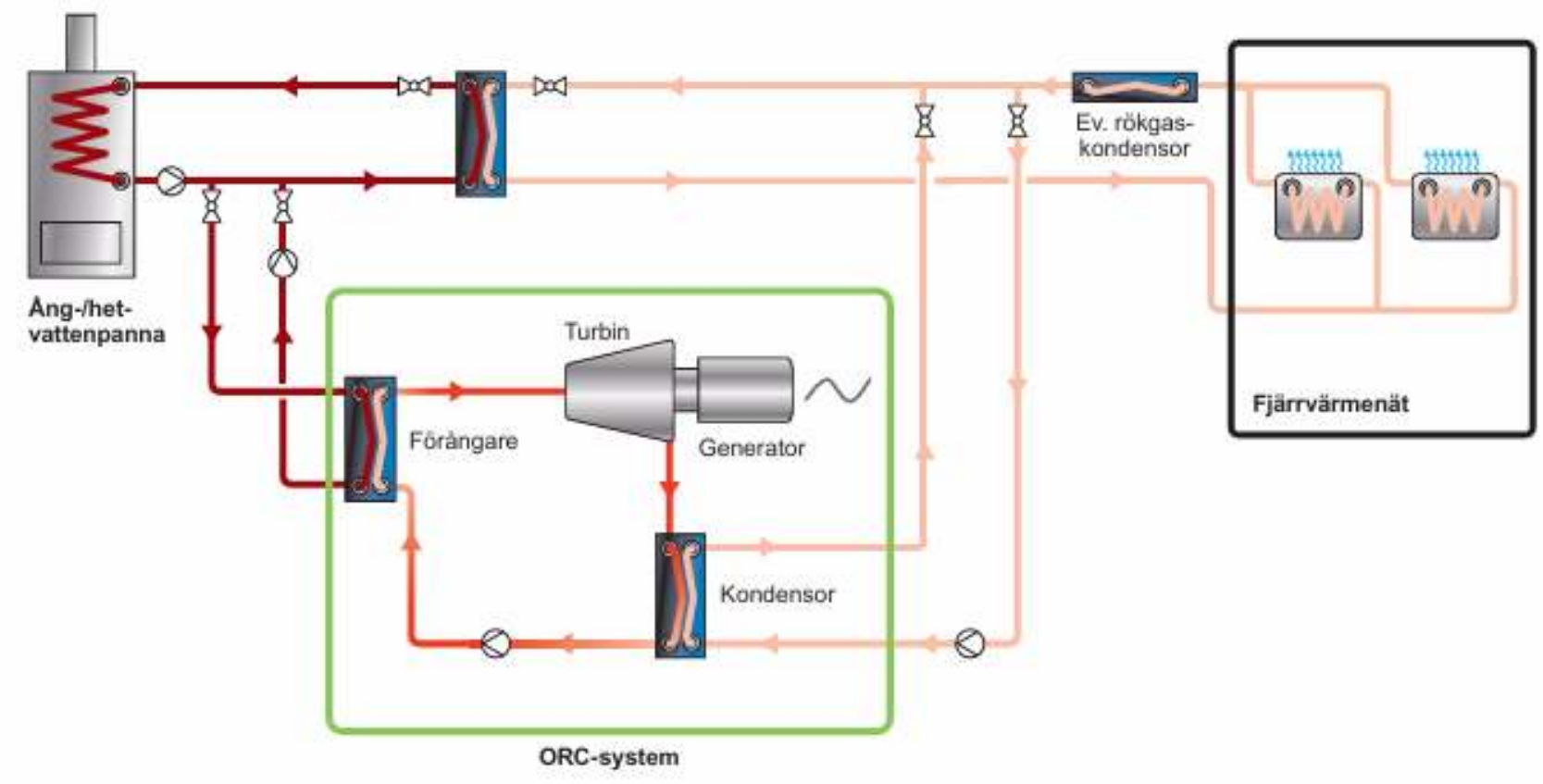
Hot water at 75-105 °C



Example ORC Integration:
Exhaust Gas



Integration with “100%” efficiency



OUR CUSTOMERS

MARITIME

- **Virgin Voyages & Fincantieri:**
  - 4 Cruise vessels (108,192 GT)
  - 6 HeatPower 150 units/vessel
- **Havila Voyages & Tersan:**
  - 4 Passenger Ferries (15,519 GT)
  - 1 HeatPower 150 unit/vessel – 2 Retrofit, 2 Newbuild
- **Viking Line & Xiamen Shipbuilding:**
  - 1 New-build Cruise Ferries: 4 HeatPower 150 units, 2 Steam turbines
  - 1 Retrofit Cruise Ferry: 1 HeatPower 150 unit
- **Maersk & HD Hyundai Heavy Industries:**
  - 1 Retrofit pilot: 1 HeatPower 150
  - 6 New-build Container ships: 1 HeatPower 300 per vessel

INDUSTRY

- **Swedish Steel AB (SSAB):**
  - 1 HeatPower 150 unit
- **NEO GROUP & Termolink:**
  - 2 HeatPower 300 units

GEOTHERMAL

- **Baseload Power Iceland:**
  - Kopsvatn: 8 HeatPower 150 units
  - Reykholt: 2 HeatPower 150 units
- **Baseload Power Japan:**
  - Sansui: 2 HeatPower 150 units
  - Shika: 1 HeatPower 150 unit
  - Kitsune: 1 HeatPower 150 unit



Climeon is not alone
A sample of competitors and their main focus

CLIMEON

orcan The Efficiency Company

Industrial & Power
15 – 200 kW_e

clean energy ahead TURBODEN

Industrial and geothermal
Up to 40 MW_e

againity

District heating
100 – 500 kW_e

ENOGIA

Industrial
10 – 200 kW_e

ORMAT

Geothermal
Very big installations
12 – 150 MW_e

Geothermal Sites can be Huge





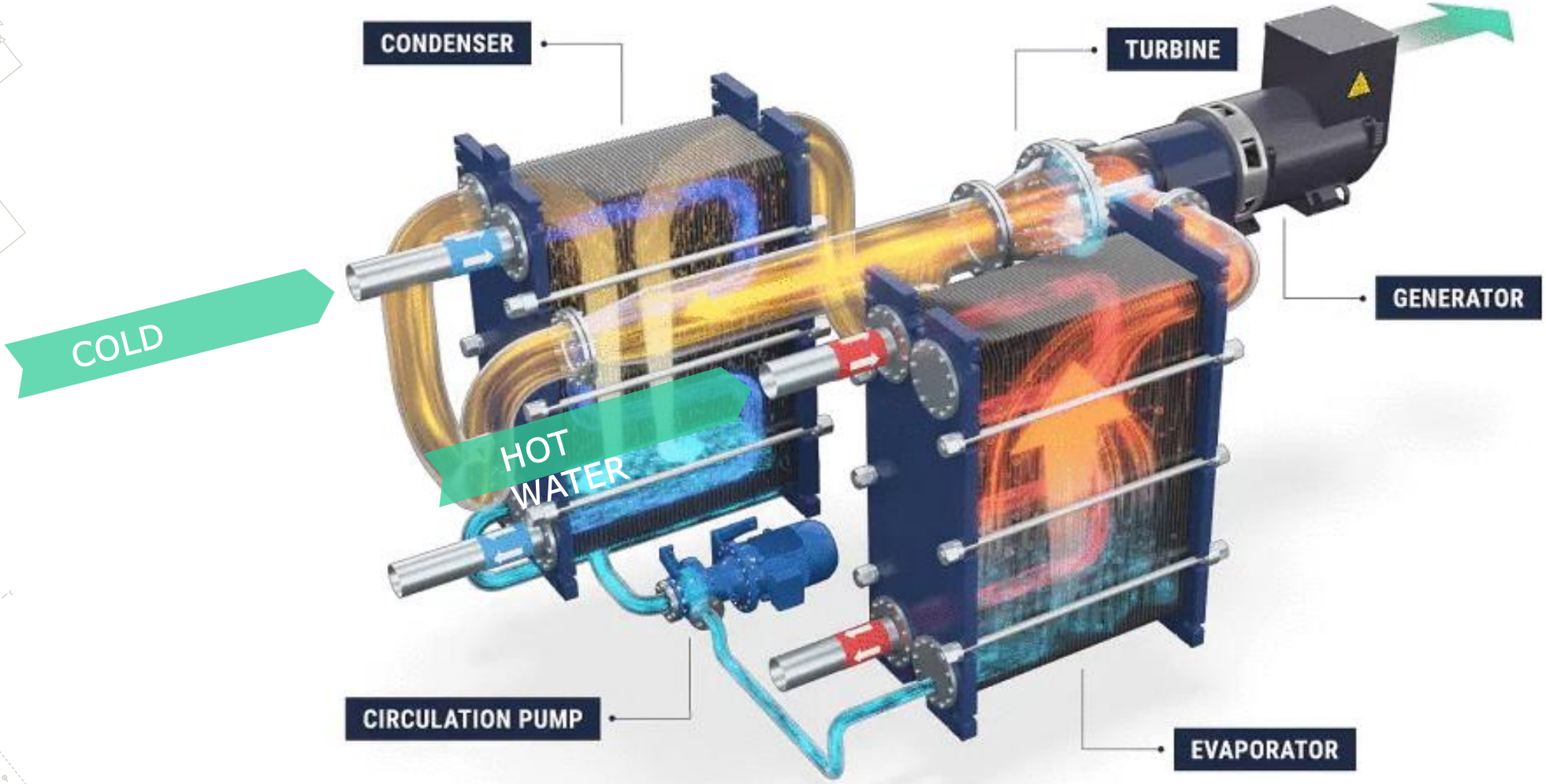
But they can be smaller as well



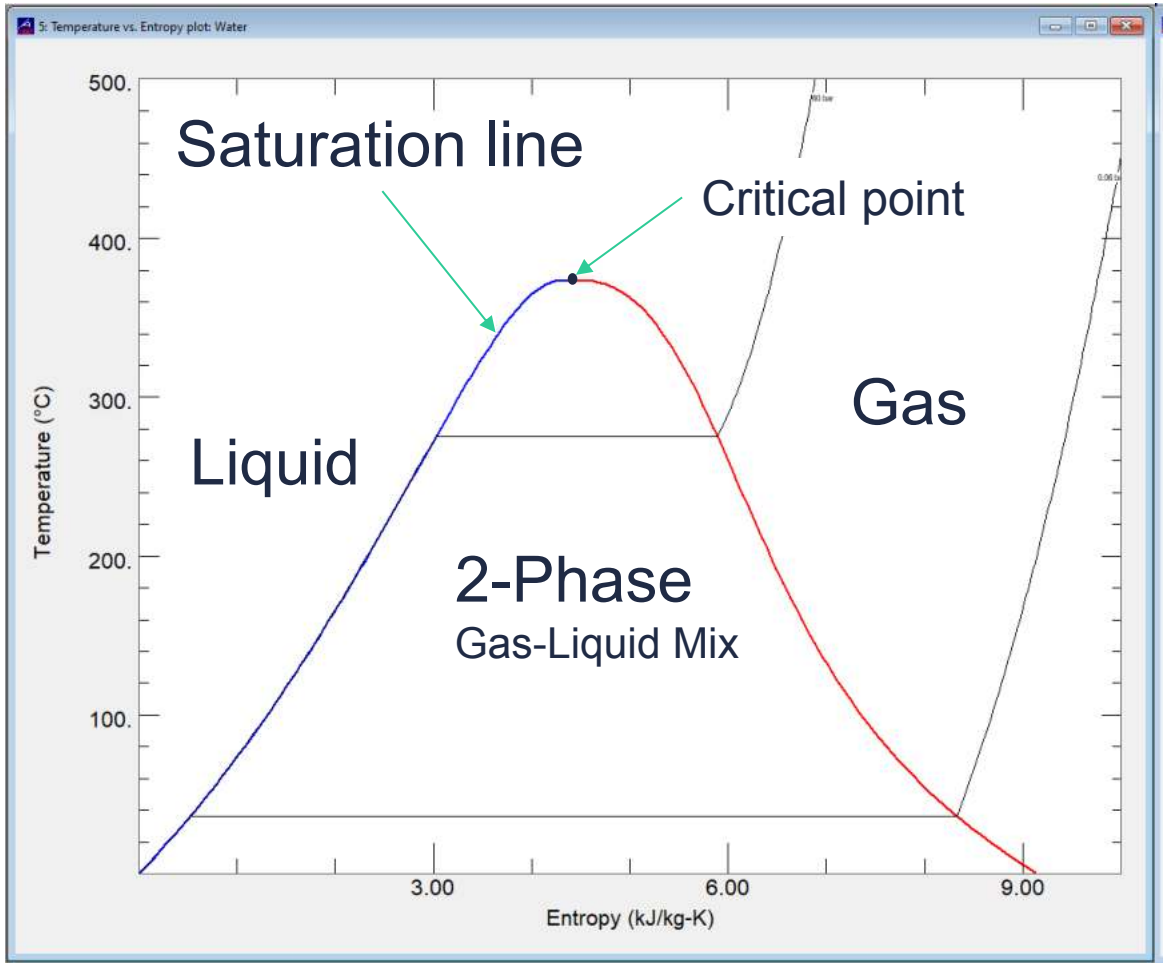
THE TECHNOLOGY

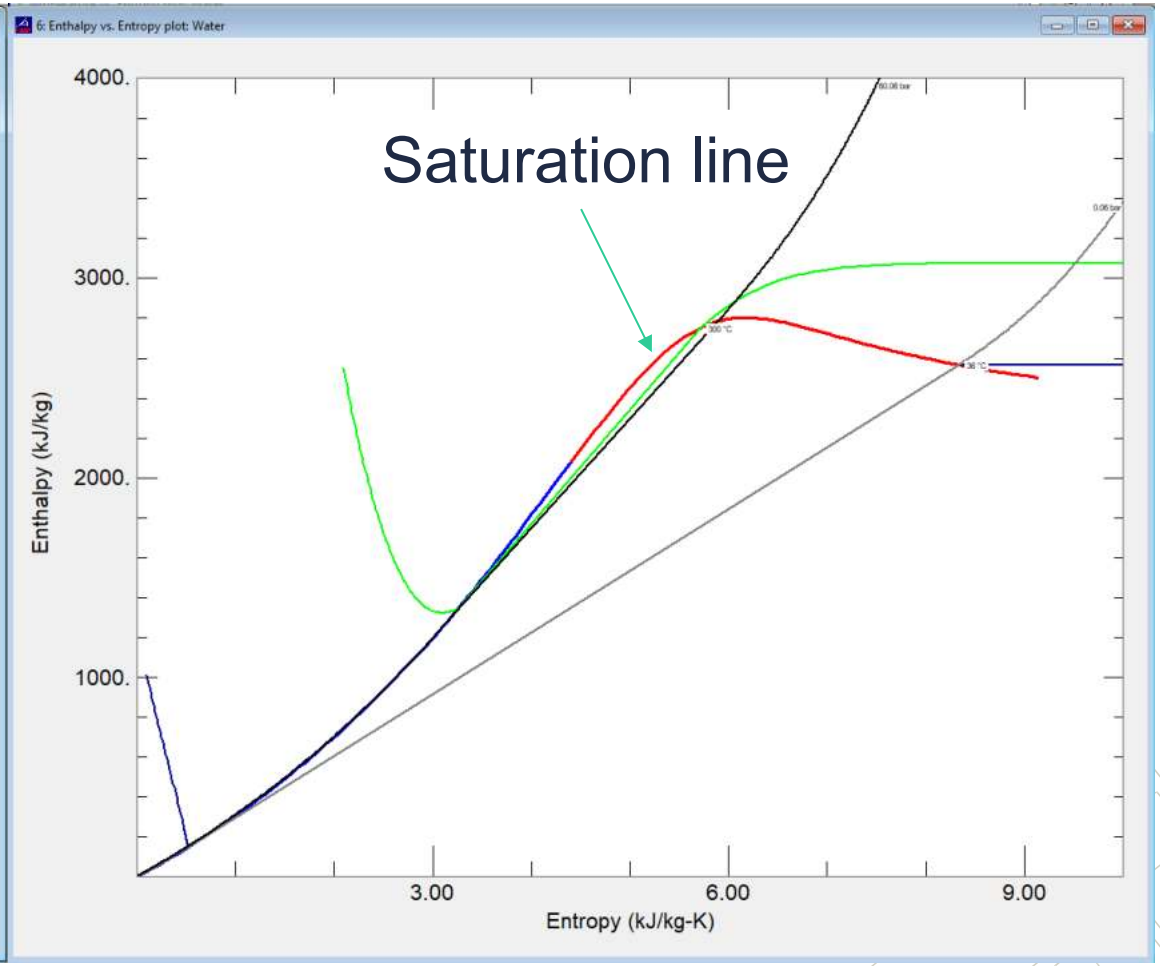
ORGANIC RANKINE CYCLE

CLIMEON

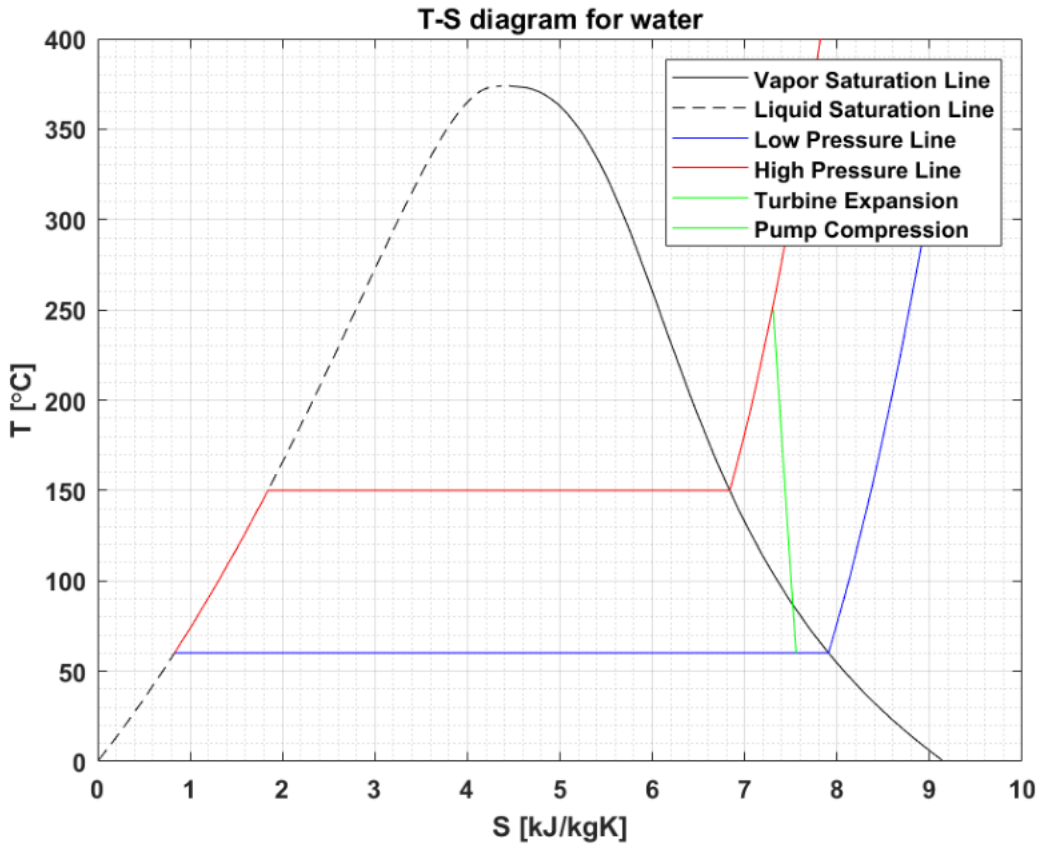


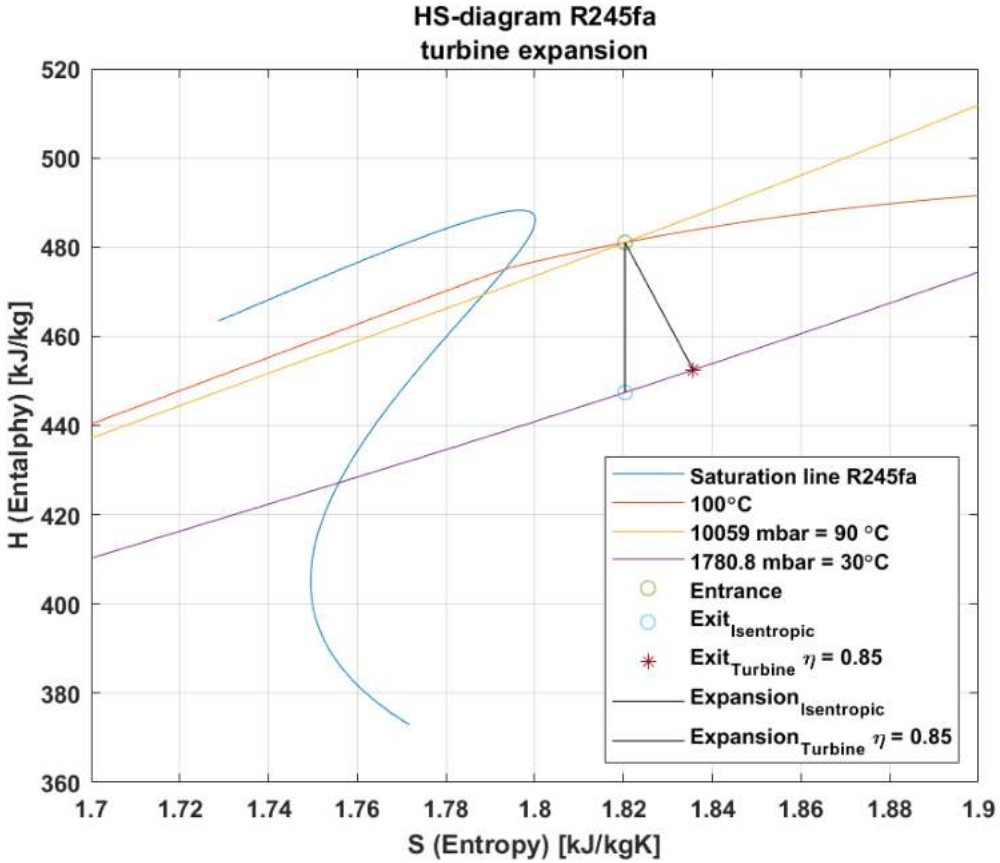
Thermodynamic diagrams



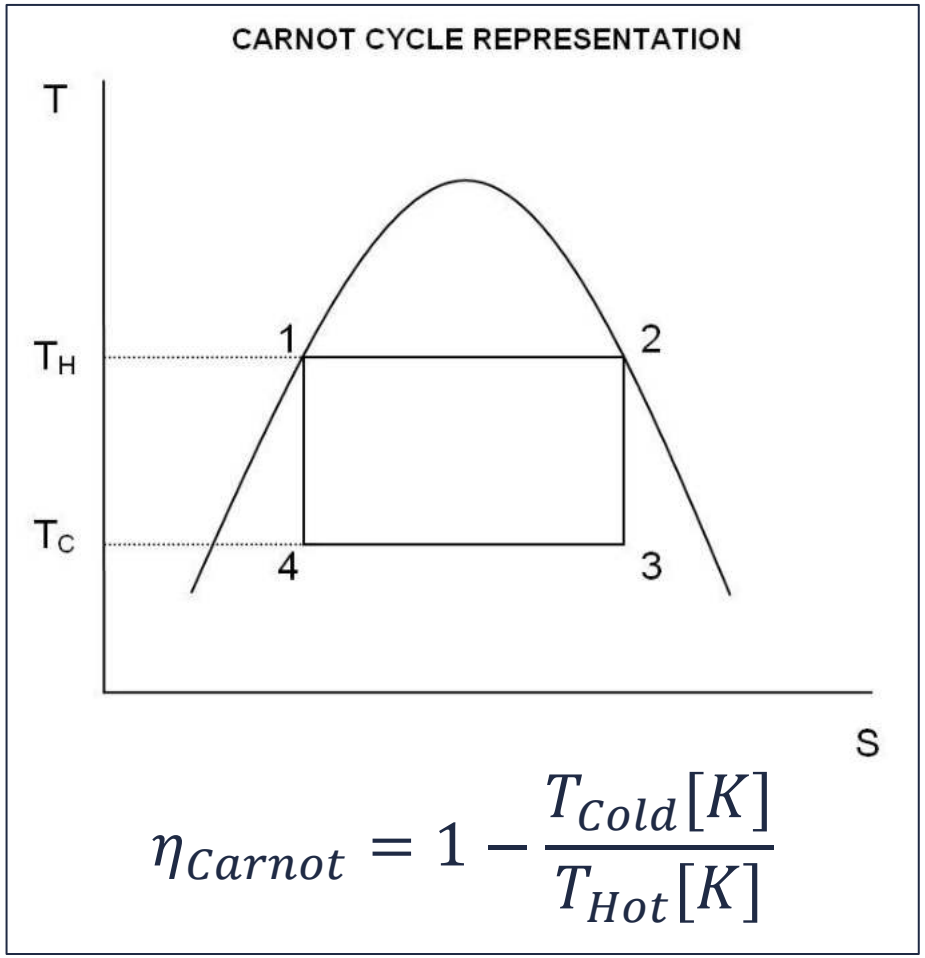


Thermodynamic diagrams

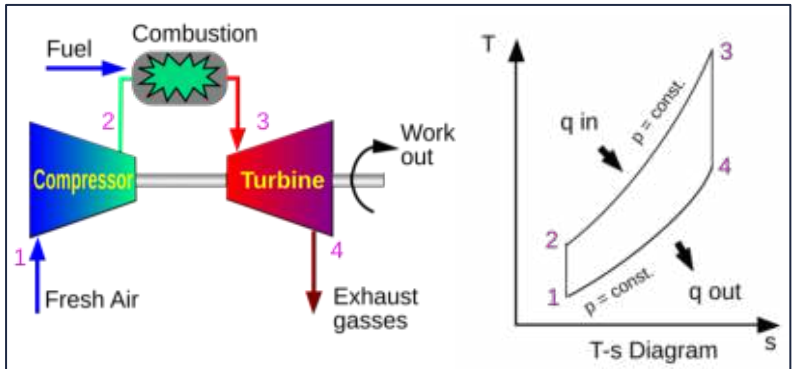




A Sample of Thermodynamic Cycles in Power Generation



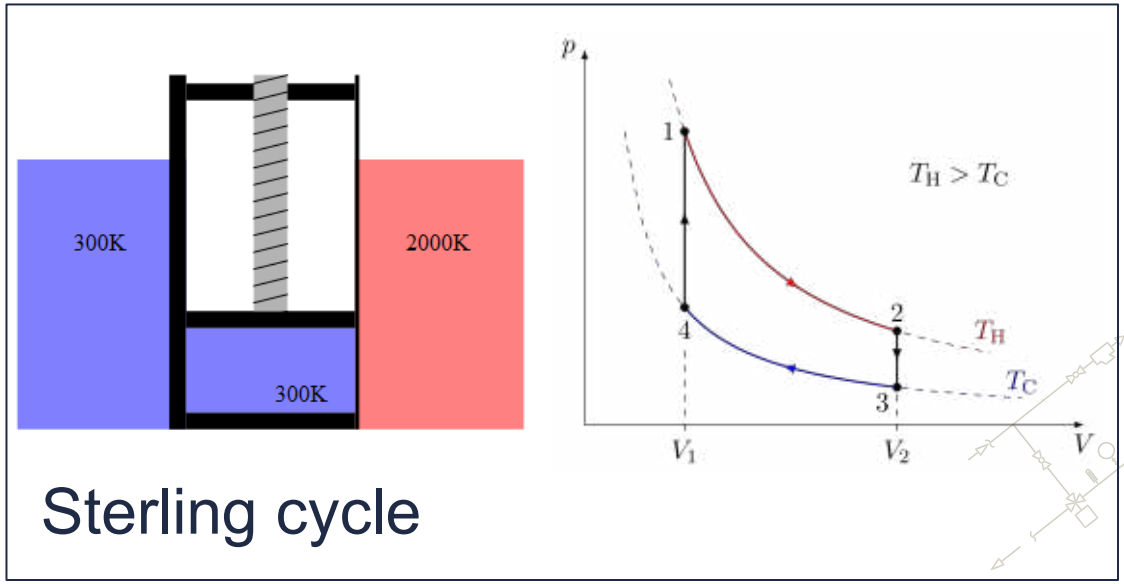
$$\eta_{Carnot} = 1 - \frac{T_{Cold}[K]}{T_{Hot}[K]}$$



Baryton cycle

Ex. Jet engines, Gas turbines

Otto cycle
Diesel cycle
…



Sterling cycle

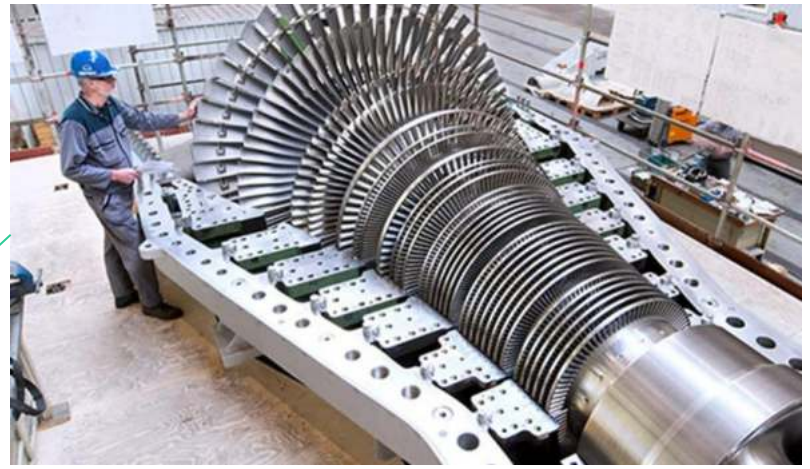
William John Macquorn Rankine (1820 – 1872)



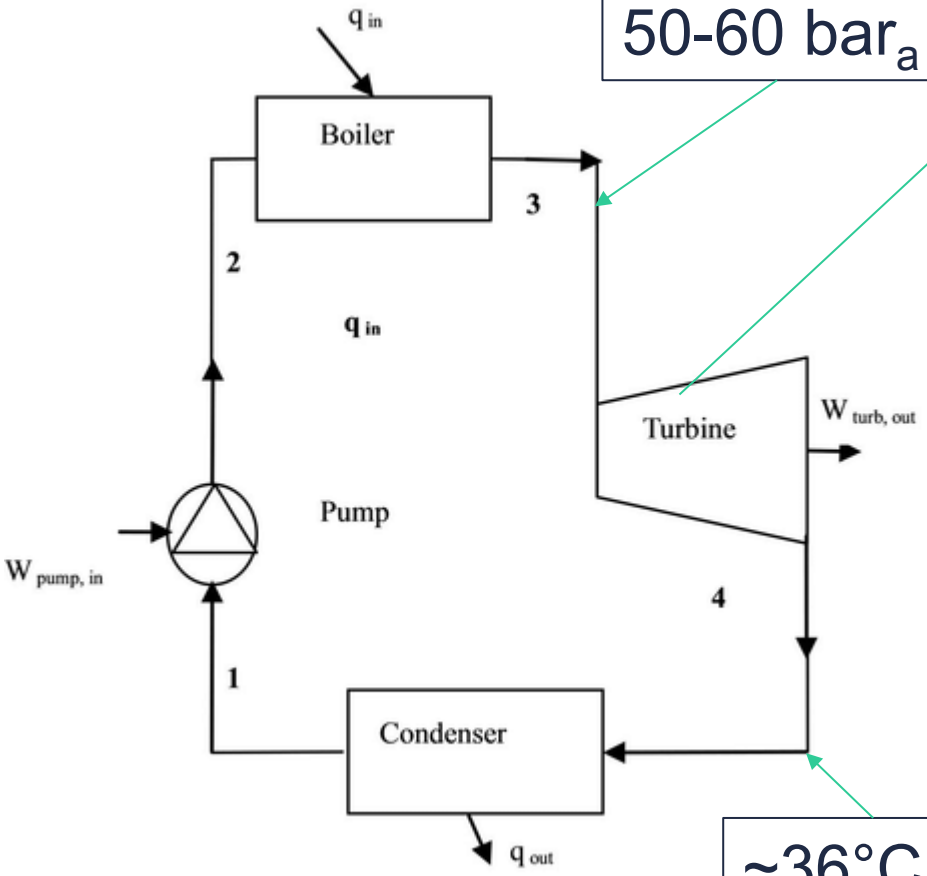
The Rankine Cycle in Power Plants

Closed loop

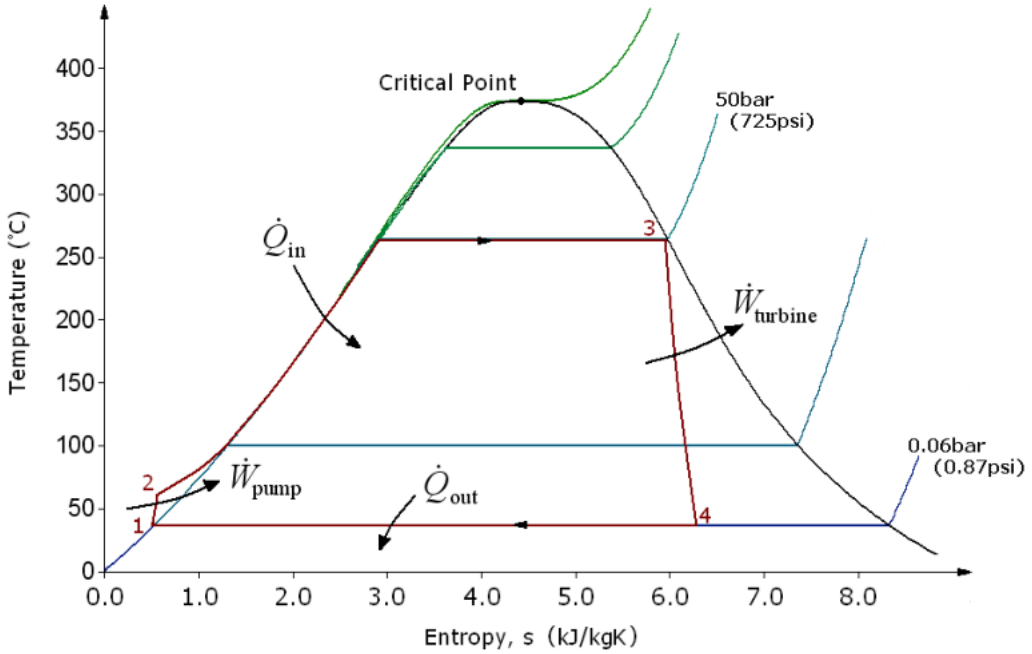
Working Media: Water



250-270°C
50-60 bar_a



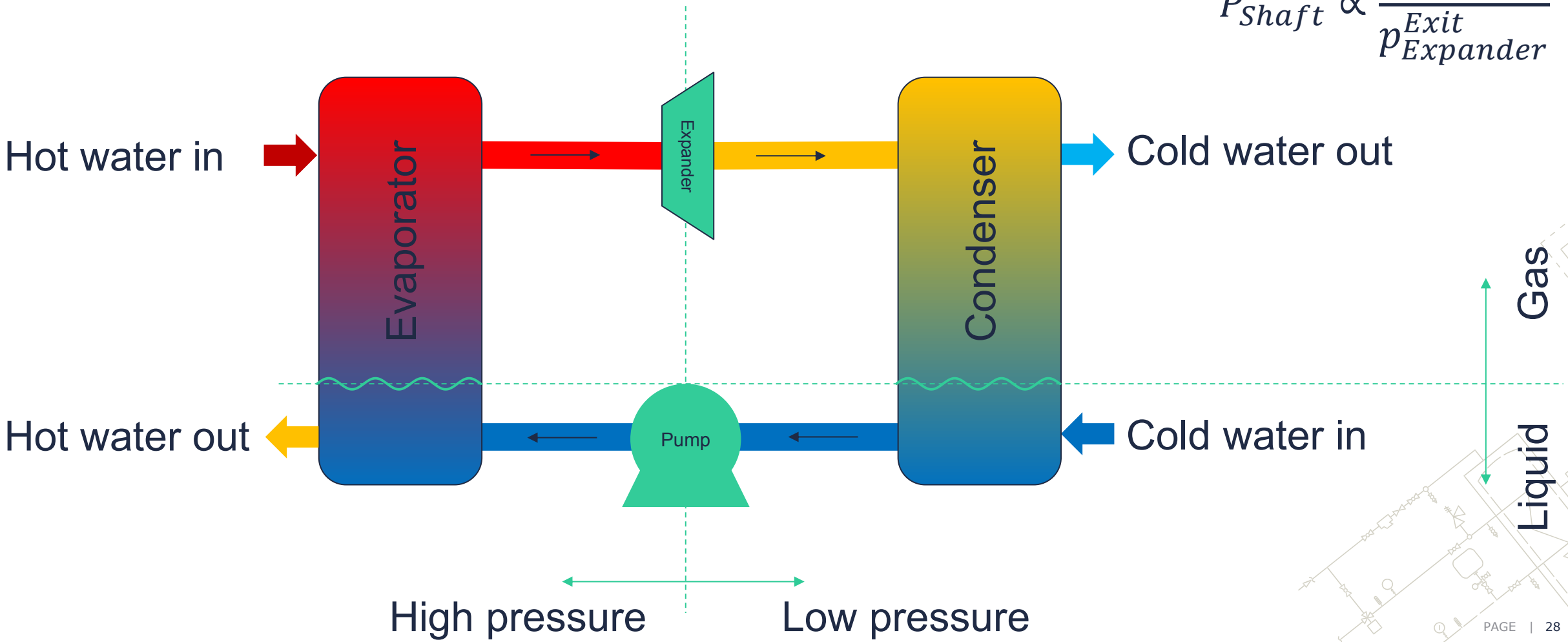
~36°C
60 $mbar_a$



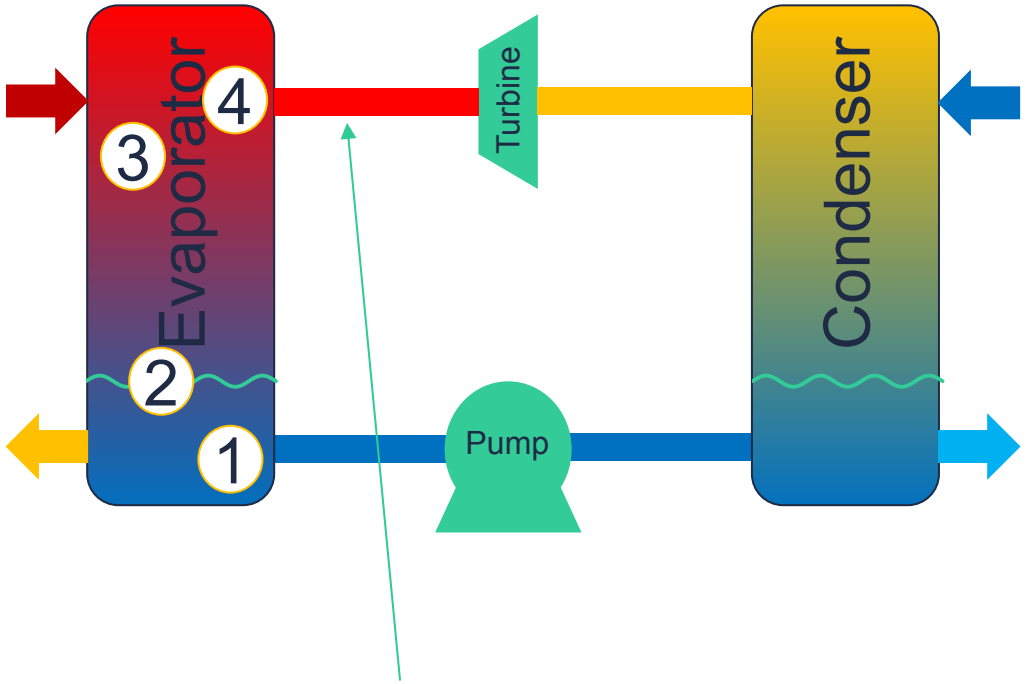
Generic ORC (Organic Rankine Cycle)

The expander runs on pressure ratio

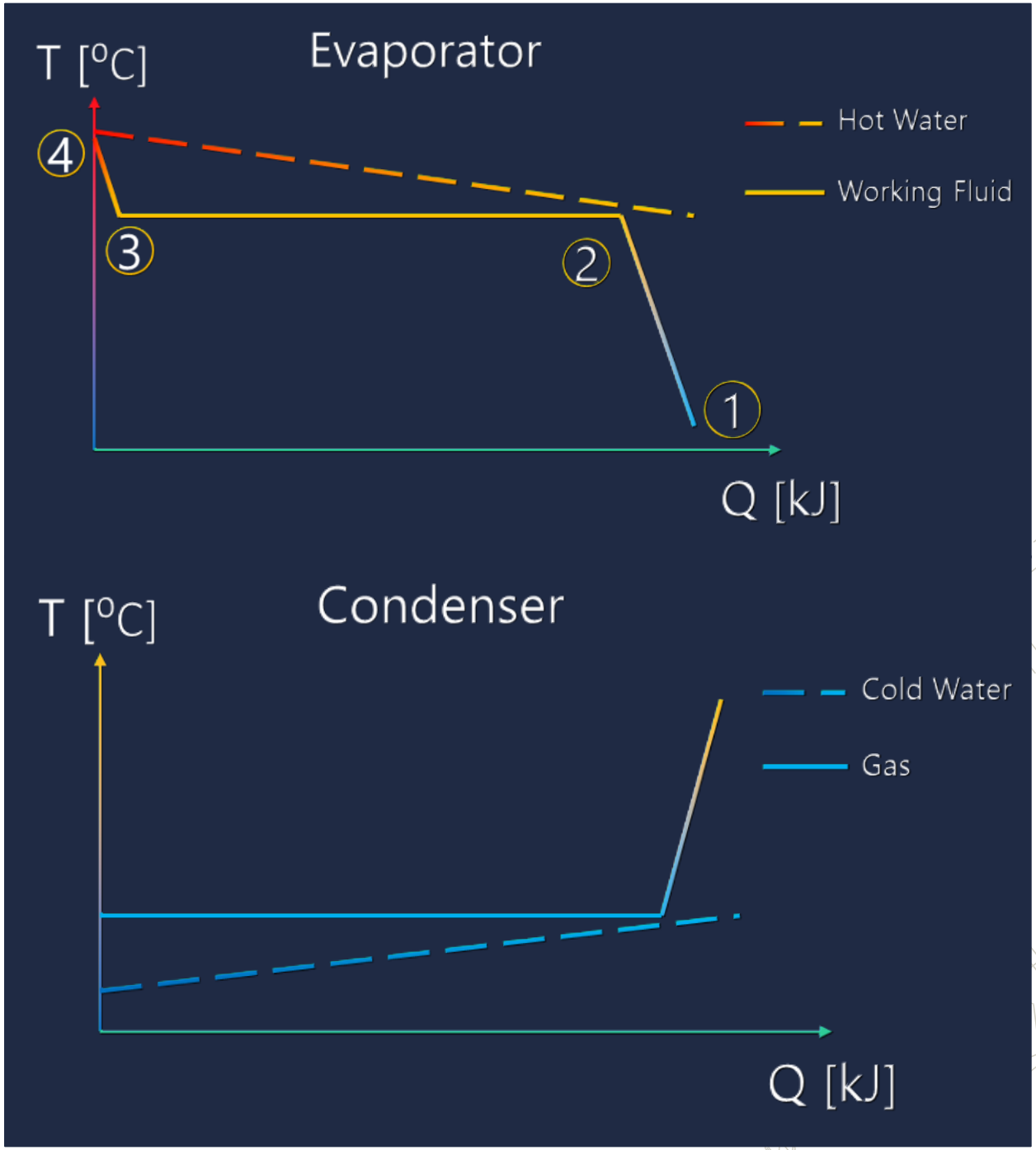
$$P_{Shaft} \propto \frac{p_{Expander}^{Inlet}}{p_{Expander}^{Exit}}$$



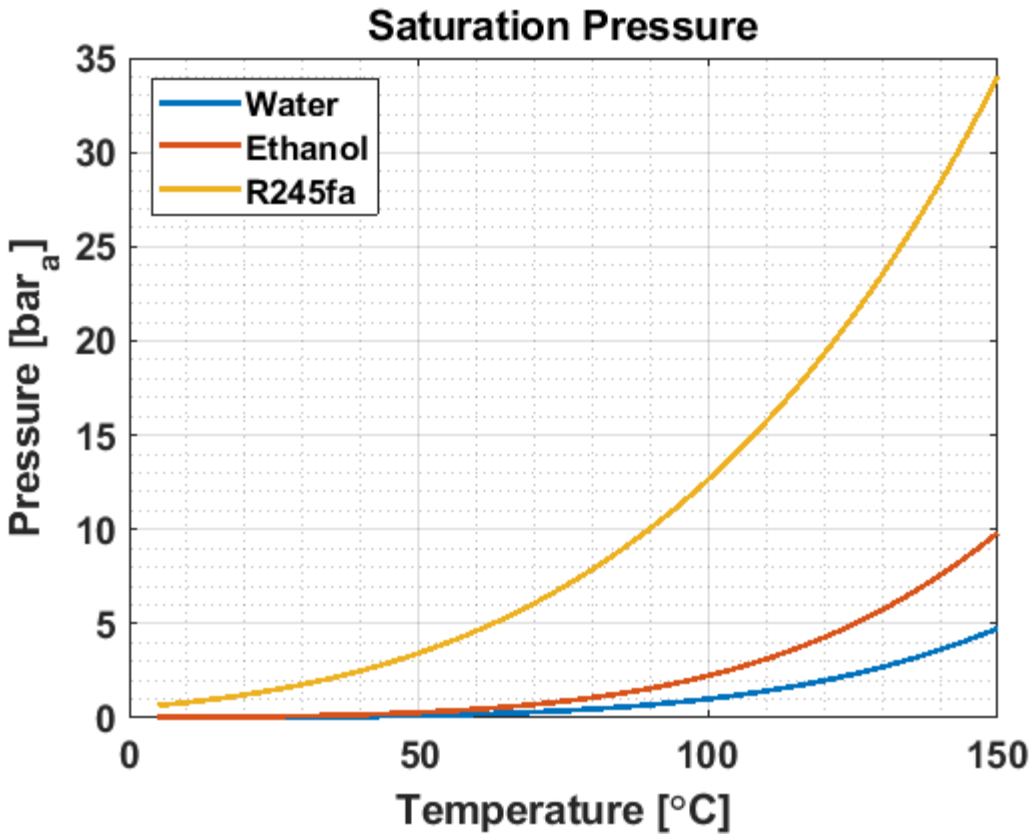
Evaporation and Condensation



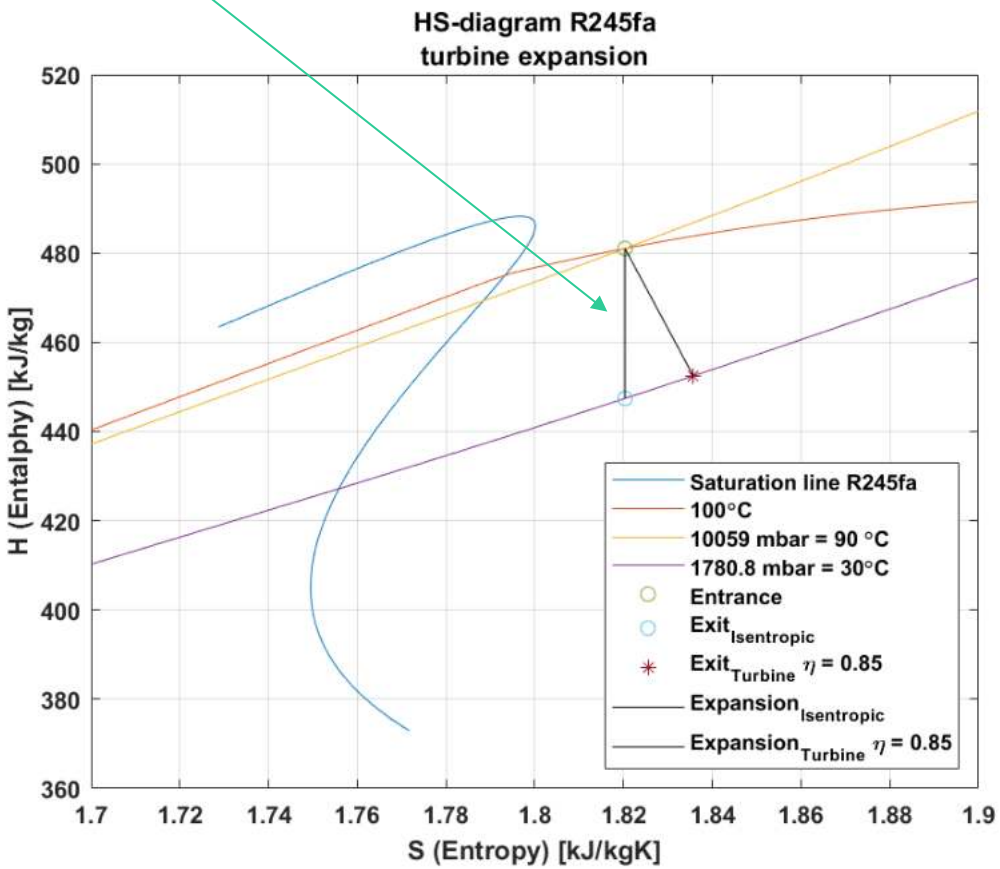
The pressure at (4) is defined by the saturation pressure of the boiling temperature, which is defined by the turbine



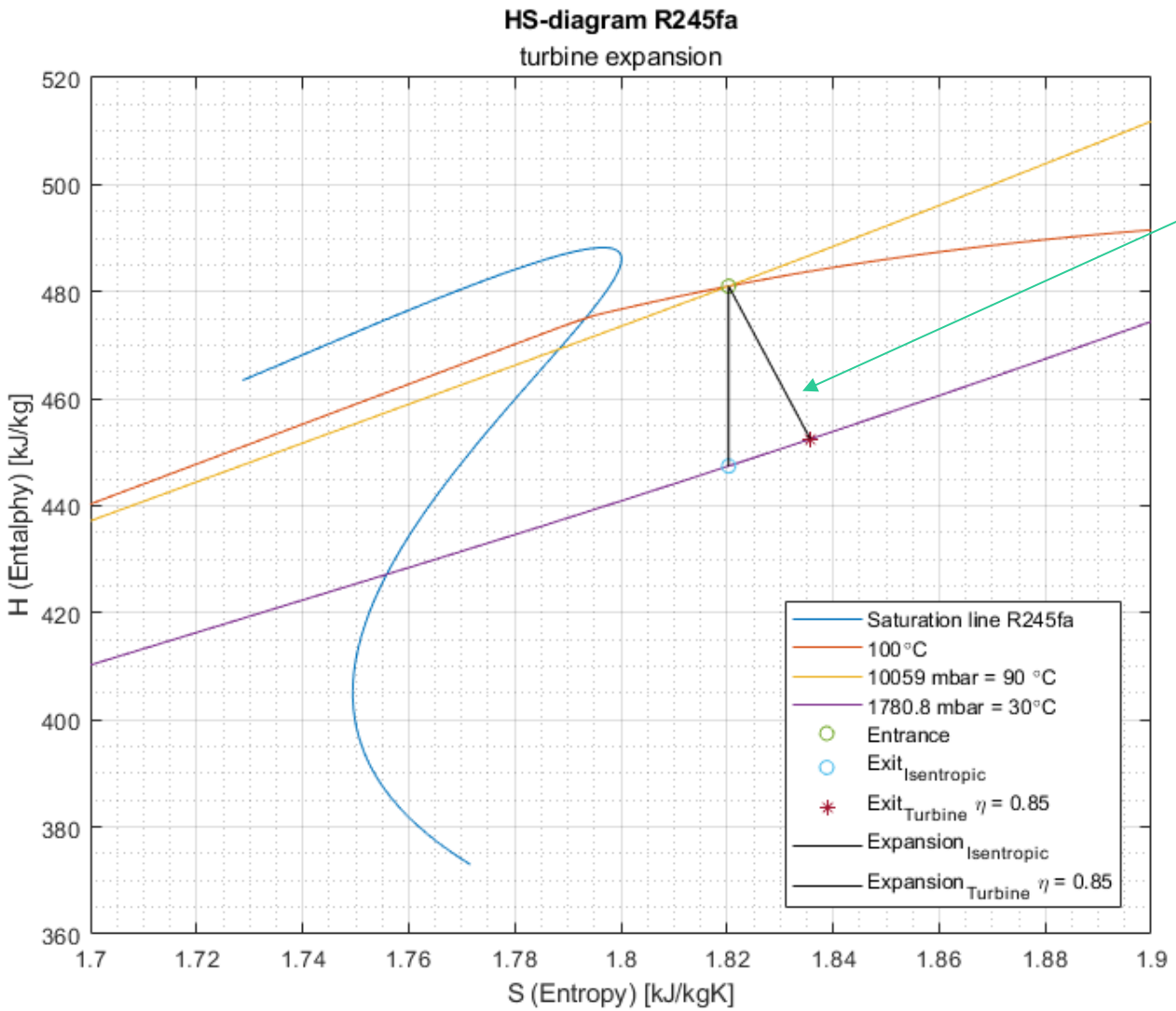
Which media to use?



Dry expansion



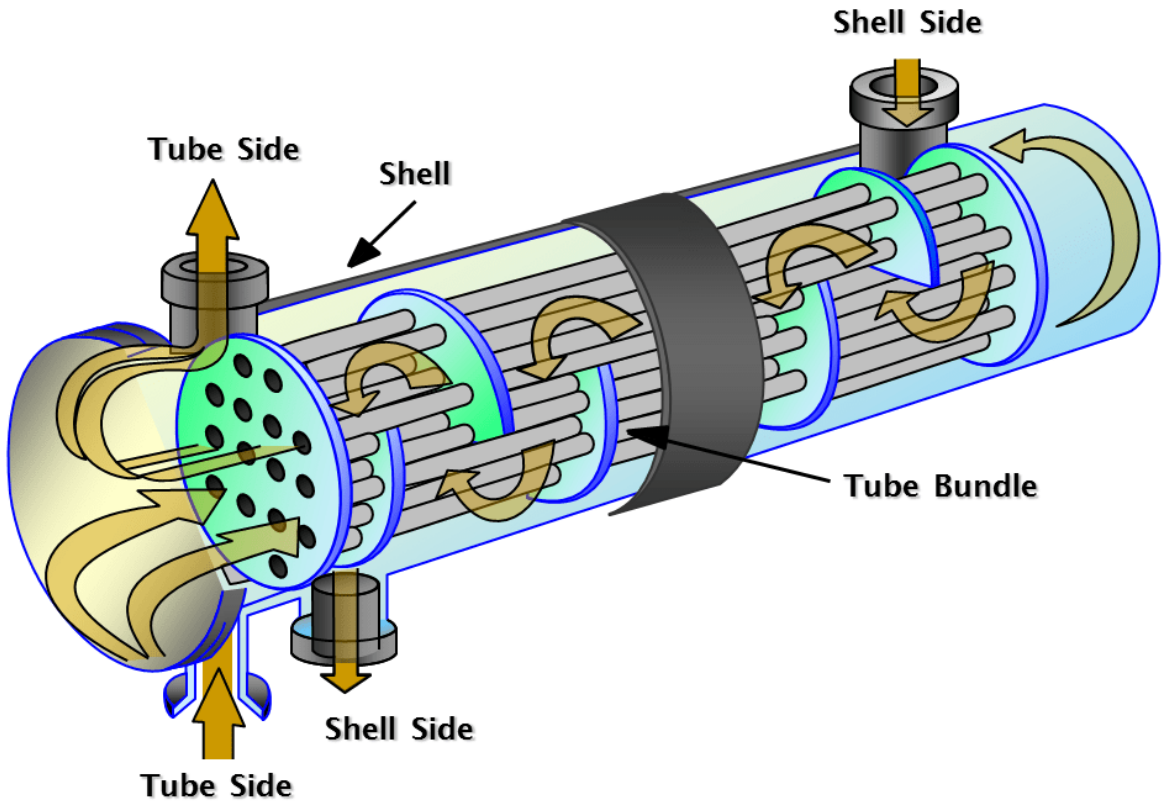
Turbine expansion



Very dry expansion

ry wet expansion
ıld lead to turbine
›sion

Evaporator and Condenser
Tube and Shell heat exchangers



Evaporator and Condenser
Plate heat exchangers





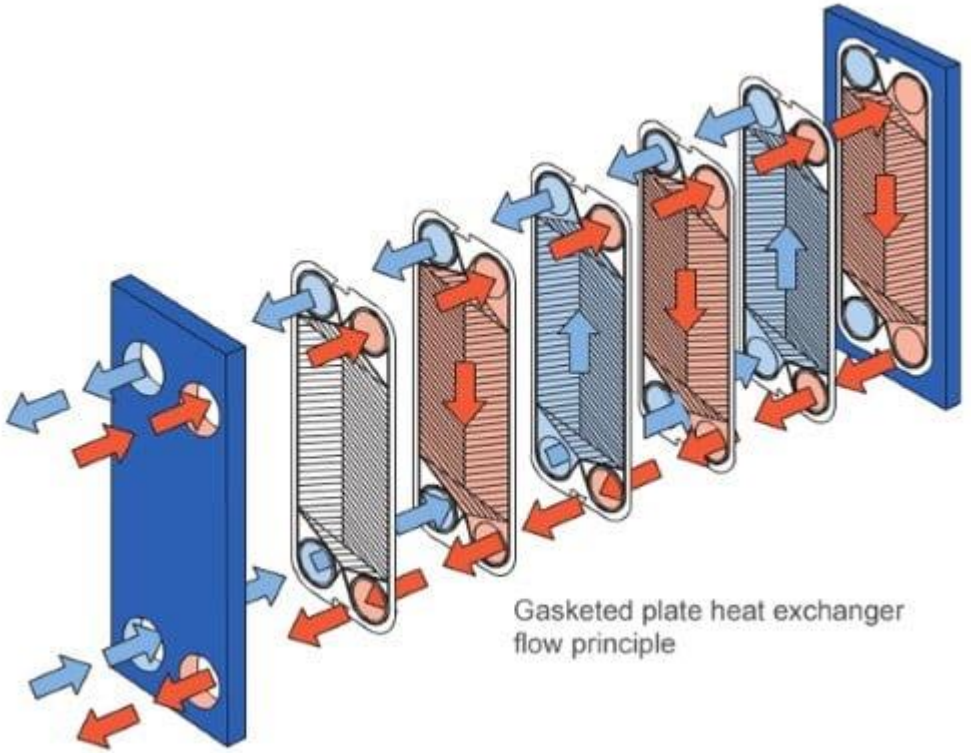
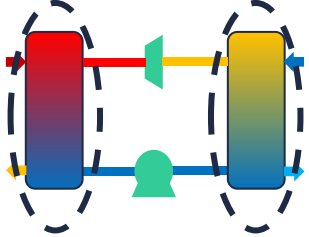
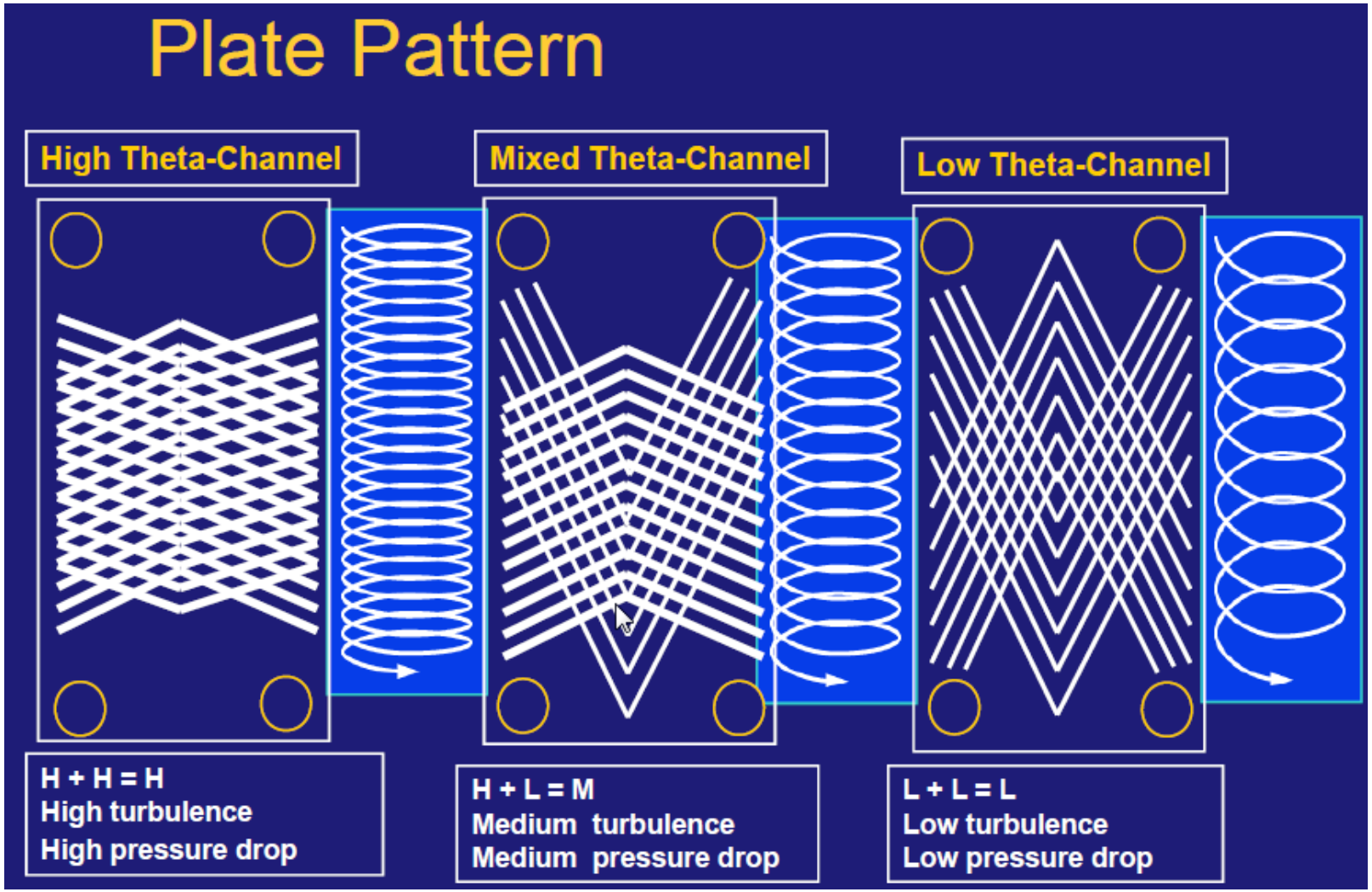


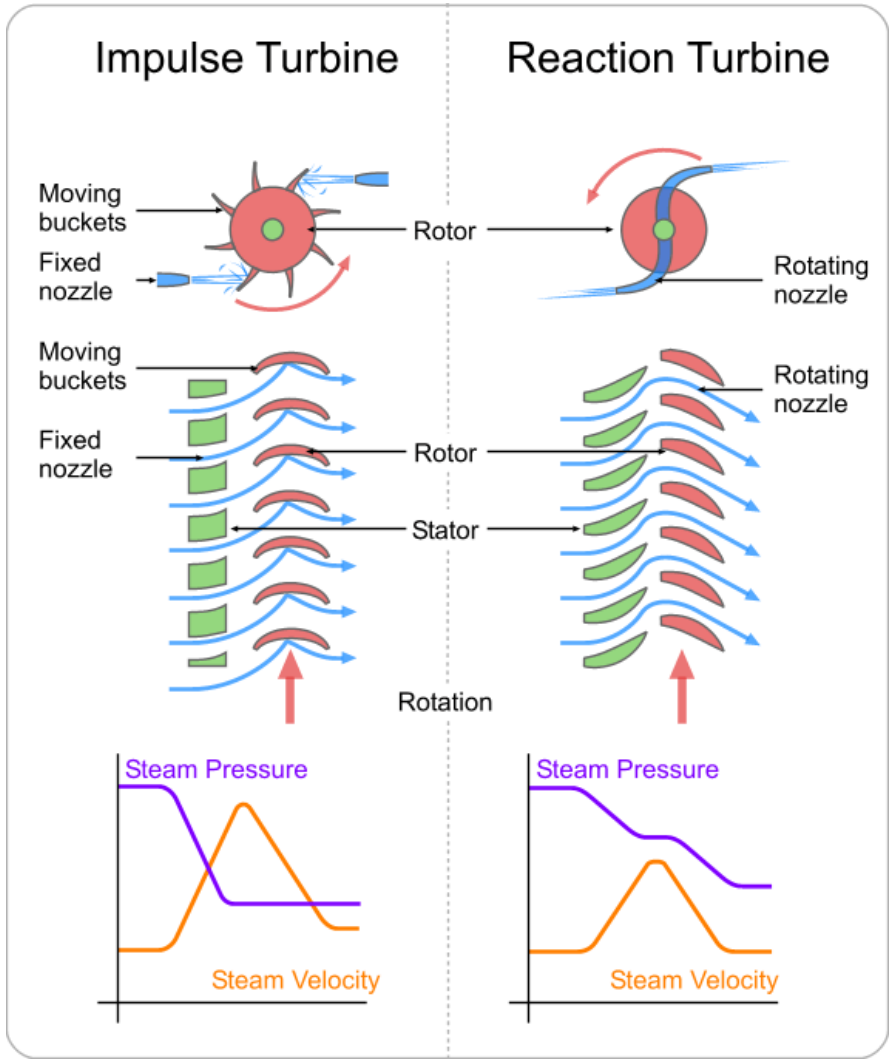
Plate configuration and flow pattern
Turbulence is good



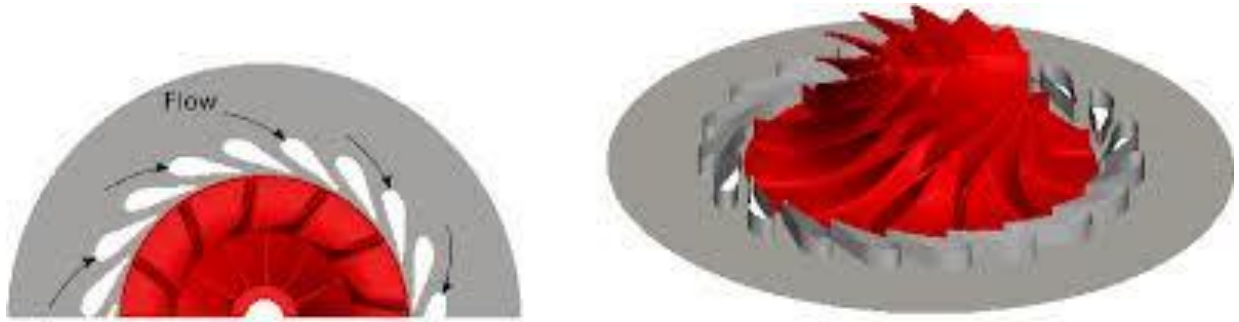
CLIMEON

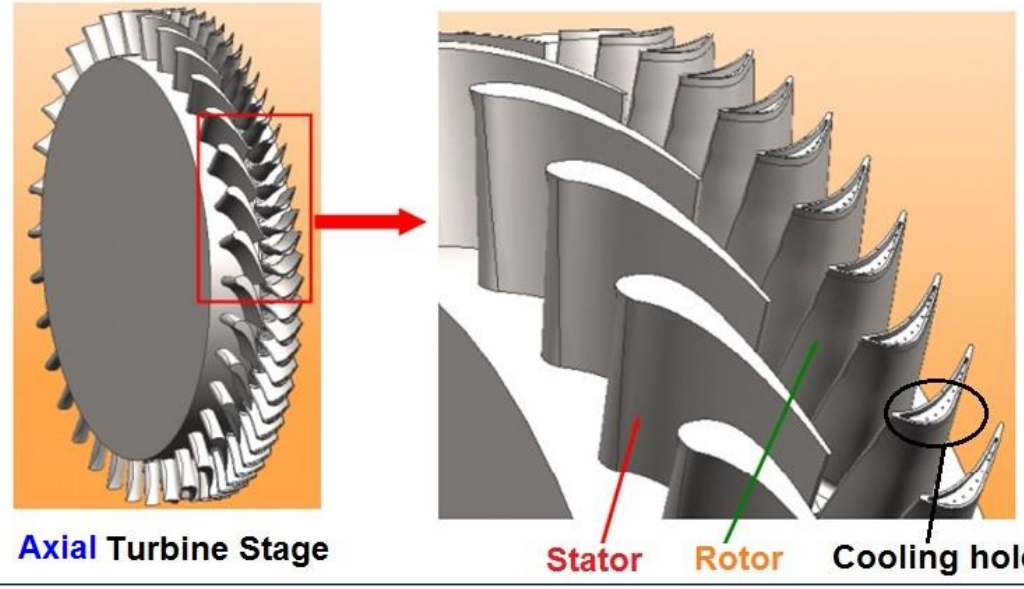


Basic turbine technology
Isentropic efficiency ~85-90%, system efficiency ~80-85%

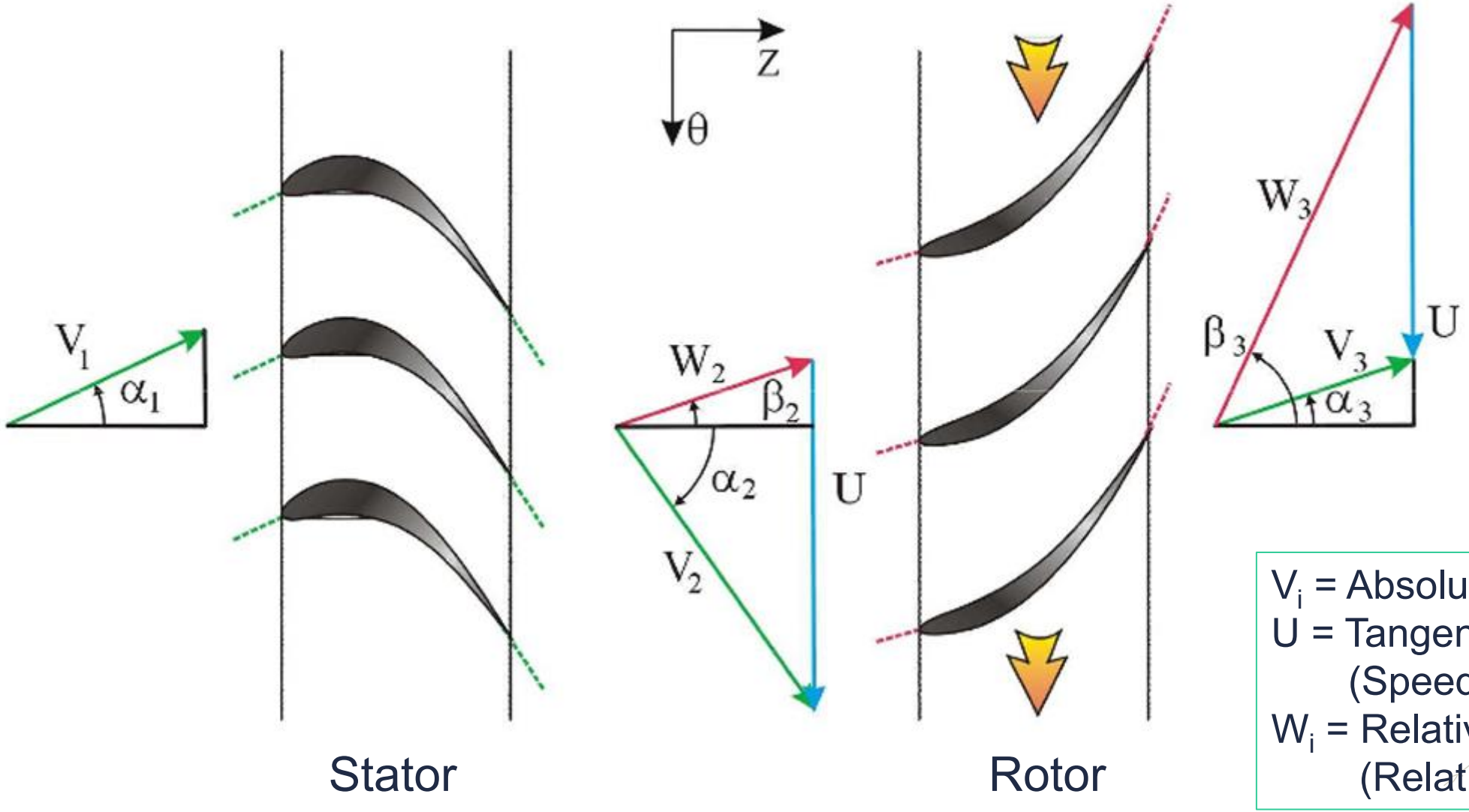


Radial turbine





Basic turbine design



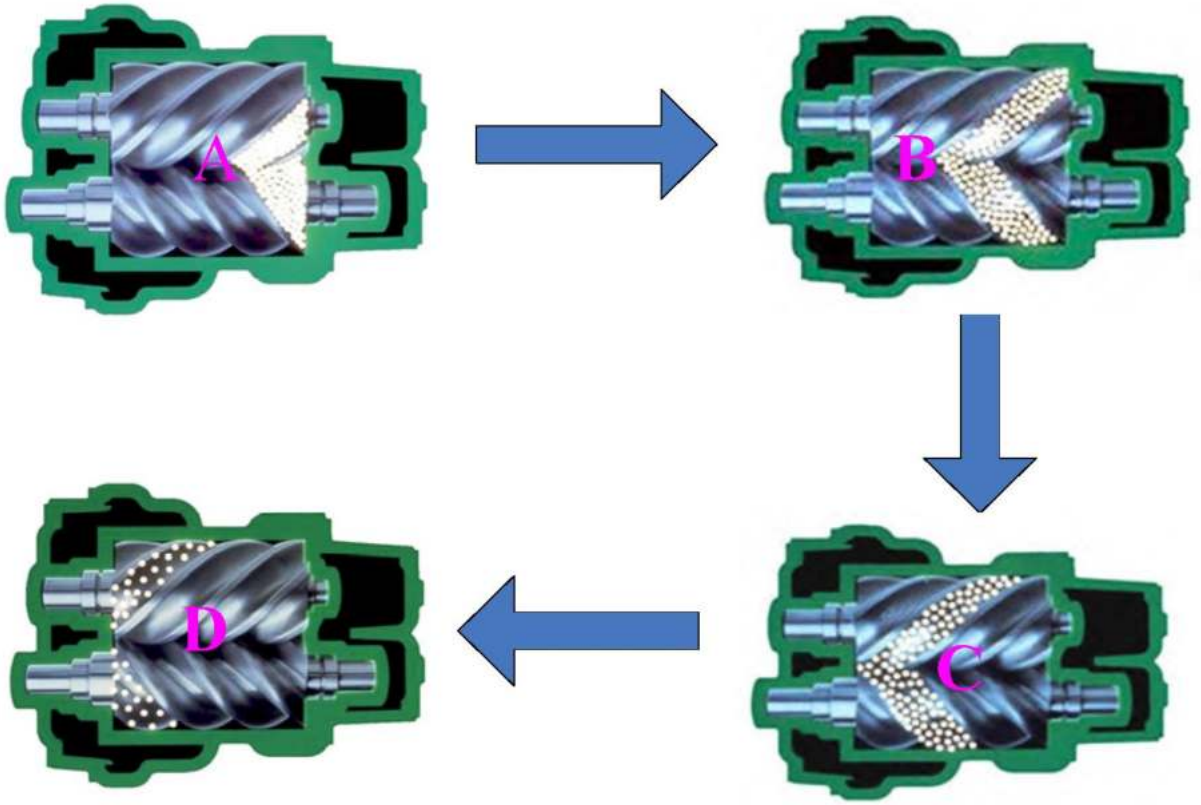
Stator

Rotor

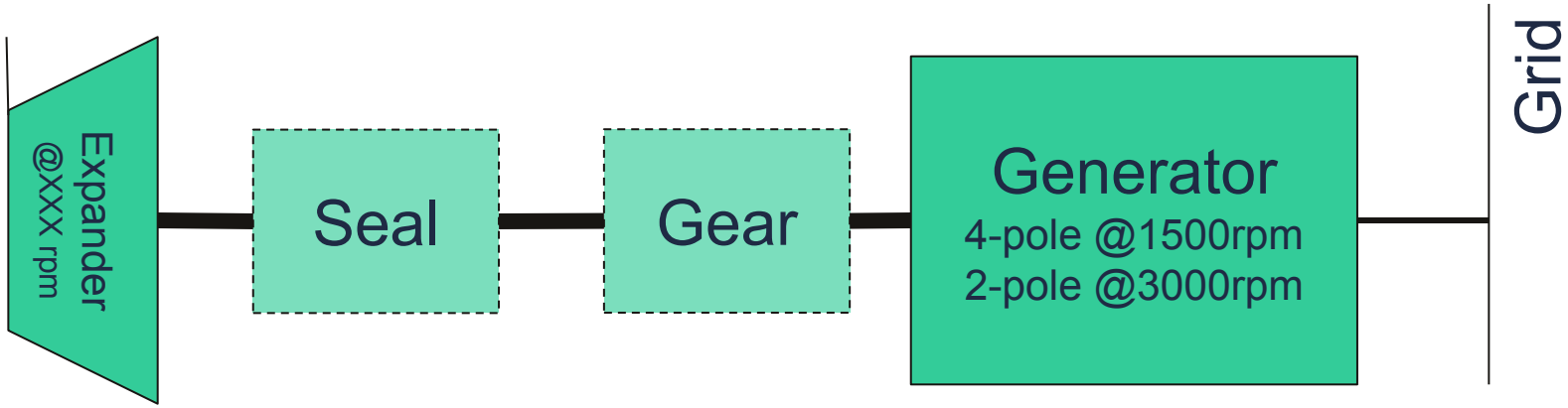
V_i = Absolute gas speed
U = Tangential speed
(Speed of the wheel)
W_i = Relative gas speed
(Relative to the wheel)

Screw expander
Isentropic efficiency ~50%, system efficiency ~30 – 40%

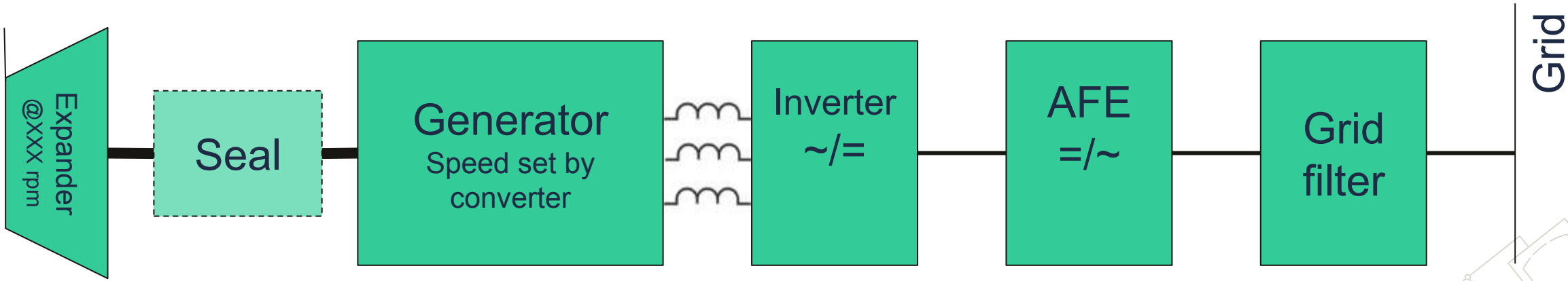




Generators and connection to the grid



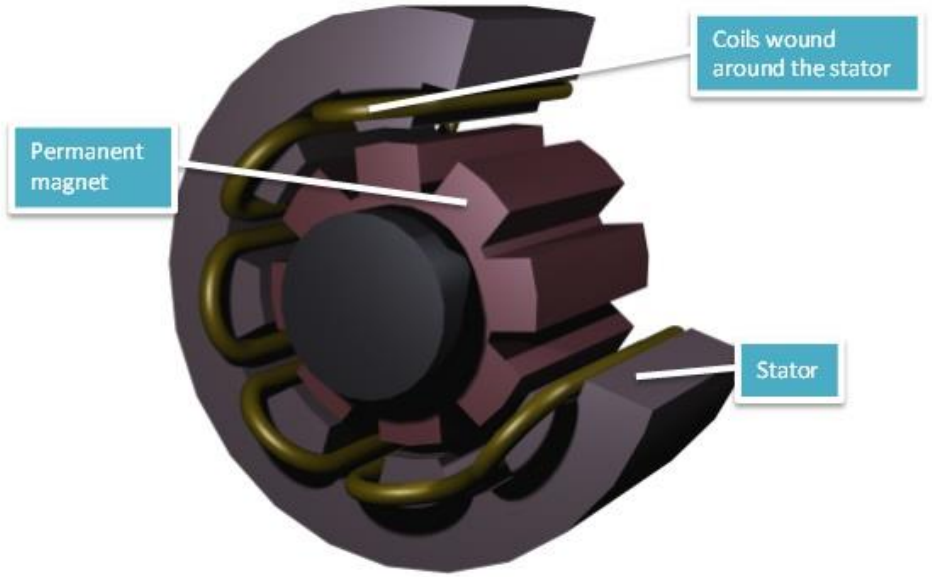
Directly connected to the grid



Converter connection to the grid

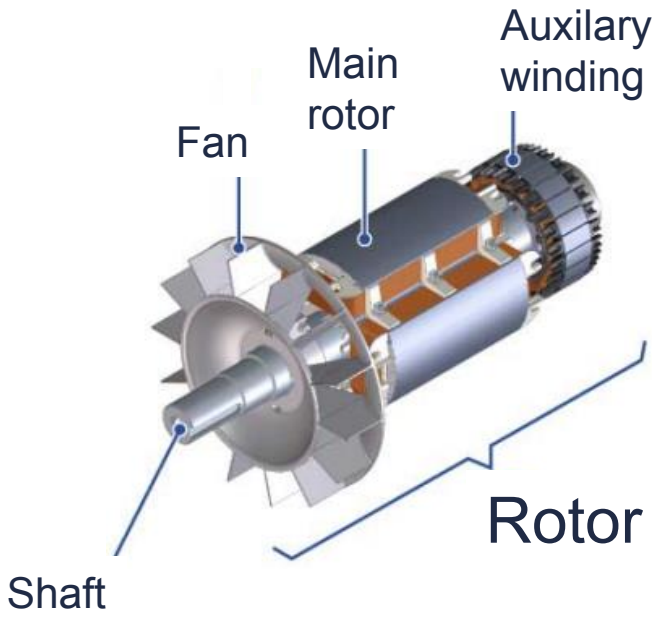
Permanent Magnet Synchronous Generators

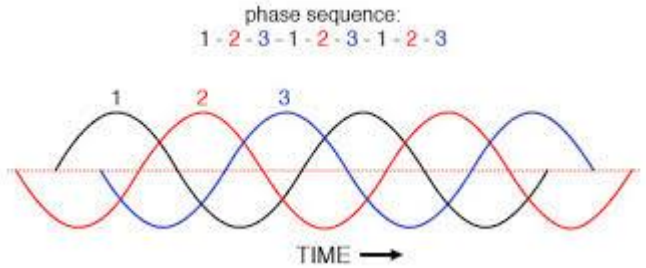
- Permanent magnets on the rotor
- Usually connected to the grid via a converter
  - The converter frequency determines the generator speed
  - Power factor can be adjusted by the converter



Synchronous Generators

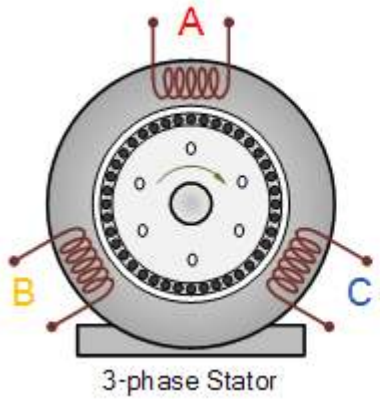
- Windings on the rotor instead of permanent magnets
  - Requires an Automatic Voltage Regulator
  - Cannot start by itself – needs a pony motor to start
- Directly connected to the grid
  - The grid frequency determines the generator speed
  - Needs synchronization before connecting to the grid – The voltage, frequency and phase needs to match the grid to connect to the grid
  - Power factor can be adjusted by adjusting the excitation current

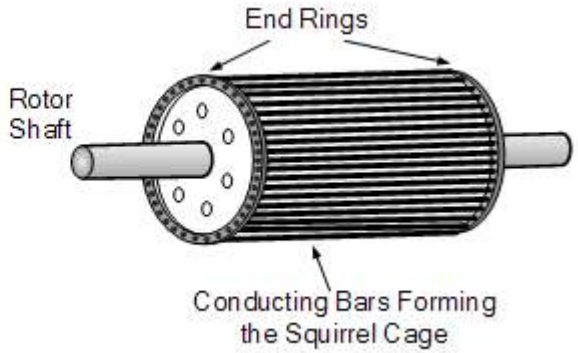


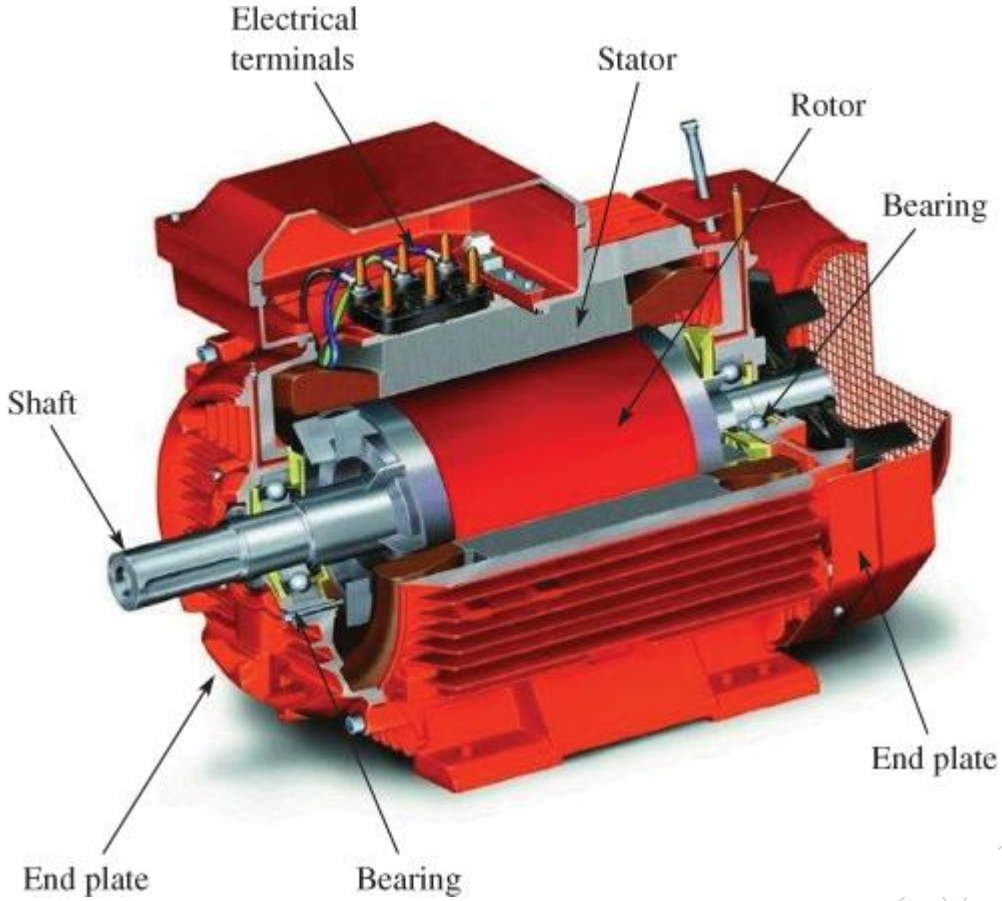


Asynchronous Generators

- Magnetic field created by induction
- No magnets or windings on the rotor
- Directly connected to the grid - usually
  - Rotor speed higher than the grid frequency
    Requires reactive power
  - Power factor can not be adjusted



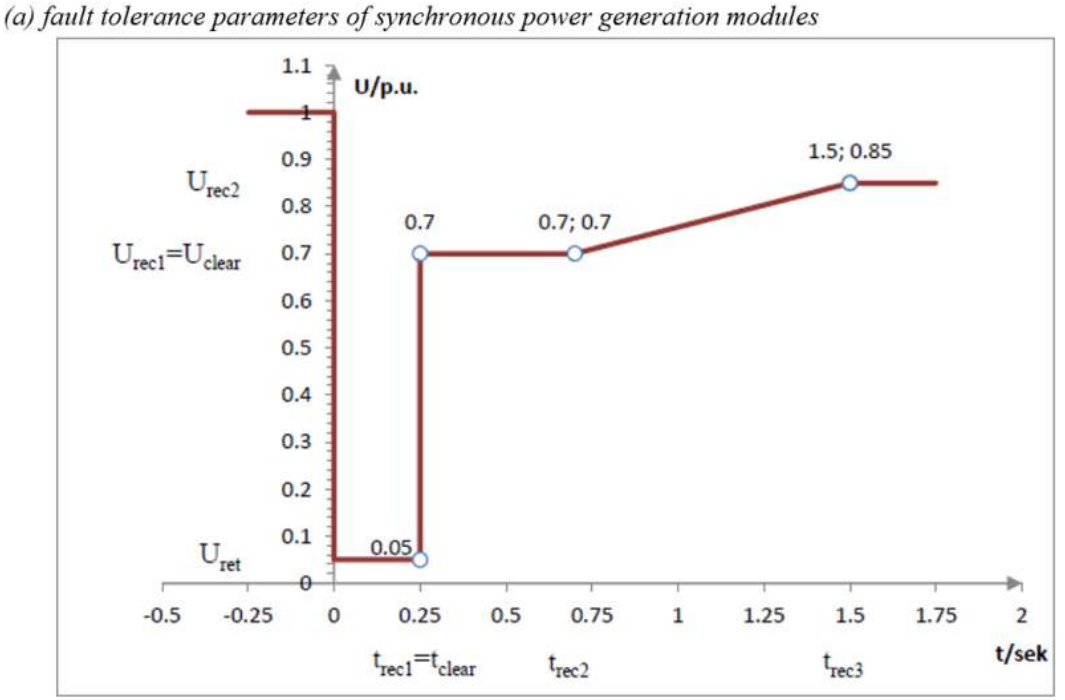




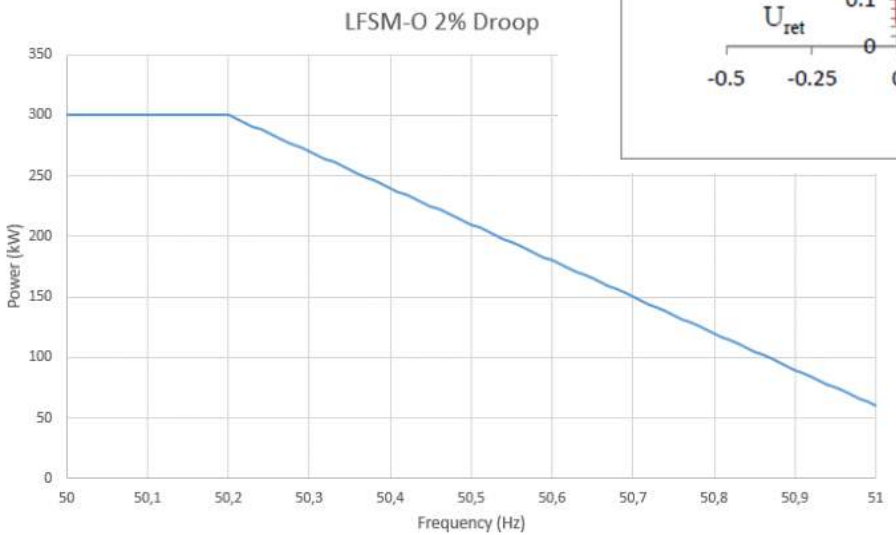
Grid codes – Some examples
Requirements on power producing units to support the grid

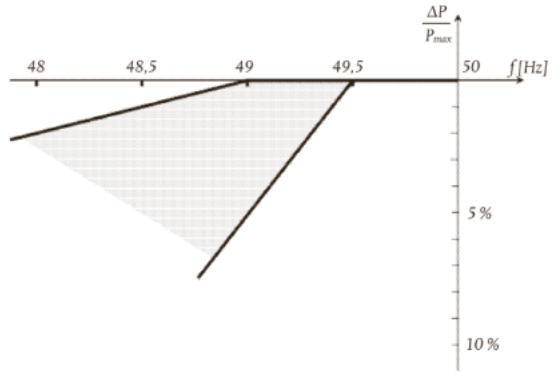
Not allowed to trip for:

- Over- and under-voltage
- Over- and under-frequency
- Voltage Fault Ride Through
- Limited frequency sensitivity mode
  - Under/over
- ...
- ...





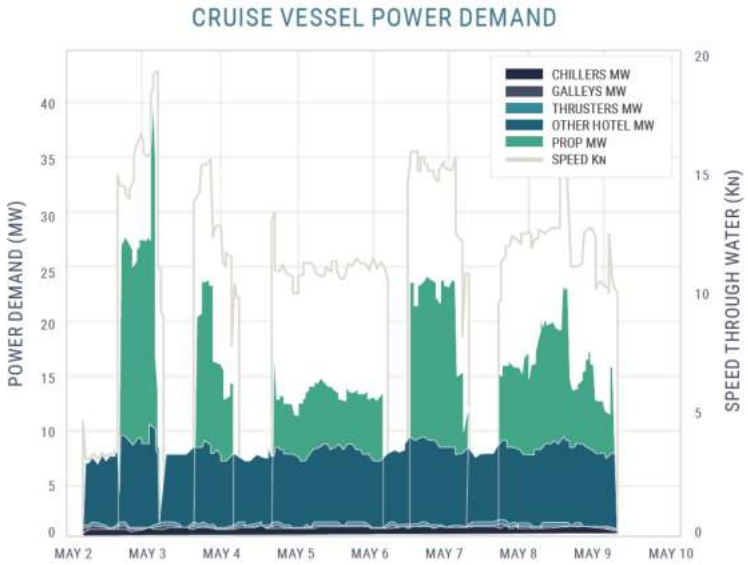




CHEK ORC FUEL SAVINGS

Emissions figures based upon latest MEPC resolution from July 2023







1 x HPM300 (ORC)

Vessel Type	Cruise
CHEK vessel	Meraviglia
Fuel type	HFO

Fuel Saving (HFO): 171 mt/year

CO_2 SAVING: 532 mt/year

Fuel saving : 0,6%



2 x HPM300 (ORC)

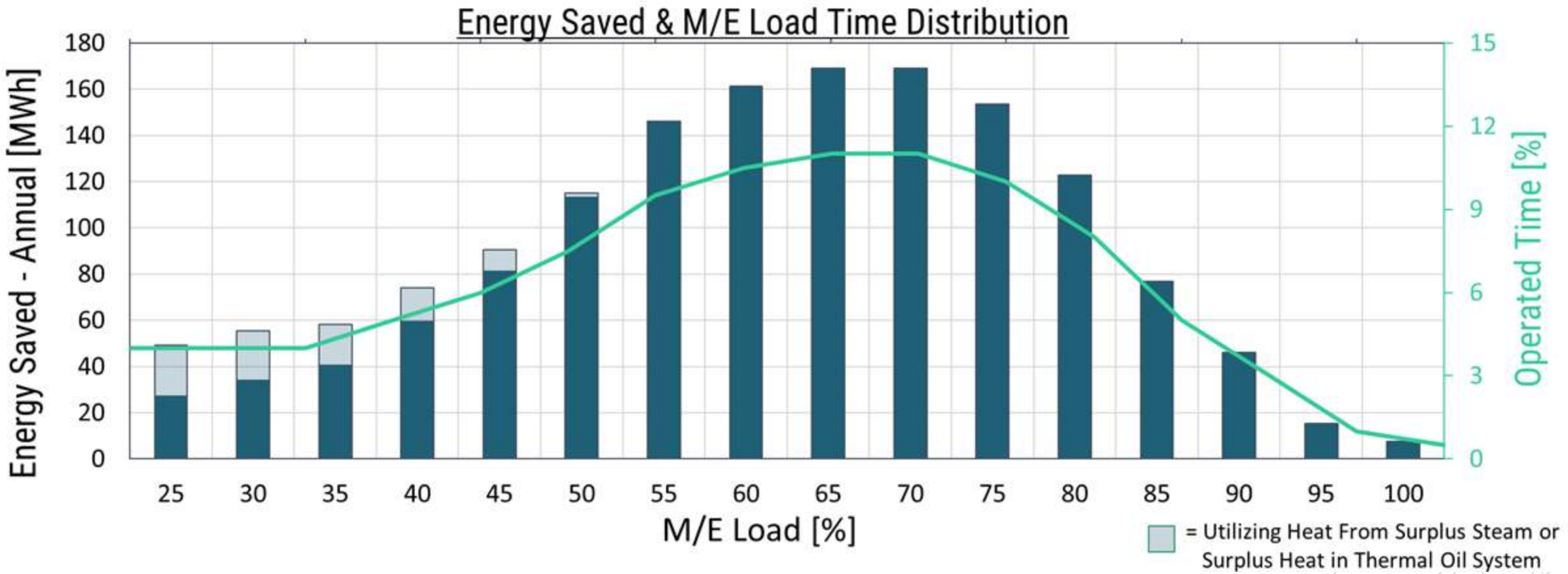
Vessel Type	Cruise
CHEK vessel	Meraviglia
Fuel type	Hydrogen

Fuel Saving (H2): 107 mt/year

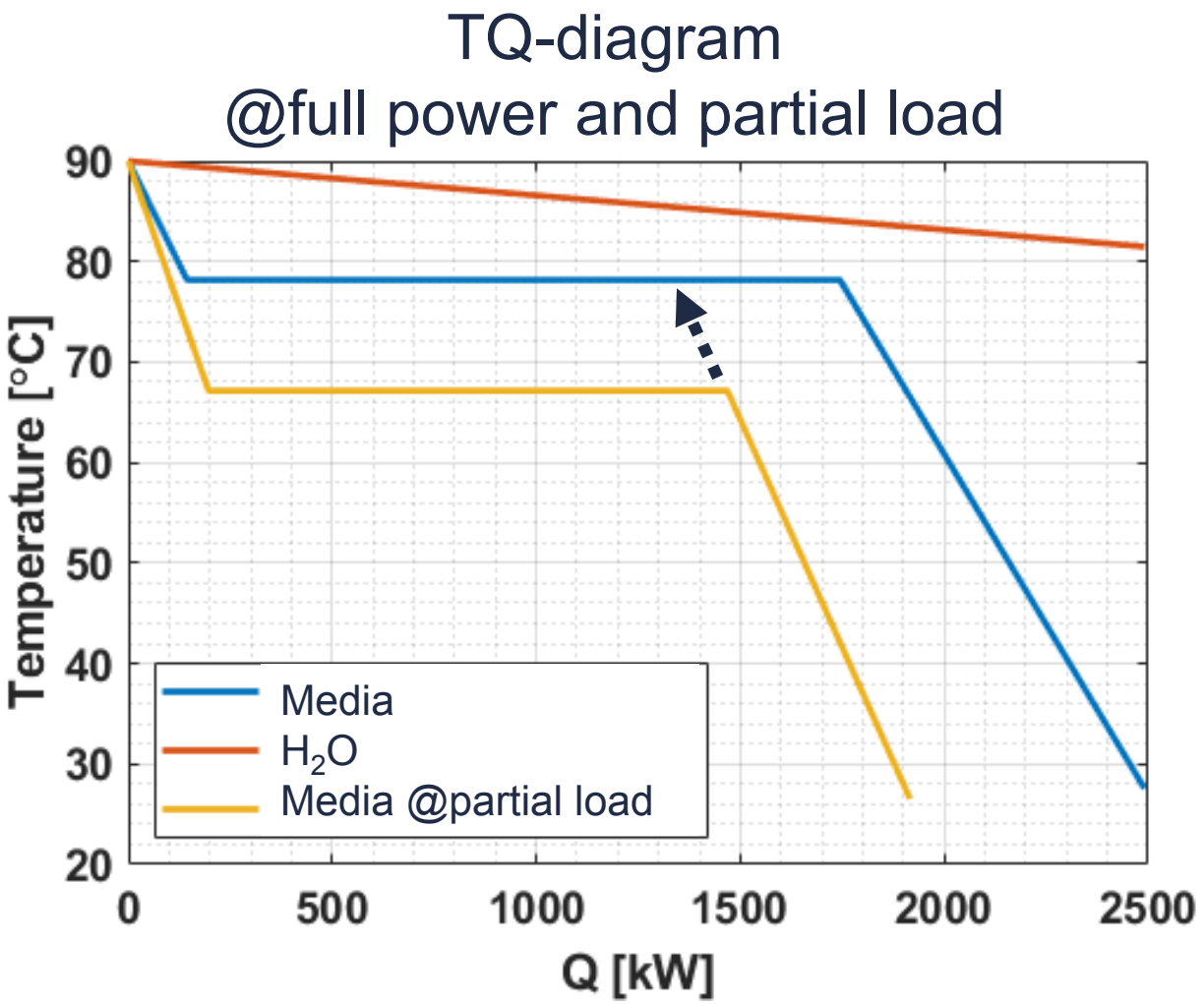
CO_2 SAVING: 0 mt/year

Fuel saving : 1,2%

CHEK Vessel Operational Profile

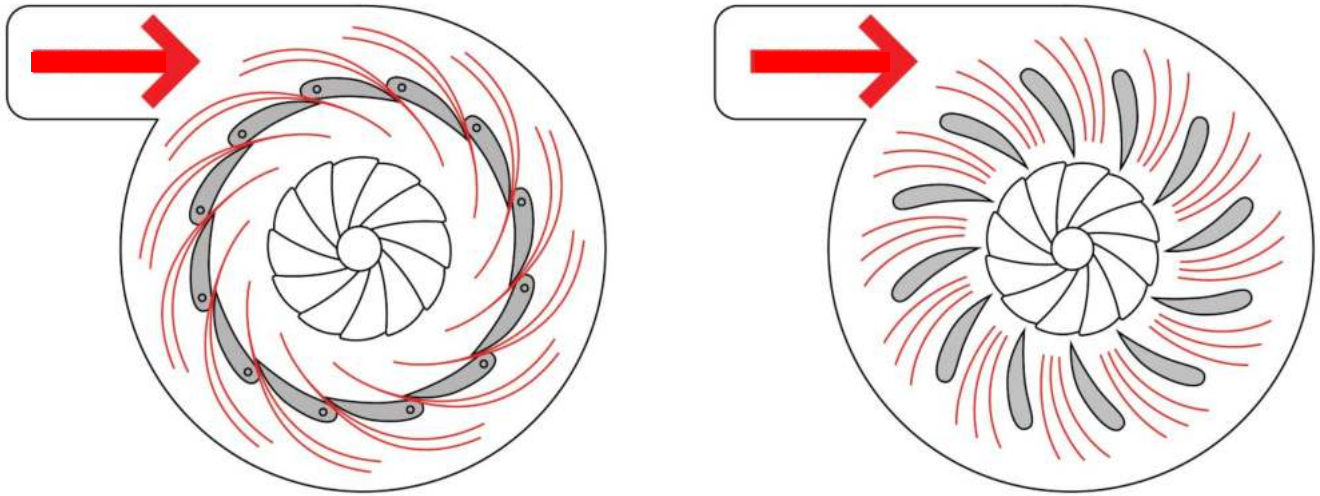


Partial load penalties

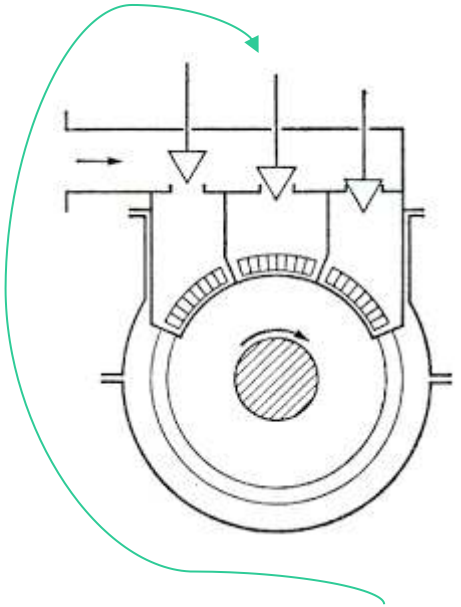


Two different principals to adjust the turbine size

Adjustable guide vanes



Partial admission

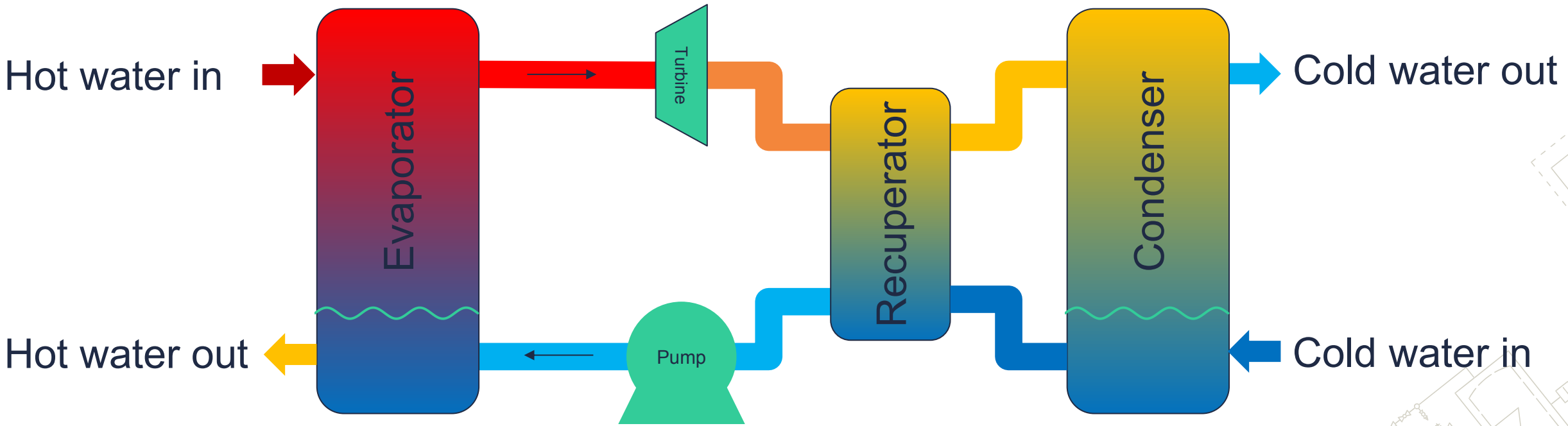


Valves open at different pressures.

Generic ORC with Recuperation
Increasing efficiency

CLIMEON

Recover residual power



CLIMEON

POWERING A SUSTAINABLE FUTURE



FOLLOW US

THANK YOU!