High-Performance Hydrogen-Powered Heat Pumps

B.Cárdenas*, S.Garvey , Z. Baniamerian, R.Mehdipour

Decarbonising UK domestic heating: Disruptive approaches

6th of November, 2024. IMechE, London

The millions of gas boilers in the UK's homes produce **twice as much CO_2** emissions as all the gas-fired power stations in the country

We need to **change** the way we heat our homes if we want to reach **Net Zero**

Source:
https://www.theguardian.com/environment/2021/sep/29/uks-home-gas-boilers-emit-twice-as-much-co2-as-all-power-stations-study

In the UK, two low-carbon heating technologies are being considered as the main options:

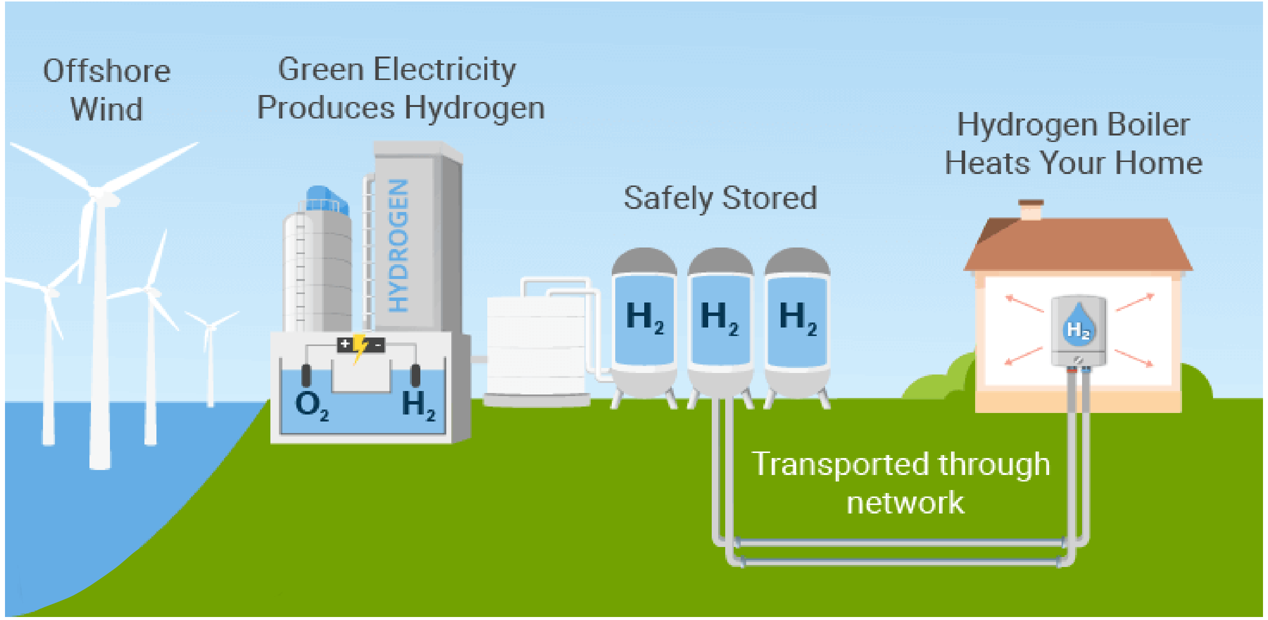
Hydrogen boilers

Air-source heat pumps

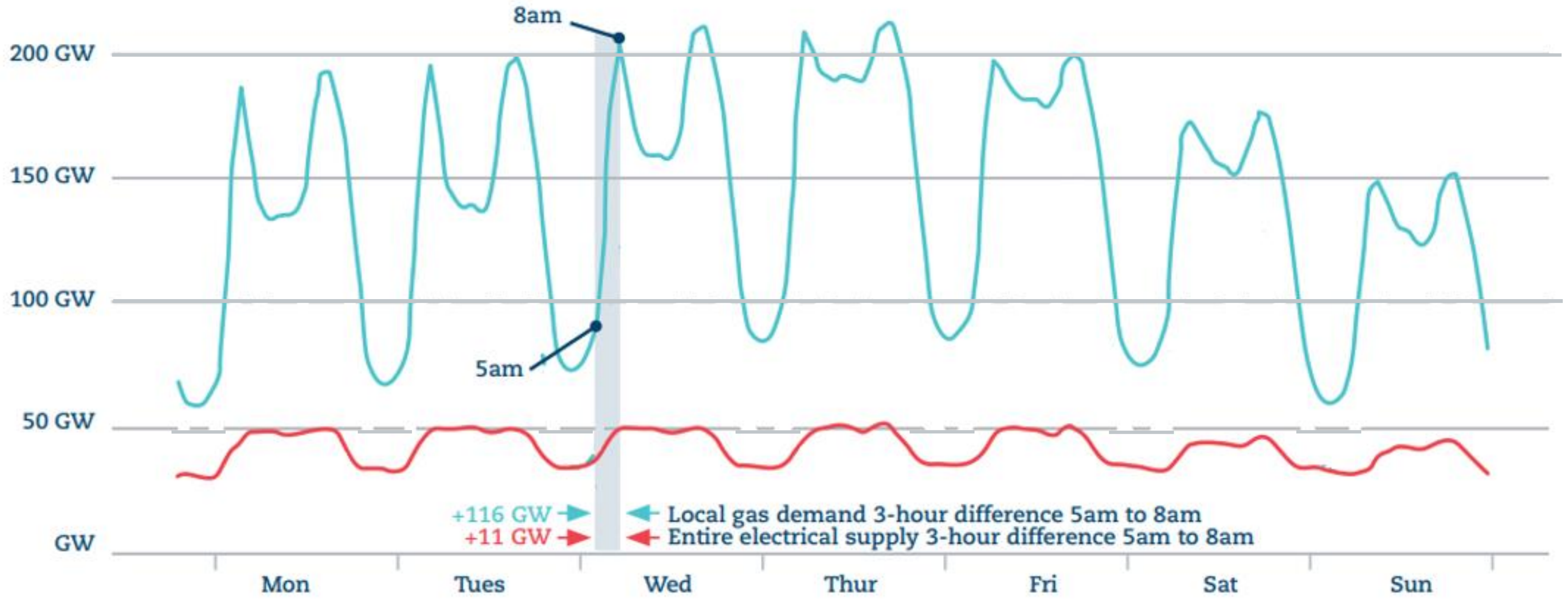
<u>Both have pros and cons!</u>

Hydrogen boilers

- ✓ Continue to exploit the gas network
- ✓ Enable the use of underground caverns for seasonal energy storage
- ✓ They are used in the same way as current gas boilers
- ✗ Only about 60% of the energy spent making H2 reaches a house in the form of low-temperature heat
- ✗ More explosive than natural gas

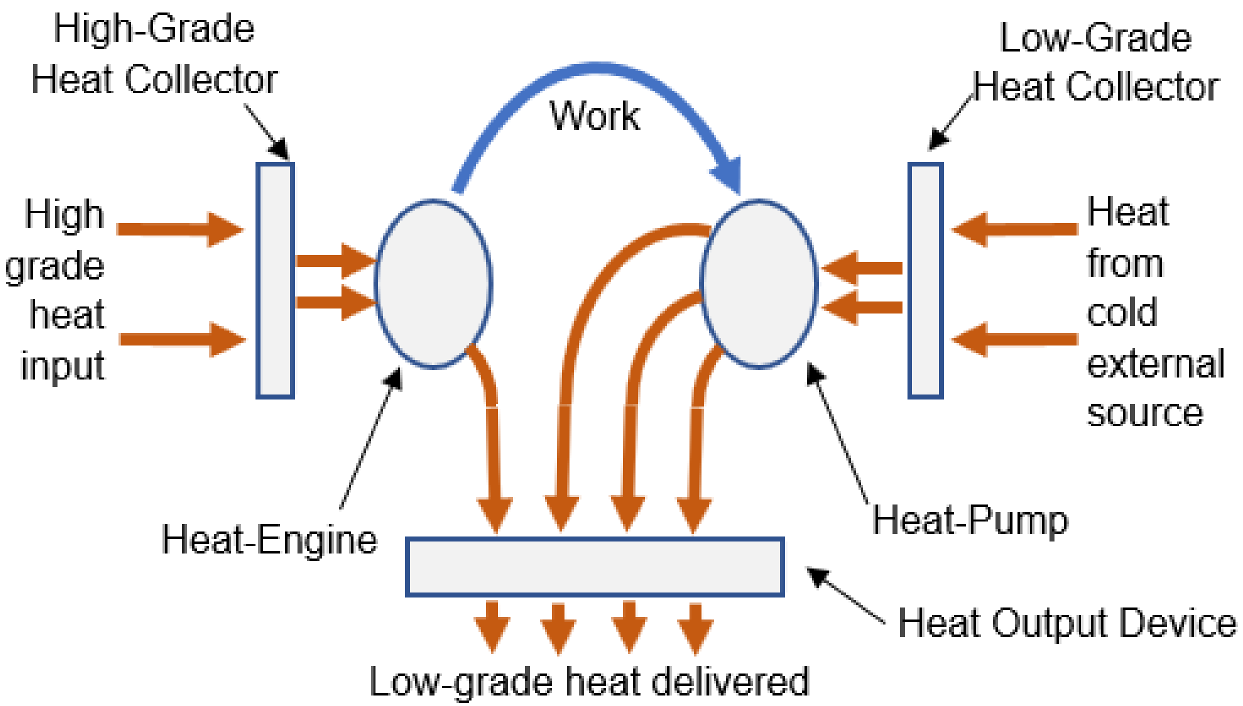


- Heat pumps make much better use of every unit of energy consumed
- The problem are demand peaks. The electricity grid does not have the capacity to provide all the power needed

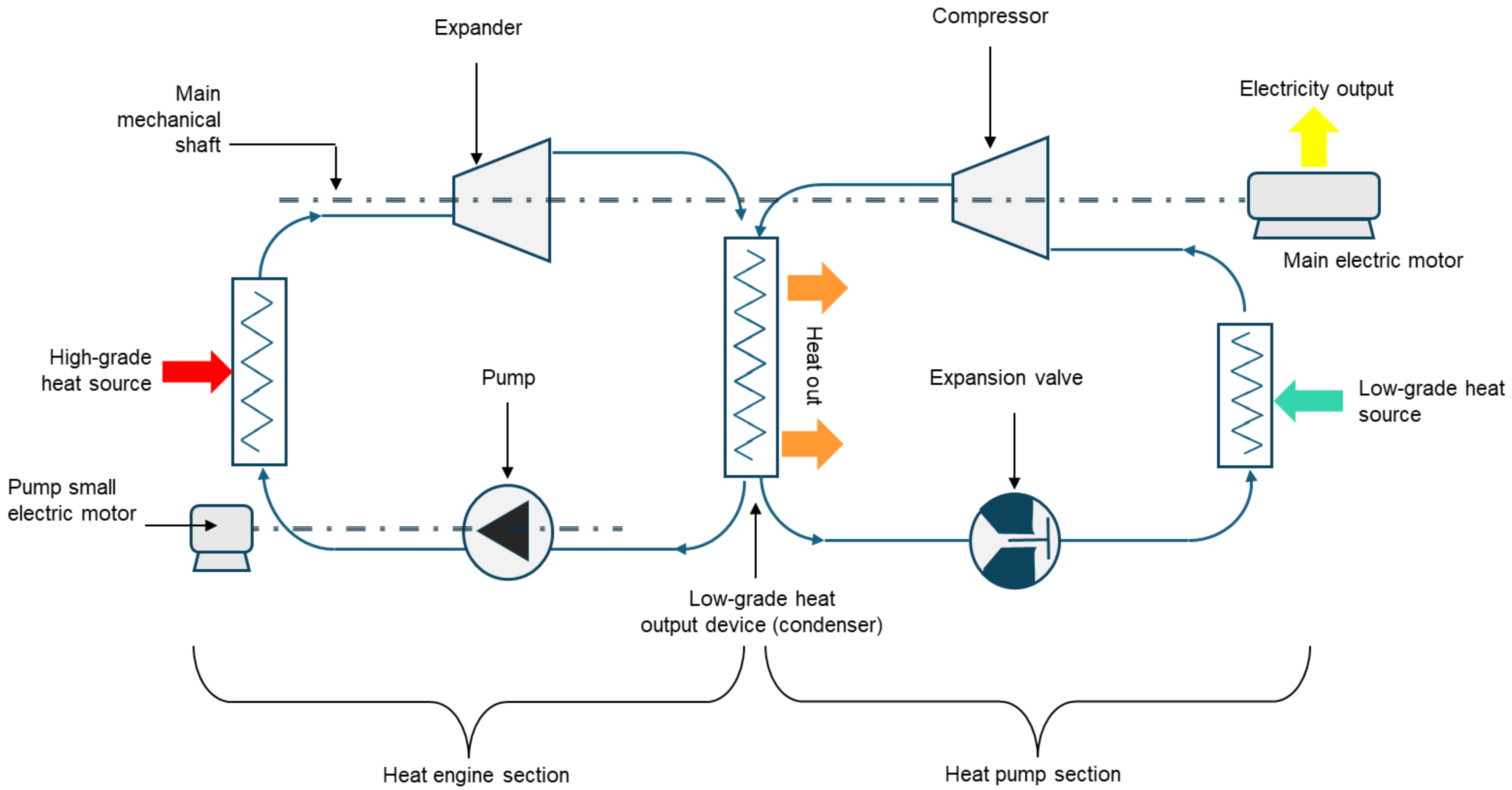


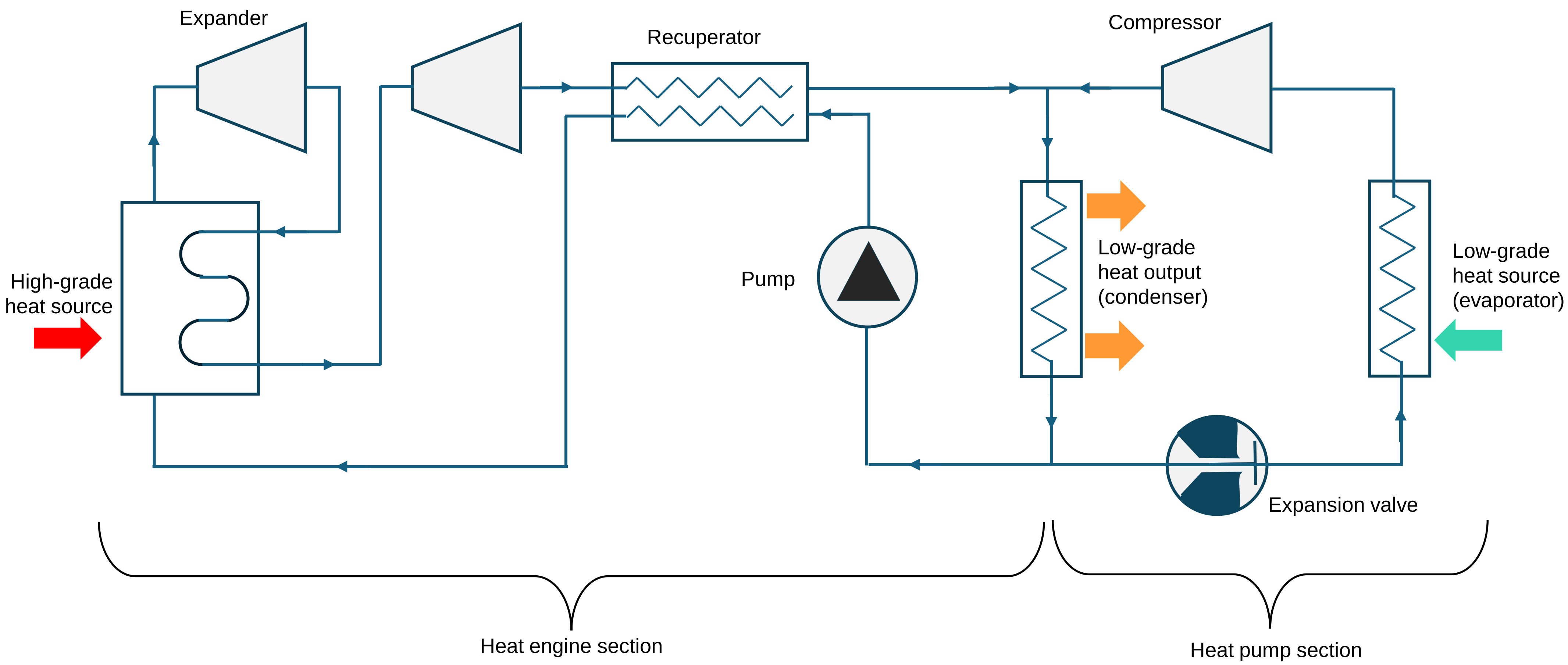
https://ukerc.ac.uk/publications/local-gas-demand-vs-electricity-supply/

What if we had a solution that **combined the best attributes** of hydrogen boilers and electrically-driven heat pumping and **removed their major drawbacks** ?



- Continue to exploit the existing gas network
- Avoid overwhelming the electricity grid
- Multiplier effect of heat pumps


Expander
Compressor
Main
mechanical
shaft
Electricity output
Main electric motor
High-grade
heat source
Heat out
Pump
Expansion valve
Low-grade heat
source
Pump small
electric motor
Low-grade heat
output device (condenser)
Heat engine section
Heat pump section

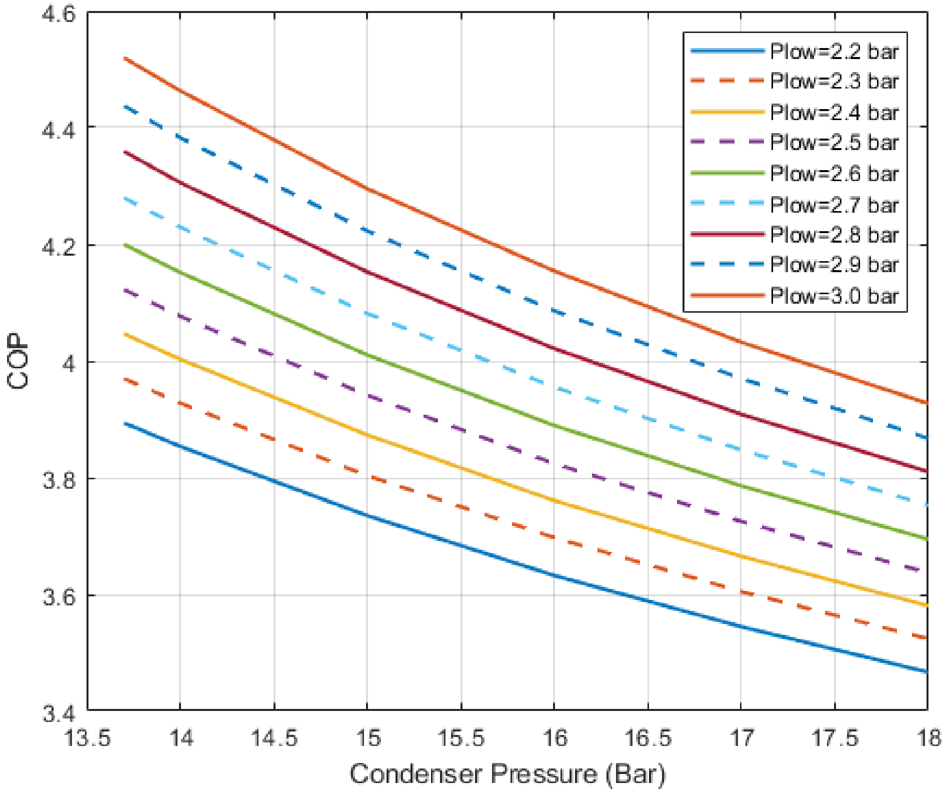

Expander
Recuperator
Compressor
High-grade
heat source
Pump
Low-grade
heat output
(condenser)
Low-grade
heat source
(evaporator)
Expansion valve
Heat engine section
Heat pump section

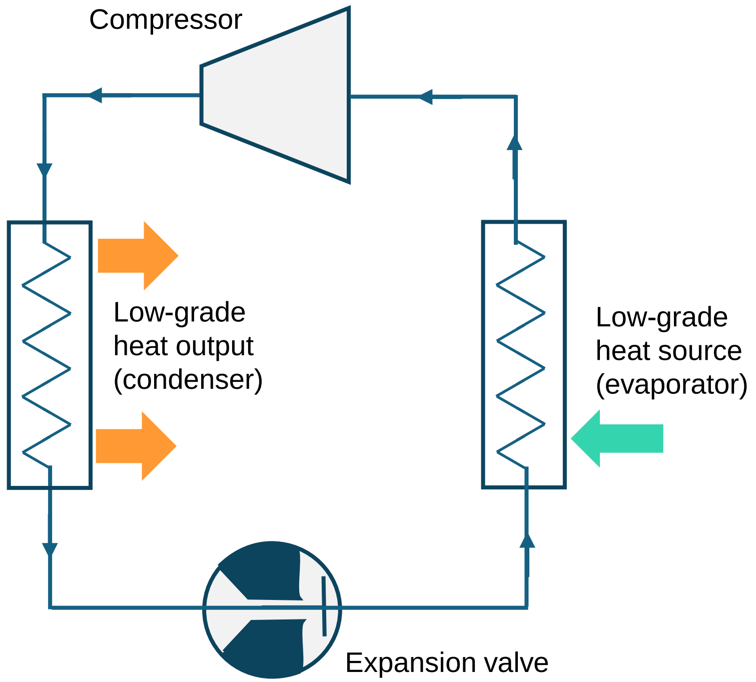
The University of Nottingham

Looking at the heat pump part of the system first

Some Assumptions:

- Ambient temperature = -9 ° C
- Evaporator temperature = -14 ° C
- Condenser temperature = 40 ° C

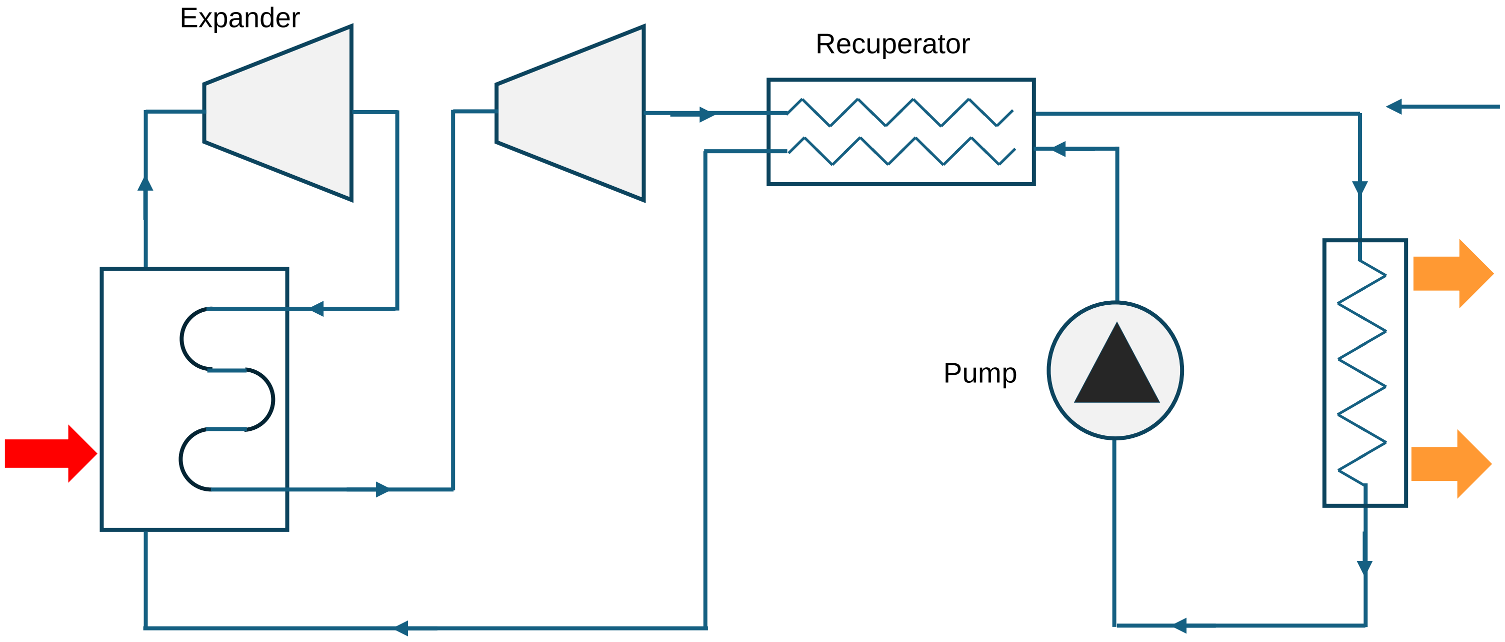




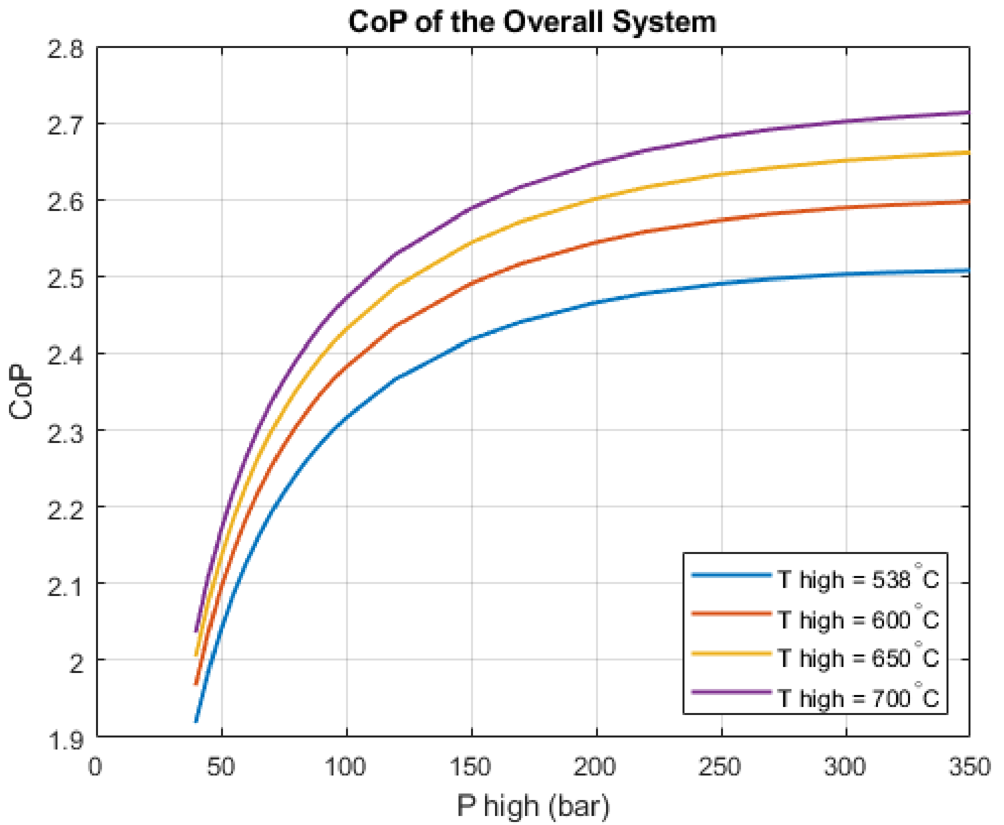
We find that optimum operating parameters are :

- Low pressure of 3 bar
- High pressure of 13.7 bar
- Compressor outlet temp. = 55.56 ° C
- Evaporator inlet temp = -14.18° C
- CoP= 4.519

Now looking at the heat engine part :



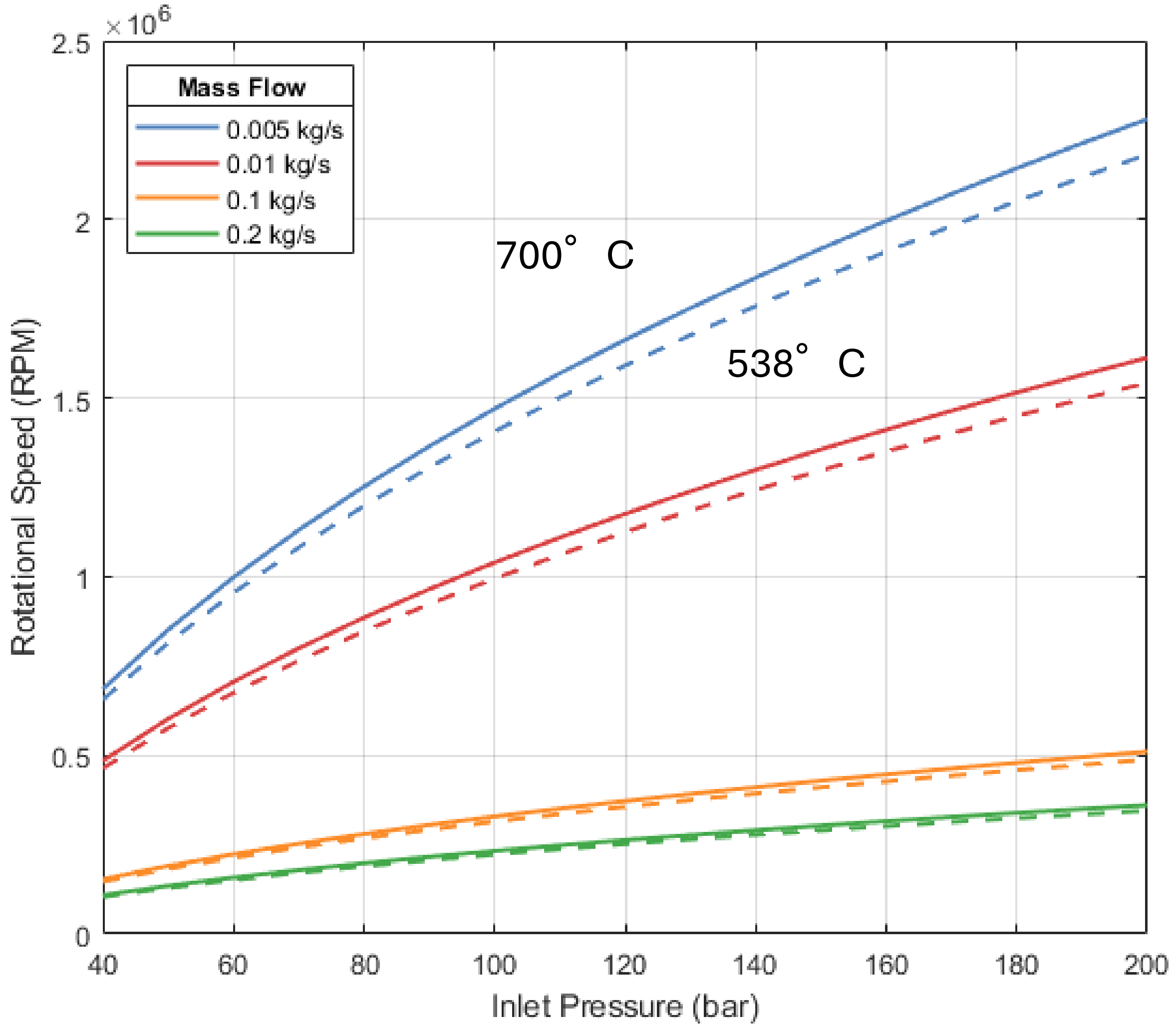
Refrigerant coming from Heat Pump
At 13.7 bar
And 55 ° C



Assumptions:

- 8 kW heat output system
- Turbine and pump efficiencies are 80 %
- Recuperator efficiency is 0.97%

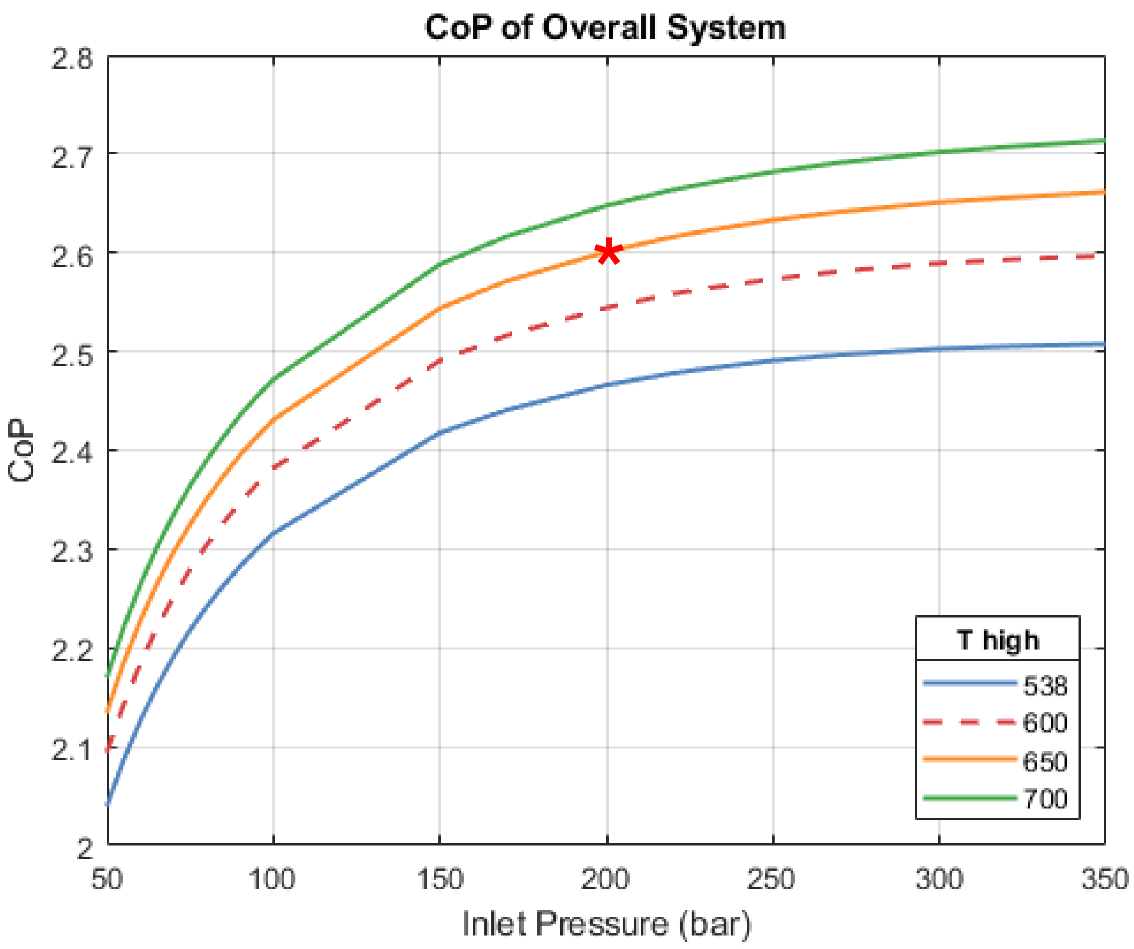
How fast do the expanders need to rotate to achieve an isentropic efficiency of 80% ?

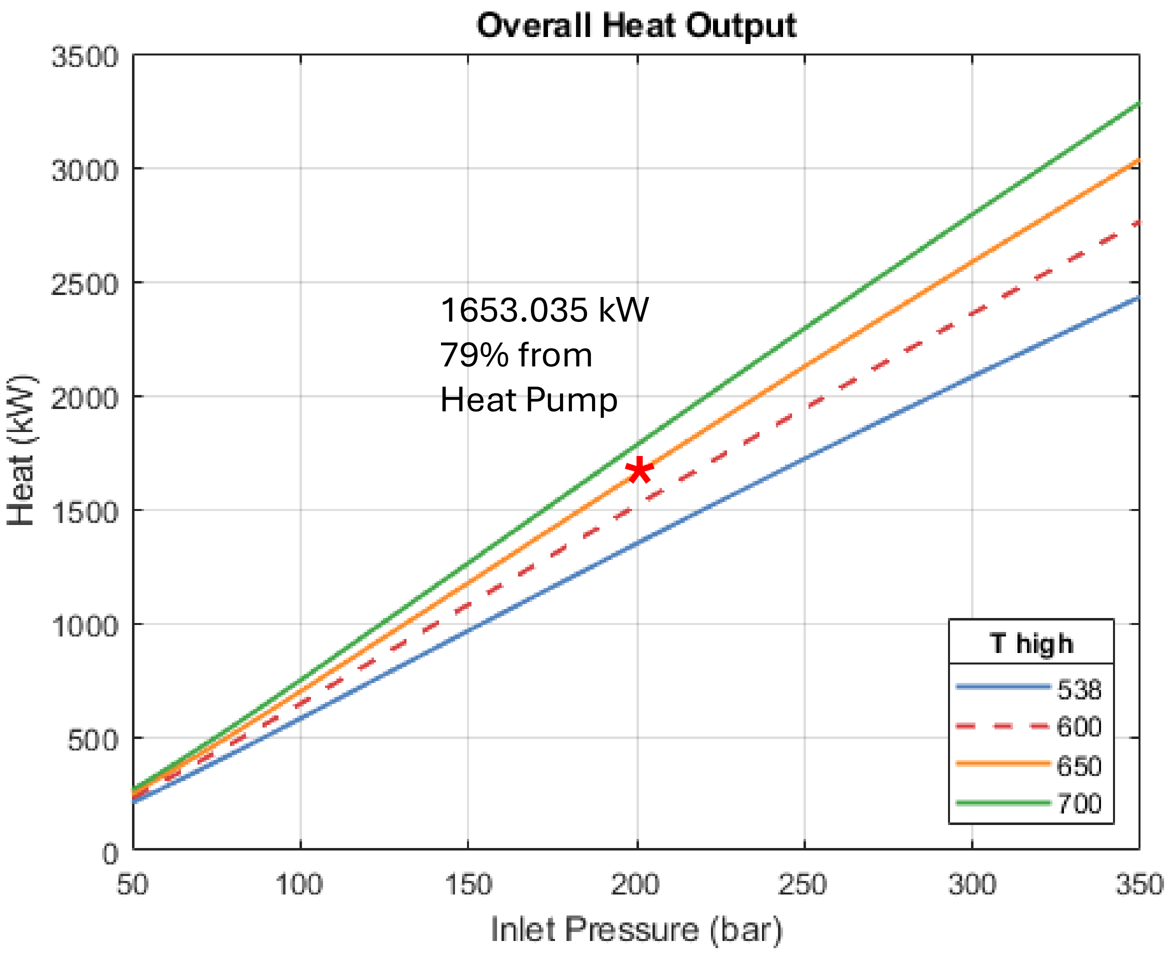


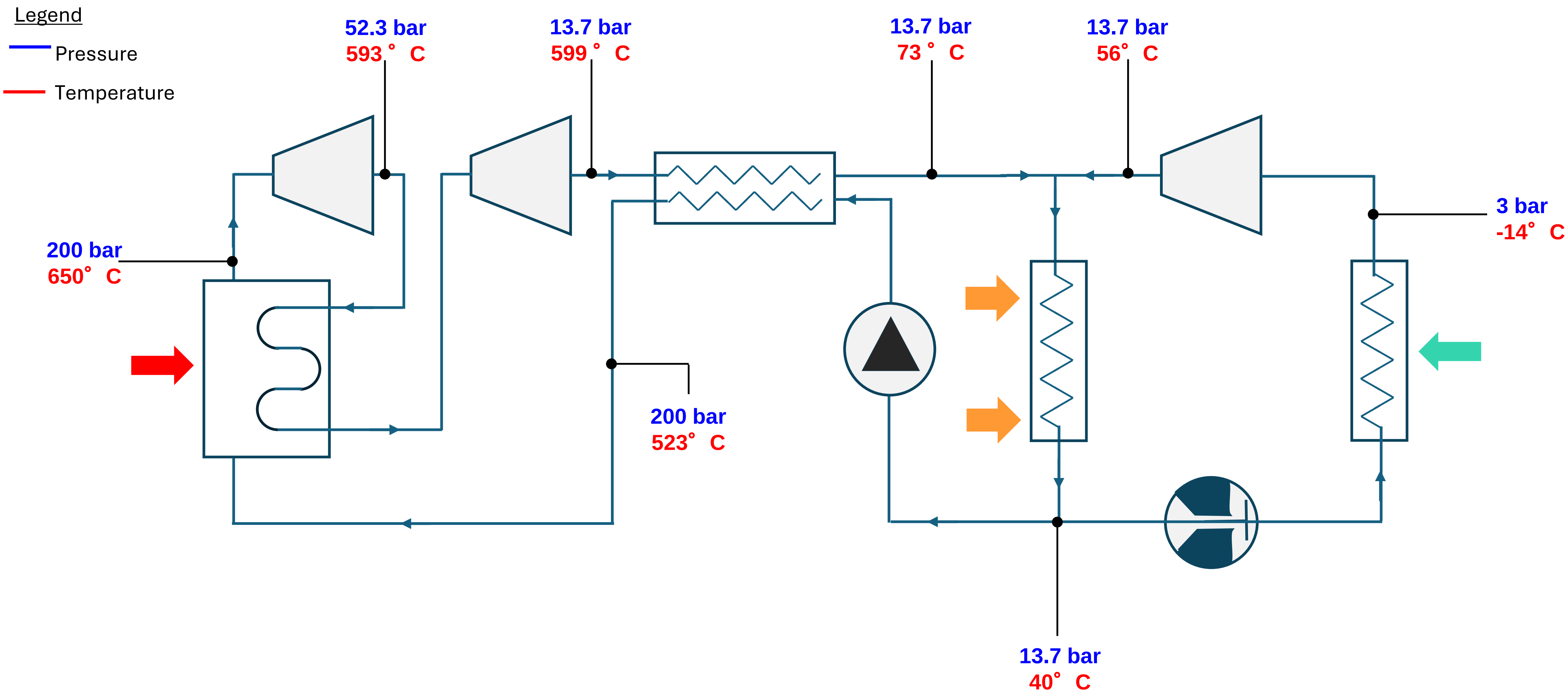
Assuming:

- Isentropic efficiency of 80% for expanders and pump in engine
- Isentropic efficiency of 80% for compressor in heat pump

Find *total heat output* needed so that:
Efficiency of expanders is 80% at 170,000 rpm

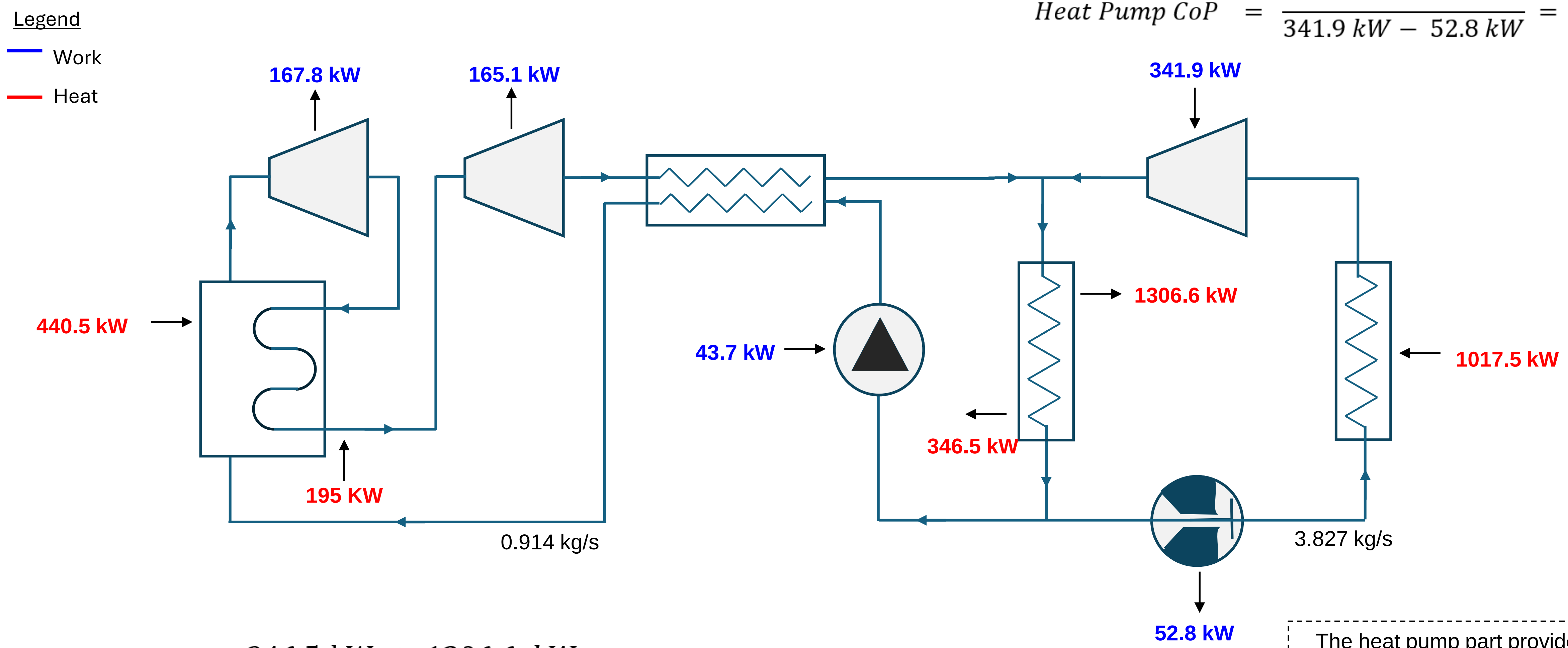






Ambient Temperature -9° C

$$Heat\ Pump\ CoP = \frac{1306.5\ kW}{341.9\ kW - 52.8\ kW} = 4.519$$



The heat pump part provides
79%
of the system's heat output

$$System\ CoP = \frac{346.5\ kW + 1306.6\ kW}{440.5\ kW + 195\ kW} = 2.6$$

Concluding remarks

- This work is still in progress, but we’ve shown that there is potential
- We should try to use electric heat pumps as much as possible wherever we can.
- If the system operator or the government determines that there is not enough capacity in the electricity grid, and we need to burn something (e.g. hydrogen)
- Then we should burn it in a smart way.
- **Why would we burn hydrogen with an efficiency of 60%, when we can get 260% or more?**
- It’s important to have projects like this that offer flexibility

University of Nottingham
UK | CHINA | MALAYSIA

Thank you !

Contact:
Bruno.Cardenas@nottingham.ac.uk