Ultra-Efficient Power Units

Waste Heat Recovery by Inverted Brayton Cycle

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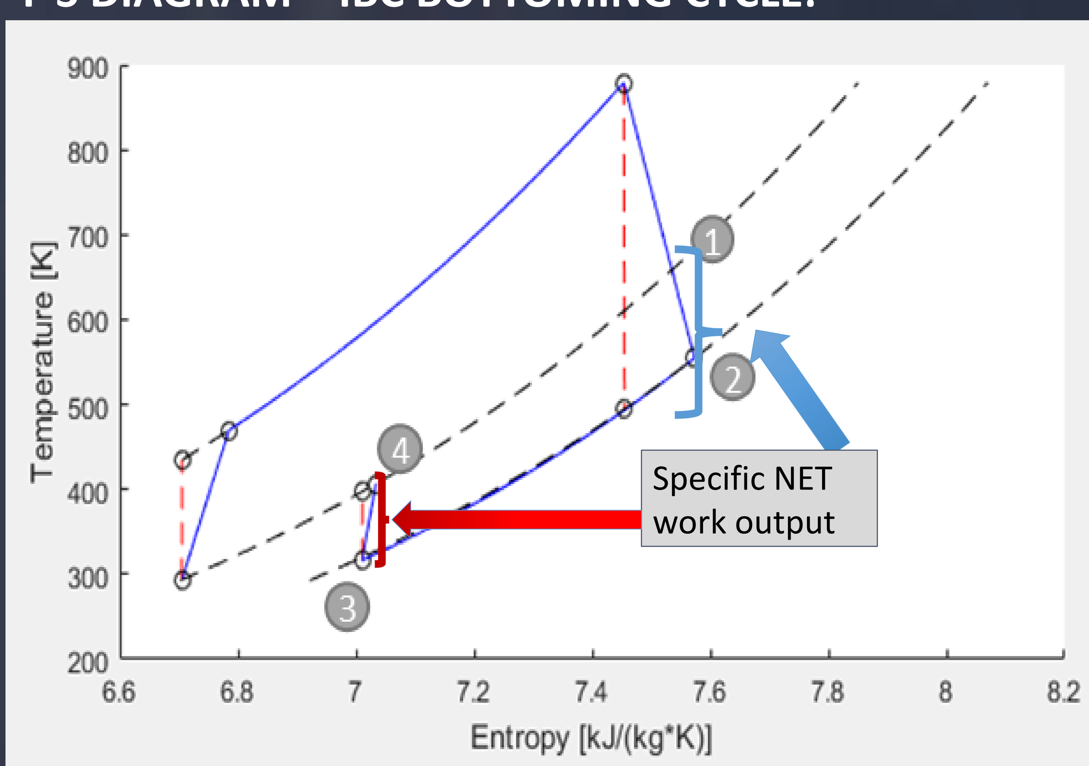
MOTIVATION

- Sustainable energy technology is a leading component in global scientific research
- Improvement in transportation technologies is one of the greatest impact areas
- To allow for broad application, improvements must be simple to employ and cost effective
- Exhaust gases from internal combustion engines (ICEs) contain up to 30% of the thermal energy from combustion
- Bottoming thermodynamic cycles aim to reclaim this waste heat and improve overall thermal efficiency

INVERTED BRAYTON CYCLE (IBC)

- Ideal for heat recovery from atmospheric conditions
- Operation characterized by Brayton cycle in reverse - beginning with expansion into vacuum, followed by cooling and ending in compression to atmospheric pressure
- Most suitable for high exhaust temperatures (above 400°C)
- This technology is applicable for internal combustion engines, micro gas turbines, solid oxide fuel cells, and solar heaters

T-S DIAGRAM – IBC BOTTOMING CYCLE:

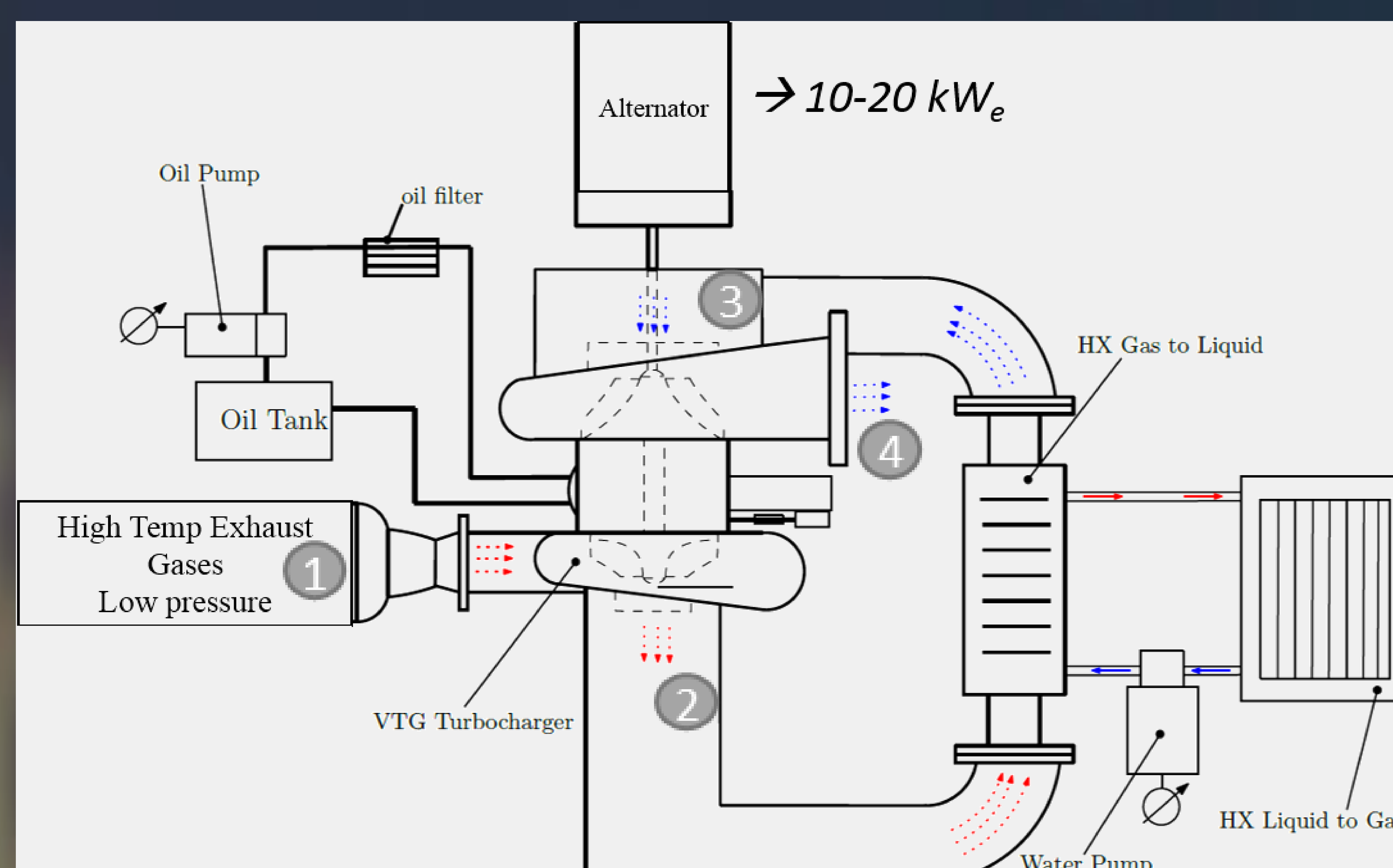


IBC cycle process:

1→2: expansion to sub-atmospheric pressure
2→3: cooling of hot fluid
3→4: compression of cooled fluid
Cooled gas is exhausted at atmospheric pressure

- Additional work is extracted due to divergence of isobaric lines

IBC APPLICATION FOR ROAD VEHICLES: SCHEMATIC



BENEFITS OF IBC FOR ROAD VEHICLES

- $10-20 kW_e$ additional power generated from waste heat
- The IBC system can connect directly to the alternator, powering auxiliary power systems and charging the battery without drawing from main engine shaft power
- All that is added to the vehicle is a turbocharger and an expanded radiator

ADVANTAGES OF IBC AS BOTTOMING CYCLE

- Does not interfere with primary engine cycle
- Operates at low backpressure
- Allows turbine expansion beyond atmospheric limitation typical for common turbochargers
- IBC system can be simply integrated into existing systems with few modifications

CHALLENGES

- Effective IBC requires high component efficiencies, particularly of turbomachinery and heat exchanger
- Optimum expansion ratio requires careful system design
- Sub-atmospheric pressures in the IBC system requires efficient sealing of cycle components and separation of condensed water

QR link: Test run of the experimental IBC facility

THERMODYNAMIC CYCLE ANALYSIS OF IBC

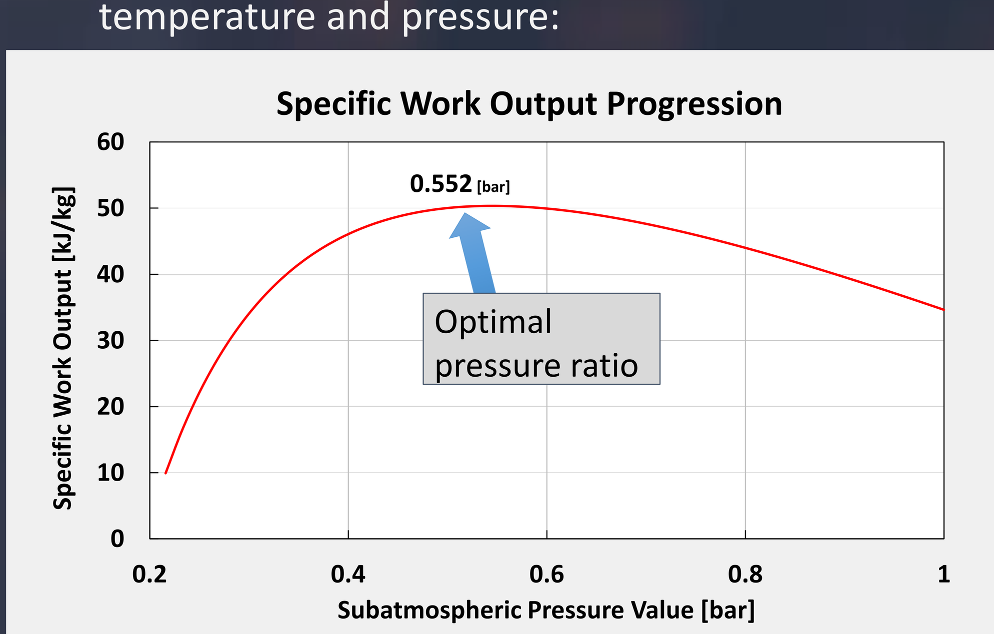
IBC performance is affected by five critical parameters:

- Number of compression stages
- Cycle inlet temperature
- Inlet pressure
- Isentropic efficiency of turbomachinery components
- Heat exchanger efficiency

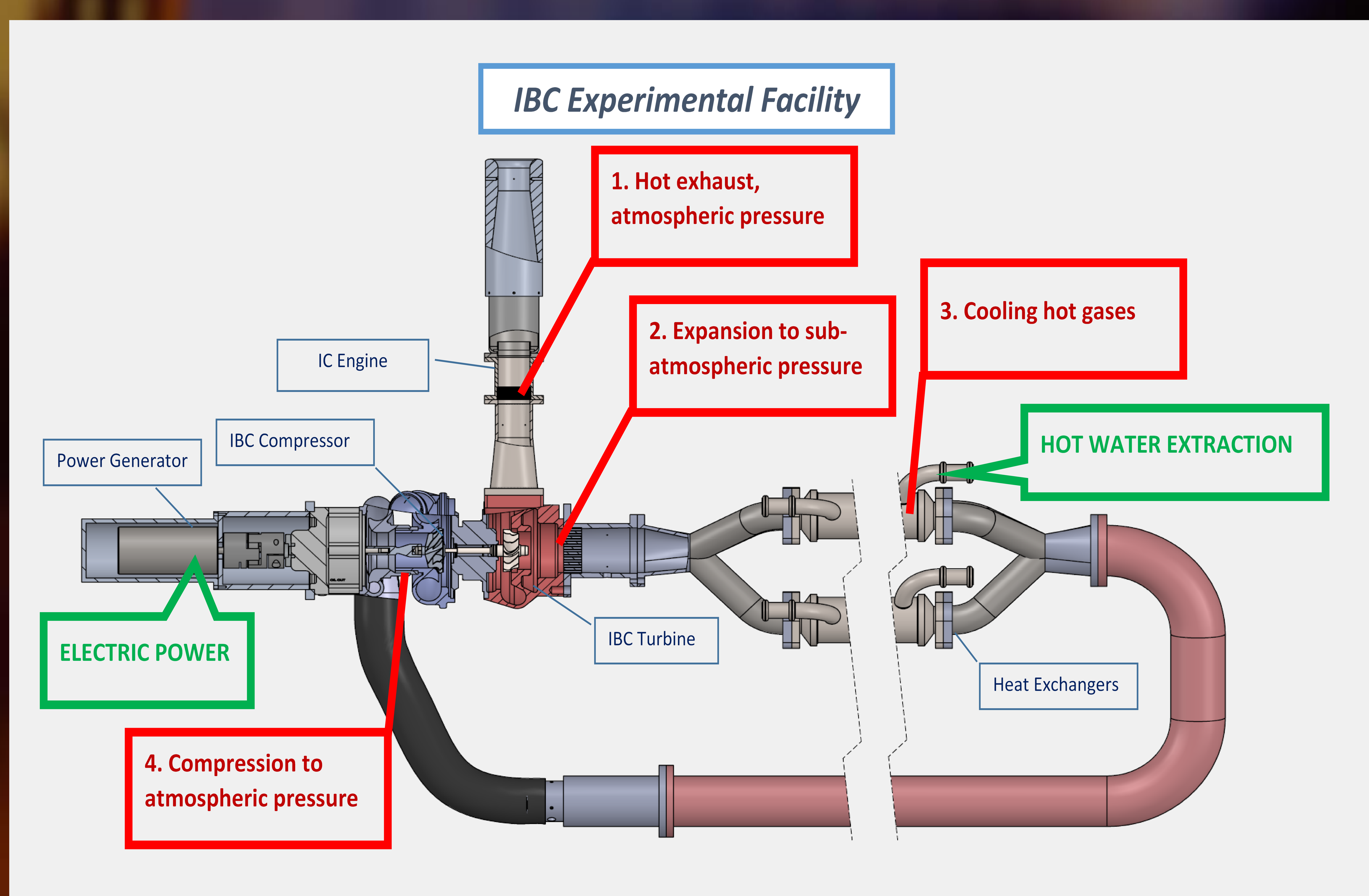
There exists an optimum pressure ratio across the IBC that delivers maximum specific power

In-house thermodynamic modelling of IBC performance has been developed to predict overall engine cycle efficiency improvements.

- Selection of optimal operating pressure drop in IBC – function of exhaust mass flow, temperature and pressure:



- Thermodynamic simulations are used for suitable turbine, compressor and heat exchanger selection, based on operating conditions per application



FUTURE WORK

- Completion of experimental IBC test facility
- Full demonstration of inverted Brayton cycle in laboratory setting
- Enhancement of cycle efficiency by improved turbomachinery components design

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Select References:

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