Development of a carbon-ammonia adsorption gas heat pump

IEA Heat Pump Workshop, London, 13th November, 2012

Prof. Bob Critoph

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Contents:

Background

Concept design

Technical progress

‘CALEBRE’ project funded by EPSRC/EoN:

- Part of funding is for proof of concept gas fired heat pump
- Funding is to University of Warwick
- University spin-out company (Sorption Energy Ltd) owns IP and hopes to develop a product
- Specification of first machine was for a 7 kW heat output

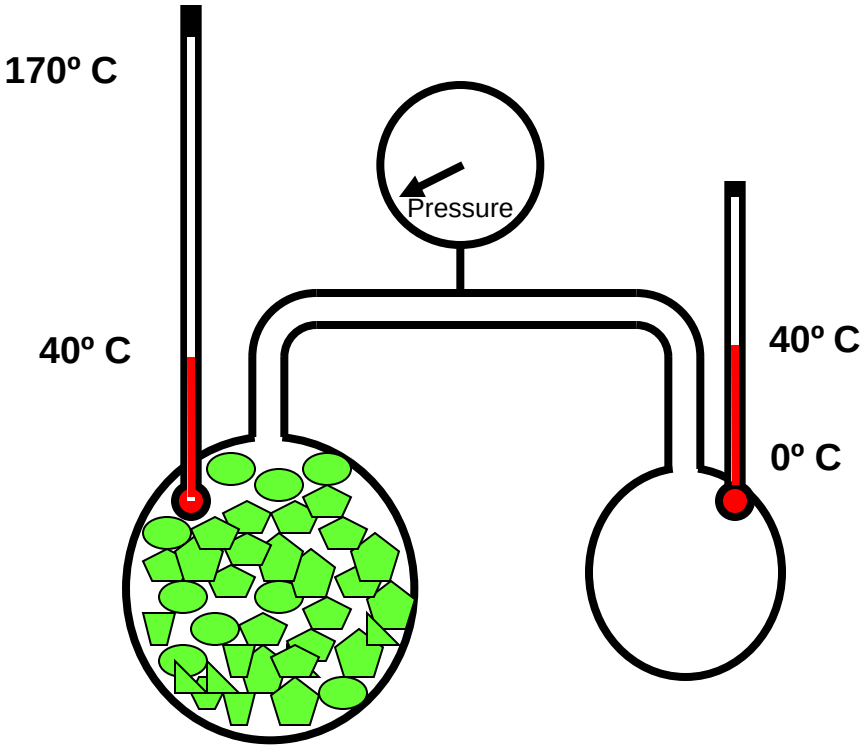
Idealised Adsorption Cycle

Initial State:

Ambient Temperature

Low pressure

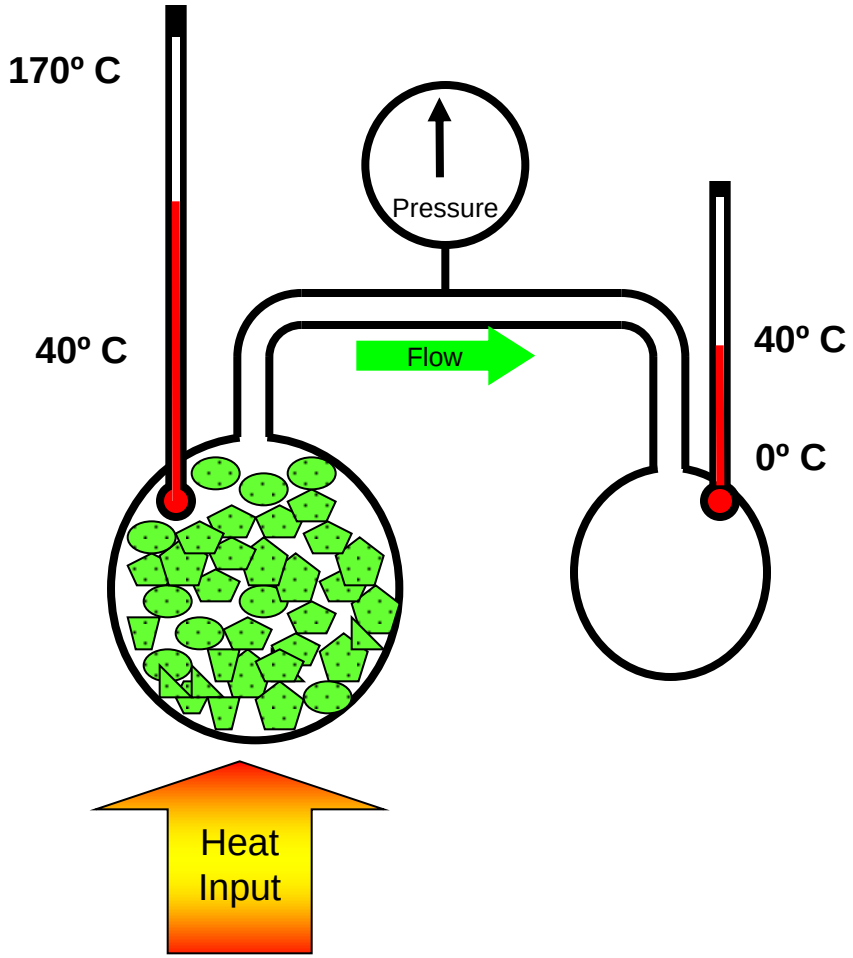
High concentration



Idealised Adsorption Cycle

Process 1

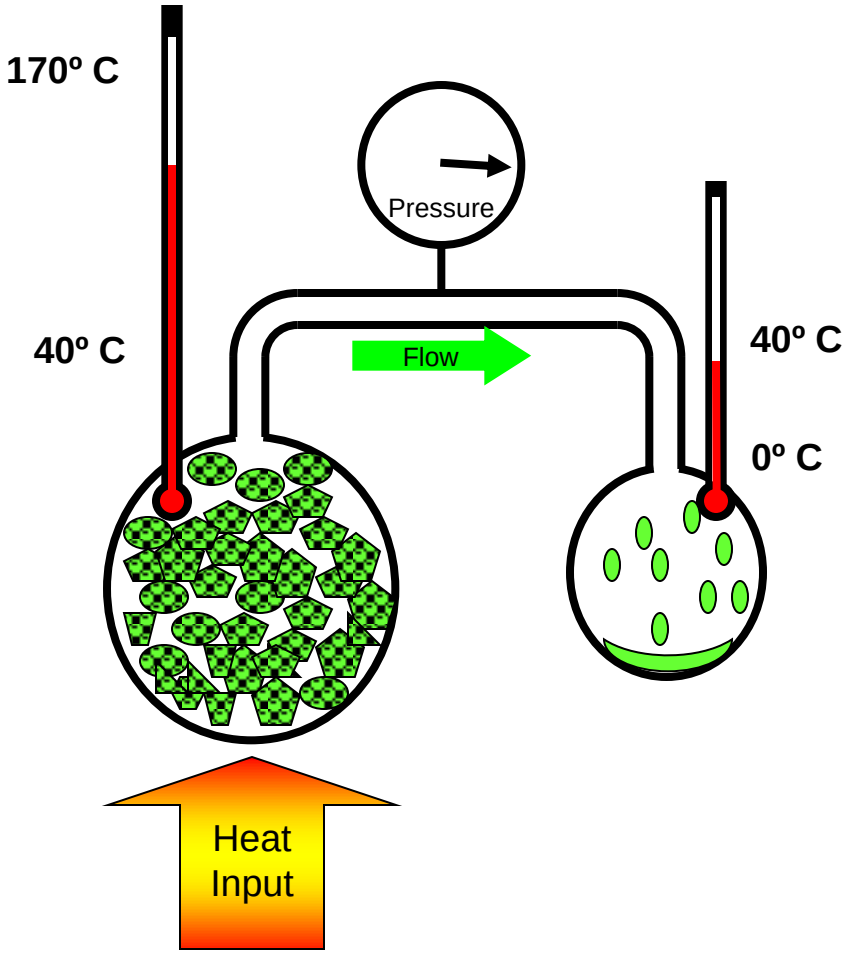
Carbon bed is heated, ammonia is driven off and pressure increases until…



Idealised Adsorption Cycle

Process 2 starts

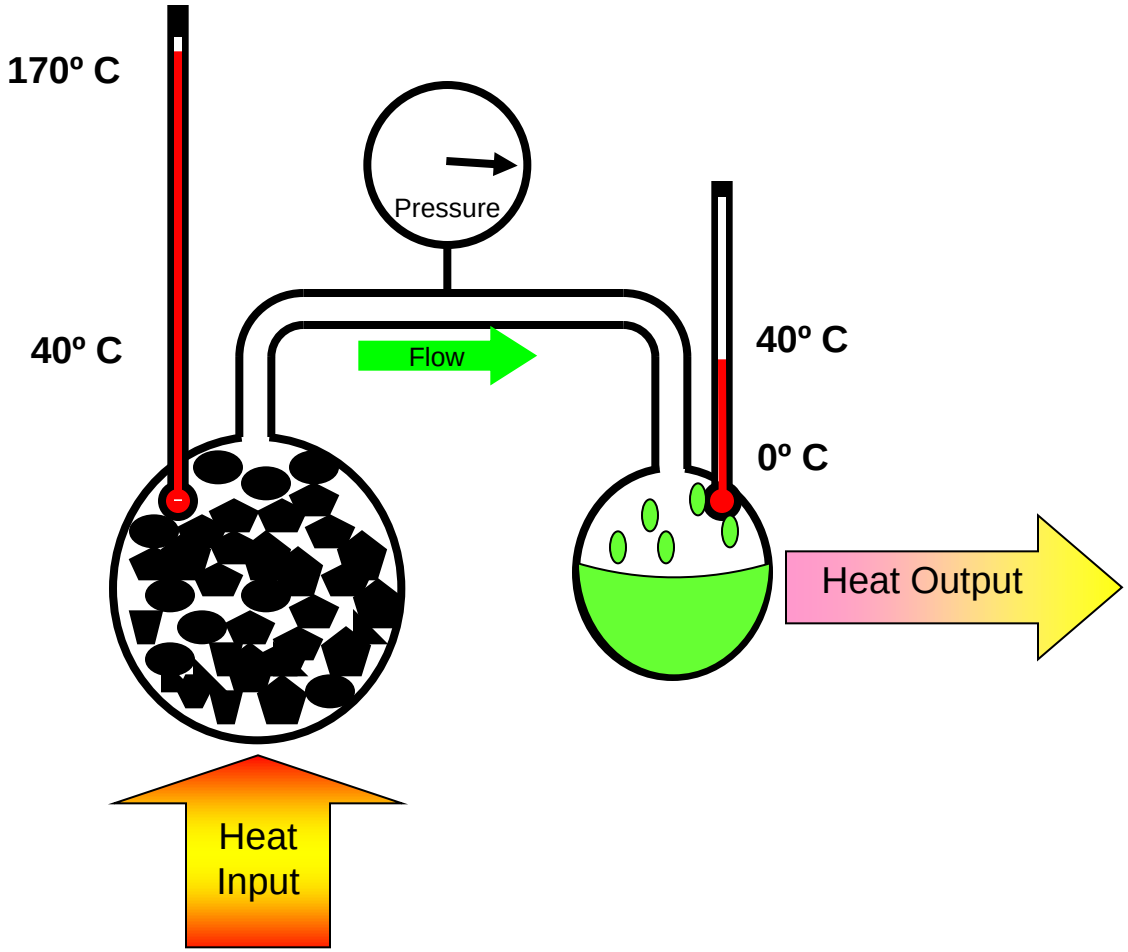
The saturation pressure is reached and ammonia condenses in the right hand vessel at ambient temperature.



Idealised Adsorption Cycle

Process 2 continues

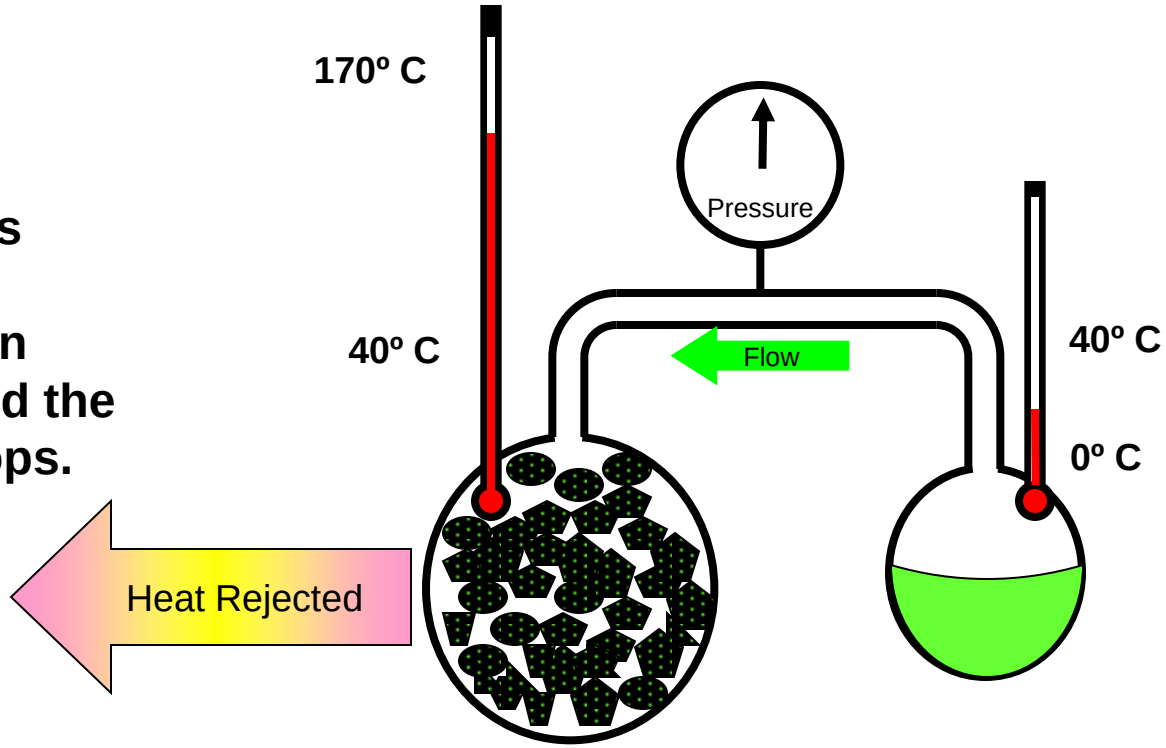
More ammonia is driven out from the carbon and condensed in the right hand vessel



Idealised Adsorption Cycle

Process 3

The carbon is cooled, the concentration increases and the pressure drops.

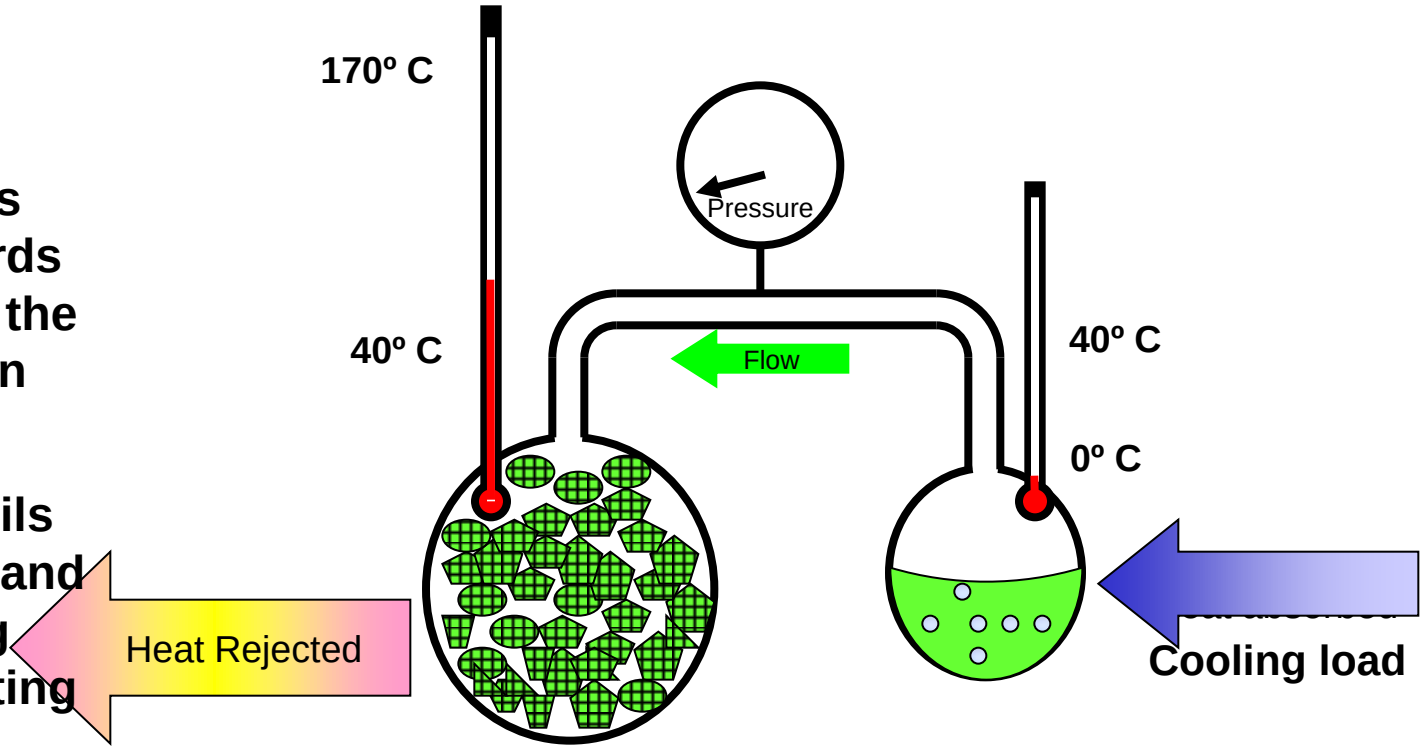


Idealised Adsorption Cycle

Process 4

The carbon is cooled towards ambient and the concentration increases.

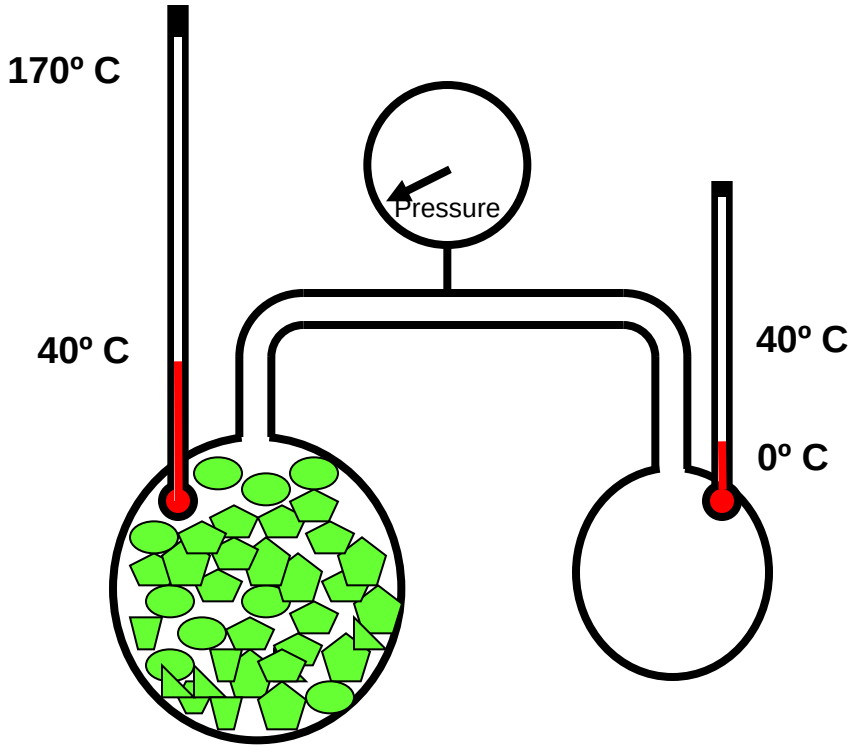
Ammonia boils in the right hand vessel giving the refrigerating effect.



Idealised Adsorption Cycle

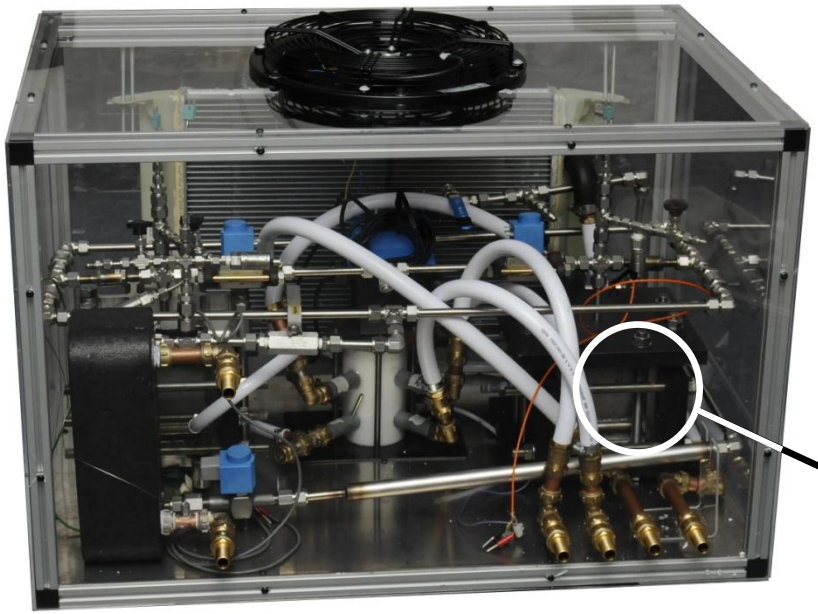
End of Process 4:

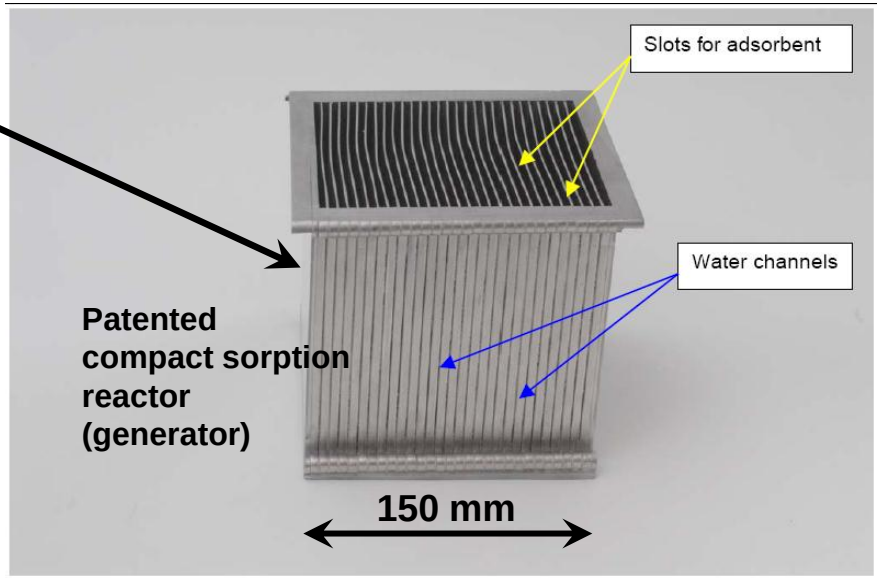
The system is returned to the starting condition



There are large capacity adsorption chillers

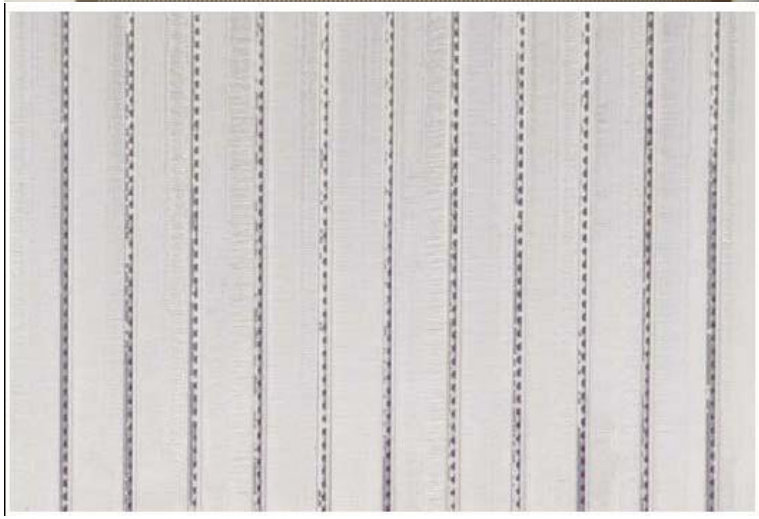
Our technology is 20x more compact (kW/litre)





Sorption Generator Design

- Nickel Brazed Stainless Steel Construction
- Etched Heat Transfer Fluid Channels
- Carbon Adsorbent Compressed Into 4 mm Thick Layers



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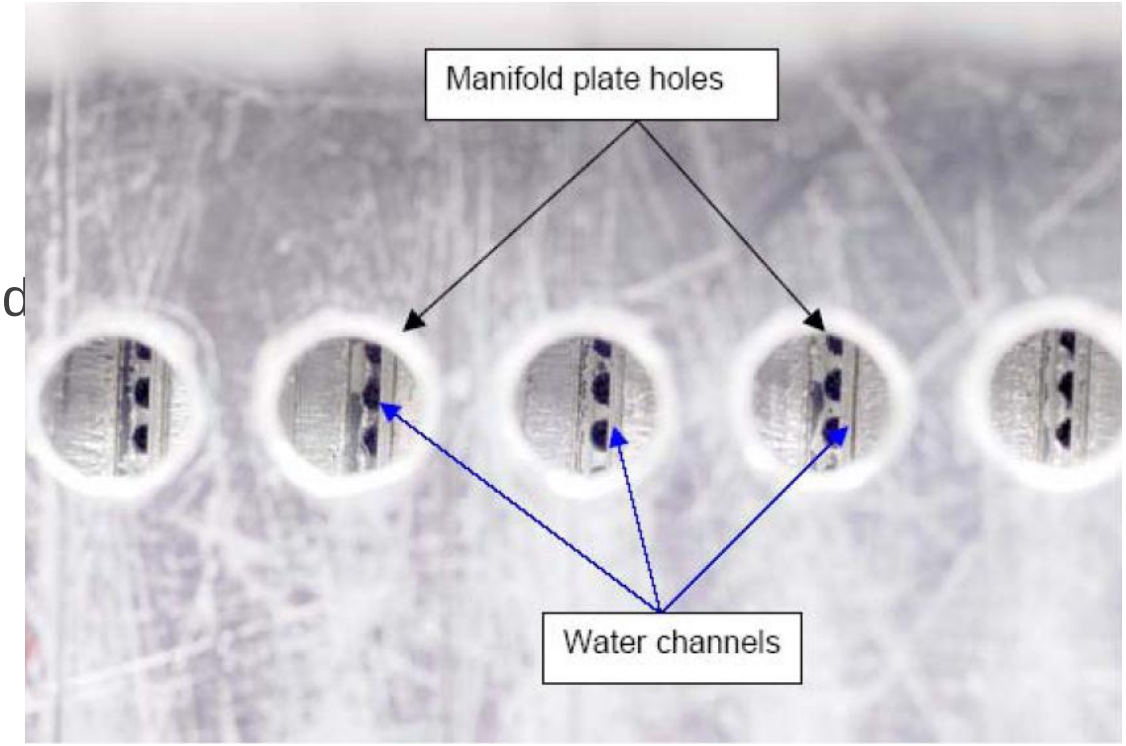
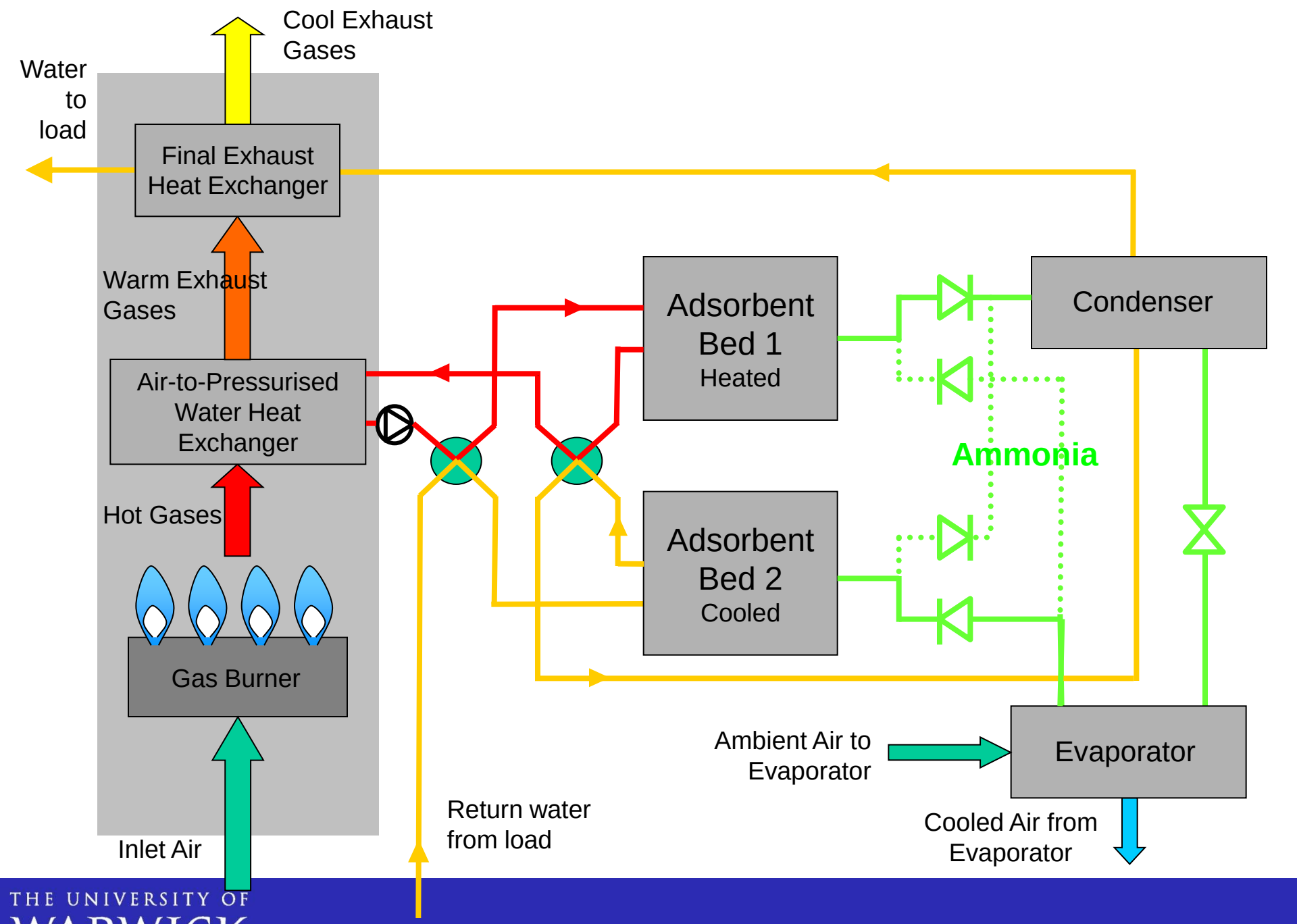
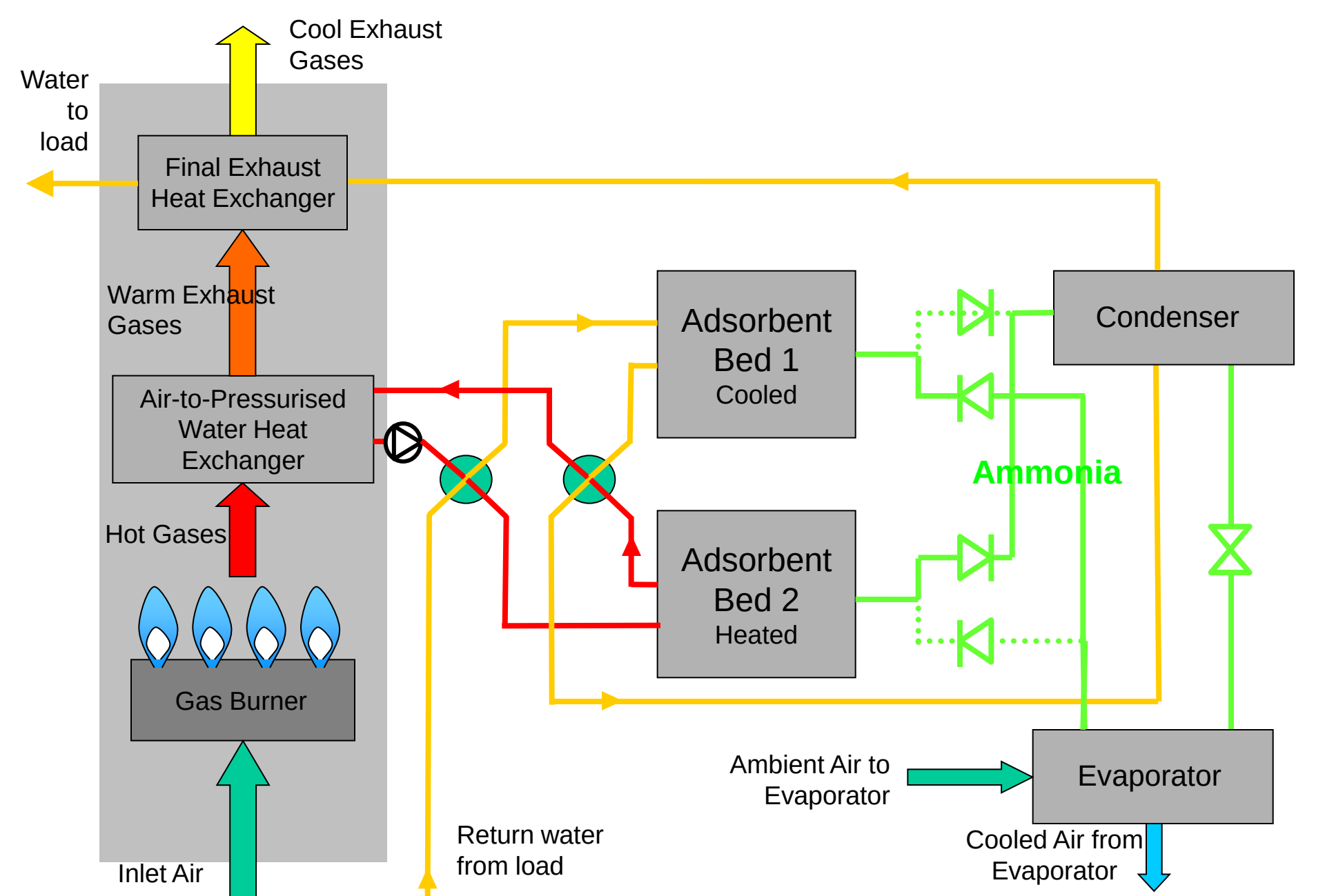


New application – replacement for condensing boilers

- Previous adsorption heating/cooling systems far too large
- Breakthrough (patented) is in making systems small enough for domestic applications
- System to fit in typical homes
- Realistic cost and payback


Cool Exhaust Gases
Water to load
Final Exhaust Heat Exchanger
Warm Exhaust Gases
Air-to-Pressurised Water Heat Exchanger
Hot Gases
Gas Burner
Inlet Air
Adsorbent Bed 1
Heated
Adsorbent Bed 2
Cooled
Condenser
Ammonia
Evaporator
Ambient Air to Evaporator
Cooled Air from Evaporator
Return water from load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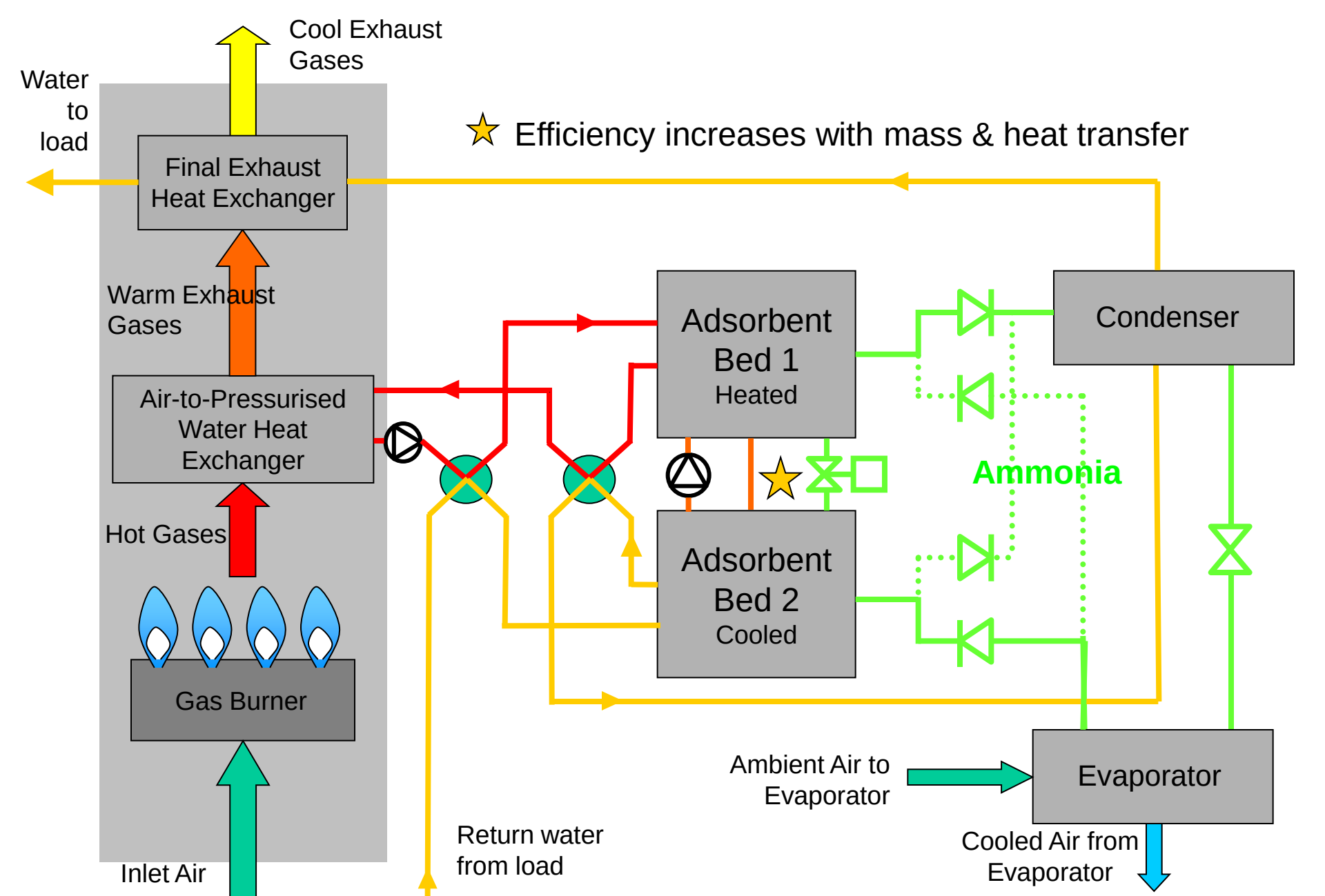
Cool Exhaust Gases
Water to load
Efficiency increases with mass & heat transfer
Final Exhaust Heat Exchanger
Warm Exhaust Gases
Air-to-Pressurised Water Heat Exchanger
Hot Gases
Gas Burner
Inlet Air
Adsorbent Bed 1 Heated
Adsorbent Bed 2 Cooled
Condenser
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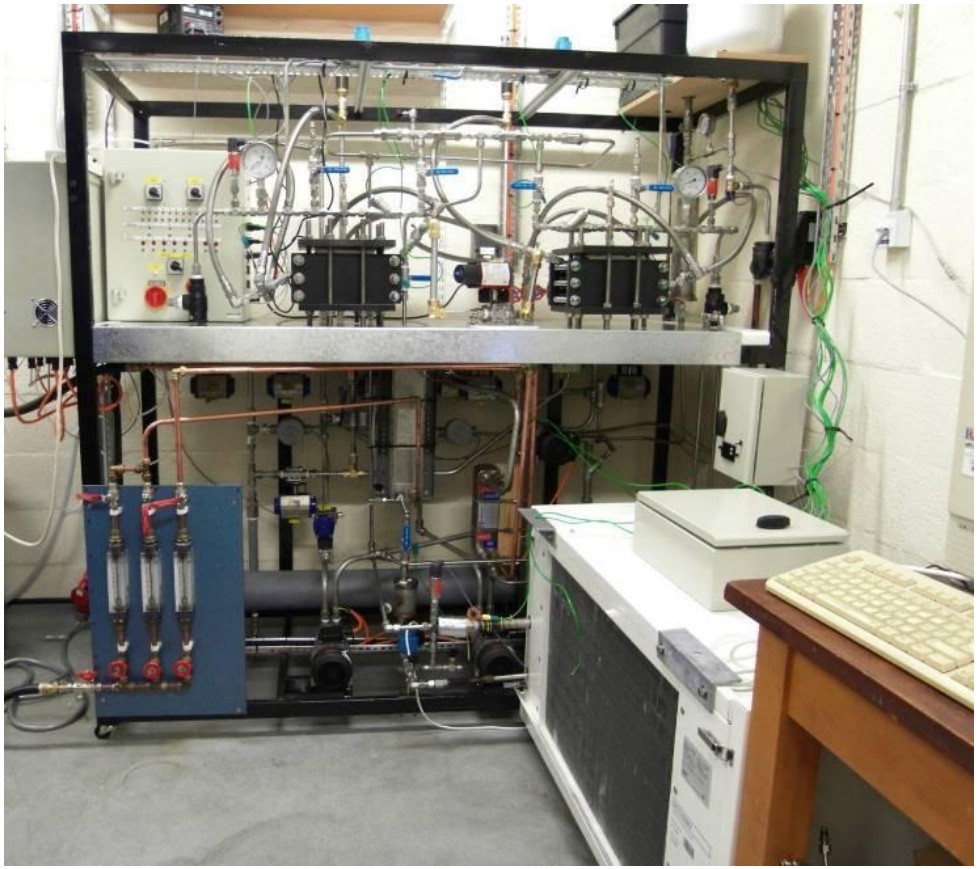
Ambient Air to Evaporator
Cooled Air from Evaporator
Return water from load

Previous research using shim generator design

- Two-bed air-source compact heat pump system proven in the laboratory
- Plate heat exchanger adsorption generators
- Powered by electric heater
- 7-11 kW heating power
- COP 1.6 (heat out / electrical heat in)



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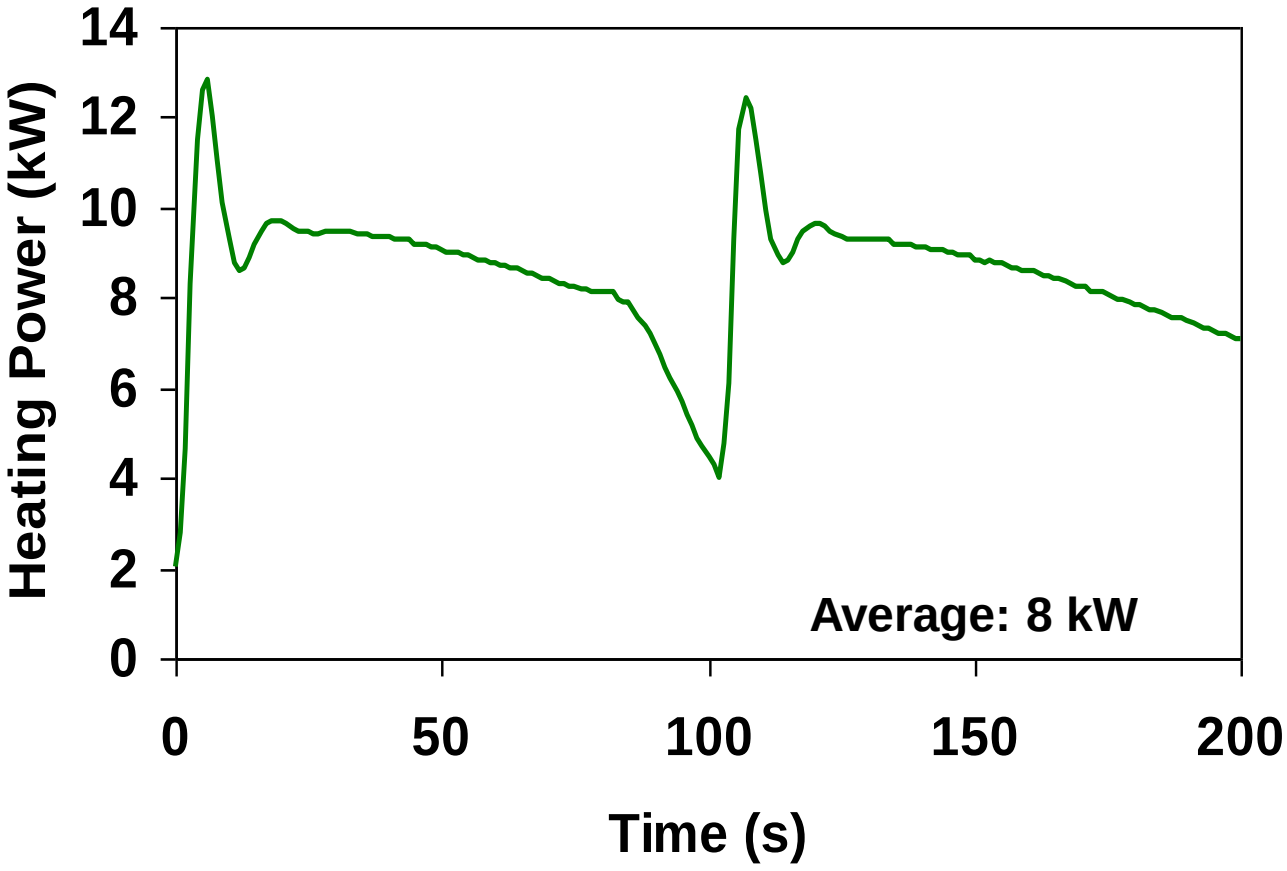

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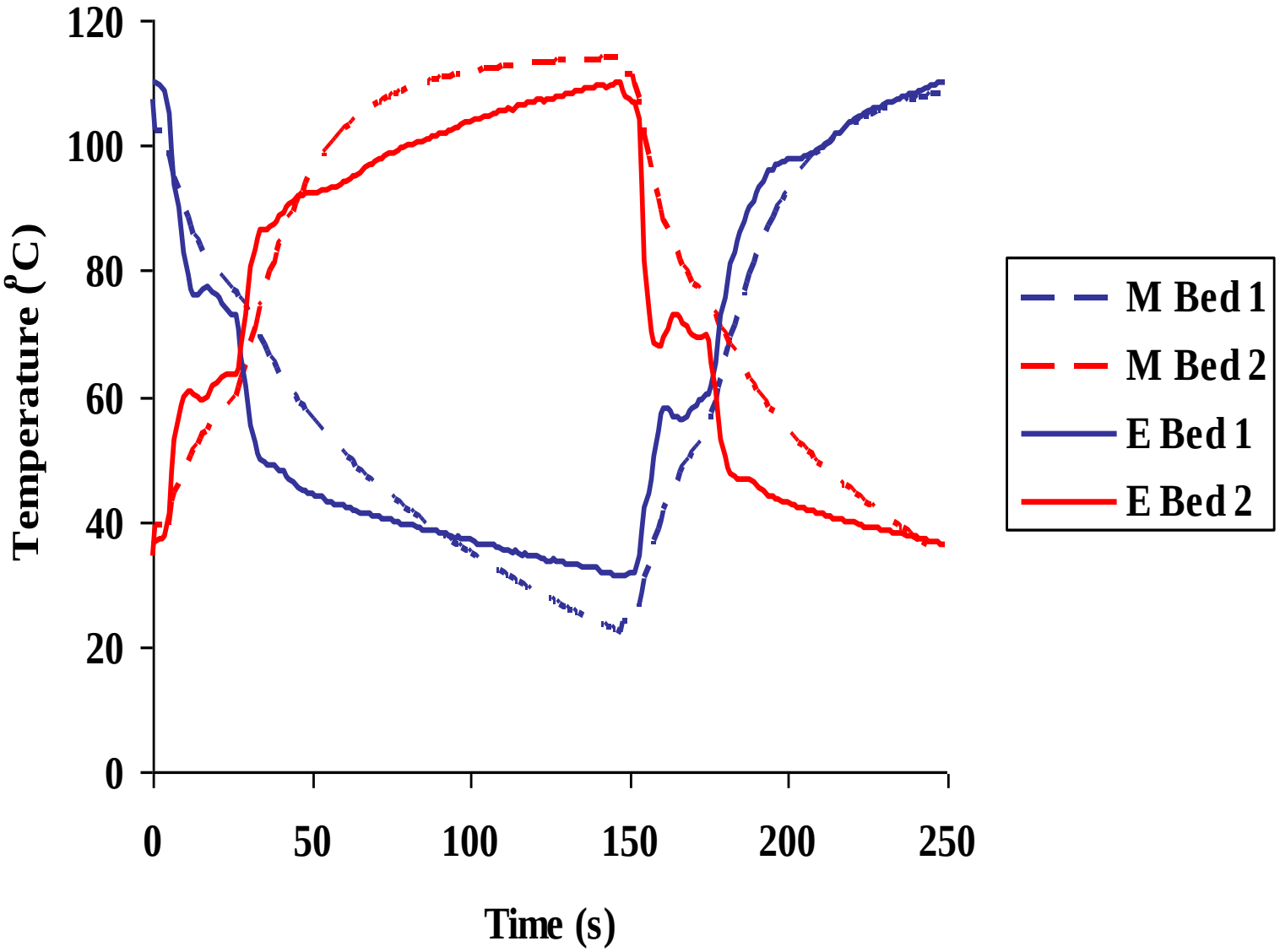
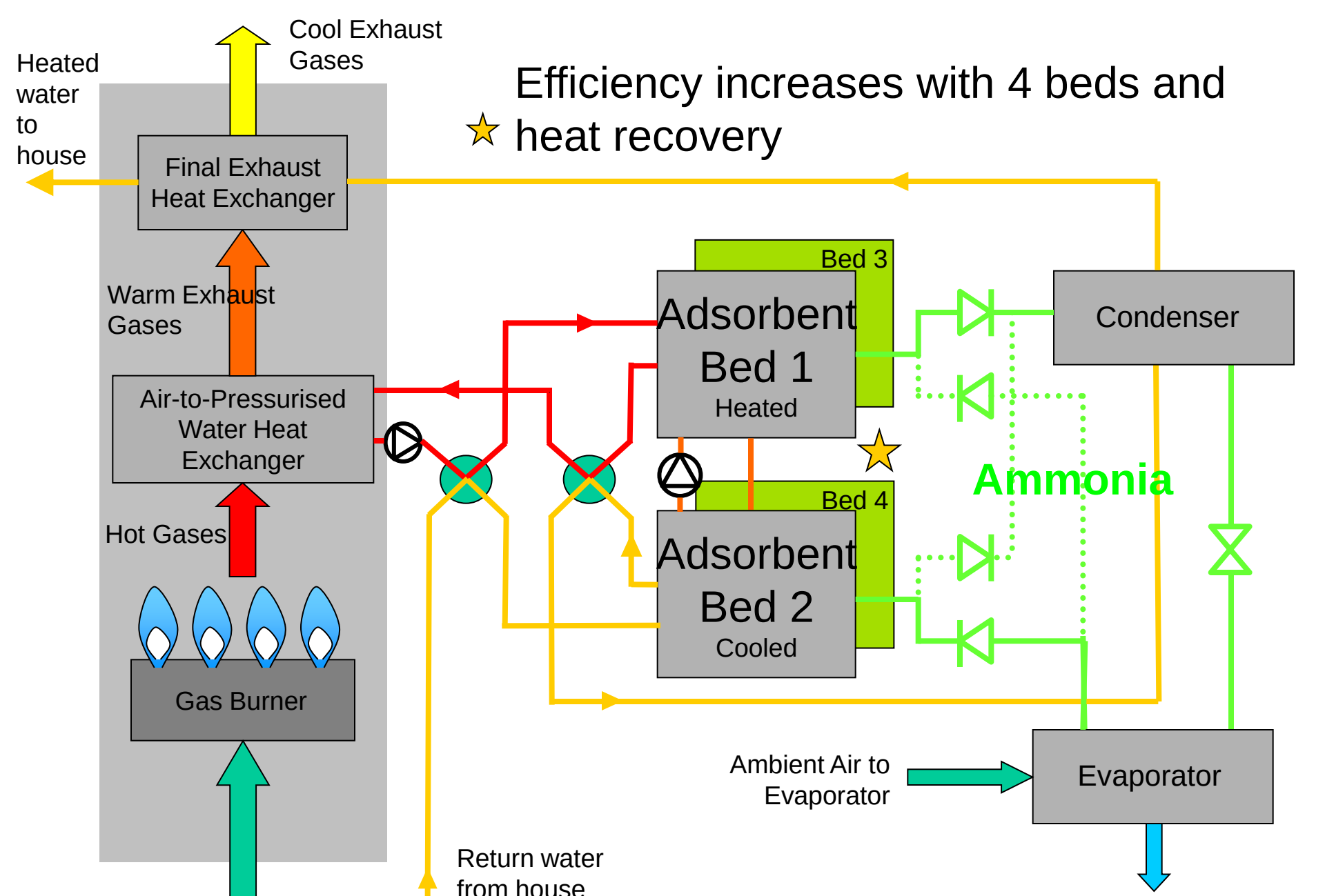


Next step to a commercial product -

- **4 bed system – 25% more efficient than 2 bed**


Efficiency increases with 4 beds and heat recovery
Heated water to house
Cool Exhaust Gases
Final Exhaust Heat Exchanger
Warm Exhaust Gases
Air-to-Pressurised Water Heat Exchanger
Hot Gases
Gas Burner
Inlet Air
Bed 3
Adsorbent Bed 1
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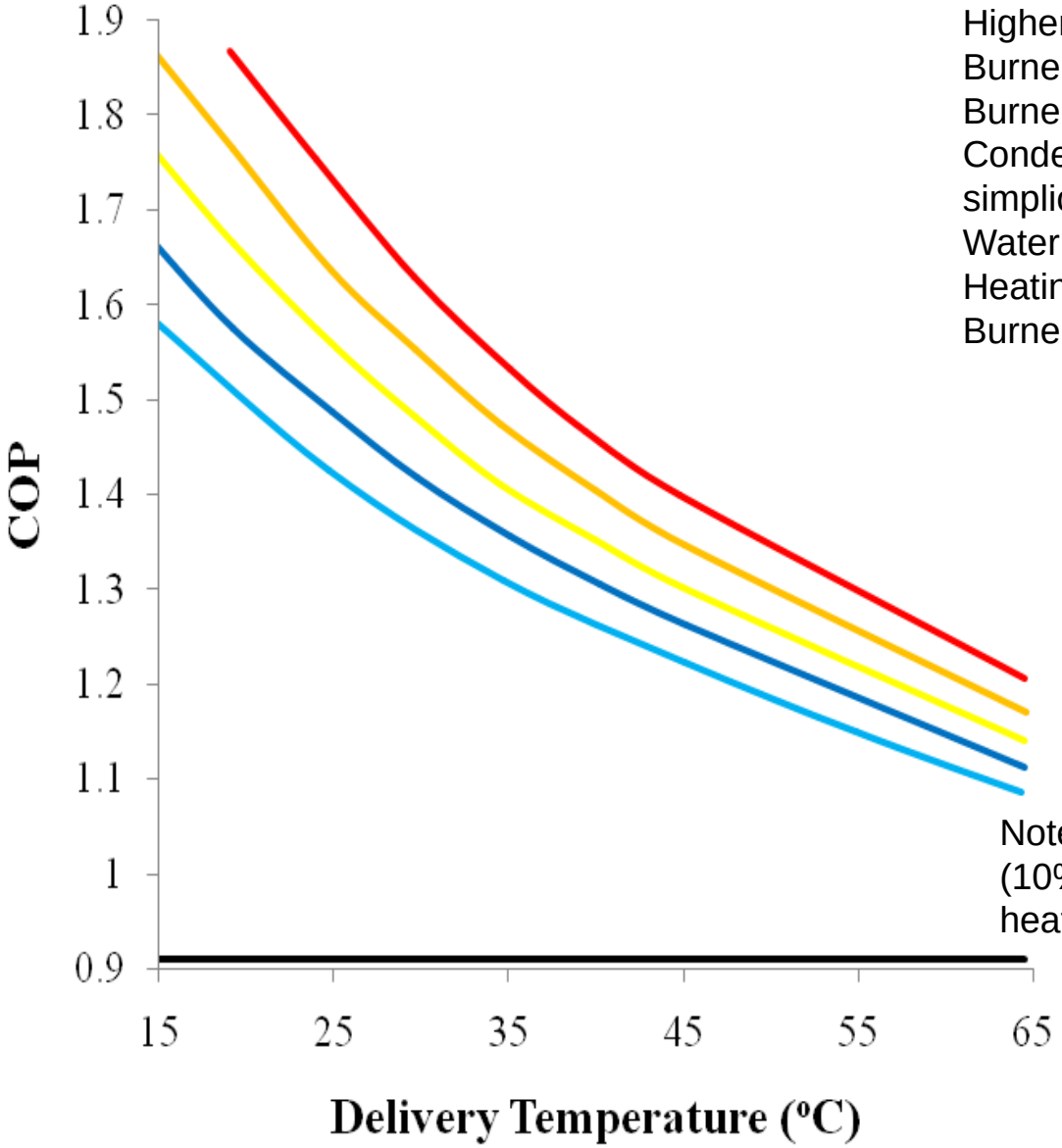
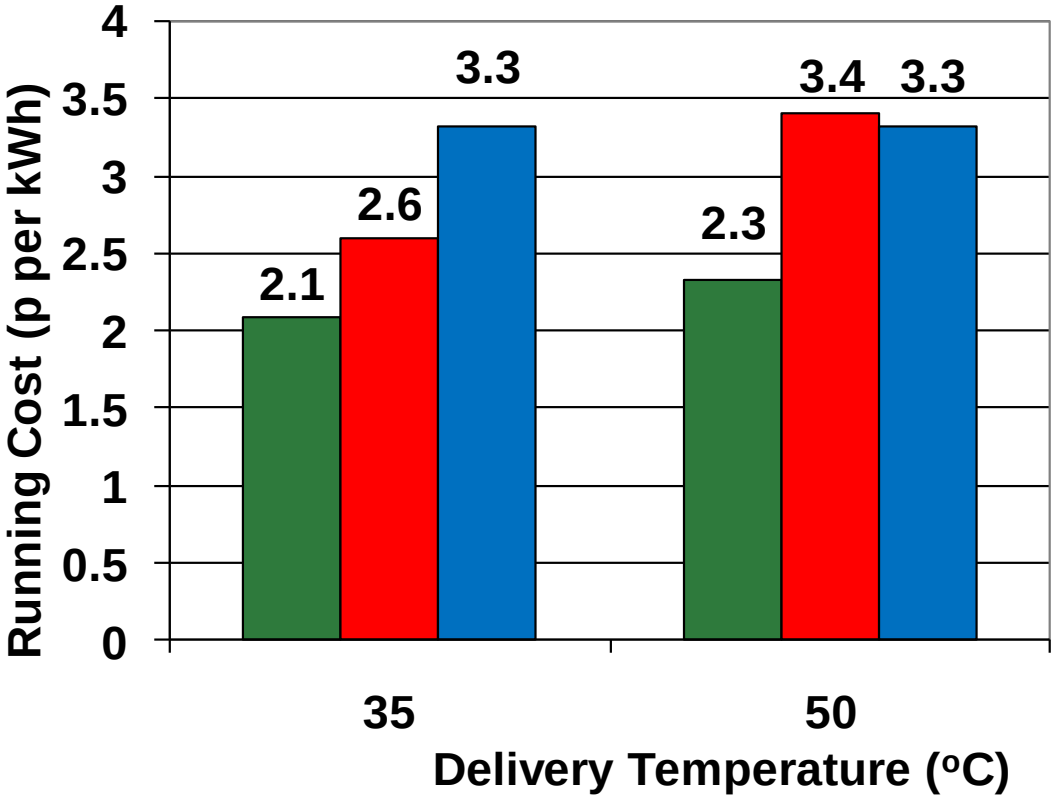
Evaporator
Return water from house
Cooled Air from Evaporator



Higher calorific value of natural gas used in all cases
Burner efficiency: 84%
Burner exhaust gas recovery: 5% of gas input
Condensing boiler efficiency (assumed constant for simplicity): 91% (SEDBUK)
Water flow rate: 20 l/min
Heating power: 6-7 kW
Burner water temperature: 120-200°C

Note that the COP should never drop below 1.0 (10% better than condensing boiler), within the heat pump operating range.

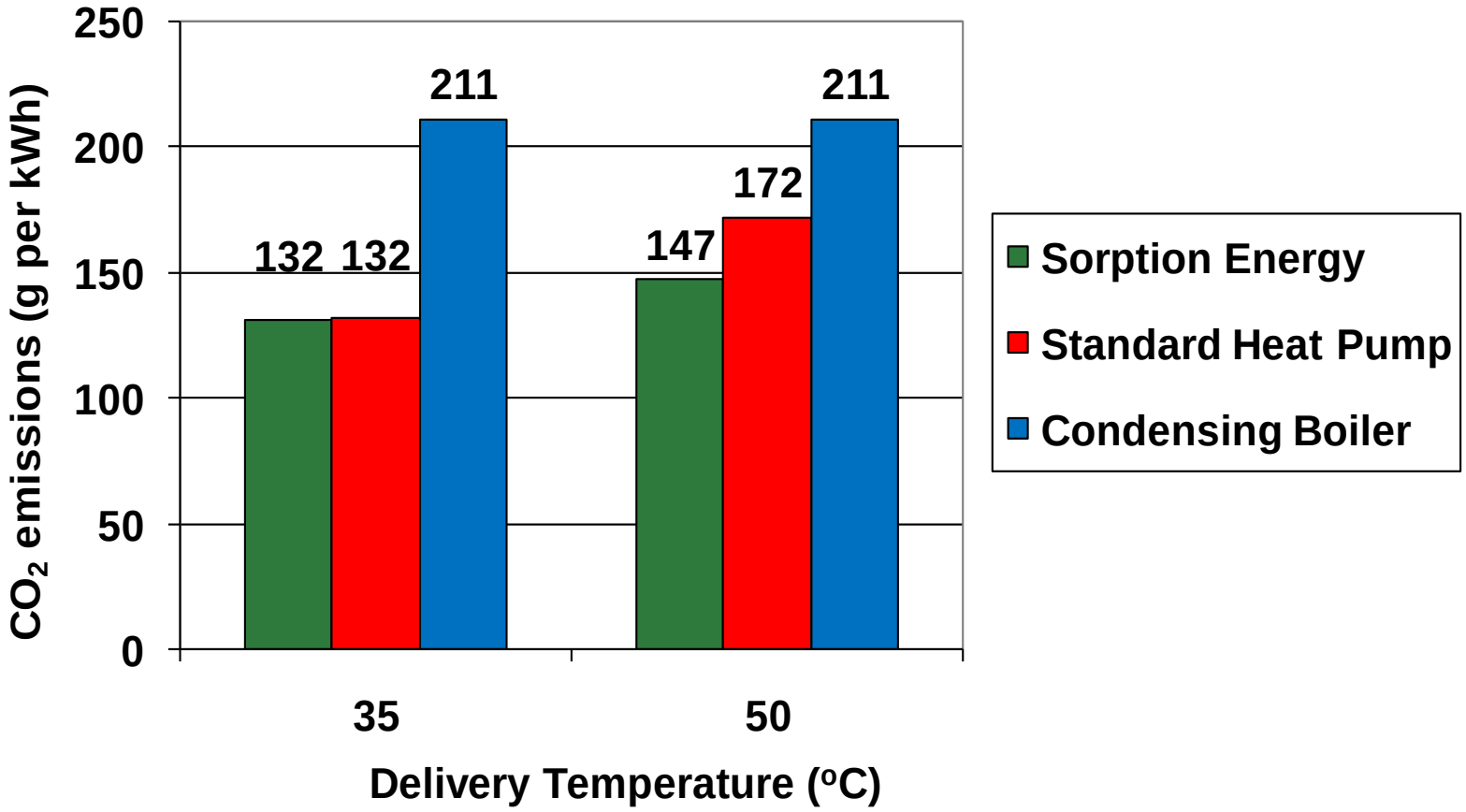
Comparison of Heating Costs (UK)



10°C ambient temperature
90% condensing boiler efficiency (HCV)
British Gas gas and electricity prices June 2010
Standard heat pump: Dimplex LI 8 MS

- Sorption Energy
- Standard Heat Pump
- Condensing Boiler

Comparison of CO_2 emissions (UK)



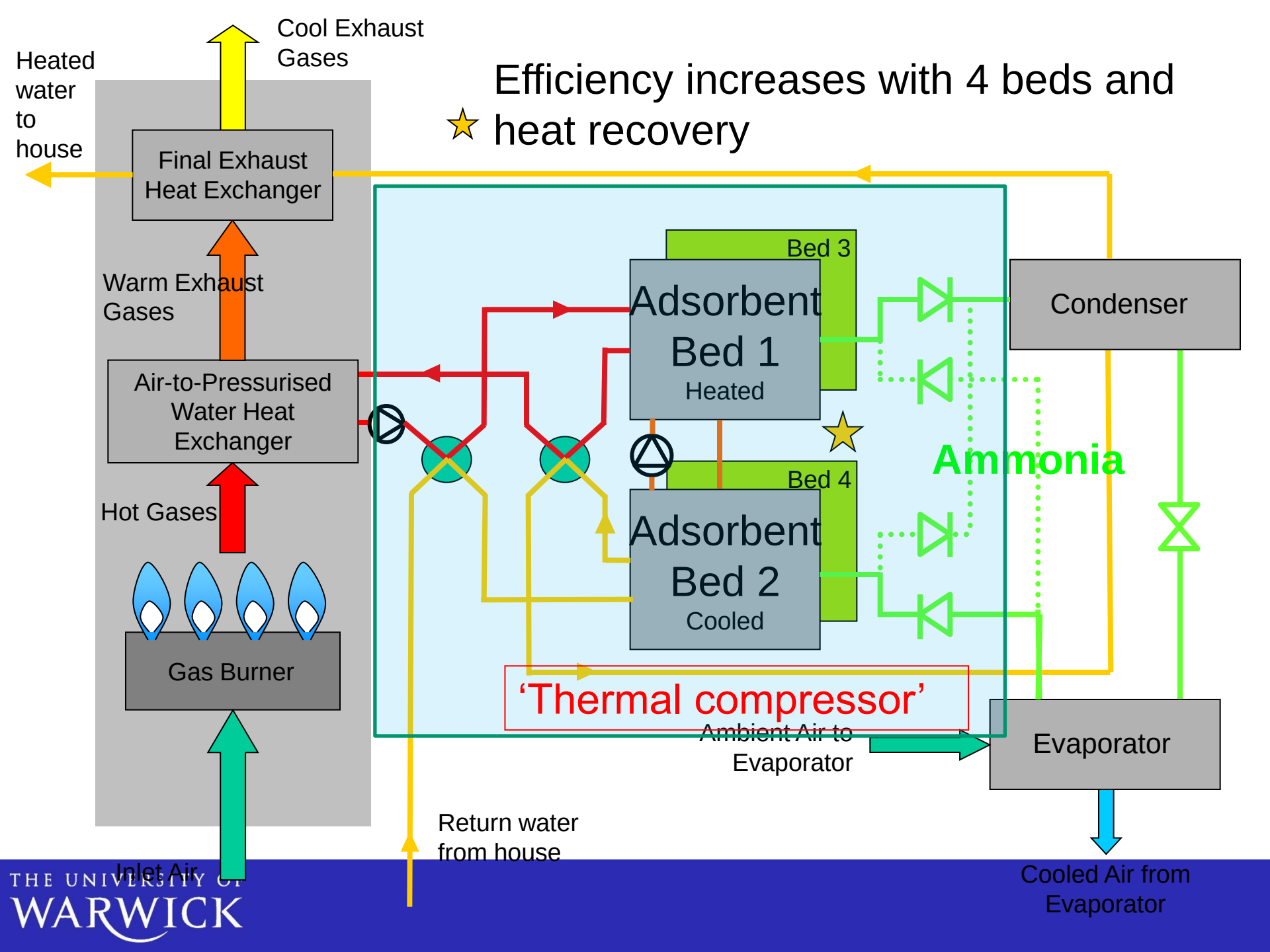
Change in product concept over time of project:

Where has the rest of the hardware gone?

Fits into standard wall-mounted casing

Adsorbent Beds (Generators)

- Box-for-box exchange for old boiler
- Key competitive advantage
  - other gas-fired heat pumps too large for wall mount
- Retrofit market >90% of annual sales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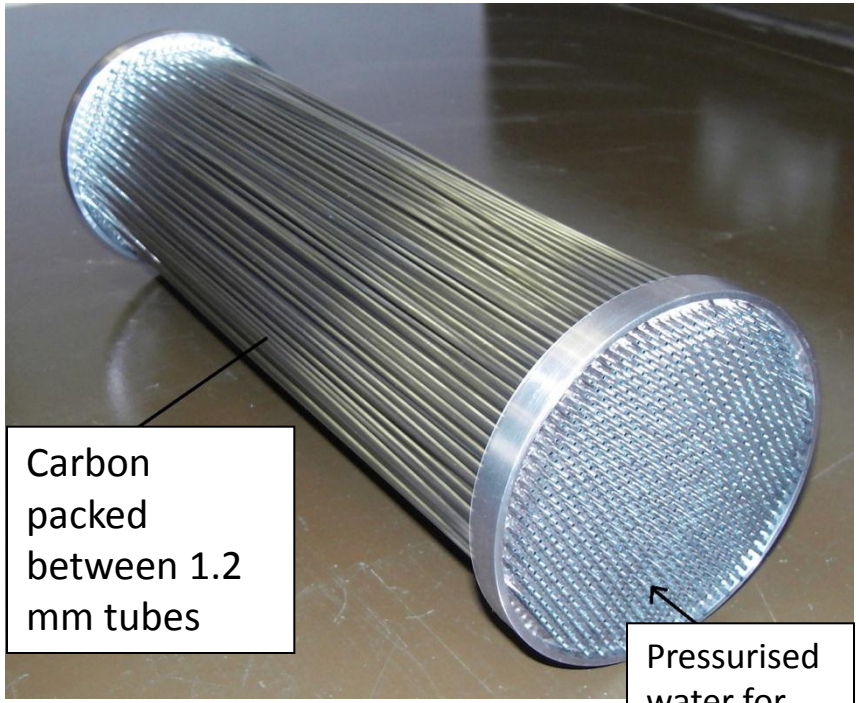
Evaporator
Return water from house
Cooled Air from Evaporator
THE UNIVERSITY OF WARWICK

Generators


Carbon packed between 1.2 mm tubes
Pressurised water for heating or cooling


Ammonia connections
Water flanges
10.11.2010 07:32

Payback within 3 years from fuel savings

About twice cost of condensing boiler

Use existing boiler installers with same trade skills

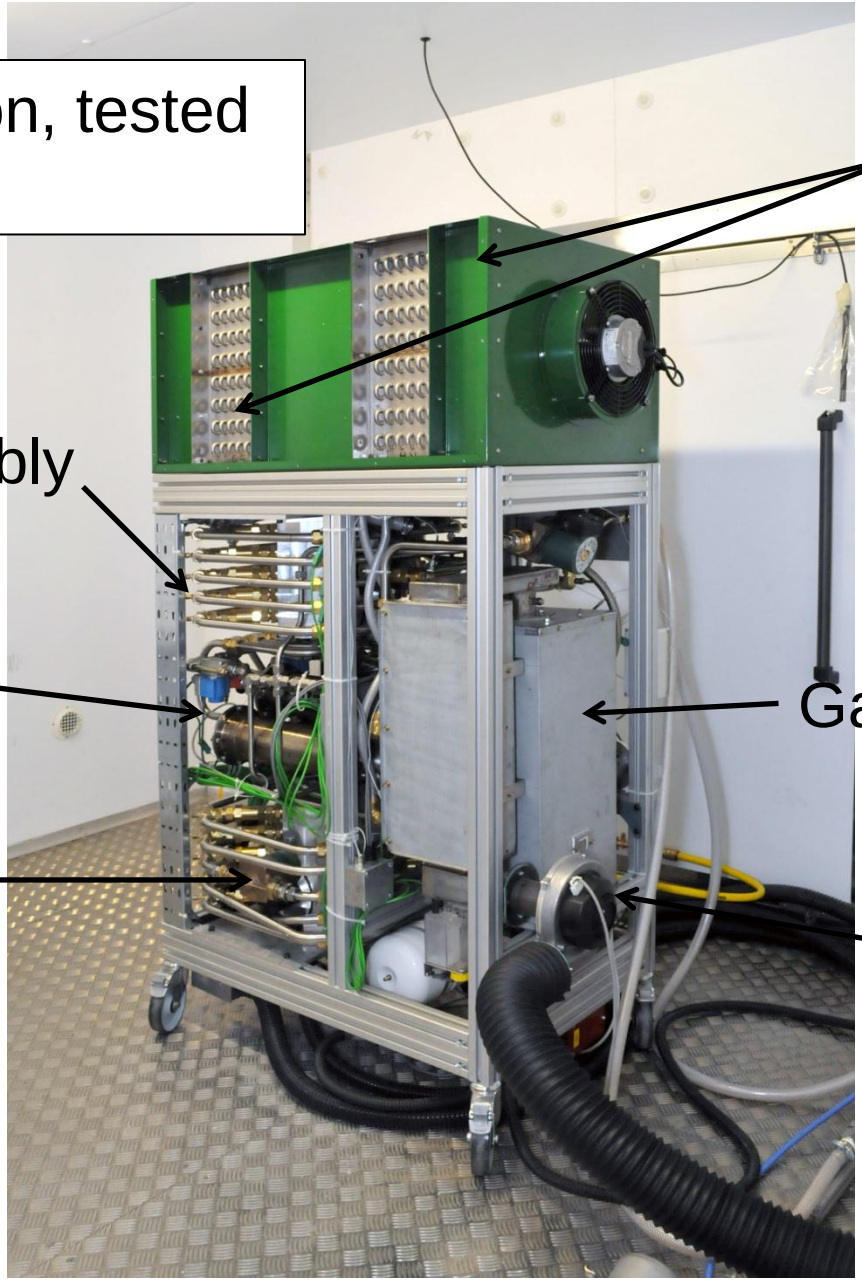
Similar installation costs inside house

- But have to mount evaporator on outside wall

Fuel savings give pay-back in ~36 months

- Compared to condensing boiler

Original version, tested May 2011



Evaporators

Top valve assembly

Generators

Gas heat exchanger

Bottom valve assembly

Burner


Original version, tested May 2011
First Aid
Environmental test chambers

Original version, tested May 2011

Initial testing:

Initial running successfully produced output water at 60°C.

The machine functioned as per design but **excessive heat losses** and **internal leakage** from valve assemblies lead us to a re-design before further tests.

- Conclusion was that we needed a ‘production valve’ and that further testing pointless without it.
- Test module built using existing ceramic discs from a commercial valve.
- Successfully tested in January 2012

Bespoke ceramic discs ordered and new valve body designed. Delivered March 2012.

Performance reduction due to poorer than expected heat transfer in carbon bed

Power, efficiency, size trade offs

Not achieving efficiency for required size, power

Problem due unexpected low heat transfer in carbon

- Achieving required density
- But accepted density/heat transfer relationship breaking down
- May be due to tube and carbon relative geometries
  - relationship is based on flat plates

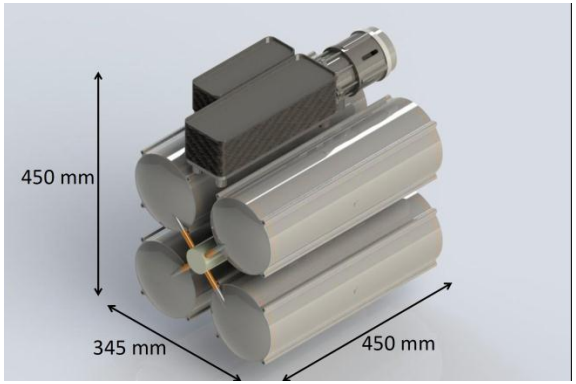
Short-term programme

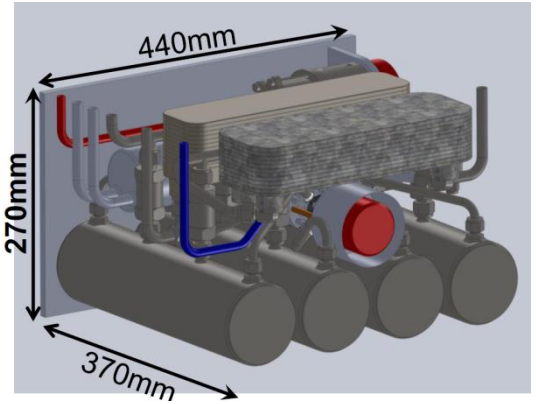
- Build and test larger-size unit rated 7kW

  [Early 2013]

- Programme to resolve thermal conductivity issues
  - Identify optimum geometry for maximum effect

- Programme of design-for-manufacture and test of commercial-sized unit
  - grant application





Thank you!