Thermal Systems R&I at Warwick:

Sustainable Thermal Energy Technologies (STET)

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- STET Facilities and Services
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  - Ammonia – Salts
- Heat Transformers
- Thermo-chemical transmission

Acronyms Galore- STET, i-STUTE and LoT-NET!

Acronyms Galore- STET, i-STUTE and LoT-NET!

What does STET do?:

Research low carbon heating, cooling and storage

Acronyms Galore- STET, i-STUTE and LoT-NET!

Who is STET?:

One technician, One facilities Manager
Three PDRA',s   Two PhD students, One Visitor
Two full-time academics
One part-time academic

The listing is by indispensability

Acronyms Galore- STET, i-STUTE and LoT-NET!

STET facilities and services

PT1600 Thermomechanical Analyzer

Mechanical properties from -150°C to 1600°C

- TMA easily and rapidly measures sample displacement to nanometre precision (growth, shrinkage, movement, etc.) as a function of temperature, time, and applied force
- Use of Liquid Nitrogen and heater gives measuring range of -150°C to 1600°C.
- For static expansion measurements, a probe rests on a sample on a stage with minimal downward pressure
- Dynamic analysis (D-TMA) also possible by applying a varying force alongside temperature changes

Differential Scanning Calorimeter

Heat Flow measurements from -180°C up to 2400°C

- Determination of a wide range of properties including enthalpy, melting energy, specific heat, glass point, crystallinity, reaction enthalpy and thermal stability

- Ultra-high temperatures of up to 2400°C

- Provides the highest calorimetric sensitivity, short time constants and a condensation free sample chamber

- The vacuum tight design enables quantitative enthalpy and C_p (Specific Heat) determination under the cleanest atmospheres and under vacuum of 10^{-5} mbar through to 300 bar

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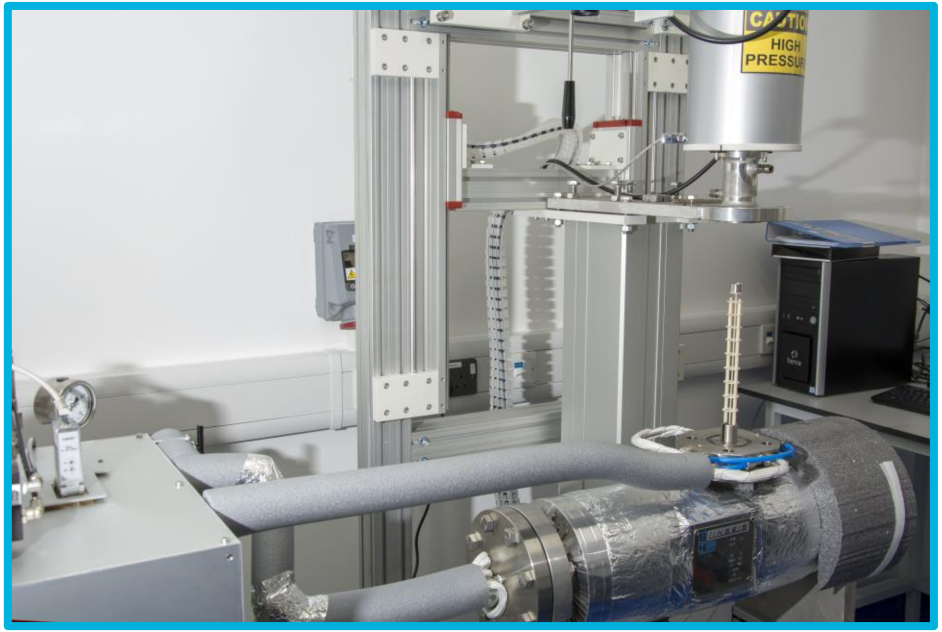

Simultaneous Thermal Analysis

Measures heat flow and weight change simultaneously

- Functions as both a calorimeter and thermogravimetric analyser, improving productivity but also simplifying the interpretation of the results
- Allows for differentiation between endothermic and exothermic events which have no associated weight loss (e.g. melting and crystallization) and those which involve a weight loss (e.g. degradation)
- Wide temperature range of –150°C up to 2400°C
- The atmosphere can also be controlled for high vacuum, inert, reducing, oxidizing or humidified applications

Heat Flow Meter

Thermal Conductivity testing of insulation materials

- HFM determines the thermal conductivity of low thermal conductivity insulation within minutes
- Allows for the testing of typical thickness materials used in real-life applications
- Temperature range of 0 °C to 40°C
- A typical measurement for most samples can take as little as 15 minutes until the temperature stabilizes

Xenon Flash Analyser

Rapid Thermal Conductivity measurements

- XFA is the most commonly used technique for the measurement of the thermal diffusivity and thermal conductivity of various kinds of solids, powders and liquids

- Sample is irradiated with a programmed energy pulse, and the resulting temperature rise is measured by a high speed IR detector. Thermal diffusivity values are computed from the temperature rise versus time data.

- Provides a cost effective method to determine the Thermal Diffusivity, Conductivity and Specific Heat Values for up to six Samples at the same time

DTC Heat Flow Meter

For low-to-medium conductivity materials

- DTC 300 is a guarded heat flow meter measuring the thermal conductivity over a wide range of temperatures
- Uses one calorimeter module, located in the bottom stack, for the measurement of thermal conductivity, and a side guard furnace to prevent edge heat loss
- Tests can be run from -20°C up to 300°C
- Typical sample size is 50mm

ThermExS Lab

Complete system tests on heat pumps, stores, heat transformers

- 4 switchable computer controlled baths, powers of 7 to 20 kW, Temperature range -40 to 200°C
- Oil, water and glycol loops
- Safety systems in place for hazardous refrigerants, e.g. ammonia.

1. Acronyms Galore- STET, i-STUTE and LoT-NET!

i-STUTE

Research low carbon heating, cooling and storage

1. Acronyms Galore- STET, i-STUTE and LoT-NET!

i-STUTE

- EPSRC project under End Use Energy Demand 2013-18
- Warwick, Loughborough, LSBU, Ulster

1. Acronyms Galore- STET, i-STUTE and LoT-NET!

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- Thermal heat pumps
- Business models

Loughborough University

- Thermal energy storage
- Consumer behaviour

London South Bank University

- Commercial and industrial refrigeration
- Engagement with SMEs

Ulster University

- Electric heat pumps
- Integration with storage

i-STUTE

1. Acronyms Galore- STET, i-STUTE and LoT-NET!

LoT-NET

- EPSRC programme grant 2019-24
- Warwick, Loughborough, LSBU, Ulster

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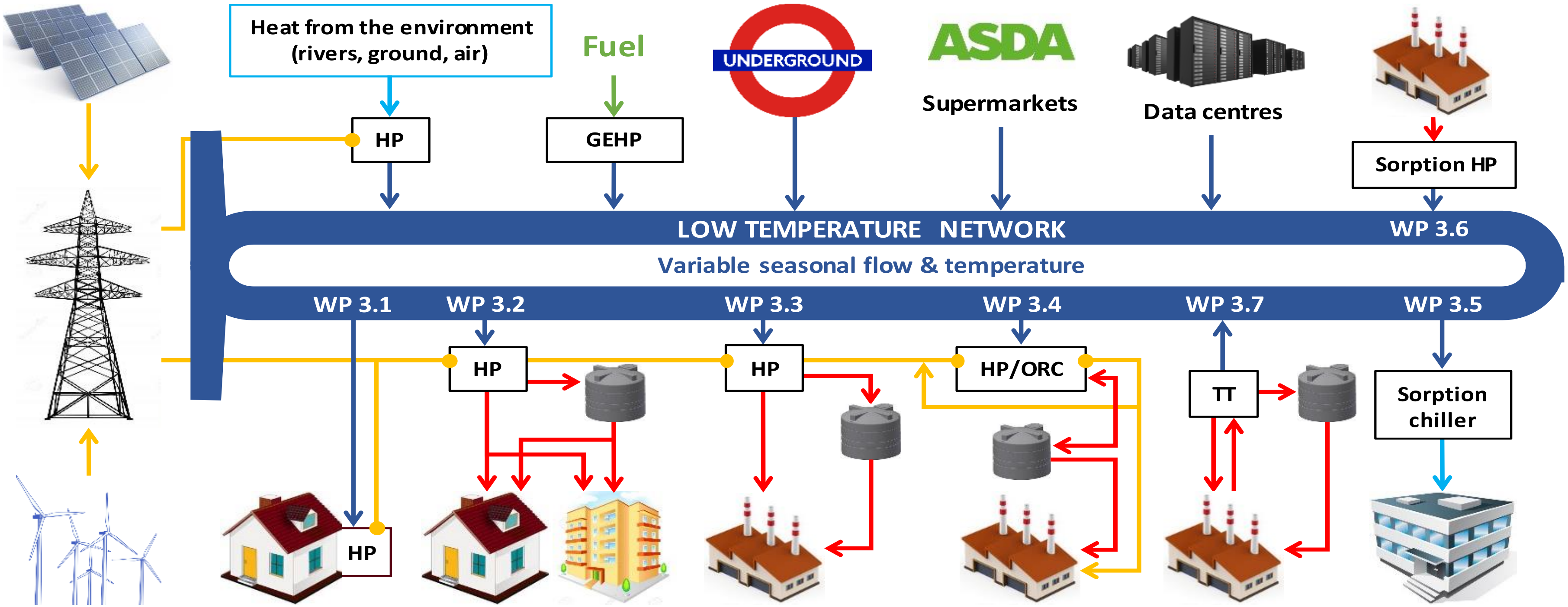


LoT-NET

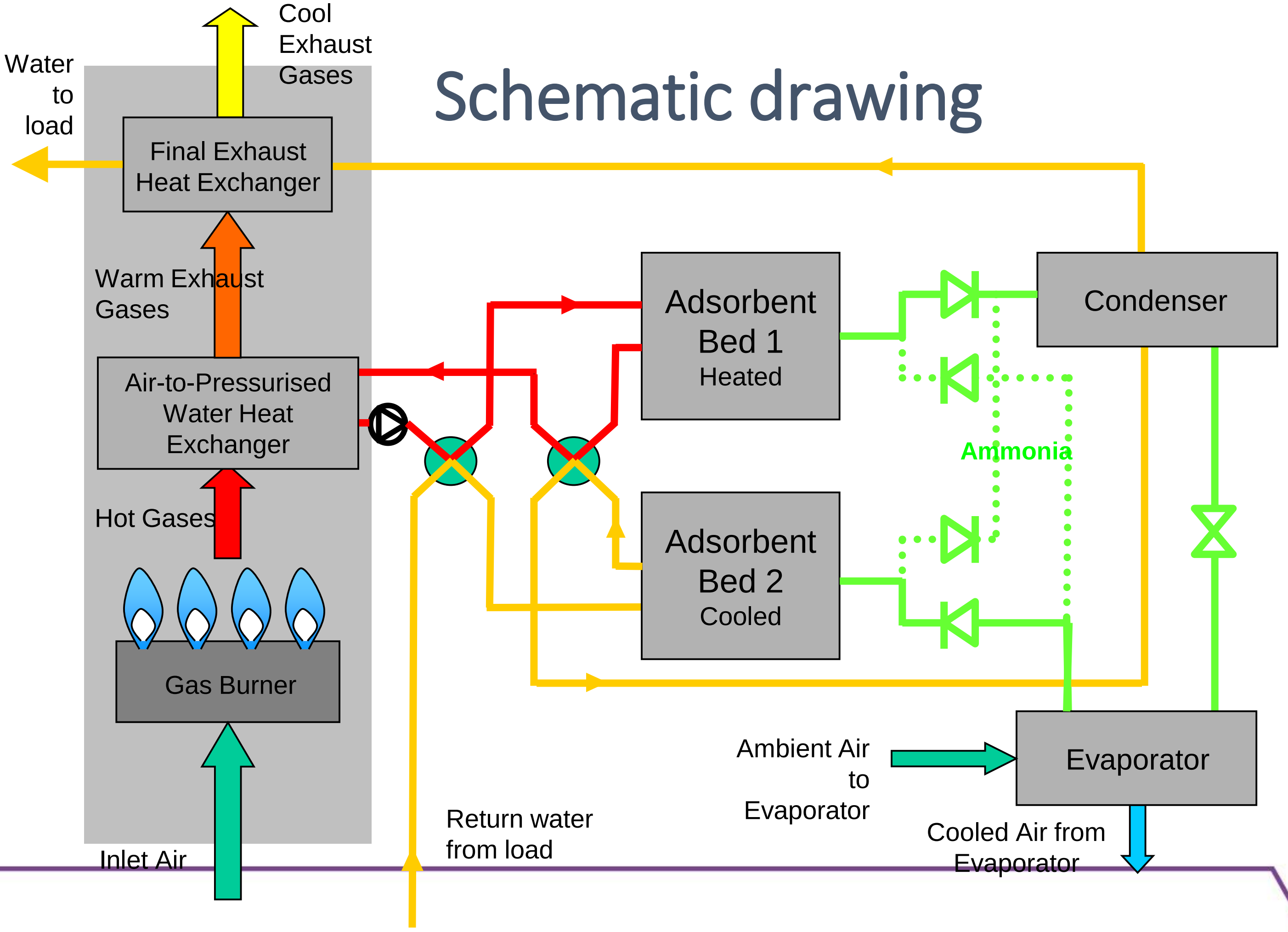
Gas Heat Pump Research:

- Ammonia – Carbon
- Ammonia – Salts

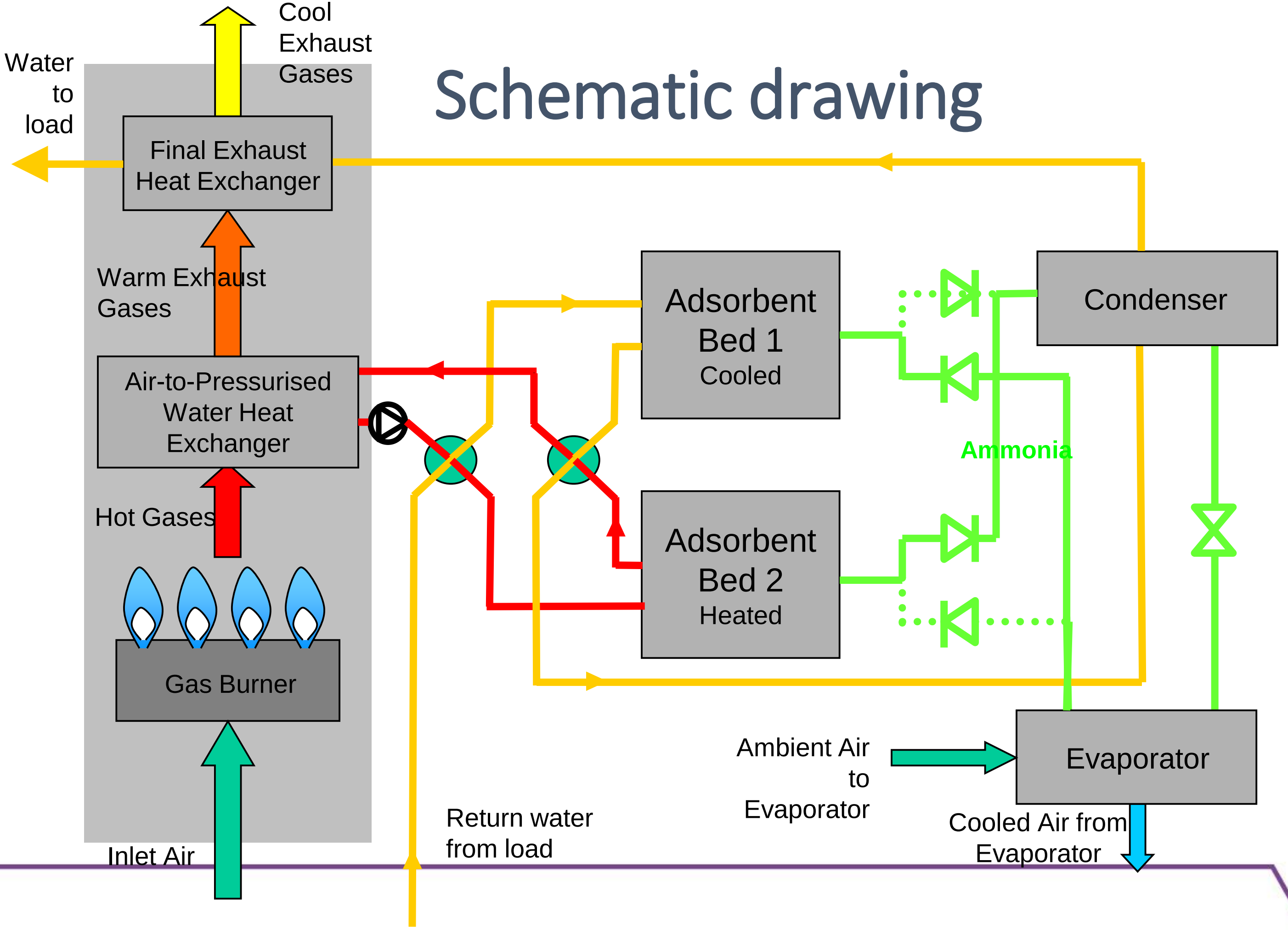
Heat pump concept

- Box-for-box exchange for conventional domestic gas boiler
- Air source for ease of retrofit
- 30% reduction in gas consumption compared to a condensing boiler
- 10 kW heat output

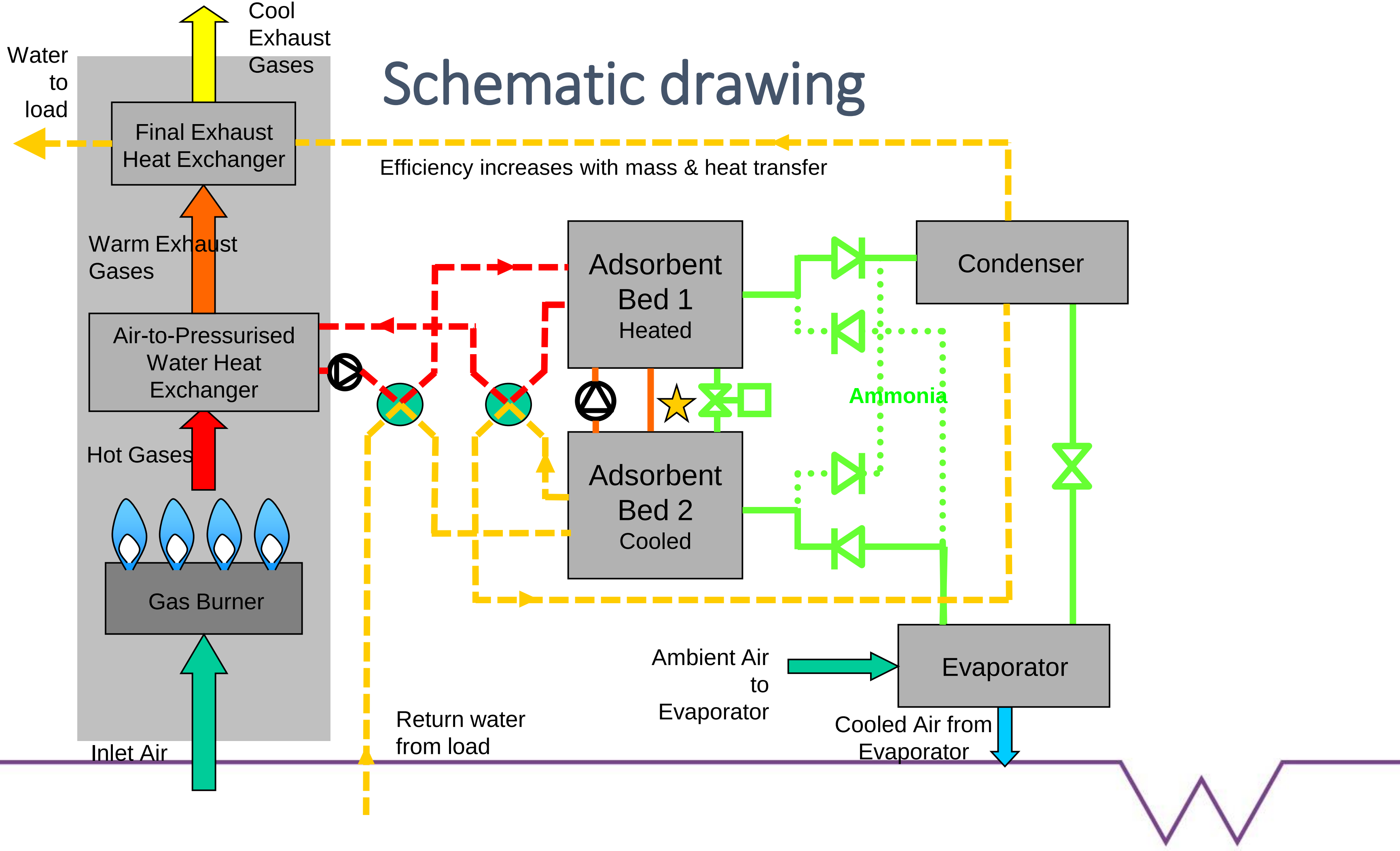
Schematic drawing



Schematic drawing



Schematic drawing



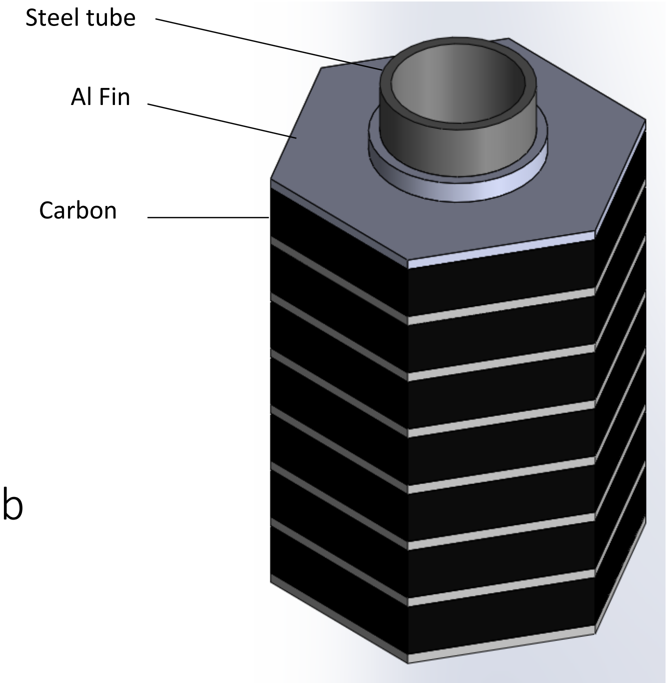
Generator design

Shell and finned tube

Design Parameters:

- Tube diameter
- Tube pitch
- Carbon thickness
- Fin thickness

Detailed simulations in Matlab

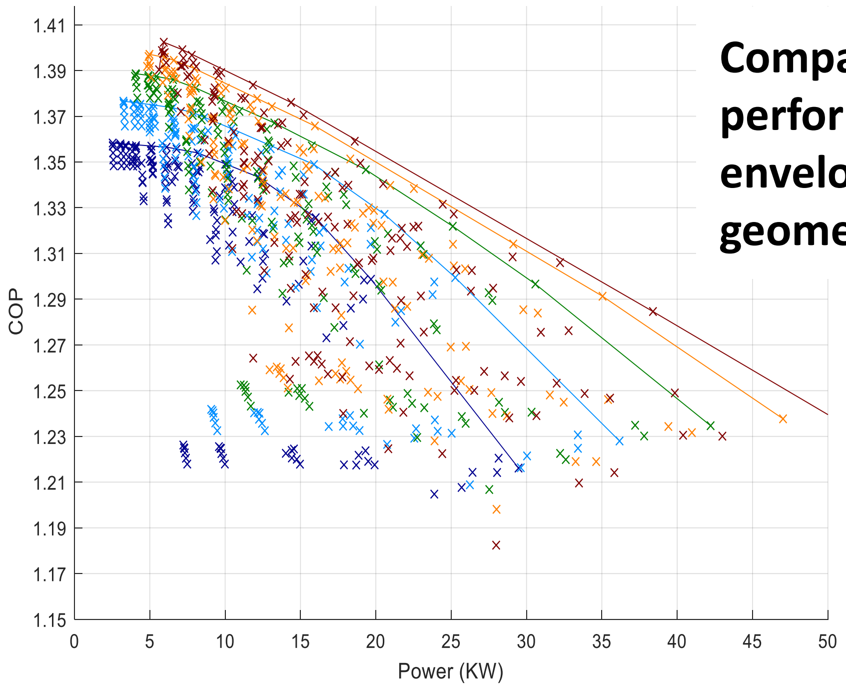


Generator design

Target performance:

- Heating power 10 kW
- Total generator volume ≤ 10 litres
- Internal COP ≥ 1.4 (GUE ~1.25)
  - Heating water delivery temperature 55°C
  - Evaporating temperature 0°C

Performance predictions



Comparison of performance envelopes for various geometries

Machine construction

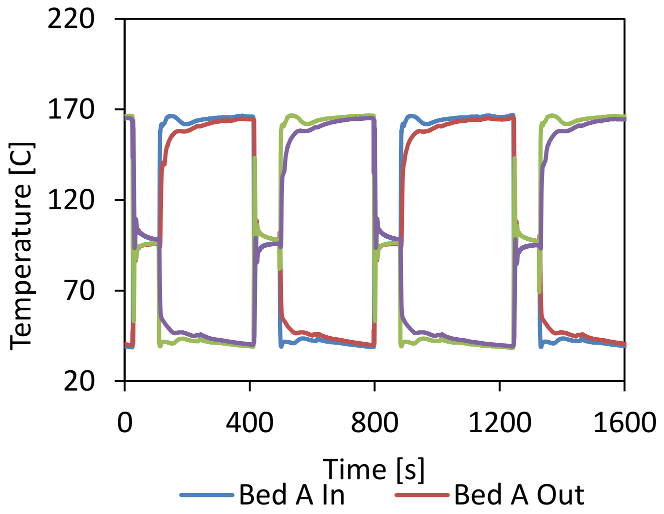
Machine testing

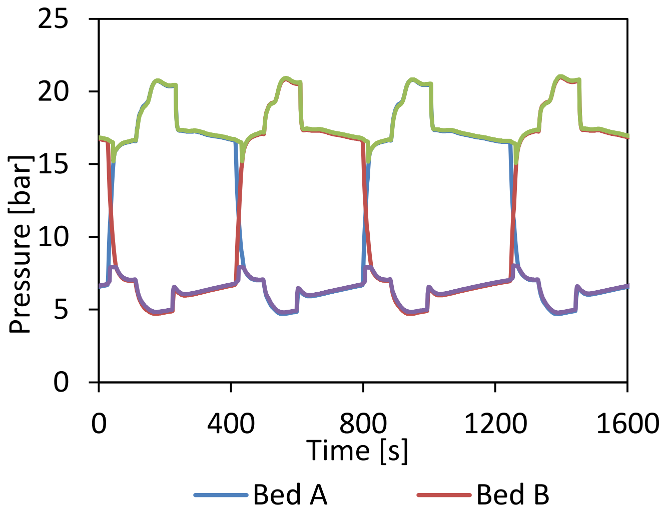
System of heating and cooling baths to provide:

- Up to 170°C pressurised water for high temperature heat input
- 10 kW of heat rejection for the condenser and cooler
- Glycol flow down to -10°C for evaporator

Machine testing results

Although temperature and pressure profiles seem correct and very repeatable, the COP and powers delivered were lower than expected.



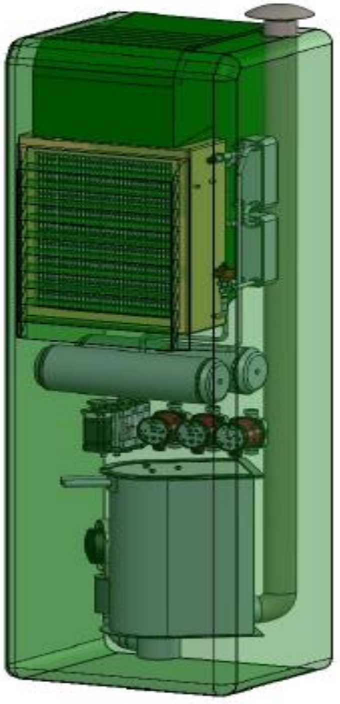


Machine testing results

- Low COP and heating power → due to an unexpected low amount of refrigerant cycled during the testing (approximately 1/3 lower than predicted.
- It is believed that some of the binder used in the carbon composite is causing blockage of the pores.
- Problem solved and new generators awaiting test.

AND

- Project funded by BEIS (UK Energy ministry) will productionise design… **Aims to have three production-ready prototypes in June 2020.**



System concept CAD model, 1.9m (h) x 0.6m (w) x 0.5m (w)

Key findings re production and costs

- With the exception of the generators ALL components can be sourced commercially and do not require bespoke development.
- There are promising mass production routes available for kebab manufacture
- Gas burner and heat exchangers currently under test with good indicative results
- Present estimates of factory cost around £2100

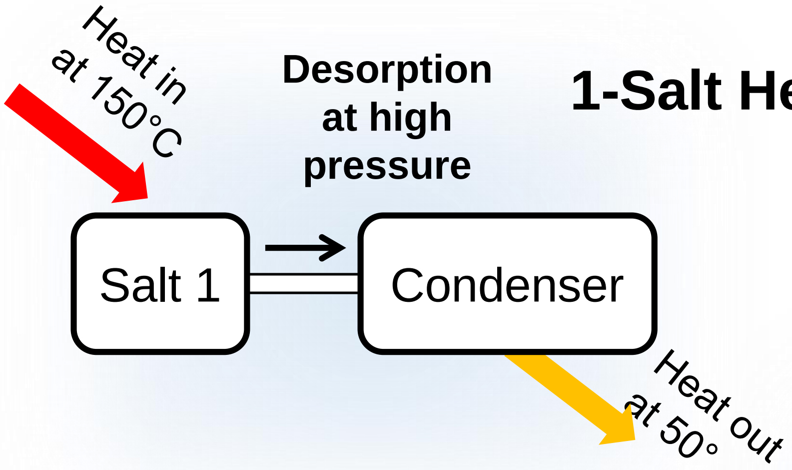
Gas Heat Pump Research:

- Ammonia – Carbon
- Ammonia – Salts

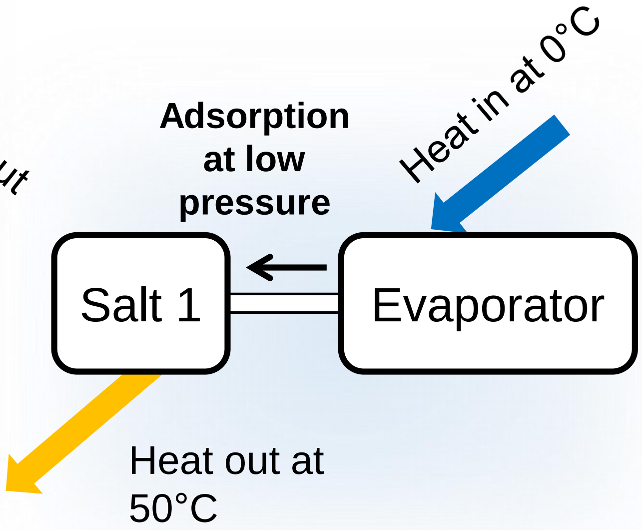
Why salts (Chemical rather than Physical Adsorption)?

- Advantages
  - Greater concentration change – typically x 3 so could be more efficient
- Disadvantages:
  - Stability, hysteresis, dynamics, corrosion………..

1-Salt Heat Pump



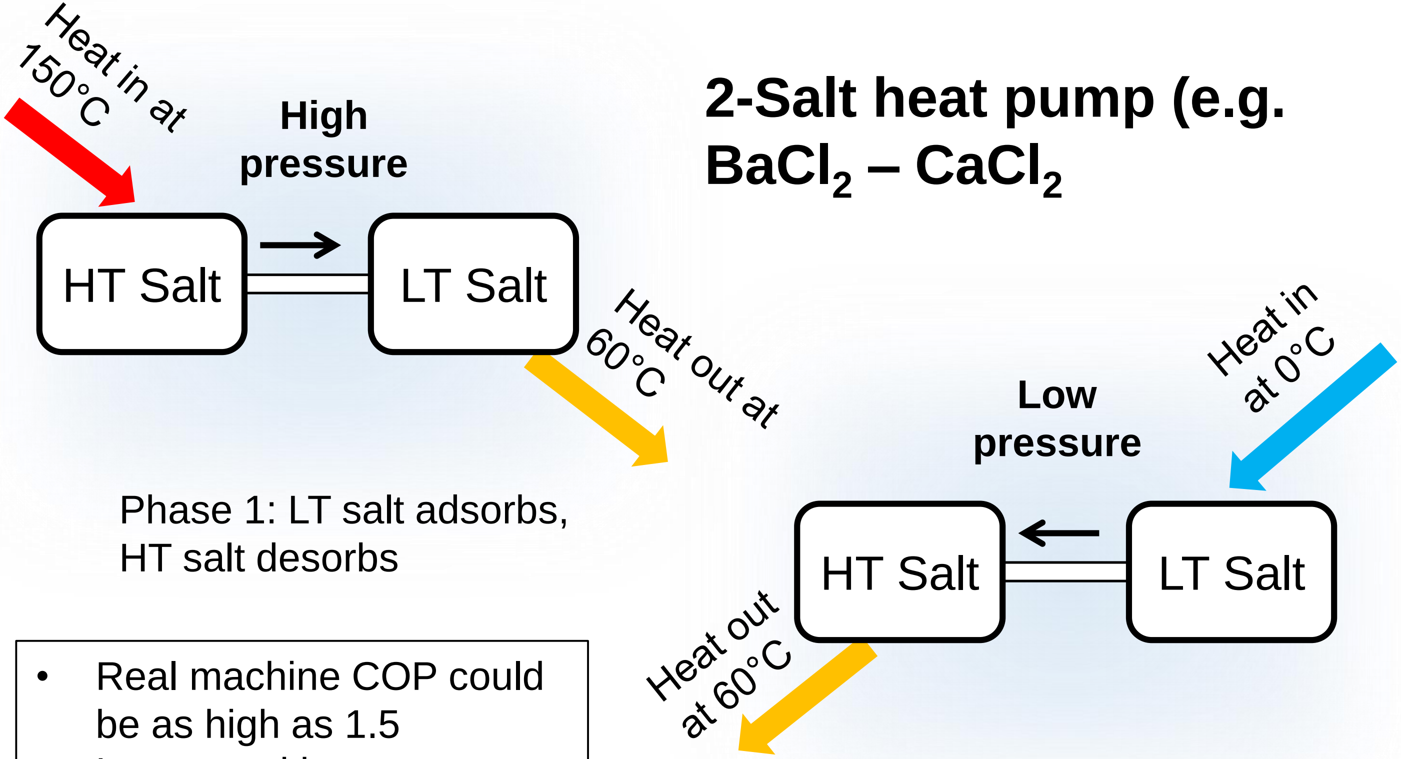
Phase 1: Desorption using high grade heat at 150°C



Phase 2: Discharge of heat at 50°C

- Ideal COP = 2
- Latent heat < < Heat of adsorption so not that good
- But with 2 salts…

2-Salt heat pump (e.g. $BaCl_2$ – $CaCl_2$



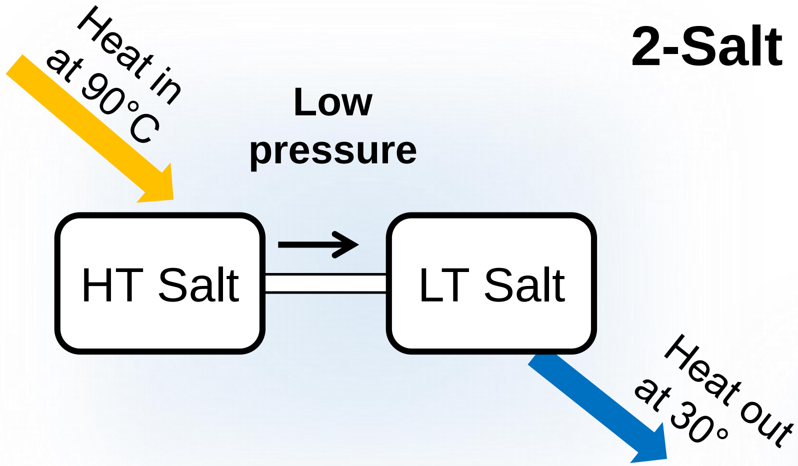
Phase 2: LT salt desorbs, HT salt adsorbs

- Real machine COP could be as high as 1.5
- Lower working pressures
- No condenser, evaporator or expansion valves etc.

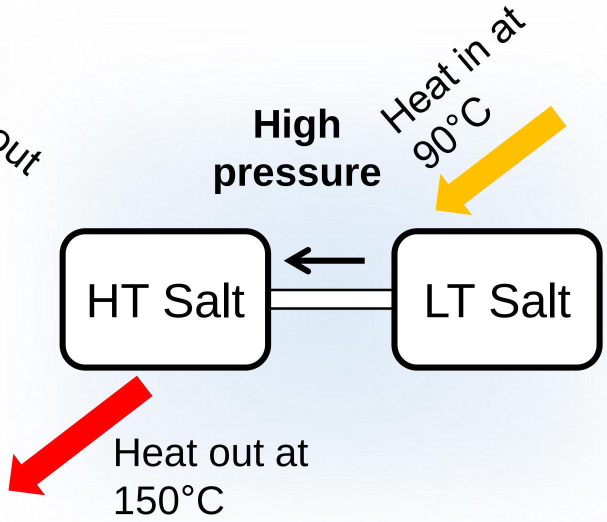
Approach to solving salt DISadvantages:

- Stability – Salt contained in Expanded Natural Graphite (ENG) for stability AND heat transfer.
- Uncertain data, both equilibrium and dynamic
  - DSC, TA, STA tests on selected salts and ENG-salt composites.
  - Large Temperature Jump (LTJ) tests on small samples
  - Prototype tests ($\approx$ 5kW) in ThermExS rig.

2-Salt Heat Transformer (TT)
($CaCl_2$ & $MgCl_2$?)



Phase 1: HT salt desorbs,
LT salt adsorbs



Phase 2: LT salt desorbs,
HT salt adsorbs

- 2 salts have lower pressures compared to 1 salt with condenser/evaporator
- less susceptible to sensible heat thermal mass losses

Sam’s talk!

Heat Network Research:

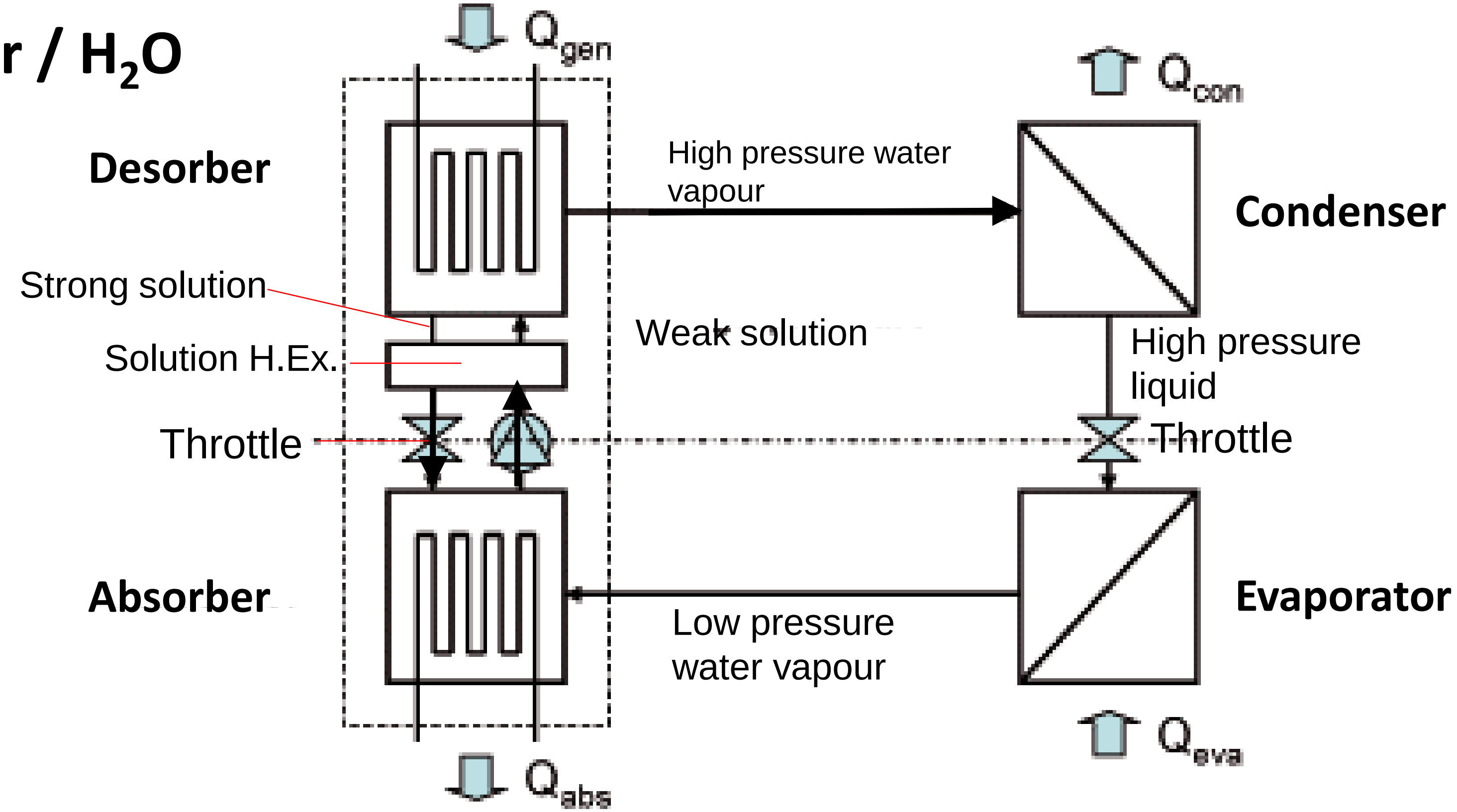
- Thermochemical heat distribution networks

- Thermochemical district heat networks are a new technology for district networks that can provide heating and cooling in one **heat loss-free** multiservice network.
- The innovation is the use of thermochemical fluids as transport medium (concentrated salt solutions).
- The chemical potential is used to generate useful heat or cold from ambient heat at the place and time of demand.

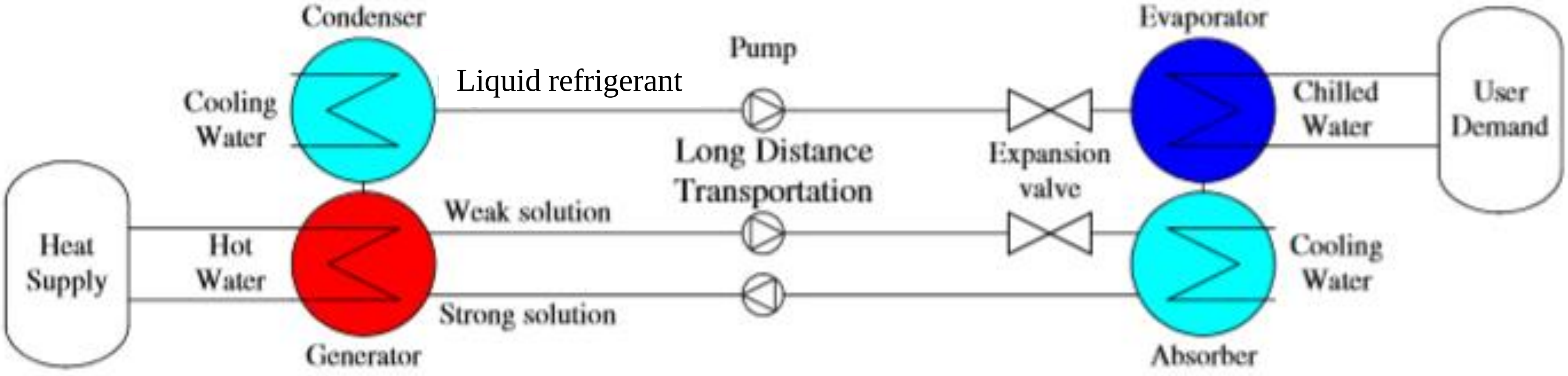
Advantages: heat loss free

- Less investment (no insulation, smaller pipe diameters)
- Longer distances

Absorption machines: example LiBr / H_2O



Re-arrange to get a thermochemical district network:



Requirements for residential space heating:

- Evaporating with air as heat source preferably as low as -15°C
- Condensation below 30°C
- Fluid vapour pressures between 0.1 and 10 bar

Refrigerants:

- Water – Minimum evaporation temperature ~ 5°C
- Ammonia - Toxic
- Methanol, Ethanol – Not as good as water thermodynamically but useable

Absorbents for water (also alcohols)

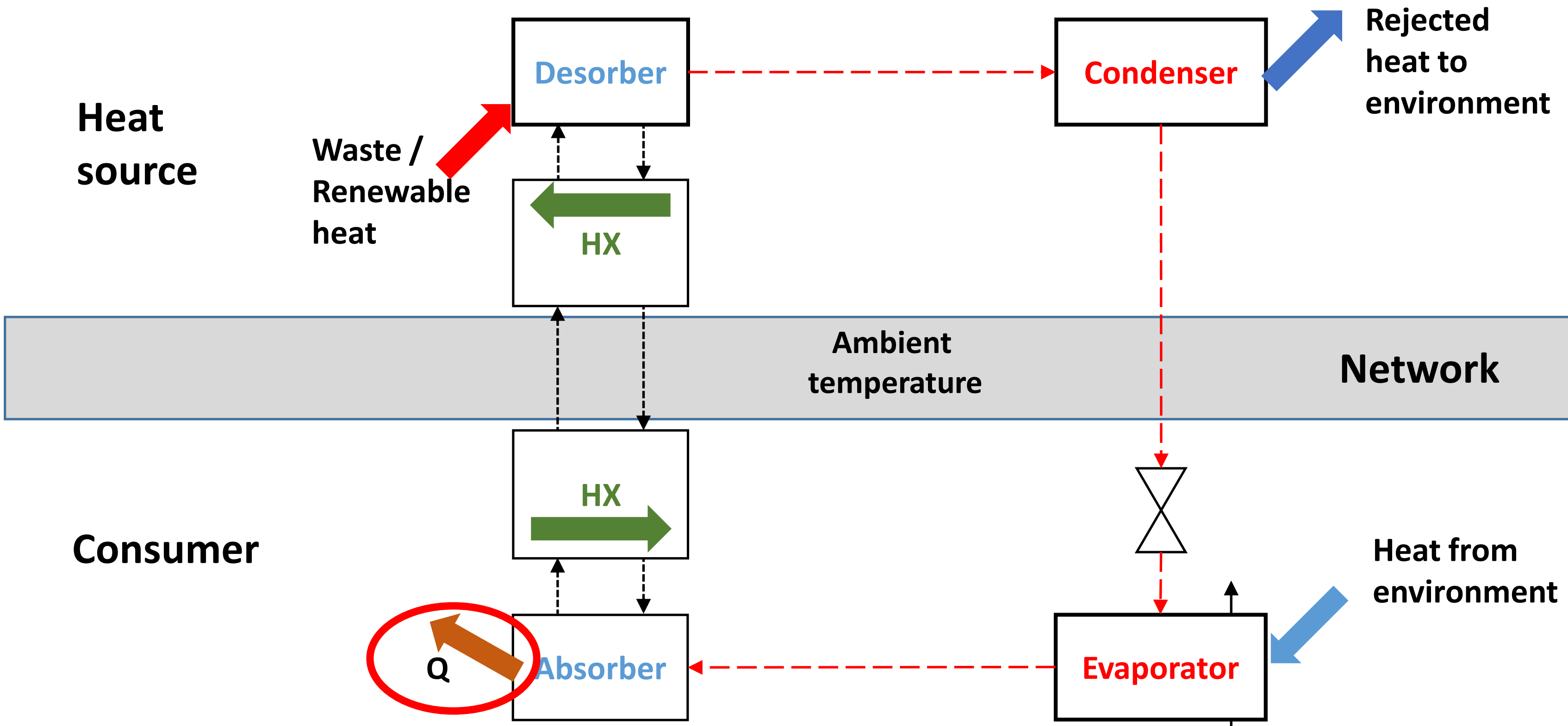
Different groups of substances such as salts, alkalis, acids, organic compounds and ionic liquids can be used as absorbents.

In addition to thermodynamic properties, the following criteria must be considered for the selection of the thermochemical fluid:

- Availability
- Price
- Environmental compatibility
- Recyclability
- Toxicity
- Chemical stability

Desiccant	Comments
Lithium bromide (LiBr)	Common in absorption plants (chillers), but not suitable in thermochemical network due to the high price.
Lithium chloride (LiCl)	Common in dehumidification systems, but not suitable in thermochemical network due to the high price.
Calcium chloride ($CaCl_2$)	High efficiency.
Magnesium chloride ($MgCl_2$)	High efficiency.
Calcium nitrate $Ca(NO_3)_2$	Not corrosive. Low efficiency at low temperatures and high efficiency at high temperatures.
Sodium hydroxide (NaOH)	Very high efficiency. Not suitable in open processes.

Example schematics



Example: LiBr – H_2O Matlab simulation

Evaporating temperature ~ Ambient -5°C

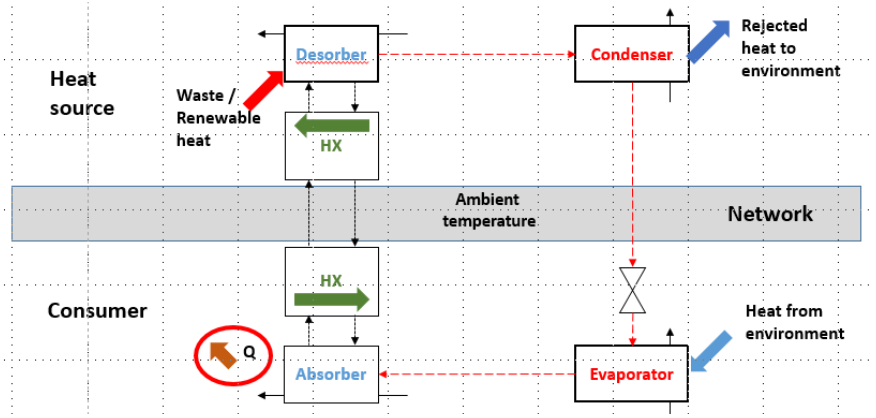
Delivery temperature

Supply temperature

Delivered heat / supplied heat

Equivalent supply – return temperature for pumping the same volume flow of water

Tamb (C)	Tabs (C)	Tdes (C)	Qa	Abs/Des	ΔTeq H_2O
5	30	35	2320.23	0.82	53.53
5	30	40	2424.35	0.87	102.59
5	30	45	2476.95	0.89	145.02
5	40	45	2295.23	0.75	45.66
5	40	50	2460.69	0.82	90.62
5	40	55	2533.41	0.85	130.07
5	50	55	2249.75	0.67	38.52
5	50	60			
5	50	65			
10	30	35	2361.48	0.85	54.48
10	30	40	2449.61	0.89	103.66
10	30	45	2496.87	0.91	146.19
10	40	45	2343.00	0.78	46.61
10	40	50	2489.21	0.84	91.67
10	40	55	2555.51	0.87	131.21



Example: LiBr – CH_3OH Matlab simulation

Evaporating temperature ~ Ambient -5°C

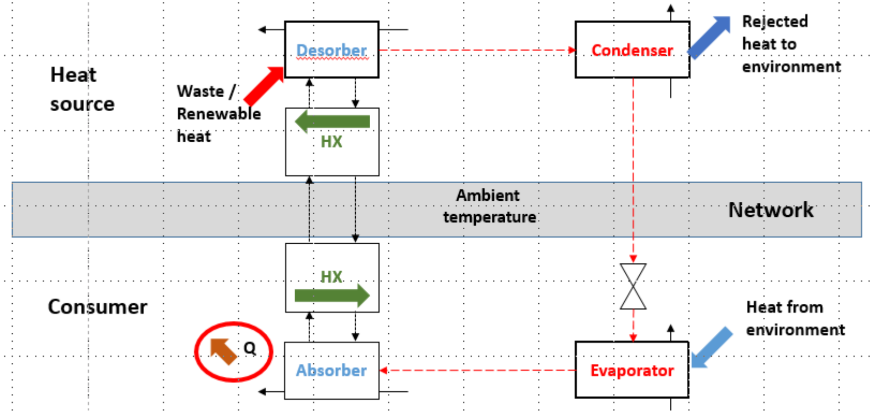
Delivery temperature

Supply temperature

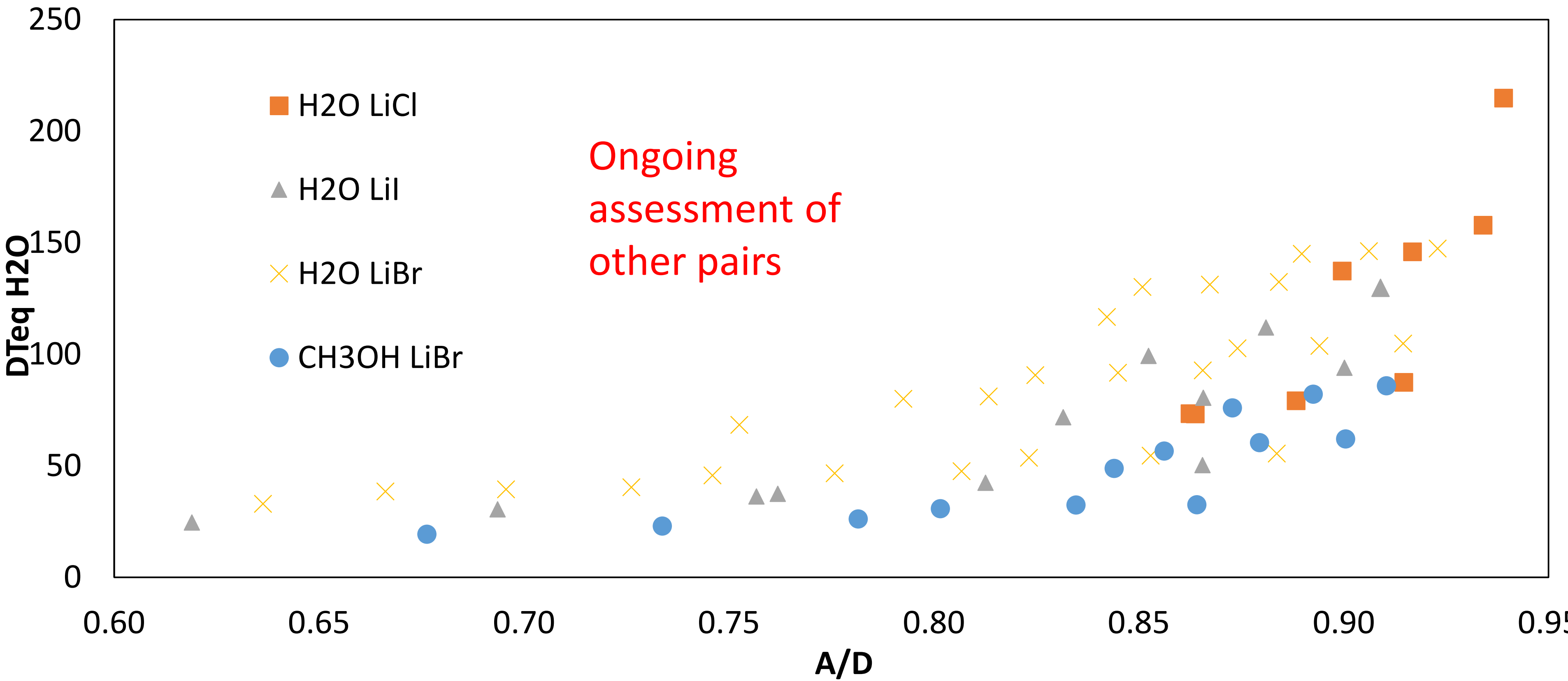
Delivered heat / supplied heat

Equivalent supply – return temperature for pumping the same volume flow of water

Tamb (C)	Tabs (C)	Tdes (C)	Qa	Abs/Des	ΔTeq H_2O
5	30	35	1404.05	0.80	30.82
5	30	40	1480.14	0.86	56.58
5	30	45	1515.96	0.87	75.94
5	40	45	1352.37	0.68	19.37
5	40	50			
5	40	55			
5	50	55			
10	30	35	1397.47	0.83	32.50
10	30	40	1463.28	0.88	60.44
10	30	45	1497.18	0.89	82.15
10	40	45	1386.81	0.73	22.97
10	40	50			
10	40	55			



Pairs comparison



Conclusions:

- Acronyms explained!
- STET Facilities and Services available to industry, researchers
- Gas Heat Pump Research
  - Ammonia – Carbon Three prototypes being manufactured with BEIS funding
  - Ammonia – Salts Lower TRL but promising
- Heat Transformers Industrial heat upgrading
- Thermo-chemical transmission - Ongoing research into ‘lossless’ transmission

Thank you!

Questions?