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Emerging refrigeration technologies – what technologies can we expect to utilise in the future?



# Classification of Refrigeration Systems for Food Engineering Applications

## In terms of prime mover

- **Electrically driven**
  - Vapour compression
  - Air cycle
  - Thermoelectric
  - Thermoacoustic
  - Magnetic
- **Thermally driven**
  - Sorption systems (absorption, adsorption)
  - Ejector (jet-pump systems)
  - Thermoacoustic
- **Hybrid**
  - Heat/Electricity
  - Solar/Electricity
  - Biomass/Engine
  - Biomass/Heat
  - Solar/Biomass/engine

# Classification of Refrigeration System for Food Engineering Applications

## In terms of temperature range

- High temperature: above 3°C
- Medium temperature: 0°C to -10°C
- Low temperature: -18°C to -35°C
- Very low temperature: -50°C to -90°C

## In terms of application

- Constant temperature
  - Transport refrigeration
  - Food storage and display
    - Display cabinets (integral and remote)
    - Cold storage
- Food processing (temperature change of product)

# Alternative and Emerging Refrigeration Technologies

- Magnetic
- Thermoacoustic
- Thermoelectric
- Sterling cycle
- Air cycle
- Tri-generation
- Sorption technologies (absorption and adsorption)
- Vapour compression technologies - CO<sub>2</sub> refrigeration systems and combinations.



# Magnetic Refrigeration

A magnetic refrigeration cycle employs a solid-state magnetic material as the working refrigerant. The material warms-up in the presence of a magnetic field and cools down when the field is removed.

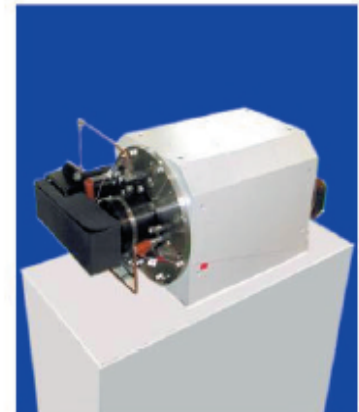
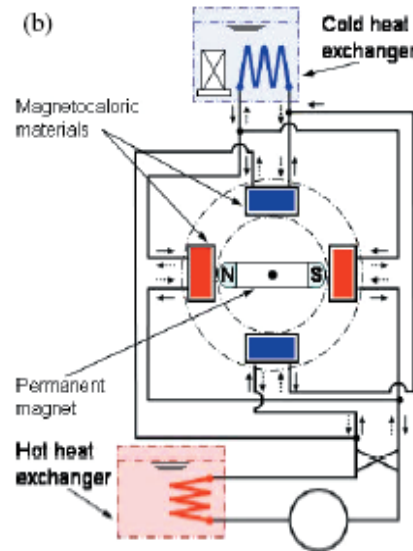
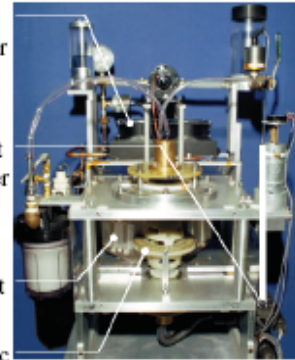
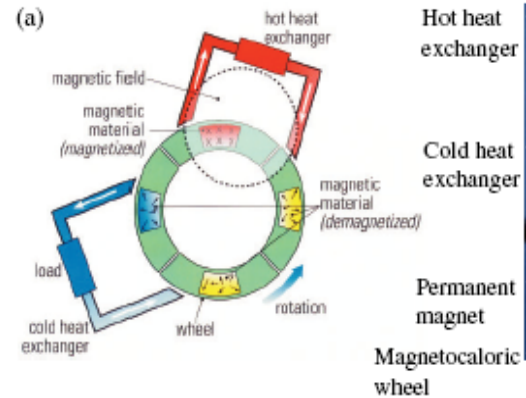
**Technology is under active development**

## Applications

Has potential for use across the whole refrigeration temperature range.

A number of prototype systems have been announced. Cooling capacities of prototype are low, maximum reported to date is 540 W with a COP of 1.8 at room temperature. It is anticipated that the first commercial applications will be for low capacity stationary and mobile refrigeration systems.

**Cambridge** – pre-production units for drinks coolers in 2011 in time for Olympics?.



# Thermoacoustic Refrigeration

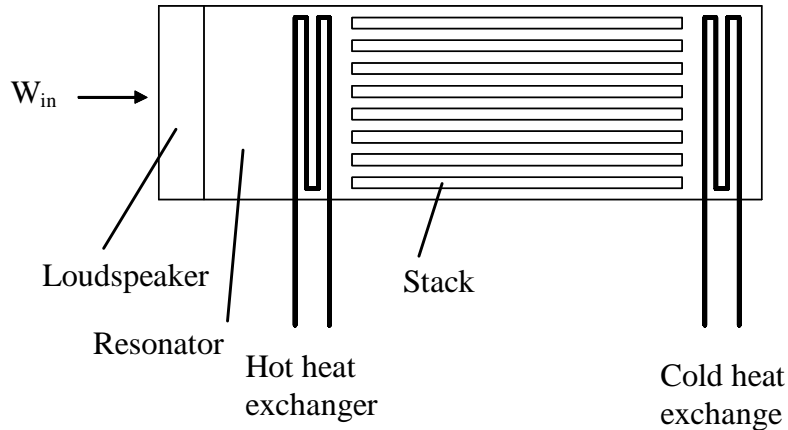


Figure 1 Sound wave Thermoacoustic engine

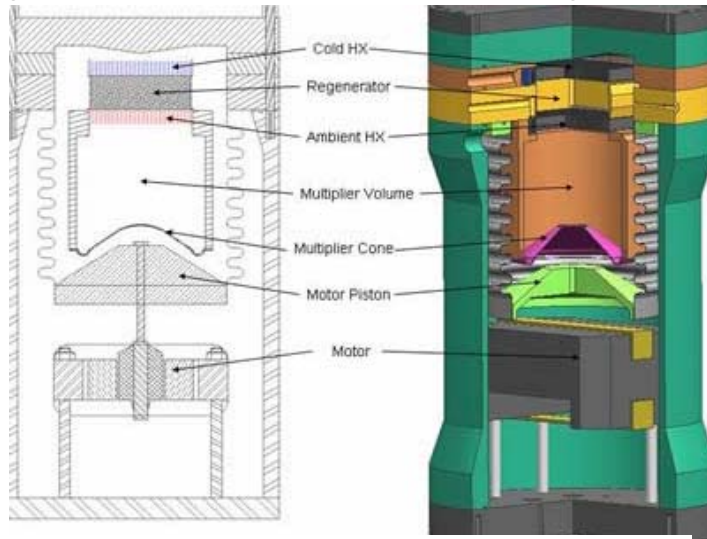


Figure 2. A travelling-wave thermoacoustic refrigerator (Source: Sounds Cool! The Ben & Jerry's Project, 2005)

Thermoacoustic refrigeration systems operate by using sound waves and inert gas in a resonator to produce cooling.

## State of development

Under active development but low COP, around 1.0 at present. Not commercially available yet.

## Applications

Have the potential to cover the whole spectrum of refrigeration down to cryogenic temperatures.

Food applications likely in the small capacity range (large domestic refrigerators and cabinets).

Use of waste heat to drive a thermoacoustic engine which in turn drives a thermoacoustic refrigerator.

# Stirling Cycle Refrigeration



Free Piston Stirling Module and Freezer

The Stirling cycle cooler is a regenerative system in which gas in the system is moved backwards and forwards between the hot end and cold end spaces.

Heat is rejected via a heat exchanger at the hot end, and heat is absorbed from the space to be cooled via a heat exchanger at the cold end.

## State of development

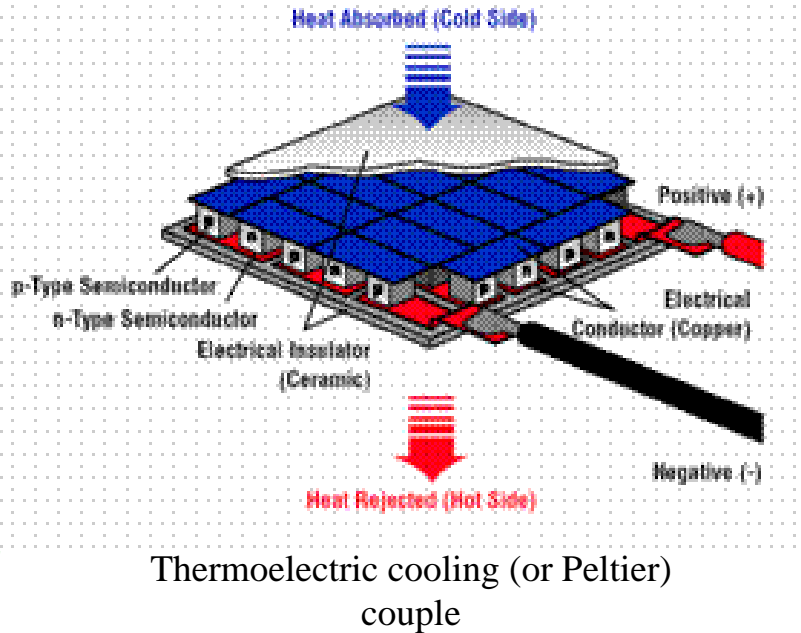
Systems are commercially available in niche sectors, up to 300 W cooling. Values of *COP* between 2 and 3 have been reported for cold head temperatures around 0° C, and values around 1 for cold head temperatures approaching -40° C

## Applications

Can operate down to cryogenic temperatures and hence can be used in many food refrigeration applications.

Most likely market for FPSCs in the food sector is domestic and portable refrigerators and freezers, can vending machines and other integral refrigerated display equipment.

# Thermoelectric Refrigeration



## Applications in the food sector

- Hotel room, mobile home, recreational vehicles and cars; portable picnic coolers; wine coolers; beverage can coolers; drinking water coolers.
- Potential applications include domestic and commercial refrigerators and freezers, and mobile refrigeration and air conditioning.

## State of development

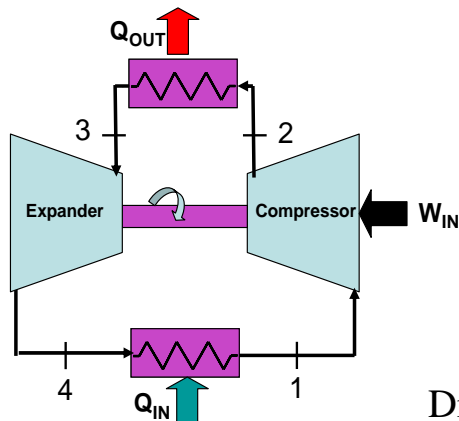
- Thermoelectric modules are available commercially with maximum cooling capacities up to 200 W and COP around 0.6 at 0°C cooling temperature.
- Interface with heat exchange systems to facilitate heat transfer adversely influences COP.



# Air Cycle Technology

## State of development

- Air is used as the working fluid.
- Reasonably well established technology.
- Closed and open air cycle systems have been developed with refrigeration capacities ranging from 11 to 700 kW.
- Current R&D on transport refrigeration (QUB) and integrated heating and cooling (Bristol funded by Defra)



## Application in the food sector

- Rapid chilling and/or freezing (including air blast, tunnel, spiral, fluidised bed and rotary tumble equipment);
- Refrigerated transport (trucks, containers, rail freight, ships)
- Integrated heating and cooling

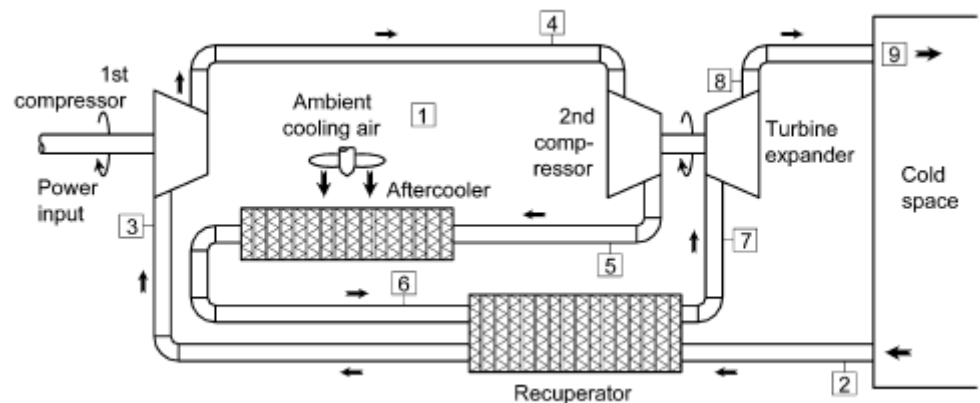
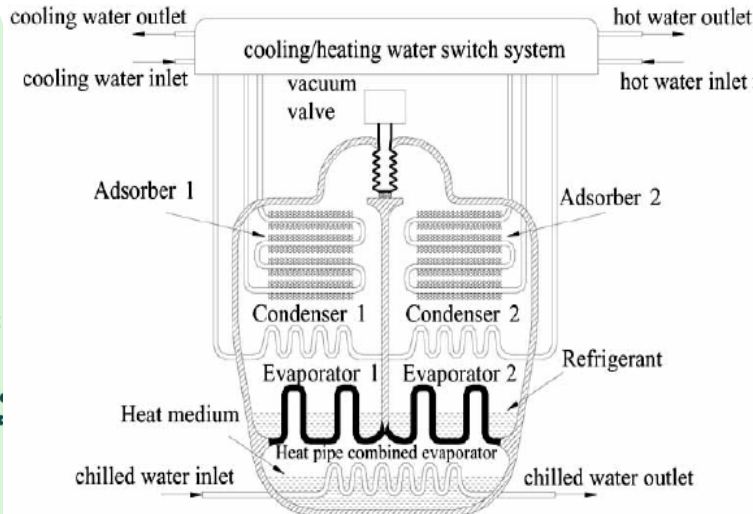


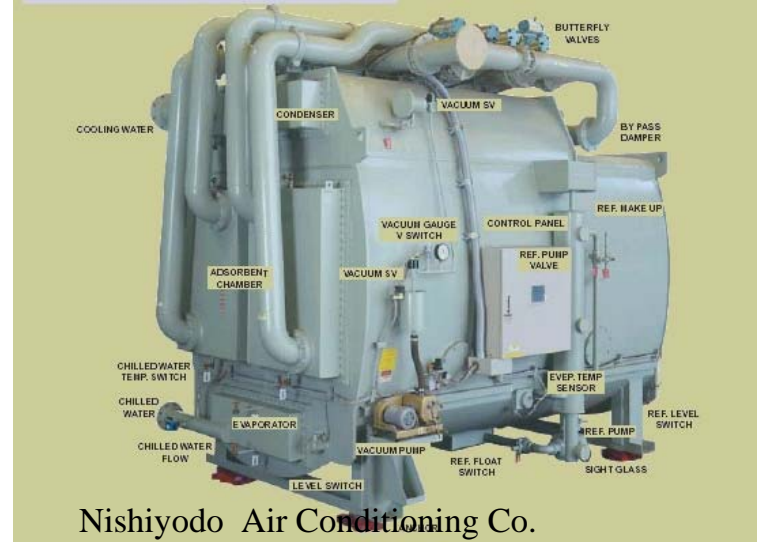
Diagram of Air Cycle (Spence et.al., 2005)

# Sorption Technologies - Adsorption



Schematic Diagram of Adsorption chiller  
(Wang, 2006)

## GENERAL ARRANGEMENT



Nishiyodo Air Conditioning Co.

## State of development

- Already available for air conditioning applications 35 to 300 kW capable of being driven by low grade heat 50° C to 90 ° C and able to give COPs of around 0.7. at temp. above 0°C
- R&D on development of systems for refrigeration applications.

## Applications in the food sector

- Applications in the food sector will be primarily in areas where waste heat is available to drive the adsorption system.
- Such applications can be found in food factories, transport refrigeration.
- Use with CHP systems for tri-generation (Weatherite in UK)

# Tri-generation

Potential for energy and GHG emissions savings

## State of development

- Progress in power systems (ICs, microturbines, fuel cells)
- Heat recovery systems
- Design and controls

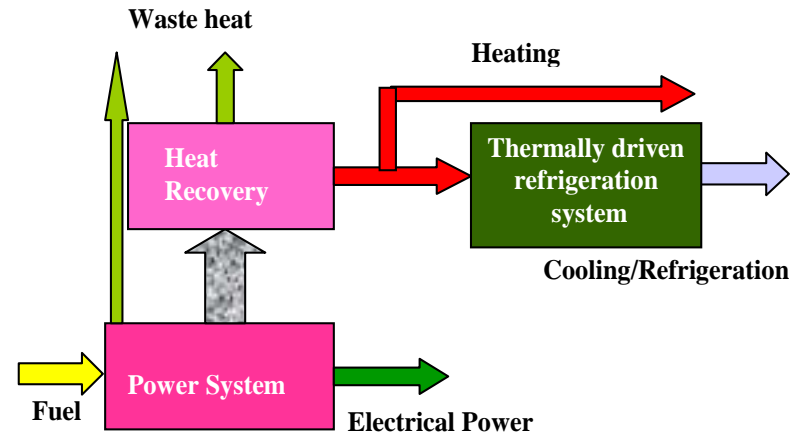
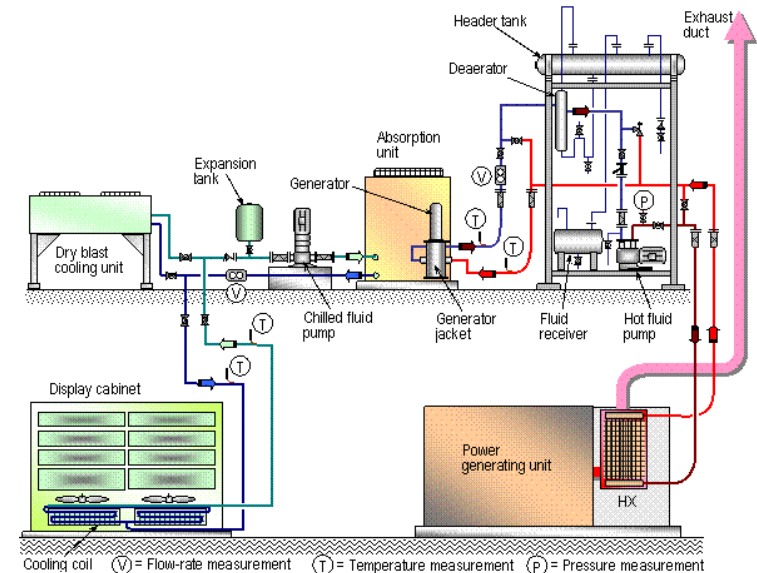


Figure 1. Schematic of a tri-generation system

## Application in the food sector

- Large food manufacturing facilities for many years
- More recently in supermarkets for HVAC applications
- Potential for the use of biofuels (food manufacturing facilities, supermarkets and RDCs)



Experimental measurement facilities at Brunel University

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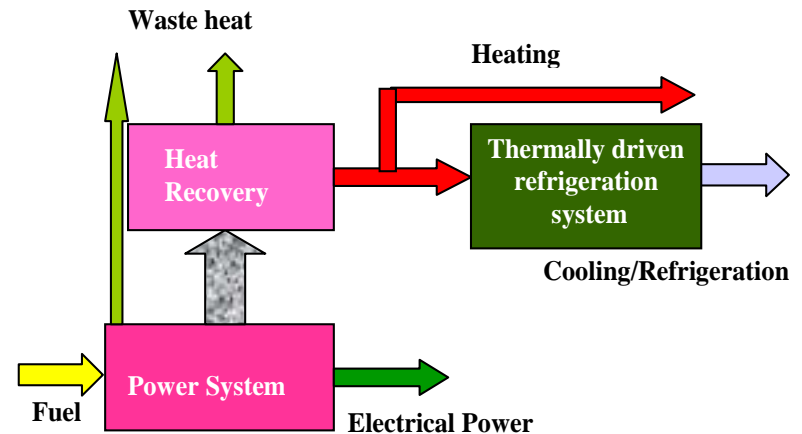
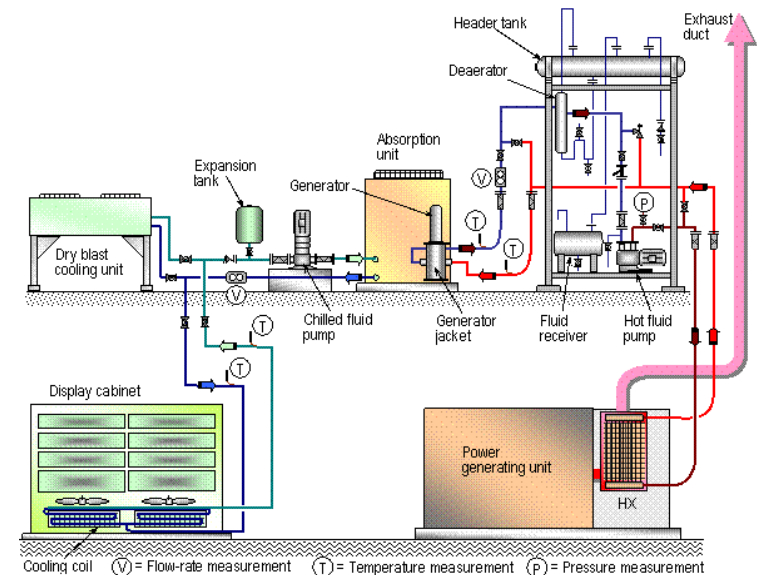


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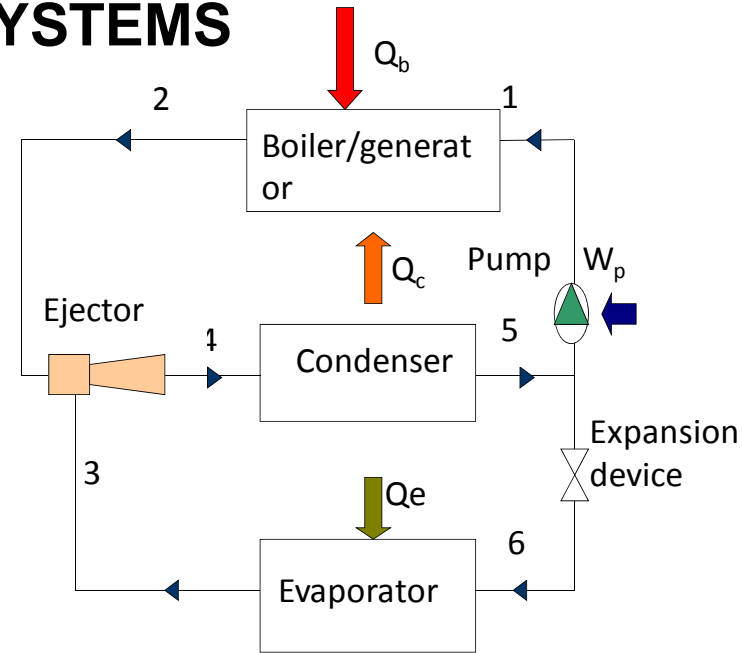
Experimental measurement facilities at Brunel University

# EJECTOR REFRIGERATION SYSTEMS

- Ejector or jet pump refrigeration is a thermally driven technology that has been used for cooling applications for many years.
- Systems have been developed with cooling capacities ranging from a few KW to 60,000 kW , COP less than 0.2.
- Not presently commercially available off the shelf. Bespoke systems using water as a refrigerant above 0 °C.

## Applications in the food sector

- Where waste heat is available to drive the ejector system.
- Food processing factories for product and process cooling and transport refrigeration.
- Other possible application is in tri-generation where the ejector refrigeration system can be used in conjunction with combined heat and power systems to provide cooling



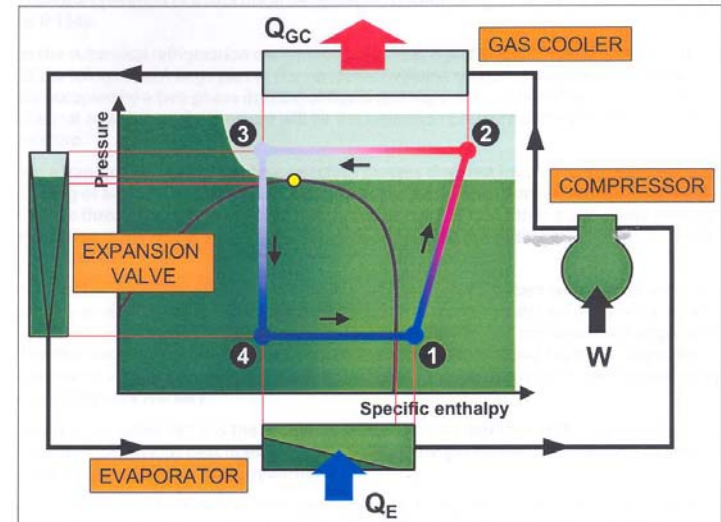
Mayekawa cooling system - prototype

# CO<sub>2</sub> refrigeration systems

- Natural refrigerant
- High pressures compared to HFCs and ammonia
- Potential for energy and GHG emissions savings

## State of Development

- Becoming established in Scandinavia, and Northern Europe.
- Different system arrangements – Cascade, Transcritical, booster etc
- Increasing no. of systems being installed in the UK



Transcritical operation  
(Courtesy Knudsen)



CO<sub>2</sub> pack  
(Courtesy Linde)

# Systems for the Future

## System Selection Considerations

- Capital cost
- Operating/running cost
- Maintenance costs

All above (Life Cycle Costs)

- Environmental Considerations (GHG Emissions, noise, vibration etc)
- Physical footprint
- Legislation
- Reliability



# Food processing

## Current/conventional technology

- Vapour compression – R717, R22, R404A

## Energy saving measures

- Head pressure control
- Multi-compressor on-off control and/or compressor variable speed control
- Evaporative cooling
- Liquid pressure amplification
- Condenser heat recovery
- Condenser heat upgrade using heat pumps.

## Alternative technologies

- CO<sub>2</sub> systems and CO<sub>2</sub> /R717 cascade systems
- Air cycle technology for low temperatures and combined heating and cooling
- Waste heat recovery for refrigeration (sorption systems) and power generation (thermoelectric, Stirling, thermoacoustic, turbo-generators; ejector refrigeration)
- Tri-generation (use of biofuels)



# Supermarkets

## Current/conventional technology

- Remote multi-compressor refrigeration packs – R404A refrigerant.
- Most new systems use head pressure control.

## Energy conservation measures

- Suction pressure control
- Variable speed on one compressor
- ECM motor condenser and cabinet fans
- Defrost on demand
- Evaporative cooling
- Liquid Pressure Amplification

## Alternative technologies

- CO<sub>2</sub> systems (different system configurations for UK being investigated)
- Thermal integration (heat recovery and Tri-generation)
- Ground cooling
- Renewed interest in secondary refrigerants

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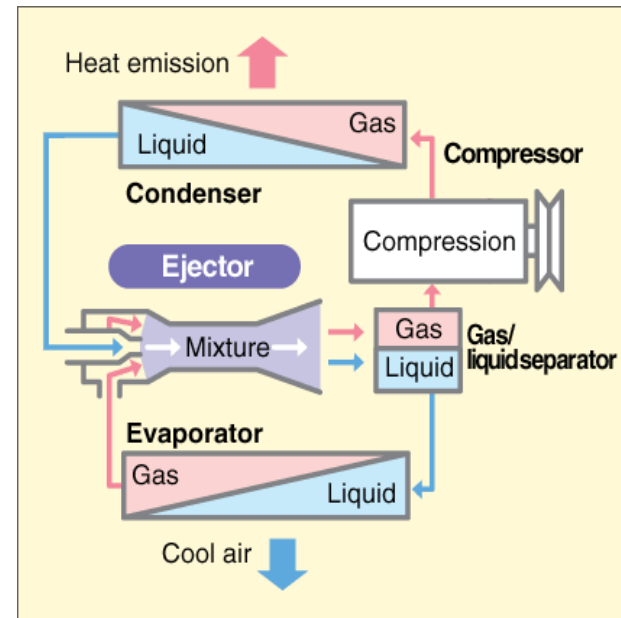
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# Transport Refrigeration

- PCM thermal storage (charge at base – RDC; also ice slurry?)
- Improved vapour compression systems-ejector?
- Total loss systems – Liquid CO<sub>2</sub> (receiving increasing attention)
- Air cycle
- Hybrid and solar driven systems
- Utilise thermal energy in engine exhaust (sorption refrigeration systems, power generation, thermoacoustic )



Denso ejector system

## Integral refrigeration systems (cabinets)

- HC and CO<sub>2</sub> refrigerants
- Thermoelectric cooling
- Stirling cycle cooling
- Thermoacoustic
- Magnetic refrigeration

## Food Storage (cold stores)

- Biomass – sorption refrigeration systems
- Biomass – tri-generation
- CO<sub>2</sub> and CO<sub>2</sub>/R717 cascade systems
- Use of solar wind to generate electricity/heat to drive vapour compression/sorption systems