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Absorption cooling

Technical Investigation of Absorption Cooling
For Northern Ireland

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MANAGEMENT SUMMARY AND OVERVIEW

It is clear from research, and from known examples, that absorption chilling offers an improved degree of energy and environmental sustainability in some, if not many applications.

Absorption and adsorption technologies are advanced, proven and adaptable technologies. However, the flexibility and effciency of vapour compression chilling and the relatively small allied cost continues to provide effective competition – even when there are obvious carbon benefits. Despite this, the integration of absorption chiller and heat pump technology with waste heat recovery, CHP and biomass can, and is beginning to offer significantly improved energy efficiency, reduced carbon footprint and life cycle cost saving.

The UK has become a net energy importer and there is increasing risk for the UK security of energy supply, balance of payments and economic well being. The national balance of payments deficit has grown steadily over the last 10 years. Reducing supplies of oil and the import of gas from, and/or through, politically unstable or unfriendly countries poses a big risk for the UK. The role of biomass cannot be certain – for biomass just simply cannot replace the amount of fossil fuels that that the UK consumes. The challenge is to persuade insustry in the UK and particularly in Northern Ireland to plan for their energy futures or indeed simply plan to survive.

The mass production of vapour compression refrigeration (VCR) has resulted in the relatively low capital costs. This relatively low cost, coupled with the versatility and flexibility of the VCR, has ensured that VCR was the preferred solution in the UK where electrical costs have traditionally been low. Until such mass production prevails in the absorption markets, the "trade-off" will be that of capital cost against operational cost saving.

There are three basic types of absorption refrigeration cycle;

- The adsorption cycle
- The lithium bromide cycle (LiBr)
- The Ammonia absorption or Ammonia Aqua refrigeration Cycle (AAR)

The adsorption and lithium bromide cycles are suitable for higher evaporation temperatures and are limited to the evaporation temperature of water at reduced ambient pressure. Thus these systems are limited to evaporation temperatures of 3°C to 4°C. The adsorption cycle may also be used as an open cycle to effect dehumidification. Research and experimentation continues into advanced adsorption pairings for reduced evaporation temperature and enhanced operational performance.

Lithium Bromide (LiBr) designs can operate with low generator temperatures and are therefore ideal for waste heat recovery, CHP and other low grade temperature sources. The single stage LiBr plant generally operates with a low COP (Coefficient of performance) but this can be significantly improved with higher grade generator heat sources. However the same limitation is posed for the evaporating refrigerant is water and the LiBr system is suitable for higher evaporation temperatures e.g. temperatures of 3°C or 4°C.

LiBr and water/silica gel systems are therefore predominantly suited to air handling, or chilled water designs. To achieve evaporation temperatures of 3°C or 4°C in the LiBr system, water is evaporated under vaccum and the pressure vessels/shell rEquired add weight and cost. However other refrigerants are also suited for the absorption cycle.

Ammonia boils at –30°C under atmospheric conditions and has a strong affinity for water. In the Ammonia Absorption System (AAR system) the water is the absorbent and not the refrigerant. The properties of ammonia allow a very large range of evaporation temperature with temeratures as low as 30°C being readily achieved. AAR requires a higher temperature generator source and is therefore suited to high grade waste heat and steam applications. The specific cost of AAR increases gradually with lower evaporation temperature. However, the cost of va[pour compression also increases and COP reduces, rapidly with lower evaporation temperature, and thus there is increasing advantage for ammonia absorption over vapour compression at lower evaporation temperatures.

Exhaust gas temperatures, waste steam perhaps, or in fact any heat source at, or above, 160°C is, in most circumstances, hot enough to allow evaporator operations to –40°C. However more recent designs can make use of multiple heat sources and operate over a range of generator temperatures.

Ammonia is treated as a toxic chemical. Releases of ammonia are controlled under the UK Pollution Prevention and Control (PPC) Regulations 2000, which implement the EC Directive 96/61 on Integrated Pollution Prevention and Control. Its release to water is regulated under the are the 'Surface Waters (Dangerous Substances) (Classification) Regulations, 1997 (SI 1997/2560). However, and to put this in perspective, Ammonia is also one of the largest commodity chemicals in the world, with annual production of more than 100 million tons. Worldwide it is the most commonly used refrigerant as R717 in both VCR and AAR systems.

The application potential for AAR and LiBr is very broad and includes:

- CHP engines
- CHP turbines
- FurnaceS
- Drying ovens
- Biomass systems
- Wate to energy incinerators
- Boiler exhausts
- process streams
- Geothermal heat (Ground source heat pumps)

The Northern Irish economy has several key sectors that have, or make extensive use of, cooling and refrigeration. These include the food and drinks industries, Health care, Hospitality Rubber and plastics, Pharmaceutical manufacturing and Government estate. In some manufacturing sectors the sector may actually only be comprised of a few key companies. In the food and drink sector, for example, and particularly in the meat and dairy subsectors there are a small number of very large energy consumers where there is significant potential for the utilisation of absorption chilling.

In the Hospitality Sector and Government estate the principal need is for AHU and higher evaporation temnperatures. The technology is virtually "off the shelf" with larger manufacturers producing LiBr at all sizes from direct gas fired units to those designed for CHP integration.

It is unlikely that retrofitted solar cooling systems will be economic for some considerable time. However the integration of solar collection, hot water heating and the boosted opeation of absorption chilled systems will increasingly and necessarily be adopted in new construction – more so in southerly latitudes but there is a role in UK and Northern Ireland.

In at least one case absorption chilling coupled with biomass is currently being pursued in Northern Ireland and there are examples of such technology integration elsewhere in the UK. However, the limited quantities of biomass fuel available make this an apparently higher risk strategy for the larger companies. Moreover, conventional financial assessments will generally show absorption chilling to be less commercially attractive. However, life cycle cost analysis would apparently favour absorption systems. Much of the food and drink sector requires evaporation temperatures well below that achievable with LiBr and thus the use of the more expensive Ammonia systems is necessary if absorption option is to be pursued. However, the importance of Hybrid Libr and AAR systems should not be overlooked for in many cases, particulary the dairy industry such hybrid systems are possible and routinely employed in other parts of the world.

There are disadvantages to absorption cooling, not least the current relatively high capital cost. Absorption chilling is not nearly as responsive and flexible as vapour compression plant and it is of much larger relative size and weight which can pose technical issue in some circumstances. The design has therefore to be considered carefully and the concepts of hybrid AAR,LibR and vapour compression must fully established in every case. Despite the economic disadvantage resulting from increased capital cost, the life cycle costs can be demonstrably lower. Looking to the future, even small increases in utility costs e.g. 20% will provide a significant improvement to the case for absorption in many circumstances.

Absorption chilling has the potential to significantly reduce energy consumption, cost and carbon impact and may well become an economic necessity for many companies into the future.

The adoption of Absorption chilling requires a strategic approach to procurement and investment decision. As previously suggested, the challenge is to persuade insustry in Northern Ireland to plan for their energy survival.

There are three significant barriers to development in the Northern Irish Market.

- **Availability** - Currently Ammonia absorption is not widely available in the UK. It is used in many other parts of the world including India and the USA, but manufacturers are wary of the established UK Vapour compression market and the extent of European regulation.

- **Knowledge** - There is little knowledge or understanding of absorption chilling tehnology in industry. A generation of cheap fuel and power prices has resulted in a generation of engineeers, plant managers facilities engineers who are familiar and comfortable with compressors and the operation of standby power to serve these units at peak power times.

- **Capital** - The capital cost is significantly higher than that of vapour compression chilling. The life cycle cost advantages and the other benefits of absporption chilling are just not understood in the UK and Northern Irish markets.

INI have for some time engaged in the process of Technology Transfer. The benefit of “seeing is believing” having been proven, not least in the adoption of biomass and now current WtE developments.

In short summary there is an increasingly good case for Absorption chilling.

1. THE UK ECONOMY AND THE CONTEXT OF THIS STUDY

1.1. Introduction

The UK was, until recently, largely self-sufficient (at least in terms of net traded goods) in terms of Energy. However this situation has changed significantly with the UK becoming a net importer of coal, oil and gas. The UK has consistently imported more gas than it has exported year on year since 2004, with indigenous production peaking in 2000 and falling ever since.[1]

In the last decade, industrial consumption has generally declined in the UK - reflecting the reduction in industrial base and a move to service sector based economy rather than energy efficiency. Whilst there has been a slight fall in annual total primary fuel consumption the very significant changes in import levels pose an increasing problem for cost management and security of supply - particularly so for Northern Ireland.

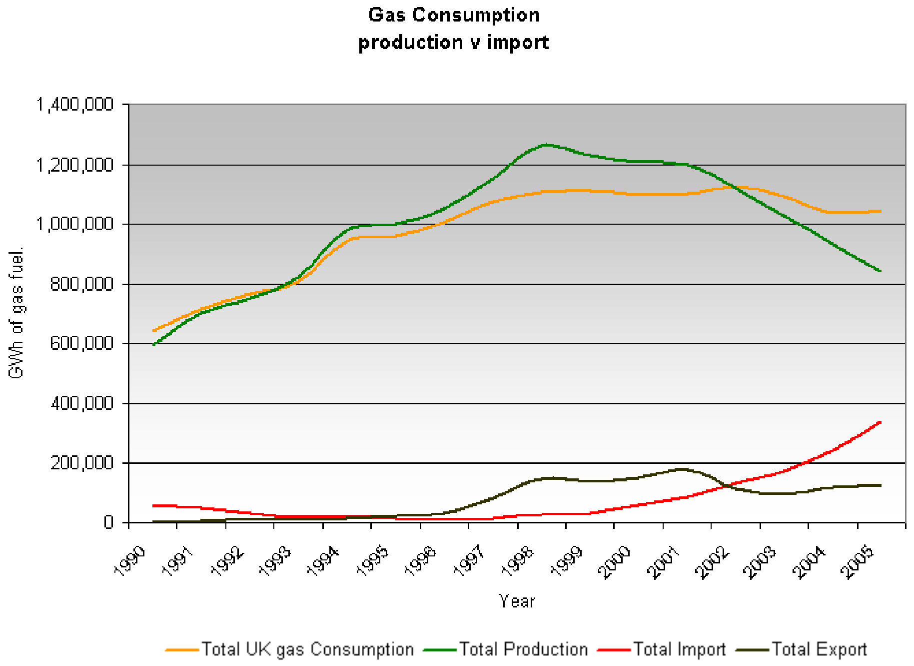

Figure 1 UK Gas Import/Exports

The impact of becoming a net importer of energy may not be immediately apparent, however the medium and long term consequences when considered in the context of a shift in economic base from goods and manufacturing to services, may present very great economic difficulty unless firm and decisive action is taken to deal with the UK's reliance on energy imports.

As exports fuels and goods decline and the import of these increases, the net effect is a rapidly increasing trade deficit and unacceptably high trade

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[1] Reference BERR

deficit. The current account deficit has been revised to £45.0 billion from £50.7 billion in 2006 and to £52.6 billion from £59.7 billion in 2007[2]

Beyond the current recession, energy supplies will become increasingly expensive and are being supplied from distant location by (or through) countries with unstable or unfriendy political or religious regime. Security of supply has very significant bearing on the UK's economic well being.

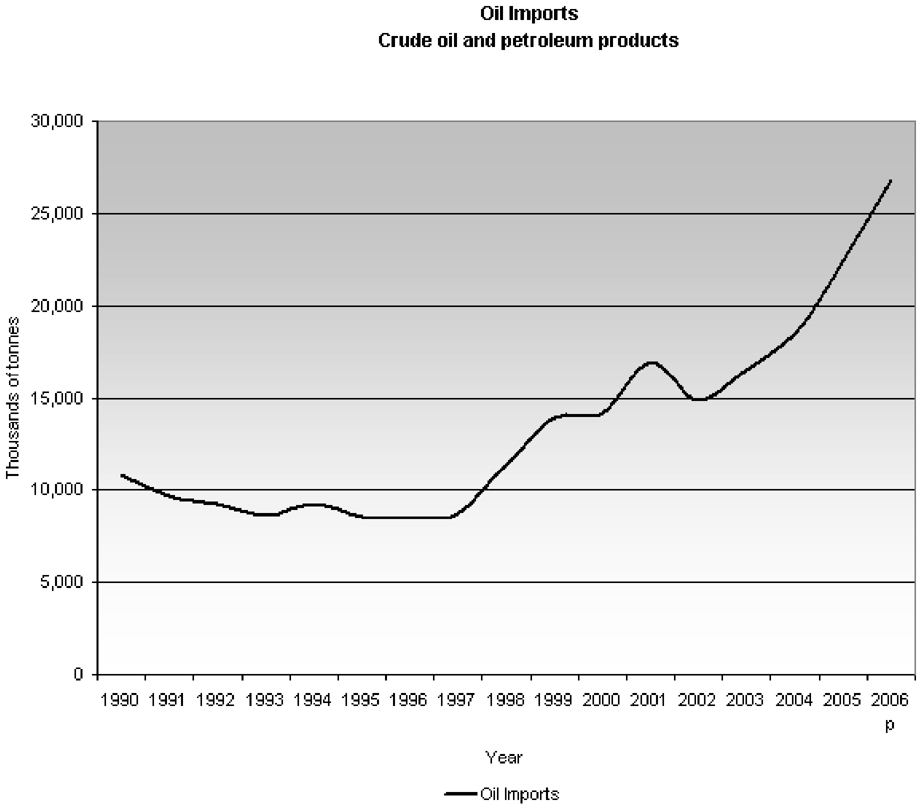

Figure 2 UK Oil Imports

A fundamental precept of the UK economy is a reliance on economic growth. An economy in recession (reduced or declining economic growth) will recover if the energy needs for the associated increased economic activity and trade can be met reliably and cost effectively. The shift in economic base, and the cumulative impact of net energy import may eventually have a devastating effect.

In light of the changes to the UK's economic base and the need for energy import, increasingly drastic solutions will be required. There is not one solution (there may be no complete solution) and it is most likely that a number of measures will be necessarily adopted into the future. This report is not intended to address these solutions or any prevailing Government's Strategy, however energy efficiency or conservation has a singularly vital role to play in reducing the rate of the UK's economic decline.

Biomass has an important role to play in the future but the current optimism for biomass is largely misplaced for generally speaking 1 hectare

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[2] Reference : Economic & Labour Market Review | Vol 2 | No 10 | October 2008, Office for National Statistics

of land will produce approximately 10 tonnes of oven dried biomass or approximately 4,500litres of fuel oil per annum (enough to energy to run a couple of family sized cars for one year). There are no miracle solutions as yet. Biomass is therefore of limited sustainability.

Of great concern at least in the UK is the failure to realise fully the potential to burn non-recyclable waste fractions for the generation of heat and power. A combination of EU legislation, the interpretation of that legislation in the UK, excessive bureaucracy, and the public mistrust borne from a legacy of poorly regulated incineration in the UK – has hampered the development of waste to energy in the UK. The culture of prosecution and litigation in part borne out of UK Health and Safety legislation has arguably increased the cost and diminished the capacity for entrepreneurial engineering innovation in the UK.

Change is inevitable. The UK and industry within the UK must embrace the concept of sustainability – "living within our energy means". The need to change will require bold and rapid action on the part of Government and Industry. Prevarication will simply require a more abrupt and painful change.

This study looks at the role of Absorption cooling within the context of Northern Irish Industry and this need for change. Absorption cooling is a well-established cooling technology that was historically marginalized by the efficiency, cost and flexibility and general convenience of electrically powered vapour compression cooling plant.

Absorption cooling plant is not common in the UK but prevalent in hotter and historically poorer countries. The urgent need to utilise waste heat, biomass, waste to energy, solar energy, and other currently wasted resources has resulted in the development and increasing and innovative use of the absorption technology. This study considers the technology, the economics and the role of absorption chilling within Northern Ireland.

2. VAPOUR COMPRESSION COOLING TECHNOLOGY

2.1. Introduction

Refrigeration is essentially a process of heat removal and or the process of maintaining a space or a material at a temperature below that of the surrounds. Heat will always migrate from hot to cold and that process of heat transfer (initially conduction and radiation) is mitigated by using materials of low thermal conductivity e.g. thermal insulation.

The evaporation of a refrigerant (phase change) is endothermic, absorbing energy from the system surrounding the evaporating refrigerant; - causing the change in energy content that will allow phase change. This process occurs at constant temperature, but the removal of heat from the system surrounding the refrigerant causes the temperature of that system to drop towards the refrigerant evaporation temperature.

The ability to absorb large quantities of heat and evaporate at low temperature are the principal requirement of a refrigerant.

The work done in cooling is defined in different ways. Historically refrigeration was generally used to produce ice for food storage and the capacity of a refrigeration system was more often than not, related to the tons of ice that the plant could produce in 24hrs or "tons of refrigeration". The terminology, still commonly used today, related to the capacity to freeze one short ton (2,000lbs) of water requiring 12,000Btu/h or 3.517 kW heat removal. Where tonnes are refernced a metric tonne equates to 13,954 kJ/h = 3.876 kW.

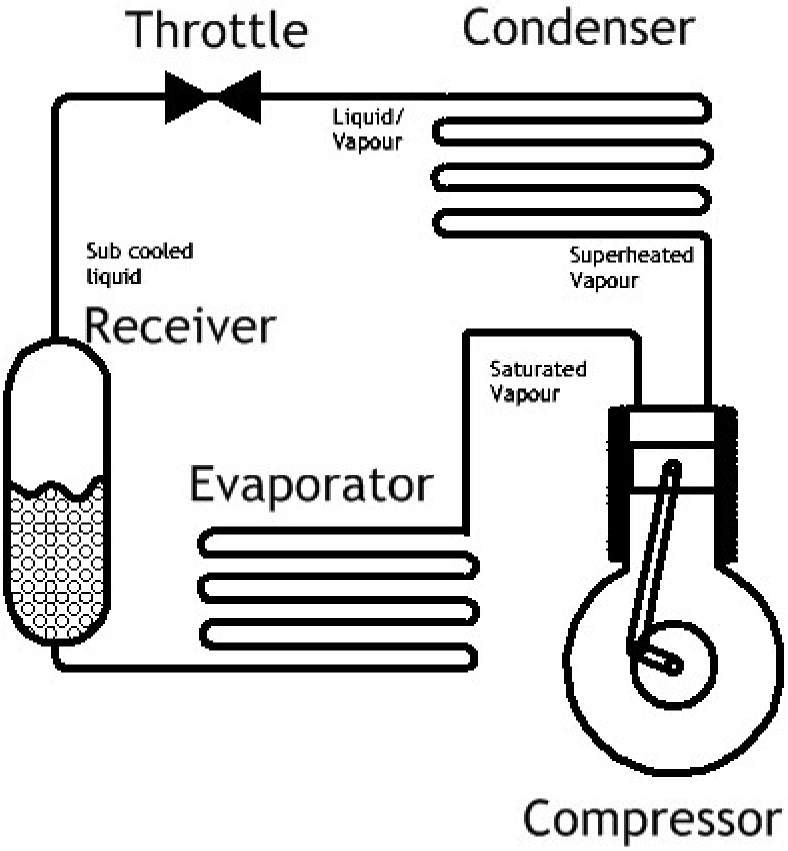
2.2. Vapour compression refrigeration

2.2.1. The vapour compression cycle

Vapour compression chilling is the refrigeration system of choice in the UK. From the smallest novelty drinks chiller to the largest industrial refrigeration plant is likely that the plant is a mechanically driven vapour compression plant. In the UK the motive force is generally electrical –there are very few applications with direct engine or turbine driven compressors.

A typical Vapour compression system is illustrated below.

Figure 3 Vapour Compression Cycle



Refrigerant, a depressed boiling point fluid is circulated as a liquid within the evaporator. Heat transferred from the refrigerated space warms the liquid refrigerant within the evaporator and the liquid evaporates as a gas within the evaporator at low pressure.

The low pressure evaporate is transferred via the suction line to a compressor. The illustration shows a reciprocating compressor but in practice this may be a screw, vane, lobe or centrifugal compressor. The refrigerant is compressed very quickly in the compressor to an elevated temperature and pressure.

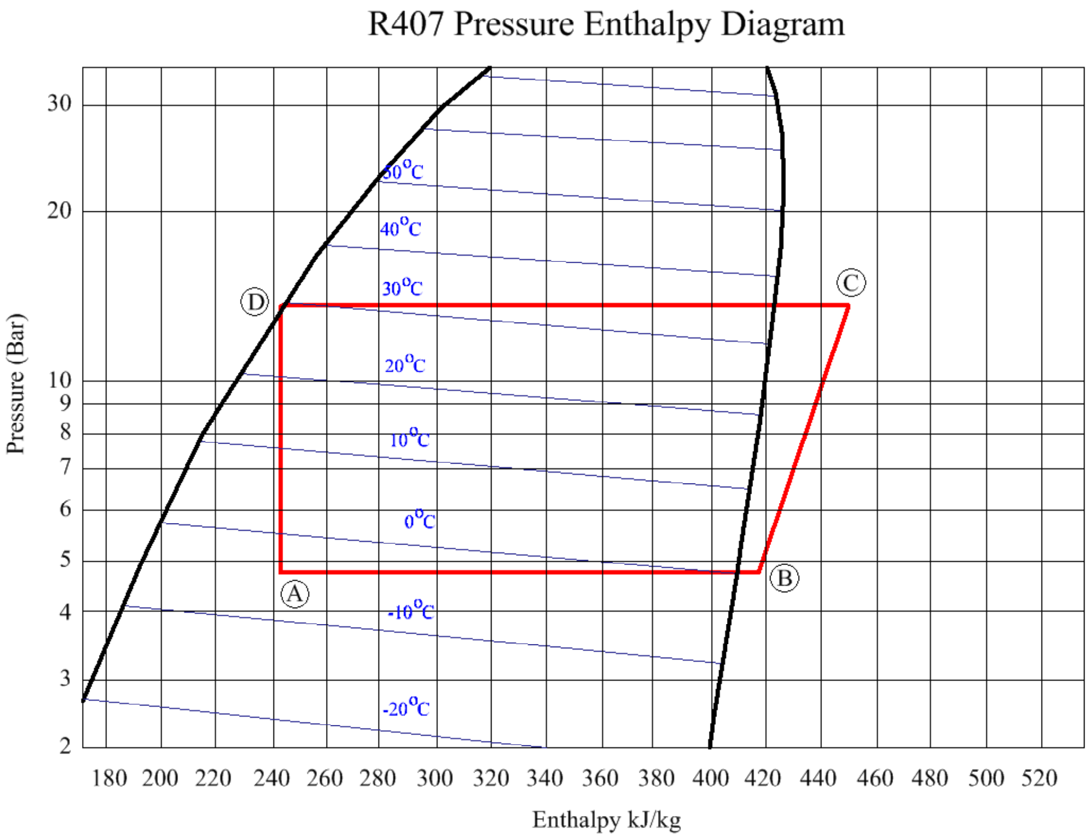


Figure 4 Vapour cycle (Example Pressure v Enthalpy)

The hot and relatively high-pressure gas is delivered to the condenser (a heat exchange matrix) usually compatible with air or water-cooled condensing temperatures that can be achieved with natural or forced convection and ambient air or water temperatures. In specialist applications evaporative water-cooling might be employed

The condenser rejects heat from the hot gaseous refrigerant causing the gas to condense. The heat rejected is the heat absorbed from the refrigeration process, the work or energy added by the compression process and the energy gained by the fluid from the system or surrounds when at low temperature.

Typically, the condensed refrigerant will be routed and stored in a receiver and delivered to evaporator by a liquid line.

Because the evaporation takes place at relatively low temperature and pressure and the condensation at higher temperature and pressure, a pressure differential must be maintained in the system. On the one hand the compressor generates a pressure differential but this has to be retained by a flow control mechanism that regulates the flow of refrigerant to the evaporator and reduces the pressure from the relatively high condenser pressure to the relatively low evaporator pressure.

In the diagram above the liquid refrigerant is evaporated from A to B and the enthalpy increases.

The gaseous evaporate is compressed from B to C. The pressure and temperature increase significantly. The enthalpy increases.

The gaseous refrigerant is condensed from C to D and the differential pressure across the system is maintained by a throttle or flow-metering device, where the pressure is dropped from D to A.

2.2.2. The operational cycle and performance constraints

Vapour compression chillers all operate in fundamentally the same way. The preceding section 2.2.1 provides a brief explanation. The vapour compression chiller has become the plant of choice because the plant is generally:

- Of low capital cost
- Is sufficiently flexible to meet variable and intermittent loads
- May be easily designed for low evaporation temperatures
- Is physically small
- Is very efficient
- Can be operated as a refrigeration cycle or heat pump
- Is relatively easy to maintain

The versatility of modern refrigerants allows very low evaporation temperatures of -30^{o}C or less to be achieved thus allowing blast freezing and similar very low temperature applications to be easily achieved. The process of compression and subsequent expansion can be achieved at typically up to 60% of the theoretical thermodynamic Carnot Efficiency between evaporation temperatures of -20^{o}C and condensing temperatures of up to 50^{o}C.

The principal benefit is the relatively large cooling effect that can be achieved for an apparently small power input. Examining **Figure 4** (refer 2.2.1), the enthalpy change required between B to C is relatively small (450 kJ/kg –419kJ/kg) e.g. 31kJ/kg. This energy is imparted by compression and requires the addition of external energy by way of the refrigeration compressor. However the work done in the evaporator (A to B), (419 kJ/kg -242 kJ/kg) represents a much greater value e.g. 177 kJ/kg. Thus for every kg of circulated refrigerant the motor has to provide a power input of 31kJ/kg but the cooling effect is 177 kJ/kg.

The ratio of cooling power to compression power is termed the coefficient of performance and for the loss free example cycle illustrated would be 5.7. In practice the compression is never without loss, there are heat gains to and from the pipework, friction losses and other thermodynamic imperfections that reduce the effective COP. Notwithstanding and depending on the application, equipment and evaporation and condensing temperatures COP of over 4 can sometimes be achieved.

In most circumstances an operating coefficient of system performance or COSP of 2.5-3.5 is more likely.

On first inspection the application of a relatively small amount of electrical energy generates a relatively large cooling effect. However the electrical power consumption does not reflect the primary energy consumption and carbon production.

The COP in terms of primary energy for a typical vapour compression plant will actually be 1.05 to 1.22.

2.2.3. The vapour compression refrigerants a legal perspective[3]

Vapour compression has been widely adopted with good reason. However it was discovered that many of the refrigerants which offered excellent thermodynamic properties, also had ozone-depleting properties and were linked to atmospheric damage and climate change

The refrigerant selected for any specific application must have a boiling point below that of the required refrigeration temperature, so that it absorbs heat in evaporation right down to the desired temperature with a margin to drive heat transfer. The boiling point of the refrigerant can be artificially depressed by reducing the evaporator pressure.

Ideally the refrigerant will posses a large heat of evaporation (the heat input required to change the phase from liquid to gas) thus improving temperature reduction and reducing the required refrigerant flow.

The refrigerant must furthermore be non corrosive to the system componenets and there is a health and safety issue to consider. If the refrigerant is toxic then a leakage cannot be tolerated. The issues associated with Ammonia are addressed specifically elsewhere in this study.

Virtually any fluid could be made to act as a refrigerant depending on the circumstances and the applied pressure regime. The use of vapour compression refrigerants is subject to increasing legislation and this is entirely relevant to the study and consideration of absorption chilling for many companies will be forced to replace plant imminently. This appears to be particularly true in Northern Ireland where R22 is routinely used.

The design, application and safe use of all refrigerant-based systems, is covered by BS EN378. Specification for refrigerating systems and heat pumps, Safety and environmental requirements. Basic requirements, definitions, classification and selection criteria *et seq.*

CFC refrigerants were commonly used because they were safe and stable and exhibeted the themodynamic properties required of a refrigerant. However it was established that if these refrigerants were released to atmosphere they decomposed under UV radiation and the chlorine molecules released catalysed the chemical breakdown of Ozone in the upper atmosphere. Ozone shields the Earth and lower atmosphere from strong UV radiation.

Initially replaced with HCFC groups of refrigerants, these also have been found to be environmentally damaging and have in turn generally been replaced with HFC (Hydrofluorcatbon refrigerants). However these also have significant Global Warming potential and are subject to much tighter regulation as is described below.

CFC groups (Chlorinated Flurocarbons)

The most commonly used refrigerants are (were) until recently combinations of chlorinated hydrocarbons e.g. R11, R12 (CFC freon 12),

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[3] Reference REFRIGERATION & AIR CONDITIONING CFC and HCFC Phase Out. BERR

and R502. The ban upon the import or production of CFCs within the European Union (EU) came into effect on 1 January 1995.

All plant containing CFC should have been replaced by 2000.

HCFC and Blends

EU Regulation 2037/2000 on ozone depleting substances came into force in 2000 and has already banned the use of ozone depleting HCFC refrigerants such as R22 in new systems.

The use of HCFCs (including R22) in new refrigeration systems was banned between 2000 and 2004 depending on the application. – for large industrial equipment the ban started by January 2001. All existing R22 refrigeration plant currently in use is therefore eight years old.

The phased banning of HCFC should have eliminated the use of all HCFC reliant products completely by 2025, However in addition to the complete ban currently applying to new plant the phase out of virgin HCFCs at the end of 2009 could have significant implications for many food and drink manufacturers. Recycled HCFC will be banned shortly thereafter. R22 systems operators (common for large chillers in the food industry) will now have to consider alternate refrigerant charges and or new plant imminently. Moreover the obligations placed on operators in terms of monitoring and disposal is most onerous

HFC and Blends (Hydrofluorocarbons)

HFC were specifically developed as an alternative for the CFC and HCFC groups. In some cases bing used in the same equipment as alternate gas charge.

In the EU, The F-gas Regulation No 842/2006 is intended to reduce emissions of HFC/PFC based refrigerants e.g. R134a, R404, and R407. The Regulation became law on 4 July 2006 and imposed obligations on "operators" of this equipment from 4 July 2007.

The regulations obligate the operator (the owner in almost all circumstances) to use best practical means to prevent leakage, to monitor leakage and for larger systems to install automatic monitoring equipment.

It is a criminal offence to release refrigerants to atmosphere. The use of HFC refrigerants and the disposal of the refrigerant and plant-containing refrigerant are controlled. Refrigerant must be reclaimed or recovered by only certified personnelfor re-use, recycling or controlled destruction. Only certified maintenance personnel may work on or carryout monitoring on the plant.

Alternate refrigerants

HC (Hydrocarbons)

Hydrocarbons, e.g. propane (**R290)** may in some circumstances be used as a refrigerant. Propane has similar properties to R22 but has reduced Ozone depleting potential and relatively low global warming potential. However Propane (LPG) is extremely flammable so there is the obvious risk of fire and or explosion. Straight substitution is not typically possible and consideration must be given to the ATEX[4] requirements for safe operation.

Ammonia

Ammonia is routinely and successfully used for larger refrigeration plant worldwide. Ammonia is also used for absorption chilling plant. Ammonia is also one of the largest commodity chemicals in the world, with annual production of more than 100 million tons. Worldwide it is the most commonly used refrigerant as R717 in both VCR and AAR systems.

Ammonia liquid and gas are both toxic and dangerous and consequently utilisation may require complete plant redesign to take account of health and safety. Releases of ammonia are controlled under the UK Pollution Prevention and Control (PPC) Regulations 2000, which implement the EC Directive 96/61 on Integrated Pollution Prevention and Control. Its release to water is regulated under the are the 'Surface Waters (Dangerous Substances) (Classification) Regulations, 1997 (SI 1997/2560).

Ammonia gas dissolves easily in water to form ammonium hydroxide, a caustic solution and is corrosive. The maintenance of ammonia plant is generally more troublesome.

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[4] the ATEX 95 *equipment* directive 94/9/EC, Equipment and protective systems intended for use in potentially explosive atmospheres;

the ATEX 137 *workplace* directive 99/92/EC, Minimum requirements for improving the safety and health protection of workers potentially at risk

3. ABSORPTION AND ADSORPTION COOLING

3.1. Introduction

Absorption and adsorption cooling offer different combinations of thermodynamic, and chemically or physically driven cycles as alternates to the Carnot vapour compression cycle.

The process of evaporation and the heat of evaporation remain as the principal cooling mechanism but the evaporation is driven by either a chemical or physical attraction rather than the application of external motive power.

The absorption and adsorption processes are similar, relatively simple and function well in colder climates.

The advantages of these cycles can be summarised as follows:

- The Process is simple and reliable
- Can be operated as a refrigeration cycle or heat pump (specific cases)
- Is relatively easy to maintain
- Extremely low operational costs
- Can be operated on waste heat
- Using heat instead of electricity reduces CO_2 - emissions
- Can be operated to –30°C (or lower) evaporation temperature (media specific)
- Use readily available low cost refrigerants.

The disadvantages are

- Larger capital cost
- Reduced flexibility
- Lower evaporation temperatures can only be achieved with loss of COP
- Is physically much larger than compression plant

This section of the report explains the operation of adsorption and absorption plant

3.2. The difference between adsorption and absorption

Adsorption is the process that occurs when a gas or liquid is caused to accumulate on the surface of a solid or a liquid forming a film on the surface of that adsorbent material which will have been engineered to have a large and chemically attractive surface area. Examples include, activated charcoal used as a scrubbing media, where Volatile organic compounds (VOC) in flue gas may be “scrubbed” from the gas by passing the gases over a bed of activated charcoal. The VOC are trapped on the surface of the adsorbent where weak chemical forces hold the VOC molecules until the adsorbent is regenerated by (usually) steam stripping.

The process of Ion exchange water softening is similar. The undesirable calcium ions in hard water are exchanged with sodium ions on an adsorbent bed.Sodium Ions do not cause fouling like calcium salts and silicates.

Adsorption is therefore a process where molecules are temporarily stored on the surface of another adsorbent material.

Working fluid pairs include

- Water/silica gel (refered also as desiccant cooling)
- Water/Zeolite
- Hydrocarbon/alcohol(methanol)/Activated carbon

Water/silica gel is a proven commercial application in chill storage and AHU. Methanol/AC must currently be regarded as more eperimental with development work going on around the world to establish innovative use with the reduced evaporation temperatures possible.

Absorption on the other hand is a process which results in the chemical solution of one fluid in the other. The ions of each fluid are diffused and in chemical balance in solution.

Working fluid pairs include

- Water/Lithium Bromide
- Ammonia/Water

Both groups are commercially established developed technology with high reliability and longeivity. Libr plant is suitable for evaporation temperatures of 3°C to 4°C whereas Ammonia is suitable for evaporation temperatures to-30°C. A technology description and specific operational characteristics follow.

3.3. Adsorption refrigeration

The adsorption chiller has four principal stages and relies on the physical affinity between two working fluids (commonly silica gel)[5]

Silica gel is in fact a hard glassy substance of Silicon di-oxide produced commercially by reacting liquid sodium silicates with sulphuric acid. The resultant sodium sulphate salts are washed off and the gel dried to produce the silica gel crystals.

In the adsorption refrigeration plant, water evaporates at reduced pressure and forms on the surface of the silica gel, thus maintaining a driving vapour pressure gradient. Water freezes at 0°C and the water silica gel pair is limited to an evaporation temperature of approximately 4°C, adequate for may cool storage and air-conditioning applications.

Once the adsorbent is saturated and cannot hold any further water, the driving force for evaporation is diminished and the adsorbent must be "regenerated" before it can be reused to cause evaporation. Regeneration is achieved by boiling raising the temperature of the adsorbent so the water held is released as vapour. This can be achieved with moderate heating e.g. temperatures of 60°C to 70°C, and means that the composite heat recovery from CHP systems and solar assisted hot water systems are suitable for regeneration.

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[5] Reference Perry's Chemical Engineers Handbook, Chapter 14 *et seq*, Air-conditioning

The water vapour produced during regeneration is condensed in a condenser and liquefied. The heat absorbed during evaporation and the heat required for regeneration must be removed in the condenser and subsequent cooling to allow the water to be returned as a refrigeration medium to the evaporator via a pressure reduction valve to maintain the pressure difference between the condenser and the evaporator.

The process is essentially cyclic and relies on the physical vapour pressure crated by the Silica Gels capacity to adsorb water. To provide a continuous cooling effect it is necessary to have more than one cycle where one regenerates as the other adsorbs and refrigerates.

The performance of the plant depends on the evaporation temperature, the regeneration temperature and heat demand, the recycle time and the frequency of regeneration, amongst other factors. At reduced evaporation temperatures e.g. 4.5°C the achieved COP may be as low as 0.4 but this is dependent on the condenser cooling temperature differentials available and the evaporation condition maintained.

The rate of evaporation and the rate of heat input required for regeneration must be controlled effectively and where for example the plant is used with the composite low grade heat out put from a CHP system, the rate of heat input must be regulated effectively requiring a bypass and alternate heat rejection system. The arrangement is illustrated below:

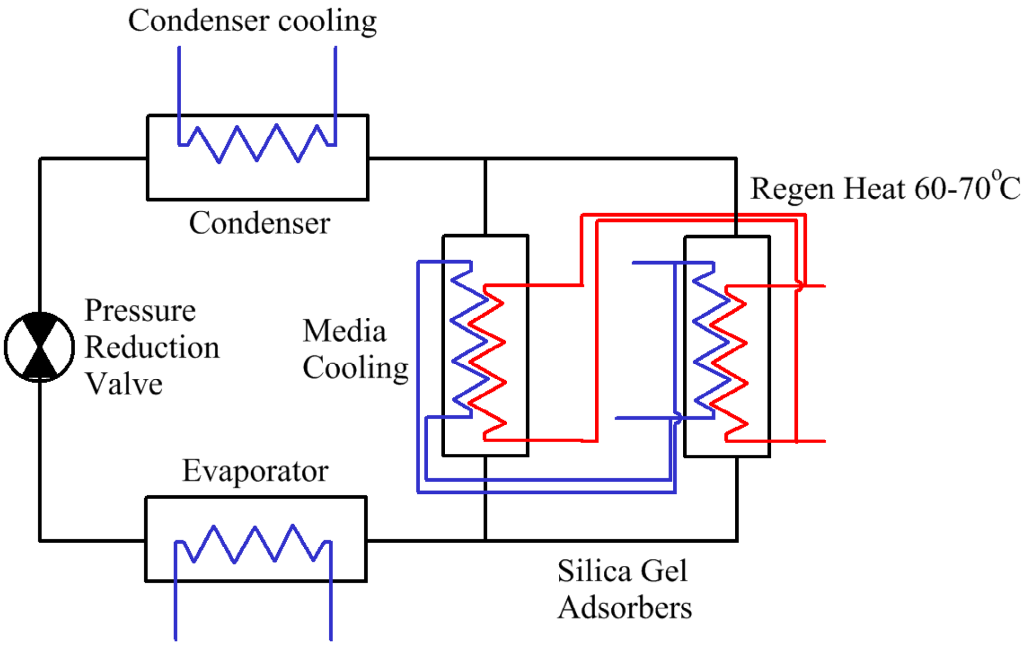

Figure 5 Basic adsorption cycle

3.4. Lithium Bromide absorption cooling

3.4.1. Single stage absorption cooling

The concept is very similar to that of the silica gel adsorption plant. However in the Lithium Bromide chiller, the chemical affinity for water to form solution with Lithium Bromide salt solution is exploited to drive a low pressure water evaporation process.

Once again the system utilises water as a refrigerant. The evaporator pressure is reduced to as little as 6mm mercury (0.11psi) where water will flash boil at 3.7°C. The water absorbs heat as it evaporates and provides the cooling effect.

The evaporated water is then sprayed with a concentrated Lithium Bromide salt solution (61.3%) the chemical affinity for water assisting the evaporation and absorbing the evaporated water. The absorbption of water vapour in the lithium Bromide solution is necssary to maintain the vacuum and the evaporative effect.

In absorbing water the LiBr solution becomes diluted and has to be reconcentrated by boiling the water out of the LiBr solution this is achieved by heating the dilute solution in a regenerator (reconcentrates the LiBR solution to 61.3%). The refrigerant vapour (water) is then cooled in a condenser.

The Lithium Bromide plant can be operated as refigeration plant or as a heat pump raising the temperature (and thus improving the useful application) of low grade heat sources.

The single stage arrangement is illustrated below:

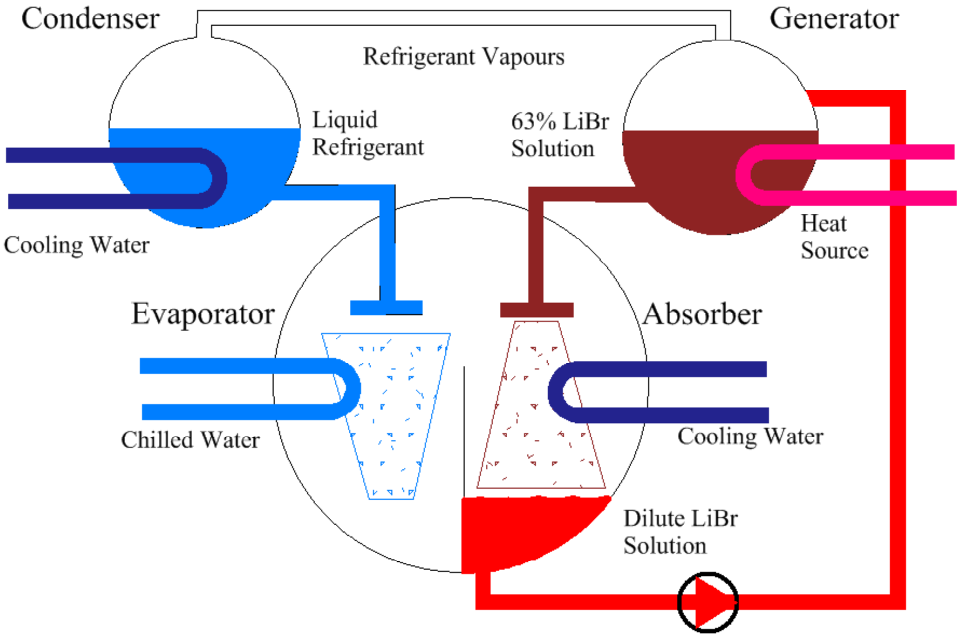

Figure 6 Single Stage LiBr Absorption Chilling

Two stage absorption cooling

The performance of the LiBr absorption plant can be greatly improved using a two stage evaporation process. In this arrangement a much higher grade heat source is required to initiate the process of refrigeration regeneration.

The use of a high grade heat source ensures that the vapour driven off from the first stage generator ar of high enough temperature to actually drive a secopnd stage of evaporative regeneration (Similar to a multistage evaporator as routinely used in the Dairy Industry)

The arrangement is shown below. The two stages do not allow any further reduction in evaporation temperature. This temperature is dictated by the refrigerant – water and the limitations imposed by freezing. However, the arrangement which makes us of a higher temperature waste heat source allows a marked imnprovement in the Coefficient of performance. So whereas a conventional single stage design might achieve a COP of 0.65-0.7, the two stage system can achieve COP of 1.2 or thereabouts depending on condenser performance.

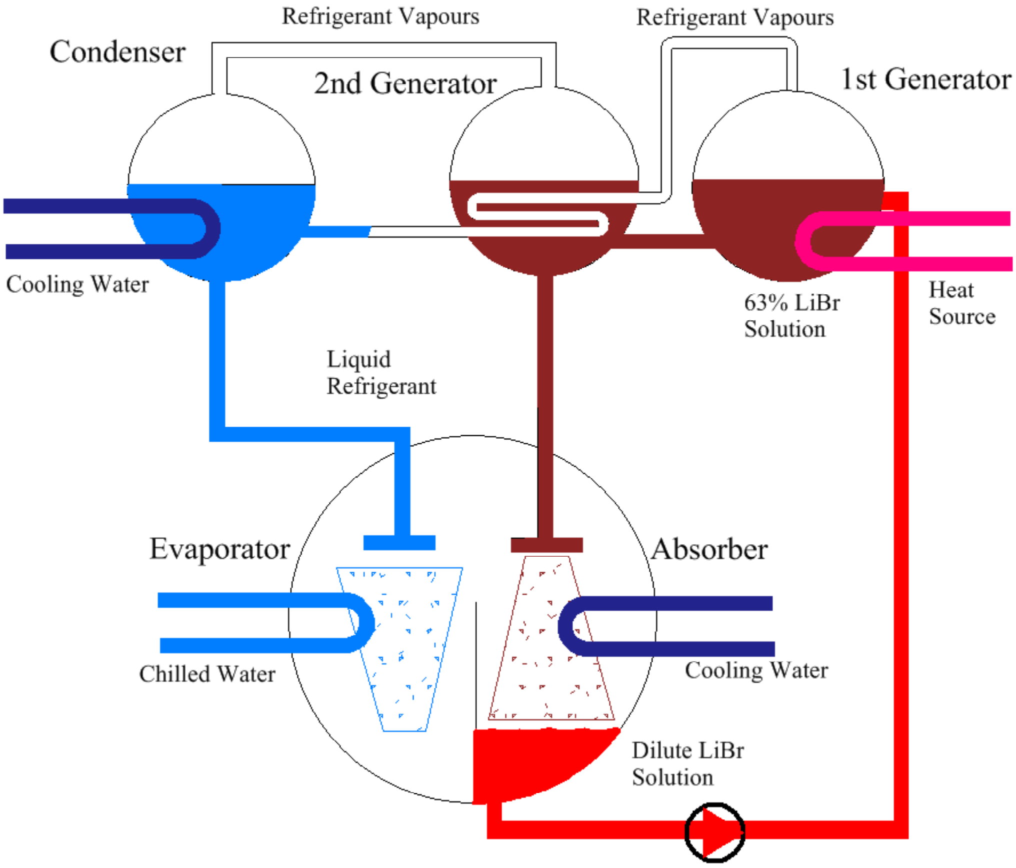

Figure 7 Two stage LiBr Absorption

LiBr Performance

The evaporation process is limited to 4.5°C with higher temperatures e.g. 5°C to 6 °C being more usual. On large custom designed LiBr plant it is possible to achieve 3.5 °C with a low shell vacuum.

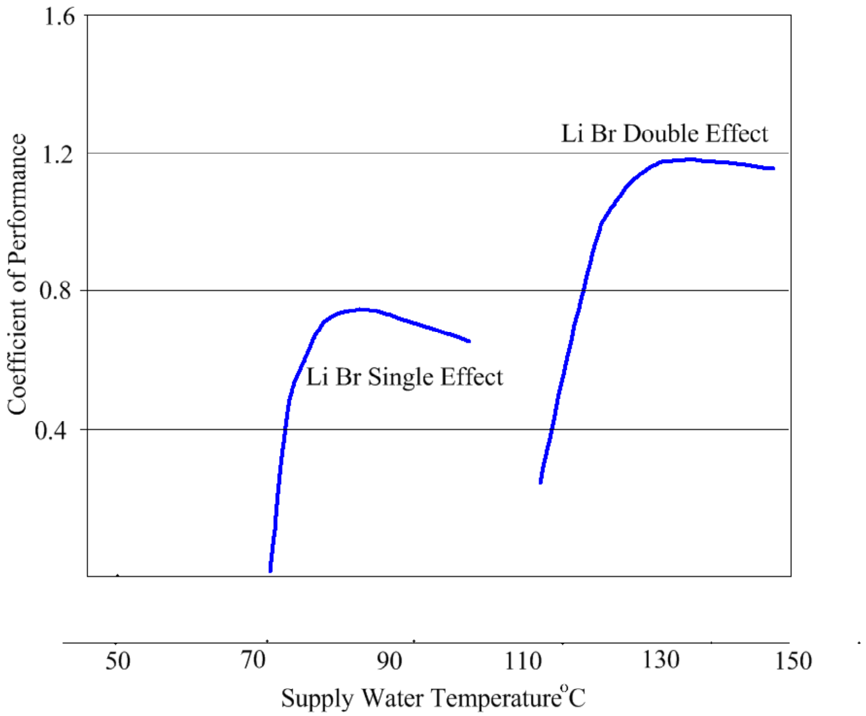

Figure 8 LiBr Performance

Single effect plants will generally operate with pressure differentials of 0.4 kg/cm²g - 3 kg/cm²g (0.3barg to 3barg) and larger units capable of operating down to 3.5 °C.

The single stage plant will operate effectively with a low grade heat source e,g, hot water – 70°C -80 °C producing a Coefficient of performance of up to 0.76. However by design it is possible to operate the plant with lower generator temperatures e.g. 55°C flow and 50°C return.

3.4.2. Critical design considerations

There are several critical issues for design, namely:

Level control - The measurement and the three term control of liquid level controls is essential for the maintnace of the system vacuum and performance. Particular attention to the extent and quality of level control is essential at the design stage.

Regeneration heat input control. An LiBr absorption chiller can be modulated effectively between 10% and 100% if the operational parameters are controlled accurately - Particular attention to the extent and quality of regenerator heat control is essential at the design stage.

Excessive concentration on low load and uncontrolled regenerator heat input will result in salt crystallisation and plant failure/damage.

Air leakage – Libr solution is extremely corrosive to mild steel. An continuous air leak to the shell will cause severe internal corrosion and evntaul blockag of the spray heads and contamination of the flash boiling(evaporative) surfaces with detriment to the physical structure and performance of the plant. The commonly used constructional materials e.g. mild steel and copper cannot really be protected with simeltameous corrosion treatments. Expert knowledge of the plant, automated detction and or parameter monitoring are requird to prevent excessive maintenance or shortened plant life. Particular attention to the extent and quality of metallurgy is essential at the design stage. On larger plant the use of Stainless steel and titanium coating will be economically viable and preferable.

Condenser sizing – The LiBr absorption chiller performance is dictated to a significant effect by condenser size, temperaturs and cooling performance. In a vapour compression plant elevated condenser temperatures (High temperature ambient conditions) will reduce plant performance and reduce efficieny, however the effect is not usually critical. In the Lithium bromide plant incorrect or inaccurate condenser sizing will affect plant performance very severely. Particular attention to the size and available condenser cooling flows and ranges must be given at the design stage.

3.5. Ammonia absorption Refrigeration (AAR)

In a conventional ammonia (continuous) absorption plant, the depressed boiling flash boiling point of strong ammonia solutions is exploited to provide cooling effect as heat is absorbed during evaporation. Ammonia, chemical formula NH_3 boils at -33.34°C but has a high latent heat of evaporation.

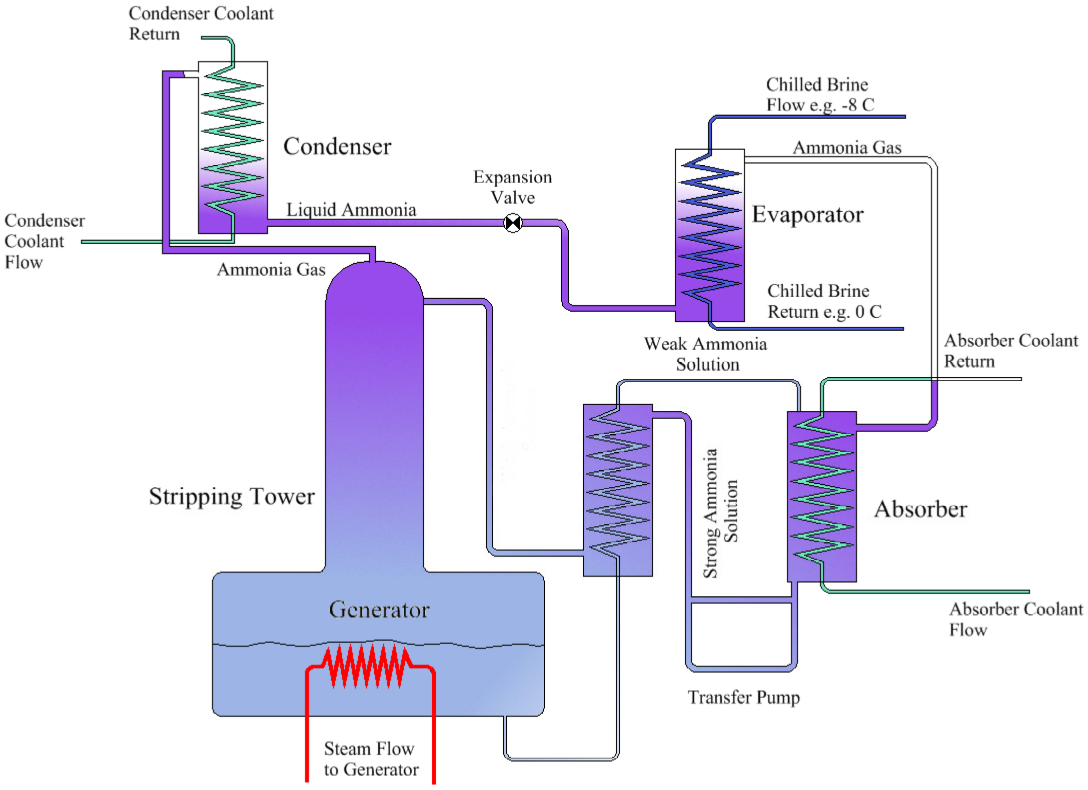

Figure 9 Ammonia Absorption Cycle

The ammonia evaporated in expansion coils similar to a conventional evaporator is drawn to and dissolved in water within the absorber. The absorber maintains by virtue of the chemical affintiy and propensity to form a solution of amonai in water, the system evaporation pressure.

The weak solution of ammonia in water is regenerated with the application of heat to flash ammonia and water vapour. The ammonia is separated from the water in a rectifier or scrubbing tower and the ammonia vapour is subsequently condensed in the condenser befor being returned to an ammonia receiver.

Ammonia is returned to the evaporator from the receiver via an expansion (throttle or pressure reduction valve to maintain the system pressure differential).

The absorber has to operate at a lower pressure than the evaporater and the generator. It is therefore necessary to install a transfer pump between the two.

3.5.1. Ammonia absorption performance

The same principals of depressed boiling point can be applied to the ammonia chiller, so whereas Ammonia will boil at approximately –33°C, the boiling point can be reduced by maintaining a lower evaporator pressure.

Accordingly the operation at vacuum can afford very low evaporation temperatures e.g. down to –50°C or more for very specialist applictions.

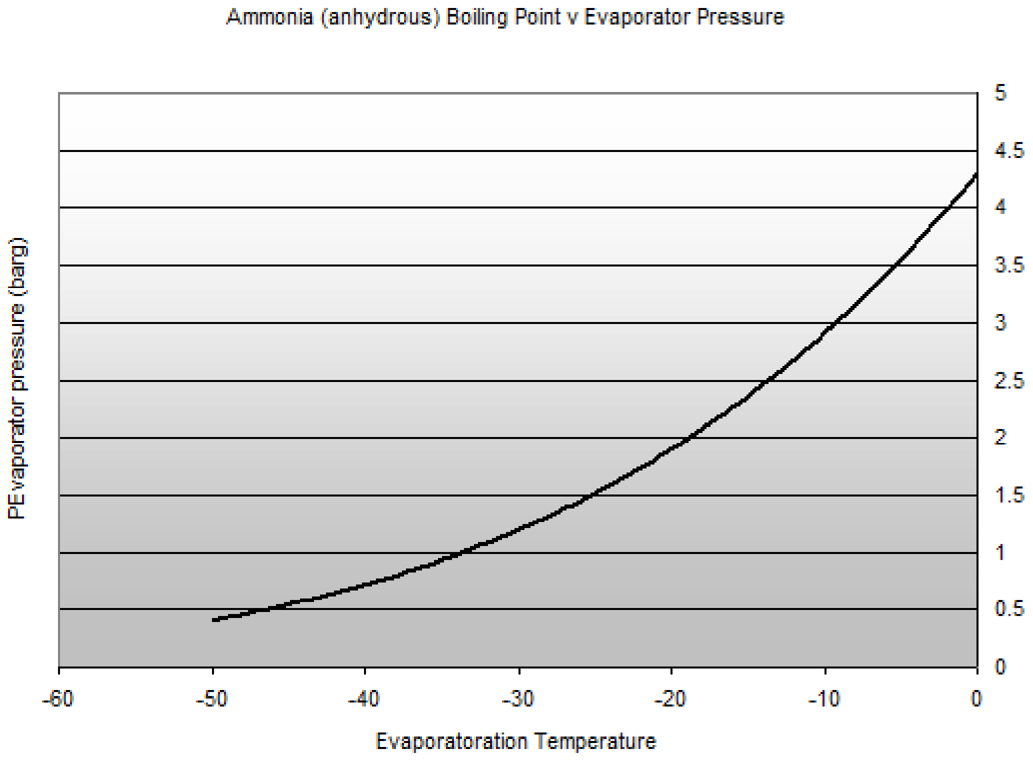

Figure 10 Ammonia Boiling Point

However a significant advantage of Ammonia chilling is the abilty to operate down to evaporation temperatures of –30°C with only moderate system pressure differentials.

The absence of solid phase (e.g. lithium bromide crystallisation) might also be considered a distint advantage particulary where there is variable load and or difficulty in controlling heat input to the generator.

The performance of the plant is once again dictated by the evaporation pressure (temperature) and the condenser temperatures (as dictated by the cooling flow temperatures).

Single stage absorption plant generally designed for those applications having multiple chilling loads of approximately the same temperature, but from anywhere between +5°C and –40°C (LiBr offfers reduced capital intensity above 4°C).

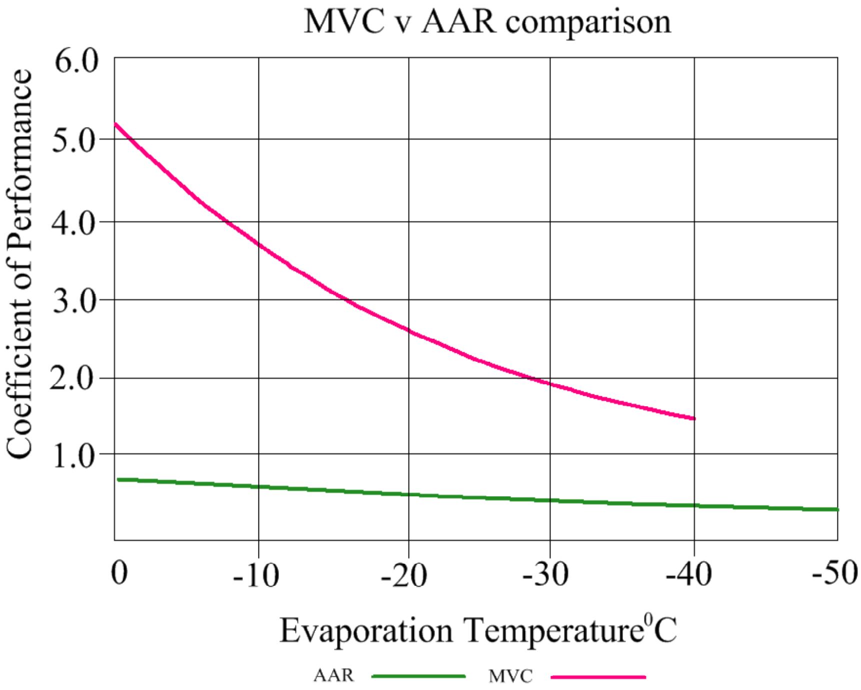

Figure 11 AAR performance

3.5.2. Critical design considerations

Absorption chilling generally is suited to continuous operation. When the plant is shut down (e.g. if there is no load) the whole system cools and the pressure differential normally maintained by virtue of thermal input and the expansion valve (refer to figure 6) is dissipated. On restart the system will take typically 5-20 minutes to reach operational temperature, pressure and evaporating performance. Whilst the COP under normal operational conditions may reach 0.7 (depending on the condenser and heat source condition) the seasonal performance resulting from cyclic reheating could be considerably less - a factor that must be considered at design stage in considering whether Ammonia absorption was appropriate

Materials of construction required for Ammonia are dependent on the operating temperature. Whilst mild steel may be used at ambient temperature special steels may be required at low temperatures to avoid embrittlement. Ammonia is also highly corrosive towards copper and zinc and therefore these materials must be used with caution in construction. Factors that must be taken into design consideration.

As with lithium bromide a thorough knowledge of the metallurgy is essential for safe and durable design.

3.5.3. The application of ammonia refrigeration plant

Ammonia chilling plant offers many advantages over vapour compression plant, not least the advantage of using ammonia over HFC given current and impending legislation. Although ammonia is naturally occurring chemical and one of the most commonly used chemicals, it is still a toxic material and dangerous if not handled safely. There are legal requirements for storage, operation, leak detection and evacuation.

The biggest advantage ammonia absorption offers is the very significant reduction in electrical power consumption. For example a 667kW Vapour compression plant might conceivably consume as much as 240kW of power input, whereas the ammonia plant will likely consume less than 20kW. The electrical power consumption is restricted to the condenser fans, aqua pumps (transfer pumps) and absorber fans. The reduction in moving parts can also afford a potential reduction in maintenance costs where compressor maintenance is eliminated.

The ammonia plant will run on waste heat (Subject to minimum stripping temperatures and accepting reducing COP with reduced regeneration temperatures)

As with the other adsorption and absorption types the ammonia chiller has virtually no moving parts and thus is almost silent in operation. This affords advantage in situations where low noise is essential e.g. auditorium, hotel, hospitality sector etc.

Ammonia absorption systems do not require lubricating oil (Unlike vapour compression systems including particularly ammonia systems). Oil management, contamination and control are thus eliminated.

High turn down ratios are possible, giving efficient part load performance. This can be improved with variable speed operation of pumps and accurate heat input control. Whereas vapour compression plant will normally be sized for the peak cooling duty, the part load power consumption of the vapour compression plant can be very poor resulting in continuously high electrical demand with reduced refrigeration effect.

In the context of retrofit, and for larger installations, the concept of "packaged" may be abandoned for the generator/stripping column and the condenser need not be located with the evaporator/absorber. This is useful in many circumstances. Ammonia is a light low-density fluid and the relatively low pumping losses make longer distance and un-insulated distribution possible unlike conventional refrigerant operations. Ammonia is therefore a versatile refrigerant.

The obvious disadvantage with ammonia absorption is the very significant cost of the plant and the physical size. The capital cost is significantly higher than that of the vapour compression plant.

The system is more complex than the vapour compression alternative and there are very few companies with experience or skill required to maintain this plant in Northern Ireland.

The stripping column requires significant temperature difference between base and top of the column and higher grade (higher temperature) waste heat is required for the process of regeneration and stripping.

3.5.4. Where and when is Ammonia chilling appropriate

Where waste heat, low cost steam or steam load consolidation is required, Ammonia absorption chilling offers a real alternative for lower temperature evaporation applications in Northern Ireland e.g.

- Meat chilling
- Poultry chilling
- Food processing
- Frozen food storage
- Ice manufacture
- Dairy industry post pasteurisation/ raw milk chill
- Other low temperature applications.

The principal benefits being reduced electrical power consumption, low noise and maintenance.

4. ABSORPTION REFRIGERATION IN THE NI ECONOMY

4.1. General overview

Absorption technology is relevant to industrial and air conditioning applications and the statistical information published by DARD, DETI and NISRA has been reviewed to provide a developed context for this report. DARD, other economic activity by DETI and some by NISRA report agricultural activity. The data presented in this section of the report is not considered definitive. It is intended as indicative and drawn from the latest data available from the various sources. The data is included to understand the relative importance of market sectors simply in terms of size. (and therefore prospective opportunity)

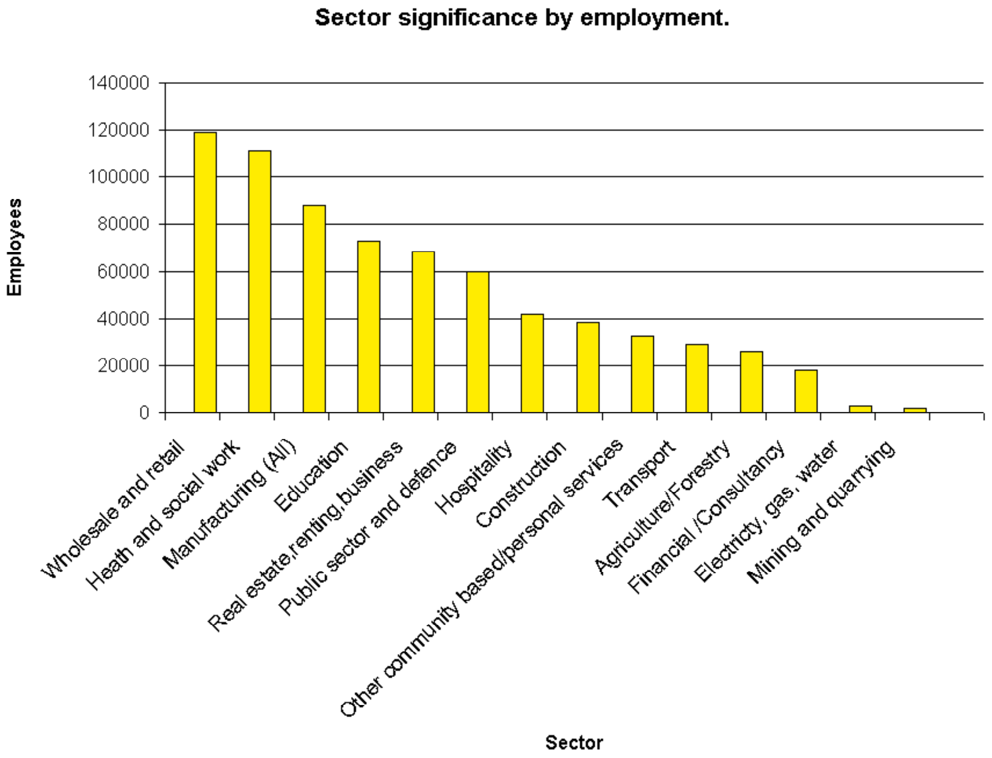

Figure 12 Sector Distribution

The breakdown of Northern Irish economic activity is considered in terms of both employment and GDP or GVA below[6]

The statistical breakdown by employment is relevant for it illustrates the very large numbers of persons employed in the public and health sectors where the predominance of activity will be office based and where there is therefore the likelihood of air-conditioning requirements. (Cooling loads are determined in significant part by the numbers of occupants and the office equipment used by the occupants). The sheer numbers employed (approximately 43% of employees work in the public sector) suggest that there will, in due course, be significant opportunities for sustainable cooling, at least within the:

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[6] References various DETI, DARD, NISRA for years of 2005 to 2009 as available

- The hospitality sector
- The government estate

The manufacturing sector analysis is illustrated in the chart below. The food and drink sector being the largest sector at 43% in Northern Ireland. A breakdown of the sectors is provided in the following sections of the report and tentative analysis (by means of examples) as to the potential and technical characteristics of appropriate absorption technology.)

Data sourced and interpreted from Northern Ireland Manufacturing Sales & Exports Survey 2007/2008

Of these manufacturing sectors, the food and drink sector also has a significant requirement for chilling and freezing and further expansion is given below

Manufacturing Sector	**Significant cooling requirement?**
Food drink and tobacco	✓
Electrical equipment	X
Other machinery and equipment	X
Transport Equipment	X
Basic Metals and fabricated products	X
Rubber and plastics	✓
Other manufacturing	X
Chemical and other man made fibres	✓
Paper and printing	X
Wood &wood products	X
Textiles Clothing and Leather	X

4.2. Primary Agriculture

Although agriculture employs a significant number of people the DARD figures refer to fundamental agricultural activity (not secondary or food processing activities) e.g.

- Dairy
- Cattle
- Potatoes
- Horticulture
- Others
- Sheep & wool
- Pigs
- Poultry & eggs
- Cereals & oilseed rape

Of the fundamental farming activities none have large chilling requirements. Dairy farming may involve local chilling or small-scale farm production however the bulk of milk is subsequently processed off site to become dairy produce where there are significant cooling demands.

The poultry rearing and horticultural industries may be of interest in the context of absorption heat pumping and the re-concentration of low-grade solar heat. The applications for solar heat pumps are discussed under the technology sections of this report.

Primary agricultural activity whilst of significant economic importance in Northern Ireland it is therefore of less significance in the context of absorption cooling. Subsequent Food and Drink processing is, however, the largest potential market for absorption technology.

4.3. Food and drink processing Industries

A breakdown of this sector by gross turnover[7] is provided. The Food, Drink and Tobacco industry contributes the largest proportion of sales and external sales to the Northern Ireland manufacturing sector, accounting for 42.8% of total sales and 45.2% of external sales.

Of the food and drink industries considered here and reported by DARD, most have heating and cooling demands. The dairy, beef and poultry sub sectors are key sectors using significant amounts of refrigeration and therefore potentially candidates for absorption chilling

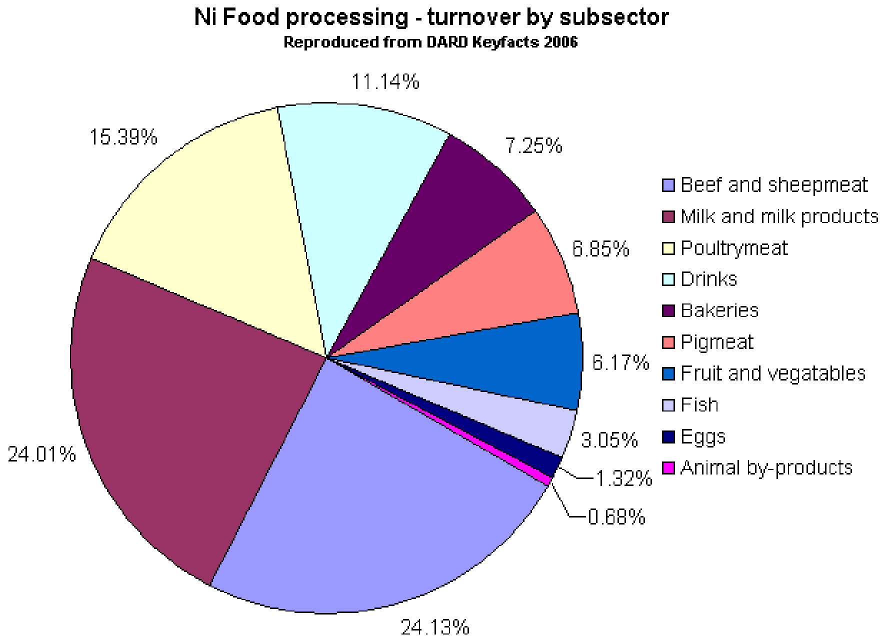

Figure 13 Sector Turnover

4.3.1. Beef and sheep meat/pig-meat Industries

The slaughter and subsequent processes of carcass chilling, and joint preparation require a mix of refrigeration temperatures.

- The product load comprises the heat given of by the product as it cools
- The heat given of as the product freezes
- The heat given of cooling from the freezing point to the final storage temperature.

Carcass chilling is commonly achieved by air blast chilling (Blast freezer). This method of freezing combines the effects of low temperature and

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[7] which is indicative of economic activity and energy use

increased convective heat transfer to improve the overall rates of heat transfer.

Typically a Meat processing site will operate a low evaporation temperature system for the blast chillers (Evaporation temperature at –25°C) and a separate system for the chilled working, cutting, de-boning and packing areas with evaporation temperature –5°C to –8°C.

The lower temperature plant may typically be ammonia vapour compression plant whilst the higher temperature systems will either be derived from a the same low temperature plant or separate higher evaporation ammonia, R22 or R407 systems.

Frozen storage areas will be operated at a rang of evaporation temperatures These temperatures will however, generally below those achievable with LiBr absorption plant.

Experience tells that defrost is normally timed electric or hot gas as opposed to defrost on demand. There is no potential for free cooling of any kind and principal considerations are product dehydration and air infiltration loads.

A larger slaughter and meat-processing site might operate up to 1,500kW of cooling requiring over 500kW of chiller power consumption. A significant proportion of this is continuous.

4.3.2. Dairy Industry

The processes include the manufacture of butter, cream, yoghurt, milk drinks, whey and dried products.

There are two principal cooling demands:

- Raw milk intake
- Post pasteurisation chilling.

The product load is generally sensible cooling load only, although the plant will be sized to afford margins of over cooling for expected tank heat gains and line gains etc.

The intake-cooling load can be very significant e.g. a medium sized dairy might handle 6,000 gallons/hr or more for the best part of the day. (The cows cannot all be milked and delivered at once) (Typically 10am – 6pm). The milk will typically be cooled from milk is cooled from 7°C to 2°C or less (as low as 0.5°C). The continuous loads are significant e.g. for this example 200kW or more.

Pasteurisation is usually accomplished with regenerative pasteurises and the Matched milk load is refrigerated (6,000 gallons/hr over up to 9 hours (e.g. typically 6am – 3pm), being cooled after regeneration from typically 12°C to 0.5°C – again a sizeable refrigeration load requiring 3-400kW of cooling.

Thus a medium sized dairy might have up to one MW of cooling capacity and 250 to 300kWh of associated electrical drives.

Ice storage is not uncommon and used either to flatten peak loads or simply to pre-cool and absorb surplus chiller capacity when the full load does not prevail.

The dairy industry demand profiles are also characterised by broadly simultaneous and significant heat demands requiring generally steam for pasteurisation, CIP and space conditioning. If the load profile is spread over an extended day there is then the opportunity for CHP and Trigeneration.

4.3.3. Poultry Meat

The meat processing industries have significant cooling demands and the typical uses for refrigeration are as follows

- Carcass chill and storage (Tunnel Blast freezing and frozen storage)
- Cutting room chill (air temperature maintenance at 1°C -2°C)
- Flash fry and value added products fast freeze and storage (Tunnel Blast freezing and frozen storage)
- Direct product /refrigerant dips

In all cases the refrigeration loads are going to have low evaporation temperatures. It is almost certainly the case that only AAR (Ammonia Absorption Chilling) can achieve suitable evaporation temperatures.

The bulk of the industry is using R22, R404, systems and thus subject to the HCFC and F gas regulations with imminent large expenditure expected. Larger sites will operate several tens of tonnes of refrigeration and will be facing conversion costs of several millions. It is critical that the lifecycle cost of refrigeration is considered as part of the procurement process.

AAR will be appropriate in some circumstances where there is the potential to integrate larger centralised refrigeration systems - but many sites have grown piecemeal making AAR integration difficult.

4.3.4. Drinks and alcoholic beverages

The drinks industry has wide and varied need for cooling but the cooling demands are very significant. In the context of soft carbonated drink production the carbonation process benefits from pre-chilling so as to support a higher dissolved CO_2 content. This is usually achieved using large shell tube chillers sometimes incorporating high specific consumption centrifugal or screw chillers.

In other specialist application, e.g. cream based liquor, the demands for chilling can be very significant, for cream pasteurisation, homogeniser cooling amounting to many hundreds of kW of cooling and possibly as much as 800,000kWh (approximately £80,000) of electrical energy consumed by vapour compression chiller motors.

In these specific applications there is simultaneous heat and power demand similar to the requirements for the dairy industry. Cooling can be effected with chilled water but the plant is designed for rapid temperature reduction.

4.3.5. Bakeries

No significant chilling demands. Wholesale and retail are discussed separately

4.3.6. Fruit and vegetables

Opportunities at primary processing and packing and at regional distribution centres refer to wholesale supermarkets and distribution. There are known primary production sector there are known refrigeration demands for seasonal fruit and vegetable storage:

Apple storage to 0.5°C will require AAR but there may be some potential for solar assisted absorption chilling (refer to the other text)

Soft fruit is a relatively small business in Northern Ireland with there being approximately 30+ growers in Northern Ireland and approximately 30 hectares under cultivation for soft fruits. The bulk of this is strawberry production and thus

Larger facilities e.g. Avondale will have significant chilling demands for fresh and processed food storage.

4.3.7. Fish

Small sector value and principal opportunity is under wholesale regional distribution centres refer to wholesale supermarkets and distribution

4.3.8. Eggs

Egg and chick production does require some air conditioning. This is not low temperature or extensive demand but the hatching process can be offset and controlled by storage temperature. Small scale LiBr is appropriate.

4.3.9. Animal By-products

The animal by-products industries do not directly use a large amount of cooling. Tallow refining (e.g. companies like Foyle, DFP, O'Kane) use large amounts of heat in the processing of tallow and chicken oils and the drying and cooking of wastes for granulated pet and animal feeds.

Moreover by products sector constitutes a very small proportion of the total food and drink sector 0.68% as reported by DARD. Thus the Animal by products is not considered as a key sector for absorption cooling technology.

However animal by products industries have relevance to this study in that they are a manufacturer of sustainable fuel products e.g. tallow and chicken oil.

4.3.10. Summary of food and drink sector

Sub sector	**Key Sector**	**Evaporation temperatures**	**Ref. Type**	**Simultaneous heat load**
Beef and sheep meat/pig-meat	✓	Variable<-20°C	AAR	✓

Industries				
Dairy Industry	✓	Variable –8°C	AAR/LiBr	✓
Poultry Meat	✓	Variable<-20°C	AAR	✓
Drinks	✓	Variable –8°C	AAR/LiBr	✓
Bakeries	X	•	•	•
Fruit and Veg.	X/✓	Variable –2°C	AAR/	X
Fish	X	•	•	•
Eggs	X	•	•	•
Animal By products	X	•	•	•

4.4. Pharmaceutical (and sterile medical equipment) Industries

A typical pharmaceutical manufacturing process uses de-ionised water at various temperatures. There is normally a demand for moth heated and chilled water. The predominant demand is for chilled DI water or chilled WFI (water for injection (process injection).

The bulk of cooling demand is therefore for chilled water e.g. 4°C -5°C and thus may be produced using single or two stage lithium bromide chilling.

Generally the demand for chilled water is a steady stable load with thermal storage coincident with a steady stable heating demand. The opportunity to deploy CHP packaged Lithium Bromide cooling is therefore a key opportunity.

A substantial part of the demand is AHU or space cooling demand where high clean room and manufacturing demands result in air change rates of up to 20 air changes per hour with commensurate cooling demands in the peak summer months.

Examination of power demand profiles in the pharmaceutical sector display characteristic seasonal daytime increases in power demand derived from the increased AHU cooling loads.

The Northern Irish economy has many pharmaceutical or medical industry and manufacturing companies where chilled water for process or AHU needs are prevalent (up to 20 ac/hr), companies including for example:

- Norbrook Laboratories
- Sepha
- Randox Laboratories
- Paradox
- Clonallon
- Clas Technology
- Rusch Manufacturing (medical equipment)

At the larger companies the cooling demands amount to many hundreds of kW of continuous cooling demand.

Sector	**Key Sector**	**Evaporation temperatures**	**Ref. Type**	**Simultaneous heat load**
Pharmaceuticals	✓	Variable<5°C	LiBr	Yes

4.5. Hospitality sector

The hospitality sector in Northern Ireland is an important growing sector with large heat and power demands. The number of overnight stays in Northern Irish hotels had risen to approximately 9.6millions/annum (approximately 26,000 beds/night) by 2006, generating over 370 millions in income. Approximately one third of this was business travel.

Approximately 37% of the hotel and guest accommodation market in northern Ireland is a hotel - The remainder being guesthouses, B&B, student residences etc.

In considering the practical application of CHP and Trigeneration, the physical size of the hotel and the occupancy patterns are going to be of significant importance and the larger 3-5star hotels average occupancy rates exceed 60% with excellent seasonal occupancies (Highest in summer with commensurate cooling loads)

Absorption chilling is now routinely coupled with small scale CHP and micro-generation in the United states. Particularly those facilities incorporating large scale conference centres. In the US the EPA (environment protection agency) has undertaken a detailed analysis of the hospitality sector and the suitability for the integration of CHP.

The American studies indicate (American energy costs are lower) that the use of turbine based CHP with steam generation and absorption chilling is practical and economic for the very largest hotel/conference facilities only.

At a smaller scale and for hotels with more than 100 beds (e.g. Belfast prestige groups) CHP is viable and where the electrical generation size exceeds 300kW(commensurate with the demands for this size of hotel as is the case for several hotels in Belfast) then LiBr two stage absorption chilling will usually be viable for those facilities with centralised AHU and air conditioning plant.

The EPA study is valuable for it sets some ground rules for site selection that with adjustment might be applied in Northern Ireland. The study recognises the large variation in thermal load profiles and thus the benefit of on site leisure and or other load balancing factors.

As an example, one of the larger Belfast Hotels has three principal chilled water systems providing cooling for the:

Executive suites	***Carrier***	***Est. 80kW***
The Function rooms 3,4 and 5	***Hitachi RCU 100 ASY1 (R22)***	***Est. 200kW***
The larger function rooms 1 and 2	***Trane LCG124 (R22)***	***Est. >200kW***

To establish the viability of absorption cooling the air conditioning loads and associated power consumption profiles would have to be established. The R22 systems become a liability from 2009 and there is therefore every likelihood these systems and others in the hospitality sector will be changed. One again procurement activity should consider the lifecycle costs.

Sector	**Key Sector**	**Evaporation temperatures**	**Ref. Type**	**Simultaneous heat load**
Hospitality	✓	Variable<5°C	LiBr	Seasonally dependent

4.6. Supermarket and retailing sectors

Retail is a critical element of the Northern Irish economy, the largest sector of employment at around 12% of the entire workforce and about 14 per cent of all VAT registered companies providing enormous tax revenue to the exchequer.

Most supermarket food and much of the food sold by independent retailers, is supplied from regional distribution centers (RDC) (large food and white good storage facilities). Food, drink, fresh and frozen produce are supplied to the RDC from the suppliers and subsequently distributed to the stores. The primary and secondary distribution haulage arrangements may be subcontracted and subject to logistical organizations that facilitate the best backhaul arrangement.

Some retailers are now revising sourcing back to more direct and local supplies even with arrangements for supplier delivery direct to shops. Regardless the food chain in the UK is very much dependent on road transport. RDC play a fundamental role in the UK food supply chain.

The RDC must cater for frozen, chill and ambient product storage. Some of the RDC sites are of very significant size with large chilling requirements. However there is no process activity and the power demands are predominantly those of lighting. The merits of absorption chilling alone have to be considered carefully for the primary and secondary power displacements of CHP/absorption combinations may not be easily accommodated.

The principal supermarket chains in Northern Ireland include

Chain	Facilities (est.)
ASDA	13
Co-op	54
Musgrave	2
Sainsbury	7
Spar	More than 140
Supervalu	39
Tesco	48
VG	3

Many of these stores are small garage forecourt type facilities and the immediate economic case for district heating will be difficult. However the larger facilities e.g. the superstore refrigeration demands will be considerable and up to 50% of the supermarkets electrical load and there is then the potential for absorption cooling coupled with CHP.

The use of smaller CHP and absorption chilling is well established in the United States where small-scale turbine absorption couples are also established e.g. Ingersol Rand/Hussman packaged turbine /AAR plant. The turbine is preferred for the higher exhaust temperature can be more readily utilised with the AAR and thus lower evaporation temperatures.

The use of reciprocating engine CHP requires more detailed consideration for the hat output may only economically be deployed with LiBr and the higher evaporation temperatures achieved are less suited to all Supermarket requirements. However the use of hybrid systems e.g. these incorporating both absorption and VCR can be used to achieve lower circulation temperatures.

The logistics of retrofitted systems have also to be taken into a count for whereas DX systems may be currently employed the adoption of an absorption solution may also necessitate significant change to the display cabinets and arrangements to accommodate centralized propylene glycol distribution.

Sector	**Key Sector**	**Evaporation temperatures**	**Ref. Type**	**Simultaneous heat load**
RDC, Supermarket, retail	✓	Variable<7°C principally cold store & chill cabinet	LiBr/AAR/CHP /hybrid VCR	Small but condenser recovery for hot water

4.7. Rubber and plastics

The rubber and plastics industries including plastics extrusion, injection moulding and other thermosetting industrial applications have a significant chilling demand. Injection moulding is an extremely energy intensive process. Homogenisation prior to injection usually requires heating and cooling.

Example companies in Northern Ireland include for example Canyon, Boxmore and some UPU extrusion operations where there is a significant chilled water demand for the film extrusion and bubble coolers.

In all cases within the rubber and plastics manufacturing sector, the demand is for chilled water at or slightly below. The loads can easily be met with LiBr Chillers.

Sector	**Key Sector**	**Evaporation temperatures**	**Ref. Type**	**Simultaneous heat load**
Rubber and Plastics	✓	Variable<7°C	LiBr	Seasonally Variable

4.8. Public sector including Healthcare

The public sector in Northern Ireland is a major employer and major energy user.

The public sector consumes the following very approximate buildings energy:

Fuel	**Consumption**

Coal	60,000MWh
Electricity	560,000MWh
Gas	560,000MWh
HFO	84,000MWh
LPG	24,000MWh
Oil	720,000MWh

And additional process energy (predominantly water pumping and street lighting) of:

Fuel	**Consumption**
Oil	68,000MWh
Electricity	420,000MWh
Other fuels	Relatively small

The largest energy consumers are the Department of Health Social Services and Public safety, department of Education and the Department of Employment. However, the public estate comprises approximately 3,500 buildings (ranging from bowling green to major hospital), 2,900 of which may be considered as cost centres.[8]

Of these public sector buildings, major civic buildings and hospitals offer the prime opportunity for Absorption cooling with CHP. The numbers of large civic buildings e.g. Stormont, Dundonald, large council HQ etc are relatively small and the principal hospitals listed below in the following sections. (Where centralised AHU exists).

Solar assisted cooling may have potential for other smaller civil buildings e.g. schools, new builds and other opportunities resulting from “ culling” inefficient stock.

The potential for absorption chilling in the health care sectors is well documented and very likely represents the best initial and demonstrative opportunities in Northern Ireland (where not already installed). For larger hospitals with continuous heating and Air conditioning demands imposed by the design air change rates for wards and the clean demands for theatres then there are significant cooling loads.

The demands are normally all Air Conditioning demands and are easily met with 1 or 2 stage lithium Bromide chillers. The benefits of coupling CHP and utilising the waste heat output are discussed later in this Guide.

The principle health care facilities include (not limited to):

Facility	**Description**
Alexandra Gardens	Pyschiatric day hospital
Altnagelvin Area Hospital, Derry	The main hospital for the North West of Northern Ireland. It provides services to the city of Derry as well as County Londonderry, but also some specialist and acute services for parts of neighbouring County Donegal, County Tyrone, County Antrim and County Fermanagh. It has 500 beds
Antrim Area Hospital	Antrim Area Hospital is an acute trust of 350 beds
Ards Hospital, Newtownards	
Belfast City Hospital	900-bed modern university teaching hospital providing local acute services and key regional specialties

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[8] Public sector energy data contributed by David Browne, Facilities and Energy Management Ltd

Cancer Centre, Belfast	60m New Build
Causeway Hospital, Coleraine	Relatively New Childrens, Maternity IC
Craigavon Area Hospital, Portadown	acute services to an estimated 241,000 people from across the boroughs of Craigavon, Dungannon and South Tyrone and the districts of Banbridge and Armagh City
Daisy Hill Hospital, Newry	is a local general hospital located in Newry
Downe Hospital,	Multifunction approxiamtely 150 BEDS
Erne Hospital, Enniskillen	Large Multi functional with A&E, Cardiology,accute, Surgery
Forster Green Hospital & Joss Cardwell Out-Patient Rehabilitation Centre	Child and Family Psychiatry; The Acquired Brain Injury and Neurology Service
Lagan Valley Hospital, Lisburn	services to an estimated 125,000 people from Greater Lisburn, the Lisburn City Council area and other parts of South East Ulster
Lakeview Hospital, Derry	Small 43 bed
Lurgan Hospital	Care of the Elderly services, providing day hospital, assessment, rehabilitation, respite and continuing care services
Mater Infirmorum Hospital	236 bed acute In-patient, A&E, Day Procedures, Mental Illness and Maternity
Mid-Ulster Hospital, Magherafelt	_
Moyle Hospital Larne	_
Musgrave Park Hospital	Regional specialist hospital, managed by Belfast Health and Social Care Trust. Non-acute hospital delivering a range of regional specialist healthcare services
Royal Victoria Hospital inc the Royal Victoria, Royal Jubilee Maternity Service, Royal Belfast Hospital for Sick Children and the Dental Hospital	The hospital, provides over a fifth of the acute beds in Northern Ireland and treats half a million patients a year. Two thirds of the Northern Ireland population live within 40 minutes travel from the 70 acre site - major AHU
South Tyrone Hospital, Dungannon	Modern Multi function hospital, will have large AHU demands
St Lukes Hospital, Armagh	_
Tyrone County Hospital, Omagh	Modern Multi function hospital, will hjave karge AHU demands
Ulster Hospital, Dundonald	The hospital provides acute services to 250,000 people in the North Down, Ards and Castlereagh council areas, as well as east Belfast. It is also one of four regional cancer units in Northern Ireland
Whiteabbey Hospital, Newtownabbey	_

The CHP/Chilling combination is already widely used in many hospitals including amongst many others:

Facility	**Description**
Guys and Thomas Hospital	London
St. James Hospital	Leeds
Adenbrooke’s Hospital	Cambridge
Ipswich Hospital	Ipswich
Heartlands	Birmingham
Royal Hospital	Shrewsbury

Sector	**Key Sector**	**Evaporation temperatures**	**Ref. Type**	**Simultaneous heat load**
Major civic buildings	✓	Variable<7^{o}C principally AHU	LiBr	Seasonally Significant
Health care	✓	Variable<7^{o}C principally AHU	LiBr	Seasonally Significant
New Build	✓	Variable<7^{o}C principally AHU	LiBr	Seasonally Significant

5. SUSTAINABLE REGENERATION HEAT SOURCES

5.1. Introduction

Burning fossil fuels at under 40% efficiency to transmit electricity long distance over an ageing and underdeveloped grid is unlikely to represent a sustainable future solution to industrial, cooling and power needs. As conventional fossil fuel stocks dwindle the sheer cost and indeed the reliability (refer to section 1 of this report) and convenient supply of conventional energy, will increasingly support advanced renewable deployment, alternate fuels and process optimisation and integration.

Process optimisation and integration is vital. That is to say waste heat from one process or one site will have to be considered as the " fuel for an adjacent process" - Waste heat will increasingly become useful heat as the economic pressure to adapt, forces technological change and innovation, hitherto considered uneconomic. That which is currently uneconomic because oil and gas are relatively cheap will rapidly become normal practice and every conceivable mechanism for integration will be adopted by surviving industry.

The term process optimisation refers to the optimisation of process parameters e.g. temperature, pressure, volume, waste and so on. In the future it is undoubtedly the case that these "parameters" will be reviewed and "trimmed" to reduce unacceptable waste rates. For example, the fixed losses associated with a steam system may dictate that production is "compressed" in time to reduce the specific energy consumption.

The term process integration used here refers to the adoption of linked process operations to avoid excess energy consumption or to allow heat recovery. For example if rolling steel billets to produce sheet it would be best to roll the billets whilst still hot from forming" hot linking" as opposed to using cold stock. Equally it will become increasingly essential to use the waste heat rejected from process e.g. compressed air systems, chiller systems condensate systems, furnaces, thermal oxidisers to provide air preheating, process preheating, space heating absorption cooling and so on.

A combination of using less energy more effectively will provide a commercially essential part of any solution for Northern Irelands future energy needs. It really is a question of when rather than how and the indisputable need for radical change will arguably come very quickly.

Sustainable should of course be interpreted as "more sustainable" than conventionally accepted fossil fuel solutions – Ultimately the most sustainable source of external energy is the sun and, again debatably, man cannot yet recover that incident energy in any form so concentrated or useful as to make any massive impact on the needs of a modern industrial economy.

The world population only reached 1 billion just prior to the turn of the last century. In the last 100 year that population has grown seven fold to a little over 7 billion. The explosion in population exactly mirrors the exploitation of fossil fuel - for it is the use of oil and allied fossil fuels that has allowed mechanised society and the mass production of food, heating lighting and the transport infrastructure that grew modern societies and populations. As a sobering thought it has been variously estimated that the UK could perhaps support only 17 millions of population with current known agricultural techniques, in a non-oil economy.

Thus the adoption of any and all mechanisms for process optimisation and process integration will be essential and will inevitably be driven by consolidated approach to carbon taxation in the future.

Freezing and cooling demands particularly associated with the food production and storage needs of modern society are essential to the mass production required. Refrigeration is an essential function of that large-scale food management system. The vapour compression refrigeration process has been widely adopted because of size and cost considerations. The vapour compression theoretical COP may be as high as 4. In other words 100kW of cooling can be achieved for 25kW of electrical compressor power. This excellent performance has resulted in the widespread adoption of vapour compression plant, however to function efficiently the refrigerant must possess properties suitable for the thermodynamic cycle and that led to the development of CFC, HCFC and subsequently HFC with the damaging environmental properties now realised.

However absorption offers the opportunity for a more sustainable solution – particularly where a waste heat source can be used for regeneration (refer to the introduction to absorption chilling). The regeneration process within the absorption and adsorption refrigeration processes is used to "regenerate the refrigerant" by boiling out the absorbent. This can be achieved at relatively low temperature and in fact temperatures of as low as 70^{o}C are possible (albeit at reduced coefficient of performance). The coefficient of performance relates the useful cooling work out to the work or energy input. The performance of the absorption plant is very much dictated by the regeneration temperature and the condenser temperature, however there are numerous opportunities for the utilisation of waste heat in industrial contexts.

Biomass and bio fuels simply cannot replace the fossil fuels that society currently consumes. This is not speculation it's a mathematical certainty. Every hectare of land has the capacity to produce approximately 10 tonnes of (oven dried tonnes) ODT biomass or approximately 180GJ of fuel energy, or very approximately 2 tonnes of liquid bio fuel e.g. RME. Thus an average family car would consume the bio diesel output of 0.5 hectare every year. The future for industry that consumes hundreds of thousands of litres of fuel oil every year has very much to be one of optimisation and integration rather than reliance on some anticipated development of bio-fuels – and why we have treated these as sustainable.

In this context some environmental legislation (e.g. the need to thermally treat some perceived pollutants), emissions regulations, and regulatory policy for waste to energy, planning and energy generally will likely have to be overhauled radically or risk being ignored as society meets its need. However fuel security, cost and scarcity of supply may bring such wholesale social change that that current regulatory positions are probably inconsequential other than to perhaps to delay much needed change.

This section of the report considers some of the prospects for heat recovery, waste heat use, bio-fuel and waste technologies that might be coupled with absorption cooling to reduce fossil fuel reliance.

5.2. Process waste heat -Technology examples

5.2.1. Chilling from flash steam

As particularly in the case of lithium Bromide single stage adsorption chilling, the regenerative heat source can be of relatively low temperature (although >70°C is best) the technology can be used with process waste heat.

For example, in the context of a large site with steam systems and elevated condensate return temperatures, there is sometimes a significant flash steam loss unless flash steam recovery is implemented.

Consequently where the processes have mean operational temperatures well above 100°C and condensate is discharged at higher temperatures it may under some circumstances be possible with larger specific plant or process to flash the condensate (or use as a pressurised liquid) for the purposes of absorption cooling.

It is more likely that this concept lends itself to specific process plant e.g. the combination of a methanol still and a chilled water plant. However the integration of flash steam recovery systems with absorption cooling is technologically simple and where the flash steam cannot easily be consumed directly for process use then absorption cooling may offer a cooling solution.

5.2.2. Condenser cooling and recovery

The integration of absorption cooling with process has to be considered carefully for there are other simple technical improvements and low cost applications that will improve the value of absorption cooling. Considering the pharmaceutical industries requirements for De-ionised water circulation temperature of 60°C or more and simultaneous demand for chilled WFI (water for injection). If gas fired CHP is used to generated electricity on site and the waste heat is used for Chilled water production. The condenser heat rejected at typically 35°C can be used to preheat the De - Ionised water heating before steam exchanger. Essentially the Absorption system condenser is being water-cooled - but providing useful preheat for the DI system.

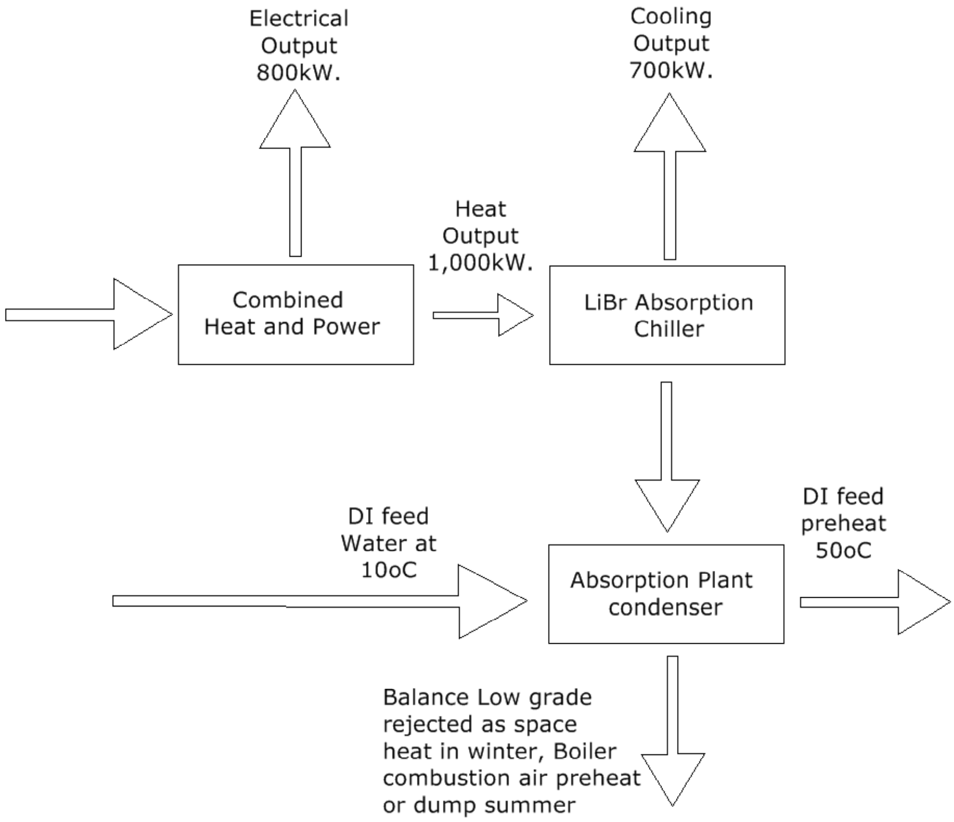


Figure 14 Condenser heat recovery

More than this, the balance of waste heat rejected from the condenser should be used for boiler combustion air preheat or seasonally for space heating. There are numerous opportunities for process integration – as yet unexploited.

5.3. Combined heat and power

Combined Heat and Power is a system that provides a mechanical power output and a heat (or some times also cooling) output and where more usually these outputs can be usefully employed in the industrial or commercial activities undertaken on site or geographically proximate sites. In some cases heat and power may be exported, however, it is often physically easier to export electricity and in some cases exporting electricity may offer an advantageous income stream. The terminology CHP covers a wide range of technologies and applications. Combined heat and power is old technology and routinely used worldwide in numerous forms.

Natural gas as fuel is the easiest of fuels to burn and the lack of any substantive carbon solids e.g. soot etc, make it relatively easy to burn in internal combustion engines and turbines e.g. in the context of CHP. Oil fuels can of course be burned in engines but heat recovery is slightly more difficult and although technically possible the lack of market demand dictates the extent of cost effective product available in the market.

A very significant capital investment is required for any fossil fuelled CHP system (circa £600 - 850/kW installed electrical capacity).

More often than not, the mechanical output from CHP is used to generate electricity. However, this need not be the case and some larger industrial plant is often used to drive compressors, and even low-pressure evaporative water treatment plants. CHP offers a diverse range of applications and integrated technologies.

The heat output from the CHP is often used for process or space heating. However, the heat output may also be used to drive single or compound absorption refrigeration plant – such that the heat output can be used to generate a cooling capacity and meet a cooling or refrigeration demand. The limitations of absorption refrigeration systems usually dictate that this type of equipment is used for cooling, rather than very low temperature applications. This is simply because to effect a high degree of recovery from the what will typically be a reciprocating engine, the temperature of the recovery system must be reduced to a lower common temperature to allow an acceptable return temperature for the engine (circa 85^oC)

Where the heat output is significant, e.g. in the case of a gas turbine, it is sometimes economic to generate high pressure steam with the exhaust gas and convert this energy to mechanical power using a steam turbine to generate additional electricity (the mechanical power output from the gas turbine would also be used to drive an power generation set. This arrangement is sometimes referred to as co-generation). The exhaust gas heat might recovered for:

- Steam generation
- Direct process use
- Absorption chilling

At the small end of the scale, CHP could essentially be similar to a car engine: a spark ignition, gas fired engine providing both mechanical and heat output. Most "packaged" CHP systems are based on reciprocating engines ranging in size from a few kW up to several MW. Many of the larger, relatively low speed engines (1,000 -1,500rpm) are extremely reliable and it is easy to generate steam and or directly fire CHP from the exhaust of larger engines. It is specifically the case that some Absorption plants are specifically designed to incorporate multi –heat sources allowing full flexibility of operational process plant. Thus the absorption plant is not tied to the CHP and vice versa

5.3.1. Why is conventional generation relatively inefficient?

At most industrial sites electricity is imported from the grid. Conventional generation using fossil fuels is not particularly efficient. The problem is that the point of generation is usually so far from the point of use that there is little opportunity to use the waste heat created from the generation process.

Burning coal and oil, a good station might have generation efficiency in the high 30%s. After transmission losses the effective generation efficiency is in the low 30%s.

Gas fired stations using a combination of GT and Steam turbine in what is termed the co-generative cycle, can achieve efficiencies in the high 50%s.

The mix of power station types, hydroelectric generation and particularly nuclear generation raise the overall UK performance to somewhere like 39% before losses.

CHP allows local generation and improved fuel efficiency. High generating efficiencies can be achieved with some reciprocating engines and if the waste heat generated by the engine is consumed on site the efficiency of primary fuel use can be very high indeed 70 – 80%.

In a typical and conventional energy supply arrangement, a site buys electricity from the grid and burns gas in conventional boilers. The imported electricity will have been generated and transmitted with an efficiency of typically 35%.

The best performance typically achieved with industrial boiler plant is an efficiency of say 80% and typically 15-20% or more of the primary energy burnt is lost as flue gas and other boiler losses. (Note boiler efficiency as opposed to combustion efficiency)

A good internal combustion (IC) reciprocating engine CHP can offer net generating efficiencies in the high 30%s (on a net basis) and additionally the waste heat can be used to reduce steam or hot water loads that would otherwise have been met with the conventional boiler.

In the broadest terms, a good IC reciprocating engine will provide a useful heat output of more than 40% of the fuel input. Overall, a good package may provide an efficiency of close to 80% and a significant reduction in primary energy consumption.

5.3.2. When is CHP appropriate?

Generating electricity on site is useful if the fuel burned to generate electricity is of low cost and electrical imports are expensive. Where imported electricity can be purchased cheaply, then CHP is generally not commercially viable.

The actual cost of electricity and fuel and the relative costs of fuel and electricity (the so-called spark gap) are therefore relevant.

To get a return on investment it is ***typically necessary to operate the equipment for a minimum of 5,000hours/annum*** but preferably more than 7,500hours/annum. Obviously, everything requires maintenance; however, most manufacturers will guarantee availability of 90%.

The heat, cooling and power outputs from a CHP are coincident i.e. they occur simultaneously. It is therefore necessary for the loads to be simultaneous and for the heat and power demands to be of the correct proportions. It is more common to size the CHP to meet electrical loads or parts of the electrical load (and in practice usually the base load) and then scale output until an economic balance on heat unit utilisation can be achieved.

A sector analysis is given in section 4 of this report. Although micro turbine close coupled absorption is cited by the EPA (Environmental Protection Agency) in America - the European experience of small-scale gas turbine has been less convincing. The market potential is therefore likely to be predominantly reciprocating engine CHP in ranging from 200kWe to possibly several MW (but more likely 800kWe to 1000kWe in the NI market.

5.3.3. Trigeneration

Trigeneration is the simultaneous production of electrical power, and heating or cooling (or sometimes both heating and cooling simultaneously). A Trigeneration system is essentially a Combined heat and power system adapted to incorporate an absorption chiller to use some or all of the waste heat from the CHP to produce chilled water. This improves the flexibility of operation allowing the recovery of heat during the winter for space heating and the cooling during the summer months for air conditioning. This maximizes the plant operating hours, the efficiency and thus the rate of return on investment.

In a typical arrangement the heat from the engine jacket and the exhaust gas are recovered through a series of heat exchangers to provide the regenerative heating required to operate a LiBr Absorption Chiller the heat is recovered from exhaust gas, lubrication oil cooler, intercooler and the water jacket cooling circuit.

As the single stage LiBr chiller is able to use lower water temperatures, the combination may be used to operate a single stage plant with a COP of approximately 0.7 whilst producing chilled water at 6°C to 8°C.

The cost of electrical distribution is considerably lower (in terms of both initial capital cost and ongoing operational cost) than the pipework required distributing hot or cold water. Accordingly the best return on investment is achieved where the generation plant can be located close to the heat and cooling demands.

The generator produces waste heat and the optimisation of heat use is the primary commercial objective. It is therefore good practice to size the CHP at some electrical size below the base load and scale back to ensure adequate heat utilization. However where absorption chilling can be used to meet a cooling load, a larger generator may be used if the waste heat produced is used to produce cooling and displace the electricity that would have otherwise been consumed in a vapour compression chiller. The balance is the additional capital cost of the generator as offset by the total additional displaced electrical load. (total to include displaced chiller motor power where this had been provided by vapour compression plant).

Where heat can be used it is always more economical to use this directly than to convert for cooling.

Many industrial and manufacturing facilities have an appropriate balance of power, heating and cooling requirements including those identified in this report of the Beef and sheep Meat/pig-meat Industries and chemical/Pharmaceutical industries.

It is unlikely that the basic Trigeneration plant can ever be designed with an optimal fit for power, heat and cooling loads and “base load” sizing must typically be employed to ensure the optimal commercial case. The integration of thermal storage (hot and cold), free cooling strategies and technology, conventional boilers and compression cooling plant will allow the maximum versatility, flexibility and commercial benefit in most circumstances. However a very thorough evaluation of the commercial case would be required in every circumstance.

5.4. Boiler flue gas heat recovery

Steam energy is still used widely in Northern Ireland and particularly in those sectors identified as key sectors for absorption opportunities. (The sectors regarded so are defined in section 4.0 of this report). Steam is very typically generated at 8barg or at a temperature of 175^{o}C. Steam is rarely used at this temperature and pressure but there are various benefits, not least, of which is the accumulation effect, derived generating at a higher pressure and reducing the steam pressure to the operational pressure.

In the boiler, the hot gases produced from the combustion of the fuel impart heat via the heat exchange surfaces to the heated medium (water) and in the multi-pass package boiler this is done with relatively high efficiency. None the less the laws of thermodynamics dictate that heat will flow from hot to cold and it is therefore the case that under most circumstances the exhaust gas temperature of a boiler will exceed (perhaps by only a few degrees) the boiler evaporation temperature. (Assumes no economiser, feed heater or super heaters). Complete combustion i.e. the oxidation of all the boiler fuel requires the addition of excess air (excess to stoichiometric requirements). Typically 20%-30% excess air will be required reducing the post combustion gas temperature and thus the thermal gradient within the boiler and increasing the volume of the flue gases.

A very significant portion of the fuel burned in the boiler is simply converted to heat that will be lost as hot exhaust gas – typically 15% of the fuel energy. Thus for a boiler that consumes 10 million kWh of gas fuel, the energy lost is 1.5 million kWh. This is an extraordinary waste of energy and money. But the heat is generally not utilisable because the evaporation temperature dictates the limits for heat utilisation.

In many cases, a substantial proportion is recovered by wet or dry scrubber and this is useful where the heat can be used in the form of hot water. However in many cases the condensate system cannot tolerate further heating, make up is small and much of this heat is simply wasted.

There is no significant technical barrier to using this waste heat for absorption chilling for sites where there is a steady steam demand. The sketch below illustrates just how heat might be recovered with a pressurised water circuit (similar to a feed heating economiser circuit). In such systems it would be necessary to ensure that heat can always be dissipated from the water circuit or that the flue gases may be by passed as shown.

The system should theoretically be capable of recovering up to perhaps 8% of the total energy in the flue gases or in the case of a 5,000kg hr steam load approximately 750,000kwh of heat energy or the equivalent of £50,000 cooling equivalent in Northern Ireland.

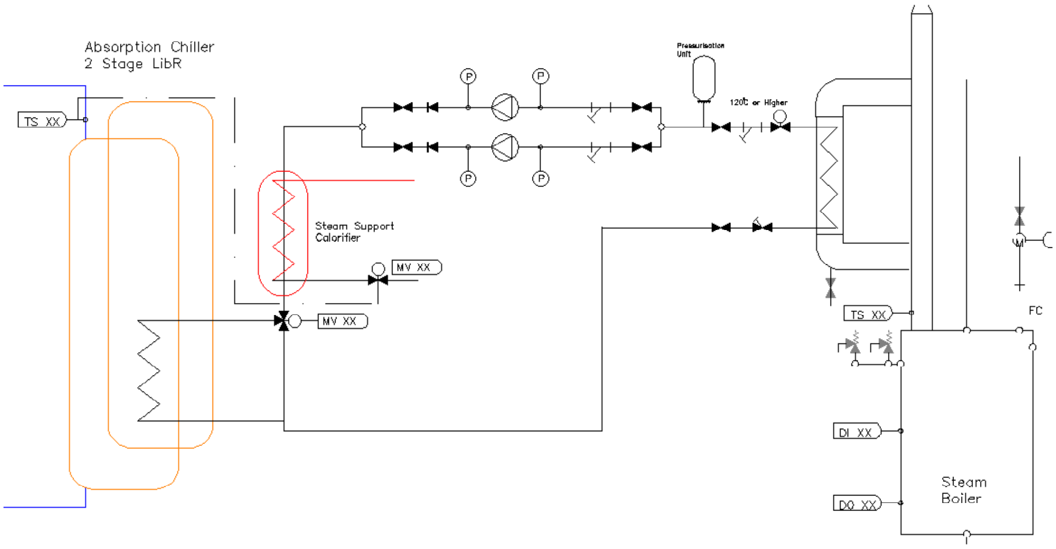


Figure 15 Waste heat and absorption recovery

Heat recovery from boiler exhaust for the purposes of cost effective absorption chilling has been employed in the USA and offers opportunity in Northern Ireland.

5.5. Biomass etc as a fuel source for absorption cooling.

Biomass may be burned to produce steam, hot water or heated thermal oil. The concept is simply the integration of two tried and tested technologies The biomass boiler and the Absorption chiller.

There are numerous combinations of plant possible. Higher regeneration temperatures are required for two stage (with improved COP) to compensate for the limitations imposed by low evaporation temperatures in AAR cold storage or chilling applications. Steam and thermal oil temperatures are suitable for two stage LiBr refrigeration plant and hot water is suitable for single stage LiBr or adsorption couples for higher evaporation temperature applications.

The economic case for absorption chilling is often supported by biomass because (currently at least) biomass offers a significant cost advantage over fossil fuels. However there are other complementary technical benefits derived from pairing absorption chilling with biomass, not least the potential to improve the load factor encountered by the biomass plant.

Biomass boilers are inherently less flexible than fossil fuel boilers. Depending on the fuel quality the plant must incorporate a great deal of refractory to retain thermal mass and inertia. Typically the rate of change of output is very significantly slower than that of any fossil fuel boiler.

In the steam plant, the thermal inertia of the boiler is not only dictated by the water volume stored at the saturated steam temperature and the control variation in upper and lower pressure control limit, but by the heat stored in the refractory mass that can be used either to support steaming or impart heat to volatilise new fuel charged. If the fuel is wet, charging new fuel will result in a steam pressure and temperature reduction until there is a net heat release.

The control of biomass steam boilers can be difficult, and like coal boilers there should be an expectation for sizeable steam pressure variation and extended recovery times. It is particularly difficult therefore to service sudden large heat demands.

As the biomass boiler incorporates a large mass of refractory, heating the boiler up and cooling it down wastes energy and results in refractory damage – this is inevitable and unavoidable. Moreover it takes a considerable time to bring the boiler (or more vitally) the furnace to operational temperature (perhaps as much as two hours) during which the boiler will (in our experience require some supervision, may be more to producing tar and will not produce steam at full pressure or respond at all well to load changes.

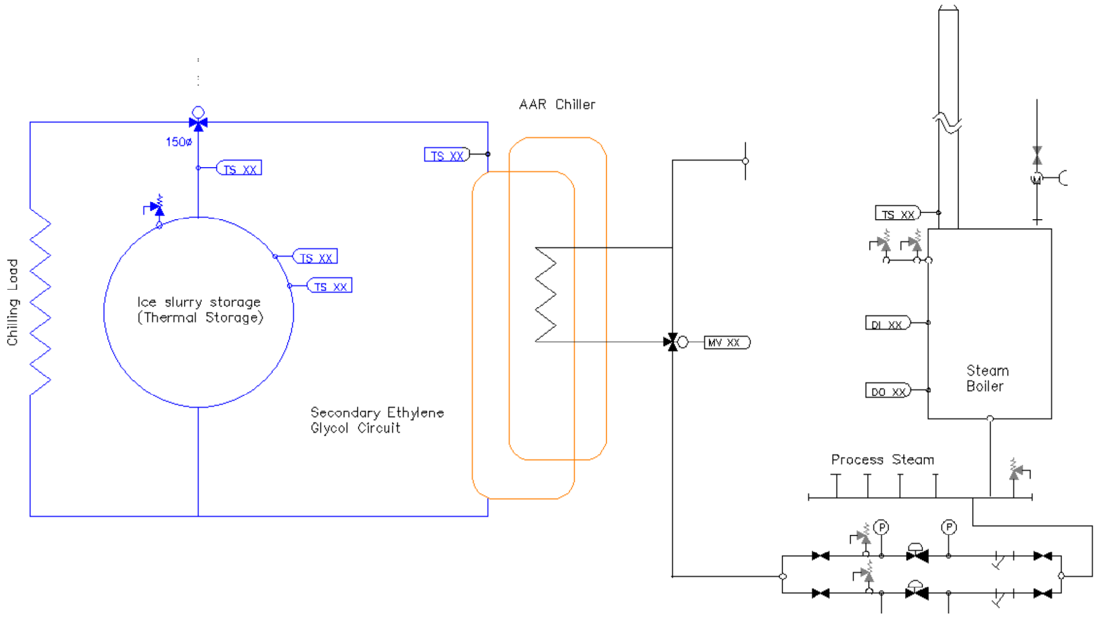


Figure 16 Ammonia AAR and Biomass Boiler

For the reasons given in the preceding paragraph, Biomass boilers are better suited to 24/7 operations. If the fuel is dry it is possible to smoulder fuel on the grate, keeping some temperature in the boiler to alleviate the stresses of complete shutdown and to accelerate the process of re start

Many Agri-food and manufacturing processes require broadly simultaneous heat and power loads. Absorption chilling can often offer a complementary and load flattening balance for process steam or heat loads and the operation of an absorption chiller offers a potentially improved commercial model for biomass.

There are therefore reciprocal technical and commercial advantages for biomass and absorption chilling.

The typical scenario is where a heat consuming production activity takes place during the day shift and the site has cold storage demands. A plant arrangement is illustrated above.

A full explanation of Biomass fuels is given in Appendix C to this report.

5.6. Waste to Energy?

Waste to energy may be otherwise considered as Biomass. However, there are some very important considerations that must be made in respect of the plant and the because of the nature of waste and the applicable legislation, the scale of operations will usually be very considerably larger than any biomass operation.

Figure 17 Celje European WID (BAT,BREF) compliant WtE

The very significant scale on which waste to energy is usually operated has led to the innovative use of absorption technology. The heat produced from a waste to energy plant can of course be used as conventional heat whether as steam or hot water.

An exceptional example of such plant is the Waste to Energy plant constructed in Celje, Slovenia. This plant is a combined heat and power plant providing power generation and district heating (no cooling). The plant is however a futuristic and small scale Waste Incineration directive compliant plant.

The plant burns the non-recyclable waste fractions form the nearby MBT plant where the cities municipal waste is processed and sewage sludge cake from the cities sewage disposal system. In this way the residents of the city use waste products to provide heat and power to Celje.

The plant has an annual Fuel input: 35.000 t of average CV 13.6 MJ/kg. The boiler produces approximately 15MWth output and this drives a steam turbine of approximately 2 MWe of steam at approximately 30bara and 350°C.

5.6.1. Absorption Heat Pumps and WTE

At a larger scale the Vestforbraending Waste to Energy Plant in Copenhagen, Denmark is the largestwaste to energy plant in Denmark. It produces 140,000 MWh of electricity and 440,000 MWh of district heating. In February 2006 the plant was upgraded including the installation of flue gas condensation and integrated absorption heat pumps.

This technology improvement represents the integrated use of waste to energy, flue gas heat recovery and absorption heat pumping. A combination that improves the sustainability of (WtE waste to energy) and represents novel but technically feasible use of absorption technology.

The waste to Energy plant operates with a conventional wet scrubbing system. The HCL and SO_2 contaminants are wet scrubbed. The flue gases are condensed using a wet scrubber and the heat in the flue gas then used to drive an absorption heat pump.

The Flue gases are cooled and condensed by a circulating cooling water system. This allows the latent heat in the flue gas to be recovered as well as the smaller sensible heat component. The heat recovered is typically 13MW but is at a temperature lower than that of the district heating system return. (It is low because at higher temperature the recovery system temperature is too high to effect condensation without excessive re-evaporation). However and as with conventional heat pumps, the low temperature energy is raised using steam driven absorption chillers to a temperature of between 60°C and 80°C adequate for the district heating return.

These projects represent multi million pound investments but they demonstrate the future for absorption chilling, waste to energy and the sustainable use of energy at large scale.

Vitally the project demonstrates the technical viability of two important concepts, namely

- Heat recovery from economisers (refer also to 5.4)
- The use of absorption technology for heat recovery and upgrade.

In the Vestforbraending Waste to Energy Plant, the low-grade heat recovered from the flue gas condenser is raised to between 60°C and 80°C by two steam driven absorption heat pumps.

The general arrangement/ concept is illustrated in the sketch below.

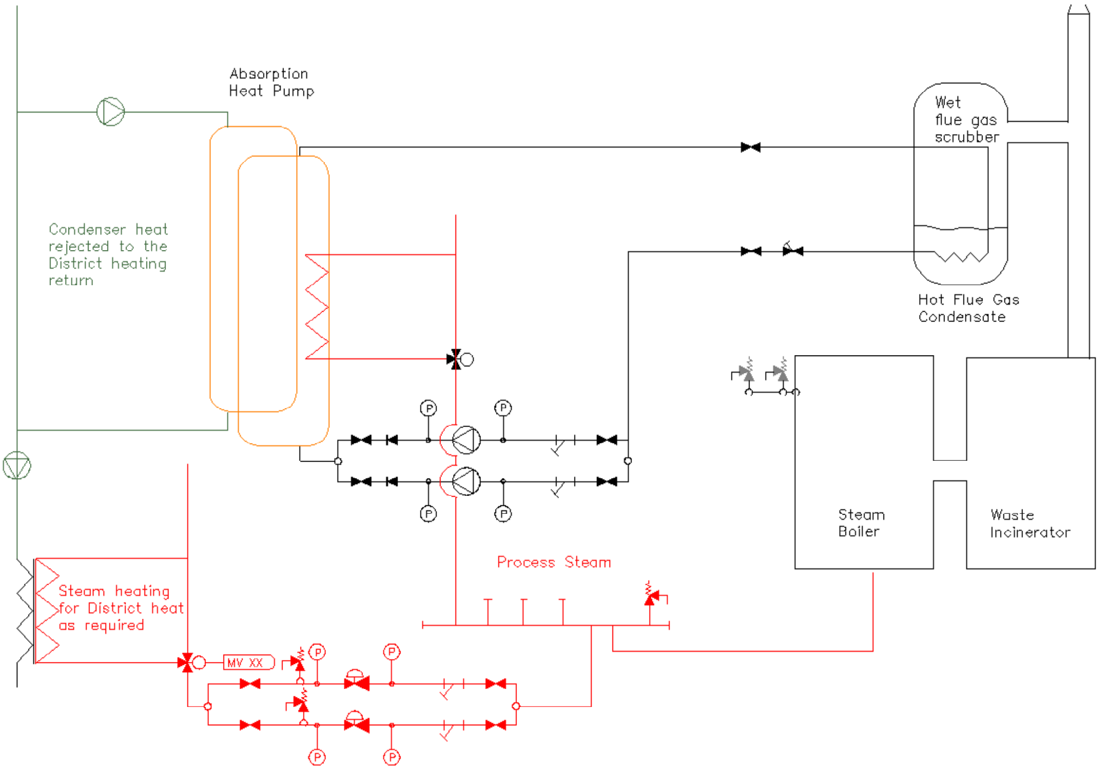


Figure 18 Absorption Heat Pump

5.7. Liquid biofuels

Refer to section 5.3 CHP of this report

5.8. Solar absorption cooling

There is currently more than 12MW or a little over 3,000 tonnes refrigeration (more than 100 systems) in Europe that use solar thermal collectors for solar air-conditioning building. The bulk of these are in Germany and the remainder in Spain and Greece. Most of the systems are realized in Germany (39.1%), Spain (27.5%) and Greece. Most of these systems (more than 60%) employ absorption based mechanisms.

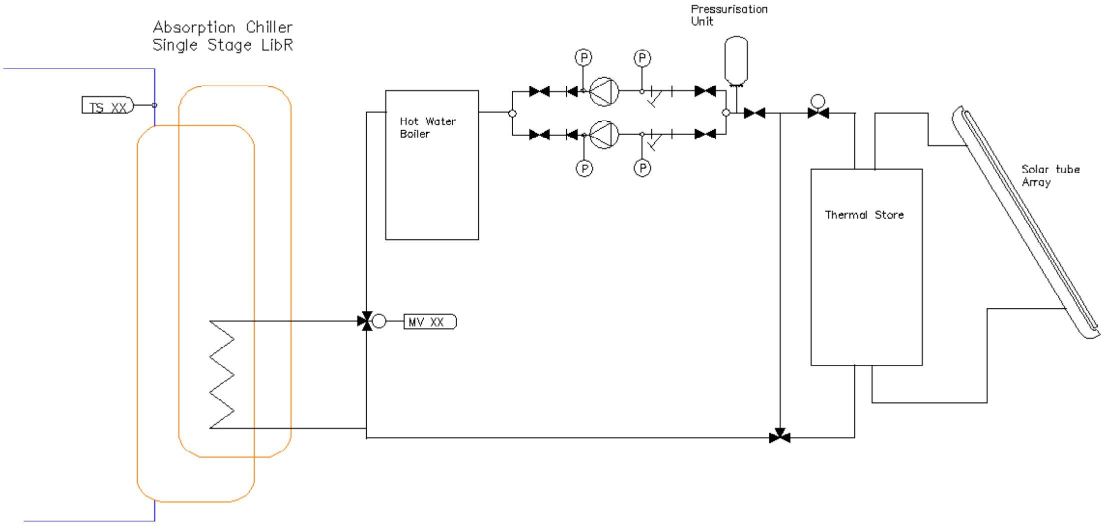
In the US there considerably more experimentation and installed cooling. There are numerous US companies and some European manufacturers supporting the installation of simple solar tube array and single stage LiBr plant.

The commercialisation of Solar Cooling is a relatively new event for Absorption chilling. The advent of evacuated tubes has allowed the recovery of a water temperature sufficiently high to directly drive or support the regeneration function in single stage LiBr absorption plants.

Conventional designs have generally have adopted the principal of a single stage LiBr absorption chiller or adsorption pair driven by low temperature hot water from solar collectors. However, Silica gel adsorption and ammonia absorption have both been used successfully with solar cooling systems. However research and development into high-temperature solar two-stage absorption chillers is now under way with various plants now being tested. The principal limitation is the solar collection (not least the pressure limitations) and the need to raise the temperature of the water to a point where an effective COP can be achieved with the absorption system. In addition the heat used for the chiller and the heat removed from the building must de dissipated effectively if the chiller is to have any commercially satisfactory COP. Thus dry air coolers, spay evaporators or cooling towers must also be employed to operate the plant.

In most cases the solar collection can be used effectively to supplement boiler heating thus providing substantive part of the heat required for the generator and educing fossil fuel consumption.

Figure 19 Solar Absorption cooling



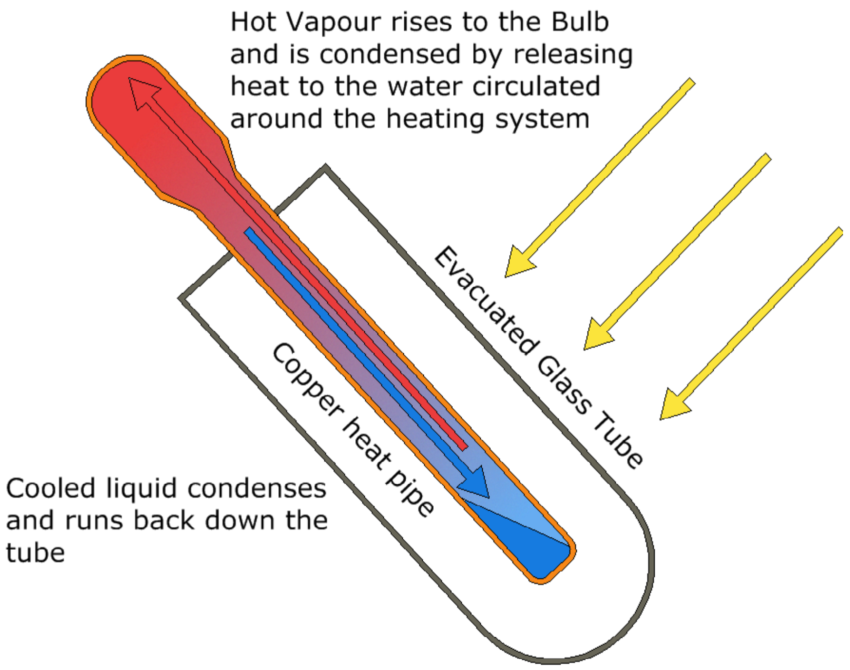


Figure 20 Evacuated solar collector

In the evacuated heat pipe collector, a copper tube sits in side the evacuated glass tube. The glass tube is generally mounted within a parabolic mirrored collector. The suns radiation shining on the tube and reflector is reflected to the glass tube and through the vacuum to heat the copper tube. A depressed boiling point fluid within the tube is boiled with the heat applied and the vapour rises within the tube to a header bulb which is cooled by the circulated domestic hot water or heating medium. The dbf condenses and runs back down the inside of the tube to be reheated by solar gain.

In Southern latitudes the temperature achieved with solar tubes can be sufficiently high to operate the solar absorption cooling plant, very reliably without boiler support. In northern latitudes there is sufficient sunshine even on a cold winters day to produce temperatures in excess of 50°C on occasion – certainly sufficient to support the heating needs of a building. However the extent to which summer solar incidence will support economic installation of solar cooling is less certain in Northern Ireland. The tubes will work as soon as there is radiation. Even on a freezing cold winter’s day solar tubes system will still provide energy. The tubes will actually function without direct solar incidence but the ambient light and radiation have to be sufficient.

Solar cooling requires careful attention to building design and often the adoption of cooling structures like chill beams and ceilings. Solar cooling is more likely to be integrated as part of a new design rather than an easy retrofit – certainly for Northern Irish applications.

5.9. Thermal storage

In sizing any plant for a heating or cooling application it must be borne in mind that the demand will in many cases, change throughout the day or the year.

One way round this is to provide thermal storage. This is particularly useful for absorption systems that must serve an intermittent load. Just like thermal storage for heating systems, cooling systems can utilise the large specific heat capacity of water or sometimes ice to store “cold” and subsequently assist the chiller at peak opeational times.

These systems serve two useful purposes in the context of purely absorption systems:

- The load variation is reduced and the need to modulate the output is reduced.
- The required plant capacity and the capital cost may be reduced

Despite being particularly useful for the absorption system, the concept of storage may be appl,ied to both absorption and vapour compression technologies, often for example allowing the operation of chiller plant to aviod peak electrical charges.

An explanation of thermal storage is given in Appendix C

5.10. Summary of sustainable technology options.

Sustainable cooling is as much about effective system integration and heat recovery as it is about fuel choice. All fuel resources are essentially finite unless the rate of fuel consumption does not exceed that which can be continuously recovered from soalr, biomass or wind energy resources. This however, is not an immediately realistic prospect for industry. Fundamental change is required What is not clear is whether that change wil be;

- voluntarily adopted in recognition of impending supply difficulty.
- achieved by active fiscal coercion, e.g. enhanced carbon taxation.
- or simply driven by market price.
- or more likely comninations of these factors.

Sustainable cooling can be cost effectively accomodated in buildings and in industry with relatively little technical difficulty as confirmed by the examples given in the precedding sections of this report.

Although there are many potential arrangments and fuels suitable for operation with absorption plant, the principal sustainable opportunities are, considered in the following table;

Sustainable Source	**Comments**	**Examples**
Biomass	Wide range of biomass fuels. Liquid biomass fules are of premium quality and this reflected in the price. Solid biomass and absorption operations offer technical benefitfrom improved load factor.	Wood chip Wood Pellets Willow Chip Miscanthus Waste to Energy
Waste Heat	Many industrial proicesses result in waste heat. Most boilers produce an exhaust gas stream at high temperature. There are numerous opportunities to integrate cooling	Boiler economiser heat recovery. Flash steam utilisation Furnace exhaust WTE thermo compression
CHP	Combined heat and power is an established technology and operated with absorption cooling can provide greatly improved utilisation and conomic return.	Hospitals Government eastates and offices Dairy industry Injection Moulding Pharmaceutical Industry Hotels and leisure industry
Solar	Solar absorption cooling may be integrated with LTHW systems to provide heating and cooling. The applications are currently limited in Northern Ireland save for new build. Research into advance adsorption pairings will likely improve low generator temperature options.	Low carbon homs Offices Small commercial applications

These principal opportunities are modelled in the following sections of this report - illustrating the current and projected commercial prospects.

6. MODELLING SUSTAINABLE ABSORPTION CHILLING

The following report sections consider the technical and commercial application of the technologies discussed in a Northern Irish context i.e. as applied to actual industries in Northern Ireland.

In some cases it is possible to cite the feasibility of real projects in others we have constructed models to provide provisional examination of the commercial viability.

6.1. Biomass fired absorption cooling

Biomass is many different things (refer to Appendices A and B). The cost and the availability have impact on the viability of absorption chilling.

To consider the economics of biomass and absorption chilling, the commercial case for a real installation in Northern Ireland is considered. The project is for a larger liquid milk dairy company, reflecting a large and vital part of the Northern Irish Economy. Cooling is used for intake chilling, pasteurisation, and solid and liquid products storage. (Refer to 4.3.2 Dairy Industry) represents a significant cost to the business.

The basic technical arrangement is that biomass is combusted to provide heat in the form of hot water or steam. The heat thus produced may be used for heating and or cooling (refer to section 5.5 also)

6.1.1. Dairy Industry - AAR for raw milk chill (evaporation at –8°C)

The project reflects a medium sized liquid milk dairy and considers the technical integration of steam biomass boiler and Ammonia absorption chiller operating with an evaporation temperature of –8°C (A case study documenting a similar project is appended to this report). The project considers the actual and intermittent operating conditions.

Biomass steam plant is not common but not difficult technology. Such plant is already installed and operational in Northern Ireland. Ammonia absorption chilling is less common in the UK but routinely used through out the rest of the world – particularly so with steam and the regenerator heating source.

At the evaporation temperature and the condensing temperatures available in Northern Ireland the plant will only achieve a COP of approximately 0.58.

The base model is considered for waste wood fuel, a non-virgin untreated fuel. (Refer to Appendices A & B). The base model adopts a real load profile.

The example site used approximately 2.2 million kWh of kerosene of approximately 214,000litres of fuel worth approximately £97,000 per annum. The site further consumes approximately 2.1million kWh of electricity worth approximately £200,000 power annum.

The cooling is used principally for the raw milk chill and the post pasteurisation cooling and these loads are incurred over an extended period, e.g. 12 hours or more over the day. Despite this there is a very significant cooling load. The site already has a 10 tonne ice store that is supplied directly from an R22 plant. The installed cooling capacity approaches an estimated 750kW of R22 plant and the daytime load is estimated to approach 500kW as supported with ice bank depletion.

The heat load at the site is currently met with two small conventional steam boilers. Steam is necessary because of the need to meet and hold pasteurisation temperatures.

The proposed expansions to the site resulted in a projected fuel consumption of 3,790,000kWh approximately £165,000 per annum. The projected cooling demands would also increase from 500kW to approximately 850kW.

In the revised and sustainable model, a single steam biomass boiler will generate steam at 8barg. The plant will be supported by the two existing kerosene fired steam boilers. The biomass boiler sized at 1.6MW or approximately 2,800kg/hr f&a 100°C, will meet virtually all of steam demands but the existing boilers will provide top up and standby if required. The boiler is operated on Non-virgin – untreated[9] timber available at £20/tonne.

The absorption cooling plant selected is designed to meet the bulk of the daytime load and produce ice with existing ice storage. (This was a project requirement). A single stage ammonia absorption chiller of 600kW cooling capacity is to be installed. Biomass boilers do not perform well at low load and the overnight and the icing duty is a useful complementary load for the biomass system. (Refer to Appendix D Thermal/Ice storage). It is recognised that peak load plant will be required,

The model is summarised as follows:

---

[9] Refer to Appendix A and B for waste definitions and classifications

Technical summary	
Boiler size (from 100@8barg)	2,838kg/hr
Boiler output	1,600kW
Steam pressure	8barg
Annual Ops Hrs	8146.8
Availability	93.00%
Existing boiler efficiency	78%
Displaced heat	2,956,500kWh
Displaced fuel	3,790,385kWh
Displaced fuel	367,999 litre
Displaced fuel cost	£165,599
Base fuel index	£0.45 per litre
Displaced power	911,162kWh
Base power index	£0.09 per kWh
Value displaced power	£83,462
Variable costs	
Fuel CV	16.00 GJ/tonne
Bio fuel cost	£20.00 per tonne
Annual fuel Input	2029 tonne
Annual fuel cost	£40,585
Fixed costs	
Salaries	Included
Maintenance	£12,000
Total costs	£52,585
Cost saving	£249,062
Op profit net of tax	£196,477
Capital Investment	£900,000
Simple payback	4.58
Carbon reduction	1,431 tonnes

The capital cost is derived from the Known cost of constructing the Biomass steam Boiler at Strabane (approximately £475,000 and capable of 1.6MWth) and the estimated cost of a 600kW AAR plant of £400,000. The cost will vary significantly from site to site and it may be possible to reduce capital cost.

The model can be improved with increased ice storage. Using Ice storage flattens the load profile and allows a smaller plant to be operated with higher utilisation. The payback reduces to a little over 4 years, reducing further where tariff benefits may be applied.

This model was constructed burning waste wood and operating with an evaporation temperature of –8°C thus necessitating the use of AAR.

Other options for improving project economics

The base model is considered for waste wood fuel, a non-virgin untreated fuel. (Refer to Appendices A and B). The base model adopts a real load profile. If the boiler utilisation can be improved then the case for investment improves dramatically.

Many processes will already have higher boiler utilisation e.g. 60% or more. However the overall system utilisation can be improved with the introduction of ice storage revised production strategies and increased production. For example in some production activities conducting the same cooling over a slightly longer period will allow a smaller cooling plant to be operated with a higher utilisation.

Sharing process boiler plant with neighbouring process industry, or selling heat to industry or local industrial parks for space heating is also a possibility.

Consider the same project with improved boiler utilisation only e.g. 70% as opposed to 51% in the model situation. In other words the utilisation of the biomass boiler is improved to 70% - There is no increase in cooling load.

Technical summary

Boiler size (from 100@8barg)	2,838kg/hr
Boiler output	1,600kW
Steam pressure	8barg
Annual Ops Hrs	8146.8
Availability	93.00%
Existing boiler efficiency	78%
Displaced heat	5,475,000kWh
Displaced fuel	7,019,231kWh
Displaced fuel	681,479 litre
Displaced fuel cost	£306,665
Base fuel index	£0.45 per litre
Displaced power	911,162kWh
Base power index	£0.09 per kWh
Value displaced power	£83,462
Variable costs	
Fuel CV	16.00 GJ/tonne
Bio fuel cost	£20.00 per tonne
Annual fuel Input	2738 tonne
Annual fuel cost	£54,751
Fixed costs	
Salaries	Included
Maintenance	£12,000
Total costs	£66,751
Cost saving	£390,128
Op profit net of tax	£323,377
Capital Investment	£900,000
Simple payback	2.78
Carbon reduction	2,238 tonnes

The payback would reduce from approximately 4 years to 2.7 years and there could be little doubt that the Waste wood/AAR absorption chilling combination would become an attractive economic proposition.

The energy content of most solid biomass materials is very similar. However the burning, fuel processing and handling characteristics are very different characteristics - resulting in significant cost implication for some fuels.

This model reflects the combustion of untreated non-virgin wood. The same model is considered for other biomass fuels.

6.1.2. AAR with dried willow chip

Willow chip is an easily burned and homogeneous fuel. The supply in Northern Ireland is limited but increasing refer to (Appendices A&B)

Willow chip is generally available dried to 16% or less moisture content expressed as % wt weight (%ww). At this moisture content the fuel has a net effective calorific value of 14.3GJ/tonne or approximately 3.9kWh/kg.

The model is recalculated as shown.

Technical summary	
Boiler size (from 100@8barg)	2,838kg/hr
Boiler output	1,600kW
Steam pressure	8barg
Annual Ops Hrs	8146.8
Availability	93.00%
Existing boiler efficiency	78%
Displaced heat	2,956,500kWh
Displaced fuel	3,790,385kWh
Displaced fuel	367,999 litre
Displaced fuel cost	£165,599
Base fuel index	£0.45 per litre
Displaced power	911,162kWh
Base power index	£0.09 per kWh
Value displaced power	£83,462
Variable costs	
Fuel CV	14.30 GJ/tonne
Bio fuel cost	£85.00 per tonne
Annual fuel Input	2270 tonne
Annual fuel cost	£192,990
Fixed costs	
Salaries	Included
Maintenance	£12,000
Total costs	£204,990
Cost saving	£249,062
Op profit net of tax	£44,072
Capital Investment	£900,000
Simple payback	20.42
Carbon reduction	1,431 tonnes

The payback soars from 4 years to 20 years reflecting the premium status of willow chip as a versatile biomass fuel. This reflects the high cost associated with willow production and drying..

This cannot be considered economic in conventional terms. Fossil fuel prices would have to rise by some 20% above the base model and willow fuel prices drop to 50 £tonne or £3.50/GJ before an economic case could be made. (This is unlikely for at these prices the costs of production could not be covered).

Improving the situation with boiler utilisation.

The base model is considered for waste wood fuel, a non-virgin untreated fuel. (Refer to Appendices A&B). The base model adopts a real load profile for one particular factory. If the boiler utilisation can be improved then the case for investment improves dramatically.

Many processes will already have higher boiler utilisation e.g. 60% or more. However the overall system utilisation can be improved with the introduction of ice storage revised production strategies and increased production. For example in some production activities conducting the same cooling over a slightly longer period will allow a smaller cooling plant to be operated with a higher utilisation.

Sharing process boiler plant with neighbouring process industry, or selling heat to industry or local industrial parks for space heating is also a possibility.

Consider the same project with improved boiler utilisation e.g. 70% as opposed to 51% in the real situation.

Technical summary

Boiler size (from 100@8barg)	2,838kg/hr
Boiler output	1,600kW
Steam pressure	8barg
Annual Ops Hrs	8146.8
Availability	93.00%
Existing boiler efficiency	78%
Displaced heat	5,562,600kWh
Displaced fuel	7,131,538kWh
Displaced fuel	692,382 litre
Displaced fuel cost	£311,572
Base fuel index	£0.45 per litre
Displaced power	911,162kWh
Base power index	£0.09 per kWh
Value displaced power	£83,462
Variable costs	
Fuel CV	14.30 GJ/tonne
Bio fuel cost	£85.00 per tonne
Annual fuel Input	3091 tonne
Annual fuel cost	£262,698
Fixed costs	
Salaries	Included
Maintenance	£12,000
Total costs	£274,698
Cost saving	£395,034
Op profit net of tax	£120,336
Capital Investment	£900,000
Simple payback	7.48
Carbon reduction	2,266 tonnes

The payback on Willow chip with a higher boiler utilisation reduces to a little over 7 years and were there also a 20% increase in utility costs the project payback would reduce to approximately 4.5 years.

The life cycle costs for the project illustrating a good strong net present cost saving over the alternate of fuel oil and electricity costs for conventional boilers and chiller plant

6.1.3. AAR with sawmill Co-products at 50%

Clean sawmill co-product is currently available in Northern Ireland. The fuel quality is variable and the chip moisture content can vary between 30% and 60% moisture content. Current chip prices are approximately £35 +/-10% delivered.

The same AAR model is re-run for this fuel.

Technical summary	
Boiler size (from 100@8barg)	2,838kg/hr
Boiler output	1,600kW
Steam pressure	8barg
Annual Ops Hrs	8146.8
Availability	93.00%
Existing boiler efficiency	78%
Displaced heat	2,956,500kWh
Displaced fuel	3,790,385kWh
Displaced fuel	367,999 litre
Displaced fuel cost	£165,599
Base fuel index	£0.45 per litre
Displaced power	911,162kWh
Base power index	£0.09 per kWh
Value displaced power	£83,462
Variable costs	
Fuel CV	7.90 GJ/tonne
Bio fuel cost	£35.00 per tonne
Annual fuel Input	4110 tonne
Annual fuel cost	£143,844
Fixed costs	
Salaries	Included
Maintenance	£12,000
Total costs	£155,844
Cost saving	£249,062
Op profit net of tax	£93,218
Capital Investment	£900,000
Simple payback	9.65
Carbon reduction	1,431 tonnes

The situation is improved dramatically with increasing utility cost and where there is 20% increase in oil kerosene cost (the alternate fuel in this case to

54p/litre and a 30% increase in electricity to 11.9p/kWh the project and for cheaper bio-fuel at 30/tonne or 3.70/GJ the project payback reduces to 5 years.

It should be understood that this is a payback as evaluated against the cost and operation of the conventional equivalent. The purchase of a vapour compression chiller is not insignificant and then that plant will continue to burn electricity over the product life cycle.

Improving the situation with boiler utilisation.

The base model is considered for waste wood fuel, a non-virgin untreated fuel. (Refer to Appendices A & B). The base model adopts a real load profile. If the boiler utilisation can be improved then the case for investment improves dramatically.

Many processes will already have higher boiler utilisation e.g. 60% or more. However the overall system utilisation can be improved with the introduction of ice storage revised production strategies and increased production. For example in some production activities conducting the same cooling over a slightly longer period will allow a smaller cooling plant to be operated with a higher utilisation.

Sharing process boiler plant with neighbouring process industry, or selling heat to industry or local industrial parks for space heating is also a possibility.

Consider the same project with improved boiler utilisation e.g. 70% as opposed to 51% in the real situation.

Technical summary	
Boiler size (from 100@8barg)	2,838kg/hr
Boiler output	1,600kW
Steam pressure	8barg
Annual Ops Hrs	8146.8
Availability	93.00%
Existing boiler efficiency	78%
Displaced heat	5,562,600kWh
Displaced fuel	7,131,538kWh
Displaced fuel	692,382 litre
Displaced fuel cost	£311,572
Base fuel index	£0.45 per litre
Displaced power	911,162kWh
Base power index	£0.09 per kWh
Value displaced power	£83,462
Variable costs	
Fuel CV	7.90 GJ/tonne
Bio fuel cost	£35.00 per tonne
Annual fuel Input	5594 tonne
Annual fuel cost	£195,801
Fixed costs	
Salaries	Included
Maintenance	£12,000
Total costs	£207,801
Cost saving	£395,034
Op profit net of tax	£187,233
Capital Investment	£900,000
Simple payback	4.81
Carbon reduction	2,266 tonnes

Thus if the biomass boiler can be well utilised displacing oil fuel, then the economic case for using a wet sawmill co product can be demonstrated. Utility price increases beyond the base case improve the economic case more significantly still.

6.1.4. AAR with commercial wood pellets

Is not considered further as these are a premium fuel of price comparable with oil or gas.

6.1.5. Summary of AAR and Biomass models.

The principal options were modelled for a real industrial scenario in Northern Ireland. The actual utilisation of 51% was considered against current costs.

Fuel	Untreated waste wood (£20/tonne)		Willow (£85/tonne)		Sawmill residues	
	Payback	CO_2 Red	Payback	CO_2 Red	Payback	CO_2 Red
Boiler Utilisation 50%, Oil 45p/litre, Electricity 9.16p/kWh	4.58	1,431	20.4	1,431	9.65	1,431
Boiler Utilisation 50%, Oil 54p/litre (+20%), Electricity 10.9p/kWh(+20)%	3.65	1,431	9.5	1,431	6.29	1,431
Boiler Utilisation 70%, Oil 45p/litre, Electricity 9.16p/kWh	2.78	2,238	7.4	2226	4.81	2,266
Boiler Utilisation 70%, Oil 54p/litre (+20%), Electricity 10.9p/kWh(+20)%	2.25	2,238	4.5	2226	3.38	2,266

Note these indications are only relevant to Northern Ireland

6.1.6. Biomass and LiBr for Chill water (evaporation 4-6°C)

The LiBr chiller (as explained in section 2 of this report) works with high vacuum and relatively high evaporation temperatures but the plant is substantially less expensive and readily available in the UK.

At the higher evaporation temperatures associated with air conditioning and chilled water production a singe stage LiBr plant will operate with a COP of approximately 0.7 in Northern Ireland (refer to the performance curves given in section 2.0 of this report)

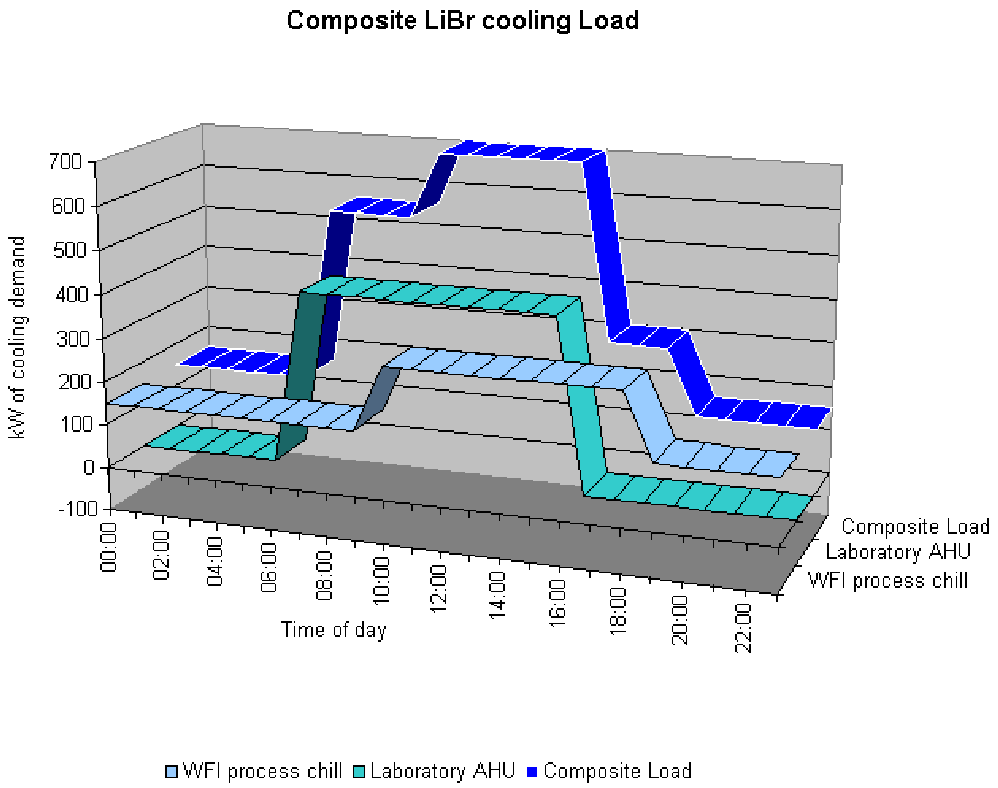
In the case of intermittent AHU loads then some consideration must be given to the relatively inflexibility of absorption cooling and biomass and the need therefore to maintain a continuous over night load.

In the context of larger buildings this can be achieved by using chilled water storage, pre-chilling the building, optimising biomass boiler sizes in respect of heating and hot water loads. Sites with high occupancy and significant 24 hour heating and cooling loads e.g. hospitals have almost ideal load characteristics.

However many industrial contexts have demands for steam and cooling at the same time e.g. numerous food and drink, pharmaceutical and chemical industries applications as discussed in section 4 of this report.

The following is constructed example considers a site with 24hr production but chilled water demands during day shifts and some but substantially reduced steam demand overnight. The model is constructed assuming the use of a 600kW (cooling capacity) chiller.

The constructed load profile is illustrated below



The model is run again initially for dry waste wood with moisture content somewhere less than 16% and a value of approximately £20/tonne.

The model summary is as follows:

Technical summary	
Boiler size (from 100@8barg)	2,838kg/hr
Boiler output	1,600kW
Steam pressure	8barg
Annual Ops Hrs	8146.8
Availability	93.00%
Thermal Output	8,598,879kWh
Existing boiler efficiency	75%
Displaced heat	4,237,650kWh
Displaced fuel	5,650,200kWh
Displaced fuel	548,563 litre
Displaced fuel cost	£246,853
Base fuel index	£0.45 per litre
Displaced power	1,017,620kWh
Base power index	£0.09 per kWh
Value displaced power	£93,214
Variable costs	
Fuel CV	16.00 GJ/tonne
Bio fuel cost	£20.00 per tonne
Annual fuel Input	2418 tonne
Annual fuel cost	£48,369
Fixed costs	
Salaries	Included
Maintenance	£12,000
Total costs	£60,369
Cost saving	£340,067
Op profit net of tax	£279,699
Capital Investment	£650,000
Simple payback	2.32
Carbon reduction	1,952 tonnes

The significantly reduced capital cost for the LiBr plant offering a notable improvement in payback. In this model the boiler is boiler is loaded at approximately 70% - a high utilisation.

The same model can be run for different biomass fuels,

6.1.7. LiBr with willow

Willow chip is generally available dried to 16% or less moisture content expressed as % wt weight (%ww). At this moisture content the fuel has a net effective calorific value of 14.3GJ/tonne or approximately 3.9kWh/kg.

The model is recalculated as shown.

Technical summary	
Boiler size (from 100@8barg)	2,838kg/hr
Boiler output	1,600kW
Steam pressure	8barg
Annual Ops Hrs	8146.8
Availability	93.00%
Thermal Output	8,598,879kWh
Existing boiler efficiency	75%
Displaced heat	4,237,650kWh
Displaced fuel	5,650,200kWh
Displaced fuel	548,563 litre
Displaced fuel cost	£246,853
Base fuel index	£0.45 per litre
Displaced power	1,017,620kWh
Base power index	£0.09 per kWh
Value displaced power	£93,214
Variable costs	
Fuel CV	14.30 GJ/tonne
Bio fuel cost	£85.00 per tonne
Annual fuel Input	2706 tonne
Annual fuel cost	£230,005
Fixed costs	
Salaries	Included
Maintenance	£12,000
Total costs	£242,005
Cost saving	£340,067
Op profit net of tax	£98,062
Capital Investment	£650,000
Simple payback	6.63
Carbon reduction	1,952 tonnes

Again the premium paid for good quality fuel reflects in the payback that can be achieved. However the reduced cost of LiBr plant and the packaged nature of this plant provide a much better payback than the AAR systems.

A modest increase in utility prices e.g. 10% so that electricity rose to 10.1p/kWh and kerosene to 49.5p/litre would reduce the payback to years.

6.1.8. LiBr with clean wood chip (sawmill co-product)

Clean sawmill co-product is currently available in Northern Ireland. The fuel quality is variable and the chip moisture content can vary between 30% and 60% moisture content. Current chip prices are approximately £35 +/-10% delivered. The model is recalculated as shown.

Technical summary	
Boiler size (from 100@8barg)	2,838kg/hr
Boiler output	1,600kW
Steam pressure	8barg
Annual Ops Hrs	8146.8
Availability	93.00%
Thermal Output	8,598,879kWh
Existing boiler efficiency	75%
Displaced heat	4,237,650kWh
Displaced fuel	5,650,200kWh
Displaced fuel	548,563 litre
Displaced fuel cost	£246,853
Base fuel index	£0.45 per litre
Displaced power	1,017,620kWh
Base power index	£0.09 per kWh
Value displaced power	£93,214
Variable costs	
Fuel CV	7.90 GJ/tonne
Bio fuel cost	£35.00 per tonne
Annual fuel Input	4898 tonne
Annual fuel cost	£171,433
Fixed costs	
Salaries	Included
Maintenance	£12,000
Total costs	£183,433
Cost saving	£340,067
Op profit net of tax	£156,634
Capital Investment	£650,000
Simple payback	4.15
Carbon reduction	1,952 tonnes

If poorer quality fuel is accepted then the system can offer an improved payback. The model as described when operated on wet sawmill chip (55% ww) gives a payback of 4 years.

A modest increase in utility prices e.g. 10% so that electricity rose to 10.1p/kWh and kerosene to 49.5p/litre would reduce the payback to 3½ years.

6.1.9. Summary of Biomass with LiBr chilling

The principal options were modelled for a constructed industrial scenario in Northern Ireland. The assumed boiler utilisation of 70% was considered against current costs.

Fuel	Untreated waste wood (£20/tonne)		Willow (£85/tonne)		Sawmill residues	
	Payback	CO_2 Red	Payback	CO_2 Red	Payback	CO_2 Red
Boiler Utilisation 70%, Oil 45p/litre, Electricity 9.16p/kWh	2.32	1,952	6.63	1,952	4.15	1,952
Boiler Utilisation 70%, Oil 49p/litre (+10%), Electricity 10p/kWh(+10%),	2.1	1,952	4.9	1,952	3.4	1,952
Boiler Utilisation 50%, Oil 54p/litre (+20%), Electricity 10.9p/kWh(+20)%	1.9	1,952	3.9	1,952	2.9	1,952

Note these indications are only relevant to Northern Ireland

6.2. Biomass and absorption chilling conclusions

- The regenerator requirements of AAR require elevated temperatures e.g. 120°C or above. This limits operation to steam or MPHW systems.
- LiBr systems will operate with water temperatures to 80°C, albeit at reduced COP.
- AAR is currently commercially viable with low cost waste wood fuel
- LiBr is currently commercially Viable with Low cost waste wood fuel.
- For any absorption biomass couple to be effective the boiler utilisation has to be very high e.g. 70% or more. Accurate plant sizing is required.
- Absorption chilling Biomass combinations are unlikely to be viable unless the absorption load is only part of the overall site heat load
- Absorption is unlikely to be viable with premium fuels e.g. pellets or willow chip
- The use of absorption chilling and thermal storage allows the improved use of biomass in circumstance where the intermittency of either heat or cooling loads make biomass a difficult technical solution.
- There will be good scope for biomass in food manufacturing, pharmaceutical and hospitality industries – three key sectors in Northern Ireland.
- Biomass fuel restriction and rapid cost escalation will be the most likely barrier to implementation
- The legal requirements for HCFC use and disposal will act as a catalyst for installation.

- Generally projects a more sensitive to electricity and then oil cost and even moderate increases in these e.g. 20% significantly improve the economic case for non premium fuel combinations.
- Significant life cycle cost savings for those industries capable of securing a biomass fuel supply contracting and indexing on GJ/tonne basis.
- The economic case for biomass and absorption would have to be considered on a case-by-case basis because the projects are sensitive to utilisation, evaporation temperature, cooling conditions and other technical factors.

6.3. CHP with Absorption chilling

Absorption chilling with CHP (combined heat and power) is an established technology (there are numerous working examples of this in the UK). The concept has not been widely adopted in Northern Ireland – although there appears to be significant potential in the food and drink and hospitality sectors (refer to section 4 of this report)

Recent consideration of a large pharmaceutical sector project in Northern Ireland confirms that CHP with absorption cooling offers a tenable commercial proposition whilst solving the difficulties arising from the HCFC and F gas regulations (refer to section 2.2.3 of this report).

The project considers the technical integration of gas fired CHP and lithium bromide absorption chilling. In practice if all the heat output of a CHP system can be met all year round then it is more economic to use the heat directly than to operate the chiller. However, where space, heat distribution, and a legal requirement to change from R22 are all factor the absorption model offered an acceptable all round solution.

In adopting a CHP system detailed feasibility is required. The recovery of exhaust gas heat and jacket heat and the integration of the Chiller are not significant issues. These elements can be procured as a packaged item. The location of the CHP, the gas supply infrastructure and the electrical interface are normally more challenging.

At the evaporation temperature 4-6^{o}C for the production of chilled water and the air-cooled condensing temperatures available in Northern Ireland the plant will achieve a COP of approximately 0.7.

The example site used approximately 16.9 million kWh of kerosene or approximately 1.64 million litres of fuel worth approximately 678,000 per annum. The site further consumes approximately 6.8million kWh of electricity worth approximately £588,000 power annum. The unit costs for electricity and oil used in calculating savings are 8.6p/kWh and 3.8 p/kWh (39p/Litre for a large consumer.) for kerosene respectively (Kerosene is current cost). These are exclusive of VAT and Climate Change Levy where applicable.

The new CHP will be gas fired and gas is assumed available at 3.0p/kWh.

The bulk of cooling at the site is provided by a series of large R22 and R407 compression chillers with screw compressors. The cooling load is not monitored but the main chiller alone is capable of 600kW cooling capacity. Thermal storage was provided by chill water tank. This is a buffer rather than a store and ensures that the critical process cooling is always met. The plant recovers water at 7+°C and chills to 4.5°C. The evaporation temperature is just within limits for LiBr but may be more suitable.

The heat load at the site is currently met with a single steam boiler rated at approximately 10,000kg/hr f@a, equipped with a Hamworthy Electrotec burner.

The electrical power demand at the site is essentially a 24/7, 800kW base electrical demand with the demand rising under some production conditions to approximately 1,000kW there is evidence of increased summer power demand - probably the result of the AHU cooling loads.

The site incorporates a large warehouse that requires heating during the winter months.

CHP was considered and modelled and determined to be economically viable at this site. This is not surprising given the consistent site heat and power demands. However the integration of CHP would be difficult for the low grade heat output would have to be interfaced with existing process hot water heating, the high grade exhaust heat would most likely have to be integrated with the steam system (for a single hot water interface of adequate size was not possible). The location of the CHP was then constrained.

An alternate solution was to use the entire CHP output for the purposes of producing chilled water, as modelled below.[10]

CHP Summary	
CHP+LiBr stand alone case	
Gas Cost EX CCL	3.000 p/kWh
Day Tariff rate INC CCL	8.600 p/kWh
Kerosene Cost	3.900 p/kWh
Electrical output	800 kW
Thermal Output =	1008 kW
Fuel Input =	2395 kW
Capital	£900,000
Annual hours operation	7,400
Load Factor =	90%
Electricity generated	5,920,000 kWh
Heat generated	7,459,200 kWh
Gas CHP fuel use =	17,723,000 kWh
Fuel Cost =	£531,690.00
Maintenance cost	£47,360.00
Electricity cost saving	£509,120.00
Heat saving assuming 75% efficiency	£298,368.00
Refrigeration COP	0.70
Cooling output	5,221,440 kWh
Average cool rate	706 kW
VP assumed COSP	2.50
Displaced electrical power	2,088,576 kWh
Value displaced power	£179,617.54
Absorption Maintenance	£10,480.00
VP maintenance	£7,406.00
Absorption Power consumption	5 kW
Power cost	£3,182.00
Low grade heat	300 kW
Total recovered	600,000 kWh
Displaced oil fuel	800,000 kWh
Displaced oil fuel cost	£31,200
Net Carbon reduction	£997.09
Net cost saving	£181,991.54
Payback period	**4.95**

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[10] The calculations are based on the published performance of a Cogenco CGC-0800GU-080-NG-50 WITH Thermax single stage absorption unit.

The model simply examines the return on investment conferred by the displacement of fuel and power and does not take account of the cost of replacing a chiller (as will inevitably be the case with age or the need to replace R22 equipment) – This would improve the economic case.If the cost of a 600kW conventional compression chiller is deducted from then the capital of the project (estimated at £75,000 commissioned) then the economic case improves.

CHP Summary	
CHP+LiBr as replacement plant	
Gas Cost EX CCL	3.000 p/kWh
Day Tariff rate INC CCL	8.600 p/kWh
Kerosene Cost	3.900 p/kWh
Electrical output	800 kW
Thermal Output =	1008 kW
Fuel Input =	2395 kW
Capital	£825,000
Annual hours operation	7,400
Load Factor =	90%
Electricity generated	5,920,000 kWh
Heat generated	7,459,200 kWh
Gas CHP fuel use =	17,723,000 kWh
Fuel Cost =	£531,690.00
Maintenance cost	£47,360.00
Electricity cost saving	£509,120.00
Heat saving assuming 75% efficiency	£298,368.00
Refrigeration COP	0.70
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Displaced oil fuel cost	£31,200
Net Carbon reduction	£997.09
Net cost saving	£181,991.54
Payback period	**4.53**

Improving the economic return with integrated heat utilisation

The heat used for regeneration and the heat removed from the chilled water system must eventually be rejected via the dry cooler/condenser – just as heat from a conventional chiller would be. This is normally dumped for it is of relatively low grade. However at a site where there is a demand for hot water, seasonal space heating or boiler air pre-heat these mechanisms may be used to improve the economic case still further. Where pursued a strategy of total integration can provide significant energy saving.

Operated at 600kW a lithium bromide chiller will reject approximately 1,395kW from the condensers (dry cooler or otherwise). Using a hybrid cooling system with water on at 10^{o}C (average ambient groundwater) the system will raise the water approximately 10^{o}C. This site has a continuous demand of 1.8l/s for hot water at 80^{o}C and the small recovery afforded by heat exchange (75kW continuous) can be used to displace a further 740,000kWh of oil fuel or approximately £30,000 per annum. (The capital cost being a of a small plate exchanger and some small bore pipework. If an additional capital of £28,000 is allowed for the heat exchange system then the payback reduces to 4 years.

Refer to the following example:

CHP Summary	
CHP+LiBr as replacement plant with process water preheat.	
Gas Cost EX CCL	3.000 p/kWh
Day Tariff rate INC CCL	8.600 p/kWh
Kerosene Cost	3.900 p/kWh
Electrical output	800 kW
Thermal Output =	1008 kW
Fuel Input =	2395 kW
Capital	£825,000
Annual hours operation	7,400
Load Factor =	90%
Electricity generated	5,920,000 kWh
Heat generated	7,459,200 kWh
Gas CHP fuel use =	17,723,000 kWh
Fuel Cost =	£531,690.00
Maintenance cost	£47,360.00
Electricity cost saving	£509,120.00
Heat saving assuming 75% efficiency	£298,368.00
Refrigeration COP	0.70
Cooling output	5,221,440 kWh
Average cool rate	706 kW
VP assumed COSP	2.50
Displaced electrical power	2,088,576 kWh
Value displaced power	£179,617.54
Absorption Maintenance	£10,480.00
VP maintenance	£7,406.00
Absorption Power consumption	5 kW
Power cost	£3,182.00
Seasonal Low grade heat	300 kW
Total recovered	600,000 kWh
Displaced oil fuel	800,000 kWh
Displaced oil fuel cost	£31,200
Continuous heat recovery	75 kW
Displaced oil fuel	740,000 kWh
Displaced oil fuel cost	£28,860
Net Carbon reduction	1,182
Net cost saving	£210,851.54
Payback period	**3.91**

The remaining waste heat is rejected at low temperature from the dry air coolers. However the temperature which will typically be mid 30°C is suitable for space heating during winter and could equally be used for boiler combustion air preheat.

Under normal circumstances a boiler will draft combustion air at ambient temperature and the colder this air is the colder the post combustion temperature -more fuel is burned to achieve the required boiler output.

The combustion air requirement at this site for a boiler operating at approximately 2MW is a little over 2,500kg/hr and in practice that is a small amount of air 20-30kW of useful heat - so boiler air preheating will only recover about 200,000kWh or 19,000litres of fuel worth £7,500. However the cost of arranging preheat is negligible and so the payback for the project can be reduced further to 3.9 years.

If the remaining heat can be used seasonally by simply ducting this into the warehouse) during winter, then return on investment will be reduced further still.

6.4. Summary of CHP and absorption chilling

It is important to understand that these are simple examples of how CHP and absorption chilling might be integrated. The exhaust heat from a gas fired CHP engine is hot enough to drive a multistage LiBr plant with much higher COP or indeed and Ammonia absorption chiller for

CHP/LiBr	CHP + LiBr stand alone economic case + seasonal space heating		CHP +LiBr (Replacement) + seasonal space heating		CHP +LiBr (Replacement) + seasonal space heating + small process heating	
	Payback	CO_2 Red	Payback	CO_2 Red	Payback	CO_2 Red
Gas 3.0p/kWh, Electricity 8.6p/kWh Kerosene (3.9p/kWh)	4.95	997	4.53	997	3.91	1182
Gas 3.5p/kWh, (+16%) Electricity 9.5p/kWh (+10%) Kerosene (4.2 p/kWh) (+10%)	5.4	997	5	997	4.2	1182
Gas 3.5p/kWh, (+16%) Electricity 10.3p/kWh (+20%) Kerosene (3.9p/kWh)	3.9	997	3.6	997	3.14	1182

Note these indications are only relevant to Northern Ireland

6.5. CHP and absorption chilling conclusions

- LiBr is currently commercially Viable with CHP
- Every scenario is different therefore feasibility is required.
- Packaged CHP and LiBr currently available
- Tried and tested technology
- LiBr systems will operate with water temperatures to 80°C, so ideally suited for operation with CHP
- CHP and absorption cooling suit 24/7 or extended loads
- The use of absorption chilling and thermal storage allows the improved load factor for CHP in circumstance where the

intermittency of either heat or cooling loads make CHP otherwise a difficult technical solution.

- There will be good scope for CHP/absorption in food manufacturing, pharmaceutical and hospitality industries – three key sectors in Northern Ireland.
- Significant life cycle cost savings for those industries capable of securing a biomass fuel supply contracting and indexing on GJ/tonne basis.
- The economic case for CHP/Absorption would have to be considered on a case-by-case basis because the projects are sensitive to utilisation, evaporation temperature, cooling conditions and other technical factors.

6.6. Absorption chilling from waste heat

A continuous steam load of approximately 10,000kghr is equivalent to a boilr fuel input of 7,000KW. The energy lost in the flue gases typically up to 1,400KW. On a gas fired plant the temperature of the flue gases may be fully condensed for hot water recovery. However if a low temperature hot water load does not exist then the same energy can be used to drive a chiller. The plant would only be suitable for sites with large continuous steam and chilled water demands e.g. the chemical, pharmaceutical or some food and drink manufacturing processes.

The arrangement in 5.4 may be used to recover water at 120°C from the flue gas, approximately 40% of the flue gas energy can be recovered dropping the temperature in a shell-tube exchanger to produce MPHW at 120°C. This equates to approximatly 600kW enough to run a single stage LiBr chiller at perhaps 400kW of refrigeration capacity.

In the VPC equivalent this would require (assuming a COP of 3) 133kW of compresser power.The economiser based absorption chiller would therefore displace the equivalent of 133kW of chiller power. If it further assumed that this plant will run 4,000 full load hrs per annum (refer to other comments re operational flexibility) then the plant would displace 532,000kWh of electrical power worth £46,000.

The cost of a 400kW absorption chiller would be approximately £60,000 and the economiser system might easily double this or closer to £150,000. The simple payback (ex pipework for transmission etc) can then be expected to approach 3 years.

Heat recovery as hot water only would be more efficienct and substantially less costly. However there may be instances where economiser use for feed heating is difficult or where the condensate is already very hot (e.g. high returns with blowdown flash recovery).

Absorption and waste heat recovery	Economiser based heat recovery (3,000hrs)		Economiser based heat recovery (4,000hrs)		Economiser based heat recovery (5,000hrs)	
	Payback	CO_2 Red	Payback	CO_2 Red	Payback	CO_2 Red
Electricity 8.6p/kWh	4.3	207	3.2	276	3.6	345
Electricity 9.5p/kWh (+10%)	4	207	3.0	276	2.7	345
Electricity 10.3p/kWh (+20%)	3.6	207	2.7	276	2.2	345

6.7. Solar absorption chilling

Reflected high temperature collection systems may possibly be technically viable in Northern Ireland but the commercially these systems are not yet market ready or commercially viable in even hotter, southerly latitudes.

Solar tube collectors are commercially viable; with a typical solar tube collector it will be possible in northern Ireland to displace approximately 850kWh/m^2/annum. However and although the tubes are capable of very high temperatures, the hot water recovered is not necessarily at a temperature suitable for the operation of an absorption chilling plant, where temperatures of 70^{o}C-80^{o}C are beneficial

APPENDIX A – FUEL, WASTE OR BIOMASS

Fuel, Waste or Biomass?

Wood has some propensity for the production of Dioxins on combustion. This is because the thermal decomposition of Cellulose and Hemi-celluloses results in the formation of Phenol and furfural groups. There has been great focus and interest placed on particulate (rightly so because benzene, furfural and other derivatives thereof will condense on or form small particles when not completely combusted), however this is only part of the problem associated with the combustion of any fuel.

The lobbying capacity of the biomass industry is significant and works to promote biomass without perhaps focusing unduly on the risks posed by solid fuel combustion. In the USA the lobbying has been less "orchestrated" or driven by vested interests and the US DOE (United States Department of the environment) places more importance on the risks of a transition to solid fuel combustion, particularly wood. Nonetheless biomass if burned correctly may only pose a risk similar to that of any other fuel. As with any solid fuel it is slightly more difficult to burn than a liquid or gaseous fuel that may be easily mixed with oxygen prior to and during combustion.

The Northern Ireland Environment Agency has set out in the document **"**The environmental regulation of wood"

Wood is classified in three distinct groups

- Virgin wood
- Non Virgin Untreated wood
- Non virgin treated wood

Virgin wood is exactly that. However the NIEA (Northern Ireland Environment Agency have extended the definition to include or timber that might include virgin sawmill residues that are untreated with chemical preservatives.

These will not be treated as waste unless mixed or contaminated with treated wood.

Non-virgin wood is essentially any wood, other than primary forestry or the processing of raw virgin wood. Non–virgin timber off cuts, shavings, chippings or sawdust from the processing of non-virgin timbers are waste and are subject to waste control

If the wood is non virgin e.g. not simply the by-product of primary forestry or timber operations then it is waste and will be subject to PPC or WMLR or both depending on how it is to be used.

However the distinction is made between treated and untreated woods

Treated wastes are those which have been treated with any form of penetrating oils, tar oil preservatives, waterborne preservatives, organic based preservatives, boron and organo-metallic preservatives, boron and halogenated flame retardants" Such waste is subject to the provisions of the Waste incineration directive.

Untreated wood -Otherwise if the wood has not been treated and can be regarded as non-virgin but untreated then the wood is not subject to the provisions of the waste incineration directive. For a plant to burn waste and be non-WID the plant must be burning material that is WID exempted under schedule 2 of the WID or However other legislative requirements apply.

Some wood glues, plywood binders and other adhesives are exemptible but you must consult NIEA. Non-virgin waste may be deemed clean or Untreated waste wood only by the NIEA

Depending on the size of the plant the process would be subject to local Council authorisation in NI and built to PG1/12 (NIPG1/12[11]) and the ELV therein. However a WMLR (waste Management Licensing Regulations) licence would still be required and the plant would be built to at least the standards required in PG1/12. (NIPG1/12)

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[11] Northern Ireland Process Guidance note PG1/12

APPENDIX B –WHAT IS BIOMASS

Biomass

Biomass is any thing that is alive or was recently alive. Coal, Oil and gas were all once biomass, but the concentration of carbon and mans rapid exploitation of these fuels distinguish them from " biomass". It is generally assumed that biomass is sustainable but nothing could be further from the truth. The wholesale destruction of forest now visually evident in some parts of Europe – may have as yet unforeseen ecological impact and therefore much more direct climatic impact that first imagined. The source of the biomass is therefore of importance – whilst it may currently be economically viable, it is not sensible, sustainable or commercially viable in the longer term to import wood chips from the Baltic states for example.

Generally the definition of biomass is taken to mean something that is of vegetable as opposed to animal origin. Biomass is also used generally to classify a potential fuel that is not a waste (Although many wastes may in fact be biomass)

There are three basic biomass fuel groups

- Crops grown for energy production and these could include

    - Short rotation coppiced willow or poplar
    - Miscanthus
    - Corn or wheat for ethanol

- Forestry and related residues

    - Harvest residues (cereal straw)
    - Brash and bentwood
    - Sawmill residues

- Agricultural residues Animal bedding, Food waste (Rice/Grain Husks)
    - Oat husks
    - Olive stones
    - Nut husks

If these materials are removed from their natural environment then the cellulose and lignin content of this material is lost from the soil on which the source "crop" is grown.

In the broadest terms energy crops produce a gross calorific value of approximately 180GJ/ha/annum the equivalent of approximately 4,000 litres of oil – enough to heat a good sized house. This is because the dry calorific value of most cellulose biomass is approximately 17-19GJ/tonne ODT. There are significant variations depending on the ratios of carbohydrate /fibre content – but in general terms this is the case.

Biomass includes a wide range of materials from animal waste to prime cereal crops and derivatives of everything in between, 1st generation fuels like bio-ethanol (largely from wheat and corn), 1st generation to 2nd generation bio-fuels like bio-butanol (from Jahtropha Curcas an oil bearing bush that can grow in marginal conditions).

Most biofuels do not contain significant amounts of carbon in the carbon form (like coal) but rather the carbon is in the form of glucose, pentose and three-dimensional lignins – the basic products of photosynthesis. These constituent components of biomass fuels burn slightly differently to other fossil fuels and generally require more expensive combustion equipment.

Biomass (generally) is perhaps only marginally more difficult to burn than coal. However the reason there are so many failed biomass installations across the UK is amongst other things, the result of a complete lack of understanding by the many parties engaged in the development from consultants to suppliers. It is possible to build a reliable and durable biomass or co-firing system – but it is necessary to design for the fuel and to understand how the fuel affects the operation of the plant.

There is also the possibility of wood waste recovered from municipal waste or demolition waste streams. This is actively being considered for specifically absorption projects in Northern Ireland now and raises a raft of legislative issues that are addressed briefly in the Appendices to this document. Refer to Appendix A - Fuel Waste or Biomass

Virgin wood as a fuel

Virgin wood will have dried calorific values of 19.533GJ/tonne gross and 18.24GJ/tonne net

In the most general terms, the wood will have an ash content of less than 2.1% on a dry weight basis and

Virgin wood chips could have a highly variable "effective" CV because of the moisture content. Wood pellets on the other hand will have a CV approaching the dry net CV because these are of such low moisture content.

Virgin wood waste as a fuel

Virgin wood waste can be obtained in various forms. Acquired as a sawmill or timber industry waste the material could also be of various forms.

When a freshly felled tree is initially processed at the sawmill it is necessary to provide basic shape for the largely automated sawing and thickness operations that follow. The bark is first removed and the stump is turned to produce a parallel cylinder.

These processes and the subsequent cutting and planning operations produce a range of by products largely classifiable as sawdust, 1st Grade bark, 2nd Grade Bark, But shavings and planer shavings, all of which can be burned effectively in a biomass boiler.

Depending on the point of generation and the storage the moisture content of these materials will range from 20-60%, and the materials have differing lignin contents.

In the most general terms, the wood will have an ash content of less than 2.1% on a dry weight basis and dried calorific values of 19.533GJ/tonne gross and 18.24GJ/tonne net

The impact of water and other contaminants is discussed in following sections of this report.

It has been previously estimated (various sources) that there is potentially 150,000 tonnes of virgin wood available. However, the bulk of Northern Irish timber and that from immediately surrounding Irish timber operations is already accounted for and that the true availability of additional fuel may be very significantly less.

Waste wood as a fuel

Waste wood could be any material recovered from demolition timber through to pallets. The bulk of wood used in construction, as packaging and as pallet wood is spruce

The wood is usually manually separated at Council owned or contracted facilities. This manual screening process removes the largest organic, metal or plastic contaminating fractions. Some metals, plastics and glass contamination remains.

Normally an additional and specialist screening process is required to shred the wood waste and to provide a nominal particle size of 60mm or less. The bulk or ferrous contamination is removed by over band magnet and as a result of screening.

The inherent water content of recycled wood is low, typically less than 16%. However chipped and stored outside this can rise considerably.

Again in the most general terms, the wood will have an ash content of less than 2.1% on a dry weight basis and dried calorific values of 19.533GJ/tonne gross and 18.24GJ/tonne net.

There have been various attempts to quantify the amount of timber available as returned from council and other recycling operations. There is no definitive figure and our best estimate based on research and some discussion suggests that there is probably of the order of 100,000 to 120,000 tonnes of such would available.

It is not possible to tell at this time what % of that could, with suitable screening and selection, be subsequently classified as clean wood and thus be allowable for non WID operations. However there are instances throughout Northern Ireland of industrial waste production streams where there is a considerable clean would input and the overall % must be quite high. However there is no real sorting system at the moment and it is extremely difficult other than in isolated instances to take wood that has been recycled and categorically state that it is clean or otherwise.

Olive cake or Almond Husks (Other residuals)

Imported olive cake may offer an alternative to both coal and wood. Olive cake is a co-product from the pressing industry but it has very low chlorine content and could only be regarded as entirely a biomass fuel.

A supply of olive cake is available to be imported from Spain, although it may equally be possible to import olive cake from Turkey. The calorific value is very high at 18.7 GJ/tonne net and very likely a useful heat of 16 or more GJ/tonne at as received moisture contents.

Willow Chips

There are several contracted farming operations in Northern Ireland producing several thousands of tonnes of wood chip annually. The delivered cost for willow fuel will currently approach £85/tonne

The calorific value is very high at 18.7 GJ/tonne net and very likely a useful heat of 16.5 or more GJ/tonne at as received moisture contents.

No detailed information is available at this time. However there is practical experience burning willow at an Irish plant for nearly two years without any evidently severe refractory erosion, ash fusion or corrosion issues and it is reported that there appears to be very few practical issues associated with burning willow.

However if the willow has been used for land remediation then the ash may well contain high concentrations of heavy metals and other contaminants and the ash must be treated as hazardous wastes

The variable quality of Biomass

The energy content of most solid biomass materials is very similar. This is because biomass is generally a mix of Cellulose, Hemi – cellulose and lignin to varying degrees. All of these materials contain carbon, Hydrogen and oxygen. The differences between plant species are largely dictated by differences in the structure of the Pentose sugars that form the basis of the hemicelluloses and lignin contents.

Biomass also contains a degree of non organic material, sodium, potassium, silica and so on, fractions that are non combustible but will give rise in part to the ash content and more importantly the ash characteristics on combustion.

Of by far the greatest importance in determining the calorific value of a fuel is the moisture content.

Virgin wood e.g. as might be available from a sawmill, usually contains a high moisture content. This can vary from 60% in winter months to as low as 20% where smaller cuts have been left to dry over summer. The variable moisture content poses a difficulty for combustion and is fairly critical to the selection of boiler plant.

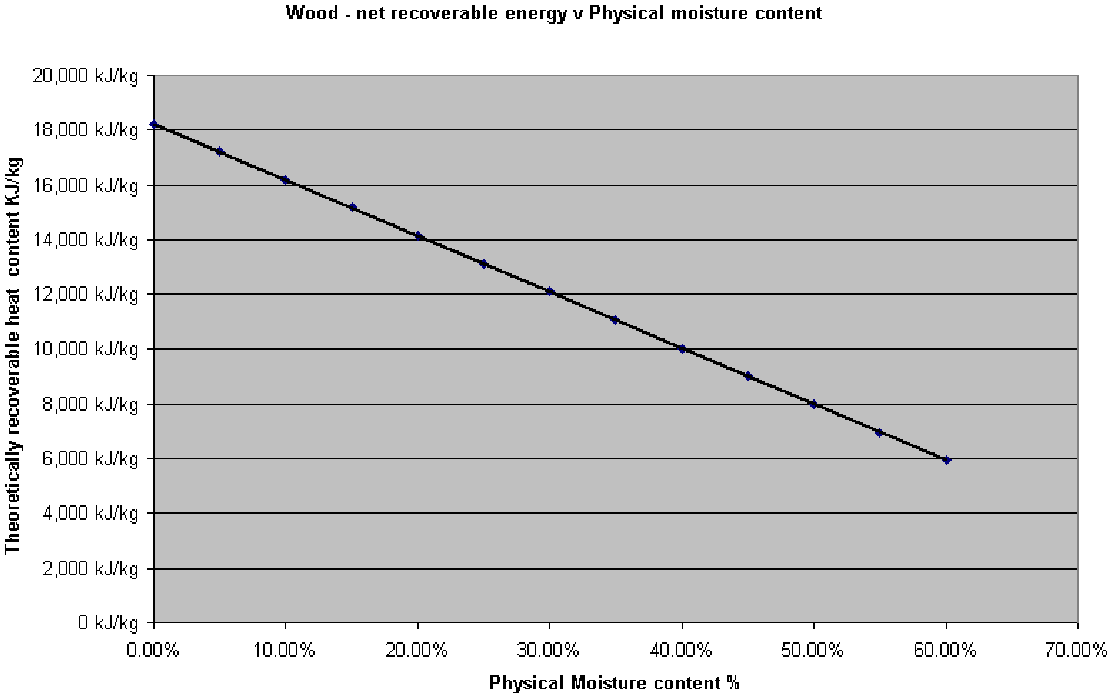

Figure 22 The CV of wet wood

Chemically and physically bound water has a marked effect on the combustion process and the way in which the fuel burns. This dictates the design, size and suitability of the combustion plant. During combustion, water, steam and pyrolysis products must be transferred in the wood and the water influences the formation of intermediate combustion products

- Unfortunately the water has to be evaporated before combustion can proceed

- Water vapour superheated to the prevailing balance furnace temperature and pressure the latent heat of evaporation + any superheat is carried out of the furnace unless you recover this by economiser

- Additional water forms from the combustion of the hydrogen (chemically bound water)

- The evaporation cools the combustion space and in many cases intermittent charging of wet fuel by auger or ram can result in a reduction in combustion space temperature. This is considered in more detail when the types of boiler, sizing and operation are considered in following report sections.

- Can extinguish or prevent sufficient transfer on the combustion bed preventing continued combustion

The impact of net recoverable heat is demonstrated in the diagram above.

A short summary of fuel availability and price

It is impossible to predict availability with any quantitative certainty, the market for bio-fuel develops daily and as oil prices rise the cost of all alternate fuels soar. The price of all fuels is extremely volatile, not least so biomass. The prices quoted below may be considered indicative only.

Some organisations have claimed to be able to import as much as 400,000 tonnes per annum into Northern Ireland from the South. However as yet there is no evidence to confirm that such volumes can be controlled or imported by single organisations – there are currently no significant contracts for supply in place.

Fuel Type	**Indicative cost £/tonne**	**Indicative cost[12] £/GJ**	**Predicted market price (5 years)**	**Current Availability**	**Predicted Availability (5years)**
Willow	£85	£5	Increasing Steadily	Limited	Increasing but slowly
Indigenous virgin wood (co products)	£35-40	£4.80	Increasing Steadily	Limited	Reducing
Imported virgin wood (co products)	£25 -35	£4.60	Increasing Steadily	Available	Available
Indigenous Virgin wood Pellets	£100-120	£5.80 – 6.90	Increasing Steadily	Limited	Some possible
Imported wood pellets	£100-150	£5.80 – 8.70	Increasing Steadily	Limited	Some possible
Imported Olive cake pellets	£87-90	£4.70	Increasing Steadily	Available	Reducing

It would be sensible were fuel to be valued by the net effective calorific value. However, in a barely established market this does not happen and the cost of fuel is currently and very broadly as shown below.

Fuel Type	**% h_2o, WW**	**Indicative cost £/tonne**	**Indicative cost[13] £/GJ**	**Current Availability**	**Predicted Availability (5years)**
Willow	16%	£85	£5	Limited	Increasing but slowly
Indigenous virgin wood (co products)	30-55%	£35-40	£4.80	Limited	Reducing
Imported virgin wood (co products)	30-55%	£25 -35	£4.60	Available	Available
Indigenous Virgin wood Pellets	>16%	£100-120	£5.80 – 6.90	Limited	Some possible
Imported wood pellets	>16%	£100-150	£5.80 – 8.70	Limited	Some possible
Imported Olive cake pellets	>16%	£87-90	£4.70	Available	Reducing
Non Virgin – Untreated waste wood	>16%	£20 - 25	£1.25	Available	Reducing

There are other solid bio-fuels available in Northern Ireland, e.g. wheat straw, Miscanthus and others but the availability is extremely limited.

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[12] Assessed at March 09

[13] Assessed at March 09

APPENDIX C - THE COST OF BIOMASS PLANT

The cost of biomass varies considerably depending on the specific installation however the graph below illustrates the broader range of cost for hot water boilers in the UK. Steam boilers should not be significantly more expensive. Hot water and medium pressure hot water produced by biomass can be used very successfully to operate single stage LiBr or AAR plant for the purposes of cooling.

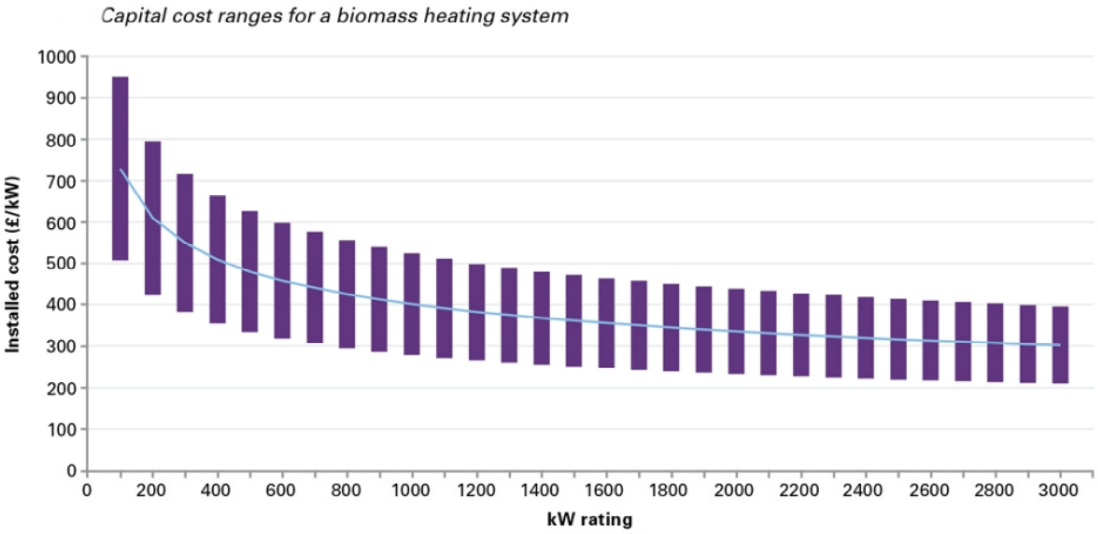
Capital cost ranges for a biomass heating system

Figure 21 Biomass installation prices -

Courtesy of the Carbon Trust and reflecting a range of prices for hot water boiler plant installed in the England.

APPENDIX D THE CALORIFIC VALUE OF BIOMASS FUELS

Source Data from Phyllis - Energy research Centre of the Netherlands

Miscanthus

	Dry	**Dry Ash Free**	**As received**
Gross CV	**19070**	20021	11442
Net CV	17860	18751	9739

Proximate Analysis %

	Dry	**Dry Ash Free**	**As received**
Ash	4.8		2.9
Water			40

Ultimate Analysis %

	Dry	**Dry Ash Free**	**As received**
C	47.9	50.3	28.8
H	5.5	5.8	3.3
O	41	43	24.6
N	0.54	0.57	0.32
S	0.11	0.12	0.07
Cl	0.18	0.189	0.108

Almond Husks

	Dry	**Dry Ash Free**	**As received**
Gross CV	**18768**	20004	17233
Net CV	17466	18616	15838

Proximate Analysis %

	Dry	**Dry Ash Free**	**As received**
Ash	6.2		5.7
Water			8.2
Volatiles	73.2	78	67.2

Ultimate Analysis %

	Dry	**Dry Ash Free**	**As received**
C	46.5	49.6	42.7
H	5.97	6.4	5.5
O	40.1	42.7	36.8
N	1.15	1.23	1.06
S	0.04	0.05	0.04
Cl	0.054	0.058	0.05

Willow

	Dry	**Dry Ash Free**	**As received**
Gross CV	**18556**	18856	10484
Net CV	17247	17525	8682

Proximate Analysis %

	Dry	**Dry Ash Free**	**As received**
Ash	1.6		0.9
Water			43.5
Volatiles	83.4	84.7	47.1

Ultimate Analysis %

	Dry	**Dry Ash Free**	**As received**
C	50.2	51	28.4
H	5.9	6	3.3
O	42.2	42.9	23.9
N	0.1	0.1	0.06
S	-	-	-
Cl	-	-	-

Sitka, Waste timber, Wood Pellets.

	Dry	**Dry Ash Free**	**As received**
Gross CV	**19533**	19948	9395
Net CV	18246	18633	7509

Proximate Analysis %

	Dry	**Dry Ash Free**	**As received**
Ash	2.1		1
Water			51.9
Volatiles	84	85.8	40.4

Ultimate Analysis %

	Dry	**Dry Ash Free**	**As received**
C	49	50	23.5
H	5.78	5.9	2.8
O	43	43.9	20.7
N	0.2	0.2	0.09
S	-	-	-
Cl	-	-	-

APPENDIX E – ICE/THERMAL STORAGE?

Thermal storage for absorption chilling systems

In sizing any plant for a heating or cooling application it must be borne in mind that the demand will in many cases, change throughout the day or the year. Consider the charts below which show how the demand in a hotel for heating will vary.

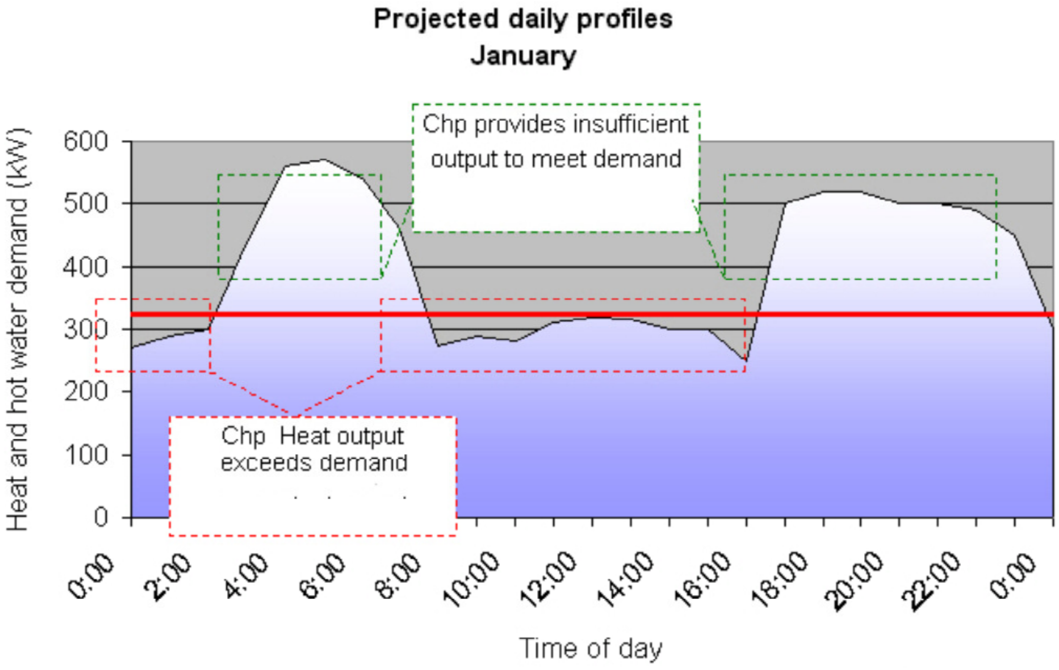

Figure 18 Thermal storage

Any equipment purchased must usually be sized so as to offer the best return on invstment whilst providing an optimal output. The chart above illustrates the problem. This shows the ability of a 300kW CHP plant as considered in conjunction with the daily winter heating load pofile in an hotel.

There will be periods when the plant cannot meet all of the demand and occasions when the demand greatly exceeds the thermal output available. At times of low thermal load the plant could be modulated to some extent. However the electrical out put of the CHP would diminish also reducing the revenue and increasing return on investment.

Thermal storage is essentially a means of manipulating and particularly flattening the load profile to reduce the peaks and improve the load factor [14]for any plant selected to meet the load. Thermal storage can improve the the load factor but does not often offer a complete solution. It is therefore common to install top up and standby plant to support biomass, CHP, absorption systems which are generally large expensive and operationally less flexible.

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[14] Load factor may be considered as a measure of irregularity and is the average load /peak load. The higher the load factor the less peak the load.

Thermal storage applies to heating as it does to cooling and the term is used reference a wide range of technologies that might for example include:

- Hot water storage
- Hot water accumulators for steam systems
- Chilled water storage
- Ice or ice slurry storage
- Phase change salt storage (common for methanol production)

Thermal storage can be used to absorb short-term peaks, flatten load or provide a means of absorbing excess heat in the case of biomass boiler outputs. In the context of cooling, the principal applications will be the production of ice or ice slurries and chilled water overnight or at times of low load to optimise the plant size and utilisation.

The heat of fusion of water, the energy required to solidify water and turn it from water to ice is 333 MJ and so 1 tonne of ice can store very approximately 92kWh of cooling. Ice storage is routinely used now toreduce the peak load experinced by compression refrigeration plant and thus allow optimum equipment sizing. For example a direct expansion loop might be used to produce 10 tonne bath of ice so as to provide up to 900kWh of cooling imparted to a principal ethylene glycol system by way of return precooling. In this way the peak laods experienced during the day can be reduced at a reate dependent on the surface area and design depletion of the store.

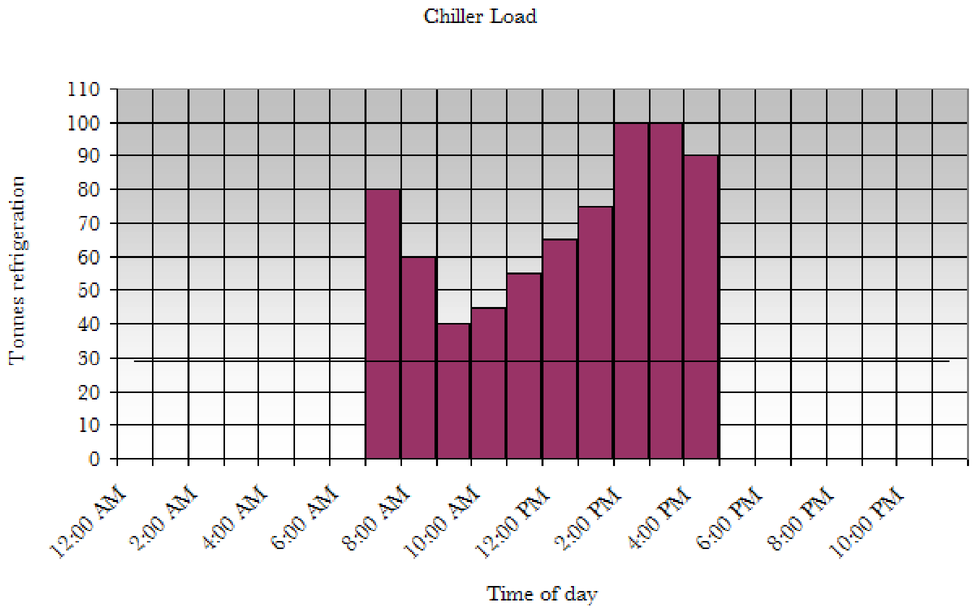
This type of system is more commonly used in the USA/Asia and other countries where ambient conditions have dictate that there are significant air handling loads and where the operation of vapour compression chilling can contribute to expensive peak electrical loads. In this situation the chiller plant (absorption or compression) is run overnight and off peak times to build up ice and the AHU chill flow is returned via the ice bank to reduce the return temperature during peak demand periods.

Despite the physical size and additional system complexity, there are numerous benefits to this type of system. Including the potential for integration with biomass systems. In the context of modern buildings with intermittent occupancy this has some real benefits. Using thermal storage allows reduced capital investment by operating chillers at perhaps 40% – 60% of standard design for perhaps as much as 16 or more hours a day whilst the plant runs using the ice store for less than a third of the day.

The extent of storage has to be carefully considered against capital cost. Full storage affords such capacity that the refrigeration plant need not be operated during peak hours but this in turn may require very significant storage volume – possibly displacing high alternate rental incomes, although the actual colume of ice storage required as a ratio of airconditioned space is small circa 0.25%. Moreover the chillers will be larger than those required for partial storage for the smaller chillers will have the benefit of support from the storage system during peak output. Peak lopping systems are used in the food and drink industry particularly for pasteurisation or other high peak demand systems.

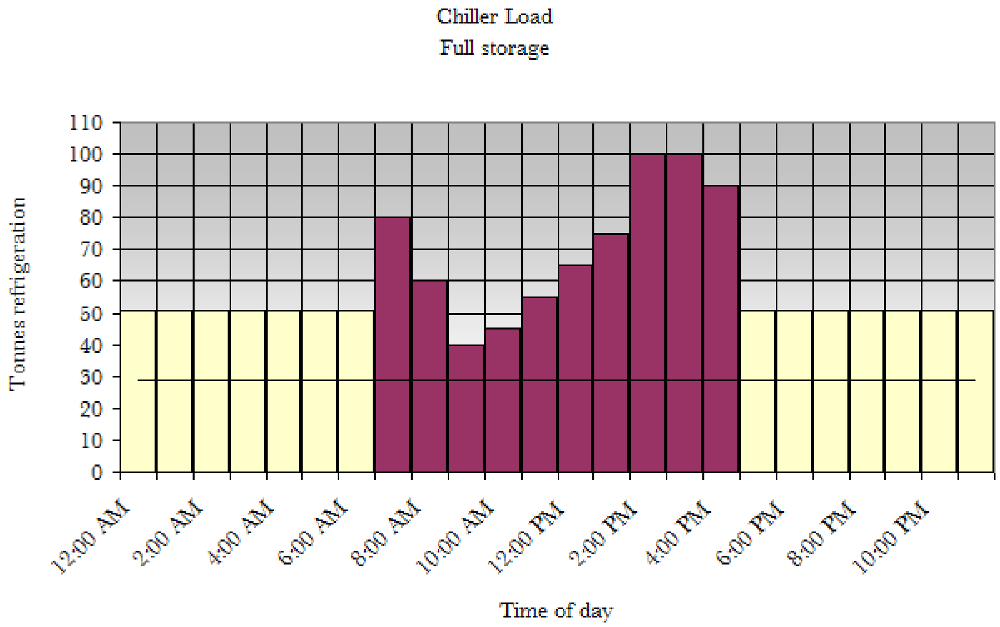
In some very specific and limited applications the ice bank built during the of peak production can be used to provide the condenser cooling function in the refrigeration cycles (refer to section 2 of this report). The efficiency benefit being derived from the reduction or elimination of extensive compression motor or fan cooling power, for the evaporated refrigerant is simply pumped back through and ice coil.

In the conventional cooling system the compression chillers will be sized to accommodate the peak cooling load. Where the office or process l,aod is intermittent this will typically occur in the afternoon when the incidental gains are highest. Accordingly the air-conditioning plant and allied chilling will be designed to accommodate these peaks. The conventional plant will operate at peak output mid afternoon on peak power rates to dissipate the heat and control temperatures as shown below.



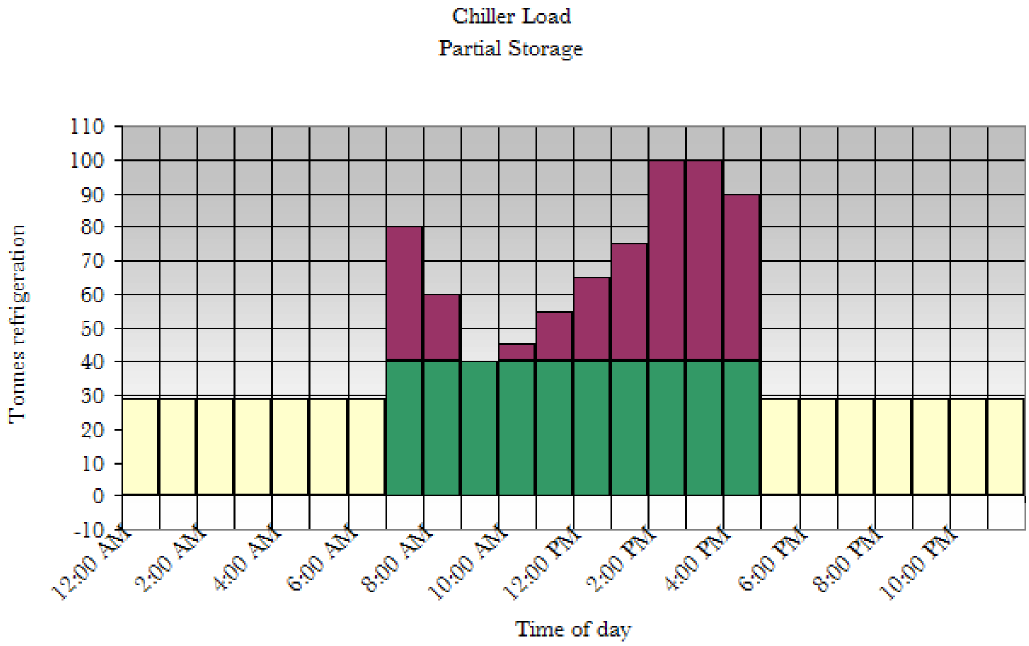
The average load in the example given is only 28tonnes refrigeration yet the installed capacity must be 100 tonnes to meet the day time peak

If Ice storage were provided and the plant size were dropped to 50 tonnes capacity, then the plant could operate throughout the night, principally on off peak electricity to subsequently cool the building during the day as shown below. This is reperesentative of what is termed a full storage system. For the ice banks would store sufficient “coolth” for all of the following days demands as shown below.



This model represented full storage and is more appropriate if there is a very large differential between peak daytime tariff and overnight off peak tariffs. However the strategy has allowed a 50% reduction in plant capacity.

An alternate is the concept of partial storage where a smaller off peak machine may be run continuously. In the illustration below a machine of 30 tonnes may be run overnight and subsequently provide over 40tonnes at time of the day time demand thus providing support to once again a smaller peak load plant of approximately 60 tonnes.



In practice and in the context to higher temperature systems for air conditioning loads, these will only beable to produce ice at a substantially derated capacity consquently the plant must be sized and the operatio evaluated accordingly. This is partly offset by much improved condenser performance in the cooler night air which may be many degrees below daytime temperatures and thus offer significant COP improvement e.g. 5% (Refer to section 2.0 also)

The balance must be considered in respect of:

- The space available for ice storage
- The cost of the ice storage
- The balance of peak and off peak tariff
- Any lost income from property rental

A typical arrangement for ice storage and an AHU chilling system is illustrated below:

GLOSSARY OF TERMS

AAR	Ammonia Absorption Refrigeration
Absorption	The process whereby a liquid or gas is absorbed fully by chemical solution in another gas or liquid – becoming diffuse in that solution
Adiabatic	The process of heating or cooling, expanding or contracting a gas with pressure change but without losing or gaining heat energy to surroundings
Adsorption	The process whereby a liquid or gas adheres to the surface of an extended surface material.
AHU	Air Handling Unit
CFC	Chlorofluorocarbon
CHP	Combined heat and power
COP	Coefficient of Performance – usually defined as the useful cooling work as a ratio of the necessary energy input to a refrigeration system
DOE	Department of the Environment (USA)
GWP	Global warming potential
HC	Hydrocarbon
HCFC	Hydro - chlorofluorocarbon
HFC	Hydro - fluorocarbon
IRR	Internal Rate of Return – the rate at which a net revenue stream offsets the initial capital value
LiBr	Lithium Bromide
Lignin	A predominantly phenol propane based constituent of wood.
NPC	Net Present Cost – a future cost presented in present day values
NPV	Net Present Value – a future Value presented in present day values
ODP	Ozone depletion potential
ODS	Ozone depleting substances
Proximate	The analysis gives moisture content, volatile content of a fuel
Ultimate	The "ultimate" analysis" gives the composition of the biomass in wt% of carbon, hydrogen and oxygen as well as sulphur and nitrogen
VCR	Vapour compression
WtE	Waste to Energy

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CASE STUDIES