Study of the Cooling Opportunities in the Humber

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Carbon Trust prepared this report based on an impartial analysis of primary and secondary sources. Carbon Trust is an organisation of independent experts with the mission to accelerate the move to a sustainable, low carbon economy. We operate at a worldwide level from London, Edinburgh, Cardiff, Beijing, Johannesburg, Delhi, Sao Paulo, and Mexico City.

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1 Executive Summary

The Humber LEP commissioned the Carbon Trust to undertake a study of its Energy Intensive Industry Cluster (EIIC). The purposes of that study were to increase understanding of the current characteristics of the EIIC, and to recognise opportunities with the best potential to accelerate economic growth, whilst aligning to the UK-wide need to decarbonise industry. During that study the Humber LEP and regional stakeholders highlighted interest in energy storage technologies, specifically batteries. In subsequent discussions the Carbon Trust highlighted the possibility that the Humber region may already have a battery storage capability through the large clustering of process cooling in the region, particularly in the food processing industry. The Humber LEP commissioned this small, supplementary study to further investigate this thermal cooling energy storage potential.

Total energy use in the Humber region in 2015 was approximately 37,200 GWh/year. Of that, 23,200 GWh was consumed by the industrial and commercial sectors, equivalent to 1.7 times the combined capacity of Killingholme A and B. Also, these sectors used approximately 1,400 GWh for space or process cooling, equivalent to 25% of the capacity of Killingholme A, and 90% of this energy was used for process cooling. There are tight groupings of process cooling load around Saltend & Hull and Immingham & Grimsby which mirror, to some extent, the similar observation from the early EIIC study.

Executive 1: Cooling maps of Saltend & Hull and Immingham and Grimsby

Given the identified energy loads there are several distinct thermal energy storage applications that could be used in the region:

1. Thermal Virtual Energy Storage: using cloud based demand side management control with onsite digital control to manage existing thermal energy storages (e.g. cold stores, fridges, HVAC systems) and in so doing so create a Thermal Virtual Energy Store. This type of energy store can be used to provide MW scale regional demand response capabilities. In reality this technology could be applied across a wider range of technologies (i.e. not just cooling) and is likely to offer significant benefits to the Humber region.

2. Thermal Cooling Energy Storage: new technologies are emerging that use the physical properties of gas or phase change materials to store renewable electricity for later release. Within this emerging technology group 5-6 MW demonstrators already exist. Importantly some of these technologies act as cooling and electricity energy store: energy can be converted to electricity and/or providing cooling for industrial processes (e.g. food...
Alongside hydro and chemical battery storage technologies, this type of cooling energy store is likely to provide medium or long duration term energy storage capabilities.

There are a number of actions that Humber could consider to as next steps. These include:

- Establish an Energy Storage Working Group to formulate a strategy for the deployment of energy storage across the Humber region.
- Incorporate a deep dive in technical application of energy storage when conducting the Humber Energy Strategy.
- Embed the local industrial strategy enhancement of energy storage competencies in the region’s universities, alongside the development of a clean cooling chain strategy and action plan.
- Seek to capture virtual energy store or thermal energy storage demonstrator projects.
2 Introduction

2.1 Purpose

Scene setting

The Humber LEP commissioned the Carbon Trust to undertake a study of its Energy Intensive Industry Cluster (EIIC). The purposes of that study were to increase understanding of the current characteristics of the EIIC, and to recognise opportunities with the best potential to accelerate economic growth, whilst aligning to the UK-wide need to decarbonise industry.

During that study the Humber LEP and regional stakeholder highlighted interest in energy storage technologies, specifically batteries. In subsequent discussions the Carbon Trust highlighted the possibility that the Humber region may already have a battery storage capability through the large clustering of process cooling in the region, particularly in the food processing industry.

The Humber LEP commissioned this small, supplementary study to further investigate the thermal cooling energy storage potential.

Project scope

The scope of this work is to highlight the cooling potential that might exist in the Humber region, specifically in the food processing and EIIC sectors. As a supplement to the Humber LEP Energy Intensive Industrial Cluster study, this study will utilise the same approaches to modelling and broadly the same data sets used in the primary study. The key aims that this study will seek to address include:

- Give a broad overview of carbon emissions related to cooling technologies in the global, national and regional context.
- Summarise the emerging concept of clean cooling and the impact it could have on the energy system.
- Outline the cooling technology landscape and identify those cooling technologies that may be applicable in the Humber region.
- Identify potential next steps.

2.2 Methodology

This supplementary study was undertaken by the Carbon Trust to give a high level assessment of the thermal energy storage opportunities that might exist in the Humber region. The following methodology has been applied to this study:

- A dataset of nearly 400 companies located in the Humber region compiled for the main study has been used as the core source of information for this supplementary cooling analysis.
- Each of the identified 400 companies was assigned to one of eleven industry sub-sectors\(^1\) and research was undertaken to estimate the average proportion of electricity consumption used to provide process or space cooling in each sector. This average proportion of cooling-related electricity was then used as the basis of the data for the presented cooling maps.
- Of these eleven sectors, those sectors that are identified as having high process cooling requirements are the EIIC and food processing.

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\(^1\) Sectors: Biofuels, brewery, chemical storage, chemical works, chemicals, dairy processing, data processing, factory manufacturing, food processing, manufacturing, pharmaceuticals, pharmaceuticals and personal care.
The cooling maps provided representative (i.e. estimated) electricity demand to deliver required cooling rather than actual electricity consumed to deliver cooling. There are several reasons for this:

I. The actual cooling load and related electricity requirement for each of the companies is unknown. The costs associated with gathering specific cooling data would be very high (e.g. surveys) and not cost-effective given the scope of this study.

II. Companies are unlikely to be able to confirm their cooling-related electricity loads, due to limited submetering and monitoring.

III. Cooling data required to identify broader cooling opportunities across the Humber region, including use of thermal battery technology, can be achieved using representative data.

3 Wider Context

3.1 Global emissions from cooling technologies

Analyses done by the Carbon Trust for the Kigali Clean Efficiency Programme, which is a US$52 million philanthropic initiative supported by the United Nations, established that total global greenhouse gas emissions due to the use of refrigeration technology were approximately 4.1 GtCO2 in 2016 (approximately 8 times total UK GHG emissions) and would be expected to rise to nearly 10 GtCO2 by 2050 if the Kigali Amendment to the Montreal Protocol were not been ratified. Of these emissions nearly two-thirds are indirect emissions due to electricity use by refrigeration equipment, and one-third are direct emissions due to the release of refrigerant gases that are greenhouse gases.

Figure 1: Breakdown of annual total global GHG emissions to the cleaning & servicing opportunities.


Analyses showed that, conservatively, 20% of the electricity used by refrigeration equipment could be saved if equipment was better operated and maintained.

3.2 UK and Humber emissions from cooling technologies

UK emissions\(^2\) from cooling technologies used in industry are approximately 44 MtCO\(_2\), which equates to 8.4% of total UK emissions (527 MtCO\(_2\)). Of these emissions approximately 31 MtCO\(_2\) are indirect emissions due to electricity use and 13 MtCO\(_2\) are direct emissions due to fugitive refrigerant gases.

\(^2\) For 2016

\(^3\) Reference to BEIS annex A greenhouse gases by sources
Based on UK government data total carbon emissions in the Humber LEP region were in the order of 5.8 MtCO₂ (2015) and of these 2.9 MtCO₂ were related to business activity. If the emissions proportion from cooling identified for the UK contribution were the same in the Humber region (i.e. 8.4%), then business related cooling emission would be approximately 243 ktCO₂ in the Humber region. Another approach to estimate cooling related carbon emissions in the region is to evaluate the Humber’s contribution to the total UK cooling load. The European Union undertook a study of future heating and cooling deployment in member states that can be used to estimate total UK cooling load to be approximately 50 TWh. Assuming this cooling load is spread evenly throughout the UK, then with 2.8% of UK landmass, the Humber region’s proportion would be 1,140 GWh, which equates to approximately 490 ktCO₂.

Based on UK government data cooling-related carbon emissions for the Humber region are approximately 243 ktCO₂. Data from a broader, less granular European study suggests that the Humber region could have a higher cooling-related carbon emissions of 490 ktCO₂. As a first order analysis it is fair to conclude that actual emissions may fall somewhere between these two points.

3.3 Global Warming Impacts of Refrigerants

Many refrigerant gases used today in both industrial and domestic applications are significant contributors to greenhouse gas emissions. The European Union implemented the Fluorinated Gases Regulation to initiate and control the phase down and phase out of the harmful refrigerant gases. This phase out began in 2015 and will continue until 2030. Similarly, in 2017 an amendment to the Montreal Protocol was agreed by all signatories to the protocol in Kigali, Rwanda to implement a global phase down in the use of refrigerant gases which are also harmful greenhouse gases. This Kigali amendment phase down runs from 2019 to 2036.

Why is this important to the Humber region? Put simply the need to remove harmful greenhouse gas refrigerants for the equipment used in the Humber will stimulate regional investment to ensure compliance with the F-Gas regulation. Equally, innovation is stimulated in the design, manufacture, installation, supply, maintenance and decommissioning of new refrigerants or refrigeration equipment. It is likely that manufacturing (e.g. BOC Gases), service & maintenance, and research and development businesses in the region have the potential to participate in this compliance driven market growth.

Regulatory compliance has stimulated strong interest by global industries and policy makers to consider alternatives to manufactured refrigerants (e.g. natural refrigerants such as ammonia, CO₂ or hydrocarbons), re-examine the conventional cooling cycle, and re-think the engineering approach to cooling - to regulate temperature and hold energy for later use.

“We are seeing flammable refrigerants coming into the market as others are phased out and the price of conventional refrigerants is rising rapidly...we may need to upgrade equipment to manage more of the flammable refrigerants as the market grows.” Industrial Interviewee

3.4 Investment in Technologies that Facilitate Clean Cooling

“As a food processing company with multiple sites, we are looking for commonalities across our site portfolio when planning plant upgrades...we are not an R&D outfit so we select tried and tested

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technologies...we have recently invested significantly in tried and tested refrigeration plant in the region to expand capacity.” Industrial Interviewee

Industrial interviewees stated that projects had to stack up against competing business priorities across the UK and internationally. If UK government funding were available then this could improve the local business case for action on clean cooling.

Since 2012 the UK government has provided sustained innovation investment through its Energy Entrepreneurs Fund (and its predecessor funds) and the call for phase 7 is expected imminently. The Government announced an additional £14m for the EEF programme in the Clean Growth Strategy. A number of the projects supported during EEF calls 1 through 6 have been related to innovative clean cooling technologies (e.g. Highview, see later), or enabling digital technologies that permit the virtual grouping of cooling technologies to act as one large cooling store for demand side management.

Other funding sources that are likely to be appropriate for clean cooling technologies include Innovate UK, the £20m BEIS Industrial Energy Efficiency Accelerator, and the £2.5bn investment of the British Business Bank.

4 Snapshot of Cooling on the Humber

4.1 Types of Cooling

In industrial and commercial applications there are two main uses for cooling:

- **Space or comfort** cooling is undertaken to keep a building at a comfortable temperature. This cooling might commonly be considered as air conditioning.
- **Process cooling** cools down materials or products as part of an operational process (e.g. to cool food products during processing).

In this study we will focus on process cooling as it accounts for 90% of the cooling requirement. Process cooling is more energy intensive because higher cooling loads are required for long periods of time.

Within the Humber region, process cooling is used at chemical plants, steel plants, food processing manufacturers, distribution warehouses and retailers. For example, to sustain sub-zero temperature controlled environments (e.g. cold storage for food products) or to provide cooling that removes heat from materials during processing (e.g. when processing chemicals).

Cooling processes with higher cooling loads are potential candidates for the adoption of emerging cooling technologies for thermal battery storage or alternatively the clean cooling chain.

4.2 Regional Process Cooling Load

The Carbon Trust study into the Humber’s EIIC estimated that total energy use in the region in 2015 was approximately 37,200 GWh/year, that 23,200 GWh/year was consumed by the Industrial and Commercial sector, and that 9,200 GWh/year was consumed by the studied industries.

As discussed earlier (see section 2.2) actual data on cooling related electricity consumption by Humber industries has not been captured. Rather an analytical modelling approach has been used to estimate electricity cooling load across the region. It is estimated that 1,400 GWh of the electricity used by the Industrial and Commercial Sectors is for cooling (see Table 1).

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6 See Page 91 of the main report.
### 4.3 Industries with Heavy Process Cooling Requirements

Food processing and EIIC sectors have significant electricity demand due to process cooling. In the food processing sector as much as 60-70% of the electricity used on site is due to providing process cooling\(^7\). In energy intensive industries between 5-20% of electricity demand is due to process cooling. However, the EIIC sector has much higher total energy consumption than most sectors so the actual cooling load can be very large.

*“We hadn’t done much work on energy efficiency until the ESOS requirements were introduced. Since then we have been able to reduce the number of cooling water pumps to reduce energy demand.”* Industrial Interviewee

### 4.4 Humber Process Cooling Maps

The process cooling maps produced as part of this supplementary study are similar in form to those produced for the main study. This is due to the use of high level assumptions.

The projected annual electrical demand densities due to process cooling identified during the study ranged from 0 to 9150 MWh/km\(^2\). The colour coding on the cooling maps presented below is based on a graded electricity demand density scale which can be summarised as: white (0 MWh/km\(^2\)), Blue (2,290 MWh/km\(^2\)), Cyan (4,575 MWh/km\(^2\)), Green (6,040 MWh/km\(^2\)), Yellow (6,860 MWh/km\(^2\)), Orange (7,777 MWh/km\(^2\)), and Red (9,150 MWh/km\(^2\)).

Other cooling loads will exist elsewhere in the Humber region but these are outside the scope of the dataset that has been used for this study. It is anticipated that the highest process cooling electricity loads have been identified in this study.

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Study of the Cooling Opportunities in the Humber Region

Figure 3: Inset A. Cooling map of Saltend and Hull

The electric cooling load in Saltend is related to chemical processing and power: cooling technologies such as chillers to remove process heat (e.g. temperature control), variable speed drive controlled fans on cooling towers to cool manufactured product, and cryogenic cooling in product separation or storage processes. Examples of cooling technologies around Hull include cold storage for food processing.

Figure 4: Inset B. Cooling map of Immingham and Grimsby

Examples of cooling technologies found in Immingham are likely to be related to cryogenic cooling for product separation or storage processes; and other process cooling technologies needed to maintain process operations. Examples of cooling technologies in Grimsby are likely to be cold storage technologies for the processing and storage of food products, but at a higher electricity densities than Hull.

Figure 5: Insert C. Cooling map of Scunthorpe

Cooling related technologies around Scunthorpe are those for industrial process cooling (e.g. at steel plants), Such as fans for air cooling and pumps for water cooling, rather than specific cooling technologies.

The process cooling maps presented in Figures 3 to 6 visually demonstrate that there are two main geographic areas with high electricity densities due to cooling: Saltend & Hull, and Immingham & Grimsby.
Given the high electricity load due to cooling in these regions\(^8\), opportunities are likely to exist for the following types of emerging technology:

- Thermal cold storage technology to store renewable electricity for later release into the electricity grid and/or to reduce demand on the electricity grid at times of peak demand.
- Virtual thermal cold storage battery to store additional coolth\(^9\) and thereby reduce the load on the electricity grid at times of peak demand.

Storage opportunities should be considered after ensuring all cooling energy efficiency measures have been applied to minimise energy needs. For example, local interviewees noted replacing cooling towers as an energy saving project that they were considering or had installed to reduce cooling load.

The emerging cooling technologies presented in Section 5 may have practical applications.

### 4.5 Energy Savings in Cold Storage

A study into the energy consumption at small (<100m\(^3\)) and large (>100m\(^3\)) food cold stores was conducted by Evans et al (2014)\(^{10}\). For this study 38 cold stores across Europe were audited: Bulgaria (5), Denmark (5), Italy (11), Switzerland (1) and the UK (16).

The energy audits identified 21 different issues that had direct impact on energy consumption. These included poor control of compressors, poor defrost cycle control and inefficient lighting (that often emits unneeded heat into the cold store), through to overcooling of the cold store and poor servicing and maintenance. Solutions to the identified issues included specifying new equipment, improvements to servicing, maintenance and monitoring processes, replacement lighting, better compressor control, and reducing air infiltration.

For larger cold stores energy savings of up to 72% were identified with 70% of these having paybacks within 3 years. Only alterations to the building or system design had payback greater than 4 years. For smaller stores energy savings of up to 28% were identified but the required solutions were not attractive - being in the region of 9 to 20 years - with the exception of adjusting evaporator controls which had a 1 year payback. Across all cold stores average energy savings of 28% were identified confirming that considerable energy savings are possible. Variation existed across product store type (see Table 2).

#### Table 2: Potential average energy savings related to product type stored. Note: (i) ‘-’denotes no data, (ii) Wide variations in energy saving observed with vegetable (to 50%), mixed (to 65%) and dairy cold storage (to 72%)

<table>
<thead>
<tr>
<th>Cold store type</th>
<th>Small (&lt;100m(^3))</th>
<th>Large (&gt;100m(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice Cream</td>
<td>-</td>
<td>8%</td>
</tr>
<tr>
<td>Vegetable</td>
<td>-</td>
<td>22%</td>
</tr>
<tr>
<td>Meat</td>
<td>19%</td>
<td>30%</td>
</tr>
<tr>
<td>Mixed</td>
<td>-</td>
<td>32%</td>
</tr>
<tr>
<td>Dairy</td>
<td>-</td>
<td>53%</td>
</tr>
</tbody>
</table>

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\(^8\) And quite possible others areas of the region not included in the study

\(^9\) The absences of heat. Coolth is to cool what warmth is to warm

Of the identified energy savings it was found that 24% could be identified by knowledgeable cold store staff, and a further 43% could be identified by a refrigeration engineer. Only 33% required additional specialist expertise.

5 Thermal Cooling Energy Storage

5.1 Cooling Technologies Landscape

A wide range of cooling technologies exist to either reduce cooling demand or provide cooling services within an enclosed space (e.g. a refrigerator, cold store, cooling tower), see Figure 7. Technologies that reduce cooling demand include thermal insulation, solar building facades and reflective coatings.

There are four main categories of technology that can provide cooling services (see Figure 7):

1. Technology based on the vapour compression cycle: Vapour compression is the dominant cooling technology used today. Such technology uses a refrigerant to move heat away from a hot space (or object) and release it to the environment. Common examples of this technology include: car air conditioner, domestic fridge, heat pump and cold store chiller. Much of the installed vapour compression technology uses harmful greenhouse gases than are in the process of being phased down in the European Union by the F-Gas Directive. Due to the current installed base, the wide range of available technologies (including some that use refrigerants with minimal greenhouse gas impacts) and strong supply chains vapour compression technology is likely to continue to have a dominant cooling role for the next 10 - 20 years.

2. Technology based on alternative cooling methods: Cooling can also be achieved through the use of novel materials (e.g. shape memory alloys, semiconductors) or processes (e.g. acoustics applied to refrigerants, heat applied to absorption-refrigerant chemical blends). Because of the wide application of vapour compression cycle technology, technology innovation funding to mainstream these technologies has been limited. However, due to the established knowledge that refrigerant gases can have significant climate change impacts, progressively more research funding is being directed at these technologies. Some of these technologies (e.g. adsorption chilling, absorption chilling) already have niche applications where sources of free heat exist (e.g. heat networks, thermal systems, industrial processes).

3. Liquefied Natural Gas cold recovery: LNG is held at a temperature of about -162°C and as a liquid is about one-six hundredth of the equivalent body of gas by volume. To return liquid natural gas to a gaseous state heat is required. This heat may be provided by an industrial reheating process. It can also be provided by a nearby heat source (e.g. an external industrial source of waste heat). Alternatively, the LNG can be used as a coolant (i.e. a source of waste cold) in place of large industrial cryogenic refrigeration units to provide chilling with the re-gasified natural gas being, for example, injected into the gas grid.

4. Thermal cold storage: technologies that provide cooling services through the physical properties of phase changes in matter (e.g. liquid to gas, water to liquid). Such technologies include evaporative cooling (water evaporation lowers local ambient temperature), ice (solid to liquid), cryogenic cooling (e.g. liquid air) and other phase change materials.

As presented earlier, vapour compression technologies are likely to remain important cooling technologies in the Humber region for the foreseeable future. Looking to the future all industrial users of such technology will have to ensure that the equipment they own complies with the EU F-Gas
regulation. Where appropriate, compulsory action will need to be undertaken by industry to ensure that harmful fugitive greenhouse emissions are appropriately minimised or removed entirely from their operations. Compulsory F-Gas related activities across the Humber region are likely to stimulate supply chain activity for the next 3 to 5 years, if not longer. At the same time some alternative methods for cooling and cold storage are likely to have (or already have) cooling applications in the Humber region.

Figure 6: Landscape map of cooling technologies. Presented at the Birmingham Cooling World Congress by Flexible Power Systems.

5.2 Future Cooling Technology Applications

The conventional vapour compression has been refined over multiple product generations spanning 160 years and therefore exhibits strong cost and energy efficiencies when compared with new cooling innovations. This doesn’t necessarily reflect superior technology, rather the embedded economic value (e.g. innovation, operational learning, and supply chains) that has been invested.

Looking to the future two technology developments are emerging that have the potential to alter the economic case for the use of certain cooling technologies. These are use of waste heat as a source of cooling and use of cooling as a thermal energy battery storage.

Absorption chillers

An absorption chiller uses heat as the energy needed to power the cooling process. An absorption chiller uses a liquid refrigerant with a low boiling point (less than -18 C) and the phase change properties of chemicals. When this liquid refrigerant boils (i.e. evaporates) it moves some of the heat away from the heat source, and thereby provides a cooling effect. The now gaseous refrigerant is absorbed by another liquid (i.e. the absorbent). This refrigerant-absorbent liquid is then heated by a separate external heat source (the energy source) causing the refrigerant to evaporate out. The evaporated refrigerant is then passed through a heat exchanger that transfers the heat outside the system, condensing the refrigerant gas in the process. The process then begins again.
Absorption chilling can be a viable technology in situations where excess heat (e.g. from an industrial process) can be used. Heat delivered through a network can be a cost-effective heat source to drive absorption chillers.

**Emerging cooling technologies**

**New cooling technology innovations are emerging that have the potential to radically alter the way electricity is stored and used.** The UK has a strong and growing academic capabilities in these new technologies, particularly at the Universities of Birmingham, London South Bank, Leeds and Herriot-Watt. Innovative technology start-ups are now emerging which often have the backing of academia and BEIS. Clean cooling has the potential to be a UK strategic technology competence.

These emerging cooling technologies offer the potential to:

- Provide thermal battery store for renewable energy
- Deliver demand side response capabilities aligned with the National Grid’s goal to encourage customers to use less energy during peak hours or shift their time of use to off-peak hours
- Deliver frequency response capabilities to meet National Grid’s requirements
- Create a new energy vector

Two thermal battery technologies stand out for potential application in the Humber region: cryogenic cooling and phase change materials. Both these technologies can be used to store and then release significant amounts of renewable electricity. Moreover, in the future these technologies could be used to transport stored energy over distance. Cryogenic storage can also be used to directly power engines without the need for fossil fuels, or equally to provide direct power compressed air without the need to firstly convert the stored energy to electricity.

Thermal batteries don’t suffer from the cycle time challenges that currently afflict many chemical batteries, i.e. chemical batteries are only able to perform a set number of charge-discharge cycles before the battery becomes ineffective.

“**BEIS has a growing interest in clean cooling technologies and is interested to see how these develop. Technologies such as Highview and Dearman are interesting UK innovations that have the potential to help shape the future of our energy system**” BEIS

Presented below is a series of cases that highlight the capabilities of using cooling technology as thermal stores or within the cold chain.

**Highview Power Storage**

Highview Power Storage (HPS) was established 2006 to take liquid air energy storage (LEAS) to market. The research underpinning LAES began at the University of Leeds in 2005 and by 2011 the world’s first LAES pilot plant (350kW/2.5MWh) was connected to the grid at SSE’s biomass plant in Slough.

There are three basic steps in LAES – see Figure 7:

1. Turn ambient air into liquid air using technology powered by electricity that cools the air down to -196°C shrinking it to 1/700 of the original volume.
2. Store the liquid air in thermally insulated low pressure air tanks.

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11 An energy vector allows the transfer, in space and time, of a quantity of energy. A non-exhaustive list of energy vectors includes fossil fuels, electricity, radiation, hydrogen, and chemical or thermal batteries.
3. Turn liquid air back into gas through exposure to ambient temperatures and use the 700-fold expansion in volume to drive a turbine which creates electricity without combustion.

**Figure 7**: Highview Power Storage LAES process. HPS improved the efficiency of the LAES process by adding storage tanks to hold heat (thermal stores) and cold (cold recycle).


HPS with Viridor was awarded a £8m UK government grant in 2014 to construct a 5MW/15MWh LAES demonstrator. In late 2017 an additional £1.5m government grant was provided to adapt the LAES system to meet the requirements of the National Grid’s new enhanced frequency response service. This plant began operating in June 2018 and is located at a landfill site at Pilsworth, Bury, Greater Manchester.

**CryoHub**

CryoHub is a 42 month, €8.1 million, EU Horizon 2020 project comprising 14 partners from across Europe including Air Liquide, London Southbank University, Cranfield University, University of Birmingham and the UK Institute of Refrigeration. The goal of Cryohub is to develop a cryogenic energy store (i.e. LAES) at a refrigerated warehouse that integrates renewable energy storage with industrial food processing refrigeration together with enhanced power grid sustainability. In this application CryoHub has many similarities with the HPS technology presented above, with the additions of a useful application for the substantial cooling energy that exists in a LAES system.

The proposed benefits of LAES include:

- Large scale thermal energy storage to aid grid balancing (i.e. load shifting)
- Store energy from local intermittent renewable energy systems before supply to the grid
- ‘Peak shave’/demand side response, i.e. remove peak power requirements from the grid
- Free cooling to cold stores during power generation periods (and cool shifting)
- Decarbonised electricity grid
- Potential to facilitate wider application for liquid air energy storage

In addition to the proposed project benefits there has been a growing realisation that real-time electricity pricing could make thermal storage technologies more commercially attractive. For example buying renewable energy when demand is low (and the price is cheaper) and selling when demand is high (and the price is higher).

“We're looking beyond CryoHub 1 to CryoHub 2. We want to locate a cryogenic energy store (CES) next to a cold store facility. As electricity is generated the CES can provide blast chilling services with lower carbon impact than conventional solutions. The Humber region could be a good candidate for

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CryoHub 2 due to the presence of food processing facilities and partners such as Air Liquide. I would be interested in future discussions...” Academic Interviewee

“...CryoHub – would like to see the technology. We’re open to try something if someone will come in and support it and if someone willing to cover risk.” Industrial Interviewee

Innovatium

Innovatium together with a consortium including the Birmingham Centre for Energy Storage at the University of Birmingham are developing another pioneering application for LAES. In 2017 BEIS awarded the consortium a grant to develop technology to utilise LAES as a thermal energy store capable of demand side response, and to also provide a source of on-tap compressed air. In the UK industrial compressed air accounts for 10% of all industrial energy use. Compressed air is widely used in industries found in the Humber region (e.g. food & drink, pharmaceuticals, chemicals, metals fabrication, primary metals, aggregates and cement).

The consortium proposes that when electricity demand and costs are high, air compressors are turned off and all compressed air process requirements are instead fulfilled by evaporating the stored liquid air. When demand and costs are low, the store of liquid air is replenished by liquefying suitably treated atmospheric air, allowing the process to be repeated. This application of LAES demand side response has the potential to significantly reduce peak power demand whilst not materially impacting industrial production.

Transport Refrigeration Units

Dearman has developed a technology that harnesses the cooling and mechanical energy of the Liquid Nitrogen to power cooling applications either in situ or on the move. Dearman could as easily utilise liquid air and may have to do so in the future as the liquid air energy vector becomes established.

Dearman has deployed its technology in Transport Refrigeration Units (TRU) because these are a key element in the cold chain, linking food producers to consumers. The Dearman TRU engine keeps the product in a refrigerated trailer at the same low temperature as provided by a traditional diesel TRU.

“The traditional diesel TRU represents c.20% of a refrigeration truck’s total fuel consumption but can account for more than 75% of its NOx emissions and 95% of its particulate matter (PM). The Dearman system has zero CO2, NOx and PM tailpipe emissions so it can help operators achieve their emissions reduction goals. The Dearman TRUs produce less noise than diesel systems allowing for quiet operations in city and urban areas and with no difference in refuelling times from diesel systems, there is no necessity for backup fleets as you would with electric based systems.” Industrial Interviewee

The Dearman TRU is equipped with a Dearman Engine, a cryogenic pack and a refrigeration cycle. The engine is similar to a standard piston engine, and the expansion of gas inside a cylinder pushes downwards on the piston. The engine harnesses energy that is released by the expansion at almost ambient pressure and temperature of liquid nitrogen to produce mechanical power. Part of the Dearman Engine work is used to drive ancillaries in the refrigeration system (alternator, fans, pumps etc.) and the remainder is used to drive a vapour compression cycle to provide additional cooling on top of that provided by the liquid nitrogen.

13 The Carbon Trust can provide introductions to the industrial and academic interviewees
Dearman TRUs have already had several successful trials with large European TRU operators such as Sainsbury’s, Unilever and M&S in Europe and in the UK. Source: provided by Dearman

Xinjiang 6MW/36MWh thermal store

“The UK is a world leader in phase change materials for thermal energy storage. Large scale demonstrators based on UK technology exist overseas, for example at Xinjiang”  Academic Interviewee

The Birmingham Centre for Energy Storage lead an EPSRC project with several Chinese universities and the Nanjing Jinhe Energy Co. Ltd to construct a thermal energy store in Xinjiang to demonstrate the potential applications of novel thermal phase change materials to store renewable energy from wind. Phase change materials are substances that absorb and release thermal energy during the process of melting and freezing. The materials recharge as everyday temperatures fluctuate, making them ideal for a variety of everyday applications that require temperature control.

Building this pilot phase change material plant in Xinjiang, one of the windiest regions in China, enabled wind energy to be utilised that would have otherwise been wasted. This wind energy was then used to heat 60,000m² of space. Harnessing 10,000KWh of wind power reduced the environmental impact of the local energy system by 3,100 tonnes of CO₂ and 10 tonnes of SO₂ per year, equivalent to ~1200 tons of coal.
5.3 Virtual Thermal Energy Stores

There is a growing need in the UK to utilise demand side response technology to reduce peak demand. Reducing peak demand has a number of benefits, including:

- Reduced risk of brown outs
- Improved grid-quality (e.g. frequency response)
- Less need to bring standby power station generation online
- Enable the decommissioning of old power generating assets or reduce the need to build new assets

The market for demand side technology is growing rapidly with companies such as Open Energi, Upside Energy and Reactive Technologies becoming established in the last decade. Each of these companies provides technology to enable management of many organisations’ existing electricity and energy store assets to create an energy store that can be used to balance regional grid demand.

These systems use digital control technology to collectively manage widely spread small energy stores (e.g. hot water tanks, fridges, UPS, EV battery) so that they can be made to act together in unison and give the demand side benefits of a much larger energy store (i.e. a virtual energy store). The energy capacity of the virtual energy store is then sold to the National Grid to help it manage (i.e. shift) grid demand. National Grid analysis shows that 600 tonnes of CO₂e can be eliminated for every MW of demand-side capacity made available.

When it comes to cooling technologies, virtual store technology could be used to over-cool product when there is reduced regional demand for electricity (e.g. the product is frozen to a colder temperature) and then cooling is reduced or switched-off when demand for electricity is higher (e.g. the product is allowed to warm-up to a warmer but still frozen temperature). By doing this the virtual storage technology turns existing cooling technology into a thermal battery.

Using virtual demand side control technology with the cold storage facilities in the Humber region opens up the possibility of providing a short-duration virtual thermal battery for demand side and frequency response management. Demand side control could be applied at one site, or a collection of sites in a sub-region or the region to provide for a level of electricity demand management. Examples of two companies that are active in the market:

**Upside Energy**

With multiple sources of funding, including Innovate UK, Upside Energy has developed a technology agnostic cloud service that aggregates the energy stored in existing equipment (e.g. uninterruptible power supplies (e.g. in datacentres), solar PV systems, electric vehicles, domestic heating systems,
fridges) to create a Virtual Energy Store™. Upside Energy sells the benefits of the VES to the National Grid to help it manage electricity demand. Upside Energy shares the revenues it generates from the services it delivers to the National Grid with the owners of the devices that it has under cloud management.

“Upside Energy VES is agnostic of the underlying technology. We provide intelligence in the cloud that manages technologies like hot water tanks or EV batteries to act as if they were a large virtual energy store. The VES could also control refrigeration equipment” Industrial Interviewee

Upside Energy has recently won further government backing to explore how the technology can be used with EV technology. Their technology could help generate revenue to pay for EV charging infrastructure. It is also leading a trial to on domestic housing – the Power. Energy. Technology. Efficiency project – to demonstrate how balancing services to the power industry can also improve energy efficiency in the home. This £2.5m project will integrate home battery systems, intelligent hot water tanks and a cloud demand side response service. Over 500 properties will get intelligent hot water tanks and 100 lithium-ion batteries across Cornwall and London.

Open Energi’s Sainsbury’s Demand Side Response

Sainsbury’s serves over 22 million customers a week from over 1,000 stores across the country. It aims to be the UK’s greenest grocer and has put in place a detailed roadmap to achieve its sustainability goals. In 2011 Open Energi signed a 10 year deal with Sainsbury’s to equip heating and ventilation systems (HVAC) across 200 stores with Dynamic Demand. The technology turns the supermarket’s HVAC into smart devices which can respond to fluctuations in electricity supply and demand in real-time, and help National Grid to keep power supplies flowing. Sainsbury’s and Open Energi are now in the process of trialling other equipment whose demand for energy can be flexed without impacting operational performance.

6 Energy Storage Applications

At the end of 2017 UK renewable electricity generation was 98.9 TWh (29.4% of total generation) and is expected to increase further as new renewable assets come on-line, or as renewable electricity storage is rolled out. Use of stored renewable electricity replaces electricity generated from fossil fuel sources, typically from gas fired power stations and furthers grid decarbonisation.

There are options for business customers, distribution network operators, and transmitters to use, at different scales, energy storage technology. The project economics of energy storage vary as a function of, among others, energy-use application, service function (e.g. in relation to the wider electricity-grid), achieved co-benefits (e.g. cooling, contingency, increased business density), source of electricity being replaced, grid constraints, location and asset size (e.g. MW/MWh).

Energy storage permits electricity to be intentionally stored for a later use, such as:

- Storing generated renewable electricity at times of low demand
- Gaining economic benefit from buying electricity at low prices and selling when prices rise
- Building grid ‘peak time’ demand resilience

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15 Coal generated electricity now stands at <7% total UK generation.
- Debottlenecking grid ‘peak time’ demand resilience
- Enabling reinforcement supporting the technology rollout (e.g. electric vehicles, heat pumps)

“We have looked at battery storage but are not convinced of the financial case for these currently. We would need a better understanding of the business case and environmental benefit, especially when space on site is in demand” Industrial Interviewee

Larger energy stores in the Humber would most likely be deployed within the electricity grid infrastructure by Northern Power (DNO) or National Grid (transmission operator). Smaller energy stores could be deployed by Northern Power, National Grid, or a business customer. Table 3 outlines potential application of energy storage that Northern Power, National Grid or a business customer might consider.
Table 3: Examples of how energy storage could be used in the Humber region

<table>
<thead>
<tr>
<th>Point of Connection Battery Connection</th>
<th>Storage application</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry (i.e. behind the meter)</td>
<td>Self-consumption</td>
<td>Maximising use of on-site renewables generation or local energy sources (e.g. cooling) in order to gain the maximum benefit from these sources, and minimise the amount of electricity purchased from the supplier.</td>
</tr>
<tr>
<td>Industry</td>
<td>Increased power quality (demand)</td>
<td>Using energy storage to improve the power quality supplying a specific load. Such power improvement is often needed in industrial applications where power quality will be of critical importance (e.g. manufacturing).</td>
</tr>
<tr>
<td>Industry</td>
<td>Peak shaving</td>
<td>Reducing demand at peak times by supplementing supply from the grid with electricity from energy storage. A form of demand management.</td>
</tr>
<tr>
<td>Industry</td>
<td>Time of use bill management</td>
<td>Storing electrical energy at times of high supply (e.g. a particularly windy or sunny day) when electricity prices are lower, to be used later when electricity prices are higher.</td>
</tr>
<tr>
<td>Industry</td>
<td>With cooling</td>
<td>Utilise the co-benefits of energy storage with a long term source of cold thermal energy for process cooling. Delivering economic benefits, processes and energy use efficiency.</td>
</tr>
<tr>
<td>Distribution network</td>
<td>Distribution deferral</td>
<td>Where the distribution system may need an upgrade to deal with increased load growth, energy storage can be used to either reduce the size of these upgrades, or remove the need entirely.</td>
</tr>
<tr>
<td>Transmission system</td>
<td>Contingency management</td>
<td>Utilising energy storage to provide generation capacity immediately in the event of an unplanned outage or contingency event.</td>
</tr>
<tr>
<td>Distribution network</td>
<td>EV charging</td>
<td>Supplement local grid requirements for EV charging areas together with load balancing at peak times.</td>
</tr>
<tr>
<td>Distribution network</td>
<td>Heat pumps</td>
<td>Support wider adoption of heat pumps through local grid reinforcement through energy storage.</td>
</tr>
<tr>
<td>Distribution network</td>
<td>Transmission congestion relief</td>
<td>Using energy storage to reduce the reliance on certain transmission corridors at specific times when they may be congested and therefore incur high charges from the transmission system operator. This could enable additional businesses to set up in an grid-constrained areas.</td>
</tr>
<tr>
<td>Transmission system</td>
<td>Energy arbitrage</td>
<td>The purchase of electricity when wholesale prices are low with a view to selling electricity back to the grid at a higher price in the future.</td>
</tr>
</tbody>
</table>
7 Technology Convergence

Several technology trends are converging that hint at the potential value of cooling as an energy vector: the need to find distinctive less environmentally damaging cooling solutions (i.e. lower CO₂, SO₂, NOx, PM), the need to store renewable energy until needed, and demand side management.

Together these trends are stimulating investment in cooling technologies that themselves are unlocking new possibilities not considered previously, including:

- The use of cryogenic liquid (e.g. liquid air) technologies to:
  - store renewable energy for future use and possibly shipment
  - provide substantial cooling to large process cooling activities (e.g. food processing)
  - provide ‘demand side reduced’ compressed air to industry
  - power engines that deliver electricity and cooling (e.g. refrigerated transport).
  - Looking to the future cryogenic technologies could also:
    - provide air conditioning for motor vehicles with the cryogen recharged at the same time it is refuelled
    - be used to transport large volumes of cold and renewable energy across large distances, possibly in a similar way to that which occurs with LNG tankers
    - as a by-product to remove CO₂ from the atmosphere.

- The use of emerging phase change material technologies to:
  - store renewable energy for future use
  - provide ‘demand side reduction’ services
  - provide widespread thermal storage applications in locations where additional cooling is not required (e.g. away from industry).
  - Looking to the future, it is quite conceivable to suggest such technologies could also:
    - Be used to store hot or cold thermal energy as and when desired.

To deliver these potential applications industry will be need to develop and integrate new technologies into the cooling and energy systems. Importantly whilst cryogenic cooling is an emerging cooling technology for energy storage applications, it has actually existed for over 100 years. The Humber region has cryogenic manufacturing capabilities within its existing chemical manufacturing processing base (e.g. Air Liquide) and is has similar service capabilities (i.e. used at site but not for commercial sale) in gas processing.

8 Summary and Next Steps

Summary

The primary focus of this study has been to identify if thermal energy storage has potential applications in the Humber region. Discussions with academia, industry stakeholders and technology companies have all highlighted the potential benefits that thermal energy storage could provide in the region. In addition, the presence of industries with high process cooling loads (particularly food processing, EII, EIC), further suggest that it is quite possible that thermal energy storage has good application potential in the region.

Two broad variants of thermal energy storage could be applicable:

1. **Turning existing cooling technologies into short duration virtual energy stores**: use cloud based demand side management technology to take control of existing industrial process
cooling technologies and reduce local ‘peak demand’ load. Businesses deploying such technology may benefit from National Grid incentives (i.e. economic benefits exist). This technology could be rolled out across a wide range of technologies.

2. **Thermal cold energy stores that provide longer term energy storage capabilities**: participate in world leading demonstrations of thermal storage technology for renewable electricity storage. Participation would reinforce and enhance the Humber region’s ambition to become the UK’s leading renewable hub.

A balanced mix of energy storage types should be considered as Northern Power, National Grid and industry have different electricity management challenges:

3. **Opportunities exist to take a UK leadership position in the deployment of other forms of energy storage** (e.g. chemical batteries) for renewable energy. Participation would again reinforce and enhance the region’s ambition to become the UK’s leading renewables hub.

**Next Steps**

Suggested next steps:

- Consider establishing an **Energy Storage Working Group** with representatives from renewable energy generators, local energy generators, National Grid, Northern Power, Humber LEP, Local Authorities and representative food processing and EIIC businesses. The Group could be tasked with formulating the storage strategy and delivery plan and identifying funding options (e.g. industry strategy, clean growth strategy funds) for the deployment of energy storage technologies across the region.

- As part of the **Humber Energy Strategy**, undertake further research into the potential use of thermal and non-thermal energy storage across the Humber. Specifically look to address questions such as: How much renewable energy might be available for local storage? Which areas might be best suited to energy storage? What should the regional mix of thermal and non-thermal energy storage be? To which sites could demand side technology be added to existing equipment to create short term, virtual, thermal energy storages for grid frequency management? What role can heat or cooling networks play?

- Through the Novel Business Model Accelerator **stimulate local enterprise incubation and business growth** in regional virtual energy storage, demand side management, and clean cooling enterprises. Examples include offshore renewables generation - onshore thermal storage business models (e.g. electricity sale at exit from thermal store not the wind turbine), or regional short-duration thermal cooling of existing cold stores to manage grid constraints, or a ‘cool battery’ company that provides its services on a “cooling as a service” basis.

- Embed in the **Local Industrial Strategy** the enhancement of energy storage capabilities (cooling, batteries) in the region’s universities. Encourage engagement between the Universities of Hull and Lincoln with the Universities of Birmingham, London Southbank, Herriot-Watt and Leeds – all of whom have world leading clean cooling capabilities. Further look to encourage research projects targeted on specific regional outcomes.

- Engage with industrial demonstration projects to identify if opportunities exists to **pull thermal energy storage demonstration projects to the Humber region**. Discussions with CryoHub representatives highlighted that the Humber region may be well placed to capture
the CryoHub 2 demonstrator due its large food processing sector and industrial base. Also look to identify new opportunities to demonstrate additional at scale applications of energy storage technologies in the UK.

- **Embed in the Local Industrial Strategy the development of a clean cooling chain strategy and action plan.** Seek to assess the capabilities of the region’s cooling chain, and how disruptive cooling technologies (e.g. liquid air, Dearman engine, phase change materials) could be engines for regional economic growth. Identify those technologies or sectors where the Humber could, with its industrial base and skills capabilities, take a leadership position (e.g. manufacture of equipment, manufacture of phase change materials, logistics).

- **Highlight to the Humber region food processing businesses that significant energy savings are likely to exist in their operations.** Deploy an awareness programme to highlight the 30-70% energy savings that can be achieved at most cold storage facilities through better maintenance and operational management.

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16 CryoHub 2 participant would be interested in discussing this opportunity further.