Cold is vitally important to modern day life. It underpins the supply of food and medicine, enables the growth of data networks and makes buildings and transportation more comfortable. The lack of cold has massive social and environmental impacts.

The demand for cooling is expected to boom, and unless we find new ways to make cold sustainable the environmental impact will be ruinous. Yet the UK Government currently spends less than 0.2% of its engineering research budget on cooling.

The 'greening' of cold is clearly an urgent global problem – but it may also offer Britain a significant business opportunity.

The University of Birmingham Policy Commission was set up to look at meeting demand for cold from a systems level to recruit vast untapped resources of waste cold, ‘free’ cold, waste heat, renewable heat, and ‘wrong-time’ energy to radically improve the efficiency of cooling, and reduce its environmental impact and cost. It also produced a high-level technology roadmap to guide next steps and longer term progress with the support of stakeholders from innovators to end-users.

Developing policy and action on clean cold will help deliver:
- reduced carbon emissions and better air quality;
- energy resilience;
- global food security;
- economic growth, in-country jobs and skills.
The roadmap for cold is intended to describe what is required to develop a vibrant British clean cold industry that will not only dramatically improve the environmental performance of cooling in this country, but also establish and maintain a lead in a new global market potentially worth £ hundreds of billions.

It is a high-level industry roadmap, developed by the Commission and external experts. It is technology agnostic and resolutely practical: it does not fix its eyes solely on what might be achieved from blue-sky technologies in 15 years, but is equally occupied with the significant short-term gains from improved maintenance of existing equipment – and all the steps in between.

The aims of the roadmap are to reduce consumption of non-renewable natural resources, pollutant emissions, greenhouse gases (CO₂, refrigerants) and the total cost of ownership for equipment operators, but at the same time generate economic value to UK plc through improved productivity and exports, and social benefits for emerging economies through the creation of clean cold chains.
Why Clean Cold?

**Global market need**
- Rapidly increasing demand for cold and cooling of all types globally, especially in the rapidly emerging and developing economies
- Growing recognition of its energy demand and environmental footprint

**Technology shifts**
- UK innovation in producing, storing and using cold
- Increasing use of cryogenic fuels, natural gas and hydrogen
- Rising use of renewables and need for grid balancing

**The opportunity**
There is a real chance for the UK to maintain the initiative and take the lead in this rapidly emerging global commercial market.
Why Clean **Cold**?

- Refrigeration and air conditioning is estimated to cause between 7% and 10% of global CO₂ emissions – two to three times more than is attributed to aviation and shipping combined.

- Global demand for air conditioning alone is forecast to grow 33-fold by the end of the century, when it would consume the equivalent of half our worldwide electricity generation in 2010.

- If nothing is done, within fifteen years cooling will require an additional 139GW – more than the generating capacity of Canada – and raise greenhouse gas emissions by over 1.5 billion tonnes of CO₂ per year, three times the current energy emissions of Britain.

- It is estimated that around 23% of perishable food is lost through a lack of refrigeration in developing countries.

- Analysis suggests that the number of transport refrigeration units on the road could reach more than 15 million by 2025. That’s more than four times the number in operation today.

- If nothing is done, 15 million transport refrigeration units will emit the same amount of pollution as would be created by more than 800 million diesel cars.
Clean cold consensus roadmap

A shared roadmap for cold aimed at

Reducing
- consumption of non-renewable natural resources
- pollutant emissions
- greenhouse gases (CO$_2$, refrigerants)
- total cost of ownership for operators

Delivering
- economic value to UK plc (UK productivity and exports)
- societal benefits for emerging economies (cold chains)
The key steps to doing cold smarter

Evidence to the Commission suggested a four-stage approach to doing cold smarter, culminating in the Cold Economy:

1. **Reduce cold load/cooling work required:** e.g. better building design, vaccines that survive at higher temperatures;

2. **Reduce the energy required for cooling:** i.e. increase the efficiency of cooling technologies – eg. cold stores could raise efficiency by an average of 30% using off the shelf solutions only – and reduce the global warming potential (GWP) of refrigerant gases;

3. **System level thinking/Cold Economy:**
   a. **Harness waste resources:** ‘wrong-time’ renewables; waste cold (LNG); waste heat, or renewable heat from biomass or ground source heat pumps; system integration across the buildings and transport;
   b. **Cold energy storage** to warehouse and shift wrong-time energy to replace peak electricity demand and diesel consumption in built environment and transport applications.

4. Having thus minimised energy demand, **convert remaining cooling loads to sustainable energy sources.**

The primary focus of the roadmap is steps two and three, since the other elements are broadly understood, whereas nobody has previously investigated the system-level efficiency of cooling, and early work suggests the gains from these two steps are potentially huge. Additionally much of the cold demand is going to come from new ‘smart’ cities yet to be built, and we have the chance to develop cold into properly planned and integrated energy systems.
The roadmap takes an integrated system approach to cold

Making cold
• Harness waste/unused resources e.g.:
  – ‘wrong-time’ renewable energy (e.g. wind)
  – waste cold (e.g. LNG)
  – ambient heat & cold (e.g. ground source)

Storing cold
• Thermal energy storage to warehouse

Moving cold
• New energy vectors and material to shift cold

Using cold
• Reduce cold loads
• Increase efficiency and reduce GWP of conventional technologies
• New technologies to harness novel thermal stores and energy vectors

Managing cold
• Data monitoring
• Intelligent controls
• System level management

System approach to cold
How does UK capture value?

Impacts for UK
- Jobs
- Revenues
- Exports
- Environment
- Energy Security

Cross-cutting enablers
- Services
- Sales
- Manufacturing

Themes
- Making cold
- Using cold
- Managing cold
- Being on the agenda

Value Creators
- Innovation
- Technology Demonstration
- Skills Development
- Measurement & Data

Business Models
- Manufacturing techniques/high value supply chain
- Export Support
- UK & EU regulation

Marketing cold
- Advocacy

Behavioural Changes
- Advocacy

Technologies
- Demonstration
- Skills Development
- Measurement & Data

Making cold
- Technology Demonstration
- Skills Development
- Measurement & Data

Export Support
- UK & EU regulation
- Manufacturing techniques/high value supply chain

Moving cold
- Advocacy

Being on the agenda
- Advocacy

Clean Cold Policy Commission Innovation Road Map
October 2015
Where is the roadmap relevant?

**Energy Systems:** grid buffering and stabilisation, district heating cooling, system level waste heat/cold recovery, storage and movement of cold

**Food:** packing, processing, manufacturing

**Cold Chain:** transport refrigeration, depots, retail & medical, domestic refrigeration

**Built Environment:** building energy, local scale energy buffering & power generation, air conditioning, data centre cooling, warehouse refrigeration

**Transport:** propulsion, waste heat recovery, interaction with ICE & electrochemical systems, LiAir, LN2, LH2 LNG or NH3 as a fuel, provision of a/c from cold

**Industrial process:** industrial gases and processes, LNG and LH2 import and distribution, industrial-scale chilling & freezing processes

**Advanced:** superconductors, nanotechnology, other fundamental or advanced concepts
# Summary features of roadmap

<table>
<thead>
<tr>
<th></th>
<th>Here now 0-3 YEARS</th>
<th>Short term 3-5 YEARS</th>
<th>Medium term 5-10 YEARS</th>
<th>Long term 10 YEARS +</th>
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</thead>
<tbody>
<tr>
<td><strong>Making Cold</strong></td>
<td>Use of existing geological and ambient cooling sources</td>
<td>Use of new cooling sources/ vectors e.g. LNG/liquid air</td>
<td>Develop small-scale air liquefaction</td>
<td>R&amp;D of very novel cooling techs e.g. wind direct drive liquefaction, ultrasonic, hydraulic</td>
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<td>Co-locating loads near waste cold sources, e.g. data centres / LNG</td>
<td>Integrate cooling &amp; heating systems, including other thermal cycles e.g. heat pumps</td>
<td>R&amp;D of solid state refrigerants</td>
<td>Elimination of all HFC coolants</td>
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<td>More efficient cooling techs and systems, including district cooling</td>
<td>Further develop new refrigerants and related codes &amp; standards</td>
<td>R&amp;D of novel cooling techs e.g. magneto and electro-caloric</td>
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<td></td>
<td>Research &amp; deploy new coolants</td>
<td>Develop currently novel cooling techs e.g. sorption systems</td>
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<td></td>
<td>Develop emerging cooling techs e.g. thermoelectric cooling</td>
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<tr>
<td><strong>Storing cold</strong></td>
<td>Use full range of currently available options e.g. water, ice, glycols, thermal piles</td>
<td>Apply developing technologies and opportunities e.g. phase change materials, composite heat/ cold systems</td>
<td>Develop next generation technologies and opportunities e.g. inter-seasonal thermal storage, denser materials</td>
<td>R&amp;D of disruptive technologies e.g. thermochemical storage, tunable phase change materials</td>
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<tr>
<td><strong>Moving cold</strong></td>
<td>Use full range of currently available options e.g. water, ice, glycols</td>
<td>Improved technologies for cold transport e.g. containerized LNG and liquid air</td>
<td>Harnessing waste cold of cryogenic fuels</td>
<td>R&amp;D of novel materials for packaged cold high energy density, cost and weight</td>
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<tr>
<td><strong>Using cold</strong></td>
<td>Maintain and repair existing equipment to improve performance. Apply efficiency measures to reduce losses e.g. doors on chiller cabinets</td>
<td>Apply cryogenic “cold and power” engines</td>
<td>Wider application of cold &amp; power systems, Systems integration in automotive – e.g. air conditioning and aux power</td>
<td>Harnessing the waste cold from liquid hydrogen infrastructure. Exploit advanced cold technologies (e.g. Magnetic, Peltier)</td>
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<td></td>
<td>Apply cryogenic cold power engines</td>
<td>Develop supply chain for cryogenic ancillaries</td>
<td>Develop low cost systems for low utilization uses</td>
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<tr>
<td></td>
<td>Develop low cost systems for low utilization uses</td>
<td>Apply super-chilling and tri-gen</td>
<td>Develop white goods suitable for integration into district heating and cooling scheme.</td>
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<tr>
<td><strong>Managing cold</strong></td>
<td>Improve measurement, data processing and control at cooling device and fleet level</td>
<td>Active management of devices for cold production. Smart fridges – grid sensing / interaction. Better processes for cold chain optimisation. Weather &amp; climate linked cooling</td>
<td>Fully integrated cold and energy chains, minimizing losses and environmental impacts; optimize system components</td>
<td>Long-term management of cold</td>
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</table>
High level roadmap for UK cold innovation

Drivers for Change:
- Air quality and/or CO₂ & GHG pressures
- Cooling TCO and energy risk management
- Rising demand for cooling
- Increasing renewables & grid balancing need
- Increased availability of waste cold (e.g. LNG, hydrogen)

System-level innovation:
- Energy network level integration of heat & cold
- District heating & cooling -> grid balancing
- Active management of smart cooling devices
- Predictive and active management of cold chain energy
- Integrate with waste sources of cold e.g. LNG
- Use liquid air for transport cooling and waste heat recovery
- Exploit existing ground source & waste cold

Technology innovation:
- Heat & cold technologies e.g. heat pumps, sorption, tri-gen
- Smart cooling devices to enable active management
- New cryogens & waste resources techs e.g. liquid air engines, liquefiers
- New storage materials e.g. phase change, thermochemical
- New refrigerants to replace all HFCs
- Develop emerging and novel cooling technologies e.g. thermo-electric, ultrasonic
- Maintain, monitor & control better
Interventions and Impacts

Where it all starts
Create a lead dept. and champion
Technology Innovation Needs Assessment
System level Modelling

Economic, (jobs and export) and environmental gains for UK plc
Cold as integral part of sustainable energy system
Cold as a growth and environmental opportunity

Interventions
Support for RD&D;
clear regulatory drivers;
manufacturing incentives;
export support

Impacts
Integrate with waste sources of cold e.g. LNG
Use liquid air for transport cooling and waste heat recovery
Existing ground source & waste cold

System Innovations

Drivers for Change

Cold as a growth and environmental opportunity
Interventions Impacts
Provide long-term energy system vision;
broker cross-sectoral linkages;
support large scale trials;
enable new infrastructure
Support for RD&D;
clear regulatory drivers;
manufacturing incentives;
export support

The Goal
Economic, (jobs and export) and environmental gains for UK plc
Cold as integral part of sustainable energy system
Cold as a growth and environmental opportunity

Interventions
Technology Innovation Needs Assessment System level Modelling

Clean Cold Policy Commission Innovation Road Map
October 2015
Potential roadmap stakeholders

**Energy Sector:** grid, power generation, liquid air and hot/cold-storage players

**Urban planners:** district cooling networks, heat island effect, integration of services and utilities

**Energy Users:** liquefaction, users with cold processes, industrial parks, city authorities

**Cold dependent businesses:** agriculture and food industry (post harvest food loss community), medical, data centres

**Vehicle manufacturers:** technology developers especially urban trucks & buses, refrigerated transport, light urban vehicles, goods handling, marine and mining

**Equipment manufacturers:** commercial and domestic refrigeration manufacturers – built environment, transport and mobile refrigeration plant and the providers of power in emission-sensitive environments

**Transport & Logistics operators:** including cold-chain, buses, urban delivery and haulage

**Component suppliers:** including heat exchangers, refrigeration compressors, electrical systems, ICEs, fuel cells and other future technologies with waste heat/cooling need

**Industrial gas suppliers:** embracing liquefaction and distribution of LN2, LiAir, LH2, LNG

**Superconductor innovators:** magnets, electrical conductors, motors

**Policymakers:** in energy, energy storage, transport, air quality & environment

**Finance community:** venture capital, asset finance, novel financing models, shared risk
For further information

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The full policy report, Doing Cold Smarter, is available for download from the Policy Commission website, via
www.birmingham.ac.uk/research/activity/energy/policy/cold/doing-cold-smarter.aspx

Birmingham energy Institute

The Birmingham Energy Institute is the focal point for the University of Birmingham and its national and international partners, to create change in the way we deliver, consume and think about energy. The Institute harnesses expertise from the fundamental sciences and engineering through to business and economics to deliver co-ordinated research, education and the development of global partnerships.