Delivering Low Carbon Cooling

Cooling is an invisible industry which is largely taken for granted by contemporary society – from the cold chains that safely deliver our food and vaccines to the air conditioners that make our workplaces and homes comfortable. At the same time hundreds of millions of people suffer the consequences daily of no access to cooling for basic needs.

Toby Peters

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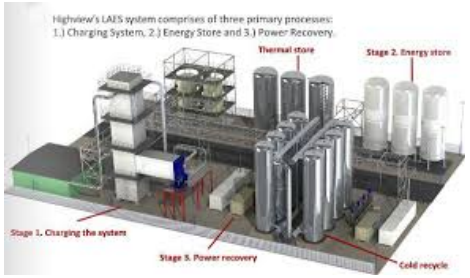
Chair, Academic Advisory Panel, CoolingEU

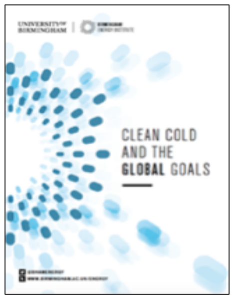
Doing Cold Smarter

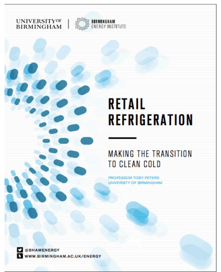
Technology background – Liquid Air as an energy vector

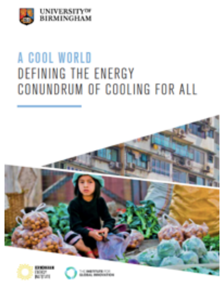


Thermal Energy
Research Accelerator

Clean cooling - System-level thinking







Clean Cooling Congress
and Workshops in *2018*

UK, UAE, Malaysia, India

Living Lab programme

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The Cold Economy

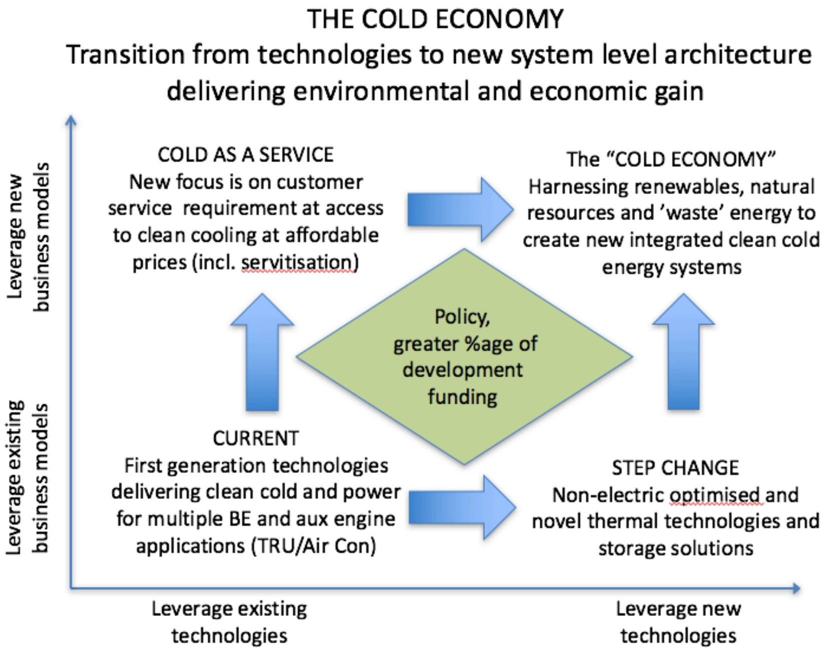
'What is the service we require, and how can we provide it in the least damaging way', *rather than* 'how much electricity do I need to generate?'

If cooling is to be sustainable, we don't simply need more efficient air-conditioners and fridges, but a fundamental overhaul of the way cooling is provided.

This demands a new needs-driven, system-level approach to understand the size and location of the thermal, waste and wrong-time energy resources and the novel energy vectors, thermal stores, clean cooling technologies and new business models to integrate those resources optimally with various cooling loads.

It also needs to be considered in the wider food-water-energy system, as well as the ripple effect and possible unintended consequences considered and planned for.

This will provide the routes for achieving the cheapest cost, greatest energy system resilience and lowest carbon emissions sustainable cooling system



Cooling Landscape Assessment

COOLING LANDSCAPE ASSESSMENT, published Dec 2018

- An overview of the market
- An explanation of the need for action
- Current investor attitudes
- A guide to where investment can create impact
- An assessment of barriers to deployment
- Strategies and responsibilities for intervention
- An overview of step-change clean cooling technologies and solutions
- A framework through which to assess technologies and solutions
- Opportunities for impact

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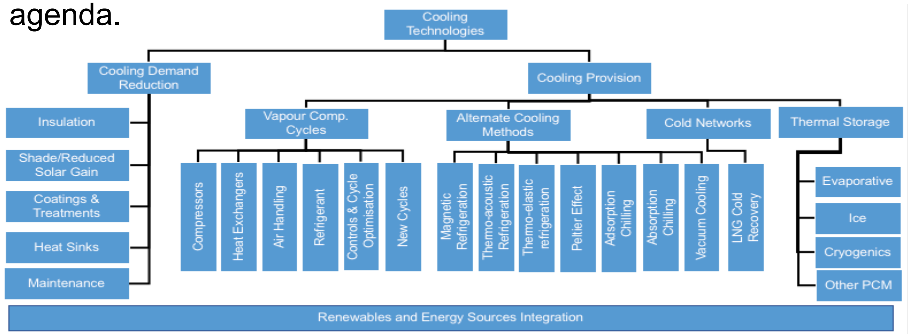
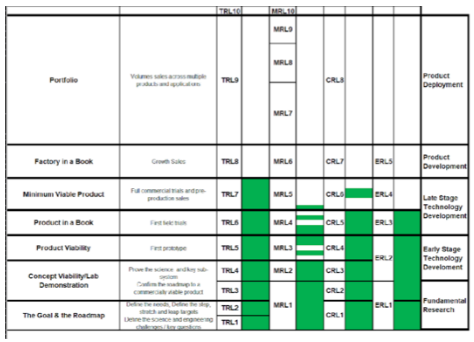
Technologies and solutions

A wide range of technologies are available to provide artificial cooling. Matching technologies with user applications and energy resources and ensuring the potential impacts of innovations are understood, is a key part of developing an effective research agenda.



Product Readiness Assessment Tool

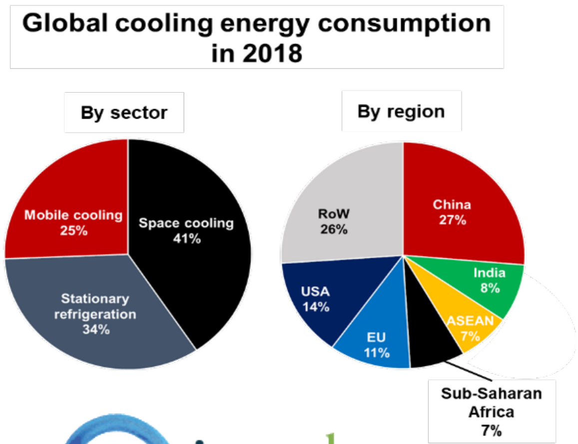


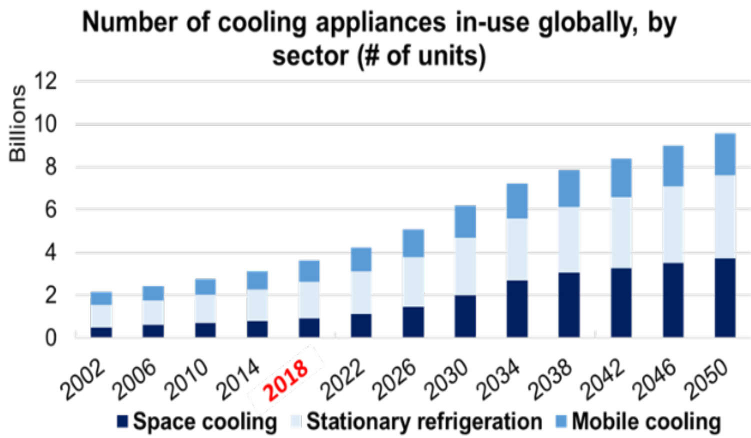
		TRL10	MRL10			
Portfolio	Volumes sales across multiple products and applications	TRL9	MRL9 MRL8 MRL7	CRL8		Product Deployment
Factory in a Book	Growth Sales	TRL8	MRL6	CRL7	ERL5	Product Development
Minimum Viable Product	Full commercial trials and pre-production sales	TRL7	MRL5	CRL6	ERL4	Late Stage Technology Development
Product in a Book	First field trials	TRL6	MRL4	CRL5	ERL3	
Product Viability	First prototype	TRL5	MRL3	CRL4	ERL2	Early Stage Technology Develoment
Concept Viability/Lab Demonstration	Prove the science and key sub-system	TRL4	MRL2	CRL3		
	Confirm the roadmap to a commercially viable product	TRL3		CRL2		Fundamental Research
The Goal & the Roadmap	Define the needs, Define the step, stretch and leap targets	TRL2	MRL1	CRL1	ERL1	
	Define the science and engineering challenges / key questions	TRL1				

A simple and easy to use technology assessment tool has been created to help investors understand technologies in development, new technology product offerings and initiate discussions with technology developers (TDs).

Artificial cooling is the backbone of our society – food, health, comfort, data

- Air conditioning = 50% of energy consumption in Gulf; 75% of peak
- >50% of data centre energy consumption is cooling
- 70% of food is chilled or frozen when produced in UK, Europe – mobile cooling accounts for 31% of cooling CO_2
- Direct losses associated with temperature excursions in healthcare come to $35 bn; PE impact multiple of this.
- 19 cooling appliances installed every second for next 30 years
- According to UNEP, 80% of emissions of cooling from energy, not refrigerants





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Cooling is not just air-conditioning

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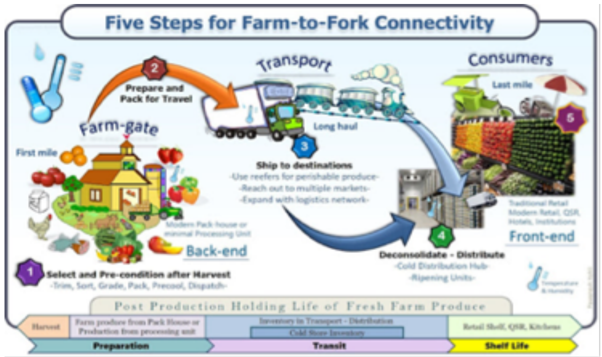
FOOD

In developing countries, 30% to 50% of perishable food produce is lost post-harvest primarily because of lack of adequate cold chain.

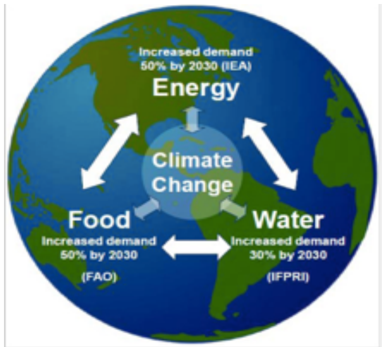
- More than 75% of the world's 1 billion people living in extreme poverty reside in rural areas, primarily dependent on agriculture for their livelihoods.
- More than 815 million people globally are now malnourished and, for the first time in decades, the number is increasing..

VACCINES

The World Health Organization (WHO) estimates 25% of liquid vaccines are wasted each year primarily because of broken cold chains and inadequate cooling provision. An estimated 1.5 million people die each year from vaccine preventable diseases.



A cold chain is an integrated, seamless and resilient network of refrigerated and temperature-controlled cooling facilities, cold stores, distribution hubs and vehicles used to maintain the safety and quality of goods, typically food or vaccines, while moving them swiftly from source point to consumption point



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Cold sits at the nexus of the the three big global goals

SUSTAINABLE DEVELOPMENT GOAL	EXAMPLES OF IMPACT OF COOLING
1. No Poverty	Cold chains enhance incomes for fishermen and farmers through improved pricing for produce and reduced food waste. Cooling has significant new employment demand from direct jobs around manufacture and maintenance to meet the massive increase in appliances to indirect jobs such as in food processing and preservation.
2. Zero Hunger	It is estimated that 1.3 bn tonnes of food is lost or wasted each year; approx 1/3 of of total food produced for human consumption. Refrigeration enhances food security through extending shelf-life of produce so that less is wasted. In addition, reduced waste increases incomes in farming and fishing communities and leads to more stable food prices.
3. Good Health and Well being	Access to refrigeration and a robust medical cold chain leads to reduced vaccine and medicine spoilage. Access to refrigeration in the food cold chain reduces food waste and food poisoning. Air conditioning offers protection from temperature extremes.
4. Quality Education	Ability to work and thermal comfort are inter-related. Reducing the risk of malnutrition also positively impacts academic performance.
5. Gender Equality	Women make up almost half the agricultural workforce in Africa, and far more in some countries – around 70% in Kenya, Nigeria and Rwanda. If combined with policies to improve women farmers' access to finance and resources, clean cold chains could benefit women preferentially and help narrow the gender gap.
6. Clean Water and Sanitation	Prevented food spoilage saves substantial amounts of water.
7. Affordable and Clean Energy	Refrigeration and air conditioning are responsible for over 17% of the worldwide electricity consumption. Global air conditioning energy demand, driven overwhelmingly by cities in developing countries such as China, India, Indonesia, and Brazil, is forecast to rise 33-fold by 2100 to more than 10,000 TWh, roughly half the total electricity generated worldwide in 2010.
8. Decent Work and Economic Growth	Agriculture and fishing are very significant employers. Enhancing the efficiency of these industries by reducing waste, as well as increasing market connectivity will improve profitability. As an example, in India, the GOI has identified cold chains as a key pillar of doubling farmers' incomes. Productivity and thermal comfort are interrelated and by 2050, heat-related work-hour losses in some countries are projected to be as high as 12% — worth billions of US dollars — in the worst-affected regions.
9. Industry Innovation and Infrastructure	All forms of cooling will require substantial infrastructure investments to be delivered and considerable innovation is required to enhance efficiencies. With the industry projected to double in size, there is an opportunity to create new manufacturing opportunities including in-country.
10 Reduce Inequalities	Clean cold technologies reduce inequality both within and between countries. Looking at income inequality, clean cold chains reduce poverty by lowering food prices and raising farmers' income. Better nutrition and thermal comfort would improve the educational outcomes of the most disadvantaged in society. In terms of gender inequality, cold chains combined with support from policy will improve access of agricultural resources to female farmers which reduces the gender gap by providing female farmers with access higher value exports.
11. Sustainable Cities and Communities	Sustainable cooling and design for buildings and transport reduce energy demand and heat island effect. Food security in cities where very little farming land is available is critically dependent on a cold chain.
12. Responsible Consumption and Production	Food and vaccine loss are reduced through proper access to refrigeration and cold chains.
13. Climate Action	Cooling uses substantial quantities of energy and causes direct emissions from refrigerant leakage.
14. Life Below Water	Wastage of marine products before reaching market increases pressure on fish stocks.
15. Life on Land	Reducing food wastage eases the main driver of deforestation and land degradation.
16. Peace and Justice	Clean cold technologies indirectly help to maintain peace by suppressing potential sources of conflict, e.g. rising food prices (Arab Spring) and urban migration due to rural poverty.
17. Partnership for Goals	In most developing countries, cooling infrastructure is currently rudimentary or non-existent. There is a brief opportunity to create partnerships through which developing countries leapfrog direct to clean cold, thereby wmaking an important contribution to everyone of the Global Goals.

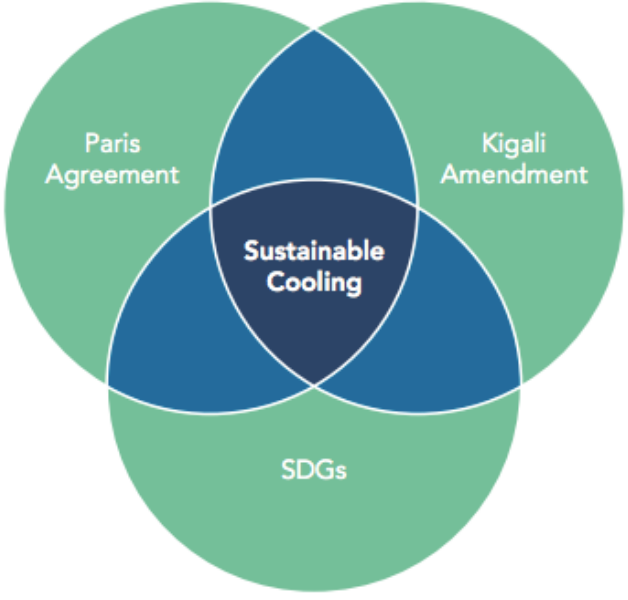
Global access to sustainable, affordable and resilient cooling to

- underpin health
- habitable, safe housing and work places
- productivity
- reduce post-harvest food loss - protect food volume and quality; ensure efficient movement from farm to consumption centre
- Enhance economic wealth and security for farmers
- Achieve nutritional security and deliver safe food to the wider population

and

ensure that the massive growth in demand for cooling is managed within the constraints of natural resources, local economies and underpins, *rather than undermines*

✓ CO_2, Climate Change and pollution targets
✓ energy efficiency and resilience
✓ sustainable and affordable infrastructure



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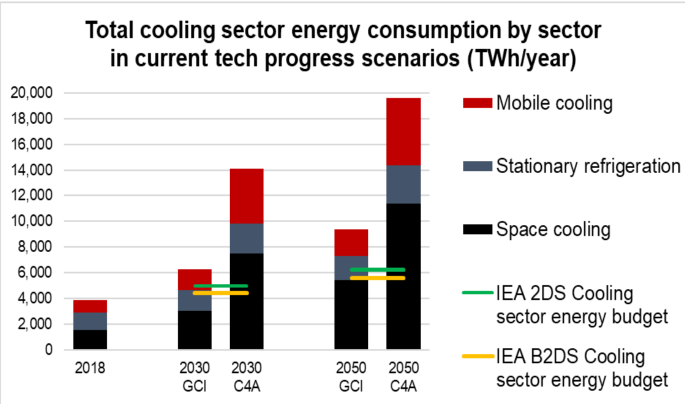
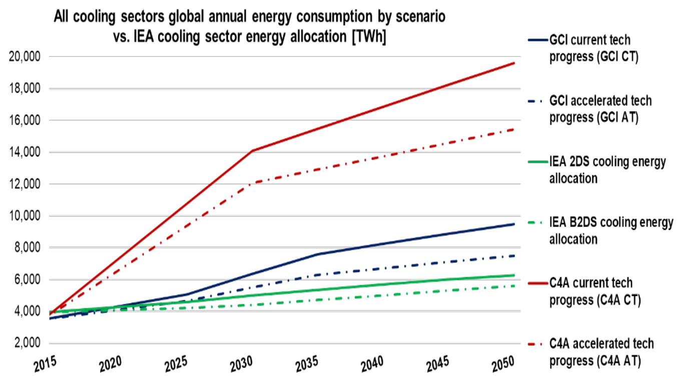
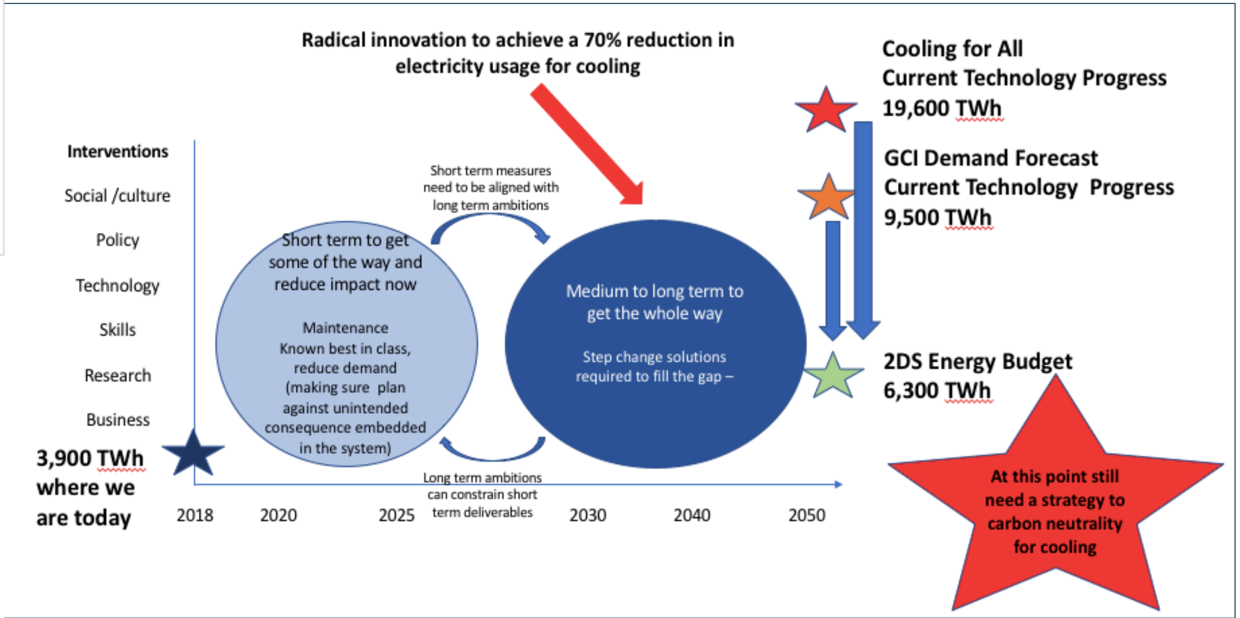
The Energy Conundrum of Cooling for All







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Thinking thermally

"When people talk about energy, they often mean electricity, and when they talk about energy storage, they mean batteries. However, a large slice of our consumption comes in the form of thermal demands; one of the fastest growing in the next twenty years will be for cooling. Cooling demands may often be better served by energy carriers other than electricity and batteries."

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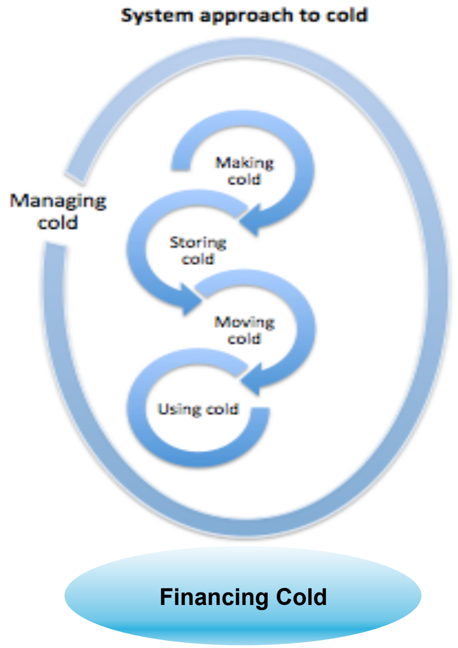
System approach to cooling



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 new stores and vectors

Managing cold
Monitoring, controls and management

Financing Cold
How do we charge and pay for cold

There are opportunities to access thermal resources to meet cooling needs sustainably.

Cold Resources – Numerous resources exist for example:
- Waste cold of Liquefied natural gas (LNG)
- Deep Lake or sea water
- Sky cooling

Low grade heat resources
- Process waste heat
- Geothermal
- Solar

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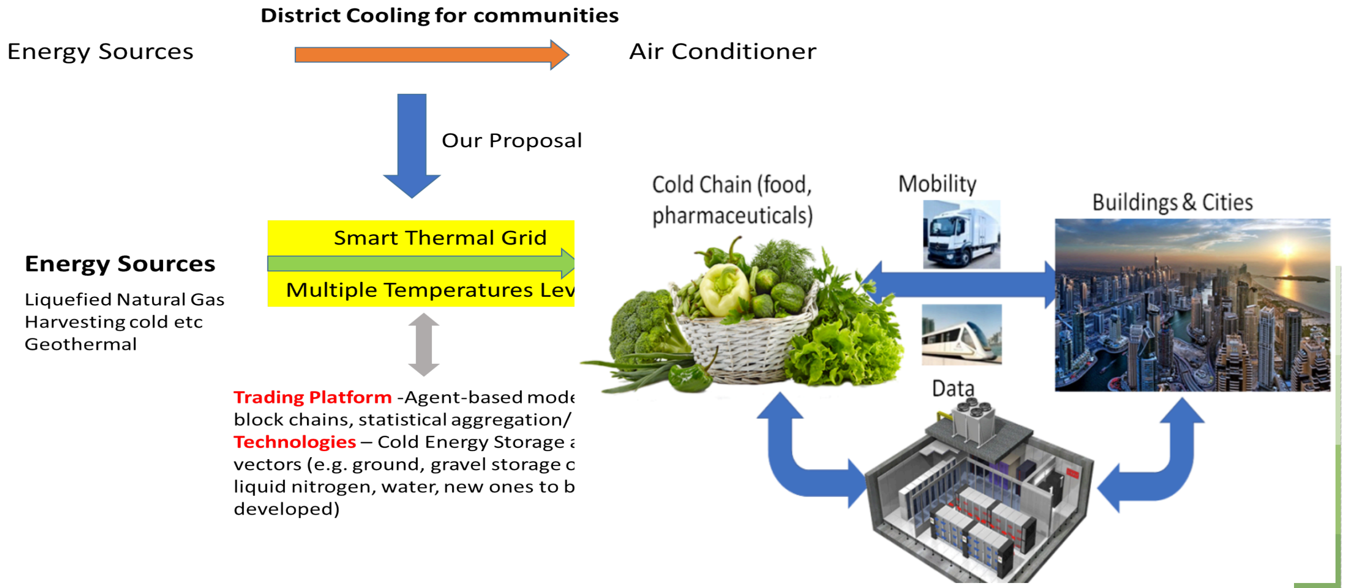
What do we need to do?

Solving the cooling challenge requires a comprehensive systems approach recognising multiple interdependencies requires bundles of technologies and integrated measures and policies. These need to be fit for market and fit for finance

1. Understand the services and thermal loads.
2. Think how cooling demand fits into the wider electrical and energy system + opportunities to use it for demand side flexibility – energy system thinking
3. Think how cooling fits into attempts to decarbonise transport – clean transport
4. Think how waste or surplus renewable resources can be accessed via process integration or storage?
5. Think about thermal trading models



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The challenge of cooling is about new growth
Different audiences – different needs and challenges

Best case scenario – cooling energy demand more than doubles; assumes best case efficiency wins

Worst case – cooling demands increases 5 times

The Rural Poor

Approximately 470 million people

- Likely to live below the poverty line and lack access to electricity to power fridges and fans
- Subsistence farmers unlikely to have access to intact cold chain, preventing sale of goods for a higher price
- Medical clinics unlikely to have cold storage, putting lives at risk from spoiled vaccines

Potential Solutions

- Off-grid solar home systems to support fans, refrigerators
- Cold storage and pre-cooling for transportation and sale of goods
- Solar refrigeration and "last mile" transport for vaccines
- Public cooling centers and local heat action plans

The Slum Dweller

Approximately 630 million people

- May have access to electricity but housing quality is very poor, income may not be sufficient to purchase or run a fan
- May own or have access to a refrigerator, but intermittent electricity can spoil food and increase risk of food poisoning
- Likely to have access to safe vaccines where health services exist

Potential Solutions

- Passive cooling through design and retrofit
- Cool roofs and walls
- Financing instruments that enable acquisition of energy efficient fans or refrigerators
- Public cooling centers and local heat action plans

The Carbon Captive

Approximately 2.3 billion people

- Increasingly affluent lower-middle class on the brink of purchasing the most affordable AC
- Limited purchasing choices favor currently inefficient devices and could cause dramatic increase in energy consumption and GHG emissions
- Likely have access to intact food and vaccine cold chains

Potential Solutions

- Minimum energy performance standards for appliances (MEPS)
- Enforced building codes
- Enhanced use of vegetation and ventilation, including green roofs

The Middle Income

Approximately 1.1 billion people

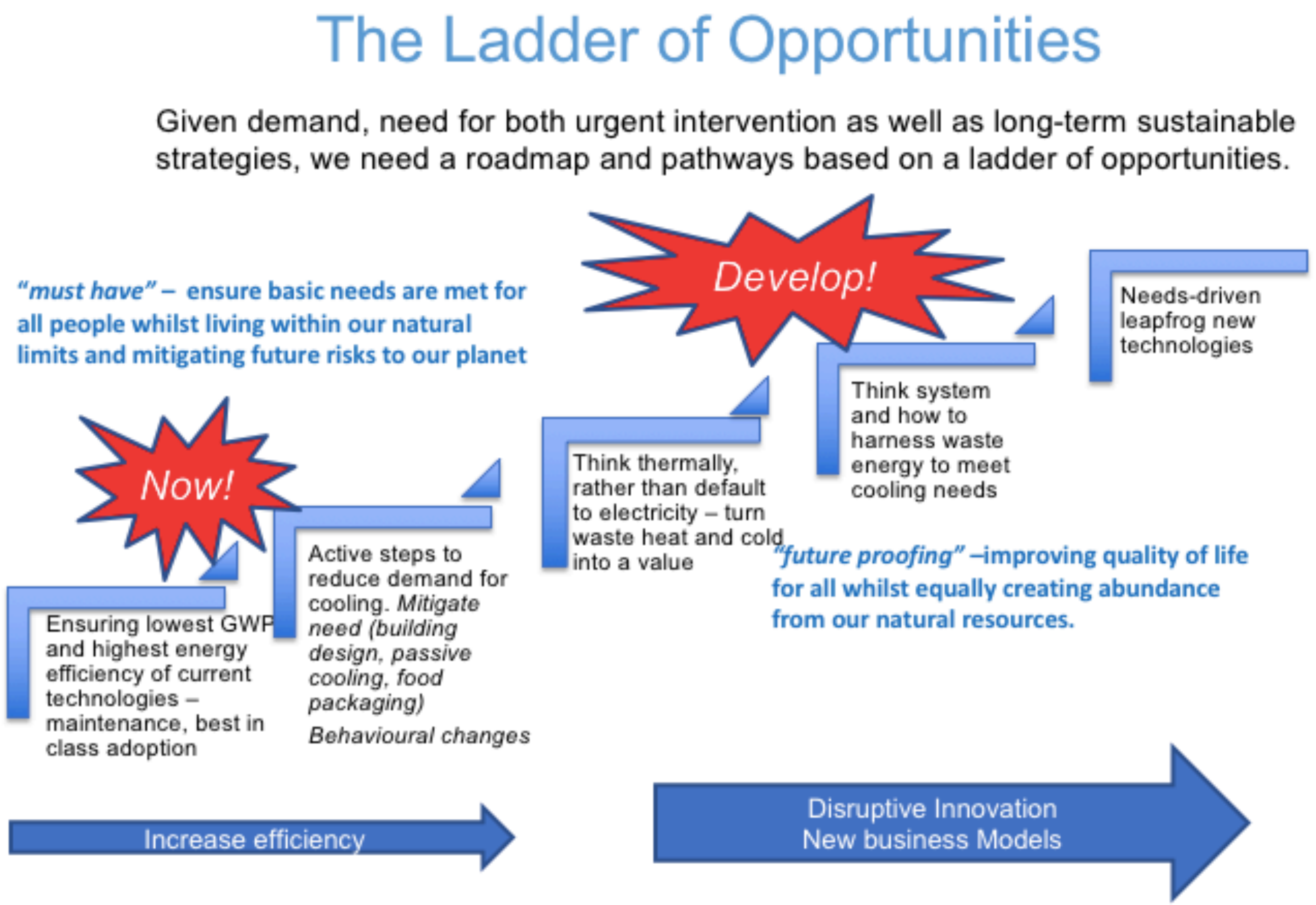
- People that have owned an air conditioner and may be able to afford a more efficient one
- Represent an established middle class where affordability may also allow them to upgrade their housing to a more sustainable design that incorporates thermal cooling systems

Potential Solutions

- Residences with thermal cooling systems
- District cooling and thermal energy storage
- Hyper-efficient appliances and MEPS

Different needs and challenges

Ladder of Opportunities



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Barriers

Market stakeholders have identified barriers to cooling equipment uptake that relate to awareness, affordability, financing, culture/ consumer attitudes, policy priorities, electricity availability, technical capability and skills as well as national interest, lack of innovation and an inadequate evidence base.

- Lack of Awareness
- Access to Finance
- Lack of Demand signals from Government
- MEPS vs the Energy System
- Higher Purchase Prices/ total cost of ownership
- Lack of Market incentive
- Industry inertia

Issue	Description
Lack of Awareness	Cooling is a blind-spot in the key energy and climate change mitigation debates as an example only 83 of 197 Nationally Determined Contributions (NDCs) even mention refrigeration and cooling (RAC), Jordan, Ghana and Vietnam are the only countries with any explicit commitments – but it has a material role in addressing socioeconomic challenges and significant impact on the energy system, climate change and pollution.
Lack of research funding	Funding for cooling research in the EU is less than 0.22% of the total engineering research budget; OEMs spend a significantly smaller % of revenue on radical innovation than in other comparable sectors.
Investment	The high impact and patient capital investment sectors are failing to scale at the rate required to solve pressing environmental and social challenges, including addressing the need for clean Cooling for All. UNEP has highlighted the need for new actors, coalitions and instruments to be part of the solution and help close the financing gap.
Access to Finance	Some types of cooling equipment are too expensive for the people who would benefit from them to purchase. This seems to be especially true of pre-cooling systems that could be used to reduce food spoilage in the agricultural sector, though also relevant to domestic refrigeration and space cooling.
Electricity Availability	The vast majority of today's available cooling technologies are reliant on electricity access. Currently about 87% of the world has access to electricity. In sub-Saharan Africa this figure falls below 43% of the population. Lack of electricity supply prevents universal access to cooling in many developing and emerging economies. In countries that do have access to electricity the robustness of the power grid and security of supply can be an issue too, as for example in India where blackouts are common both in the urban and rural environments.
Skills	The skills challenge is two-fold. Firstly, using refrigeration, and by extension a cold chain, effectively to preserve food and medicine requires training. Secondly, installation, maintenance and servicing of refrigeration and space cooling equipment typically requires skilled technicians. Frequently, those skills are lacking in emerging economies and deployment of equipment at scale creates a substantial skills requirement.
Lack of Policy In	
Split incentives	

Issue	Description
National Interest vs. MEPS	Minimum efficiency performance standards (MEPS) and similar initiatives can be a very effective mechanism for enhancing the efficiency of equipment sold in a market place. However, attempts to protect national producers can lead to varying efficiency standards between markets. MEPS also tend to focus on performance of traditional VPC units, rather than deployment of more radical innovations and system-based solutions for cooling
Higher Purchase Prices for more efficient equipment vs. total cost of ownership savings	Frequently, more efficient technology comes with a price premium. Often customers in both domestic and commercial markets tend to be more sensitive to purchase prices as opposed to total cost of ownership. Few customers consider the in-life energy usage of their cooling appliances completely and because high quality consumption data is frequently lacking, comparisons between offerings are difficult for them to make. In many markets energy is so cheap or subsidised that conserving it is not incentivised.
Pipeline	Deploying the 'best in class' technologies available today is unlikely to be enough to avoid energy consumption and emissions that substantially exceed the sector's allocation in 2DS. OEMs also operate to short strategic timescales, for example 2020 as a focus with 2030 being the absolute limit of planning.
Proving Integrated Systems	A desire by many companies and organisations to get more out of their technology portfolio is forcing the combination of existing technologies in novel ways in a drive for an optimal overall system. Whilst in principal this approach could have significant benefits, currently outside of district cooling networks used for space cooling in dense urban environments and a small number of Asian LNG cold recovery projects, there are few working examples of integrated cooling systems. There appear to be no examples that attempt to leverage a wide range of technologies at district scale. As a result, the benefits remain unproven and tools that could be used to design these systems unvalidated by experience.
Culture vs. Refrigeration	In some cultures there is a perception that refrigerating food somehow compromises its freshness. Carrier UTC encountered this when exploring rural Indian agricultural markets.
Lack of Market incentives	OEMs and Tier 1s do not feel as if their customers are demanding "step-change" solutions and so are offering only incremental improvements between product releases. The general consensus among OEMs and Tier 1s is that traditional vapour compression cycles, paired with energy storage and niche usage of sorption technologies, will meet future cooling demands.
Industry	There are limited (<5) major companies in many of the segments; the incumbents are enormous and global which means that any new innovation can only access the market through them. The vapour compression cycle technology dominates all sectors with long established manufacture, supply and servicing chains with no incentive or demand to invest in change. (internal combustion engine vs EV or bagged vacuum cleaners vs Dyson).
Data	Lack of data collection (real-time) to connect fork to farm and have demand-led harvesting and supply chains

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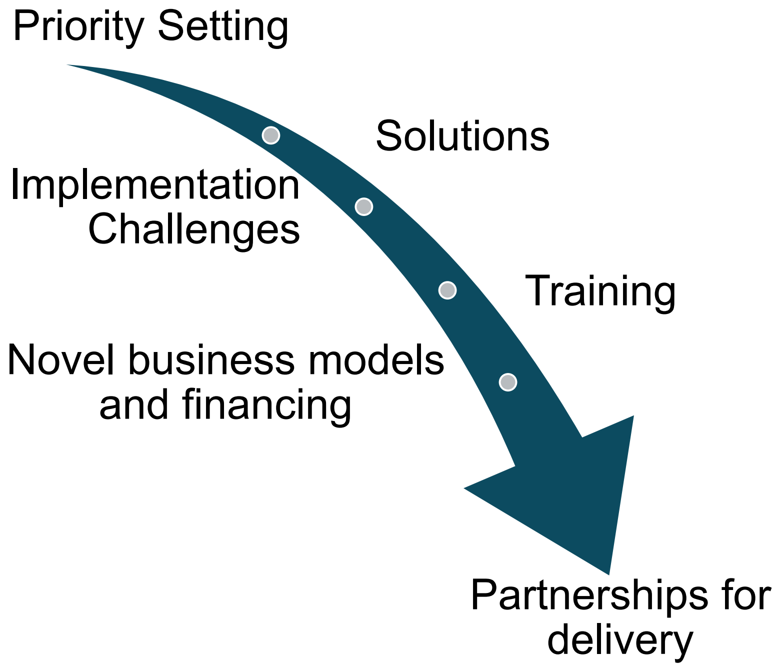
Demand-side management and behavioural change

- **Low GWP refrigerant legislation is driving change in cooling**
- As we migrate from fossil fuels to renewables, we need new approaches which harness the portfolio of available resources including free and waste cold and heat.
- Cooling spans many sectors – we need a comprehensive and system approach.
- Additionally, we have to design the novel finance and business models required to create economically sustainable systems for all customers in different markets.

=> Solutions will be complex, integrated across sectors; and need to be "fit for market"



The goal - The co-design, implementation and demonstration *through Living Labs* of frameworks for the provision and accelerated roll-out of fit-for-market and fit-for-finance, end-to-end, *clean and sustainable* cooling networks and post-harvest food cold chains that are attractive to end-users, civil society, governments, policy makers, industry and the finance community to ensure impact, lasting legacy and scalability.

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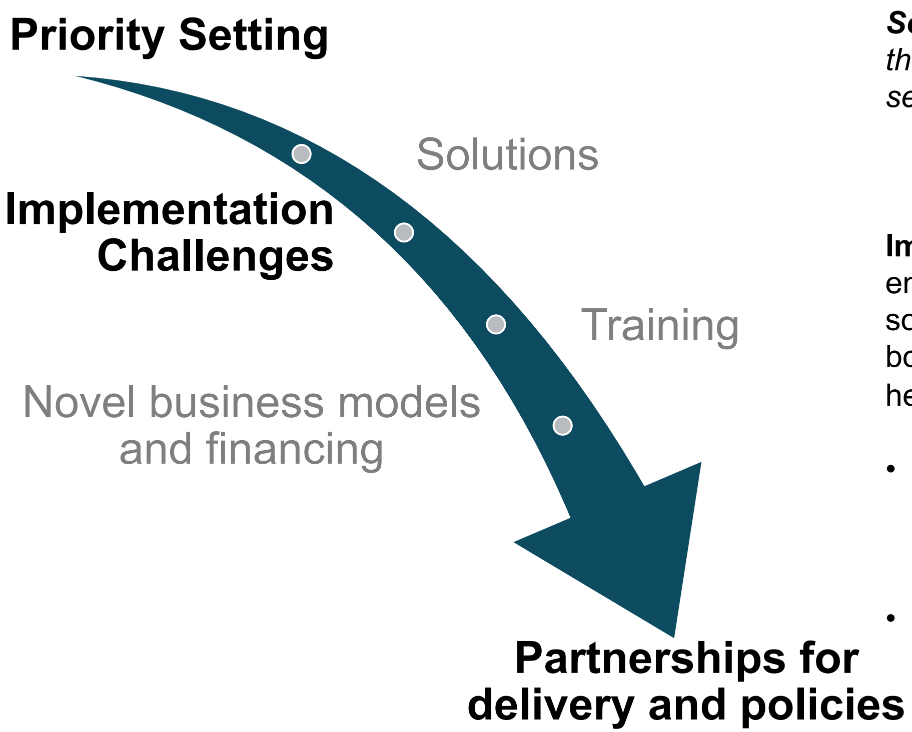
Where do we start?

3-4 markets



Priority Setting Cost-impact analysis of when and where demand-side management (behavioural change as well as technology, system level intervention) would be most valuable to lower demand and carbon intensity **and impact SDGs**

Solutions *What is the service we require, and how can we provide it in the most efficient way, incl. bundles of technologies across different services and thermal storage,*

Are we pre-supposing a need?
Are we pre-supposing a solution?

Implementation Challenges Identify non-technical barriers, incentives/ enablers to behavioural *and* technological change to low carbon cooling solutions which can then inform the development of strategies designed both to remove or overcome the blockages and encourage and diffuse helpful practices.

- **Training** – Maintenance, system design are key as is transition to Low GWP refrigerants; we do not have adequately trained cooling workforce.
- ***Novel business models and financing – Cold as a Service to*** *unlock integrated maintenance benefits of enhanced leases, scale benefits of district cooling* ***and*** *delivery system optimisation opportunities including AI and automated management.*

Partnerships and policy interventions
involving governments, the cooling industry, international financial institutions and others so that each partner contributes and benefits. Define appropriate policies and regulations.

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Novel business models … Cooling as a service

	Equipment	Usage Management	Monitoring and Maintenance	Energy
Equipment sale	Buy or lease	In-house	Contract	3rd party or own generation
Existing service based approach bringing maintenance and management into a single contract	Single "lease" based contract Can have a success-related payment structure linked to efficiency			3rd party or own generation
District Cooling model.	Single contract possibly with two elements to the bill based on RT (Refrigeration Tonnage) – 1. **Demand charges** are associated with the system costs for infrastructure, operations, and maintenance and based on the amount of cooling your property requires. 2. **Usage charges** are the energy costs to produce refrigeration (i.e the chilled water in the case of District Cooling). This is metered. This could be charged as either a variable against demand or as a flat rate plus an excess fee.			
Cooling as a Service	Single contract based on service provided by cooling i,e. per ton of food produce stored or moved (Coldhub model extended) or size of flat and hours of cooling whilst I am home (moving to a temperature delvery)			

*CaaS in this form could unlock integrated maintenance benefits of enhanced leases, scale benefits of district cooling **and** delivery system optimisation opportunities through servitization*

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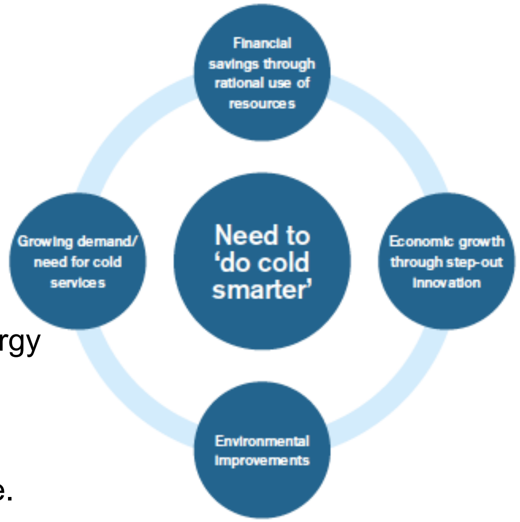
SUMMARY

Although the enormous potential of cooling and refrigeration to help achieve energy targets for diversification, decarbonisation, efficiency and greenhouse gas emissions, the public and political awareness of these energy-intensive technologies is still insufficient.

- Most sectorial analyses and policies spotlight heating, whereas cooling is mentioned just pro forma for linguistic symmetry.
- Focus is often on low-GWP refrigerants, GWP from energy is far bigger impact
- We are profligate with cooling with little understanding of its energy and environmental cost.
- Low carbon cooling must start with what we can do today to reduce demand by influencing customer behaviour.
- But though these interventions are important, they will not deliver the required reductions in energy usage, emissions and pollution, nor will they adequately increase resource productivity.
- Clean cooling is, therefore about radical reshaping of cooling provision; addressing technology, operations, financing and consumer behaviour in an holistic approach with a system perspective.
- Solving the cooling challenge requires a comprehensive systems approach. There are no separate elements or solutions; instead, multiple interdependencies require integrated measures.
- By pooling demand and fully understanding the portfolio of resources available, a re-mapping of processes and technology to achieve efficiencies is facilitated that would not be possible from a sub-system perspective. Equally, it will enable the new business models to make cooling affordable and accessible to all.



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Doing cold Smarter

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