Centre for Sustainable Cooling

INDIA'S THIRD **AGRICULTURAL REVOLUTION**

Doubling farmers' incomes through clean cold chains

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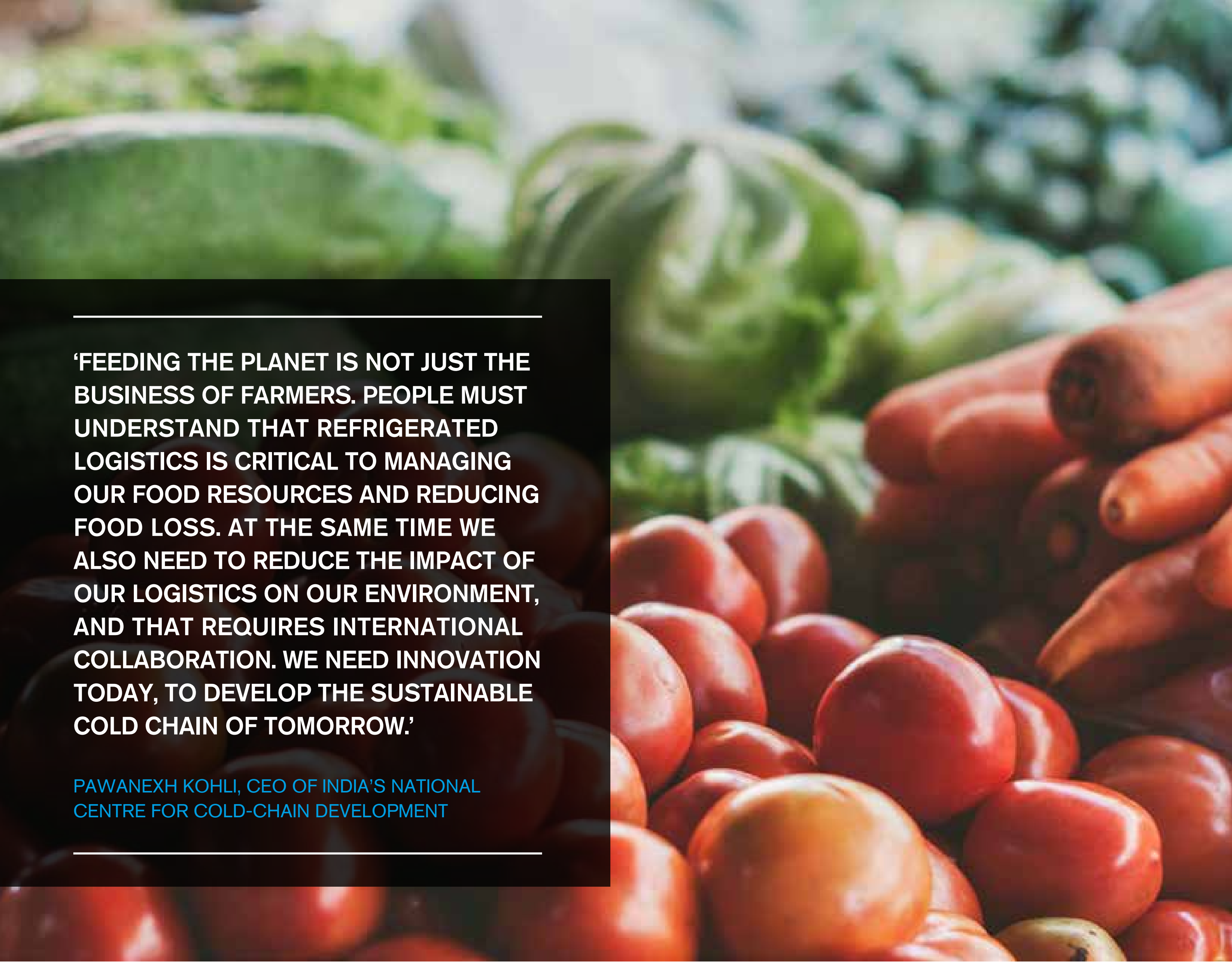

‘FEEDING THE PLANET IS NOT JUST THE BUSINESS OF FARMERS. PEOPLE MUST UNDERSTAND THAT REFRIGERATED LOGISTICS IS CRITICAL TO MANAGING OUR FOOD RESOURCES AND REDUCING FOOD LOSS. AT THE SAME TIME WE ALSO NEED TO REDUCE THE IMPACT OF OUR LOGISTICS ON OUR ENVIRONMENT, AND THAT REQUIRES INTERNATIONAL COLLABORATION. WE NEED INNOVATION TODAY, TO DEVELOP THE SUSTAINABLE COLD CHAIN OF TOMORROW.’

PAWANEXH KOHLI, CEO OF INDIA’S NATIONAL CENTRE FOR COLD-CHAIN DEVELOPMENT

ABOUT THE CENTRE FOR SUSTAINABLE COOLING

The Centre for Sustainable Cooling (CSC) is a global collaborative coalition, bringing together a consortium of international academic institutions from the fundamental sciences and engineering through to business, economics and social sciences to work with governments, industry, development agencies and NGOs to deliver sustainable and equitable cooling for all. The CSC will develop new systems approaches integrating technological, policy, social, economic, energy, finance and business pathways to better manage cooling demand and deliver sustainable solutions, including to help the most vulnerable in our society. By sharing experiences and expertise, the CSC will lead the way in radically reshaping cooling provision – translating research into practical, affordable solutions applications whilst helping to develop innovative policy and business process that result in a cooler world. A focus for the CSC will be to develop the right mix of novel energy solutions, thermal storage, cooling technologies, business models and policy interventions to give people who need to use sustainable cooling an opportunity to maximise their business whilst helping to limit global warming.

FOREWORD

Agriculture is the backbone of the Indian economy, employing almost half its workforce – over 250 million people[1]. The sector has been transformed since independence in 1947 through the 'green revolution', which staved off famine by dramatically increasing crop yields, and the 'white revolution', which turned India into the world's largest milk producer. Yet most of the country's farmers work plots of less than two acres and most remain trapped in the cycle of poverty.

To reach its full economic potential, Indian agriculture urgently needs a third revolution: the 'cool' revolution to build efficient market links through a sustainable cold chain. It is hard to overstate the importance of this apparently narrow technical issue to achieving India's environmental, economic and social goals. Cold chains don't just reduce post-harvest food loss but also allow farmers to earn more by maintaining the quality of their produce and selling it further afield at incremental value – especially when this means they can reach the fast-growing middle class in distant cities. The overwhelming majority of India's small farmers, who produce most of the country's high-value and high-nutrition foods, have little access to integrated cold chains.

The importance of cold chain is already well understood at the highest levels of India's government. The challenge is that conventional diesel-powered cooling of transport refrigeration units and pack-houses, for example, emits not only CO2 but also high levels of nitrogen oxides (NOx) and particulate matter (PM). To double farmers' income by expanding the use of conventional, highly polluting cold chain technologies would simply mitigate one problem by significantly worsening another.

India recognises, therefore, that it needs cold chains that are not only effective but also zero-emission and powered by renewable energy. To meet the needs of small farmers, the equipment will also need to be mobile and economic. And because the challenge is urgent, we need clean technologies that are ready to be demonstrated and deployed immediately. Potential solutions are on the point of commercialisation, but these technologies will only be deployed widely and quickly once they have been demonstrated to work in India and adapted to its unique sub-continental backdrop. This has not yet happened.

It isn't enough to simply demonstrate that each of the new clean cold technologies works individually. Instead we need to test, evaluate and demonstrate the cold chain as a chain connecting farm to consumption centre, rather than as a series of isolated facilities. We must also demonstrate new business models that will make the clean cold chain viable for Indian farmers with an average farm size of less than two acres. During our study tour of Haryana and Punjab we concluded that the lack of a comprehensive clean cold chain demonstrator – one that demonstrates both technologies and business models, and which is fully engaged with the farming communities – was the biggest single barrier. We also concluded the best way to overcome this barrier quickly would be through international collaboration – global science, local solutions. Our key recommendation is that India and Britain should work together to establish a series of clean cold chain centres to hasten the development of this vital infrastructure. The centres must be technology neutral; regionally, socially and culturally inclusive; and test not only technologies but also business models.

The centres must also be designed to expand into commercial deployment where successful; the point is to accelerate market impact. The new clean cold chains catalysed by the centres will conserve huge amounts of food that currently never make it to the consumer, leapfrog the old polluting technologies that dominate in the developed countries, and help achieve Prime Minister Modi's target of doubling farmers' incomes by 2022.

For these front-line demonstration projects to be effective, we must start by listening to the farmer on his or her two-acre farm, so that we have a better chance of understanding what is needed in terms of the right clean cold technologies, knowledge transfer, business rewiring and channel growth – all of which will help connect small farmers sustainably with the opportunity offered by a fast-growing urban middle-class market.

We cannot stress strongly enough that – as with all transformational innovation – technology is only part of the solution. The problem we hope to solve is huge, and to succeed we must involve all the main players in the potential market. It is vital that the work of the clean cold chain centres brings together farmers, logistics operators, retailers and regulators; this can make the difference between success and simply digging another grave in the cemetery of pilot schemes. Engaging the main players allows us to understand the cultural and business model issues that must be tackled to create the market, and prepare the manufacturing supply chain and skills training needed to scale up the infrastructure. We believe this approach will make the difference. And if so, we could catalyse a cool revolution to rank alongside the green and white revolutions.

This report is the result of a study tour and workshop led by the University of Birmingham, with help from the Foreign and Commonwealth Office, the Department for International Trade, the state government of Haryana, and India's National Centre for Cold-chain Development. Its purpose is to identify how an Indo-British partnership can meet the challenge of developing sustainable cold chains in India – and quickly. If we succeed, the same approach could be applied in other rapidly emerging countries, with potential export opportunities for both India and Britain.

Professor Toby Peters
Professor, Cold Economy,
University of Birmingham

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Michael Reid, Solar Polar

With special thanks to Dipankar Chakraborty of the British Deputy High Commission in Chandigarh, and Swati Saxena of the Foreign and Commonwealth Office in Delhi.

Editor
David Strahan

Image courtesy of UN Sustainable Development Goals website.

EXECUTIVE SUMMARY

In a speech in February 2016 Prime Minister Modi declared 'I wish to double the income of farmers by 2022 when India will celebrate 75 years of its independence'[2]. The following month he set out a 7-point plan to achieve the target and established a high-level committee to see it through[3].

One of the plan's key measures is to develop 'cold chains' – an integrated network of refrigerated buildings and vehicles to transport produce from farm to shop quickly and in good condition (see Introduction to cold chain, page 30). India's cold chain capacity is minimal, and as a result as much as 40% of some harvested crops has to be discarded before reaching any consumer. This represents not only a huge waste of food – with serious consequences for agricultural resources and carbon emissions – but also a major loss of revenue and opportunity for Indian farmers.

The farmer's loss is all the greater because India's booming cities are home to a rapidly growing middle class hungry for high quality fresh food and processed food products, and this demand is increasingly being met by imports delivered by air freight. If India developed a nationwide cold chain, it would connect farmers with these premium markets and raise their incomes. Since half the workforce works in agriculture, the benefits would spread throughout Indian society. A recent report found that building clean cold chains in developing countries would have a positive impact on all seventeen of the United Nations Sustainable Development Goals[4].

The benefits of developing cold chain in India have already been demonstrated. A recent pilot project that transported citrus fruit from farms in Abohar (Punjab) to the city of Bangalore (Karnataka) found that cold chain reduced wastage by 75% and raised profits at the farm gate ten-fold. Yet the conventional cold chain technologies that dominate in developed economies are highly polluting and often powered by diesel, especially in transport, so extending them to India would only solve one problem by worsening others. This means we need to demonstrate clean cold chains – low carbon and zero-emission – so that India can build the infrastructure that not only allows it to double farmers' income, but also to do so sustainably.

Britain is at the forefront of developing clean cold technologies, which its government has been quick to recognise and support with grant funding of tens of millions of pounds. Britain's farmers also have experience of moving up the value chain to develop their own regional brands, which might be relevant to Indian farmers competing with imported produce in their major cities.

In February 2017, the University of Birmingham led a study tour of Punjab and Haryana states, India's biggest agricultural producers, and held a two-day workshop in Delhi. The trip was organised with the help of the Foreign and Commonwealth Office, the Horticulture Departments of Haryana and Punjab, and India's National Centre for Cold-chain Development (NCCD). The workshop was attended by almost 100 Indian and British delegates, comprising farmers, technologists, academics and financial experts, and was addressed by India's Secretary of the Ministry of Agriculture and Farmers' Welfare, Mr S.K. Pattanayak. Through two days of intensive debate we developed our recommendations and established a strong case for collaboration between Indian and British governments to accelerate the deployment of clean cold chains in India.

It is hard to overstate the importance of cold chain in delivering Mr Modi's target. The International Institute of Refrigeration (IIR) has estimated that if developing countries had the same level of refrigeration equipment as the developed, they would save 200 million tonnes of food, or around 14% of their food supply. In India, the NCCD calculates the country has less than 15% of the refrigerated trucks it needs, and less than 1% of the pack-houses, the vital first stage of the cold chain that preconditions the produce for onward transport. On our study tour we visited two farms – one huge and one quite small – that are investing in cold chain for their horticultural produce, but at the moment such examples are scarce.

This lack of infrastructure means just 4% of India's food is moved through the cold chain compared to 70% in the UK. As a result, for some crops as much as 40% of the harvest is estimated to be lost between farm and market. This reduces farmers' income, which in turn limits their capacity to invest and their incentive to grow more food.

The missing link is a seamless 'cold chain' in the form of modern pack houses, distribution hubs and refrigerated transport to maintain the safety, quality and quantity of food – while moving it swiftly from farm gate to consumption centre. This can raise farmers' incomes in several ways:

- Increasing the proportion of food that gets to market
- Improving food quality and value to the customer
- Increasing the range of distribution to more valuable markets or export
- Incentivising farmers to grow more high value temperature sensitive crops
- Encouraging farmers to precondition and package their crops at the farm to protect value

Cold chains don't just reduce post-harvest food loss, but also allow farmers to earn more by maintaining the quality of their produce and selling it further afield – especially when this means they can reach distant cities. The same lettuce that sold for three rupees at the farm gate in Haryana state can fetch 100 rupees in downtown Delhi – but only if the farmer can get it there in the same condition as one imported by air-freight from a highly developed global agri-business and cold chain. At the smaller of the farms we visited, investment in cold chain had tripled revenue and doubled net income.

By empowering and enabling farmers to sell into distant markets, cold chains also incentivise them to raise their output, because they will earn more from the extra they produce. By contrast, in the absence of cold chain, any efforts to increase yields will also cause higher wastage – so dousing the incentive.

India is the world's fastest-growing economy, and its urban middle class is expanding fast. But with inadequate cold chains, India is losing this opportunity to foreigners: apple imports, for example, have risen six-fold since the turn of the century[5], while domestic production has fallen in recent years[6]. India cannot hope to stem this trend without developing its own extensive cold chains. The smaller of the farms we visited, which had invested in cooling, was already selling produce in Delhi, 250km to the south, and its owners even hope to export in future.

Cold chains also allow the farmer to expand into higher value but perishable horticultural produce and into animal husbandry, rather than remain tied to the low margin staples. And the really entrepreneurial farmer or farming co-operative can move right up the value chain by developing their own processing and food products. In the UK, many farmers have become independent national food brands with their own ice-creams and dairy products, fresh juices, and even chilled and frozen ready meals.

All of this depends on cold. Without it, the farmer will probably deliver produce that does not meet the expectations of target consumers – and their order book will be short-lived. 'The epitaph of brands', says Abraham Koshy, Professor of Marketing at the Indian Institute of Management in Ahmedabad, 'is written in false and exaggerated claims'.

Access to cold chains can turn subsistence farming into agri-businesses. It is no wonder that the Indian government has identified investment in cold chain logistics, which mitigates post-harvest losses and allows food to be moved quickly to distant markets, as a vital component in its 7-point farm income strategy, nor that the state government of Haryana has just launched a Crop Cluster Development Scheme with cold chain at its heart. Reduction in post-harvest food waste also conserves key resources such as water, labour, land and fertiliser; reduces reliance on imported produce, often transported by air freight; and improves health through improved food quality and safety.

A recent pilot by Carrier UTC and overseen by NCCD demonstrated that a cold chain carrying kinnow (a low-value citrus fruit) from Abohar in Punjab to Bangalore reduced food waste by 75% and CO_2 emissions by 16% while increasing profits ten-fold. As Pawanexh Kohli of NCCD explains: 'The world needs to move away from traditional measures of productivity towards measuring gainful productivity'.

As part of its climate change initiatives, India has also set ambitious targets to make agriculture and the food supply more sustainable – which is in any case what many consumers want. It is therefore vital that any new cold chain infrastructure should be clean. Conventional diesel-powered cooling of transport refrigeration units and pack-houses, for example, emits not only CO_2 but also high levels of nitrogen oxides (NOx) and particulate matter (PM). India can ill-afford any further increase in emissions of these toxic pollutants; its outdoor air pollution is already thought to cause almost 3,300 premature deaths per day – or almost 1.2 million per year[7]. To double farmers' income by expanding the use of conventional, highly polluting cold chain technologies would simply mitigate one problem by significantly worsening another.

The answer then is to identify clean cold chain technologies that are economic, efficient and sustainable, and to accelerate their deployment. This will produce an environmentally sustainable system that minimises loss, raises farmers' incomes, and underpins wider economic growth. The study tour and workshop heard from a spread of British and Indian companies developing technologies to provide clean cooling for the crucial pack house and transport stages of the cold chain. These included ecoZen, Cartwright Group, Solar Polar, Sangha Refrigeration, New Leaf Dynamic, Pluss, Hubbard Products, Nextek, J&E Hall, Petronet LNG, Dearman, as well as the University of Birmingham and Heriot-Watt University.

These solutions cannot be imposed from outside or above, however; only by engaging with local communities and understanding their needs and aspirations can we come up with solutions that are resilient and long-lasting. One major obstacle is that most farmers are too small to invest in new technologies individually, with the majority farming less than two acres. They have scant financial resources and little-to-no flexibility about when and where they sell their crops. Without access to cold chain they are obliged to accept whatever price the aggregator offers at harvest time, when their crop is likely to be facing a local glut and the price is low. But at the same time, within the country there are demand opportunities that go unmet.

Cold storage on its own isn't the answer either. For example, in India small farmers traditionally arrange their daughters' weddings for the month following harvest when they have sold their crop. While access to cold storage might enable them to delay sale to a time when they could fetch a higher price, they do not have the financial freedom to wait two months; they need the money today. It would be far better if they could sell into a complete cold chain, which would offer both exposure to the higher prices of distant markets and immediate payment. This would prevent the hoarding of produce for a later transaction, and satisfy the needs of both the farmer and society. The cold chain should be designed to maximise the speed of delivery to the urban markets – although with buffers built in to the system – rather than being driven by warehousing alone.

India has already shown that the poverty and powerlessness of individual farmers can be overcome through collective action. The Amul Dairy co-operative was founded in the 1940s, with just two villages pooling 247 litres of milk, but eventually became the driving force of the 'white revolution'. Today it combines 15 million milk producers in an organisation that controls processing and marketing, and has helped turn India into the world's largest milk producer. This concept of collaborative farming could be extended and adapted to bring clean cold chain to perishable produce, allowing farmers to join forces to benefit from new technology, centralised services and new business models.

India is already developing a framework that could support a rapid expansion of cold chain infrastructure. As we learned, Haryana state has just launched a programme to organise 13,000 horticultural farmers into a system of 140 crop clusters, intended to speed up the adoption of agricultural and post-harvest management technologies, each with its own logistics centre and refrigerated transport. The system will be 90% financed by the Haryana state government, with a budget of 510 crore rupees (£63 million) over three years, and 10% by the farmers themselves.

The Haryana crop cluster programme is clearly important and timely. The problem is that the most readily available cold chain technologies are conventional and highly polluting – such as those demonstrated by the Carrier/NCCD pilot project. And if nothing is done to prevent it, these technologies will be deployed by default. For the crop cluster programme to deploy clean cold chain technologies, they too must be demonstrated locally. Haryana also hosts the Centre of Excellence for Vegetables, a joint venture between India and Israel that provides a useful model for the kind of intervention needed to speed the uptake of innovative technologies and approaches.

It is not enough simply to demonstrate that each of the new clean cold technologies works individually; India is sometimes known as a graveyard of pilot projects. The challenge is to accelerate the development of clean cold chains to the point where they start to make a meaningful impact and their growth becomes self-sustaining.

RECOMMENDATIONS

India clean cold chain centres

Our key recommendation is to create a series of regional 'living labs' called the India Clean Cold Chain Centres (I4C) to solve all of the interlinked challenges of clean cold chain development simultaneously and coherently.

In brief, these centres would demonstrate and evaluate the cold chain as a continuous chain of sustainable technologies connecting farm to consumption centre, rather than as a series of isolated facilities. They would demonstrate not only clean cold technologies, but also the business and funding models, skills and market engagement needed to support them in the Indian context, and would also catalyse the growth of manufacturing supply chains.

The centres would bring together the key groups – farmers, local and national governments, technology developers, investors, bankers and manufacturers – under one organisational roof. This would ensure that the solutions that emerge work for all the stakeholders and therefore have the greatest chance of commercial success. The centres would be technology neutral, regionally, socially and culturally inclusive, and – critically – would start by understanding the needs and aspirations of farmers.

This approach has a far greater chance of success than conventional technology demonstrators, and could be co-funded by India and donor countries along the lines of the Indo-Israeli Centre of Excellence for Vegetables. Its results could then be replicated in other developing countries – with potential export opportunities for both India and Britain. This recommendation is explained in detail in the next section.

India-UK study tour and workshop

Our study tour and workshop in India was highly successful. We learned so much from our discussions with farmers, technologists and officials that we feel certain an Indian delegation to Britain would find the trip equally valuable. Here they could meet representatives of world class supermarkets, logistics operators, manufacturers, clean cold technology companies, investors and academics, as well as farmers who have expanded into food processing and developed their own brands. Both sides could learn a great deal about the challenge of commercialising clean cold in India, and a UK tour and workshop would solidify knowledge-transfer in this area. The trip would strengthen existing relationships and start new ones. We recommend that the British and Indian governments consider supporting the visit of an Indian clean cold delegation to Britain for a study tour and workshop later this year, which the University of Birmingham would be delighted to host and organise.

India LNG waste cold/ cold chain study

Our workshop also highlighted the potential of India's LNG import terminals to provide enormous quantities of low cost, low carbon, zero-emission cooling through the recycling of waste cold from LNG re-gasification as liquid nitrogen. This is a potentially a major opportunity since Petronet LNG is keen to exploit its waste cold, and its terminals at Dahej and Kochi re-gasify continuously as 'baseload'. This cold could be used to provide clean cooling to India's new cold chains.

Building on high-level work to date, we recommend a site-specific feasibility study should be carried out to investigate the economic, environmental and engineering aspects of integrating India's LNG waste cold into its new cold chains. This would quantify the scale of cold chains that could be served economically, including the nature of the cold chain services, and their volume, location and distance from LNG terminal.

PROPOSAL: THE INDIA CLEAN COLD CHAIN CENTRES

India has only a tiny fraction of the cold chain infrastructure it needs to meet current demand, never mind cater for future growth. The country needs to find a way to expand its cold chain capacity quickly – and sustainably. We propose a series of regional 'living labs' to demonstrate a clean cold chain from farm to consumption centre, providing a launch-pad for accelerated deployment. We suggest the network be called the India Clean Cold Chain Centres (I4C), and propose the first regional centre could be the Haryana Clean Cold Chain Centre.

These centres would be technology neutral, socially and culturally inclusive, and test, not only technologies but also business and funding models. They would be designed to expand into commercial deployment where successful. They could be co-funded by India and donor countries along the lines of the Indo-Israeli Centre of Excellence for Vegetables in Haryana, and their results could then be replicated in other developing countries – with potential export opportunities for both India and Britain.

India needs cold chains that are not only effective but also with minimum environmental impact. Most Indian farmers – and also banks – have little if any experience of any kind of cold chain, still less of novel clean cold chain technologies, and will not invest before they have been shown to work well and cost-effectively. Since the value of cold chain comes from connecting suppliers to distant markets through several logistical stages, the entire chain must be demonstrated for the exercise to be convincing. That means the proposed centres will have to demonstrate not only a range of British and Indian technologies but also the business and financing models needed to make them accessible to small farmers and collectives.

The new cold chains need to run on renewable energy such as solar or biomass, and incorporate thermal as well as electrical cooling. They will also integrate energy storage – largely thermal – to smooth intermittent renewable generation, and unreliable grid supply. Many of the necessary technologies are already well advanced, but they have yet to be demonstrated together to prove they can provide farmers with a clean, sustainable, fast, and resilient cold chain from field to the cities where their produce will command higher prices.

Although many of these technologies are well advanced, they will only be taken up if farmers and other supply chain actors can afford them, and this is likely to require new business and funding models. So the centres will also demonstrate these 'soft' aspects, turning a technology demonstrator into one that also tests a real commercial proposition, where users take part day-to-day and help shape its development. This will ensure that new thinking on systems, service integration and business models can be properly designed and tested, and the impacts on stakeholders, and the system as a whole benchmarked and audited.

The I4C could be modelled on the successful Centre of Excellence for Vegetables, the Indo-Israeli joint venture in Haryana, and could integrate with other existing initiatives such as Haryana's Crop Cluster Development Scheme.

The I4C will demonstrate real impact through an end-to-end renewable clean cold chain. This approach is essential to accelerate deployment and secure the social, health and economic benefits that clean cold chain offers. It will provide a solid business case for finance providers; secure buy-in from the end users, and build the right skills, training and capacity for delivery. It will provide a manageable but real-world environment where the 'unknown unknowns' can be safely discovered and addressed.

This comprehensive clean cold chain demonstration will not only help shape the design of future-proof, resilient clean cold chains, and the business models and policies required to support their expansion, but also develop a better understanding of what's needed to nudge behaviour throughout the supply chain.

The centres will help us understand how renewables combined with energy storage, and new systems can support sustainable fuel substitution in agriculture and fishing as well as the associated food and drink sectors. They will also support supply chain engagement, skills and training programmes to ensure equipment is properly installed, operated and maintained.

The I4C will also provide the necessary connectivity to support testing of novel, internet-based sales or trading models. They will catalyse the formation of new enterprises and business models – some known today but others developed as opportunities are identified through the work of the centres. They will also show what does not work, with limited exposure and system-level damage. They will also help us understand the skills and capacity requirements needed to deploy cold chains quickly in India and other markets.

Towards the India Clean Cold Chain Centres

The I4C are intended to demonstrate complete cold chains from farm to consumer, through projects that will engage current and potential cold chain actors, speed technology and knowledge transfer – 'global science, local solutions' – and accelerate market impact. They will be technology neutral, and will demonstrate a range of technologies that can be combined to create a clean cold chain from farm to consumption centre.

The proposed clean cold chain centres will not simply demonstrate clean cold technologies, but rather provide a live demonstration of a farm-to-consumer clean cold chain with all the opportunities and challenges embedded in the system. It will therefore have to develop a methodology to assess not simply the technical performance of candidate clean cold technologies, but also that of their business models, skills requirements, and wider agricultural and economic impacts.

This means we need to develop an accurate 'granular' model of the model cold chain to measure inputs, outputs and flows within the system. This would allow us to audit and test the real world impact of a technology on the system but also take a technology or concept, and see how it works within the model. This would allow new arrangements to be tested and modelled accurately before they are tried for real, reducing the risk associated with physical projects. Such a model would also help with optimisation studies as well as testing new business and financing models.

One early task will be to identify exactly what needs to be measured, the locations where data will be collected, and how the data will be modelled to produce a baseline against which new technologies and approaches can be tested.

Another early task will be to gather partners representing all stages of the potential cold chain and identify the kinds of projects they might be interested in taking part in or hosting.

Outputs

Within the whole system approach of the I4C, new technologies, services, and products could be tested in different operating scenarios; combined to create a single cold chain that can be measured, demonstrated to local farmers, investors and bankers; and trialled within live projects.

The centres should also work to integrate the cold chains they develop into India's National Agriculture Market[8], its new online trading portal that allows farmers to find out where prices are highest and sell into that market. Indeed, cold chain is essential to making the National Agriculture Market work.

At a minimum, the centres will need to measure:

- Reduction in wastage
- Reliability ('uptime')
- Increase in value
- Distribution of value
- Cost (capital, operational, whole of life)
- Impact on farmer and commercial model:
  - Income and profit
  - Payment model
  - Financing model
- Environmental footprint
- Impact on natural resource efficiency

This data can then be modelled to analyse economic and environmental impacts including whole of life, assess new business and financing models, and demonstrate value to investors and bankers. If successful, demonstration projects will then provide the platform to engage with sales, supply chain and assembly partners, training programmes for installation, maintenance, after-sales service, and full-scale commercialisation.

New product development and research

While the centre would focus on accelerating the in-country deployment of proven technologies, it would also be used for technology research and trials for new product development at three key stages in the product development cycle:

- Early stage – performance modelling to define product using robust market data and analysis
- Mid-stage – testing and demonstration (including 'voice of the customer') in a controlled, market environment ie, proving ground or appropriate external test facility
- Late stage – testing extensively to prove durability in market to a point where servicing and warranty requirements can be met (can overlap with new technology testing and demonstration)

At our workshop in Delhi, farmers said it was important that equipment should be lightweight, robust, mobile, and secure against theft; offer multi-temperature functionality; reduce handling stages; and be made in India.

International partnership and shared funding

The Haryana Centre of Excellence for Vegetables is a successful Indo-Israeli joint venture that provides a proven model that the I4C could follow. Under this model:

- The Indian government would fund the building of assets and infrastructure and provide in-country management and market analysis teams (with knowledge transfer support)
- The UK government would:
  - Lead academic partners to set-up test beds and tools for modelling, and associated knowledge transfer and skills development designed to address the needs of a fully integrated cold chain
  - Support UK technologies and associated expert teams to deploy at the centre for extended periods (eg, two years); to include knowledge transfer and in-country skills development
  - Strengthen capacity for research and innovation within both the UK and India – promoting agricultural welfare and economic development

The I4C would lever this government backing with commercial partnerships and innovative technologies, and business models to demonstrate clean cold chains in India. We are convinced this is the most effective way to commercialise and accelerate clean cold chains, connect Indian farmers with high-value markets of India's cities and abroad, and achieve Mr Modi's target of doubling their income by 2022.

What Britain has to offer

Britain has long been a world leader in cryogenics, and more recently has bred a new generation of innovative clean cold technology companies including Sure Chill, Solar Polar, Simply Air, Camfridge, Iceotope, Sunamp and Dearman. Britain is also home to world-class academic and industrial research into cooling, at institutes including: The Birmingham Centre for Cryogenic Energy Storage at the University of Birmingham; Heriot-Watt Energy Institute, and its research and demonstration work in Malaysia and Dubai; Loughborough University's new Cryogenic Energy labs; the CryoHub, led by London South Bank University, and the Midlands Thermal Energy Research Accelerator (T-ERA).

Another British strength is that our supermarkets and health industries are world-leaders in supply chain management, which means the UK is in a good position to further develop clean cold initiatives. From the other end of the chain, many of our farmers have moved up the value chain by expanding into food processing and building their own brands. We are also leading work in broader areas such as intelligent packaging to monitor temperature and quality through the cold chain, essential for both pharmaceuticals and food. In short, Britain has deep expertise in all the steps that add value along the cold chain, and which India needs to develop (see Figure 2), and also in food processing, which levers the value of each step still further (Figure 3).

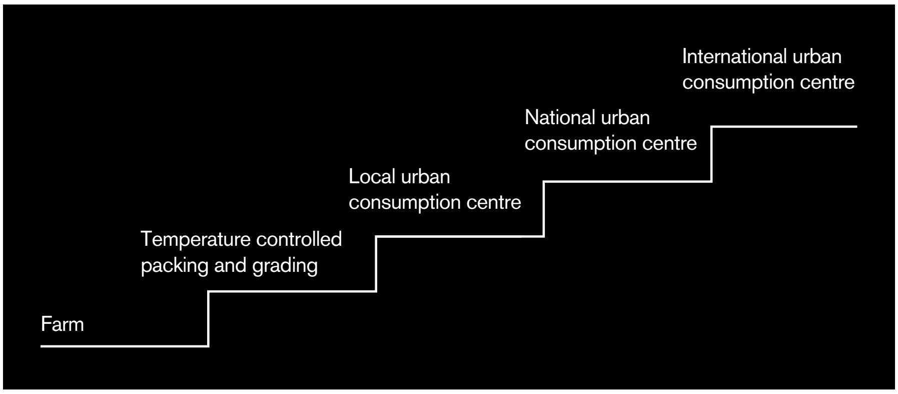


Figure 2: *Value adding steps of cold chain*

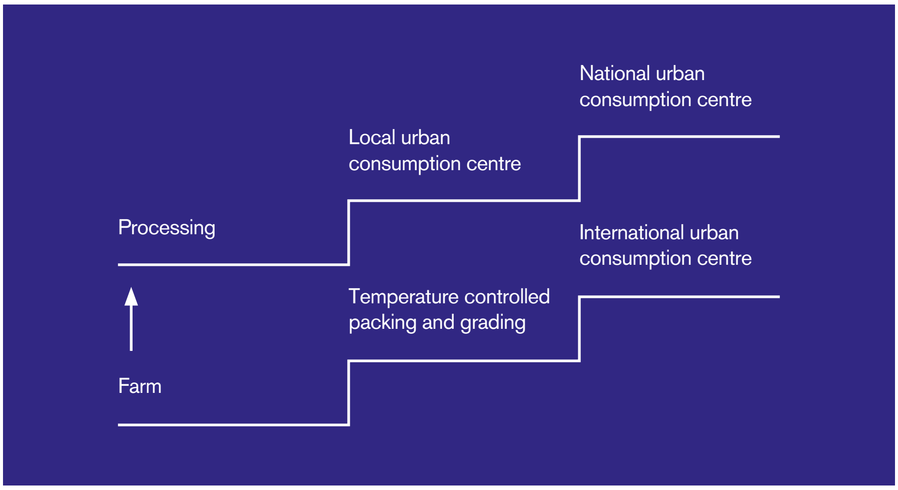


Figure 3: *How processing levers the value of cold chain*

FULL REPORT

Introduction

Agriculture is the backbone of the Indian economy, employing almost half its workforce – over 250 million people[9]. The sector has been transformed since independence in 1947 through the 'green revolution', which staved off famine by dramatically increasing crop yields, and the 'white revolution', which turned India into the world's largest milk producer. Yet most of the country's farmers work plots of less than two acres, and most remain trapped in the cycle of poverty.

To reach its full potential, Indian agriculture urgently needs a third revolution: the cool revolution to build a sustainable cold chain. It is hard to overstate the importance of this apparently narrow technical issue to achieving India's environmental, economic and social goals. The importance of cold chain is already well understood at the highest levels of India's government. The purpose of this report is to help make sure the new cold chain is built as quickly as possible – and is sustainable.

In a speech in February 2016, Prime Minister Modi, declared 'I wish to double the income of farmers by 2022 when India will celebrate 75 years of its independence'[10]. The following month he set out a 7-point plan to achieve the target and established a high-level committee to see it through[11].

One of the plan's key measures is to develop 'cold chains' – an integrated network of refrigerated buildings and vehicles to transport produce from farm to shop quickly and in good condition (see box). India's cold chain capacity is minimal, and as a result, it's estimated that for some crops more than 40% of the harvest rots and has to be thrown away before reaching any consumer. This represents not only a huge waste of food – with serious consequences for agricultural resources and carbon emissions – but also a major loss of income and opportunity for Indian farmers.

The farmer's loss is all the greater because India's booming cities are home to a rapidly growing middle class, hungry for high-quality fresh food and processed food products. This demand is increasingly being met by imports delivered by air freight. If India develops a nationwide cold chain, it would raise farmers' incomes and the benefits would spread throughout Indian society. A recent report found that building clean cold chains in developing countries would have a positive impact on all seventeen of the United Nations Sustainable Development Goals[12].

The benefits of developing cold chain in India have already been demonstrated. A recent pilot project that transported citrus fruit from Punjab to Karnataka found that cold chain reduced wastage by 75%, and raised profits at the farm gate ten-fold. Yet the conventional cold chain technologies that dominate in developed economies are highly polluting, so extending them to India would only solve one problem by worsening others. This means we need to demonstrate clean cold chains – low carbon and zero-emission – so that India can build the infrastructure that not only allows it to double farmers' income, but also does it sustainably.

Britain is at the forefront of developing clean cold technologies, which its government has been quick to recognise and support with grant funding of tens of millions of pounds. Britain's farmers also have experience of moving up the value chain to develop their own regional brands, which might be relevant to Indian farmers competing with imported produce in their major cities.

In February 2017, the University of Birmingham led the study tour of Punjab and Haryana states, India's biggest agricultural producers, and held a two-day workshop in Delhi. The trip was organised with the help of the Foreign and Commonwealth Office, the Department for International Trade, the Horticulture Departments of Haryana and Punjab, and India's National Centre for Cold-chain Development (NCCD). The workshop was attended by almost 100 Indian and British delegates, comprising farmers, technologists, academics and financial experts, and was addressed by India's Secretary of Ministry of Agriculture and Farmers' Welfare, Mr S.K. Pattanayak. Through two days of intensive debate we developed our recommendations and established a strong case for collaboration between Indian and British governments to support the demonstration of clean cold chains in India.

The importance of cold chains

In developed countries, cold chains are generally invisible, or at least taken for granted – although without them the supply of food and temperature-sensitive medicines such as vaccines would quickly break down. In developing countries, however, billions of people live with little or no access to cold chain and suffer the consequences daily through hunger, ill-health and poverty. The lack of adequate cold chain causes two million vaccine preventable deaths each year[13], and the loss of 200 million tonnes of food[14].

The impact of cold chains spreads far beyond food and medicine, because global food wastage of 1.3 billion tonnes per year – 30% of global food production[15] – has enormous knock-on effects on resources and pollution. The Food and Agriculture Organisation of the United Nations (FAO) estimates that food wastage occupies a land area the size of Mexico, consumes 250 km^3 of water per year, three times the volume of Lake Geneva, and accounts for 3.3 billion tonnes of carbon dioxide emissions, making it the third biggest emitter after the US and China[16].

If cold chains in the developing world could be brought up to the levels of those in the developed world, the benefits would extend far beyond the immediate reduction in wastage, hunger and food prices. Asia and Africa account for two-thirds (67%) of the food wasted worldwide[17], and 90% of food wastage in developing countries occurs in the supply chain[18].

The impact of cold chains extends even beyond the environment into social and development issues. Since so many of the world's poor and hungry are employed in agriculture, raising farmers' incomes by building clean cold chains would have huge indirect impacts on health, education, gender equality and other social goals. A report published by the University of Birmingham earlier this year, Clean cold and the Global Goals, found that clean cold chains would help achieve all seventeen of the United Nation's Sustainable Development Goals[19].

Cold chains in India

India's cold chain capacity is extremely limited. The country has the world's largest capacity of cold storage warehouses, but these are designed almost exclusively for long-term storage of potatoes, reflecting the priorities of decades past when India simply needed to produce enough food to stave off famine. As we heard during our visit to Sangha Refrigeration in Jalandhar, Punjab, these cold stores are not typically integrated into cold chains because potatoes require neither pre-cooling (which would damage the tubers) nor refrigerated transport after coming out of cold storage.

Horticultural, dairy and meat cold chains are quite different, however, since they are not intended to store produce for long periods, but to transport it quickly to market in good condition. For this reason they require not just cold storage hubs to act as a buffer, but also pack-houses with pre-cooling and refrigerated trucks. These are the assets that India needs to develop.

In a major study, India's National Centre for Cold-chain Development (NCCD) calculated the country has less than 15% of the refrigerated trucks it needs, and less than 1% of the pack-houses (see Table 1)[20]. As a result, scarcely 4% of India's food is moved through the cold chain compared to 70% in the UK, and for some crops post-harvest losses exceed 40%. The NCCD has calculated that building cold chains to marry India's current food production and consumption would require investment of some $15 billion[21].

Type of Infrastructure	Infrastructure Requirement (A)	Infrastructure Created (B)	All India Gap (A–B)	% share of shortfall
Pack-house	70,080 nos.	249 nos.	69,831 nos.	99.6%
Reefer Vehicles	61,826 nos.	9,000 nos.	52,826 nos.	85%
Cold Storage (Bulk)	341,64,411 MT	318,23,700 MT	32,76,962 MT	10%
Cold Storage (Hub)	9,36,251 MT			
Ripening Chamber	9,131 nos.	812 nos.	8,319 nos.	91%

Table 1: *Shortfall in India's cold chain capacity. Source: NCCD All India Cold-chain Infrastructure Capacity, Assessment of Status & Gap, 2015. NB since this report was written, NCCD estimates that the number of refrigerated (reefer) trucks in India has risen to around 10,000, but this is still less than a sixth of what the country needs.*

Farmers' incomes

It is hard to overstate the importance of cold chain in delivering Prime Minister Modi's target. The lack of cold chain infrastructure, and resulting high levels of post-harvest food loss, reduces farmers' income, and this in turn limits their capacity to invest and their incentive to grow more food. The missing link is a seamless cold chain in the form of modern pack houses, distribution hubs and refrigerated transport to maintain the safety, quality and quantity of food while moving it swiftly from farm gate to consumer.

Cold chains don't just reduce post-harvest food loss, but also allow farmers to earn more by maintaining the quality of their produce and selling it further afield – especially when this means they can reach distant cities. The same lettuce sold for three rupees at the farm gate in Haryana state can fetch 100 rupees in downtown Delhi – but only if the farmer can get it there in the same condition as one imported by air-freight from a highly developed global agri-business and cold chain. What's more, the cold chain enables and incentivises farmers to raise their output because they will earn more from the extra they produce, whereas its absence means that any effort to increase yield will also cause higher wastage – so dousing the incentive. Since they invested in cold chain, Seema and Amit's revenue has tripled and net income doubled (see page 21).

India is the world's fastest growing economy, and its urban middle class is expanding fast. But with inadequate cold chains, India is losing this opportunity to foreigners: apple imports, for example, have risen six-fold since the turn of the century[22], while domestic production has fallen in recent years.[23] To reverse this trend, India urgently needs to invest in cold chains.

Cold chains also allow the farmer to expand into higher value but perishable horticultural produce and into animal husbandry, rather than remain tied to the low margin staples. And the really entrepreneurial farmer or farming co-operative can move right up the value chain by developing processing and food products, as shown by India's successful Amul Dairy co-operative. In the UK, many farmers have become independent national food brands with their own dairy products, fresh juices, and even chilled and frozen ready meals.

Kinnow cold chain pilot

The benefits of developing cold chain in India have already been demonstrated. A recent pilot project carried out by Carrier and overseen by NCCD established a cold-chain to transport kinnow, a low-value citrus fruit, from orchards around Abohar in Punjab to the city of Bangalore, which is 2,500km and five days' travel to the south. The project analysed the operation of a real cold chain comprising pack house, pre-cooling, refrigerated trucks and cold storage hub, and compared several scenarios against a baseline of no cold chain. The study found the cold chain reduced wastage by 75% and CO_2 emissions by 16% while raising profits at the farm gate ten-fold.

The pilot showed not only that cold chains work, but also that demonstrations work. Since the end of the project in June 2016, 250 refrigerated trucks (reefers) have started to operate from the region, whereas before there were none, although most of these have been drawn in from other regions. The aggregator who took part in the project has, however, bought eight new reefers, and nine pack-houses have been built – all without recourse to subsidy schemes. And it seems that if the benefits of cold chain are clearly demonstrated, some farmers also have the resources to invest in cold chain.

The downside of conventional cold chain technologies

Yet the conventional cold chain technologies that dominate in developed economies are highly polluting, so extending them to India would solve one problem by exacerbating others.

Conventional cooling technologies typically run using refrigerant gases ('F-gases') that are themselves extremely powerful greenhouse gases and tend to leak. Pound for pound, some F-gases cause thousands of times more warming than CO_2. Conventional cooling technologies also typically rely on diesel or grid electricity, and so cause further large emissions of CO_2 from their energy consumption. In addition, since many of the technologies are powered by lightly regulated secondary diesel engines, they also emit grossly disproportionate amounts of local air pollution.

Work in the UK has shown that transport refrigeration units (TRUs), the secondary diesel-powered units that provide cooling on large trucks and trailers emit far more nitrogen oxides (NOx) and particulate matter (PM) than a modern truck propulsion engine. Analysis conducted by E4tech, the clean energy consultancy for Dearman, has found that auxiliary transport refrigeration units can emit up to six times as much NOx and 29 times as much PM as a Euro VI truck propulsion engine[24]. NOx and PM are two of the key toxic pollutants in India's outdoor air pollution, which is already thought to cause almost 3,300 premature deaths per day – or almost 1.2 million per year[25].

Since India's electricity grid is weak and power cuts happen daily, most cold storage facilities operate diesel powered electricity generators (diesel gensets) for back-up power, and these also emit high levels of NOx and PM. The cold storage facilities we visited maintained diesel gensets to safeguard their contents against daily power-cuts.

The combination of India's urgent need to build large amounts of cold chain capacity, and the pollution caused by conventional technologies poses a major risk. If India pursues the default option, it will simply solve one set of problems by worsening another. This means we need urgently to demonstrate clean cold chains – which are low carbon and zero-emission – so that India can build the infrastructure it needs to double farmers' income sustainably.

Clean cold technologies

Luckily there is no shortage of clean cold technologies with which to build a sustainable cold chain in India. The study tour visited several agricultural and cold chain sites, including one large clean cold project, and the workshop heard presentations from a range of Indian and British manufacturers, and technology developers whose products are either already commercial or on the brink of commercialisation. It became clear that every stage of the cold chain – from pack house pre-cooling to vehicle refrigeration to cold storage hub – could be freed from its current dependence on grid electricity or diesel.

The technologies reviewed included several powered by solar photovoltaic panels (ecoZen, Cartwright), others that provide cooling though solar powered absorption chilling, which converts sunlight directly into cooling without an intermediate electrical stage (Solar Polar, Sangha Refrigeration), and others that power off-grid refrigeration through biomass gasification (New Leaf Dynamic, Sangha Refrigeration). It also covered the use of eutectic plates or advanced phase-change materials that can be charged at night to provide cooling on smaller vehicles during the day (Pluss), and novel energy carriers such as liquid air or nitrogen to provide cold and power for vehicle cooling (Dearman).

The workshop also heard from Rajinder Singh, Technical Director of Petronet LNG, about the enormous amounts of waste cold given off during re-gasification at India's LNG import terminals. This could be recycled as liquid air or nitrogen to provide low carbon, zero-emission distributed cooling.

Cold chains also require advanced packaging to keep produce in prime condition by controlling the atmosphere and moisture levels to which it is exposed. Here too the environmental footprint can be reduced through the use of biodegradable or recyclable packaging by blending vegetable starch with the conventional petroleum-derived materials (Nextek).

For more detail on other clean cold technologies not reviewed here, such as geothermal and other forms of 'free' cooling, which are also relevant, please see the report of the University of Birmingham's Commission on Cold, Doing Cold Smarter.

Barriers

Most of India's farms are tiny. 85% are smaller than two hectares (five acres), accounting for 44% of the agricultural land[26]. The average farm size has fallen over the past 40 years and is now just 1.2 hectares. Small farmers are typically poor and lack the financial resources to invest in equipment such as pre-cooling and cold storage individually. This keeps them poor, because it means they must accept whatever price the aggregator offers at harvest time, when their crop is likely to face a local glut.

The government provides financial support for farmers under several schemes (eg. MIDH), which extends to 35% subsidies for investments in agricultural equipment. Cold chain equipment is included, but the farmers we spoke to describe a number of difficulties in accessing this support, mostly related to bank financing (see Seema and Amit's Story, page 21).

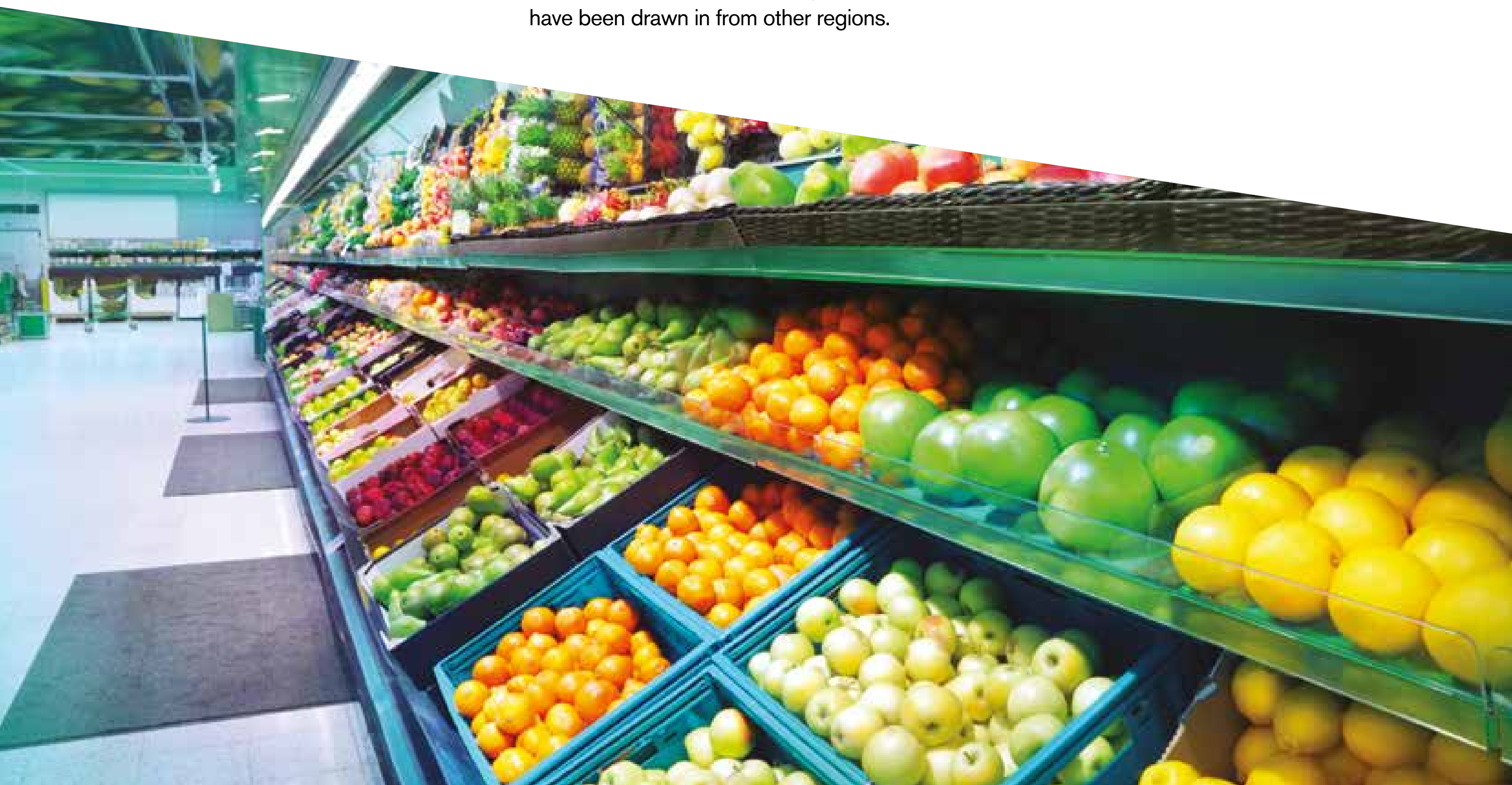
The subsidies are in any case back-end-loaded – only paid into the farmer's account when he or she has paid off the rest of the loan. Some farmers report that the banks charge up front arrangement fees and demand urban property as collateral, which most small farmers do not possess. If granted, the interest on a loan for cooling equipment may be 12.5% compared to 4–6% for a tractor and trailer. High interest rates are particularly challenging for clean cold technologies, because although they usually offer lower lifecycle costs than conventional equipment, most if not all of the cost is paid up front.

Large and mid-sized farmers do have financial resources to deploy, however, and here the barriers may be easier to overcome. Since the Carrier/NCCD cold chain pilot concluded last year, the aggregator who took part in it has bought nine refrigerated trucks, and eight pack-houses have been built – all without recourse to subsidy. Altogether there are now some 250 reefers operating in Abohar (Punjab), whereas previously there were none, although the vast majority of these have been drawn in from other regions.

From this it seems the biggest obstacle preventing at least some farmers – perhaps wealthier than average - from taking up a new technology was simply its unfamiliarity, and the fact that its benefits had not yet been demonstrated. Once that was put right, farmers quickly invested. The remaining problem is that the pilot demonstrated conventional and highly polluting technologies powered by diesel and grid electricity. We need to do the same for clean cold chain technologies.

Solutions

The barriers to rapid expansion of clean cold chains in India that we identified comprise 1) the predominance of small farms and poor farmers, 2) a lack of projects to demonstrate clean cold chains, and 3) some issues with the administration and bank financing of existing support schemes. We believe 1 and 2 are the critical points, and these are where we concentrate our recommendations – although demonstration projects should also help address point 3 by educating bankers about the value of cold chains.



How small farmers can combine to gain market clout

India knows at least one way to tackle the problem of the poverty and powerlessness of small farmers, because it has already done so in the dairy sector. The Amul Dairy co-operative was formed in 1946 to solve precisely the problems faced by horticultural farmers in India today[27].

To escape the low prices offered by milk contractors, a handful of villages in Gujarat clubbed together to market their milk collectively. Soon they were producing so much they had to start producing butter and milk powder, later expanding into cheese, chocolate, baby food and cattle feed. In the 1960s, Amul led the 'white revolution', or 'Operation Flood', which turned India into the world's largest milk producer. The co-operative now collects almost two million litres of milk per day from over 680,000 producer members organized in more than 1,200 village co-ops. Its revenue has risen from $160 million in 2006 to $736 million in 2016, and it now exports worldwide[28].

There is obviously very little that outsiders can teach India about the co-operative approach to agriculture. We simply note that the Amul model could be extended into horticulture, which now faces precisely the problems that the dairy co-operative has already solved.

Amul took several decades to become a truly national force, however, and the need to develop clean cold chains in India is now urgent. The state government of Haryana has recently introduced several initiatives which we hope will deliver quicker results, and which we believe our proposed I4C could do much to support.

In January, Haryana launched a Crop Cluster Development Scheme to organize some 13,000 farmers living in 340 'Bagwani' or horticultural villages into a system of 140 crop clusters. Each cluster will specialise in a single crop – say peppers, tomatoes, beans – and each will have its own 'logistics centre' or pack-house, with equipment for sorting, grading, packing and cooling. Each cluster will also have access to a refrigerated truck to carry produce direct to consumers such as food processors, retailers and government institutions. 'The logistics centres will link to a cold chain so that farmers can sell directly to consumers', explains Dr Ranbir Singh, Haryana's Joint Director of Horticulture, 'the extra money goes into the pockets of farmers'.

The idea is not simply to increase farmers' incomes, but also to speed up the penetration of modern technologies, and raise productivity through the investment in infrastructure and village training programmes. The state government will provide 90% of the funding, with a budget of 510 crore rupees (£63 million) over three years, and 10% will come from the farmers themselves.

Haryana has also set up farmer's markets in cities as another means of allowing farmers to capture a bigger slice of the final price fetched by their produce by selling directly to consumers. We visited one in Panchkula near Chandigarh, where the government has set up the necessary infrastructure including sheds, cold storage, and a ripening unit next door to the covered market. We believe these programmes – particularly the Crop Cluster Development Scheme - could provide an excellent live platform within which to trial clean cold chain technologies.

How to demonstrate clean cold chains in India

Haryana also hosts the Centre of Excellence for Vegetables, a joint venture between India and Israel that provides a useful model for the kind of cooperation needed to speed the uptake of innovative technologies and approaches. The Centre was founded to increase productivity, crop diversity and resource efficiency in Indian horticulture, and does so through applied research and training programmes. In its huge greenhouses at Gharaunda near Karnal, the Centre conducts plant breeding work to develop cultivars suited to local conditions, and sells high-quality seedlings to farmers. It also demonstrates new irrigation and cultivation techniques that farmers can then adopt, including one that has increased tomato productivity ten-fold.

The basis of the joint venture is that India provided the site and buildings, while Israel provides the know-how. This model seems to have been successful, and we believe could be a model for a new centre to demonstrate Indian and UK clean cold technologies. There would be differences, however, because the scope of the clean cold chain centre would be much wider than that of a conventional technology demonstrator:

- Since the value of cold chain comes from moving produce from farm to consumer through several distinct stages, the project needs to demonstrate the entire clean cold chain in operation, rather than a series of isolated facilities or individual technologies;
- As a range of different clean cold chain technologies are being developed, the project should be technology neutral, and assess a range of competing and complementary technologies with equal rigour;

- Because the clean cold chain will require new approaches to address the financial constraints of poor farmers, and the capital cost of clean cold technologies, the project must demonstrate not only technologies but also business models.
- The project should be designed to expand into commercial deployment where successful, and should be regionally, socially and culturally inclusive to ensure the best chances of success.

The importance of international collaboration

If India were to extend international collaboration to the development of clean cold chains, Britain would have much to offer.

Britain has recently emerged as a leader in clean cold technologies, based on the radical innovation of developers such as Dearman, Surechill, Solar Polar and others. These appear entirely complementary to the work of Indian clean cold developers such as ecoZen and Pluss. Britain has also led the development of the 'cold economy' concept, and the idea of recycling the vast amounts of waste cold given off by LNG re-gasification through novel energy vectors such as liquid air to provide clean distributed cooling – which India's Petronet is keen to develop.

Britain also has world-class academic and industrial research into cooling, at institutes including: the Birmingham Centre Cryogenic Energy Storage at the University of Birmingham; Heriot-Watt Energy Institute; Loughborough University's new Cryogenic Energy labs; the CryoHub, led by London South Bank University; i-STUTE, the interdisciplinary centre for Storage, Transformation and Upgrading of Thermal Energy, which groups four universities; the National Centre for Sustainable Energy Use in Food Chains (CSEF), at Brunel, and the Thermal Energy Research Accelerator (T-ERA). Public and private investment into UK-based research and development of innovative clean cold technologies has reached well over £100 million.

Britain also has a strong tradition of farmers expanding into food processing and developing their own brands – such as Copella apple juice, or Yeo Valley yoghurt. This experience may also be relevant to Indian farmers or cooperatives intent on supplying premium markets in Indian cities, once they are connected by cold chains.

Helping to develop clean cold chains in India would exactly fit Britain's agenda for industrial strategy, overseas development aid, and research and development funding. The UK's new Industrial Strategy published in February 2017 promises to support 'new businesses and new industries which will challenge, and in some cases, displace the companies and industries of today'. The government has also channelled £1.5 billion of the Overseas Development Aid budget into a new Global Challenges Research Fund to support cutting edge research and innovation that addresses the challenges facing developing countries[29].

Britain has committed a further £735 million to developing science and innovation partnerships with developing countries through the Newton Fund[30] – which operates in India as the Newton Bhabha Fund. The UK will contribute £104 million to Newton Babha to 2021, which India will match. The fund's top three priorities are the food-water-energy nexus, public health and wellbeing, and sustainable cities – all of which are addressed by clean cold chains.

Conclusion

We believe there is a strong case for the British and Indian governments to support a centre to demonstrate clean cold chain and accelerate its deployment. The India Clean Cold Chain Centres could be organised and funded along the lines of the Indo-Israeli Centre of Excellence for Vegetables in Haryana (see Proposal chapter). Its results could then be replicated in other rapidly emerging countries – with potential export opportunities for both India and Britain.

Seema and Amit's story

Seema Gulati and Amit Gupta have been farming at Karnal in Haryana for twelve years. Today they work five hectares (12.5 acres) growing staples such as potatoes, onions and carrots; 'exotics' including salad leaves and iceberg lettuce, sweetcorn and mushrooms; and flowers. They employ 20 people full time and a further 50 during harvest. They sell locally, and into Delhi and beyond. Their story illustrates the enormous potential that can be unleashed through entrepreneurial flair and investment in cold chain.

Seema and Amit have always invested to improve their business. They bought a tractor and trailer, built a 2,000m^2 greenhouse, and installed an irrigation system powered by 5kW solar panels with battery storage. But for years, they produced largely staples, and were forced to accept whatever price the aggregator offered at harvest time – when the crops were likely to face a local glut and low prices.

In 2014 they joined the National Centre for Cold-chain Development (NCCD), and went on a cold chain training course provided by the cooling component manufacturer Danfoss. NCCD also arranged for them to travel to Paris for a further eight days' training with Cemafroid, the cold chain consultancy.

Armed with their new knowledge, they invested in a pre-cooling chamber, a 200 tonne cold store, a ripening chamber, and equipment for grading, washing, drying, and packaging their produce. They also bought four small three-wheeler vans – equipped with GPS to keep tabs on their drivers' progress – which they have insulated. They are now investigating which cooling technology to install on the vans, and have also bought a larger (15 tonne) refrigerated truck. They paid for it all by giving up the lease on 37 acres they had previously farmed, taking out bank loans and some government support.

Their investment in cooling has transformed the business. At its simplest, they are now able to hold product in cold storage, and time their sales to coincide with higher prices. For example, the price of vegetables can rise just ahead of wedding celebrations when demand is higher, so holding produce in the cold store for a few days makes financial sense. The prices of popular vegetables can double or even triple during the peak wedding and festival season in the summer. Longer term, the price of premium potatoes might rise from R2-R5/kg during harvest to R15 – R25/kg during off-season.

More importantly, investing in cold means Seema and Amit have been able to move into higher value crops, value added products, new sales channels and distant markets. Today Seema and Amit sell lettuces and other 'exotic' vegetables that have been sorted, graded, pre-cooled and packaged under the brand name 'Elle'. They sell direct to urban households nearby through their four small delivery trucks, and to city malls in Gurugram and Delhi, 250km to the south. Whereas 1kg of lettuce sold at the farm gate to an aggregator would fetch just R10, local delivery fetches R50 for a single lettuce, and the city malls pay R100 per piece. There are around three lettuces per kg, so the investment in cooling has allowed the business to increase the price realised by up to 33 times.

The larger refrigerated truck is needed to collect supplies mushroom compost, which has to be kept cool, but is also further extending the reach of Seema and Amit's business. They currently use it to transport butter produced at a nearby farm to Hyderabad in the south, and plan to start bringing bananas north on the return journey.

Seema and Amit have succeeded in spite of some hurdles that smaller farmers might find difficult to overcome. The government provides financial support for farmers under several schemes (eg. MIDH), which extends to 35% subsidies for investments in agricultural equipment, and which the couple were able to claim for a quarter of their investment in the cold store (ie. 35% of the investment needed for 50 tonnes of their 200 tonne facility).

The subsidies are in any event back-end-loaded – only paid into the farmer's account when he or she has paid off the rest of the bank loan. But the couple were only able to secure the loan because they owned urban property to offer as collateral, which most smaller farmers would not possess. They also found that interest charged on a loan for cooling equipment was 12.5% compared to 4–6% for a tractor and trailer, because bankers do not yet understand the importance of cold chain to horticulture. High interest rates would be particularly challenging for clean cold technologies, because although they are usually cheaper overall than conventional equipment, they often have a higher capital cost. 'The rate of interest should be lower on zero-emission products', says Seema.

But investing in cold is certainly paying off for Seema and Amit. The farm's revenue has tripled and its net income doubled, and they expect income to keep rising as the business grows; they have just signed a deal to supply Walmart in Chandigarh. They are even thinking of making further investments in cooling, such as blast-freezing, to add further value to their produce.

At a personal level, Seema and Amit have already beaten Mr Modi's target of doubling farmers' incomes largely by investing in cold and five years ahead of his 2022 deadline. By then – in further sign of the potential unleashed by cold chain – they hope to be exporting specialist mushrooms to other countries.

OFFICIAL PERSPECTIVES FROM THE DELHI WORKSHOP

India is already committed to building cold chains, led by its experts at the National Centre for Cold-chain Development. But the government is now looking for international collaboration to speed up the development of this vital infrastructure and help double farmer's income by 2022. And the new cold chains must be not only economic but also sustainable. Those were the messages delivered by ministers and officials in speeches, presentations and interviews at the cold chain workshop held in Delhi in early March 2017.

The ministers' remarks underlined the fundamental importance of cold chain to achieving Prime Minister Modi's target. Mr Ashok Dalwai, Additional Secretary at the Ministry of Agriculture and Farmers' Welfare, who leads the Doubling Farmers' Income Committee, explained that raising farmers' incomes would mean encouraging them to shift from producing low value grains to higher value but perishable fruit and vegetables, which would in turn depend on developing cold chains.

S.K. Pattanayak, Secretary, Ministry of Agriculture and Farmers' Welfare, stressed the importance of cold chains to reduce post-harvest food losses and integrate Indian agriculture better into global markets, which would both raise farmers' incomes and help 'satisfy the hunger of the world'.

Both stressed that the new cold chains must not only be low cost but also sustainable. 'The cold chain can be very dirty, and therefore, the emphasis is on clean cold', Mr Pattanayak told the workshop, 'otherwise we will lose the race'. In an interview later, the Secretary emphasised again India's enthusiasm for clean cold, stressing the government's commitment to the Paris climate change agreement, and highlighted the huge potential of solar energy to power it as one example.

The Secretary also explained that cold chains were essential to make a success of the government's National Agriculture Market[31], its new online trading portal that allows farmers to find out where prices are highest and sell into that market, so reducing the number of intermediaries and increasing the flow of produce between states. 'A farmer can complete the trade electronically, but then he needs to transfer the produce to the consumer, and that's why we need cold chain logistics.'

Pawanexh Kohli, Chief Executive of India's National Centre for Cold-chain Development and Chief Advisor to the Ministry, elaborated on the various ways in which cold chains would raise farmers' income. The most basic is by minimising post-harvest losses, which in India reach 30%–40% for some crops, simply because there is currently no way to get them to where they are needed in good condition. Cold chains would solve that, says Kohli: 'Whereas before I could only sell 60% of what I produced, now I can sell the remaining 40% – that's almost double!' Not only is the farmer better off, but so too is the consumer, since increasing supply of food should reduce its price.

The cold chain not only allows farmers to minimise food wastage, but also to increase their sales through a huge 'multiplier' effect on productivity. If 40% of your harvest goes to waste, there is little incentive to put in the extra effort and investment needed to grow more; if most of your crop reaches market, there is far more incentive to increase your output. Mr Kohli cites the example of grape production in India, where productivity was low until the deployment of 135 pack-houses, which allowed farmers to export to Europe. As a result, India's grape productivity per acre has risen three-fold and is now among the world top 10. 'That has only happened because of cold chain', says Kohli. The incentive to increase productivity also encourages farmers to expand into higher value crops, and up the value chain into processing and packaging (see Seema and Amit's story).

So, the challenge is how to extend the experience of India's vineyards to the rest of horticulture, and the meat and dairy sectors. India's cold chain capacity is extremely limited. The country has the world's largest capacity of cold storage warehouses, but these are designed almost exclusively for long-term storage of potatoes, and cold chains require far more than bulk cold storage to perform their function of moving produce from farm to market quickly and in good condition. In a major study, the NCCD found the country has less than 15% of the refrigerated trucks it needs, and less than 1% of the pack-houses, the vital first stage of the cold chain that preconditions the produce for onward transport. These are the 'missing links' needed to connect farmers to existing cold storage facilities in distant cities and other centres of demand, says Kohli, who estimates that to build cold chains to marry India's current food production and consumption requires investment of some $15 billion.

While India's current cold chain capacity is limited, the barriers to further expansion are well understood, and include a general lack of awareness, and the difficulty of securing bank loans to invest in cold chain assets. India has already shown that both can be overcome through rigorous demonstration projects.

One example is the cold chain project to transport kinnow (a low-value citrus fruit) from orchards around Abohar in Punjab to Bangalore, carried out by Carrier and overseen by NCCD. The project reduced crop wastage by 75% and CO_2 emissions by 16%, and raised profits ten-fold. Since the end of the project, the aggregator who took part in it has bought nine refrigerated trucks, and eight pack-houses have been built – all without recourse to subsidy. According to Mr Kohli, these investments would probably not have happened but for the demonstration project: 'Now banks are more open to giving credit, because this study is convincing proof of the business opportunity'.

In other words, demonstrators work. The remaining problem, however, is that what has been demonstrated so far is the dirty cold chain, powered by grid electricity and diesel. What's needed then is to demonstrate clean cold chains in the same way.

Mr Kohli argues that for what he calls 'front line demonstrations', which demonstrate not just individual technologies, but the entire cold chain from end to end, and which also take into account local climate and human factors. There is no single answer, he says, so 'individual technology providers have to get together and create the overall solution'. He is also keen for more collaboration with international stakeholders 'because it gives so much more oomph and impetus'. There are also indigenous technologies ready to scale up that may need international partners to expand.

Similarly, Secretary Pattanayak is looking for transfer of clean cold technologies from developed countries that have done advanced research in the sector: 'if they can pass these technologies onto us it will be greatly helpful'.

For foreign governments, the case for helping develop India's clean cold chain is two-fold, says Mr Kohli. First, if they want to advance the UN Sustainable Development Goals, for instance on reducing food waste, 'they should be working where technological innovation will have the biggest impact'. Second, there is an enormous business opportunity. For example, as Mr Kohli notes in a recent report, India currently has some 10,000 refrigerated vehicles to serve a population of around 1.2 billion, while Britain has around 80,000, with a population of just 64 million.

From officials' remarks at the Delhi workshop, it seems India is certain to develop a cold chain in the next few years, and the potential growth is huge. The remaining questions are will it be sustainable, how quickly it will grow, and who will help develop it.

THE POTENTIAL OF LNG WASTE COLD

India needs to build a large amount of cold chain capacity quickly. That much is clear from the work of NCCD and the Delhi clean cold chain workshop. But at the same time, like many countries, India discards enormous amounts of cold during the re-gasification of Liquefied Natural Gas (LNG) at its import terminals. This 'waste' cold could be recycled as liquid air or nitrogen to supply zero-emission cooling to Indian cold chains, so further reducing their cost and environmental impact. This is one of the central ideas of the 'cold economy' discussed in presentations to the workshop by Professor Toby Peters of University of Birmingham Energy Institute, and Mr Rajinder Singh, Technical Director of Petronet LNG.

LNG is simply natural gas that has been cooled to -162°C to make it liquefy and become compact enough to transport by super-tanker. The cold can be considered the packaging in which the gas is transported. On arrival, the LNG must be warmed up to re-gasify before entering the natural gas pipeline, and during the process each tonne of LNG releases up to 240kWh of 'coolth' or cold energy. The coolth is quite separate from the chemical energy contained in its molecules and this 'packaging' is usually discarded. Of the 111 LNG import terminals worldwide, only 23 do any form of cold recovery. And those that do usually provide cold only to industrial plants close to the terminal, and only at times when LNG is actually being re-gasified, which limits the amount of cold that can be recycled. The waste cold could however be used to produced low-cost liquid air or nitrogen, allowing the cold energy to be stored and transported for use on demand in vehicles and buildings – for instance in the cold chain.

One of the key insights of the cold economy is that our concept of energy storage cannot be limited to lithium ion batteries, and that cold thermal energy vectors such as cryogenic liquid nitrogen are vital if we are to recycle the vast LNG waste cold resource. One estimate suggests that in some markets this approach could generate more than $50 per tonne in economic and social benefits. At a projected global LNG trade of 500 million tonnes, this new 'waste recycling' market could be worth $25 billion per year by 2025 – so capturing even a fraction could be worth billions.

Petronet LNG is investigating the feasibility of building import/export hubs for perishable produce close to its terminals at Dahej and Kochi, both of which are 'baseload' plants that re-gasify LNG - and therefore generate cold - continuously.

Natural gas is a relatively small part of India's energy mix, but demand is forecast to jump six-fold by 2040. Domestic production will supply half the gas, but most of the rest will come from imports of LNG, which the IEA forecasts (Figure 4) will almost quadruple from around 18bcm in 2013 to almost 70bcm by 2040. India currently has four LNG import terminals, and Petronet LNG expects that number to double. According to the business consultancy Accenture, 'India has the potential to be one of the highest growth markets for LNG'[32].

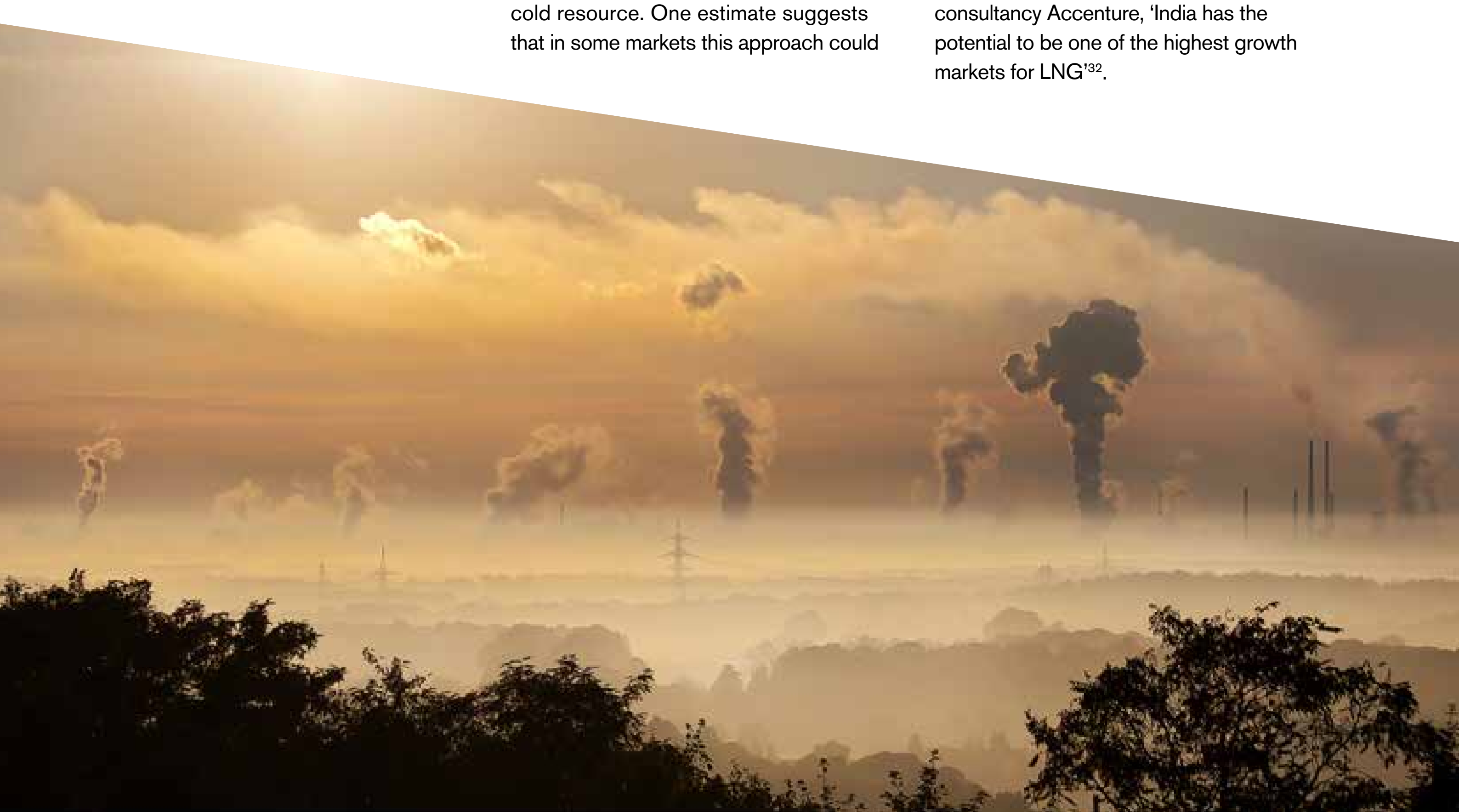
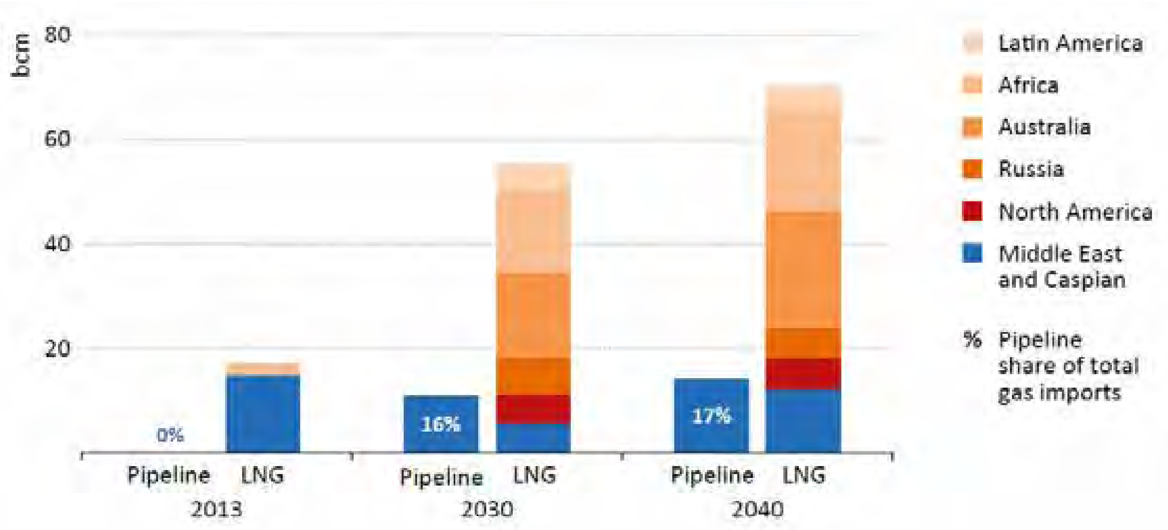


Figure 4: *India's gas imports to 2040. Source: IEA*[33]



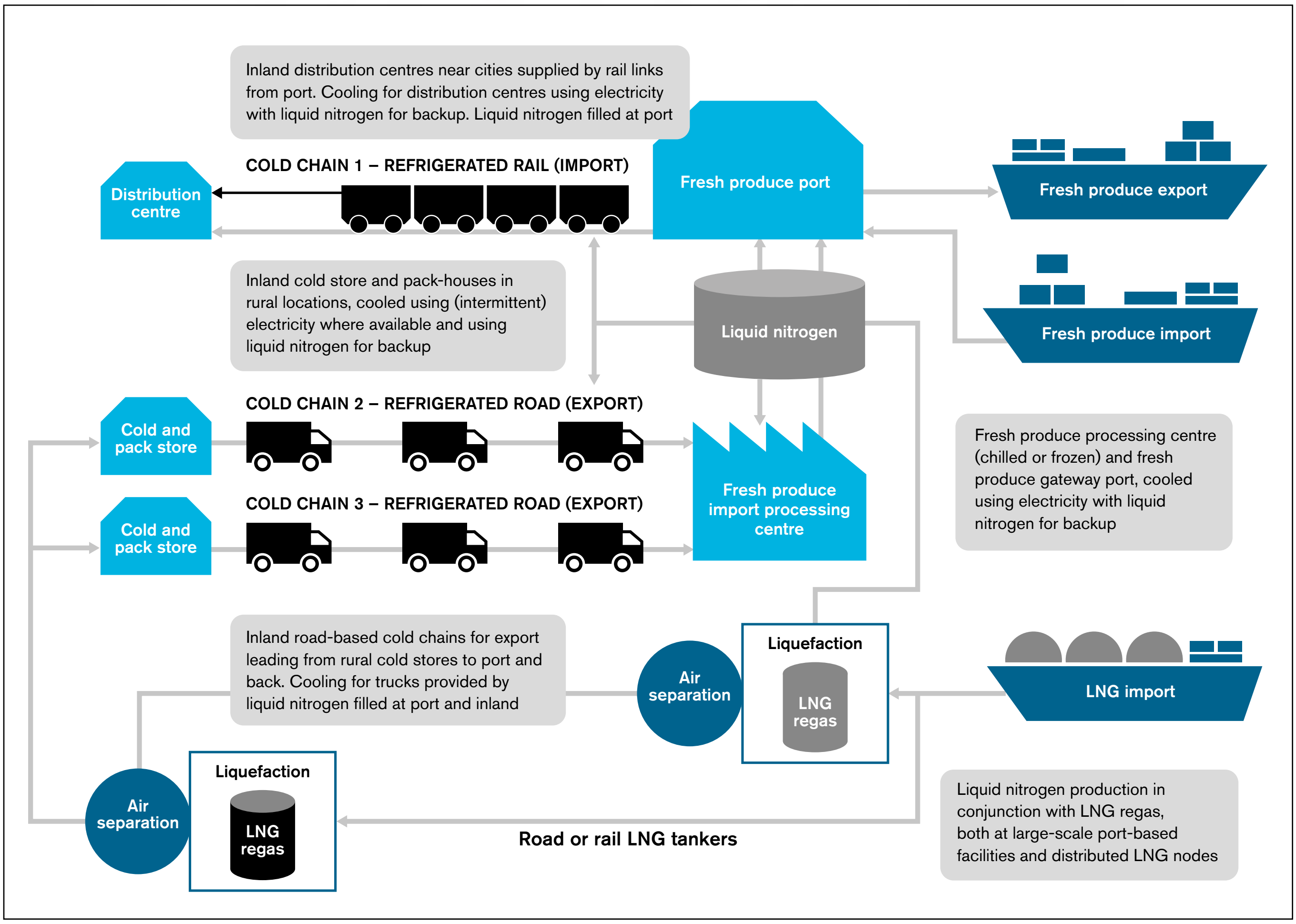


Figure 5: *How waste cold from LNG re-gasification could power zero-emission cold chains in India.*

LNG import terminals could become the hubs of extensive import-export cold chains in developing countries such as India (Figure 5), and even develop into a broader cold economy. The analysis shows how an LNG terminal re-gasifying 7,100 tonnes of LNG per day (a small fraction of the capacity of Dahej) could produce 2,600 tonnes of liquid nitrogen (LIN), enough to provide the cooling for almost 1,100 chilled and frozen refrigerated trucks operating around the clock and peak time cooling (three hours a day) for 7,500,000m^3 of chilled and frozen buildings, both at the port and at inland warehouses at the other end of the cold chain. For reference, the largest such facility in the world measures around 600,000m^3, and the UK has a total cold store capacity of 25,000,000m^3.

If all the LIN were used for transport refrigeration, a fleet of more than 20,000 trucks could be supported. The refrigerated vehicles would be zero-emission, emit less CO2 and could be as much as 40% cheaper to run than diesel.

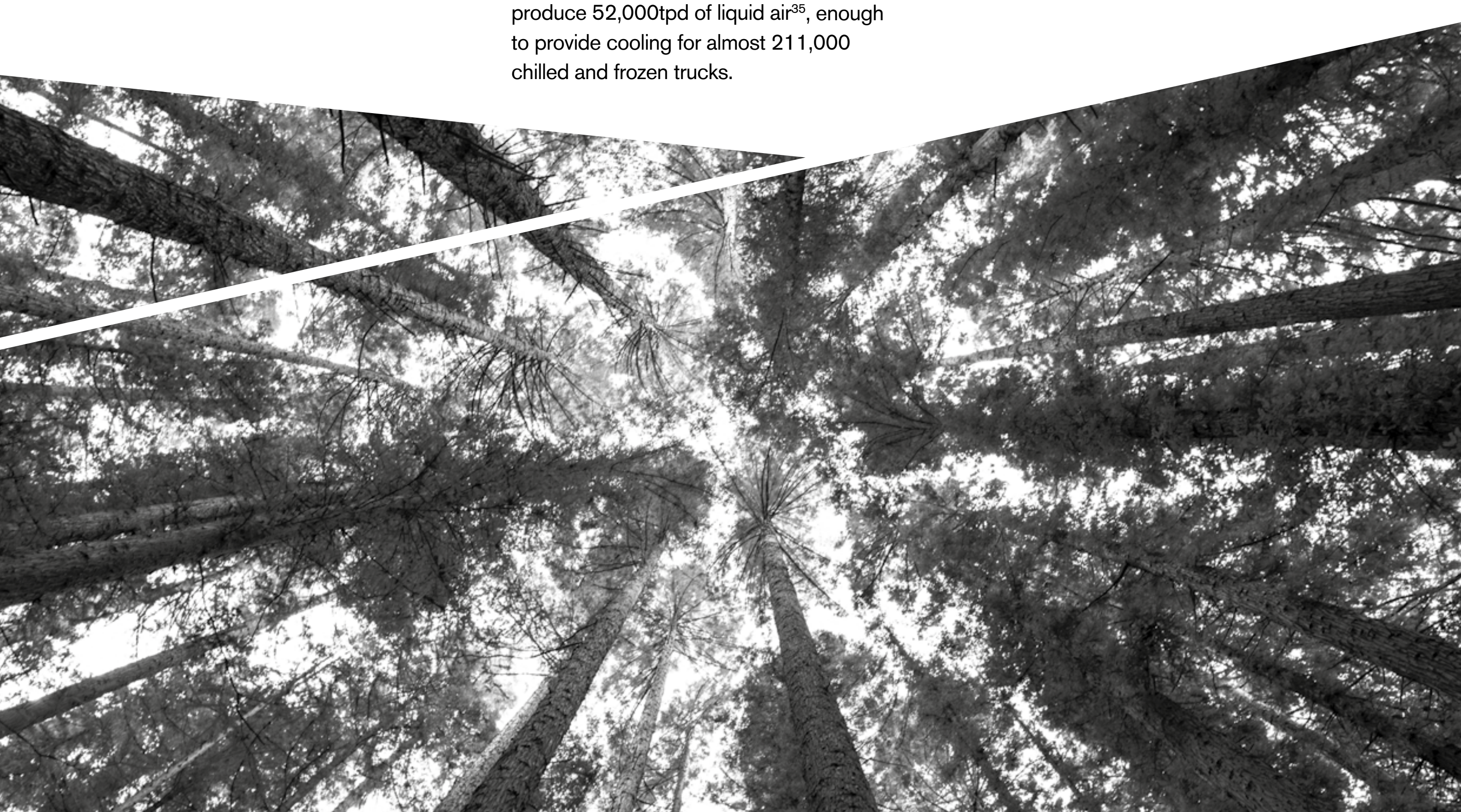
Another report, published by Heriot-Watt earlier this year, found that if liquid air were produced with waste LNG cold at Dahej and then distributed by rail up to 500km, the TRUs running on it would cost up to 57% less based on projected energy costs in 2020[34]. If India were to fill the deficit in refrigerated vehicles identified by NCCD with TRUs running on liquid air rather than diesel, the annual savings in 2020 would be $179 million.

The report makes a compelling case for the use of LNG-assisted LAIR TRU cooling anywhere within 500km of the Dahej LNG terminal—or any other that re-gasifies large volumes daily—and up to 1,000km for frozen TRUs in 2020. It means LAIR reefer cooling would be competitive for both long distance transport of produce from rural pack-houses to urban distribution hubs, and for distribution from those hubs to shops.

The report also found that India's projected LNG imports in 2040 could in principle produce 52,000tpd of liquid air[35], enough to provide cooling for almost 211,000 chilled and frozen trucks.

'India's LNG imports are booming, and at the same time it needs to develop clean cold chains as quickly as possible', said Professor Peters in an interview, 'so the country looks perfectly placed to pioneer the cold economy'.

The workshop agreed that integrating LNG waste cold into India's new cold chains could represent a major opportunity, since Petronet LNG is keen to exploit its waste cold, and its terminals at Dahej and Kochi re-gasify continuously as 'baseload'. It recommended the British and Indian governments consider funding a feasibility study on the economic, environmental and engineering aspects of integrating India's LNG waste cold into its new cold chains.



IF THE TRUCK DOESN'T COME TODAY, **HALF OUR SPINACH WILL ROT.** WE WILL **LOSE ALL OUR PROFIT.**

THE MANDI OPENS **ONCE A WEEK**, I LOSE **HALF MY FRUIT** WAITING TO SELL AT THE MANDI.

CAPSICUM **PRICE WILL BE HIGH** AFTER FOUR DAYS, BUT I CAN'T **KEEP IT FRESH** TILL THEN.

Figure 6: *Problems faced by our farmers every day*

Figure 7: *Demountable body with hydraulic self-levelling system. Source: Cartwright Group*

CLEAN COLD TECHNOLOGIES

Luckily there is no shortage of clean cold technologies with which to build a sustainable cold chain in India. The study tour visited several agricultural and cold chain sites, and the workshop heard presentations from a range of Indian and British manufacturers and technology developers whose products are either already commercial or on the brink of commercialisation. It became clear that every stage of the cold chain – from pack house pre-cooling to vehicle refrigeration to cold storage hub – could be freed from its current dependence on grid electricity or diesel.

ecoZen solutions is a start-up based in Pune that has developed ecofrost, a portable solar-powered cold room. The unit comprises a 20' x 8' x 8' insulated container with six cooling compartments, and a refrigeration system driven by an oversized and tilted solar roof (see figure 7). When the sun shines the solar panels power the refrigeration system, which simultaneously cools the produce and recharges the unit's built-in cold storage panels made of phase-change materials. These panels store some of the cold generated during the day to keep the produce cool at night. If the system were to fail for any reason, the thermal storage panels alone would keep the unit cool for up to 30 hours. The unit can pre-cool 500kg of produce, holds 5.5 tonnes in total at temperatures between 2C and 10C depending on the crop. The cold room also controls humidity and can be monitored and managed from a smartphone. ecoZen offers the unit on a short-term lease for the duration of an individual crop harvest. This means four different farmers can make use of the cold room in four different locations during the course of a year. 60 units are in operation.

Figure 8: *Ecofrost solar-powered cold room. Source: ecoZen*

The British truck body builder **Cartwright Group** is developing another solar powered mobile cooling concept. Known as SPICES – Solar Powered Indian Cold-chain Eutectic Solution – the device comprises a demountable truck body with a solar roof. During harvest the unit is detached from the truck and left at the field, where farmers can load their crops to be pre-cooled and then transported directly to market in the same vehicle without further handling. Temperature is maintained through the combination of solar power and eutectic cold storage, and needs no external power supply or infrastructure investment by farmers. The truck body will combine laminated panels integrating vacuum insulated panel insulation and thin-film photovoltaic cells in a single structural element.

Solar Polar is a British company that has developed a small-scale solar-powered absorption chiller. Absorption chilling is a well established technology that turns heat directly into cooling – without any electrical stage – through the vapour absorption cycle. It is widely used in large-scale tri-generation energy schemes, and in gas powered camping fridges. Whereas most absorption chillers are driven by heat from combustion, Solar Polar has cracked the problem of developing a small scale unit driven by solar heat. Each module measures 1.6m x 60cm x 40cm and produces 200W of cooling, and modules can be combined to increase cooling power. The units have no moving parts, no electrical components, no maintenance or running costs, and Solar Polar says that at mass production its unit will offer the world's lowest cost solar powered cooling. One application will be to provide cooling for an off-grid containerised cold room, the prototype of which will be installed at Anna University in Chennai in July 2017.

Figure 9: *Small-scale solar absorption chiller. Source: Solar Polar*

Figure 10: *The Dearman transport refrigeration unit*

Solar energy researchers at **Heriot-Watt University** are working in partnership with Solar Polar, as well as other British-based manufacturers of solar thermal technologies, to develop a solar powered absorption chiller for the residential market. A prototype will be installed at the university's Dubai campus in 2018. Work is underway to design and build a zero energy solar powered villa at the campus, where the prototype will provide cooling for both air conditioning and refrigeration. The system will also incorporate condensate recovery technology, extracting water from air and providing a grey-water source. This will then be coupled with a solar thermal water treatment system, under development at Heriot-Watt University, to treat the condensate and produce potable water. If successful, this technology could be relevant to off-grid agricultural applications in hot countries such as India.

Sangha Refrigeration, part of a 5,000-acre potato farm near Jalandhar, Punjab, is building a state-of-the-art 15,000-tonne cold store, partly powered by 1MW of solar PV panels on the roof. The project will also demonstrate a smaller scale solar absorption chiller.

New Leaf Dynamic installs bulk milk chillers and cold stores powered by cow dung and other farm wastes, so solving two problems at once – especially now that the burning of rice stalks in the field is penalised in India. Marketed as GreenCHILL the systems have been installed at dairies, horticultural and fish farms across India. Its installed cold stores can hold 10-15 tonnes of produce at temperatures as low as -5°C. The company has developed its own refrigeration cycle with no moving parts, and its systems are cheaper to run than diesel and can operate off-grid. The company has won several awards, including one from the UK Royal Academy of Engineering Leaders in Innovation in 2016.

The British clean cold technology developer **Dearman** has developed a low carbon and zero-emission transport refrigeration unit (TRU) for trucks and trailers, powered by its innovative piston engine which runs on liquid nitrogen. The Dearman TRU extracts both cooling and shaft power from a single tank of cryogen, making it efficient and cost effective. Testing has shown it outperforms diesel TRUs in cooling power, speed of pull-down and temperature accuracy. Since it is fuelled by a cryogenic liquid, the Dearman TRU will work better in extremely hot countries such as India than conventional diesel TRUs, which struggle to expel enough heat to keep their cargoes cool. The system is currently in commercial trials with Sainsbury's in the UK.

Liquid nitrogen is widely produced in India, and could in the future be produced with the help of waste cold from re-gasification of LNG at import terminals, which would further reduce the cost of cooling.

Dearman, the University of Birmingham, and several academic and industrial partners have recently launched an innovative research project to prepare the Dearman TRU for the Indian market, with funding from the Newton Fund UK-India Research and Innovation Bridges Competition. Part of the project will be to develop a liquid nitrogen tank tailored for conditions in India, which would cause high levels of nitrogen boil-off and require more frequent re-fuelling were a standard tank to be used. It will use fluid flow analysis and modeling, and mechanical design optimisation to reduce sloshing in the tank, and is expected to lead to new commercial products and IP.

The project will be conducted in collaboration with the Indian Institute of Technology Bombay (IITB), Arctic Refrigeration, Cartwright Group and ColdEX. It is supported in the UK by state-of-the-art facilities housed within the EPSRC-funded Birmingham Centre for Cryogenic Energy Storage at the University of Birmingham, Birmingham's BLUEBear high performance computing facilities, and the International Thermal Energy Manufacturing Research Accelerator (part of the Thermal-Energy Research Accelerator, T-ERA), which is funded by Innovate UK.

Another way to cool vehicles is with eutectic plates or phase change materials, whose properties mean they can store large amounts of cold, which is released at a constant temperature as they thaw. The plates are then recharged with cold simply by placing them in a freezer overnight – so displacing diesel with grid or renewable electricity. **PLUSS** is an Indian materials research and manufacturing company that produces phase change materials for a range of applications including transport refrigeration.

To keep produce in the best condition means controlling not only its temperature but also its atmosphere. This is usually achieved through various types of plastic packaging or more sophisticated (and expensive) polymer films that control the rate at which gases and moisture escape. But these are petroleum-based and major source of pollution. So the British consultancy **Nextek** has launched a project called **Biofreshpak** to develop a new generation of food packaging films in which much of the conventional petroleum-derived material is displaced with waste plant starch – for instance from tapioca. These will be both cheaper and recyclable, and will be produced at a pilot plant in Pune.

Introduction to cold chain

Cold chains comprise an interlocking series of refrigerated operations designed to transport perishable products to market quickly and in good condition. They create value by reducing wastage, preserving quality and expanding the size of the market that a farmer can supply.

In horticulture, the cold chain starts at the farm pack-house, where the harvested crop is sorted and graded. It is then pre-cooled to remove field heat and bring it down to the appropriate temperature: 2°C for spinach, for example, 7-10°C for peppers, green beans and tomatoes, and 13°C for mangoes. The crop may then be packaged and briefly stored in a cold store until collection by refrigerated truck. The truck transports the crop to a cold distribution hub close to a city, where the load is deconsolidated for distribution by refrigerated vehicle to local retailers. The cold distribution hub may also have ripening chambers to bring produce that has been harvested immature to the point where it is ready to eat. Once produce has reached a distribution hub, it can then also be exported by truck, ship or plane.

In Britain, 70% of our food – worth some £56 billion – is transported by cold chain, but in India the figure is just 4%. As a result, post-harvest food losses can be as high as 40%, which depresses farmers' incomes and results in a huge waste of agricultural inputs.

India has the world's largest capacity of bulk cold storage warehouses, but these are designed to store single harvest crops such as potatoes for up to a year, and are not integrated into cold chains. What India lacks most is pack-houses and refrigerated transport. According to the National Centre for Cold-chain Development, India has just 10,000 refrigerated trucks and zero refrigerated containers for domestic multi-modal uses, and scarcely 250-350 packhouses to serve a population of 1.2 billion. Compared to NCCD's estimate of India's immediate cold chain needs, these figures represent shortfalls of 85% and 99% respectively.

Just as India's current lack of cold chain causes huge food losses and waste of agricultural inputs, so building a modern, clean cold chain would have multiplier effects. By reducing food losses, maintaining quality, and connecting farmers to distant markets where their produce can fetch premium prices, cold chains encourage farmers to increase yields, grow higher value crops, and move up the value chain into food processing and branding (see Official perspectives from the Delhi workshop). As Seema and Amit's Story shows, farmers can double their income through these kinds of initiatives. Developing clean cold chains is therefore essential for India to achieve Mr Modi's target.

Type of Infrastructure	Infrastructure Requirement (A)	Infrastructure Created (B)	All India Gap (A–B)	% share of shortfall
Pack-house	70,080 nos.	249 nos.	69,831 nos.	99.6%
Reefer Vehicles	61,826 nos.	9,000 nos.	52,826 nos.	85%
Cold Storage (Bulk)	341,64,411 MT	318,23,700 MT	32,76,962 MT	10%
Cold Storage (Hub)	9,36,251 MT			
Ripening Chamber	9,131 nos.	812 nos.	8,319 nos.	91%

Source: *NCCD All India Cold-chain Infrastructure Capacity, Assessment of Status & Gap, 2015. NB since this report was written, NCCD estimates that the number of refrigerated trucks in India has risen to around 10,000, but this is still less than a sixth of what the country needs.*

ENDNOTES

1. www.cia.gov/library/publications/the-world-factbook/geos/in.html

2. www.deccanchronicle.com/nation/current-affairs/280216/wish-to-double-the-income-of-farmers-by-2020-narendra-modi.html

3. http://timesofindia.indiatimes.com/india/PM-Modi-outlines-7-point-strategy-to-double-farmers-income/articleshow/51587588.cms

4. www.birmingham.ac.uk/research/activity/energy/research/clean-cold-and-the-global-goals.aspx

5. https://www.indexmundi.com/agriculture/?country=in&commodity=apples&graph=imports

6. https://gain.fas.usda.gov/Recent%20GAIN%20Publications/2013%20Apple%20Product%20Brief_New%20Delhi_India_6-19-2013.pdf

7. www.thehindu.com/sci-tech/energy-and-environment/India-overtook-China-in-number-of-deaths-due-to-pollution-Report/article16643789.ece

8. www.enam.gov.in/NAM/home/about_nam.html#

9. https://www.quora.com/What-percentage-of-the-Indian-population-depends-on-agriculture-and-what-is-the-agriculture-sectors-contribution-to-Indias-GDP

   https://home.kpmg.com/content/dam/kpmg/in/pdf/2017/01/KPMG-Flash-News-India-Economic-Survey-2015-16%E2%80%93Key-Highlights-3.pdf

10. http://www.deccanchronicle.com/nation/current-affairs/280216/wish-to-double-the-income-of-farmers-by-2020-narendra-modi.html

11. http://timesofindia.indiatimes.com/city/delhi/Modi-outlines-7-point-strategy-to-double-farmers-income/articleshow/51587682.cms

12. Clean Cold and the Global Goals, University of Birmingham, http://www.birmingham.ac.uk/research/activity/energy/research/clean-cold-and-the-global-goals.aspx

13. Clean water, cold vaccines, cell phones = a simple way to save lives, OECD Insights, 22 JUNE 2010, Harvey Rubin MD, http://oecdinsights.org/2010/06/22/clean-water-cold-vaccines-cell-phones-a-simple-way-to-save-lives/

14. The role of refrigeration in worldwide nutrition, International Institute of Refrigeration, June 2009, www.iifiir.org/userfiles/file/publications/notes/NoteFood_05_EN.pdf

15. www.fao.org/docrep/018/i3347e/i3347e.pdf

16. Food wastage footprint, Impacts on natural resources, FAO, 2013, www.fao.org/docrep/018/i3347e/i3347e.pdf

17. http://blogs.worldbank.org/voices/food-waste-doing-math

18. www.rockefellerfoundation.org/app/uploads/Waste-and-Spoilage-in-the-Food-Chain.pdf

19. www.birmingham.ac.uk/research/activity/energy/research/clean-cold-and-the-global-goals.aspx

20. NCCD.2015. All India Cold-chain Infrastructure Capacity (Assessment of Status & Gap), Delhi. (www.nccd.gov.in)

21. http://nccd.gov.in/PDF/Strategy Options for CCD 2016.pdf

22. https://www.indexmundi.com/agriculture/?country=in&commodity=apples&graph=imports

23. https://www.indexmundi.com/agriculture/?country=in&commodity=apples&graph=imports

24. Liquid Air on the Highway, Centre for Low Carbon Futures, June 2014, http://static1.squarespace.com/static/54858edee4b0b0ce78c2e93c/t/5486c99be4b04af8a8c94ea0/1418119579115/Liquid-Air-on-the-Highway-Low-Carbon-Futures.pdf

25. www.thehindu.com/sci-tech/energy-and-environment/India-overtook-China-in-number-of-deaths-due-to-pollution-Report/article16643789.ece

26. www.firstpost.com/business/india-enough-land-farming-bigger-issues-worry-2032327.html

27. www.amuldairy.com/index.php/about-us/history

28. www.amul.com/m/amul-topical-story

29. www.rcuk.ac.uk/funding/gcrf/

30. www.gov.uk/government/publications/newton-fund-building-science-and-innovation-capacity-in-developing-countries/newton-fund-building-science-and-innovation-capacity-in-developing-countries

31. www.enam.gov.in/NAM/home/about_nam.html#

32. Gas Grows Up Part 1: Developing New Sources of LNG Demand, Accenture, 2016, www.accenture.com/t20160210T155111__w__/us-en/_acnmedia/PDF-7/Accenture-Gas-Grows-up.pdf#zoom=50

33. www.worldenergyoutlook.org/

34. Capturing the Waste Cold of Liquid Natural Gas, Heriot Watt University

35. 1bcm LNG = 0.73mt. So 70bcm LNG = 51.1mt LNG. 51.1mt / 2.7 = 19mt LIN, 19mt / 365 = 52,000tpd.

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