MP ENSYSTEMS Advisory Pvt. Ltd.

UNIVERSITY OF BIRMINGHAM

SHAKTI SUSTAINABLE ENERGY FOUNDATION

PROMOTING CLEAN AND ENERGY EFFICIENT COLD-CHAIN IN INDIA

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APRIL - 2019

ACKNOWLEDGEMENT

The project team acknowledges inputs provided by several individuals from different stakeholder groups. Particularly, we acknowledge inputs from Mr. Jagmohan Singh, Optimal Agro Producer Company Ltd., Ambala, Haryana; Mr. Satbir Singh, Crown Fruits and Vegetables Producer Company Ltd., Kurukshetra, Haryana representing Farmers' Producers' Organizations in Haryana and Mr. Vilas Shinde of Sahydri Farms in Maharashtra. We acknowledge inputs from private sector fruits and vegetables value-chain providers that included Mr. Binwant Nain, AHA LLB, Shahbad, Haryana; Ms. Seema Gulati, Elle Farms/ Mushrooms, Karnal, Haryana, Saravjeet Singh, FreshproAgri Solutions Pvt. Ltd., Kurukshetra, Haryana; Mr. V.P. Patil and Dr. Homaji Bhangale, Jain Farm Fresh, Jalgaon, Maharashtra. Above-mentioned individuals contributed to the case studies documented in this report. This report benefitted a lot from the insights provided by Mr. Pawanexh Kohli - CEO and Chief Advisor, National Cold-chain Development (NCCD) whose thought-leadership has been useful to our team's exploration. We also thank Mr. Gyanesh Bharati- Jt. Secretary (Ex), Ministry of Environment, Forests and Climate Change (MOEF&CC) and Mr. Ajay Bakre, Director General at the Bureau of Energy Efficiency. We also thank Government of Haryana officials – most notably Mr. T. L. Satyaprakash, I. A. S., Managing Director, Haryana State Industrial and Infrastructure Corporation (HSIIDC); Ms. Deepika Handa, Assistant General Manager, HSIIDC; Dr. Hardeep Singh, Chief Administrator, Haryana State Agriculture and Marketing Board; Dr. Arjun Saini, Director General, Horticulture Department; Dr. Ranbir Singh, Jt. Director, Horticulture Department; Mr. Yoginder Singh, State Consultant, Small Farmers Agribusiness Consortium Haryana (SFACH). Inputs and support provided by Mr. Dipankar Chakravarti of the UK Trade Initiative was timely and useful in reaching out to several stakeholders in the state of Haryana and Punjab. During the course of the project, we interacted with several technology providers who shared important insights related to the cold-chain technology innovations. This report is a result of collaborative effort between the University of Birmingham led by Prof. Toby Peters who has been a backbone to the propositions made by our team: Shakti Sustainable Energy Foundation and MP Ensystems'.

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Toby Peters and Pawanexh Kohli

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Today compared with the start of the 1960s, India now harvests 40 times as much tomato; 14 times more potato; 8 times more wheat; three times as much in poultry and meat, 13 times more fish; 8 times more milk, and almost 40 times more eggs. India's food production has massively outpaced population growth which grew 2.8 times from 461 million in 1961.

In India, despite sufficient and surplus production, under-nutrition prevails and hunger is not eradicated. An underlying problem is that historically we have correlated population (or demand), with food production (or supply). But production alone is not sufficient to ensure supply of food - the missing condition is physical and effective market connectivity. As we strive to produce more food, if the logistics mechanism is unable to cope with the flood of farm produce, the production does not equal supply, and the losses that result will wipe out much of the benefits.

Ineffective delivery systems also limit the producers' valuation to near-farm demand. Cold-chain is essential to connect a farmer to new urban markets further afield for increased volume demand and higher prices. But whether produce has a holding life of a week or forty weeks, the inventory must reach consumers in time, and in the right quality.

Cold stores are only one piece of the cold-chain. Storage by itself is not a solution. Cold-chain is not about preservation, it applies technology to stretch the marketable time of a perishable product, for a finite duration. In short, cold-chain buys time, to temporarily extend the saleable life. The time in hand should be fruitfully utilised to expand market reach, especially for highly perishable fresh produce.

Cold-chain is an integrated, seamless and resilient network of refrigerated and temperature controlled pack houses, distribution hubs, vehicles and processes to maintain the safety, quality and quantity of food, while moving it swiftly from farm gate to consumption centre. These need to be suitably indigenised and ideally made in country. Cold-chains enhance economic wealth, cash flow and security for farmers and improve food quality, safety and value to the customer; and must achieve this with minimum environmental impact.

However, here is the conundrum. While food lost in the delivery chain is avoidable through use of technology, cold-chain itself is an energy intensive application, often relying on diesel for off-grid and on-vehicle cooling. Any indiscriminate use of technology can lead to undesired hazards. Future development must harness the portfolio of renewable energy resources, new thermally-focused energy systems, innovative thermal management; not merely focus on optimising its existing fuel or electricity consumption.

How to use the integrated components of storage and transport for cross-geography access or distance-price arbitrage, time-arbitrage or even cross-seasonal trading becomes as important as the physical infrastructure to flow of food from farm to fork. Within this, the infrastructure is only half the solution. Equally important is, the flow of key information from wholesaler, retailer or consumer to producer – from fork to farm - which can help shape time of planting and harvest as well as choice of produce to grow. This will drive resource conscious robust business models and viable financing models to underpin the investment in clean cold-chain.

But whereas the cold-chain will morph over time, driven by market demand, the motivation for specific interventions should not simply be to accelerate deployment, but also address the challenge outlined above: the need to deliver market connectivity in an environmentally sustainable way. We welcome the opportunity to be associated and involved in this study by Shakti Foundation to explore how India can build out clean cold-chains.

PREFACE BY Krishan Dhawan

CEO, Shakti Sustainable Energy Foundation

The Government of India (GoI) has placed substantial emphasis on increasing farmers' income by 2022 through productivity gains. In 2016, the GoI launched 'Operation Green' to support agri-logistics, food processing units and food producer organizations. Developing "cold chains" is one of the key measures under "Operation Green" to arrest food loss from the farm gate to consumers.

Cold-chains are expected to proliferate rapidly in India during the next few years through a combination of market and policy driven efforts. According to India's Cooling Action Plan, under a business-as-usual scenario, the energy consumption and greenhouse gas emissions from cold-chains is likely to increase manifold by 2037.

But unplanned investments in the cold-chain sector can create a carbon intensive stand-alone infrastructure of cold storages, reefer vehicles and ripening chambers instead of a sustainable and cohesive agri-supply chain. As a signatory to the Paris Agreement and the Kigali Agreement, India will need to reassess the development of its cold-chains in order to reduce GHG emissions from this sector.

Recognizing this, Shakti in collaboration with key partners is supporting efforts to advance cleaner and more energy-efficient cold chains in India. A critical way to enable this transition is to introduce clean technologies, which will help prevent the long-term lock-in of fossil-fuel intensive technologies. This study, commissioned by Shakti and developed by MP Ensystems Advisory Pvt. Ltd. with support from the University of Birmingham, assesses existing technologies, energy consumption, use of renewable energy, and Global Warming Potential (GWP) of refrigerants that are currently used in India's cold-chain infrastructure.

Based on the empirical assessments in the state of Haryana, this study makes key recommendations for the development of clean cold chain in India: Promoting new business models (viz., IT enabled services for managing harvesting and logistics from fork to farm and delivering Refrigeration as a Service), developing cold-chain living labs and innovation centres, creating infrastructure for training and outreach, facilitating hackathons and preparing IT based agri-supply chain solutions.

I trust that this study will serve as an important reference for policy makers, farmer producer organizations, private sector and other stakeholders working to deliver cleaner and more energy-efficient cold chains while assisting India in meeting its ambitious climate goals.

Krishan Dhawan
Chief Executive Officer
Shakti Sustainable Energy Foundation

ABBREVIATIONS

APEDA:	Agricultural and Processed Food Products Export Development Authority
APVAC:	Atmospheric Pressure Vacuum Drying
ACFW:	Agriculture & Farmers Welfare
BAU:	Business-As-Usual
BEE:	Bureau of Energy Efficiency
CA:	Controlled Atmosphere
CFCs:	Chlorofluoro carbons
CCDP:	Crop Cluster Development Program
CTARA:	Center for Technology Alternatives for Rural Areas
CSISAC:	Central Sector Integrated Scheme on Agricultural Cooperation
DFI:	Doubling Farmer's Income
FCI:	Fixed Capital investment
FPCs:	Farmer Producer Companies
FPOs:	Farmer producer organizations
GHG:	Greenhouse Gases
GWP:	Global Warming Potential
$GtCO_2e$:	Gigatonnes of Carbon Dioxide Equivalent
HFCs:	Hydrofluorocarbons
HFOs:	Hydrofluoroolefins
HSAMB:	Haryana State Agricultural Marketing Board
HSIIDC:	Haryana State Industrial Infrastructure Development Corporation
HWDT:	Hot Water Dip Treatment
IOT :	Internet of Things
ICAR-CIPHET:	Indian Council for Agricultural Research-Central Institute of Post-Harvest Engineering and Technology
LOI:	Letter of Intent
LULUCF:	Land Use, Land-Use Change and Forestry
MIDH:	Mission for Integrated Development of Horticulture
MOEF CC:	Ministry of Environment Forest and Climate Change
NABARD:	National Bank for Agriculture and Rural Development
NABCONS:	NABARD Consultancy
ICAP:	India Cooling Action Plan
NCCD:	National Centre for Cold-chain Development
NITI Aayog:	National Institution for Transforming India
NDC:	Nationally Determined Contribution
ODP:	Ozone Depleting Potential
ODS:	Ozone Depleting Substances
PCM:	Phase Change Material
QSRs:	Quick Serving Restaurants
REEFER:	Refrigerated Transport
SFACH:	Small Farmer Agri-Business Consortium, Haryana
STL:	System for Low Temperature
SWOT:	Strength, Weakness, Opportunity and Threats
UoB:	University of Birmingham
VAMs:	Vapour Absorption Machines
VCC:	Vapor Compression Cycle
VFD:	Variable Frequency Drive
VHT:	Vapour Heat Treatment
WRI:	World Resources Institute
ZECC:	Zero Energy Cool Chambers

NOTE:
Currency equivalence considered in the report: 1 US $ = INR 70

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BACKGROUND and Introduction

Context

- Agriculture and allied sub-sectors is a substantive part of the Indian economy, contributing up to 14.4% of GDP and half (49.8%) of the country' employment (NITI Aayog, Govt. of India 2015).
- The Indian food and grocery market is the world's sixth largest (India Brand Equity Foundation 2018).
- Presently, on average there is a 120% increase between the price Indian farmers typically receive for their produce and the price at which it is sold to the retailer (Ernst & Young Pvt Ltd, 2013). According to NCCD, the price wedge between farm-gate sales and terminal wholesale can be as high as 1000% for perishable produce. This price wedge can be bridged through cold-chains.
- For some crops, up to 40% of the harvested produce is lost between the farm gate and the market. This reduces the farmer's income, his capacity to invest and fails to provide him an incentive to grow more produce. Also, in a rapidly urbanizing market place, such huge loss of produce negatively impacts the cost of food and subsequently affects the end consumer. (Inter-Ministerial Committee for Doubling Farmer's Income, 2017).
- Future agricultural development requires developing a systems approach, cutting across pre-production, production and post production. Agriculture, can no longer be perceived from a narrow traditional vision, as activities relating to cultivation, rearing or harvesting of crops or animal produce. It is most appropriate to adopt a holistic attitude, one that includes the delivery mechanism.
- Applications of cold-chain have been proven to enhance the income, economic wealth and financial security of farmers, growers and fishermen as well as improve the food's quality, safety and value.
- Clean cold-chain is delivering cold-chain in a sustainable manner with minimal environmental and natural resource impact and within the country's CO_2, natural resource and clean air targets
- A cold-chain is an integrated, seamless and resilient logistics network of refrigerated and temperature-controlled pack houses, transport modes, cold storages, distribution hubs and merchandising platforms, that are used to maintain the safety, quality and quantity of food produce, while moving it from point of harvest to consumption point. Where possible, swift connectivity with demand results in faster cash flows and reduced risk of inventory. The non-availability of cold-chain leads to an average of 15-20% loss of food (i.e 50% of the post-harvest food loss), as well as an imbalance in linking demand with supply that can often result in large scale discarding of produce during harvest season.

- A lack of information to farmers and inadequate supply-chain management, as well as the unavailability of appropriate cold-chain technologies, hinders access to better markets, which could increase selling prices by as much as 4 – 5 times.
- There are positive examples of how small farmers have used cold-chains plus business management to create direct market access and significantly increase turnover and profit.
- The Government of India (GoI) has set the target of doubling farmers' incomes by 2022. It has identified investment in cold-chain logistics as a vital component of its farm income strategy (Inter-Ministerial Committee for Doubling Farmer's Income, 2017) and (NITI Aayog, Govt. of India 2015), and recently launched its national cooling action plan titled India Cooling Action Plan (ICAP) on 8-March-2019.

Objectives

The objective of this study was to identify the scope of the business, technical and operational improvements required to deliver clean cold-chains in India. The work also aimed to develop a vision for clean cold-chains alongside innovative implementation and financing options.

Methodology

Primary research was conducted in the states of Haryana, Punjab, Maharashtra and Karnataka. It included:

- Rapid assessment of the existing cold-chain landscape (infrastructure, take-up, status etc.);
- Assessment of existing technologies (including their energy intensity) used to deliver farm fresh produce to the marketplace;
- Understanding of existing market failures and barriers to deployment of cold chains;
- Understanding of existing local capacity to design and manage cold-chain assets;
- A focus on closed-loop opportunities rather than conventional structures where only one end-use is addressed.[1]

Data was gathered via

- Field visits with Farmer Producer Organisations (FPOs), Farmer Producer Companies (FPCs) and Farmer Cooperatives;
- Workshops with policy makers and representatives from the cooling industry, agriculture and food industry, and third sector organisations;
- Field visits and interviews to develop case studies of organisations currently using, or proposing to use, cold-chain technologies and infrastructure;
- Socio, technical and financial analysis of possible clean-cooling solutions, identifying the economic gains for certain crop clusters in the state of Haryana.

[1]By closed-loops we mean considering waste or secondary outputs from one process to be used as an input in the other processes. In case of thermal processes, this could mean harnessing waste heat or cold from other applications through heat transfer methods.

FINDINGS

1. Current failures and barriers to the deployment of cooling technology

Barriers to the deployment of cooling technologies were identified throughout the perishable produce food supply chain, from first mile (the flow of produce from the farm-gates to a local aggregator) to last mile (final haulage of produce from the wholesale markets closer to the centres of food demand in towns and cities – to retail chains). In addition, a number of overarching issues that have implications across the cold-chain were noted.

> "COLD-CHAIN NEEDS TO BE CREATED THROUGH BOTTOM-UP APPROACH AND THERE IS HUGE SCOPE IN IMPROVING FIRST AND LAST MILE LOGISTICS"
>
> - Ms. Seema Gulati, Elle Farms Haryana

First Mile failures and barriers

There is currently limited availability of infrastructure and technology suitable for first mile business processes, including:

- Limited capacity for storage at farm gates;
- Lack of adequate/ continuous power supply;
- Inadequate knowledge and skills to carry out processes efficiently to ensure productivity and financial viability.

Furthermore, for many farmers operating at small-scale, the use of existing cold-chain facilities incurs high costs.

Despite some government activity, there is an overall lack of policy support to facilitate first mile processes in the cold-chain; the focus remains further along the value chain, closer to last mile processes. Even where the government has developed pack-houses, there is often poor use of these facilities due to:

- Lack of appropriate infrastructure to transport the produce from the farm-gate to the pack-house. First mile transportation is dependent on farm vehicles such as tractor trailers, which are inadequate in maintaining freshness of horticultural produce and lead to losses. Conventional refrigerated reefer vehicles are financially unaffordable for farmers unless the services are grouped under an FPO or cooperative;
- Limited financial capacity of marginal and small farmers to store the produce at the farm-gate;
- Higher cost of electricity coupled with lower operational efficiencies;
- Poor operation and maintenance of facilities;
- Lack of understanding of business, specifically farm to fork business models.

> "TOMATOES THAT FETCH YOU RS. 20 PER CRATE IN ONE SEASON, CAN FETCH RS. 200 PER CRATE IN OFF-SEASON"
>
> - Mr. Satbir Singh, Crown Fruits & Vegetables Company Ltd.

Last Mile failures and barriers

A lack of appropriate infrastructure and utilisation of equipment as well as a failure to take full advantage of the potential of new technologies is resulting in barriers in the last mile of cold-chains in India.

- Many businesses providing logistical support from warehouses to retail shops are not organised businesses (businesses that are not formally registered businesses and use formal logistical network planning), which results in haphazard network management.
- Even with the advent of e-commerce in India, the logistics process is not fully developed to optimize supply and demand in the food produce value-chain.
- There is low use, if at all, of IT techniques to optimise haulage using a hub-and-spoke model.
- There is a lack of infrastructure (e.g. right of way to food supply vehicles) and technology (e.g. low-carbon transportation including refrigerated small trucks using phase-change materials to retain produce quality), which prevents appropriate transportation of goods from large warehouses (close to town/city centres) to retailers.
- The equipment used in the transfer of produce from physical to mobile infrastructure is not always best suited to handling perishable food produce.
- There is a lack of space and infrastructure within retail stores leading to sub-optimal management and storing of produce.

Failures and barriers with implications across the cold-chain

- Attention has been focused in India on cold storage rather than the cold-chain as a whole. During the fieldwork, it was evident that policy-makers continue with an approach of incentivising cold-rooms, instead of supporting the transfer of goods from farmgate to retailers. In several states, such as Haryana and Maharashtra, current policy is to create large cold-rooms instead of locating smaller cold-rooms/pack-houses close to farmgates, which would facilitate better use of storage. The latter would also enable better mapping of the release of produce to markets, resulting in maximised use of surplus food
- There is a lack of knowledge and skills which hampers the use of the cold-chain:
  - There are varying literacy levels amongst farmers;
  - Many farmers lack knowledge of optimum post-harvest care of produce;
  - A lack of knowledge and skills about cooling equipment operation and maintenance - hence, when equipment is available, it is often not used as effectively or efficiently as it could be.
- There is a poor understanding among farmers and policy makers of the techno-economics of the cold-chain, from farm to fork, and the benefits it can bring, in terms of reducing food produce losses and maximising income to farmers.
- Market data does not reach farmers, preventing them from maximising the profit from their produce. All the produce harvested in a given location tends to be transported from crop clusters to the marketplace at the same time, creating a surplus and depressing produce prices, and this is exacerbated in areas of crop clustering. If farmers could access timely

information of market demand and pricing they could instead stagger harvesting and release produce to the market at stabilized/assured pricing.

- There are no direct incentives to farmers to adopt cold-chain technologies, particularly in comparison to schemes like 'Minimum Sales Price of produce,' which insures farmers against contingencies.

2. Review of existing pack-houses and cold-storage facilities

A review of the existing pack-house and cold-storage facilities in India found that there is significant scope to improve the operating efficiency of units as well as increase the use of alternate technologies. This would reduce emissions and increase the affordability for farmers.

Existing large format cold storage units are used for storage of potato seeds and apples, and less commonly bananas, flowers and horticultural produce. Ice-production using brine is typically a daily output for many cold-storage service providers and a predominant/assured revenue earner for the cold storage unit, at least in certain seasons. Many of these units were built between 12 to 30 years ago, and attracted up to 40% funding from Government schemes for incentivisation. Capacity utilisation is typically around 80% - in some cases lower. Older units have a basic single compartment design, utilising masonry walls and external insulation, combined with ammonia-based vapour compression cycle (VCC) refrigeration systems. Younger units have a more sophisticated design featuring multiple compartments to store different products and state-of-the-art equipment using Controlled Atmosphere (CA) with environment-friendly VCC refrigeration systems. Solar PV systems for electricity generation have been installed on some units, which can provide up to 10% of the operational energy required, but opportunities of utilising solar-thermal systems have not as yet been explored.

Interviewees in the states of Haryana, Punjab, Maharashtra and Karnataka revealed that the new projects implemented or planned under government schemes utilise the conventional compression cycle - Freon-based technologies for pack-houses and cold storage. There is considerable scope and opportunity to improve on the electricity consumption for these units by providing clean, energy efficient and affordable solutions, particularly for large capacity cold-chains.

> "FARMERS CAN GROW ANYTHING, BUT THEY CANNOT SELL"
>
> - Mr. Jagmohan Singh, Optimal Agro Food Producer Company

Smaller cold-chains catering to 250 Megatonnes (MT) capacity pack-houses are planned. However, they are based on conventional VCC using Freon-based refrigerants, Ozone Depleting Substances (ODS), fossil fuel-based grid electricity, and diesel vehicles, all of which will have high operational cost, and more environmental impact. The adoption of more sustainable and resource efficient techniques and technologies would lead to lower operational costs and reduced environmental footprints for these proposed smaller cold-rooms.

To date, there has been a limited focus on alternative technologies. There is however considerable opportunity to improve the resource efficiency and reduce the environmental impact of the cold-chain through the application of:

- Renewable energy technologies, including solar thermal;

- Phase change materials (which can be charged using renewable energy sources; for use in storage and transportation over reasonable distances;
- Waste heat recovery systems for cold storage and refrigerated reefers.

Furthermore, given the energy storage potential of cold food produce in cold-rooms, the FPCs owning cold-room assets could also benefit financially from enhanced grid stability/demand response projects, and could create revenue streams through net metering for solar-PV.

Simple architectural and design interventions, such as shading and improved insulation, can be very effective in reducing the energy consumption of a cold-store and consequently help reduce cooling related operational costs and environmental impact. Existing energy efficiency building codes are not applied to cold-chain infrastructure in India. Also, current guidelines pertaining to cold-chains focus on maintaining food quality and not on the energy efficiency and sustainability of the system. This should be a consideration in the commissioning and regulation of new aspects of pack-houses and cold-storage facilities.

3. End-to-end cold-chain – assessment of impact on energy and emissions

Cold-chains can be major consumers of energy and contributors of GHG emissions and other pollutants - directly through refrigerants, and indirectly through energy consumption. The India Cooling Action Plan (ICAP) predicts that the energy consumption from the nation's cold-chains is likely to almost double in the next 10 years from 71 Terawatt hours (TWh) in 2017-18 to 130 TWh in 2027-28, and increase further by 1.6 times (compared to 2027-28) to 212 TWh by 2037-38. (Ministry of Environment Forest and Climate Change, 2019). This increased energy use corresponds to the technology adoption scenario considered in the ICAP and may not necessarily reflect the actual real-world diffusion of cold-chains in India.

The ICAP projections are an important starting point for estimating the future cold-chain requirements of India, however, they need to be better defined with respect to the anticipated volumes of food. For example, India currently has the second highest yield of potatoes and the highest yield of bananas in the world despite productivity of potato farming being half that of the USA, Germany and Netherlands and that of the banana farming being at two-thirds that of Indonesia (NITI Aayog, Govt. of India 2015). By the introduction of modern farming technologies and practices, there is scope to improve average agricultural productivity and overall yield. With the increasing involvement of large-scale Agri-food businesses and Quick Service Restaurants (QSRs) in the sector, many farmers in India are moving in this direction. However, the resulting increased output of perishable food will need a parallel deployment of cold-chain infrastructure to support market connectivity and minimize produce losses.

It is estimated that in India only 4% of the produce that could benefit from a cold-chain actually does so, compared to around 70% in the UK (Birmingham Energy Institute 2017). A recent NCCD report estimates that India currently needs 34 million metric tonnes of cold storage (10% more than current); 70,080 pack-houses (as against the current 249); the 9,131 ripening chambers (as against current 812); and 52,286 refrigerated reefer vehicles (as against the current 9,131) (NCCD 2015). Achieving these targets may reduce agricultural food produce losses, but it must not do so at the cost of environment and climate. In a business-as-usual scenario (i.e. assuming that efforts to reduce the global warming impact of refrigerants are not increased beyond current levels) the ICAP estimates that refrigerant demand will double from 2,500 MT in 2017-18 to 4,900 MT in 2027-28 and increase four-fold to 9,900 MT in 2037-38, which could have a major impact on emissions.

There is scope to maximise energy conservation and reduce GHG and other emissions through the application of new technologies throughout the cold-chain. Specific new technologies such as Thermal Energy Storage Systems and Low Ammonia Charge Systems have the potential to reduce GHG emissions by 30 – 100% and have zero or low ODP.

Assuming that a 30% improvement in energy efficiency can be achieved from alternative and clean technologies and closed-loop systems, and using the ICAP projection figures for the energy consumption of cold-chains in India by 2037-38, an energy saving of 105 Twh may be achievable. The project team calculated this to be equivalent to 10% of the net available energy in India in 2016-17 translating to a reduction of around 107 million tonnes of CO_2 emissions.

Despite the potential benefits of clean cold-chain technologies, based on interviews with farmers and FPO representatives, technology providers and government officials in Haryana, it is clear that almost all of the current efforts for 'Doubling Farmers' Income' are focused towards adding cold-chain infrastructure using conventional 'business as usual' cooling technologies, rather than emerging clean-cooling technology.

4. Clean cold-chain technologies

WHAT IS CLEAN COOLING?

'Clean cooling' is the delivery of comprehensive access to cooling efficiently and sustainably within the CO_2, natural resource and clean air targets. Clean cooling, including clean cold-chains, necessarily must be affordable, financially sustainable and accessible to all to deliver societal, economic and health goals.

There are many technical, logistical and investment challenges as well as economic opportunities related to the use of the cold-chain in India. For example, In pack houses and cold stores, conventional cooling technologies viz., grid-based electricity (which in India is largely generated from the burning of fossil fuels) or standalone diesel-fueled generators as a power source is used. To date, ammonia-based VCC systems have traditionally been deployed in India in such facilities, as evident across the nation in the large-scale storage of potatoes. However, ammonia-based low capacity and low-charge systems are being developed (Association of Ammonia Refrigerants, 2018). Natural refrigerants such as ammonia have zero global warming potential, as compared to the CFCs and HCFCs used in cold-chains of the Western world. The latter typically have several 1,000 times the global warming potential of CO_2, along with high ozone depleting potential. However, one challenge related to using ammonia as a refrigerant is that it has high toxicity and its increased use in the emerging cold chains of India will therefore require greater focus on the safety aspects of design, operation and maintenance. This might be a significant challenge in terms of education, training and skill development/ capacity building, in addition to ensuring compliance to any regulatory environment established for safety reasons.

The principal technological innovations currently emerging in the area of cold-chains are mainly related to the use of alternative sources of energy for cooling. It is estimated that across the globe, the current requirement of cooling for refrigeration combined with requirement of space cooling in buildings will together account for the largest share of electricity consumption as well as GHG emissions. Renewable energy resources can be used, along with closed-loop energy approaches, such as waste heat recovery systems, with-in the cold-chain to mitigate the environmental impact of this demand and reduce emissions. Further, the demand itself can be reduced by increasing energy efficiency that can be achieved through the application of more efficient technologies such as, variable frequency drives, more sophisticated controls and the Internet of Things. Development of more sustainable and resource efficient cold-chains requires system level thinking, identifying the opportunities for the integration of efficient and affordable clean energy technologies such as 'free' and waste energy recovery systems, across the cold chain.

There is a wide-range of efficient (low energy consumption) and clean (low global warming potential and low ozone depleting potential) technologies that are relevant to the flow of goods along the cold-chain. Technologies that could be utilised in an efficient and clean cold-chain include:

- Zero energy and low-cost vegetable storage using evaporative cooling at the farm, depending on the ambient humidity conditions and technical feasibility at the farm site location;
- Phase Change Materials (PCM) for storage at the farm gate and first mile transportation up to pack-house;
- PCM technology based solar-powered cold rooms;
- Concentrated solar thermal coupled with Vapour Absorption Machines (VAMs);
- Low Ammonia charge and CO_2 brine system for cold storage of 50 tonnes of refrigeration (TR) and above;
- PCM technology based refrigerated reefer trucks;
- Engine Exhaust Heat Recovery using a Matrix Heat Recovery Unit (for mobile and static engines);
- Solar dryers and Atmospheric Pressure Vacuum Drying Systems, which can enhance the value of produce with minimum cost, effort and environmental impact;
- Super heat recovery water heaters can be applied at any stage of the cold-chain to recover waste heat, as well as utilise hot water for cleaning and washing applications in pack-houses.

This study has found that clean and energy efficient technologies for cold-chain are available in India. However, apart from a small number, they are still at the early adoption stage and localisation through adaptation to in-country and regional, cultures, skills and practices, is required. In order to accelerate the adoption of such clean technologies, government action is required, that can include:

- Research and development related to affordable, sustainable, efficient and appropriate clean technologies for specific farm clusters and crops. According to industry experts, currently only around 4% of the Indian Council for Agricultural Research budget is for agricultural extension services and engineering, including cold-chain. Therefore, the sector requires, a significant increase in investment in research and development.

- Guidelines for energy efficiency in cold-chain facilities and extensions of appliance standards and labelling programmes for commercial refrigeration appliances and facilities, taking into consideration appropriate operation and maintenance practices.
- Capacity building programmes for technicians to be trained in energy efficient equipment and appliances.
- Policies that create a suitable environment for financial models in order to help facilitate access to finance for cold-chain investment and development.

5. Merit order of clean-cooling interventions

There are a variety of possible cooling interventions, its associated capital and operating costs, energy demand and the potential of direct and/or indirect emissions of GHGs and other pollutants. The study established a merit order of ranking to aid such decision making.

CLEAN COOLING INTERVENTIONS-DESCENDING ORDER OF MERIT

Following is the list of interventions in the descending order of merit:

- Demand mitigation via behaviour or operating practice change – for example market data driven harvesting of produce to avoid unnecessary storage and food loss;
- Demand mitigation via system or application design – for example efficient and effective insulation and natural ventilation, and the use of shade;
- Making use of free cooling resources that are highly localised – for example evaporative or sky cooling;
- Making use of more remote free cooling resources via district cooling type network infrastructure – for example cooling systems that make use of bodies of surface water, underground aquifers or industrial waste cooling such as that resulting from LNG regasification;
- Making use of other free cooling resources via conversion technologies – such as sorption cooling technologies capable of converting waste heat resources into cooling, including engine exhaust heat recovery in refrigerated reefer vehicles;
- Energy consumption demand flexibility – for example via deploying thermal energy storage to enable better integration with renewable energy resources;
- Optimum energy efficiency improvements and low GWP refrigerants in cooling equipment selection – for example via enhanced performance or seasonal energy efficiency rating (SEER);
- Sourcing of energy for cooling from renewable resources, including electrical power from solar PV, wind turbines, small-scale hydro, biogas etc. and heat for sorption processes from solar thermal and biogas;
- Sourcing of energy for cooling from the use of fossil fuel resources with carbon capture and storage.

COMPONENTS OF COLD-CHAIN IN INDIA

Cold-chain should enhance the income, economic wealth and financial security of farmers, growers and fisherman and improve food quality, safety and value to consumers; and it should achieve this sustainably with minimum environmental and natural resource impact and with-in the CO_2 natural resource and clean air targets.

- Use of technologies such as zero-energy cold storage at the farm gate where farmers can store their produce until transportation to the pack-house. This includes efficiently insulated cold-rooms
- A cold store of 250 MT capacity located in close proximity (1 – 5 km) to the farm as a component of post-harvest infrastructure, to include:
  - Provision of an integrated pack-house with automatic sorting, grading and packing of round fruits and vegetables (2 MT per hour), and an additional manual processing line for other none-round produce;
  - 2 pre-cooling units of 6 MT each; handling 2 batches of pre-cooling per day;
  - 2 cold rooms of 125 MT each designed for a temperature range of 0 to 8 degrees centigrade to suit the requirement of a variety of products.

This facility should be a PEB steel structure, with insulated panel construction for the cold rooms, and have a total plinth area of 1260 square metres. It should include: pack-house; pre-cooling units using Ammonia DX system; cold rooms for staging using brine chillers and thermal storage; ante room; loading/unloading docks; machine room; office; toilet.

- PCM based or exhaust heat recovery reefer trucks for transportation of produce to retail market.

BUSINESS, TECHNICAL AND OPERATIONAL IMPROVEMENTS

The research undertaken in the current study identified a suite of business, technical and operational improvements that if adopted within food producer organisations (FPOs) and businesses would support cold-chain development and use. These were as follows:

Create and develop strong FPOs, co-operatives and businesses

- Engage farmers in the operations by assigning roles and addressing the specific needs of all members of a cooperative or business or FPO.
- Develop groups or committees within a clearly defined governance structure for the better management of business, human and natural resources and technology.
- Assign tasks to experienced and literate members for dealing with paper work related to government and banks.
- Create a legal cell headed by an FPO member or committee to scrutinise contracts, address financial issues and profit distribution.
- Develop programs for members to engage beyond business ties through exhibitions and social events, to foster engagement and build trust among members.
- Conduct regular training programs and talks to impart knowledge and share experience among members.

Collaborate to expand market reach.

- Source new in-country markets with better prospects and/or export opportunities outside India (perhaps include identification of new crops or cropping techniques).
- Develop entrepreneurship and negotiating skill sets among members.
- Negotiate collectively with end market retailers and route to market logistics providers to obtain best deals on price and supply volumes.
- Resource planning - identify manpower, equipment and funds required for short and long term improvement of the business across value chains.
- Negotiate collectively to purchase or access cold chain equipment and infrastructure to obtain best deals on purchase price or usage fees.

Maximise effectiveness and efficiency of cold-chain.

- Plan for optimum utilisation of cold-chain – pre-coolers, cold storage, refrigerated reefer and other facilities – making it economically viable.
- Conduct energy audits under State and Central Government schemes and upgrade equipment and system – including adding non-fossil and renewable-based systems.
- Carry out the equipment manufacturers' recommended maintenance and service schedules to ensure efficient operation, and minimize energy cost and environmental impact

6. Recommendations

Based on the findings of the study, MP EnSystems Advisory Pvt. Ltd. and the University of Birmingham have developed 4 core recommendations, and these are discussed in detail below:

- Promote new business models, specifically: *'IT enabled services to manage harvesting and logistics from fork to farm' and 'Cold as a Service',*
- Living Labs,
- Training,
- Hackathons and a framework for IT solutions.

These recommendations should be delivered in parallel and be combined with the steps being taken by the Government of India in order to build a system-level approach, that addresses the needs from the first to last mile of the cold-chain as well as those of the broader rural community.

It should be noted that the business models are intended to take full advantage of information flow from the demand side (market) to the supply side (production/harvesting). The existing barriers highlighted in the research clearly indicate the need to build the capacity of operators and stakeholders to make technology adoption seamless. Adding to the need for new business models and training components, it is important to demonstrate the efficacy of new technology and techniques. We propose the creation of technology exemplars through crowdsourcing innovations such as Hackathons and create real-life living labs to demonstrate proposed techniques and technologies.

RECOMMENDATION-1

Promote New Business Models – The development of new business propositions, specifically 'IT-enabled services to manage harvesting and logistics' and 'Cold as a Service'.

BUSINESS PROPOSITION 1:

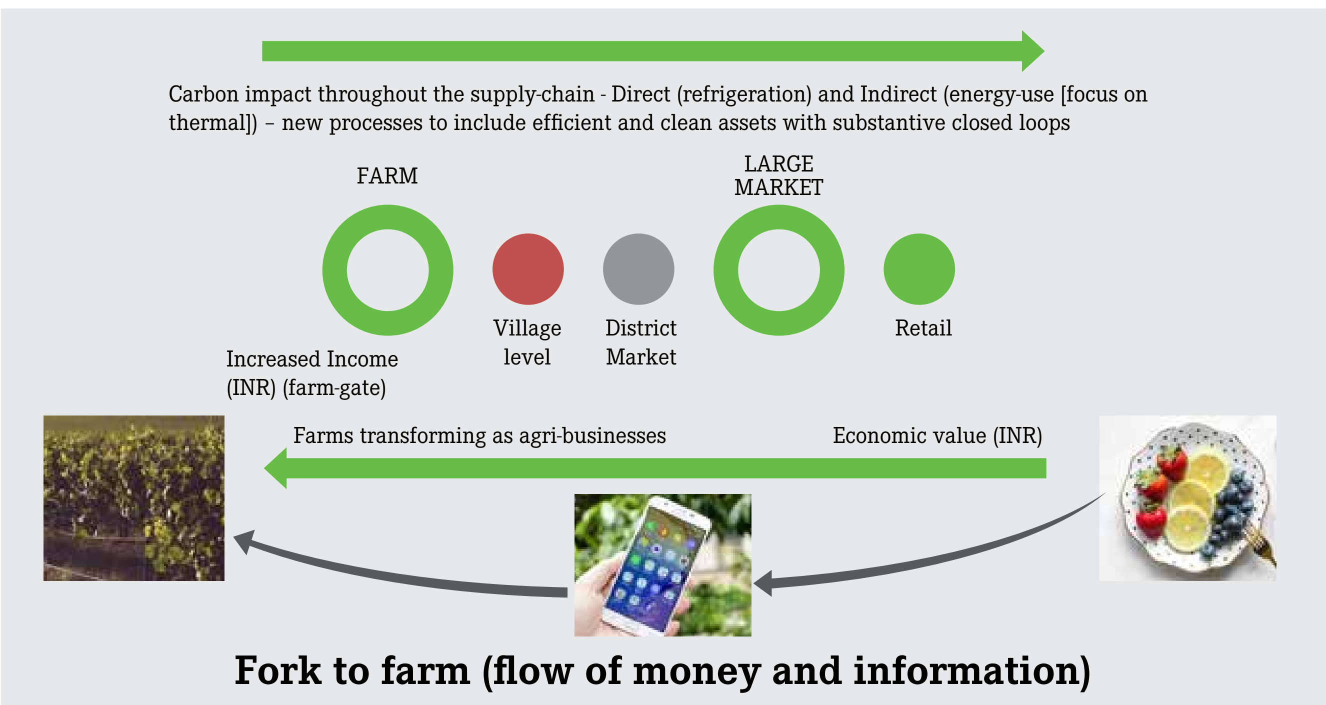

Figure 1: Circular flow of information from fork to farm

IT enabled services to manage harvesting and logistics fork to farm

With increased penetration of mobile-based apps and technologies in rural areas, there is a significant potential to leap frog into an information-based system that economically empowers individuals to make informed marketing decisions and deliver increased financial value for farmers. Similar projects have already been introduced in the agri-sector. Large-scale dissemination through targeted programs can radically accelerate this phenomenon. The proposed model would enable the assessment of the value of a fork-to-field flow of information and explore the best way to capture and present data to farmers to support their immediate and long-term commercial decision-making. Table 1 below sets out more detail of this proposition.

Table:1 Business proposition–1

IT-enabled services to manage harvesting and logistics
Primary goals: • Linking the market requirement for fruits and vegetables with the time of harvesting. • Reduce food produce losses in the supply chain by accurately linking time of harvesting, storage and market.
Prospective businesses: • Farmers' Producers' Organisations created subsidiary companies or business units. • Social entrepreneurs supported through impact investors – start-ups with IT skills. • Established Indian and overseas brands.
Pre-launch activities: • Market assessments, understanding of holding life of produce in each of the food logistics supply chains. • Understanding of inventory management at the farm-gate, within haulage and at the markets (wholesale and retail). • IT platform development considering connectivity in the rural sector, data capture of commodity prices etc.
Cost and revenue model: • Initiation costs to include setting up of IT platforms, and development of Apps that operate robustly with 3G/4G connectivity. • Revenue generation through a subscription-based model – an annual fee to be charged to the group of farmers and create advertisement sales.
Other benefits: • Computer literacy within villages - including adult education and skills acquisition. • Local youth engagement creating community IT hubs to assist villagers to access global platforms, and associated job creation. • Extension of logistics support services in health and educational systems.

BUSINESS PROPOSITION 2:
Cold as a Service

Rather than the conventional business-as-usual approach of selling cooling equipment to farmers and burdening them with the capital and financing costs of aquiring the assets, an alternative approach is proposed in which the specific thermal (hot or cold) requirements necessary for establishing the food supply chain are assessed, alongside the broader needs of local communities, and delivered by a third party through the most effective and efficient means. In such a model, cooling infrastructure becomes a service not a product, is funded by potential asset owners such as entrereneurs or logisitics companies, and would be utilised for multiple purposes in addition to agricultural production, including for example: storage of vaccines and medicines; support to secondary agriculture and processing activities; preparation and use of ice for fisheries, etc.

Table: 2 Business proposition-2

Cooling as a service that provides affordable access, improves market connectivity, and maximises efficiency for the lowest carbon footprint.

Primary goals:

- Create affordable access to clean and efficient cold-chains – first and last-mile transportation, cold-rooms with energy efficient and low GWP/ODS use systems.
- Promote waste-to-energy and solar-thermal/solar-PV systems to reduce use of fossil-based systems.
- Create grid-support services through the use of cold-chain assets.
- Promote innovative technologies such as phase-change-materials and eutectic plates for use in cold-store construction and transportation networks.

Prospective businesses:

- Energy service companies, equipment leasing companies and integrators creating a "pay-as-you-go" model for number of hours of operations of cold-rooms and miles travelled during the transportation phase.
- Farmers' Producers' Organisations created subsidiary companies or their business units or social entrepreneurs carrying out the above-mentioned activities.

Pre-launch activities:

- Standardised designs for alternate refrigerants, alternate energy technologies.
- Understanding of operation and maintenance requirements.
- Development of a business model and plan to launch one service extended to multiple states.
- Understanding of energy markets and possible renewable energy integration/grid-support opportunities.

Cost and revenue model:

- Project development and implementation costs considering the Central and State government subsidies/incentives available.
- Revenue generation through a monthly fixed fee and/or operating expenses benchmarked to the use of cooling as a service.
- Cross-sale of hot water and secondary cooling to healthcare and rural industries.

Other benefits:

- Job creation for local young women and men involved in the operation and maintenance services.
- Extension of logistics support services in health and rural industries, e.g. storage of vaccines and medicines.

RECOMMENDATION-2

Develop Living Laboratories - A series of Clean Cold-chain Living Lab and Innovation Centres to test, validate and demonstrate innovative and integrated solutions (technology and business model) for sustainable clean cold-chains, as well as community cooling solutions, in real world based controlled environments (see Community Cooling Hubs Table). These entities will not only test and demonstrate the technologies but also the potential for climate change mitigation, funding models, business models and approaches by governments. These labs will be technology agnostic and identify the positive and negative consequences of deploying any new interventions.

Labs will also be physically permanent entities with appropriately skilled and trained staff complements, equipped with essential technologies and test bed facilities (packing, cooling and/or temporary cold storage, leasing reefer vehicles and other equipment and tools for improved postharvest handling), to provide training and advisory services through evidence-based demonstrations. Audiences would include, local trainers, outreach teams, extension service providers, growers, farmers, logistics operators and other stakeholders involved in food supply chains. Labs would conduct training programs to build and improve local capacity and share knowledge on improved technologies, business, marketing, etc.

RECOMMENDATION-3

Training - Development of a roadmap for awareness, training, skill development and capacity building to address the technical, technological and social aspects of providing clean cold-chain infrastructure. A training and skills programme should include seven key elements:

- **Clean Cold-chain Living Labs and Innovation Centres** (as described above)
- **Business incubation training** – to support the establishment and development FPOs, Farmers' Producers' Companies, social entrepreneur organisations and businesses to maximise prospective value-chains
- **Enhanced IoT, AI and Block-chain applications** - The Living Lab can provide the knowledge base and platform to test the solutions arising from competitions and hackathons virtually against specific targets in a safe environment. The Living Lab can also embed real-time proof-of-concepts by creating on-going learning-by-doing and doing-by-learning loops.
- **Curriculum development for university students and professionals** – for the next generation of professionals who will be involved in the sector, across activities which include: technology development; system design and build; financing providing training or maintenance; and setting strategy and policy at local, national government and with supranational agencies.
- **Massive Open Online Courses (MOOCs) and e-Learning Programs** – open access online learning platforms to support and encourage mass participation of farmers and other relevant stakeholders involved in the development and delivery of the cold chain to learn about cold-chains and its benefits/impacts.
- **Information and communication technologies (ICTs)** – use of such technologies to disseminate timely 'fork-to-farm' information for market-based harvest decision-making. Interactive e-programmes and ideas should be used to reach wide range of audience and transfer messages accurately, overcoming language, literacy or other related barriers.
- **Written communication/ Publications** – a wide range of various types of written information should be used in order to provide information to the variety of audiences.

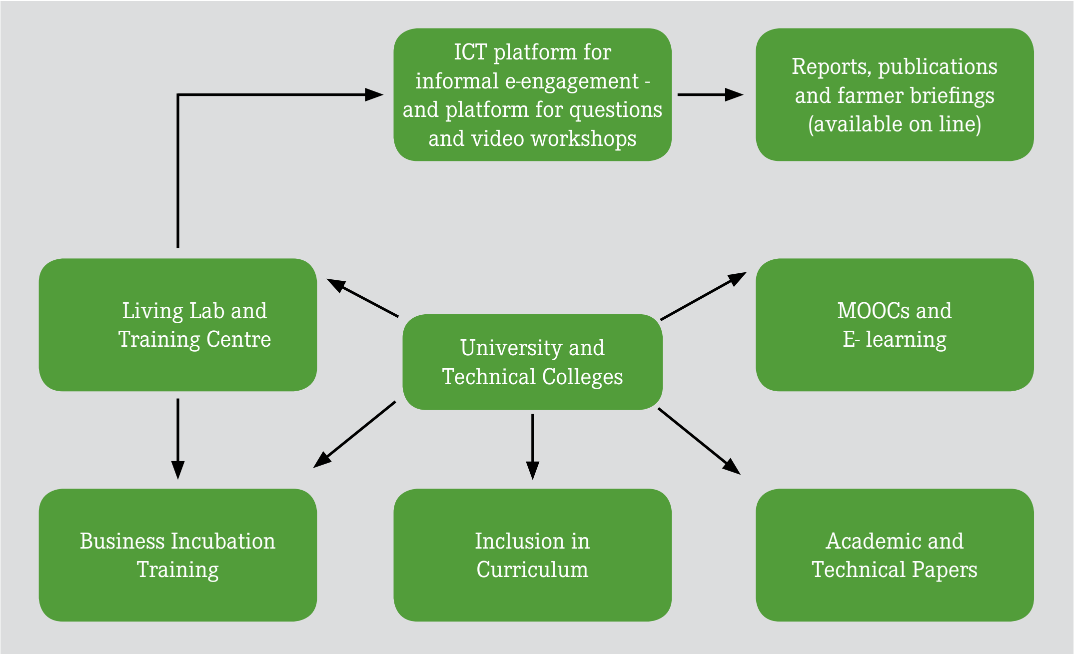

Figure 2: Training and Development for Clean Cold-Chain Network Diagram

Source: MP EnSystems Advisory Private Limited and University of Birmingham

Additionally, information and knowledge building should include:

- Training for farmers on better management of produce both pre-harvest and post-harvest.
- Development of interlinked R&D centres in existing agriculture universities to support cold-chain related research and information required by farmers.
- R&D to study and support clean cold-chain technologies suitable to a region, preparation of a roadmap for implementation and cost-benefit analyses.

RECOMMENDATION-4

Facilitate Hackathons and prepare a framework for IT solutions for developing clean cold-chain in India using the latest block-chain technologies. Participants could include representatives from FPOs, technology consultants and providers, government representatives, funding agencies, bi-lateral organisations, consultants, and entrepreneurs, or interested individuals and organisations including designers, programmers, coders, developers, recruiters, CEOs. Participants could develop possible 'open-source' solutions and software codes for developing, deploying and adopting a clean cold-chain either independently or in group.

This activity will require an informed needs assessment process developed with the farming community, and the identification of the drawbacks, gaps and requirements of the existing system. After, taking into account, existing schemes and infrastructure, it would address how IT can enable enhancements achieved through cold-chain infrastructure and deliver value back to the farm from the fork.

Policy action to support clean cold-chain implementation

In addition to these core recommendations, some policy recommendations have also been identified, which would support Government of India's objectives for doubling farmer income and supporting a sustainable agriculture sector as a national economic growth engine. Specifically, these are:

- Integration of national and state-level government schemes across ministries in order to deliver a unified clean cold-chain program. This intervention will involve, but will not be limited to the Ministry of Environment Forests and Climate Change, Bureau of Energy Efficiency, State Agricultural Marketing Boards, as well as inter-state departments viz., IT and Agriculture.
- Decentralisation of government schemes and subsidy programs with maximum outreach through NGOs. Schemes should incorporate energy efficiency norms, standards and design guidelines for installation and maintenance.
- Technical and administrative support for effective adoption of schemes.
- The provision of a voluntary star rating for cold-chain facilities to encourage efficiency and create awareness
- Development of a model cold-chain to demonstrate end-to-end clean cold-chain infrastructure.
- Create a suitable environment for appropriate financial models to help facilitate access to financing cold chains.

COMMUNITY COOLING HUBS

The provision of cold-chains to support food production and distribution is one very important component of meeting the requirement for cooling in a rural community. However, within such communities there are a broad range of cooling needs, which include for example: veterinary and human vaccines and medicines; health services; comfort; workplace and school house productivity; domestic refrigeration; commercial services and in some cases humanitarian logistics. Currently, these needs tend to be considered in isolation and, therefore, the cooling solutions for each is typically delivered separately. An integrated Community Cooling Hub (CCH) is proposed by the University of Birmingham as a more sensible systems - level approach which has the potential to meet community cooling needs in a more efficient, affordable and sustainable way.

Community Cooling Hubs would be focused on all social and development goals, not just cold chains, and be built on the principle of community-ownership. They would consider the wider opportunities - and unintended consequences - of cooling. An assessment of local needs would provide the foundation for a localised portfolio of clean cooling solutions.

A CCH model should:

- Evaluate and aggregate cooling demand across the community (with food logistics as the primary cooling load) to optimise system, enhance energy efficiency and manage resources in a sustainable way .
- Combine system - level thinking with innovative 'Cooling as a Service' models – to enable centralised services and maintenance, leading to better performance and resource efficiency.
- Stack (bundle) revenues in business models to maximize the economic opportunity for the local community.
- Not pre-suppose a technology solution but understand the portfolio of needs and potential, matching the supplies in a sustainable way, and develop the optimum mix of cooling solutions in order to meet those needs (see Merit Order Ranking box for help on determining an appropriate mix of solutions)
- Harness free, waste to thermal, thermal to thermal solutions, and thermal storage

An example of the range of needs that could be met via a CCH is illustrated below:

- Food: precooling, packing and storage; food logistics; community domestic refrigeration, retail refrigeration.
- Business opportunities: temperature-controlled spaces for third party food processing; temperature-controlled stalls for vendors of fresh or short-life products; and ice vendors.
- Community cooled meeting area providing comfort from the heat e.g. via shading, and chilled benches. Could be used by school during the day and broader community in the evenings.
- Human and animal health: secure vaccine and medicine storage; front-line disaster storage; veterinary logistics; human vaccine and health logistics; and humanitarian logistics.

Next steps to deliver Community Cooling Hubs

Through engagement with Pilot communities across a range of States, a collaboration led by University of Birmingham working with MP EnSystems, Shakti Foundation, NCCD, NIFTEM and IMechE intends to:

- Explore wider economic, environmental and social reasons to bring affordable cooling to communities and understand collaborative economic and business models;
- Investigate the viability of integrating food cold-chains with other cold-dependent services such as secondary agriculture, vaccines, community health facilities and humanitarian logistics;
- Understand Willingness to Pay (WTP) and benefits of the business model vis-à-vis Business-as-Usual scenario;
- Develop strategies and co-benefits to create sustainable community cooling services;
- Explore community refrigeration and common services models to be developed for test-case communities in India assessed and evaluated through Living Labs.

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