Intelligent, Connected and Sustainable

Defining the Smart Cold Chain
A Primer

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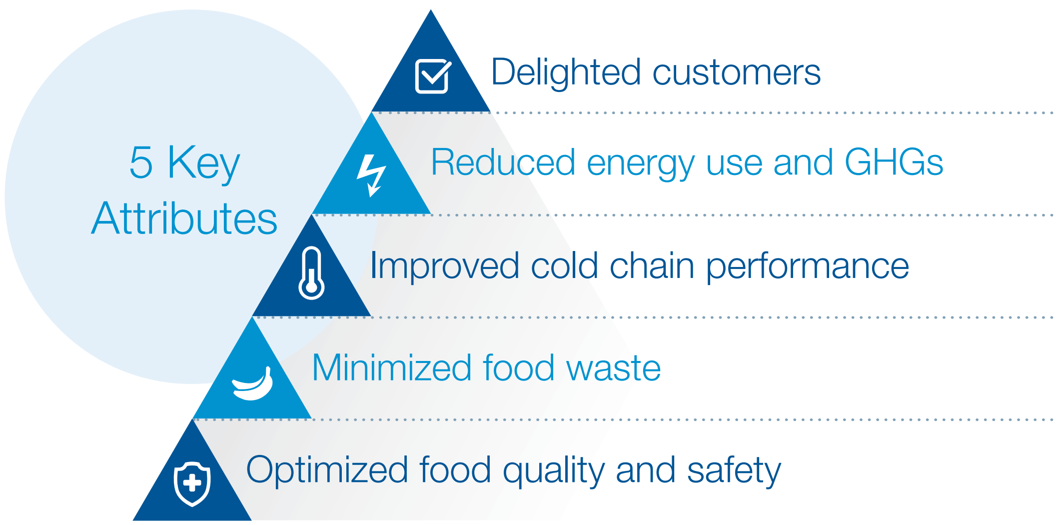
In Brief

The world produces enough food to feed 10 billion people—more than the current global population—yet nearly 800 million people are chronically undernourished. One proven solution to delivering nutritious food and enhancing food security is investment in the modern cold chain.

The modern cold chain is a vast, interconnected network that moves perishable product seamlessly around the globe. Comprised of refrigerated containers, trucks, trailers, rail cars, aircraft, cold-storage warehouses, retail display cases, home refrigerators, people, processes, sensors and data, the modern cold chain reduces waste, promotes food security, extends shelf life, and protects the brand and integrity of food products.

By adding and integrating new sensors and robotics, automation, telematics, new data flows and analytics, the modern cold chain is evolving into the "smart cold chain," holding the promise of continuous improvement along five key attributes:



As the smart cold chain evolves, it will reinforce the traditional cold chain benefits of improved quality and accountability. It will also address broader issues identified by the United Nations Sustainability goals and U.S. EPA food waste targets, enhance links between farms and fast-growing urban areas, ensure food security around the world, and help growers, distributors, and consumers all better cope with disruptions caused by weather extremes.

While the smart cold chain does not exist today as a complete, integrated, and readily-accessible supply chain platform, important components already provide value, and signs of new offerings are everywhere.

One element capable of enhancing this powerful goods-and-information network is cold chain transport equipment, which is already global, covers air, land, and sea, and has improved sensors, telematics, and rich analytics capabilities over the last decade. United Technologies Corp., through its Sensitech and Carrier Transicold & Refrigeration Systems business, has led efforts to develop the modern cold chain as a means of reducing food waste and associated greenhouse gas (GHG) emissions, and extending cold chain benefits into retail settings—all key attributes of the smart cold chain.

Preserving the Food We Produce

There are 7.4 billion people on Earth. Some 815 million are chronically undernourished.[1] **That means one in every nine people—nearly the entire population of the United States and European Union combined—goes hungry on a regular basis.**

In addition, another two billion people experience micronutrient deficiencies that put them at risk to weakened immune systems and reduced cognitive abilities.[2]

The U.N. forecasts growth of 1.2 billion people by 2030, or a global population of 8.6 billion.[3] Given the already extraordinary level of hunger and malnutrition, there is a pressing need to improve agricultural yields. Talented people around the world are engaged in initiatives that include agroecology, plant genetics, precision farming, and new protein sources.

However, **global agriculture already produces enough food to feed *everyone* on the planet**—some 2,903 calories per person per day against a United Nations recommendation of 2,248.[4] In 2015, Pope Francis called the world's attention to this issue by citing the "paradox of abundance,"[5] the fitting words of an earlier Pontiff, Pope John Paul II. Why, they wondered, is there such misery in the face of such plenty?

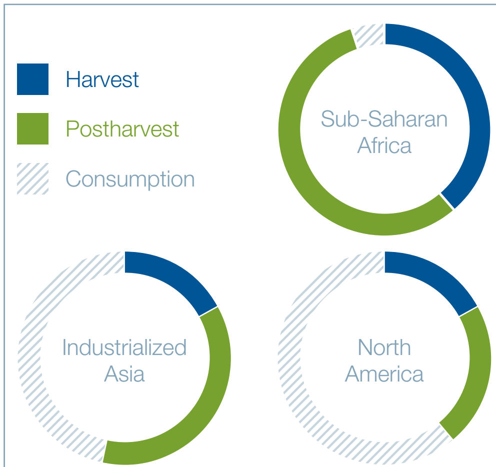
Some hunger is the result of poverty. In the world's poorest countries, smallholder farmers can struggle to purchase seed and fertilizer, or might suffer losses from weather extremes caused by rapidly changing climate. During post-harvest, smallholder farmers can lack storage, passable roads, or adequate transportation for their crops. Produce spoils before it reaches market, or decays because local consumers are simply too poor to purchase it.

In the richest countries, where farm yields are high and food is both affordable and accessible, massive consumer waste occurs at retail and in the home, a function of marketing and consumer habits.

Taken together, about one-third of all food intended for human consumption is lost or wasted between farm and fork.[6]

In developing countries, some two-thirds of this loss occurs "upstream" during harvest, handling, and storage. In developed countries about two-thirds occurs "downstream" at processing, distribution, retail, and in the home.[7]

Food Waste By Cold Chain Segment (kcal/per/day)



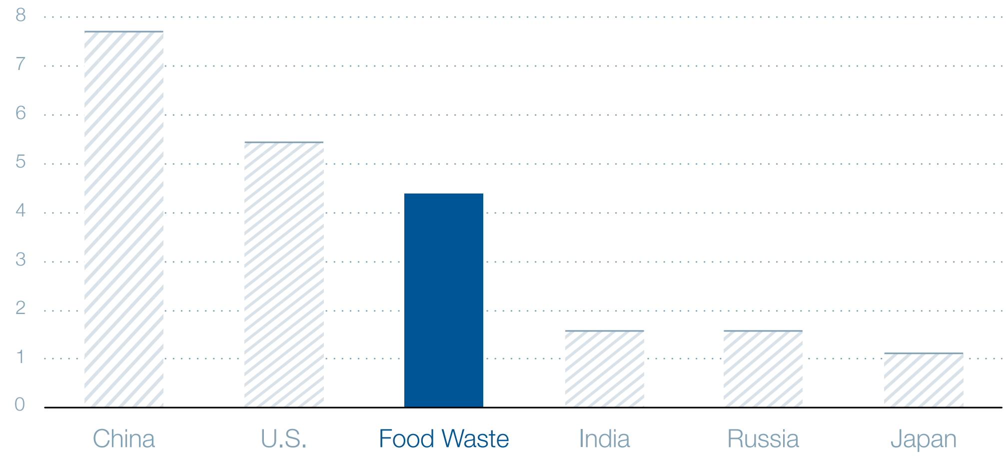
Source: "Creating a Sustainable Food Future," World Resources Institute.https://www.wri.org/sites/default/files/wri13_4c_wrr_online.pdf, adapted from 31.

In all cases, great loss provides great opportunity; forecasts by the World Resources Institute indicate that halving losses and waste along the global food supply chain by 2050 would reduce the caloric food gap to feed the world by 20 percent or more.[8]

Along with reducing hunger and misery, there are other important benefits to improving the efficient use of the food we already produce. The carbon footprint of food waste is 4.4 Gt, including 3.6 Gt from embedded carbon in the food itself plus .8 Gt from deforestation and managed organic soils associated with the global agricultural footprint.[9] This represents eight percent of total anthropogenic GHG emissions, which is equal to about 87 percent of global road transport emissions.[10]

Said another way, **if food waste were its own country, it would be the third largest emitter of GHG, behind only China and the United States.**

Greenhouse Gas Emissions, CO_2 equivalent (billions of metric tons)



Source: Ecoclimax, 2017, http://www.ecoclimax.com/2017/02/an-atlas-of-pollution-world-in-carbon.html.

In addition, wasted food consumes a quantity of freshwater capable of serving the annual needs of the entire continent of Africa, and occupies close to 30 percent of the world's agricultural land area.[11] The direct cost of food waste is estimated to be at least $2.6 trillion dollars annually, equal to the GDP of France.[12]

The cost of food loss and waste has captured the attention of the world. The International Food Policy Research Institute reported that "nutrition shot up to the top of the global development agenda in 2014."[13] Likewise, the Second International Conference on Nutrition recommended improved "storage, preservation, transport and distribution technologies and infrastructure to reduce seasonal food insecurity food and nutrient loss and waste."[14] The United Nations Sustainable Development Goal 12, to ensure sustainable consumption and production patterns, targets substantial reductions in waste related to post-harvest handling, storage, distribution and consumption.[15] If targets related to Goal 12 are reached, the FAO estimates a reduction in the carbon footprint of food loss and waste of 1.4 Gt annually, equivalent to the GHG emissions of the entire Japanese economy.[16]

Higher agricultural yields and new food sources will most certainly play an important role in feeding humankind. But, the world can focus on preserving and consuming the food it already produces. "Billions of dollars are currently invested in genetic modification, advanced agricultural chemicals and farm machinery," says Jonathan Foley, executive director of the California Academy of Sciences. "Where is the comparable investment in reducing food waste?"[17]

Before 150 delegates from 36 countries gathered in Singapore at Carrier's 2016 World Cold Chain Summit to Reduce Food Loss, John Mandyck, Chief Sustainability Officer, United Technologies Corp., asked the audience to think of food loss and waste not as a problem but an enormous opportunity. "Where else can we immediately create a new source of food that can feed four billion people?," he asked. "Where else can we find reductions in carbon equivalent to emissions from all the cars and trucks driven each year? Where else can we save enough water to serve the annual needs of the entire continent of Africa? It's hiding in plain sight," Mandyck concluded. "This is an opportunity that can be unlocked by everyone in this room. It truly is the opportunity for how we can sustainably feed the planet."[18]

The modern cold chain is uniquely able to transform food that would be lost or wasted as it moves through the supply chain into a source of nutrition that can help feed the world.

From Farm to Fork: The Global Cold Chain

The cold chain is one of the invisible wonders of the modern world. This vast, interconnected network moves perishable product seamlessly around the globe. Comprised of refrigerated containers, trucks, trailers, rail cars, aircraft, cold-storage warehouses, retail display cases, home refrigerators, people, processes, sensors and data, the cold chain reduces waste, promotes food security, extends shelf life, and protects the brand and integrity of food products. As Professors Jean-Paul Rodrique and Theo Notteboom write, the cold chain is a "science, a technology and a process."[19] In its ability to adapt to a variety of products, geographies, environments, and human needs, it is also an art.

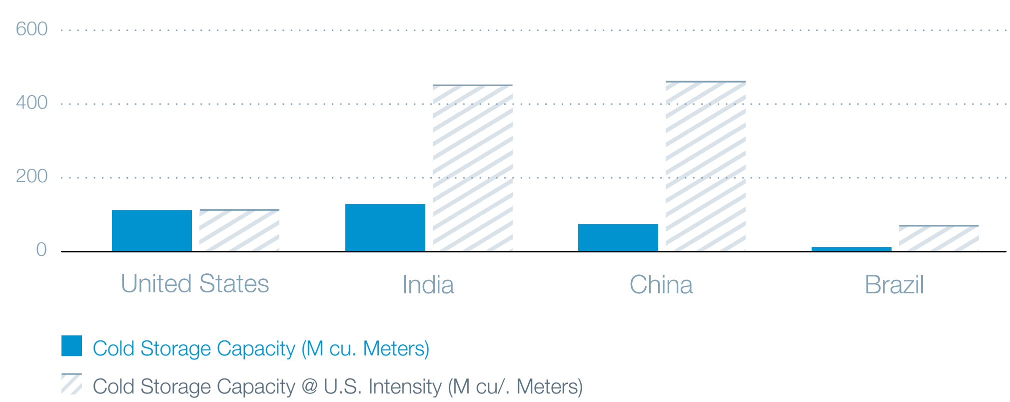
Global cold chain services that support the flow of food are valued at $110.2 billion, and are expected to grow 13.9 percent annually through 2020.[20] In the U.S., a mature, resilient, and ubiquitous cold chain moves about 70 percent of all food consumed.[21] In other developed nations, penetration rates for the cold chain are similar.[22] Where the modern cold chain is run effectively, losses due to temperature abuse can be held to two percent or less.[23]

However, experts believe that only about 10 percent of perishable foods are refrigerated worldwide,[24] **and as much as 25 percent of food production is lost specifically to incomplete or nonexistent cold chains in developing countries.**[25]

In a rapidly developing nation like China, where the grocery segment exceeds $1 trillion, only about 25 percent of beef flows through the cold chain.[26] Some 80 percent of all fruits and vegetables in China are transported in open trucks at room temperature, leading to spoilage rates that can exceed 40 percent.[27] India, the world's second largest producer of fruits and vegetables, also loses as much as 40 percent of its produce due to inadequate cold storage and transport.[28] In sub-Saharan Africa, losses of perishable fruits and vegetables can reach 50 percent annually.[29]

The uneven implementation of cold chain technologies around the globe indicates that this invisible wonder is still early in its lifecycle. Investment is growing, however. Between 2008 and 2014, refrigerated warehouse capacity—only a single segment of the entire chain, but often a leading investment[30]—grew at nine percent annually in the United States, 26 percent in Brazil, 35 percent in China, and 43 percent in India. The cold storage capacity in these four countries in 2014 was 338 million cubic meters, with India the world's largest cold storage player.[31] Around the world, cold storage capacity stood at 552.1 million cubic meters.[32]

Population & Cold Storage Capacity in 2014, and if Expanded to U.S. Level



Source: "2016 Top Markets Report: Cold Chain," International Trade Administration, https://www.trade.gov/topmarkets/pdf/Cold_Chain_Executive_Summary.pdf, and Sensitech Inc.

If nations of the world scaled cold storage capacity to the same level as the United States, total volume would grow nearly five-fold. **This suggests that the modern cold chain is about one-fifth the size it could be if fully built and deployed. In financial terms, this indicates annual potential spending of a half trillion dollars.**

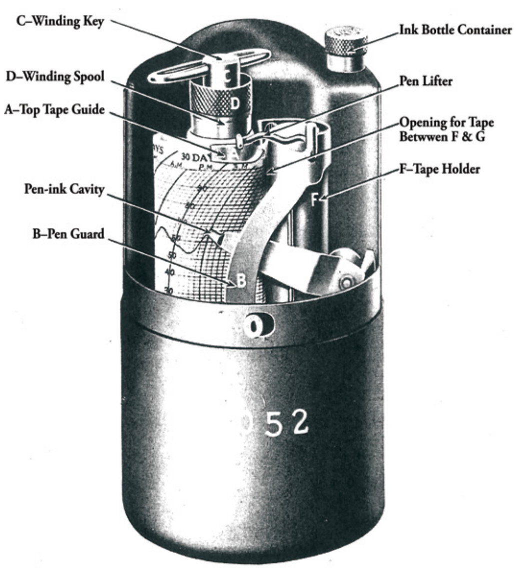
The cold chain is designed to keep fresh produce between 0°C and 13°C depending on the type of fruit or vegetable, dairy products just above freezing, meat and poultry a few degrees below freezing, and frozen products from -23°C and below. Food preservation plays a critical role in feeding the world; fresh fish held at optimal temperature can last for ten days, while fresh green vegetables might last a month.[33] Refrigeration also slows bacterial growth in foods.[34] "No other processing technology combines the ability to extend product shelf life and in parallel maintain the initial physical, chemical, nutritional and sensory properties desired by consumers to the same extent as refrigeration," the International Institute of Refrigeration writes. "Greater use of refrigeration technologies would ensure better worldwide nutrition, in terms of both quantity and quality."[35]

By protecting food, the cold chain also creates new markets, generates exports, and can raise the standard of living for smallholder farmers. India, for example, is the world's top producer of bananas, growing some 28 percent of the world's supply but exporting just .3 percent—with losses between farm and fork as high as 50 percent. Experts believe that with an advanced cold chain, India could grow its banana exports from 3,000 containers to 190,000 containers, benefiting 34,600 smallholder farmers.[36]

The cold chain is a proven system, constantly being enhanced but fully deployed in environments around the world. No miracles of technology are required—simply a commitment to invest and build. **"Preventing produce losses," the Institution of Mechanical Engineers has written, "is in most cases about the application of relatively basic engineering and management practice."**[37]

Accountability, Quality & Claims

The cold chain has seen dramatic growth over the last century, expanding not just geographically, but in sophistication and capabilities. Its earliest uses in the 18th and 19th centuries, to transport fish by sea and meat by rail, generally relied on speed, luck and copious amounts of ice. As late as the 1930s, writes author Nicola Twilley, a railcar full of California cantaloupes destined for New York City "was packed in an extraordinary 10,500 pounds of ice—and re-iced with another 7,500 pounds several times during its 11-day journey."[38] The results of such heroic efforts were often measured by a single metric: Was there any ice remaining at the end of a journey?



The Original Ryan Recording Thermometer

Source: Sensitech Inc.

The industry began a fundamental transformation in 1921 when the Recording Thermometer Company (RTC) was incorporated to monitor the temperature of railroad refrigerator cars carrying fresh fruit and vegetables. Entrepreneur Thomas F. Ryan devised a product that involved a spring-wound motor, a bimetallic thermometer, and a paper tape and pen to record temperatures. At 2.5 pounds each, the original "Ryan" monitors came packaged in a cylindrical steel case to reduce vibration, and were able to record trips up to 33 days.[39]

In 1923, RTC produced 970 monitors, representing the full extent of global cold chain monitoring activity. Business remained flat over the next few decades, with RTC the sole competitor. By 1941, the company—renamed the Ryan Recording Thermometer Company—had manufactured a grand total of 1,470 original monitors with 540 lost over the prior 18 years, 450 sold, and the rest rented on a monthly basis from $7.40 to $11.00, or on a per-trip basis from $6.50 to $9.00. Just two employees ran the operation, the grand total of all personnel in the global cold chain monitoring industry.

In 1947, Booz, Allen & Hamilton (Booz Allen) prepared a study for the company to identify new opportunities, providing a window into the industry. The consultants noted that customers were monitoring frozen food (66 percent), perishable fresh foods (29 percent), flour, cosmetics, film, and flowers. Customers on the West Coast of the U.S. comprised 83 percent of all users, and described to Booz Allen their primary rationales for monitoring:

Accountability

Temperature monitors verified the refrigeration service of the carriers. “The railroads always show a perfect ice record,” one shipper told consultants.

“The burden of proving the contrary is on the shippers. If thermometers were in the cars, they would show up leakages.”

Another noted that railroads guaranteed ice, not temperature.

Quality

Customers cited the ability to assure themselves that their product arrived in good shape.

One said, “What’s the use of spending a lot of money advertising a quality product if you can’t deliver it to the public?”

Claims

Ryan monitors were important as evidence if claims were made for inferior product.

“We don’t know whether the tapes will stand up in court,” one shipper said, “but they will be useful in presenting the claims to the carrier.”

Booz Allen determined that long-haul trips comprised the greatest future potential for cold chain monitoring, a prescient observation in a world in which agriculture would globalize throughout the second half of the 20th century.

They also recommended to the company a stronger selling and marketing program. “Ryan’s present capacity is far below market potential,” the consultants wrote, forecasting a potential of 100,000 units, the number of refrigerated rail cars and trucks in operation in 1947.[40]

The Rise of the Modern Cold Chain

While Ryan (acquired by Sensitech Inc. in 2000) was focused on product-related temperature monitoring, efforts were being made by other industry players to provide visibility into cold chain performance. These new initiatives included inspection services, atmosphere control, and recorders fixed within trucks to measure environmental conditions.

The development of a mechanical refrigerator capable of cooling large trucks in the late-1930's revolutionized the shipping and grocery businesses, helping to found the modern cold chain that operates today. That design was modified and improved for use with railcars and ships,[41] reducing the traditional role of ice in many cold chain applications.

Ocean shipping took a dramatic step forward with the application of the modern shipping container, helping to launch the first container ship in 1956. This invention permitted product pre-loading to occur while the ship was still at sea, and allowed containers to be removed from ships and placed directly onto trucks and railcars. By 1980, one-third of all refrigerated transport capacity in maritime shipping was containerized, rising to 72 percent by 2013.[42]

Sea containers were supplemented by a growing refrigerated truck industry, with forecast growth of five to nine times over the next decade to as many as 15.5 million vehicles.[43] The result is, today, many parts of the world have access to fresh produce, meat and dairy throughout every season of the year.

"Any major grocery store around the world is likely to carry tangerines from South Africa," Rodrique and Notteboom write, "apples from New Zealand, bananas from Costa Rica and asparagus from Mexico."[44] Access to fresh foods throughout the year has become so commonplace in some developed countries that consumers take for granted food options that would have been unimaginable a century earlier.

Defining the Smart Cold Chain

The Sensitech TempTale® Geo provides real-time condition and location updates worldwide

As the cold chain emerged in the 20th century, energy was inexpensive and information difficult to capture. In the 21st century, that equation has been reversed. Companies today are focused on energy efficiency and minimizing their carbon footprints. Meanwhile, services like cold chain monitoring have become sophisticated and ubiquitous.

Bimetallic strip chart recorders, the workhorse of the industry for 75 years, are now cast in molded plastic and offered in various configurations by several competitors. These rudimentary mechanical recorders remain viable in certain geographies and segments of the cold chain. By the late 1980s, however, small, robust, and accurate electronic monitors using ceramic thermistors, batteries, and non-volatile memory were introduced. Since then, electronic temperature monitors—some including sensors for humidity and other environmental factors, RFID, GPS, and/or communications technology—offered by a host of competitors have taken the lion's share of the cold chain monitoring segment.

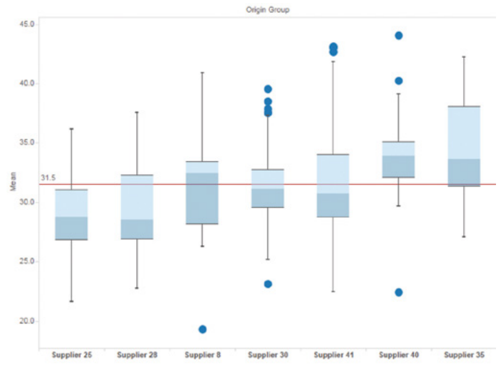
The use of electronic monitors provides a number of important advantages to food shippers, carriers, and receivers that build upon the initial benefits of accountability, quality, and claims. In-transit alerts and alarms are now possible. Information about highs, lows, and the extent of temperature excursions is available. The ability to correlate condition with location can reinforce the traditional benefits of accountability and claims. And the capacity to aggregate and manipulate data from thousands of trips allows players along the cold chain to measure performance by vendor, warehouse, season, and other captured attributes. The result of electronic monitoring has been a wholesale improvement in benchmarking, improved standards, and ultimately, higher quality product and improved cold chain performance.

Industry veteran Jeff Leshuk summarized the impact of this shift from mechanical to electronic temperature recorders on the perishables industry:

"At the most basic level both devices did the same thing, providing a record of temperature over time. But there was a multifold increase in the value provided by the electronics as the data could now be easily stored in a database. This meant that information could be made available to interested parties quickly and easily via the Internet, but more importantly, the data could be aggregated from hundreds or thousands of shipments and analyzed to identify trends and patterns. Now, the cold chain performance of transportation companies, different shipping locations, perishable product categories, etc. could be characterized and compared."

"In other words," Leshuk says, "electronic monitors made it possible to determine where and why cold chain problems were occurring and to implement continuous improvement efforts to proactively make the cold chain better, not simply react to problem loads."[45]

A Statistical Comparison of Supplier Performance Across Thousands of Cold Chain Trips



Source: Sensitech Inc.

This improved use of information is just the beginning. Today, as “Big Data” techniques advance, sensors become less expensive and more pervasive, cold chains expand around the world, efforts mount to reduce food waste, and pressure grows on the food industry to deliver ever-safer and higher quality product at lower costs, the rise of the smart cold chain is at hand.

While the smart cold chain encompasses a variety of technologies covering every segment of the food supply chain, its current and future impact can be captured in the following working definition:

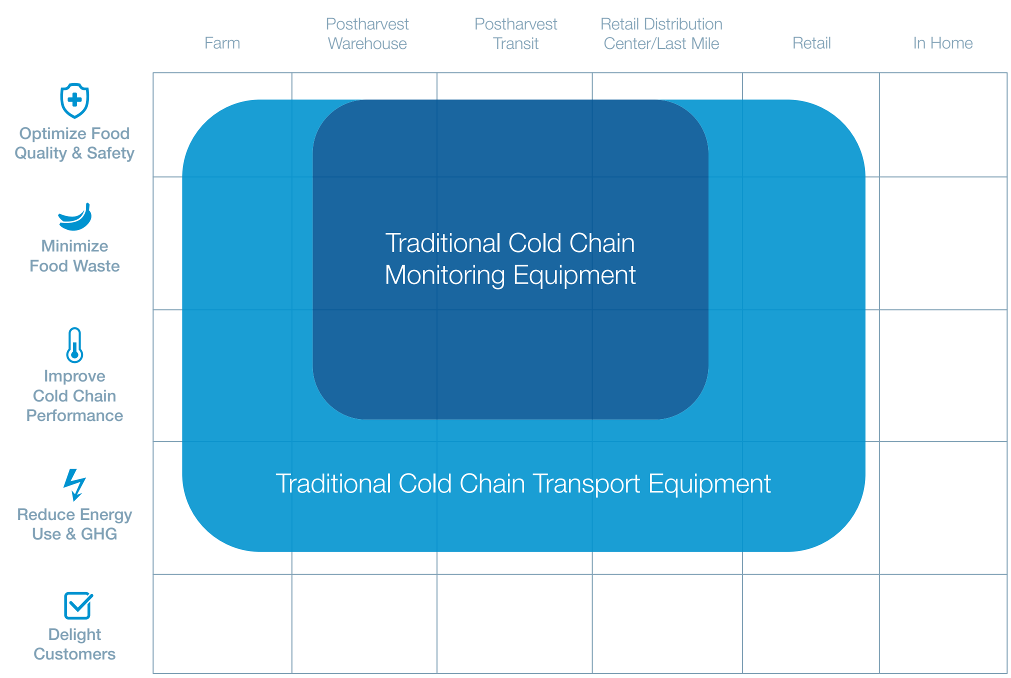
The smart cold chain enables the collection from farm to fork of information about product, environment, equipment, and human performance. This information moves freely along the cold chain, providing performance metrics and alarms that enhance the delivery of fresh, safe food. Data generated by the smart cold chain is automatically processed, creating actionable information that is optimized using telematics, reducing the need for human intervention.

Benefits of the smart cold chain include **optimized food quality, safety, minimized food waste, improved cold chain performance, reduced energy use and greenhouse gas (GHG) emissions, and delighted customers at retail through enhanced transparency and choice.**

A cold chain becomes “smart” when it has the capacity to efficiently sense its own performance and use that information to optimize both short-term transactional activities and long-term supply chain visibility outcomes.

Based on this definition, the landscape of the emerging smart cold chain can be portrayed graphically as follows:

The Smart Cold Chain Landscape



Source: Sensitech Inc.

There are several industries capable of becoming platforms for this powerful goods-and-information network, including international cold chain companies that already offer benefits across several segments and geographies.

One well positioned set of players is those offering traditional cold chain transport equipment, which is already global, covers air, land, and sea, and has improved sensors and analytics capabilities over the last decade. Some of these companies have also been leaders in reducing GHG emissions, and in extending their benefits into retail settings.

Current Impact: Sensitech, Carrier and United Technologies

David Appel, President, Carrier Transicold & Refrigeration Systems

Sensitech, Carrier, and parent company United Technologies (UTC) have emerged as leading players in the evolution of the smart cold chain space.

Over the past three years, Carrier has hosted 300 delegates from 36 countries at its annual World Cold Chain Summit to Reduce Food Loss. Speaking at the December, 2016 Summit, David Appel, president, Carrier Transicold & Refrigeration Systems (USA), described some of the company's newest products to enhance and extend the smart cold chain, including a low-cost version of Carrier Transicold's Citifresh™ Direct Drive truck refrigeration unit designed to improve perishable product quality and shelf life while reducing loss and waste during transport.

Carrier's Commercial Refrigeration business in Europe has made investments in telematics, which today allow the company to remotely monitor equipment and dispatch service technicians when needed. Likewise, Sensitech's cold chain monitoring capabilities allow it to track and analyze the temperature and geographic location, often in real time, of more than 13 million customer shipments annually.

These are all essential building blocks of the smart cold chain.

"Our goal is to leverage our digital technology even further to break down information barriers, so we can better understand what is happening to our food as it moves along the cold chain from farm to fork," Appel said. "This will provide greater visibility to our customers and help maintain food quality, and reduce food losses and waste during transport."

Appel also addressed the issue of engines and engineless technology. While conventional refrigeration units use a stand-alone diesel engine as a power source, he told the audience, many in the industry believe that this technology will be phased out over the next 10-20 years as regulators continue to focus on reduced emissions. Earlier in 2016, Carrier acquired a Europe-based company with technology that uses the vehicle engine to power hydraulics to run the refrigeration unit, eliminating the need for a second stand-alone diesel engine. The result is zero emissions fuel savings and less noise.

"Engineless technologies are here to stay," Appel said.

The Summit included presentation of a pilot study conducted in India in 2016 designed to demonstrate how the cold chain can help reduce food loss and carbon emissions. Funded by Carrier, the pilot examined the extent to which the cold chain can help increase the quality, reach and profitability of kinnow, a citrus fruit rich in micronutrients and common to the Punjab region of India and Pakistan. Enabling out-of-season selling and connections to distant vendors is of critical importance to India, which is the world's second largest producer of fruits and vegetables but accounts for just 1.5 percent of global produce exports due to losses of up to 20-50 percent of total production.[46] The study, which measured the effects of cold storage and refrigerated transport from Abohar, in northern India to Bangalore, in southern India—a trip of roughly 2,500 km (1,600 miles)—resulted in a food loss decrease of 76 percent, a carbon emissions decline of 16 percent, increased supply chain profits, and a payback for pre-cooling equipment of about two years and for refrigerated trucks just over four years.

"The cold chain is a modern agri-logistics system that is transformational in its impact," said Pawanexh Kohli, chief advisor and CEO, National Center for Cold-chain Development of India, "and key to bringing about the next agricultural revolution."[47]

Other efforts to reduce GHG emissions include Carrier's development of CO_2 technology for transport and commercial refrigeration, using CO_2—with a global warming potential (GWP) of 1—as a natural refrigerant to help reduce the level of CO_2 emissions. CO_2 is part of the natural atmosphere that we breathe. It is injected into carbonated soft drinks like soda, and naturally occurs in beer and sparkling wines. As those familiar with container atmosphere control technologies know, CO_2 can even be helpful in slowing the ripening rate of perishables being shipped in transit. Carrier has nearly 4,000 CO_2 supermarkets systems installed across Europe. The company also uses CO_2 refrigerant in its NaturaLINE® container unit, and is field-testing CO_2 trailer units with two major grocery fleets in Europe.

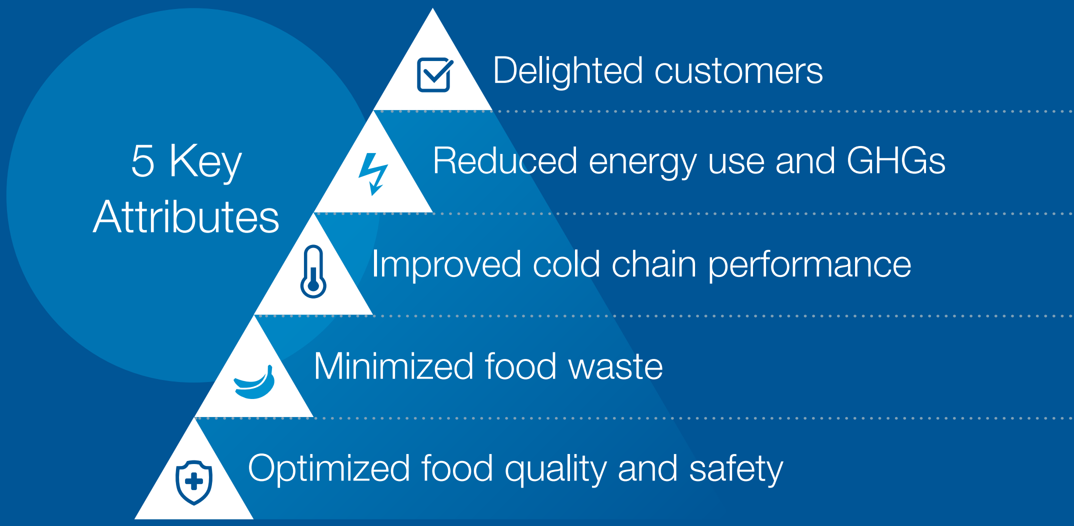
New products and pilot studies are consistent with Appel's concluding remarks to attendees at the 2016 World Cold Chain Summit. "Not only can we green the cold chain," Appel said, "but by better managing our food supply with cold chain technology, we can reduce food loss and waste, feed more people, and reduce greenhouse gas (GHG) emissions associated with the supply of food."

Future Impact: The Emerging Smart Cold Chain

While the smart cold chain does not exist today as a complete, integrated, and readily-accessible supply chain platform, important components already provide value and signs of new offerings are everywhere.

Sensitech's investments in real-time cargo tracking, automated data capture, data analytics and digitized food quality management are just a few indications.

Other examples on the following pages further define the key attributes of the smart cold chain, and highlight the promise of its future impact.



Optimized Food Safety

Monitor location and multiple product environmental conditions

Mistake-proof sanitation and handling processes to reduce foodborne illness

Enhance traceability, including recall

Apply new technologies that allow for rapid and precise ID of product origin, ingredients, allergens and contaminants

Optimized Food Safety is fundamental to the smart cold chain. In the emerging model, information about the source, condition and handling of product will be automatically gathered by sensors and integrated with systems capable of adjusting environmental and handling parameters to protect food, or to alert operators when some action is needed to respond to risk. By creating more transparency throughout the cold chain, sources of foodborne illness can be quickly identified and eliminated.

Of special note is the recent emergence of blockchain as a potential technology for improving transparency across the cold chain. A blockchain, defined by *Supply Chain Digest*, is a "data structure that makes it possible to create a digital ledger of transactions and share it among a distributed network of users." Once recorded, blocks of data are secure and difficult to change or remove. Algorithms evaluate and verify each transaction and, if the distributed nodes agree, the transaction is approved. "This setup means the entire network, rather than a central authority, is responsible for ensuring the validity of each transaction."[48]

Imagine if data about product source, handling, condition, chain-of-custody, and estimated shelf life could be shared easily and securely in real-time across the entire cold chain. Imagine how much more quickly and efficiently a recall could be executed, thanks to this enhanced traceability. And imagine sharing this information with customers to help inform their purchase decision.

According to a Nov. 21, 2016 article in *Supply Chain Digest*, Walmart is testing blockchain-based tracking of a packaged produce item in the U.S., and of pork in China, seeking to obtain data in a single source on where the food was produced, who inspected it, and all suppliers involved, with visibility to the pallet and perhaps item level.[49]

Optimized food safety also includes equipment sanitation and employee hygiene, an added layer in the smart cold chain. Hand-washing and cleaning practices can be monitored and recorded in more accurate and automated ways. This information can be used to identify areas of risk and reinforce best practices among those who come in direct contact with food or manage equipment that handles or transports food.

Minimized Food Waste

Optimize shelf life and reduce retail waste

Predict conditions that would likely damage perishable product

Enhance food waste networks by insuring seamless connections among all players

Adjust retail pricing or repurpose product based on quality and remaining shelf life

Minimized Food Waste in the cold chain is aided by following best practices in handling, minimizing time spent in storage and transit, and using appropriate equipment to control product environment. For nearly all perishable foods, shelf life is a degree of freshness that starts to degrade from the moment of harvest. Freshness and shelf life are extended by holding food as close as possible to optimal conditions—not just within a range considered "safe." Food that has lost enough freshness is not able to be sold because consumers can often detect this as a loss of quality, including lackluster appearance, reduced weight, and less flavor. Thus, freshness is closely tied to minimizing food waste.

The smart cold chain will minimize food waste by continuously identifying incidents of improper handling or abuse. These incidents are detected through automated and accurate measurements of the environment and through assessments of product quality attributes. Wageningen University in the Netherlands, for example, is a leader in piloting robots and sensors to objectively assess the quality of produce in the postharvest segment of the cold chain. One project, Green Change Fruit and Vegetables, is seeking ways to automatically measure variations in the quality and ripeness of strawberries, green bean, table grapes, and other fresh produce items. "At the moment we are very active with a Brazilian grower of mangoes," said postharvest technology scientist Eelke Westra, "and even doing measurements in the fields to correlate that with post-harvest behavior of mangoes."[50]

Ocado, the world's largest online-only grocery retailer, operates a 350,000-square foot warehouse near Birmingham, England. Most of the 48,000 lines of goods the company sells are perishable, so Ocado has turned to technology to optimize product delivery and freshness, and to reduce waste. Thirty kilometers of conveyor belts carry packaging throughout the warehouse, robots restock shelves, algorithms monitor demand to map out an optimal storage scheme, and vans are sent on delivery routes that factor time, traffic and weather. Officials suggest that eventually this system could be tied into a consumer's smart refrigerator or recipe preferences, insuring that perishable goods are delivered on time and in the freshest condition.[51]

The problem of food waste also involves consumer behavior. Perfectly good food is rejected or thrown out because it does not meet certain standards in appearance or because shelf life is underestimated. The smart cold chain can help change consumer behavior so less food ends up in landfills or compost heaps by providing information about the origins and prior handling of the food, suggesting when foods should be consumed, reminding consumers about optimal handling practices, and providing transparency into the sustainability of what they are about to buy or eat. (See "Delighted Customers" below for examples of how these systems are being piloted.)

Improved Cold Chain Performance

Capture economic data about goods, and facilitate the flow of goods, funds and data among all segments

Increase use of automation in refrigeration controls and inventory management, and optimize anticipation of, and responsiveness to issues

Optimize asset and operating efficiencies, including asset location, usage and maintenance data

Improve equipment and system design

Improved Cold Chain Performance adds measures of capital spending, technology choices, operating costs, carbon footprint, trip and delivery variables, and system resiliency into traditional cold chain equations focused primarily on product. How do we ensure safe and fresh food while optimizing for weather delays, energy and travel costs, human factors, contract demands, and time?

Carrier's pilot study in India (described above) was designed to weigh improvements to food freshness and loss while measuring cold chain performance factors such as payback on equipment and carbon emissions. Over time, these kinds of data flows can help to guide capital and technology decisions while adjusting for unique regional conditions around the world.

A term that has become common in the agriculture world is Big Data, shorthand for describing the capture of relevant data from numerous sources and integrating the data in ways that create new insights into process and product improvements. For example, at the origin of the food cold chain, farmers around the world are now introducing field sensors that measure soil moisture and nutrients, and tractor sensors that help measure crop yields, as well as sensors on drones and satellites that provide information about field conditions.

Use of these new data flows now helps farmers know when and where to water, how much fertilizer, herbicide or insecticide to apply, and when to harvest. All of this information can be compared to historical results, resulting in a plan for "precision farming" that optimizes yields and profits. This new data can then be fed into the smart cold chain, informing postharvest, storage, transport, and retail decisions along the line.

A smart cold chain system will be able to integrate the many new flows of Big Data, intelligently manage the movement of perishable products, and reduce the cost of the system while minimizing its carbon footprint.

Reduced Energy Use and GHG Emissions

Monitor energy usage to benchmark against best practices and new technologies

Automatically optimize energy use vs. product safety and shelf life

Invest in R&D and regularly introduce new, enhanced technologies adapted to specific geographies

Target a carbon-neutral cold chain

Reduced Energy Use and GHG Emissions is an imperative in the 21st century and a top priority among leaders in the cold chain industry. Thanks to technological advances, the cold chain itself is becoming more sustainable. Carrier's development of CO_2 technology for transport and commercial refrigeration, shown above, is one example. And because wasted food has such an enormous impact on increased carbon emissions, the introduction of cold chain practices can have a tremendous positive impact on carbon reduction.

In September 2015, research by the Global Food Cold Chain Council concluded that the decrease in emissions of food loss and waste from cold chain expansion "clearly outbalanced the newly created emissions, by a factor of ten, approximately."[52]

The smart cold chain will not only be more effective in protecting perishable goods and reducing overall systems costs, but it will help heal the planet.

Delighted Customers

Provide product information and transparency at the point of purchase

Provide consumer education to reduce waste at home

Provide new tools for retailers to optimize safety, freshness and revenue

Allow customer feedback to flow from retailers across the entire cold chain

Delighted Customers are the final payoff of the smart cold chain. Information developed along the cold chain about the source, quality and safety of perishables can be shared with consumers so they understand that the food purchased is still good, or that certain imperfections are perfectly safe—or even that brown bananas can make delicious banana-nut-bread. Education can be a meaningful antidote to food waste, and the smart cold chain is poised to provide that information.

In late 2016, the "Supermarket of the Future" debuted in Milan, Italy, the newest offering of Coop Italia, the country's largest grocery chain. Some 6,000 products are arranged on interactive shelves and tables.

"When a customer moves to grab a specific product, relevant formation such as nutritional value, presence of allergens, and waste disposal instruction are displayed on sleek screens suspended above as 'augmented readers.'"[53] Other monitors provide shopping and preparation information. Designer Carlo Ratti says, "In the near future, we will be able to discover everything there is to know about the apple we are looking at: the tree it grew on, the CO_2 it produced, the chemical treatments it received, and its journey to the supermarket shelf."[54]

Taken together, these five attributes—optimized food safety, minimized food waste, improved cold chain performance, reduced energy use and GHG emissions, and delighted customers—will define the smart cold chain. By building on the benefits of the traditional cold chain, the smart cold chain can help to feed the world and heal the planet.

About

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About United Technologies

United Technologies Corp., based in Farmington, Connecticut, provides high-technology systems and services to the building and aerospace industries. By combining a passion for science with precision engineering, the company is creating smart, sustainable solutions the world needs. For more information about the company, visit our website at www.utc.com or follow us on Twitter: @UTC.

About Carrier

Founded by the inventor of modern air conditioning, Carrier is a world leader in high-technology heating, air-conditioning and refrigeration solutions. Carrier experts provide sustainable solutions, integrating energy-efficient products, building controls and energy services for residential, commercial, retail, transport and food service customers. Carrier is a part of UTC Climate, Controls & Security, a unit of United Technologies Corp. For more information, visit www.carrier.com or follow @Carrier on Twitter.

About Sensitech

Headquartered in Beverly, Mass., Sensitech offers a robust portfolio of products and services designed to help monitor and manage the cold chain of the world's most temperature-sensitive, perishable products: food, pharmaceuticals, biologics, and industrial chemicals. Sensitech is a part of UTC Climate, Controls & Security, a unit of United Technologies Corp. For more information, visit www.sensitech.com or follow @Sensitech on Twitter.

Appendix

1 "World Population Prospects: The 2017 Revision," United Nations Department of Economic and Social Affairs, Web November 7, 2017, https://www.un.org/development/desa/publications/world-population-prospects-the-2017-revision.html, and "World Hunger Again on the Rise, Driven by Conflict and Climate Change, New UN Report Says ," September 15, 2017, Web November 7, 2017, http://www.who.int/mediacentre/news/releases/2017/world-hunger-report/en/.

2 C.G. Winkworth-Smith, T.J. Foster, W. Morgan, "The Potential Value of Reducing Global Food Loss," The University of Nottingham, Division of Food Sciences, School of Biosciences, March 2015, 26-27.

3 "World Population Prospects: The 2017 Revision," United Nations Department of Economic and Social Affairs, Web November 7, 2017, https://www.un.org/development/desa/publications/world-population-prospects-the-2017-revision.html.

4 Based on FAO Food Balance Sheets, daily calories available from both plant- and animal-based foods globally in 2014 were 2,903 kcal/person/day. The FAO's suggested average daily energy requirement (ADER) in 2010 was 2,248 kcal/person/day. Multiplying the 2,903 kcal/person/day in 2014 by the global population of 7.2438 million yields total daily global calories, and by dividing this by the 8.5 billion people forecast in 2030 yields 2,475 kcal/person/day.
"FAO Statistical Pocketbook: World Food and Agriculture 2015," Food and Agriculture Organization of the United Nations, 2015, Web October 3, 2016, http://www.fao.org/3/a-i4691e.pdf, 48. For suggested ADER, see "Creating A Sustainable Food Future," World Resources Report 2013-14: Interim Findings, World Resources Institute, 2013, Web October 3, 2016, https://www.wri.org/sites/default/files/wri13_report_4c_wrr_online.pdf, 125.

5 "Pope Focuses on Paradox of Abundance in Address to Experts," Slate, February 7, 2015, Web October 3, 2016, http://www.salon.com/2015/02/07/pope_focuses_on_paradox_of_abundance_in_address_to_experts/.

6 Food loss is the unintended decrease in edible food mass at the production, post-harvest, processing, and distribution stages of the food supply chain. Food Waste is the discard of foodstuff at the retail and consumer levels. "Food waste" is often used as shorthand to capture all loss and waste.
See "Creating A Sustainable Food Future," World Resources Report 2013-14: Interim Findings, World Resources Institute, 2013, Web October 3, 2016, https://www.wri.org/sites/default/files/wri13_report_4c_wrr_online.pdf, 3.

7 "Creating A Sustainable Food Future," World Resources Report 2013-14: Interim Findings, World Resources Institute, 2013, Web October 3, 2016, https://www.wri.org/sites/default/files/wri13_report_4c_wrr_online.pdf, 3.

8 "Creating A Sustainable Food Future," World Resources Report 2013-14: Interim Findings, World Resources Institute, 2013, Web October 3, 2016, https://www.wri.org/sites/default/files/wri13_report_4c_wrr_online.pdf, 3.

9 "Food Wastage Footprint & Climate Change," Food and Agriculture Organization of the United Nations, 2015, Web October 6, 2016, http://www.fao.org/documents/card/en/c/7338e109-45e8-42da-92f3-ceb8d92002b0/.

10 "Food Wastage Footprint & Climate Change," Food and Agriculture Organization of the United Nations, 2015, Web October 6, 2016, http://www.fao.org/documents/card/en/c/7338e109-45e8-42da-92f3-ceb8d92002b0/.

11 "Food Wastage Footprint: Impacts on Natural Resources," FAO, 2013, Web October 4, 2016, http://www.fao.org/docrep/018/i3347e/i3347e.pdf, 27.

12 "Food Wastage Footprint: Full-cost Accounting: Final Report," Food and Agriculture Organization of the United Nations, 2014, Web October 4, 2016, http://www.fao.org/3/a-i3991e.pdf, 7-8. These factors, along with urbanization, food security, and national security, are discussed in Food Foolish: The Hidden Connection Between Food Waste, Hunger and Climate Change (2015, United Technologies).

13 2014-2015 Global Food Policy Report, Washington, D.C.: International Food Policy Research Institute, 2015, http://www.ifpri.org/sites/default/files/publications/gfpr20142015.pdf, 6.

14 "Second International Conference on Nutrition," United Nations Food and Agriculture Organization, October 2014, Web October 12, 2016, http://www.fao.org/3/a-mm215e.pdf, 3.

15 "Food Wastage Footprint & Climate Change," Food and Agriculture Organization of the United Nations, 2015, Web October 6, 2016, http://www.fao.org/documents/card/en/c/7338e109-45e8-42da-92f3-ceb8d92002b0/.

16 These goals also include a 5 percent reduction and 15 percent reduction in food loss at the production and processing phases in developed and developing countries respectively. "Food Wastage Footprint & Climate Change," Food and Agriculture Organization of the United Nations, 2015, Web October 6, 2016, http://www.fao.org/documents/card/en/c/7338e109-45e8-42da-92f3-ceb8d92002b0/.

17 Andrew Porterfield, "Eliminating Food Waste Requires Behavioral Changes, But GMOs Can Help Too," Genetic Literacy Project, September 14, 2016, Web October 20, 2016, https://www.geneticliteracyproject.org/2016/09/14/eliminating-food-waste-requires-behavioral-changes-gmos-can-help/.

18 Presentation by John Mandyck, World Cold Chain Summit, Singapore, December 2016.

19 Dr. Jean-Paul Rodrique and Dr. Theo Notteboom, "The Cold Chain and its Logistics," The Geography of Transport Systems, 2013, Web October 11, 2016, https://people.hofstra.edu/geotrans/eng/ch5en/appl5en/ch5a5en.html.

20 "Global Cold Chain to Grow 13.9% Through 2020," Food Logistics, January 22, 2016, Web October 6, 2016, http://www.foodlogistics.com/news/12161216/global-cold-chain-to-grow-139-through-2020.
A second estimate shows the global cold chain market at $167.24 billion in 2015, growing seven percent annually to $234.5 billion in 2020.
See "Cold Chain Market Worth 234.49 Billion USD by 2020," Markets and Markets, Web October 6, 2016, http://www.marketsandmarkets.com/PressReleases/cold-chain.asp.

[21] Nicola Twilley, "What Do Chinese Dumplings Have to Do with Global Warming," The New York Times, June 25, 2014, Web October 4, 2016, http://www.nytimes.com/2014/07/27/magazine/what-do-chinese-dumplings-have-to-do-with-global-warming.html?_r=0.

[22] "Assessing the Potential of the Cold Chain Sector to Reduce GHG Emissions Through Food Loss and Waste Reduction," Prepared by BIO Intelligence Services for the Global Food Chain Council with Support from United Technologies, Food Waste Reduction & Cold Chain Technologies, September 2015, Web October 4, 2016, http://naturalleader.com/wp-content/uploads/2016/04/coldchainGHGemissionstudy.pdf, 12.

[23] The estimate is 2 percent to 23 percent, with an average of 12 percent. But much of this can be attributed to intentional out-grading. See Julian Parfitt et al., "Food Waste Within Food Supply Chains: Quantification and Potential for Change to 2050," Philosophical Transactions of The Royal Society, September 27, 2010, Web October 6, 2016, http://rstb.royalsocietypublishing.org/content/365/1554/3065.full. The experience at Sensitech is that many loads of perishables flowing through a well-run, modern cold chain experience virtually no unintentional loss due to environmental conditions.

[24] C.G. Winkworth-Smith, T.J. Foster, W. Morgan, "The Potential Value of Reducing Global Food Loss," The University of Nottingham, Division of Food Sciences, School of Biosciences, March 2015, Web October 7, 2016, 10, http://naturalleader.com/wp-content/uploads/2016/04/UTC-Nottingham-Report_3-30_FINAL.pdf.

[25] "Assessing the Potential of the Cold Chain Sector to Reduce GHG Emissions Through Food Loss and Waste Reduction," Prepared by BIO Intelligence Services for the Global Food Chain Council with Support from United Technologies, Food Waste Reduction & Cold Chain Technologies, September 2015, Web October 4, 2016, http://naturalleader.com/wp-content/uploads/2016/04/coldchainGHGemissionstudy.pdf, 10.

[26] Nicola Twilley, "What Do Chinese Dumplings Have to Do with Global Warming," The New York Times, June 25, 2014, http://www.nytimes.com/2014/07/27/magazine/what-do-chinese-dumplings-have-to-do-with-global-warming.html?_r=0.

[27] Melanie Lee, "E-commerce Heats Up Cold-Chain Logistics in China," Internet Retailer, October 12, 2014, https://www.internetretailer.com/commentary/2014/10/12/e-commerce-heats-cold-chain-logistics-china.

[28] "A Tank of Cold: Cleantech Leapfrog to a More Food Secure World," Institution of Mechanical Engineers, June 2014, Web October 4, 2016, http://www.imeche.org/docs/default-source/reports/a-tank-of-cold-cleantech-leapfrog-to-a-more-food-secure-world.pdf?sfvrsn=0, 9.

[29] "A Tank of Cold: Cleantech Leapfrog to a More Food Secure World," Institution of Mechanical Engineers, June 2014, Web October 4, 2016, http://www.imeche.org/docs/default-source/reports/a-tank-of-cold-cleantech-leapfrog-to-a-more-food-secure-world.pdf?sfvrsn=0, 9

[30] Melanie Lee, "E-commerce Heats Up Cold-Chain Logistics in China," Internet Retailer, October 12, 2014, https://www.internetretailer.com/commentary/2014/10/12/e-commerce-heats-cold-chain-logistics-china.

[31] "2016 Top Markets Report: Cold Supply Chain, A Market Assessment Tool for U.S. Exporters," U.S. Department of Commerce, International Trade Administration, May 2016, Web October 4, 2016, http://trade.gov/topmarkets/pdf/Cold_Chain_Top_Markets_Report.pdf, 7.

[32] "Global Cold Chain to Grow 13.9% Through 2020," Food Logistics, January 22, 2016, Web October 6, 2016, http://www.foodlogistics.com/news/12161216/global-cold-chain-to-grow-139-through-2020.

[33] C.G. Winkworth-Smith, T.J. Foster, W. Morgan, "The Potential Value of Reducing Global Food Loss," The University of Nottingham, Division of Food Sciences, School of Biosciences, March 2015, October 7, 2016, 17, http://naturalleader.com/wp-content/uploads/2016/04/UTC-Nottingham-Report_3-30_FINAL.pdf.

[34] "Refrigeration Food and Safety," United States Department of Agriculture Food Safety and Inspection Service," Revised May 2010, Web November 15, 2016, http://www.fsis.usda.gov/shared/PDF/Refrigeration_and_Food_Safety.pdf. The report adds: "Bacteria grow most rapidly in the range of temperatures between 40 and 140 °F, the "Danger Zone," some doubling in number in as little as 20 minutes. A refrigerator set at 40 °F or below will protect most foods."

[35] The Role of Refrigeration in Worldwide Nutrition, "5th Informatory Note on Refrigeration and Food," Intergovernmental Organization for the Development of Refrigeration, International Institute of Refrigeration, Paris, June 2009, Web October 7, 2016, http://www.iifiir.org/userfiles/file/publications/notes/NoteFood_05_EN.pdf, 1.

[36] C.G. Winkworth-Smith, T.J. Foster, W. Morgan, "The Potential Value of Reducing Global Food Loss," The University of Nottingham, Division of Food Sciences, School of Biosciences, March 2015, , October 7, 2016, 17, http://naturalleader.com/wp-content/uploads/2016/04/UTC-Nottingham-Report_3-30_FINAL.pdf, 67-69.

[37] "A Tank of Cold: Cleantech Leapfrog to a More Food Secure World," Institution of Mechanical Engineers, June 2014, http://www.imeche.org/docs/default-source/reports/a-tank-of-cold-cleantech-leapfrog-to-a-more-food-secure-world.pdf?sfvrsn=0.

[38] Nicola Twilley, "The Chill Ride Your Food Takes to the Supermarket Is Heating Up the Planet," TakePart, June 28, 2015, Web October 11, 2016, http://www.takepart.com/article/2015/06/29/coldscape-refrigerated-trucking.

[39] "Market Survey for the Ryan Recording Thermometer Company," Booz, Allen & Hamilton, November 10, 1947, 1-2.

[40] "Market Survey for the Ryan Recording Thermometer Company," Booz, Allen & Hamilton, November 10, 1947, 3-47.

[41] "Fred Jones: Inventor of the Refrigerated Truck," The Black Inventor Online Museum, March 23, 2012, Web October 11, 2016, http://blackinventor.com/fred-jones/.

[42] Dr. Jean-Paul Rodrique and Dr. Theo Notteboom, “The Cold Chain and its Logistics,” The Geography of Transport Systems, 2013, Web October 11, 2016, https://people.hofstra.edu/geotrans/eng/ch5en/appl5en/ch5a5en.html.

[43] Nicola Twilley, “The Chill Ride Your Food Takes to the Supermarket Is Heating Up the Planet,” TakePart, June 28, 2015, Web October 11, 2016, http://www.takepart.com/article/2015/06/29/coldscape-refrigerated-trucking.

[44] Dr. Jean-Paul Rodrique and Dr. Theo Notteboom, “The Cold Chain and its Logistics,” The Geography of Transport Systems, 2013, Web October 11, 2016, https://people.hofstra.edu/geotrans/eng/ch5en/appl5en/ch5a5en.html.

[45] Email to author from Jeff Leshuk, October 28, 2016.

[46] “India Pilot Study Shows How the Cold Chain Can Help Reduce Food Loss and Carbon Emissions,” Carrier Transicold, December 2, 2016, Web January 4, 2017, http://www.carrier.com/carrier/en/us/news/news-article/india_pilot_study_shows_how_the_cold_chain_can_help_reduce_food_loss_and_carbon_emissions.aspx.

[47] “India Pilot Study Shows How the Cold Chain Can Help Reduce Food Loss and Carbon Emissions,” Carrier Transicold, December 2, 2016, Web January 4, 2017, http://www.carrier.com/carrier/en/us/news/news-article/india_pilot_study_shows_how_the_cold_chain_can_help_reduce_food_loss_and_carbon_emissions.aspx.

[48] “Can Blockchains Bring Transparency and Validation to Complex Extended Supply Chains?”, Supply Chain Digest, September 12, 2016, Web January 4, 2017, http://www.scdigest.com/ontarget/16-09-12-1.php?cid=11245.

[49] “Walmart Is Jumping on the Blockchain Bandwagon”, Supply Chain Digest, November 21, 2016, Web January 4, 2017, http://www.scdigest.com/ontarget/16-11-22-1.php?cid=11572.

[50] Wageningen University Developing Robots for Produce Quality Control,” FreshFruitPortal.com, November 22, 2016, Web January 4, 2017, http://www.freshfruitportal.com/news/2016/11/22/wageningen-university-developing-robots-for-produce-quality-control/.

[51] Jamie Condliffe, “The Robotic Grocery Store of the Future Is Here,” MIT Technology Review, December 29, 2016, Web January 4, 2017, https://www.technologyreview.com/s/603229/the-robotic-grocery-store-of-the-future-is-here/.

[52] “Assessing the Potential of the Cold Chain Sector to Reduce GHG Emissions Through Food Loss and Waste Reduction,” Prepared by BIO Intelligence Service for the Global Food Cold Chain Council with support from United Technologies, September 2015, Web November 1, 2016, http://naturalleader.com/wp-content/uploads/2016/04/coldchainGHGemissionstudy.pdf, 4.

[53] Jenny Xie, “’Supermarket of the Future,’ With Augmented Reality, Opens in Milan,” Curbed, December 14, 2016, Web January 4, 2017, http://www.curbed.com/2016/12/14/13958522/supermarket-interactive-milan-carlo-ratti.

[54] Jenny Xie, “’Supermarket of the Future,’ With Augmented Reality, Opens in Milan,” Curbed, December 14, 2016, Web January 4, 2017, http://www.curbed.com/2016/12/14/13958522/supermarket-interactive-milan-carlo-ratti.

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