

QUEST

Quality and Energy efficiency in Storage and Transport of agro-materials

Final public report September 2002 - December 2005

Consortium:

Agrotechnology and Food Innovations B.V.

A.P. Moller-Maersk A/S

Carrier Transicold, Container Products Group, Division of Carrier Corp.

Carrier Transicold Ltd.

Frugi Venta

Haluco B.V.

P&O Nedlloyd B.V.

R&R Mechatronics B.V.

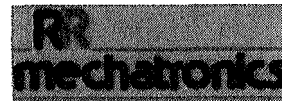
The Greenery B.V.

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Report 657



economy**e**cology**t**echnology

Colophon

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Samenvatting

Wereldwijd worden enorme volumes verse agro-producten getransporteerd. De totale waarde van de export was 58.5 miljard euro in 1998 en in 1999 werd 27.7 miljoen ton van deze agro-, voedsel producten getransporteerd in zee containers. Het energie gebruik voor de klimaat conditionering van zee containers is vaak hoger dan nodig. Het doel van het Quest project was het (verder) ontwikkelen van een nieuw agro-container concept met gereduceerd energie gebruik en optimalisatie van de product kwaliteit.

Het onderzoek is uitgevoerd door een consortium van bedrijven en onderzoeksinstituten, namelijk: Agrotechnology and Food Innovations (voormalig ATO), Carrier, Frugi Venta, Haluco, P&O Nedlloyd (gedurende het project gekocht door A.P. Moller-Maersk A/S), R&R Mechatronics en The Greenery. Deze partners bestrijken samen het brede spectrum van onderzoek, hardware productie, uitvoering van verschepingen, opslag op land en in- en export. Elke paar maanden hebben de partners gezamenlijk de projectvoortgang, onderzoeksrichting en -strategie te besproken. De verschillende onderzoeksactiviteiten zijn uitgevoerd door onderling verbonden subgroepen van bedrijven, die samenwerkten en kennis en ervaring in de diverse keten onderdelen uitwisselden.

Het Quest project is erin geslaagd het nieuwe agro-container concept met gereduceerd energie gebruik en optimalisatie van product kwaliteit te ontwikkelen:

- Quest Regular reduceert het energie gebruik bij klimaat conditionering voor transport van bederfelijke producten met 15 tot 75% (het doel van 50% of meer is dus gehaald). Tevens is voor twee hardware componenten het energie verbruik met 30% verlaagd.
- Gedurende het Quest Regular product onderzoek, is de product kwaliteit intensief gevolgd en getest om de marktacceptatie van het nieuwe agro-transport concept te vergroten. (Het monitoren tijdens verschepingen is beperkt tot het volgen van het klimaat, zodat het concept makkelijk geïmplementeerd kan worden in de vele reeds operationele reefer containers.) Voor avocado is het kwaliteitsbehoud verbeterd. Ook Quest Pro verbetert de product kwaliteit, door geregelde rijping aan boord mogelijk te maken.
- De ervaringen met klimaat regelingen in bewaarplaatsen op het land is gebruikt voor het ontwikkelen van Quest Regular technologie voor reefer containers. Hiernaast is de vergaande optimalisatie van reefer klimaat systemen toegepast voor bewaring. De Quest geregelde reefer containers kunnen ook worden gebruikt voor inlands transport.

Het Quest Regular concepten is meermalen op levensechte schaal getest, voor reefer containers zowel aan land als tijdens een pilot verscheping en in bewaar faciliteiten met de geoptimaliseerde hardware en instellingen.

Trefwoordenlijst: Energie verbruik, CO₂, Reefer Container, Opslag, Verscheping, Fruit, Groente, Koeling, Rijping, Klimaat, Regeling, Kwaliteit

Summary

World-wide large volumes of fresh agro-products are transported. The total value of export of agro-food products was 58.5 Billion Euro in 1998 and 27.7 Million ton of agro-food products were transported in sea containers in 1999. Energy used for climate conditioning of sea containers is often higher than needed. The Quest project aimed at the further development of a new agro-container concept with reduced energy use and optimisation of product quality.

The research has been carried out by a consortium of companies and research institutions, namely Agrotechnology and Food Innovations (former ATO), Carrier, Frugi Venta, Haluco, P&O Nedlloyd (during the project acquired by A.P. Moller-Maersk A/S), R&R Mechatronics and The Greenery. The Partners together covered the wide range of research, hardware production, shipment performance, land storage operators, in- and exporters. Every few months meetings were held to discuss project progress, focus and strategy between partners. Research activities were performed by several inter-linked company groups, cooperating and exchanging knowledge and experience in the various chain links.

The Quest project successfully achieved its aim of further development of a new agro-container concept with reduced energy use and optimisation of product quality:

- Quest Regular reduces energy consumption for climate conditioning in transport of perishable products with 15 up to 75% (thus the aim of 50% or more showed possible). Additionally hardware improvements were made, reducing component energy consumption by 30%.
- During Quest Regular product research, product quality was intensively monitored and tested to increase market acceptance of the new concept for agro-transport. (Monitoring during shipments was decided to be limited to climate checking for easy implementation in currently operational reefer containers) For avocado quality maintenance was improved. Also, Quest Pro improves quality maintenance, by enabling controlled on-board ripening.
- The experience in climate control of on-land storage facilities was transferred to the use of Quest Regular technology in reefer containers. Also, the practise of using highly optimized reefer climate systems was transferred to storage. The Quest controlled reefer containers can also be used in inland transport.

Ultimately, the Quest project led to both an on-land and a shipment pilot of the new Quest Regular concept, as well as real life tests of optimized hardware use and settings in storage facilities.

Subject Index: Energy consumption, CO₂, Reefer Container, Storage, Shipment, Fruit, Vegetable, Refrigeration, Ripening, Climate, Control, Quality

Introduction

This report describes the research performed in the Quest project during September 2005 until December 2005. First the project goals and project partners are described in chapter 1 and 2. The results of the project are given in chapter 3. Chapter 4 discusses the achievement of the project aims. Future activities are described in chapter 5, while the contribution of the project to the EET goals is described in chapter 6. Finally, chapter 7 sums up the available reports and presentations.

The cooperating company names are abbreviated as follows:

A&F:	Agrotechnology and Food Innovations B.V.
Carrier:	Carrier Transicold, division of Carrier Corporation with divisions: Carrier CPG: Carrier Transicold, Container Products Group and Carrier Ltd: Carrier Transicold Ltd.
Frugi Venta:	Frugi Venta
Haluco:	Haluco B.V.
Maersk:	A.P. Moller-Maersk A/S with division Maersk Sealand (integrated with PONL into Maersk Line from February 12 th 2006)
PONL:	P&O Nedlloyd B.V.
R&R:	R&R Mechatronics B.V.
The Greenery:	The Greenery B.V.

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1 Project goals

World-wide large volumes of fresh agro-products are transported. The total value of export of agro-food products was 58.5 Billion Euro in 1998 and 27.7 Million ton of agro-food products were transported in sea containers in 1999. Energy used for climate conditioning of sea containers is often higher than needed. The Quest project aimed at further development of a new agro-container concept aiming at reduction of energy use and optimisation of product quality, which includes:

- Reduction of energy consumption for climate conditioning in transport of perishable products (the aim is a reduction of energy consumption of 50% or more).
- Monitoring of product quality to reduce product losses, improve quality maintenance and increase market acceptance of the new concept for agro-transport.
- Possibilities for a transfer of technologies to storage and inland transport.

Ultimately, the project would lead to practical pilots of the new concept during sea transport and storage.



2 Project partners

The research has been carried out by a consortium of companies and research institutions. The partners together covered the wide range of research, hardware production, shipment performance, land storage operators, in- and exporters. Every few months meetings were held to discuss project progress, focus and strategy between partners. Hosting of these meetings was rotated between partners to give opportunity to get to know each others work environment.



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A&F has acted as overall project leader. Also, A&F has been involved with the product quality studies, development of interactive control of the container climate and marketing and logistics studies. Carrier was involved with the technical integration of the new control strategy with the container hardware, and provided technical support for the container scale tests. The development of a new concept should be supported by the potential users. Therefore, the potential users Frugi Venta and Haluco have been included as partners in the project. Frugi

Venta is the association for import and export companies in The Netherlands. The contributing company as member of Frugi Venta was Haluco, sharing its importing and exporting experience and involved in the full-scale testing. Maersk (former PONL) has been involved in the marketing and logistics studies, and also with the container scale tests. R&R Mechatronics would have been involved in the development of a sensor to measure product response, but unfortunately, a feasibility study showed that technology had not been developed far enough to produce the necessary receptive layer. The Greenery has been involved in the land storage optimization studies and the transfer of knowledge and experience between land storage and reefer container transport.

2.1 A&F (former ATO)

Agrotechnology and Food Innovations is the multidisciplinary research institute of the Agrotechnology and Food Sciences Group of Wageningen UR. A&F plays a prominent role in enhancing the know-how and technology level of agribusiness, trade and industry. A&F co-operates with a great variety of enterprises, including large multinationals, co-operatives, auctions, food processing industry, chemical industry, trade and export. The institute is involved in various national and EU research programmes. A&F is the certifying organisation of Reefer containers for transport of perishable products (ATO-certification). Complementary to the ISO certification aspects like box design, unit specifications and ventilation and circulation rates are judged.

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2.2 Carrier Transicold

Carrier Corporation is one of the companies included in United Technologies Corporation. United Technologies is a corporation whose businesses provide a broad range of high-technology products to aerospace and building systems throughout the world. Carrier Transicold specialises in the transport applications of refrigeration and air conditioning in five main areas: Container, Truck/Trailer, Marine, Bus/Rail, and Replacement Components. To serve these sectors on a truly global scale, Carrier Transicold operates 5 manufacturing facilities in 5 countries, and oversees a network of dealers, service locations, and parts depots world-wide. The Container Products Group produces refrigeration equipment for the shipping container industry. Carrier has been producing container refrigeration machines since the early 1970's and leads the market in new equipment sales. Carrier equipment is known for its reliability. Both Carrier Transicold, Container Products Group based in Syracuse USA and Carrier Transicold Ltd in Rotterdam have contributed to the Quest project.

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2.3 Frugi Venta

Frugi Venta is a Dutch trade organisation for fruits and vegetables. Approximately 700 companies trading in fruits and vegetables fall under this umbrella, with a turnover of 7 billion Euro and 12.500 employees. The importing and exporting companies are the main end-users of the new container concept developed in this project.

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2.4 Haluco

Haluco is one of Europe's most modern marketing and distribution organisations for fruits and vegetables. Haluco has customers world-wide, which ensures a balance between supply and demand year-round. Quality and quantity of the agro-products are an important bench base of the companies strategy. Haluco is part of the Dutch trade organisation Frugi Venta.

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2.5 Maersk (former P&O Nedlloyd)

At the start of the project, project partner P&O Nedlloyd was the second largest container carrier in the world. P&O Nedlloyd had over 70 established trade lanes and provides connections to more than 250 main ports serving 120 countries worldwide. P&O Nedlloyd's fleet numbers 146 owned and chartered vessels, and the company has a container fleet of some 700,000 owned and leased TEUs (Twenty-foot Equivalent Unit). These elements, combined with well-developed feeder lines, extensive inland transport capabilities and first-rate port facilities, formed the base of the product of P&O Nedlloyd. In August 2005 PONL was acquired by A.P. Moller-Maersk A/S. PONL's shipping activities are combined with Maersk Sealand's into Maersk Line. Maersk Line will be by far the largest carrier of refrigerated container cargo in the world.

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2.6 R&R Mechatronics

R&R Mechatronics develops, manufactures and markets instruments for in-vitro diagnostics and systems for laboratory automation. Continuous development and co-operation with scientific research- and medical centers lays the foundations of their products. Micro processor technology plays a vital role in every aspect. R&R Mechatronics has a well equipped industrial premises, where product development, manufacture and sales are undertaken. About 90% of the total production is exported all over the world through a world-wide network of exclusive and well trained distributors.

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2.7 The Greenery

The Greenery is an internationally operating marketing and sales organisation for fresh produce, representing over 9,000 growers in The Netherlands. The Greenery has or is developing close relationships with the top 30 retailers in Europe. The storage capacity of the Greenery for fruits is 75.000 ton. Today, The Greenery has an annual turnover of approximately 1 billion Euro, employs over 1000 people and has offices in The Netherlands, Germany and the U.K. Year-round supply of vegetables and fruits, is another corporate objective for The Greenery. Effectively this will mean that, during the counter season, product will have to be sourced from areas with more favourable climatic conditions.

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3 Results

During the Quest project new climate control concepts for perishable products have been developed, aiming at reduction of energy use and optimisation of product quality. Quest Regular significantly reduces energy consumption for climate conditioning in transport and storage. Quest Pro gives new opportunities to deliver produce ripened on demand, reducing additional storage time and increasing controllability of ripeness level.

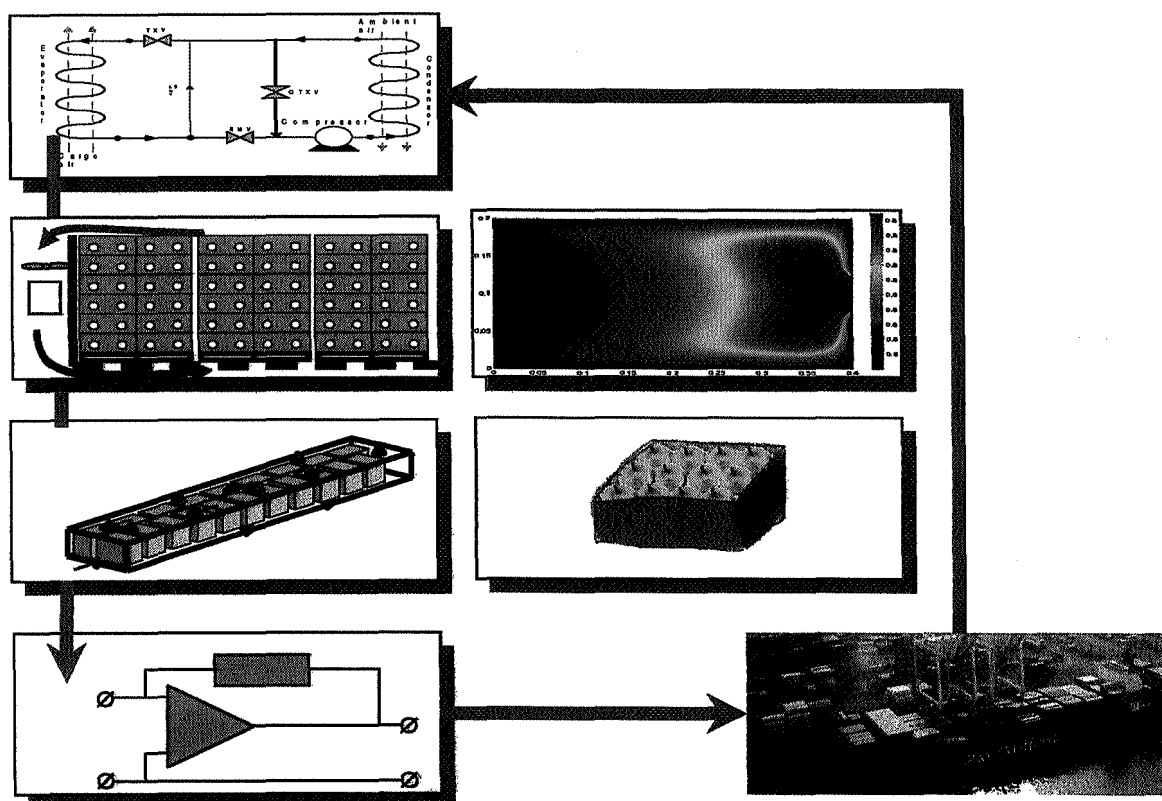


Figure 1 Quest models and controller

3.1 Quest Regular summary

Quest Regular significantly reduces energy consumption for climate conditioning in transport and storage, while maintaining produce quality. The Quest Regular software protocol, settings and guidelines were developed on basis of product research and climate modelling.

Three climate models have been developed, predicting energy consumption and indoor climate of a refrigerated container at various scales. The models can be used separately to study separate climate parts or the general behaviour. Also, the models can be coupled, to study the interaction of the macro- and microclimate. The models have been used to determine the controller settings

and to discuss opportunities for energy savings and the influence on the climate surrounding the products.

Energy savings in reefer containers can range between 15 and 75%. Additionally, a new condenser fan was developed that has a 28% lower power consumption. During an on-land pilot with bell pepper, the mean power usage was reduced from 4.8 to 1.2 kW. For bell pepper, apple, kiwi, pear, pineapple, grapes, banana and avocado the cycling control regime showed possible energy savings without reducing quality compared to standard storage conditions. For “MD2” Pineapple results were inconsistent. For avocado Quest Regular application even showed positive effect on colour development and softening. Thai dessert bananas “Sucrier” and “Gros Michel” show improved quality, i.e. longer storage time, when stored under cycling temperature conditions.

A field trial version of the embedded software was provided for a real life Quest Regular trial shipment with mangoes from Brazil to Rotterdam. Since the trial shipment could only be started at the end of the project, its results, market introduction strategy plans and practical guidelines will have to be addressed further after the project.

The Quest Regular control principle has been derived and grounded on the experience in climate control of on-land storage facilities. At the same time climate control of the on-land facilities could be improved by optimizing the use of the evaporator surface, defrost settings and the settings of the evaporator fans. Both moisture loss and energy consumption were reduced. Also, powerful, short cooling actions were tested, which give more flexibility to the cooling planning, while not harming product quality.

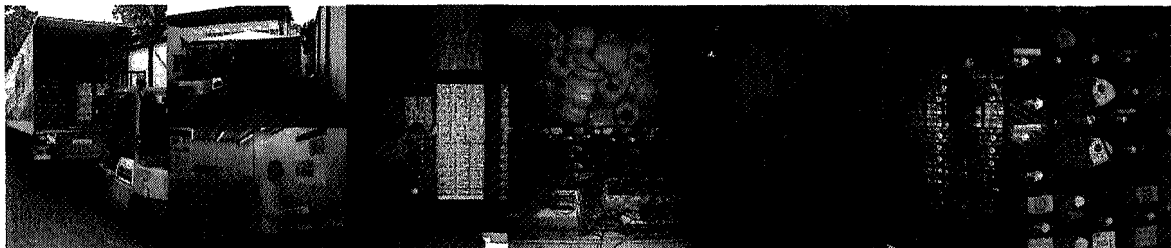


Figure 2 Photos of the set-up of the full scale on-land trial

3.2 Quest Pro summary

Quest Pro gives new opportunities to deliver produce ripened on demand, reducing additional storage time and increasing controllability of ripeness level. It focuses on automated on-board ripening of Hass avocado, because of the trend of fresh and ready-to-eat products. By ripening on-board, ripening after transport could be skipped or shortened. Additionally, a new air compressor with 30% reduced energy consumption was developed, which in future unit implementation could be used for QUEST Pro control efforts.

Numerous avocado ripening experiments were performed to develop a model, which describes firmness development based on on-line measurements, as a function of temperature and storage time. Also, a lab-scale set-up was built for lab scale testing of automated ripening and produce monitoring. The lab-scale set-up also includes the newly developed Quest Pro controller. This is a software tool that repetitively calculates the climate control settings to reach a desired firmness at a given final time. It was tested in two controlled ripening experiments. At the end of both subsequent test periods, the pre-defined ripening stage (just before ready to eat) was achieved satisfactory.

Because of the novelty of the searched techniques and the difficulty of the necessary research, a proof of principle has been given for Quest Pro, but further development is necessary to make it ready for commercialization.



Figure 3 Manual measurement of firmness and softness after ripening

4 Achievement of project aims

The Quest project successfully achieved its aim of further development of a new agro-container concept with reduced energy use and optimisation of product quality:

- Quest Regular reduces energy consumption for climate conditioning in transport of perishable products with 15 up to 75% (thus the aim of 50% or more showed possible). Additionally hardware improvements were made, reducing component energy consumption by 30%.
- During Quest Regular product research, product quality was intensively monitored and tested to increase market acceptance of the new concept for agro-transport. (Monitoring during shipments was decided to be limited to climate checking for easy implementation in currently operational reefer containers) For avocado quality maintenance was improved. Also, Quest Pro improves quality maintenance, by enabling controlled on-board ripening.
- The experience in climate control of on-land storage facilities was transferred to the use of Quest Regular technology in reefer containers. Also, the practise of using highly optimized reefer climate systems was transferred to storage. The Quest controlled reefer containers can also be used in inland transport.

Ultimately, the Quest project led to both an on-land and a shipment pilot of the new Quest Regular concept, as well as real life tests of optimized hardware use and settings in storage facilities.

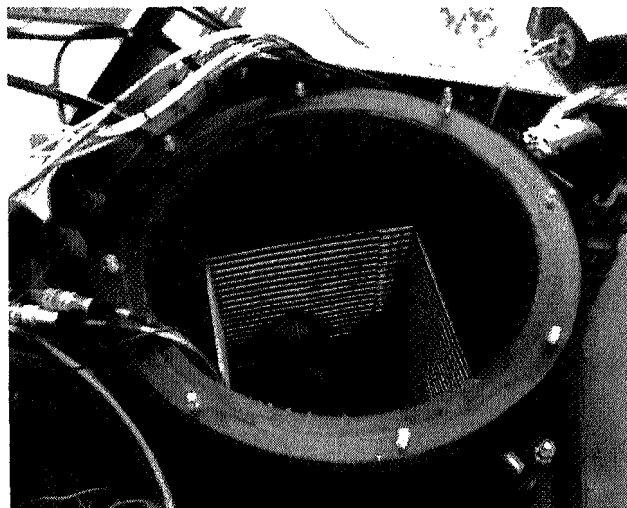


Figure 4 Opened ripening vessel just after a successful automated ripening test

5 Future activities

The following research results are ready to be commercialized:

1. Quest Regular for reefer containers:
 - a. software protocol (developed by A&F)
 - b. settings and guidelines (developed by A&F)
 - c. embedded software (developed by Carrier)

After the project, the trial shipment will arrive in Rotterdam and the results of this sea trial will be evaluated by Maersk, Carrier and A&F. Expecting positive results of this trial, Maersk, Carrier and A&F are evaluating to further test the concept. Commercialization by cooperating companies Maersk, the largest carrier of refrigerated container cargo in the world, Carrier Transcold, a world leader in reefer climate control systems, and Wageningen UR, an international leading research organisation for life sciences, will ensure global impact of the Quest Regular principle.

2. Quest Regular for land Storage:
 - a. optimization of machinery and settings (developed by A&F and the Greenery)

During 2005, the Greenery on-land storage organisation decided to reject the on-land fruit storage facilities. Therefore, the results of the studies are being adapted to be used at other storage facilities (distribution centres) operated by Greenery. Also, A&F is contacting the new operators of the fruit storage facilities to be able to advise them on the possibilities for energy savings.

For Quest Pro, a proof of principle has been given, but further development is necessary to make it ready for commercialization. A&F is looking for partners to further develop the automated ripening techniques and commercializing them.

6 Contribution to EET aims

This project is supported with a grant of the Dutch Programme EET a joint initiative of the Ministries of Economic Affairs, Education, Culture and Sciences and of Housing, Spatial Planning and the Environment. The programme aims at the development of economy, ecology, technology and cooperation. In the following paragraphs the contribution of the Quest project to these four fields is described.

6.1 Economy

Direct cost savings due to the reduced energy consumption using Quest Regular during transport of agro-products will be significant. When applying Quest Regular to all shipments of hard fruit, citrus and tropical fruit, a 15 - 75 % reduction would mean savings of 293 – 1466 M kWh per year, which is approximately 6 - 35 million Euro per year. Hereby we are counting the low price of € 0,024 per kWh. With the current increasing oil prices, possible savings become larger everyday. Extending the cost savings for energy consumption to the entire volume of fresh products in sea containers would mean cost savings over 19 - 91 Million Euro per year.

Cost savings by the reduction of the energy consumption are illustrated for a group of products in Table 1 given an average transport duration of almost 15 days, cost of energy use 0.028 USD/kWh and USD-Euro conversion rate of 1.14286.

Table 1. Savings by reduction in energy consumption for a group of products						
Product (M ton)	Year			Energy consumption of transport (in 2010)		
	1990	1999	2010 ¹	Current (M kWh)	Savings 50% reduction (M kWh)	Savings 50% red. (M Euro)
Bananas	9.4	12.3	15.7	1356	678	21.59
Hard fruit	4.1	6.5	10.3	890	445	14.24
Citrus	4.9	5.6	9.7	838	419	13.41
Tropical fruit	0.6	1.4	2.6	225	113	3.62

¹ estimated. A. Penfold (2000). "Predicting future market, trends in reefer shipping". proc. Reeferbox 2000.

Additionally, there will be indirect cost savings. The general knowledge developed and shared in the Quest project contributes to improved transport of agro-materials with respect to energy usage and product quality maintenance, reduction of product losses and improved chain efficiency. Cost savings and indirect energy savings due to reduced loss of fresh products are substantial. In Table 2 the volume of fresh products transported in sea-containers is shown, and the cost savings in sea-transport due to a reduction of product loss of 1%.

Table 2. Trend in increase in volumes of fresh products transported in sea containers, and calculated cost savings due to reduced product loss

Products in sea container (M ton)	Year			Savings in product loss of magnitude 1% (2010)
Product category	1990	1999	2010 ¹	Savings (M Euro)
Bananas	9.4	12.3	15.7	157
Hard fruit	4.1	6.5	10.3	103
Citrus	4.9	5.6	9.7	97
Tropical fruit	0.6	1.4	2.6	26

¹ estimated. A. Penfold (2000). "Predicting future market, trends in reefer shipping". proc. Reeferbox 2000.

If cost savings are calculated based on the total export of agro-produce, cost savings are even higher considering a world export value of 58.5 Billion Euro (1998) of total agro-food products and a value of 27.0 Billion Euro for fresh fruits and vegetables.

The improved storability concept for Thai bananas gives opportunity for a new market, possibly enabling shipping of Thai bananas to Western Europe or the USA. Quest Pro opens opportunity for the new marketable concept of ready to eat fruit, ripened during transport.

In land storage savings a full implementation of all collected knowledge will decrease the energy use with at least 15 %. Based on a yearly energy cost of € 2,- per 500 m³ storage room, for the Greenery locations a total of € 1.300.000,- based on 325.000 m³, the 15 % leads to an advantage of € 200.000,-. Change of settings will ask for more intense control of conditions, mainly (product) temperature within the room and moisture lost. Change of controllers and extra temperature measurement will lead to investments in the total of approx. 800 storage rooms of at least € 1.500.000,-. The return on investment will be at least 6-8 years.

6.2 Ecology

World-wide product losses in postharvest are still estimated at 25-40%. Because The Netherlands are and will stay an important trade country, these losses also have a direct influence on the Dutch transport sector. Optimisation of the chain from producer to consumer is, therefore, essential to embank these losses. To prevent that one environmental problem (waste problem) is reduced, while another (increase of energy use) is increased, a durable way of multi-modal transport has been chosen in this project. In Table 3 the reduction in energy consumption for the transport of a group of agro-products is shown.

Table 3. Reduction in energy consumption for a group of products					
Product (M ton)	Year			Energy consumption of transport (in 2010)	
	1990	1999	2010 ¹	Current (M kWh)	Savings – 50% reduction (M kWh)
Bananas	9.4	12.3	15.7	1356	678
Hard fruit	4.1	6.5	10.3	890	445
Citrus	4.9	5.6	9.7	838	419
Tropical fruit	0.6	1.4	2.6	225	113

¹ estimated. A. Penfold (2000). “Predicting future market, trends in reefer shipping”. proc. Reeferbox 2000.

The achievable energy savings for hard fruit, citrus and tropical fruit, a 15 - 75 % reduction amounts to 293 – 1466 M kWh per year.

The energy efficiency of the cooling unit forms a large contribution of reefer containers to the global warming problem (in TEWI - Total Equivalent Warming Impact in kg CO₂). For the emission factor (kg CO₂ per kWh) a reasonable figure to assume for shipboard supplies is 0.77, leading to a reduction in emission of CO₂ of 226 - 1129 M kg. Extending energy savings to the entire volume of fresh products in sea containers would mean a reduction in CO₂ emission of 466 - 2331 M kg.

Additionally, there will be indirect savings due to reduced produce loss. The general knowledge developed and shared in the Quest project contributes to improved transport of agro-materials with respect to energy usage as well as product quality maintenance, reduction of product losses and improved chain efficiency. Additionally, noise reduction of the improved hardware components has been achieved.

In land storage energy savings will be 15% at full implementation of the developed knowledge.

6.3 Technology

The research has aimed at preventing unnecessary strict climate conditioning during container transport of agro-materials as is currently common practice to deal with problems in this field. This research has taken a fundamentally different approach to maintaining product quality without wasting energy by applying the correct climate settings for the product. Also, an optimal control strategy for container climate based on models and on-line measurements of product state on container scale has been developed and tested interacting with the product quality monitoring system. Basing climate setpoints following on direct feed-back from monitoring of

product status, allows determination of the most energy efficient climate conditions. For successful introduction of the new technology in practice and for achieving a wide acceptance, it is of highest importance that is demonstrated that the new technology is safe and reliable. Therefore, for Quest Regular, several full-scale tests have been performed. Due to the complexity of the automated ripening research, Quest Pro was only tested on lab-scale, leading to a proof of principle. For further information on the technological results, we refer to chapter 3.

6.4 Cooperation

The research has been carried out by a consortium of companies and research institutions. Partners together covered the wide range of research, hardware production, shipment performance, land storage operators, in- and exporters. Every few months meetings were held to discuss project progress, focus and strategy between partners. Hosting of these meetings was rotated between partners to give opportunity to get to know each others work environment. A&F has acted as overall project leader and brought in the scientific background knowledge and concepts. Industrial partners Carrier and PONL/Maersk focussed the research to the most relevant products and applications, while potential users Frugi Venta and Haluco represented experience and interests of the end-users. The Greenery's participation enabled transfer of technology and experience between land storage and sea transport applications.

For the development work, A&F, Carrier, Haluco and PONL/Maersk worked closely together in developing and testing Quest Regular for reefer containers, each fulfilling their necessary unique role in this highly chain focussed research. Also, the technical inventory and optimisation of the land storage facilities was performed in close cooperation of A&F and The Greenery. The more fundamental research for Quest Pro was largely performed by A&F but closely monitored and focussed by Carrier and PONL/Maersk. Additionally, the feasibility study on the development of a more selective ethylene sensor was performed by third party Lionix. Results and implications were thoroughly discussed by A&F and R&R.

7 Reports

During the project several internal and external reports have been made, as well as papers and presentations. Below a list of the external reports and presentations is given in order of appearance. These reports and presentations can be made available on request submitted to the project managers G. van den Boogaard or J. de Kramer at A&F. Costs are E50 per printed report or presentation, plus E5 per printed page. For most documents, pdf versions can be emailed for free. For the participants of the project a selection of these documents can be addressed via the web-site of the project: <http://www.agrotechnologyandfood.wur.nl/Quest/> (this will be changed into <http://www.afsg.nl/Quest/>).

7.1 External reports and papers

- R.G.M. van der Sman, G.J.C. Verdijck. Model predictions and control of conditions in a CA-reefer container *Acta Horticultura* 600: 163-171 (2003).
- R.G.M. van der Sman. Simple model for estimating heat and mass transfer in regular-shaped foods. *J. Food Eng.*, 6(4): 383-390 (2003).
- R.G.M. van der Sman. Prediction of firmness of apples under dynamic chain conditions. Model-it 2005 conference proceedings. *Acta Horticultura*. (2005).
- R.G.M. van der Sman, Finite Boltzmann schemes. accepted for *Computers & Fluids* (2005).
- R.G.M. van der Sman. Lattice Boltzmann scheme for natural convection on square and rectangular grids. Submitted to *Phys. Rev. E* (2005).
- R.G.M. van der Sman. Coarse-graining heat conduction in solids with simple geometries. in preparation for *Int. J. Heat Mass Transfer* (2006).
- Automatic produce quality monitoring in reefer containers, L.J.S. Lukasse, M.G. Sanders, J.E. de Kramer. ATO, Wageningen, The Netherlands. Abstract. Quality In Chains, An Integrated View on Fruit and Vegetable Quality, Third International And Multidisciplinary Conference, Wageningen, 6-9 July 2003

7.2 External presentations

- Validation airflow model at Food Science Australia, J. de Kramer
- Poster presentation at the MODEL-IT conference from May 29 to June 2, 2005 in Leuven, Belgium (see also www.model-it-2005.be): "Airflow and Climate Distribution in Reefer Containers - a Network Model", J. de Kramer, J. Kelder, R. Canters