CEET2005

Final Management Report

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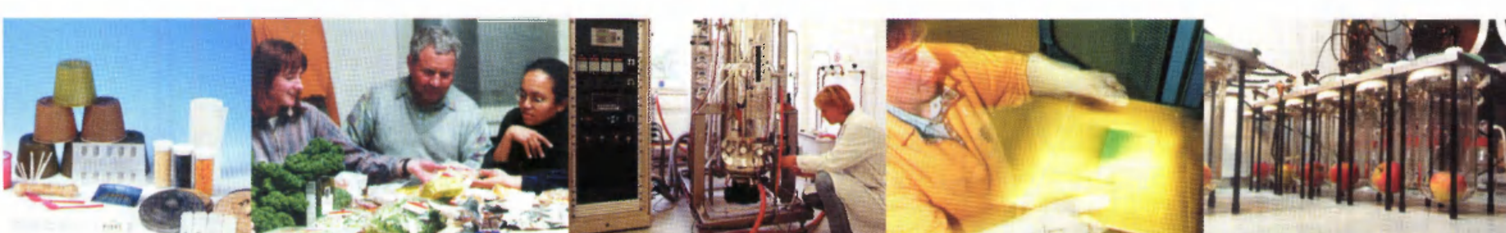

WAGENINGEN UR

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ATO B.V.
Agrotechnological Research Institute
Bornsesteeg 59
P.O. Box 17
6700 AA Wageningen
The Netherlands
Tel: +31.0317.475024
Fax: +31.317.475347

Final Report CEET2005

The final report of the CEET2005 project consists of two parts, which are the Final Management Report (this one) and the Final Scientific Report.

Contents

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Samenvatting van projectresultaten

In dit rapport wordt een overzicht gegeven over de voortgang van het project CEET 2005 tot juni 2002, waarbij de nadruk ligt op de derde fase: Integratie van taken. In deze fase worden de resultaten en deliverables van alle taken gecombineerd. Aan het einde van deze fase is een full-scale container test uitgevoerd. Dit experiment geeft antwoord op de vraag hoeveel energiebesparing behaald kan worden bij klimatiseren in zeecontainers. De configuratie van de container die getest is, is beschreven in de EET rapportage van juni 2000 als configuratie 2. De inhoudelijke voortgang van het project tot januari 2002 staat uitgebreid beschreven in het wetenschappelijk voortgangsrapport 'CEET2005 Scientific Report, April 2001 – January 2002'. De periode van januari 2002 tot juni 2002 wordt beschreven in het bij dit rapport behorende 'Scientific Report'. Onderstaand wordt een samenvatting gegeven van de belangrijkste resultaten:

Full-scale container test

- In een full-scale container test is aangetoond dat een energie besparing van 63% behaald kan worden bij gebruik van een energie-efficiënt koelscenario in vergelijking met conventionele koeling. Van deze energiebesparing voor klimatiseren was 40% toe te schrijven aan een verminderd energiegebruik door het reduceren van de ventilatiesnelheid (full-speed naar half-speed) en 23% energiebesparing kon gehaald worden uit het periodiek en gecontroleerd aan- en uitschakelen van het koelsysteem.
- De gemiddelde stevigheid van appels bewaard in de container met het energiezuinige koelscenario was gelijk aan de stevigheid van appels bewaard onder conventionele koeling.

Taak 1: Optimalisatie van productkwaliteit onder variabele condities voor een beperkte klasse van producten

- Gaswisseling van appels (Elstar) en tomaat (Prominent en Evident) zijn gekwantificeerd als functie van zuurstofconcentratie en temperatuur.
- Hoewel grote verschillen zijn gevonden tussen snelheden van gasuitwisseling (O_2 en ethyleen) van tomaten bewaard onder CA condities of lucht, zijn geen verschillen in kwaliteitseigenschappen (stevigheid, kleur, schilafwijkingen, rot) waargenomen.
- Er zijn lineaire relaties gevonden tussen temperatuur en gaswisselingsparameters die de O_2 opname en afgifte beschrijven. Dit maakt het mogelijk O_2 opname en afgifte te beschrijven en voorspellen als functie van temperatuur en gascondities.
- Gaswisselingssnelheden en stevigheid van appels zijn vastgesteld in relatie tot transport temperatuur, transport condities (CA en lucht), transportduur en transportperiode.
- Door gebruik te maken van logistieke informatie zoals transportduur en transportperiode kunnen energiezuinige klimatiseringsscenario's gekozen worden en kan energiegebruik gereduceerd worden terwijl productkwaliteit gehandhaafd blijft.
- Stevigheid blijft gehandhaafd tijdens transport en neemt langzamer af tijdens shelf-life bij hogere temperaturen (5°C en 9°C) gecombineerd met CA condities in maar neemt af bij deze hogere temperaturen en lucht.
- De snelheid van afgifte en opname van O_2 en CO_2 kan niet gebruikt worden om het kwaliteitsverloop tijdens shelf-life te voorspellen.
- Ethyleenproductie lijkt een goede indicator voor het voorspellen van het stevigheidsverloop van appels tijdens shelf-life.
- Uit verschillende testen van transportscenario's met variërende temperatuur is gebleken dat temperatuurschommelingen geen invloed hebben op stevigheid van appels en op zowel de stevigheid als de kleur en gewichtsverlies van tomaat en rode en groene paprika.
- Rode paprika bewaard bij 10°C ± 3°C (met een frequentie van 12 uur) heeft een hogere O_2 opname en CO_2 productie dan bij bewaring bij een constante temperatuur van 10°C. Dit wordt niet gereflecteerd in kwaliteitsverlies.
- O_2 opname en CO_2 productie kunnen niet gebruikt worden voor de voorspelling van kwaliteit van rode paprika.

- Experimentele resultaten laten zien dat kwaliteitsverlies beïnvloed kan worden door verandering van gascondities.

Taak 2: Optimalisatie van klimaatbeheersing

- Er is in simulatiestudies aangetoond dat, door middel van een nieuw regelalgoritme waarin setpoints voor klimaatcondities dynamisch veranderd worden, energieverbruik in gekoeld containertransport significant verminderd kan worden bij een gehandhaafde productkwaliteit.
- Deze benadering kan ook toegepast worden in post-harvest behandelingen tijdens transport, zoals gecontroleerde rijping of uitgestelde bewaring ter voorkoming van koude-schade.

Taak 3: Ontwikkeling van een robuust, geïntegreerd en duurzaam energiesysteem

- De huidige containers en container infrastructuur is verregaand geoptimaliseerd om aan de marktvraag te voldoen. Het ontwikkelen van een geaccepteerd energiesysteem dat efficiënter is, betrouwbaarder of gebaseerd is op duurzame energie is daarom niet triviaal. Tijdens zeetransport worden containers in de regel voorzien van elektriciteit van het schip. Het is mogelijk om het energiesysteem efficiënter te maken of het gebruik van duurzame energie toe te passen, maar deze systemen zullen niet gebruikt worden in de praktijk omdat het kostentechnisch geen alternatief is voor diesel generators die momenteel gebruikt worden
- Transport per trein of vrachtwagen vereist normaal gesproken een aparte energievoorziening per container. Dit biedt de mogelijkheid om duurzame, schonere en meer efficiënte energievoorzieningen te gebruiken zoals zonnecollectoren op het dak van de container, brandstofcellen, het gebruik van biodiesel of absorptiewarmtepompen.
- Geconcludeerd kan worden dat de integratie met de intermodaliteit van de container het belangrijkste probleem is bij de keuze van een duurzaam efficiënt energiesysteem. Daarnaast zijn technologieën zoals brandstofcellen, absorptiewarmtepompen of biodiesel nog niet dusdanig ver ontwikkeld dat ze een kosteneffectief alternatief zijn. Ook in de komende 2-5 jaar zal een dergelijk energiesysteem dat aan alle eisen voor de totale koude-keten niet beschikbaar zijn.

Taak 4: Ontwikkeling van slow-release systemen voor green chemicals

- Er is een systeem ontwikkeld waarbij tijdens bewaring van verse producten op kleine schaal vluchtige oliën in een constante concentratie toegediend kunnen worden. Zo is voor trans-2-hexanal aangetoond dat binnen een bepaalde concentratie range de groei van schimmels op appels onderdrukt wordt zonder dat schade aan de appels ontstaat. Deze experimenten zijn uitgevoerd bij 5°C terwijl huidige bewaring van appels normaal gesproken bij 0-1°C plaatsvindt. Door gebruik te maken van green chemicals zou dus de hoeveelheid energieverbruik voor koeling teruggebracht kunnen worden. Deze technologie zou ook gebruikt kunnen worden in andere sectoren waar aantasting door schimmels belangrijke verliezen van vers product veroorzaakt.

Taak 5: Monitoring van de productomgeving en productrespons

- De huidige e-nose systemen zijn niet geschikt voor metingen van vluchtige verbindingen in de atmosfeer rond verse producten in een container. De technologische ontwikkelingen op dit gebied zijn echter snel en het lijkt aannemelijk dat in de toekomst goedkopere sensoren met een grotere specificiteit, stabiliteit en reproduceerbaarheid beschikbaar komen.
- De gecombineerde O_2 en CO_2 sensor die binnen dit project ontwikkeld is maakt nauwkeurige meting van CO_2 en O_2 mogelijk. De sensor is een goed alternatief voor de huidige sensoren. Verder werk is nodig om de stabiliteit verder te vergroten.

Taak 6: Ketenoptimalisatie en marketing

- Het is gebleken dat energiebesparing tijdens transport de meest interessante verbetering is die gemaakt zou kunnen worden ten opzichte van huidig reefer container transport. De meest veelbelovende strategie voor container carriers voor de komende jaren is een verder uitbouwen van het marktaandeel in de conventionele reefer markt met gangbare apparatuur en optimalisatie naar volume en kosten.
- Er is geen echte markt voor geoptimaliseerde product kwaliteit waarbij de actoren willen betalen voor een verbeterde kwaliteit. Supermarktketens zullen de andere actoren in de keten dwingen om de eventuele extra kosten van verbeterde kwaliteit te dragen, omdat kwaliteit wordt gezien als een standaard vereiste en niet als een meerwaarde.

- Het verminderen van de niveau van schade aan het product of verminderen van productverlies is niet van zeer groot belang, omdat slechts 10% van alle claims gerelateerd is aan de werking van de reefer apparatuur.
- Analyses hebben aangetoond dat er zeker interesse is bij exporteurs voor de vervanging van luchttransport door zeetransport bij producten die momenteel per luchtvracht vervoerd worden. De verwachting is echter dat het een klein volume betreft waarvoor investeringen gedaan moeten worden voor specifieke apparatuur.
- Uit een grondige analyse van de positie ven strategie van de container carrier is gebleken dat zolang het reefer segment geïntegreerd is in de corporate strategie van de carrier die zich richt op minimaliseren van kosten en maximaliseren van volume, de nadruk niet zal moeten liggen op de ontwikkeling van specialistische apparatuur voor een markt niche, maar op het ontwikkelen van apparatuur die breed inzetbaar is over verschillende productcategorieën.
- Op dit moment en ook binnen een tijdhorizon van 5 jaar, biedt intermodaal transport geen goed alternatief voor geklimatiseerd wegtransport. Zowel aan de aanbod als aan de vraagkant zouden veranderingen moeten plaatsvinden om intermodaal containertransport mogelijk te maken.
- Verder eisen die de markt stelt aan een nieuw concept voor container transport zijn:
  - On-line monitoring
  - Controle van luchtvochtigheid

Taak 7: Ontwikkeling van een geïntegreerd dynamische controlestrategie
- Gebruikmakend van het voorspellend vermogen van de verschillende modellen is het mogelijk de meest optimale setpoints voor container transport vast te stellen. Energieverbruik wordt hiermee teruggedrongen omdat niet meer energie gebruikt wordt voor klimatiseren dan nodig is. Door meting en schatting van de product responsie is het mogelijk om niet alleen de status van het product te monitoren maar ook te controleren en op die manier direct kwaliteit te sturen/handhaven.
- Ondanks de problemen die gepaard gaan met het schatten van product responsies is het mogelijk gebleken om een maat voor productactiviteit te meten/schatten als respons op klimaatveranderingen. Zowel in simulaties als experimenten zijn veelbelovende resultaten verkregen (met afwezigheid van lek).
- Om toekomstig gebruik mogelijk te maken moeten nog enkele problemen worden opgelost (oscillaties en opschaling).
- Een Model Predictive Controller is speciaal voor het transport ontwikkeld. Desondanks blijven er nog enkele tijdschaal gerelateerde problemen op te lossen om zowel een energie efficient transport als een goede product kwaliteit te waarborgen.

Gezien de afloop van het huidige project hebben meerdere discussies plaatsgevonden tussen zowel de bestaande als mogelijk nieuwe partners. Nieuwe partners betrof partijen die producten transporteerden en als eindgebruikers van de nieuwe technologie op kunnen treden. Dit heeft geleid tot het opstellen van een projectvoorstel "Quest: Quality and Energy efficiency in Storage and Transport of agro-materials" (2002T1151) dat is ingediend bij het E.E.T.-bureau.

Summary of project results

Although the work described in this report covers the entire project period, the focus will be on phase 3: Integration of all tasks. In this phase, the results and deliverables from all tasks have been combined. At the end of this phase, a final container experiment was performed. This experiment gives an answer to practical feasibility of the new container configuration (e.g. how much energy can be saved in the new container). The description of this container has already been given in EET-report June 2000 and is filed as configuration 2. De scientific progress is described in detail in the scientific report 'CEET2005 Scientific Report, April 2001 – January 2002'. The period January 2002 – June 2002 is described in the 'Scientific Report', which is a part of this report. An overall summary of the scientific progress for all tasks is given here:

Full Scale Container Experiment
- In a full-scale container experiment it was demonstrated that energy savings of 63% can be achieved between conventional cooling and an energy efficient cooling scenario. Of this reduction in energy use for climate control, 40% was due to reducing the fan speed to half speed and another 23% reduction could be achieved by periodically cycling the cooling system on and off.
- The average firmness of apples stored in the container under this scenario with reduced energy use did not differ from firmness of apples stored at constant temperature.

Task 1: Optimisation of product quality under varying conditions for a limited class of products
- Gas exchange rates of apple (cv. Elstar) and tomato (™ Prominent and Evident) have been quantified as function of oxygen concentration and temperature.
- Although large differences were found between gas exchange rates (O_2 and ethylene) of CA and Air stored tomatoes (™ Prominent), no difference in quality parameters (firmness, colour, skin disorder, rot) were observed.
- Linear relations were found between the O_2 gas exchange parameters (apple and tomato) and temperature. This makes it possible to calculate O_2 gas exchange rates as function of oxygen at different transport temperatures and gas conditions.
- Gas exchange rates (O_2, CO_2 and ethylene) and firmness of apples have been quantified in relation to transport temperature, transport conditions (air and optimal CA), transport time and transport period.
- Based on logistic data (transport time and transport period) it is possible to choose transport conditions in which firmness will be maintained and energy costs for climate conditioning reduced.
- Firmness is retained during CA storage at elevated temperatures (5°C and 9°C) and decreases slower during shelf-life compared to air storage.
- O_2 and CO_2 gas exchange rates during transport do not predict quality decay during shelf-life.
- Ethylene production seems to be predictive for firmness decline during shelf-life.
- Various temperature fluctuation patterns were tested and it was shown that they did not influence the firmness of apple, nor the firmness, colour development and weight loss of tomato and bell pepper (green and red).
- Red bell pepper stored for 5 and 10 days at 10.0 ± 3.0°C (frequency 12 hr) have higher O_2 and CO_2 gas exchange rates compared to storage at constant 10°C. However this was not reflected in additional quality loss.
- O_2 and CO_2 gas exchange rates can not be used to predict quality of red bell peppers.
- First results confirm that manipulating gas conditions can prevent quality decay.

Task 2 Optimisation of climate control under energetic and quality constraints
- We have shown that by means of a new control algorithm, which dynamically changes set points, significant energy reduction in refrigerated container transport of perishables can be obtained without unacceptable loss of product quality.
- Furthermore, we think our approach has potentials for incorporation of post-harvest treatments during transport, such as delayed storage (for prevention of chilling injury) or fruit ripening.

Task 3 Development of a robust integrated sustainable energy system

- Current containers and container infrastructure are highly optimised to meet actual market demands. Developing an energy supply system that is more efficient, more reliable or based on renewable sources is therefore challenging. During sea transport, containers will usually be supplied with electricity from the ship. Efforts to improve the efficiency or apply renewable sources can turn out favourable, but will not take effect on the containers installation. On the ship there is no cost-effective alternative for use of diesel generators available now.
- Transportation on trains or trucks usually involves a per-container energy supply. This offers possibilities to apply renewable, cleaner or more efficient sources, such as: photo-voltaic cells on the roof of the container, fuel cells, the use of bio-diesel in conventional gensets or absorption heat pump.
- It can be concluded that compatibility with the intermodality of the reefer containers is the most important problem. Besides that, techniques as the fuel cell, the absorption heat pump or bio-diesel are not developed into a cost-effective alternative yet. There is no alternative energy supply system available within 2-5 years that meets all criteria for the total cold chain.

Task 4 Development of slow-release systems for green chemicals

- A system has been developed for the postharvest storage of fresh products under a constant overflow of volatile plant oils. With trans-2-hexenal as an example, it has been shown that a concentration range can be identified where the oil suppresses fungal development on apples without causing damage to the apples. Since the storage experiments were conducted at 5°C while apples are normally stored at 0 – 1°C, this technology could lead to a reduction of energy required for cooling of the container during transport. This technology may also be used in other sectors where fungal decay of fresh products results in significant product losses.

Task 5 Monitoring the surrounding environment and the product respons

- The currently commercially available e-nose systems seem not to be suitable for the measurement of important volatiles in the product atmosphere in a container. However, technological developments in this area are progressing at a high rate. It seems feasible that in future cheaper sensors with a higher specificity, stability and reproducibility become available.
- With the combined O_2 and CO_2 sensor developed within this project accurate measurement of O_2 and CO_2 seems possible. The device offers a good alternative for the currently available equipment. Further work is needed on the stability of the O_2 sensor.

Task 6 Chain optimisation and marketing opportunities

- Energy savings have proven to be the most interesting improvement that can be made to current reefer transport containers. The most promising strategy for container carriers for the coming years is to break further into the conventional reefer market with standard equipment with a volume and cost driven mind.
- There is no real requirement for the improvement of product quality, for which the actors are willing to pay the additional costs. Supermarkets would force the other actors in the supply chain to absorb additional costs, as quality is not seen as an additional service but as a standard.
- Diminishing the level of damage and loss by improving the product maintenance function of the reefer machine is not very much an issue as only a fraction of claims (not more than 10%) is related with the working of the reefer machine.
- Analysis has shown that there is certainly an interest with European exporters of products that are transported by air in the actual situation for a shift from air to sea. For a container carrier this would only mean a small volume, for which high investment risks in specific equipment should be made.
- Thorough analysis of the position and strategy of a container carrier in the reefer market has shown that as long as the reefer segment is integrated in the corporate strategy of the container carrier, which aims at cost minimisation and volume maximisation, focus should not be put on development of a variety of special equipment for small market niches.
- At the moment and also within the time horizon of five years, intermodal modalities are not offering a viable alternative to climate controlled road transport. Both on the demand side as on the supply side things should be changed to make a match eventually possible.
- Additional requirements that the market imposes for a new to develop reefer container are:

- on-line monitoring
- relative humidity control.

Task 7 Development of integrated dynamic control strategies

- With the use of the predictive capacities of the different model components it is possible to determine the most accurate and optimal settings for the container transport of agro-material. This means that energy consumption is largely reduced as it is directed towards the actual needs of the product. Through the measurement and estimation of product response it will be possible not only to monitor, but also to control the product and its quality directly.
- Although the estimation of product response is difficult, it is possible to get a measure for product activity and its response on climate changes and both in simulations and small-scale experiments promising results were achieved for apples (with absence of leakage).
- To allow for future implementation some remaining problems need to be solved (oscillations and upscaling).
- A Model Predictive Controller was developed specifically for the transport operation, although several time-scale related problems remain to be overcome in further research to realise both an energy efficient transport as well as a good product quality of the transported products.

With respect to future co-operation several discussions were held between the existing partners as well as with new partners. New projects partners should be transporting products and act as end-users of the developed technology. An important milestone was the submission of the proposal "Quest: Quality and Energy efficiency in Storage and Transport of agro-materials" (2002T1151) to the E.E.T.-office.

1 General

1.1 Introduction

The focus of the CEET2005 project is to substantially reduce energy within the transport sector, according to EET theme 4. Key tasks are:

- maintenance of product quality (Task 1),
- optimal climate conditioning (Task 2),
- energy savings (Task 3),
- application of green chemicals (Task 4),
- integration of climate and product sensors (Task 5),
- logistics (Task 6) and
- overall system control (Task 7).

Most of the results presented in this report are obtained by the work carried out in the integration phase. In the integration phase, all information from the individual tasks will be combined.

1.2 Project layout

The work plan for each task is described at the end of this report. The following persons have made contributions to the work carried out in this report:

Carrier Transicold:	M. Griffin, S. Duraisamy, C. McHugh, M.N. Fleming	
P&O Nedlloyd:	P. Eekel, D. Marjoram, D. Godfrey, L. van der Lugt, F. Waals	
The Greenery International:	J. Smits, J.C. de Leeuw, K. de Kat, J. Rodenburg	
Ecofys:	H. Opdam, R. Heller	
ATO:	W. van den Broek	G. van den Boogaard
	M. Strous	H. Peppelenbos
	R. van den Boogaard	R. v.d. Sman
	M. Sanders	H. de Wild
	L. Lukasse	H. Timmer
	P. de Leeuw	R. Moezelaar
	D. Somhorst	J. Slotboom
	T. Koopen	

1.3 Publications and PR actions

- Intermodal conference & Exhibition, Rotterdam, The Netherlands, 1-3 December 1998: oral presentation "Gene modification and the impact on the world wide fresh produce trade", H. de Vries
- RPPC Food seminar, Rotterdam, 17 November 1998: oral presentation "De toekomst van transport van verse en minimaal verwerkte producten", H. de Vries
- Ademhalende appel zorgt zelf voor ideaal klimaat, Nieuwsblad Transport, 28 November 1998.
- Container met zonnepaneel in de maak; energiezuinig transport brengt verre markten dichterbij, Vakblad Oogst, LTO Nederland, 26 maart 1999.
- Transportkrant (June 99): interview J. Sillekens (ATO)
- TransAsia conference (August 99): oral presentation H. de Vries (ATO)
- Fluent User Seminar, UK (Sept 99): oral presentation and paper R. vd Sman (ATO)
- Reefer conference, UK (Sept 99): oral presentation T. Gaubatz (Carrier Transicold)
- G.J.C. Verdijck, L.J.S. Lukasse, J.J.M. Sillekens, Aspects of control structure selection in post-harvest processes, Agricontrol 2000, 10-12 juli, Wageningen, The Netherlands, (2000)

- R. van der Sman, Modelling heat transfer processes in packed beds of fresh food products at pore and macro-scale, IIR Post harvest Refrigeration Conference, Oct. 2000 Murcia, Spain
- R.G.M. van der Sman, Modelling air flow in vented box packed with produce, Murcia (see appendix 1).Sillekens JJM and Govaert KAY. CEET2005: towards an improved conditioning for agro-produce, at reduced energy levels. Proc. Intermodal 2000, Genova, Italy.
- Gerwald Verdijck, Leo Lukasse: Control of Quality Evolution of Agricultural Products in Climatised Storage and Transport using Product Quality Evolution Models. Journal A, Vol. 41, no. 3, september 2000, 37-43.
- G.J.C. Verdijck, G. van Straten, H.A. Preisig, A control methodology for product quality control in climate controlled operations involving agro-materials-with an application to controlled atmosphere container transport of agro-materials, ESCAPE 11, Kolding, Denemarken
- Leo Lukasse, Gerwald Verdijck, *Beheersing van kwaliteitsverloop van AGF-producten tijdens geklimatiseerde opslag en transport,* Koude & Luchtbehandeling, vol. 94, no. 4, 32-38.
- Leo Lukasse, Riki van den Boogaard, Mark Sanders, Gerwald Verdijck, Ruud van der Sman, Gerard van den Boogaard en Herman Peppelenbos, *Koelcontainers: stand van zaken en nieuwe ontwikkelingen,* Koude & Luchtbehandeling, vol. 94, no. 6, 22-27.
- R. van der Sman: Lecture modeling at Carrier Transicold, Syracuse USA.
- Container transport of fresh products: saving energy, securing product quality; H.A.G.M. van den Boogaard, M.G. Sanders, S.O. Tromp, G.J.C. Verdijck; ATO, Wageningen, The Netherlands. Lecture at CA 2001, 8th International Controlled Atmosphere Research Conference, 8-13 July, Rotterdam, The Netherlands.
- Model predictions and control of conditions in a CA-reefer container; R.G.M. van der Sman, G.J.C. Verdijck ATO, Wageningen, The Netherlands. Lecture at CA 2001, 8th International Controlled Atmosphere Research Conference, 8-13 July, Rotterdam, The Netherlands.
- On-line estimation of respiration/fermentation rates in CA facilities: the (im)possibilities; Lukasse, L.J.S., Ooijen, H.H.J. van, Budding, J. ATO, Wageningen, The Netherlands. Poster CA 2001, 8th International Controlled Atmosphere Research Conference, 8-13 July, Rotterdam, The Netherlands.
- Respiration rates of apples (cv. Elstar) during changes in temperature and gas conditions; Sanders, M.G., ATO, Wageningen, The Netherlands. Poster CA 2001, 8th International Controlled Atmosphere Research Conference, 8-13 July, Rotterdam, The Netherlands.
- G.J.C. Verdijck, J.J.M. Sillekens, H.A. Preisig, A model structure for product quality in processing agro-material for process control purposes, Journal of Food Engineering, Vol. 51 Issue 2. P. 151-161
- G.J.C. Verdijck, G. van Straten, A Modeling and Control Structure for Product Quality Control in Climate Controlled Processing of Agro-material, Control Engineering Practice, Vol. 10, issue 5, p. 533-548.

1.4 Progress versus project planning

According to the original project planning the project should be finished shortly after the large scale container test (results of which are shown in CEET2005 Scientific Report April 2001 – January 2002). However, to enable a thorough analysis of the results the projects was extended to June 2002. Although, as mentioned before, in this report the main results of the whole project are presented, the focus will be on phase 3: *integration of all tasks*. The results are in accordance with configuration 2 as described in EET report June 2000.

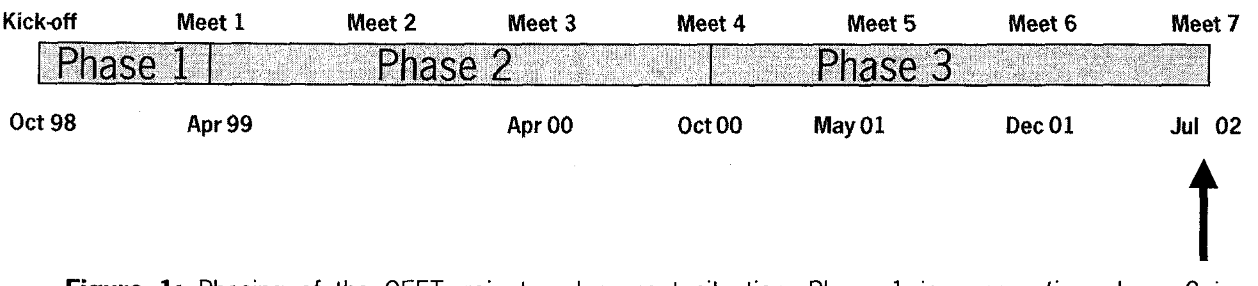

Figure 1: Phasing of the CEET-project and present situation. Phase 1 is *preparation*, phase 2 is implementation phase and phase 3 is *integration of all tasks.*

1.5 Realization project aims

Product quality and energy reduction

We have shown that by means of a new control algorithm, which dynamically changes set points, significant energy reduction in refrigerated container transport of perishables can be obtained without unacceptable loss of product quality. In a full-scale container experiment it was demonstrated that energy savings of 63% can be achieved between conventional cooling and an energy efficient cooling scenario. Of this reduction in energy use for climate control 40% was due to reducing the fan speed to half speed and another 23% reduction could be achieved by periodically cycling the cooling system on and off. The average firmness of apples stored in the container under this scenario with reduced energy use did not differ from firmness of apples stored at constant temperature.

The outcome of a quantitative assessment of the feasibility of a solar system showed that usage of a solar system is only beneficial when the energy demand can be reduced by 75-80%. Since the present estimations for power reduction are in the range of 30-50%, it is not likely that the required reduction can be achieved for solar systems. Therefore, the presently used gensets are chosen for further experimentation.

1.6 Bottlenecks

As mentioned in EET report April 2001 the main bottlenecks were the communication protocol and the availability of resources at ATO.

The communication protocol for communicating between computer and refrigeration unit was extremely important for the full-scale container test performed in this phase of the project. For the experiment the refrigeration unit communicated with an external PC calculating the optimal settings for energy savings (without harming the product). The integration of the control concepts into a saleable product will require some further efforts.

With the granted extension of the project to June 2002 the bottleneck concerning the availability of resources at ATO was solved and all results (e.g. full-scale container experiment) will be analysed thoroughly.

1.7 Milestones

In the 3rd phase of the project a big milestone was the full-scale container experiment. This experiment will show the possibilities for significant energy reductions, while keeping product and product quality at the desired levels. Furthermore, results of the experiment will be used for validation of all models and calculations from the previous phases of this project. The experiment demonstrated that significant energy reduction for climate conditioning can be realized (63%) without negative effects on product quality. Further details are described in the CEET2005 Scientific Report April 2001 – January 2002.

2 Financial Progress

The financial report has been sent to the E.E.T. office on 21 March 2002.

The planned budget and the budget realised until 31 December 2001 is as follows:

Planning budget:	F.O.: euro 3.545.416	I.O.: 1.631.548	P.O.: 79.412	tot: 5.256.375
Realisation budget:	F.O.: euro 3.167.806	I.O.: fl 876.156	P.O.: fl	tot: fl 4.043.961

Due to the results of the study on solar energy in container transport Shell Solar Energy did not consume their full budget (remaining budget F.O. fl. 99.370). At the end of the project the budgets for ATO and P&O Nedlloyd will be consumed for about 100%. Estimated total realisation of the budget will amount to fl. 4.900.000.

3 Evaluation Parameters

The evaluation parameters for this project (Evaluatieparameters E.E.T. project EETK97132) will be evaluated listed by Economic, Ecological, Technological parameters and Co-operation. If relevant a reference to a specific task will be mentioned and more details concerning this topic can be found in the documentation concerning this task in the CEET2005 Scientific Report April 2001 – January 2002.

3.1 Economic evaluation parameters

3.1.1 Market share of container transport of agro-products
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.

3.1.2 Change from road transport to rail and inland waterways
Analysis has shown that there is certainly an interest with European exporters of products that are transported by air in the actual situation for a shift from air to sea transport. For a container carrier this would only mean a small volume, for which high investment risks in specific equipment should be made.
Thorough analysis of the position and strategy of a container carrier in the reefer market has shown that as long as the reefer segment is integrated in the corporate strategy of the container carrier, which aims at cost minimisation and volume maximisation, focus should not be put on development of a variety of special equipment for small market niches.
At the moment and also within the time horizon of five years, intermodal modalities are not offering a viable alternative to climate controlled road transport. Both on the demand side as on the supply side things should be changed to make a match eventually possible.

3.1.3 Economic growth and container units
For all companies involved in the project, introduction of a new container concept is expected to contribute to an increase in market share due to exploration of new markets, improved competitiveness of the improved product and an improved image due to the use of sustainable technology. However, to achieve this, the product should be developed further. This was the main motivation of the project partners for a follow-up of the project.

3.1.4 Competitive market developments
There is a potential market for replacing air transport by sea transport. However, this replacement market seems to be small and the benefits of the technology are dependent on product price, which itself will be influenced by transported volumes.

3.1.5 New commercial activities as spin-off from the project
The project resulted in several new co-operations between partners as described in Section 7 of this document. For ATO the activities in the project contributed to other activities in the areas of sensor development (ethylene sensor), packaging development, control in long-term storage operations (potatoes).

3.1.6 Integration with existing equipment
Thorough analysis of the position and strategy of a container carrier in the reefer market has shown that as long as the reefer segment is integrated in the corporate strategy of the container carrier, which aims at cost minimisation and volume maximisation, focus should not be put on development of a variety of special equipment for small market niches.
At the moment and also within the time horizon of five years, intermodal modalities are not offering a viable alternative to climate controlled road transport. Both on the demand side as on the supply side things should be changed to make a match eventually possible.

3.1.7 Market acceptation

To get an insight in the dimensions of the benefits for the different market actors that are involved with a reefer container, a supply chain analysis was performed. Results of the supply chain analysis are:

- The power of the supermarket organisations in the supply chains of fresh produce is increasing.
- Supermarket organisations focus both on quality control as on cost control.
- Importers have changed their role and position in the supply chain under influence of the retailers' taking control over the supply chains.

Supermarket organisations will probably outsource supply chain activities to one dedicated partner combining product knowledge, logistics knowledge, trading capabilities and IT knowledge. This partner, probably a partnership between actual actors in the supply chains, will translate market requirements into transport requirements:

- cost control is very important
- year round supply and availability of variety is important.

Energy savings have proven to be the most interesting improvements. The most promising strategy for container carriers for the coming years is to break further into the conventional reefer market with standard equipment with a volume and cost driven mind.
There is no real requirement for the improvement of product quality, for which the actors are willing to pay the additional costs. Supermarkets would force the other actors in the supply chain to absorb additional costs, as quality is not seen as an additional service but as a standard.

To assure market acceptance the potential end-users should be involved in the new project. Especially an association for import and export companies in the Netherlands such as Frugi Venta would be beneficial.
Additional requirements that the market imposes for a new to develop reefer container are:

- on-line monitoring
- relative humidity control.

3.1.8 Return on investment related to competitive products

As mentioned earlier market acceptance requires, among other things, a close monitoring of product quality. This will be one of the main objectives in the proposed project.

3.1.9 Savings on energy reduction

In a full-scale container experiment it was demonstrated that energy savings of 63% can be achieved between conventional cooling and an energy efficient cooling scenario. Of this reduction in energy use for climate control 40% was due to reducing the fan speed to half speed and another 23% reduction could be achieved by periodically cycling the cooling system on and off.

The energy savings would be significant in the transport of perishables, as e.g. a margin of 20 Euro for transhipping a container from New Zealand to Europe would be relatively high. Energy savings with the new transport concept for this route amount to 65 Euro for one container shipment. On average 4 shipments per container per year are realised resulting in cost savings of approximately 250 Euro due to energy reduction. If the new transport concept would be applied to all containers used on the trade from New Zealand to Europe for sea transport of apples, a yearly energy saving of 8.6 M kWh could be realised. This relates to a saving of about 1600 ton of fuel. Certainly, this would mean a significant cost saving in relation to the current margins.

Another cost saving would be the shift from air transport to containerised sea transport. E.g. tomatoes on the vine is an important greenhouse product for Dutch export (0.275 Mton tomatoes on the vine of in total 0.52 Mton tomatoes production in The Netherlands). 12% of Dutch tomatoes on the vine export is to the United States and most of this transport is by air. For a distance of 5847 km (Amsterdam-New York) and averaged energy consumption rates of 9.76 MJ/ ton km (air transport) and of 0.0977 MJ/ton km (sea transport), a modal shift would result in a potential energy saving of 1.58 10^9 MJ each year. This corresponds to 439 M kWh and this would result in a cost saving of 14 M Euro for tomatoes on the vine alone (S.O. Tromp & F.I.N.G. Kreft, Energiebesparing bij de export van trostomaten naar de VS, ATO, Wageningen, maart 2002).

A reduction in energy consumption of 50% for the total volume of transported agro-products in sea containers would lead to cost savings of 56.67 M Euro.

3.1.10 Return on investment for (end)user

Investments are estimated to be 500-700 Euro, which means that a return on investment in 2-3 years is possible given on average 4 shipments per container per year. Extending these cost savings for energy consumption to the entire volume of fresh products in sea containers would mean cost savings of approximately 60 Million Euro per year.

Based on a lifetime of a reefer container of 10 years a present value of the cost savings of $1850 can be counted, based on which the investment decision can be based.

3.1.11 Economic life cycle for product

Through the cycling of the product the achievable life span of the climate unit can be extended. For robust equipment this could be doubled.

3.1.12 Effect of project on market position of partners

In the current project the partners gained from the improved image as quality supplier and an improved image due to the use of sustainable technology. In the proposed project concepts need to be developed that will realise the huge potential for energy reduction.

3.2 Ecological evaluation parameters

3.1.1 Energy savings

In a full-scale experiment for transport of apples different strategies were compared. First, the current transport strategy (A) was tested and compared with new strategies (B and C). Results are shown in Table 1.

Table 1: Energy consumption in full-scale experiment

Phase	Characteristics	Average energy consumption [kW]
A	Cooling full speed	4.907
B	Cooling half speed	2.896
C	Transport period with medium frequent cycling	1.806

This experiment resulted in energy savings between phase A and C of 63%, of which 40% between phase A and B, and 23% between phase B and C.

For the simulated transport between New Zealand and Rotterdam with a duration of 4 weeks the energy reduction (2083.9 kWh) corresponds to a reduction in CO_2 emission of 1604.6 kg.

A 50% reduction in energy consumption for the total volume of transported agro-products in sea containers would lead to a reduction in energy use of 1771 M kWh.

Considering the shift from air transport to containerised transport, as mentioned before, would result e.g. for tomatoes on the vine in a potential energy saving of 1.58 10^9 MJ each year. This corresponds to 439 M kWh 338 M kg CO_2.

3.2.2 Contribution of product to national aim of 20% energy efficiency

For the simulated and tested transport of apples in a full-scale container the reduction in energy consumption amounts to roughly 60% Therefore, more efficient transport operations can contribute significantly to the national aim for energy efficiency.

3.2.3 Savings on waste and losses (in % per unit product)
Cost savings due to reduced product loss are estimated to be 383 Million Euro per year based on an estimate of 1% reduction of product loss of the total volume of transported agro-products in sea containers.
Application of green chemicals (trans-2-hexenal) during storage decreased the number of apples infected with fungi by up to 70%.

3.2.4 Reduction in emission of waste products (related to transport)
Application of the green chemical trans-2-hexenal during storage could lower the amount of chemical compounds used in transport of fresh products. This would not only be beneficial from a ecological point of view, but also for economic reasons regarding the rules of admittance that differ between countries.

3.2.5 Ecological effects of used materials
Materials used in addition to the current equipment are software algorithms and sensors. The main benefit with respect to ecological effects could result from newly developed dedicated equipment, such as the compressor, that is fitted to the new operating strategy (e.g. cycling of compressor). This needs to be studied further.

3.2.6 Increase in life time and quality of transported products
From the full-scale experiment it was concluded that the transported products (apples) were of the same quality as the reference batch transported under current conditions. This certainly motivated the consortium to invest in a new project.

3.2.7 Use of sustainable energy
Current containers and container infrastructure are highly optimised to meet actual market demands. Developing an energy supply system that is more efficient, more reliable or based on renewable sources is therefore challenging. During sea transport, containers will usually be supplied with electricity from the ship. Efforts to improve the efficiency or apply renewable sources can turn out favourable, but will not take effect on the containers installation. On the ship there is no cost-effective alternative for use of diesel generators available now.

Transportation on trains or trucks usually involves a per-container energy supply. This offers possibilities to apply renewable, cleaner or more efficient sources, such as:

- photo-voltaic cells on the roof of the container: with the current energy demand achieved for the CEET2005 container it does not generate enough power. Photo-voltaic cells are also too fragile for handling the containers in the harbour. It could be an option to put cells on the roof of the distribution centre.
- fuel cells: cost-effective, small cells are not available yet, but after 2010 it is an applicable technology which has the potential to reduce the energy demand of containers with another 50%.
- the use of bio-diesel in conventional gensets: could be interesting depending on the location (fuel should be available at any point in the cold chain).
- absorption heat pump: still too fragile for transport application and the heat source is only available when the vehicle is driving.

It can be concluded that compatibility with the intermodality of the reefer containers is the most important problem. Besides that, techniques as the fuel cell, the absorption heat pump or bio-diesel are not developed into a cost-effective alternative yet. There is no alternative energy supply system available within 2-5 years that meets all criteria for the total cold chain.

It is shown in this report that sustainable or more efficient alternative energy supply systems, such as photo voltaic cells, fuel cells, bio-diesel or absorption heat pumps all have their drawbacks compared to the conventional systems. Not one of them can be integrated in the total cold chain within 2-5 years. This does not mean that no alternative for parts of the cold chain can be developed. Especially transportation on trains or trucks involves a per-container energy supply, which offers more possibilities for photo voltaic cells, fuel cells or absorption heat pumps than transport on ships. Still, research should be done to improve the now available techniques. Also dedicated transport from one place to the other gives more opportunities especially for bio-diesel because the supply problem is more easily to handle when only one rout has to by supplied.

3.3 Technological evaluation parameters

3.3.1 Risks

The most important risk for a successful application of developed technology is the acceptance by the end-users. Therefore, the development of a new concept should be supported by the potential users. For this, potential users such as the trade platform for fruits and vegetables Frugi Venta and importing and exporting companies such as Haluco should be included as partners in a follow-up of the project.

3.3.2 Transfer of technology to other sectors

Putting the algorithm to the market can be quick, as it just concerns a piece of software. Parts of the developed algorithms will be applicable to any refrigerated storage facility.
Also, opportunities for applications of the technologies developed for the new container concept in continental chains (improving climate and quality control in trucks, transfer of concepts to storage operations) will be assessed in the new project (Task VII).

3.3.3 Relevant new competitive developments and their impact on the project

The oxygen sensor we are developing is a good alternative for the accurate but heavy, fragile and expensive paramagnetic oxygen analysers. Competing technologies deploying the same photochemical effect for oxygen detection use remote fiber optic sensing and are more complex and much more expensive. The combination of both O_2 and CO_2 sensors in one cheap device is a major advantage compared to using separate sensors.
An accurate measurement of climate and product status allows for larger variations in climate regulation, which saves on energy for the cooling system. Proper climate control during storage and transport minimises the risk of product loss.

3.3.4 Publications, conferences, symposia and workshops

A list of publications and contributions to conferences, symposia and workshops is given:
Intermodal conference & Exhibition, Rotterdam, The Netherlands, 1-3 December 1998: oral presentation "Gene modification and the impact on the world wide fresh produce trade", H. de Vries
RPPC Food seminar, Rotterdam, 17 November 1998: oral presentation "De toekomst van transport van verse en minimaal verwerkte producten", H. de Vries
Ademhalende appel zorgt zelf voor ideaal klimaat, Nieuwsblad Transport, 28 November 1998.
Container met zonnepaneel in de maak; energiezuinig transport brengt verre markten dichterbij, Vakblad Oogst, LTO Nederland, 26 maart 1999.
Transportkrant (June 99): interview J. Sillekens (ATO)
TransAsia conference (August 99): oral presentation H. de Vries (ATO)
Fluent User Seminar, UK (Sept 99): oral presentation and paper R. vd Sman (ATO)
Reefer conference, UK (Sept 99): oral presentation T. Gaubatz (Carrier Transicold)
G.J.C. Verdijck, L.J.S. Lukasse, J.J.M. Sillekens, Aspects of control structure selection in post-harvest processes, Agricontrol 2000, Wageningen, The Netherlands, (2000)
R. van der Sman, Modelling heat transfer processes in packed beds of fresh food products at pore and macro-scale, IIR Post harvest Refrigeration Conference, Oct. 2000 Murcia, Spain
R.G.M. van der Sman, Modelling air flow in vented box packed with produce, Murcia (see appendix 1).Sillekens JJM and Govaert KAY. CEET2005: towards an improved conditioning for agro-produce, at reduced energy levels. Proc. Intermodal 2000, Genova, Italy.
G.J.C. Verdijck, G. van Straten, H.A. Preisig, A control methodology for product quality control in climate controlled operations involving agro-materials-with an application to controlled atmosphere container transport of agro-materials, ESCAPE 11, Kolding, Denemarken
Leo Lukasse, Gerwald Verdijck, *Beheersing van kwaliteitsverloop van AGF-producten tijdens geklimatiseerde opslag en transport,* Koude & Luchtbehandeling, vol. 94, no. 4, 32-38.
Leo Lukasse, Riki van den Boogaard, Mark Sanders, Gerwald Verdijck, Ruud van der Sman, Gerard van den Boogaard en Herman Peppelenbos, *Koelcontainers: stand van zaken en nieuwe ontwikkelingen,* Koude & Luchtbehandeling, vol. 94, no. 6, 22-27.

R. van der Sman: Lecture modeling at Carrier Transicold, Syracuse USA.
Container transport of fresh products: saving energy, securing product quality; H.A.G.M. van den Boogaard, M.G. Sanders, S.O. Tromp, G.J.C. Verdijck; ATO, Wageningen, The Netherlands. Lecture at CA 2001, 8th International Controlled Atmosphere Research Conference, 8-13 July, Rotterdam, The Netherlands.
Model predictions and control of conditions in a CA-reefer container; R.G.M. van der Sman, G.J.C. Verdijck ATO, Wageningen, The Netherlands. Lecture at CA 2001, 8th International Controlled Atmosphere Research Conference, 8-13 July, Rotterdam, The Netherlands.
On-line estimation of respiration/fermentation rates in CA facilities: the (im)possibilities; Lukasse, L.J.S., Ooijen, H.H.J. van, Budding, J. ATO, Wageningen, The Netherlands. Poster CA 2001, 8th International Controlled Atmosphere Research Conference, 8-13 July, Rotterdam, The Netherlands.
Respiration rates of apples (cv. Elstar) during changes in temperature and gas conditions; Sanders, M.G., ATO, Wageningen, The Netherlands. Poster CA 2001, 8th International Controlled Atmosphere Research Conference, 8-13 July, Rotterdam, The Netherlands.
G.J.C. Verdijck, G. van Straten, A Modeling and Control Structure for Product Quality Control in Climate Controlled Processing of Agro-material, Control Engineering Practice, Vol. 10, issue 5, p. 533-548.

3.3.5 Technological spin-offs

The project resulted in several new co-operations between partners as described in Section 7 of this document. For ATO the activities in the project contributed to other activities in the areas of sensor development (ethylene sensor), packaging development, control in long-term storage operations (potatoes).

3.3.6 Surplus value of new developments/spin-offs

With the new developments the transport sector is realising that technological developments should be based on product knowledge. Only the interaction between different actors will lead to market acceptance and maximum profit can be achieved.

3.3.7 Remaining technological developments for further development after project

Additional requirements that the market imposes for a new to develop transport concept are:

- on-line monitoring of product status
- relative humidity control (e.g. condensation).

The monitoring involves research on new sensors that measure product response in relation to climate conditions. Using the new transport strategies for transport of fresh products hardware components may be dedicated to these new circumstances. Preventing e.g. condensation problems in large containers requires research on distribution of climate conditions over the stowage space, e.g. moisture.

3.3.8 Maintenance of product quality

Based on observations of task 1, further research on the relationship between climate conditions and product quality is recommended, which will be necessary for successful implementation of the concept of reduced energy use for climate conditioning and maintenance of product quality. This research should focus on:

- the response of fresh products to changes in climate conditions (temperature and gas conditions),
- the possibility to monitor product response under static conditions and variable climate conditions,
- the possibility to preserve quality by changing climate conditions based on signals from a product monitoring system and
- the perspective to use product response for a dynamic control of transport (storage) conditions.

Product response might be monitored by ethylene production or gas exchange rates, differences in storage temperature (T_{in} vs T_{out}). Although ethylene production seems to be a powerful tool to monitor product response, other on-line measurements or a combination might even provide more accurate way to control product quality.

3.3.9 Monitoring Product Quality

There seems to be plenty of scope to develop product monitoring during transport or storage further. In order to avoid unnecessary climate conditioning and energy use, input from sensors giving information about product status seems very useful.

Measurements that should be investigated further are firstly the measurement of ethanol and ethylene. These compounds give important information about unwanted ripening of the product. ATO has recently developed an ethanol sensor for use in commercial fruit storage. First tests have shown that with modifications this sensor may also be suitable for the measurement of ethylene.

Other measurements that should be investigated further are the (two- or three- dimensional) measurement of temperature in the container, the monitoring of water loss by the product and the measurement of condensation on the product. Technological advances in these areas are fast and implicate that further development of these techniques for application during storage or transport seems feasible.

3.3.10 Optimisation of climate control under energetic and quality constraints

The product quality change model needs to be validated using subsequent experiments. Also, similar models will be developed for other produce such as tomatoes, bell peppers etc. The focus of these models will be the link with measured product response such as respiration and ethylene production of the produce. If this link can be established, monitoring quality during transport can give an indication of the quality change of the product.

Crucial to the final success of the new method for energy reduction by dynamically changing set points is that no condensation occurs on the packed product. This aspect has not yet been investigated fully. Condensation may limit the amount of cycling of the cool unit. Hence, interaction between fluctuation of the supply air temperature and condensation has to be investigated. In container experiments using open trays as packaging for the product, we have observed that condensation has occurred very locally, namely mainly in the top layer of the pallets. For a reliable prediction of condensation, a more detailed description of the macro- and micro-climate inside the cargo space is needed. In the new project this will be studied in Task III. This knowledge, together with extensive product knowledge, should be incorporated in the control algorithms that calculate most efficient climate settings. These algorithms should be developed further from already available algorithms and some should be newly developed and dedicated to the transport of fresh products. These developments are part of Tasks IV and V in the new project.

The model describing the energy consumption of the cool unit, assumes that no ice frost occurs on the evaporator coil. During transport of produce requiring low temperatures, such as apples, this is not a valid assumption. Frost formation is known to have a significant impact on the cooling efficiency of the cool unit. Hence, for optimal operation of the supervisory control algorithm this effect has to be incorporated in the cool unit model.

During several container experiments we have observed a temperature gradient between front and backside of the cargo space. This is due to a quite non-uniform distribution of the airflow in the cargo-space. Preliminary calculations have shown that the airflow mainly flows between the first rows of pallets. Better airflow distribution can possibly be obtained by a 'false ceiling' in the headspace of the container. By extension and improvement of the preliminary model on the airflow distribution we can obtain a good design of this 'false ceiling'. Other benefits can be obtained by this false ceiling. By directing the airflow in the headspace directly above the pallets, to flow from front to back, also the risk of condensation can be reduced significantly, because now this airflow will not be cooled, and therefore will not give condensation. Furthermore, redirection of the airflow will mean that during cycling of the cool unit, temperature fluctuations in the return air will be less pronounced than in the system nowadays. Hence, this also may lead some extra energy reduction. These ideas will be considered for their applicability in Task VI.

3.3.11 Sustainable energy and energy supply systems

It is shown in this report that sustainable or more efficient alternative energy supply systems, such as photo voltaic cells, fuel cells, bio-diesel or absorption heat pumps all have their drawbacks compared to the conventional systems. Not one of them can be integrated in the total cold chain within 2-5 years. This does not mean that no alternative for parts of the cold chain can be developed. Especially transportation on trains or trucks involves a per-container energy supply, which offers more possibilities for photo voltaic cells, fuel cells or absorption heat pumps than transport on ships. Still, research should be done to improve the now available techniques. Also dedicated transport from one place to the other gives more opportunities for especially bio-diesel because the supply problem is more easily to handle when only one rout has to by supplied.

Summarised, the recommended research is to investigate the feasibility of the implementation of the techniques developed in this project in combination with photo-voltaic cells for continental transport and distribution centres, bio-diesel for dedicated routes, fuel cells for continental transport and absorption heat pumps for continental transport.

3.3.12 Application of green chemicals

In the research concerning the use of green chemicals for preservation of product quality, one variety of apple has been studied and the apples were mechanically damaged and artificially infected with spores of *Penicillium expansum.* In future research, the efficacy of trans-2-hexenal as natural anti-fungal agent should be confirmed with other apple varieties, apples of various ages, apples infected with spores of other postharvest pathogenic fungi, and with un-inoculated apples. Also other products and volatile plant oils should be considered.

3.3.13 Market introduction strategy

Market analysis has shown that development of a continental reefer unit is not viable (at least for the next five years). Result of the analysis is that for the coming five to ten years road transport will remain the main mode of transport for fresh products. Application of the technology as developed by ATO to the road transport sector or to storage facilities in order to gain energy savings in road transport or during storage of fresh products should be considered.
Both technological as market and logistical research is needed in order to come to market implementation.

3.4 Co-operation

3.4.1 Projectleadership

In the project CEET2005, ATO has been projectleader and ATO will also be projectleader for the follow-up of the project. Although P&O Nedlloyd was willing to be projectleader of the whole project, it was decided that ATO would continue their role as projectleader, because it was not possible to fit in the administrative part of the projectleadership in the P&O Nedlloyd organisation.

3.4.2 Change of partners

P&O Nedlloyd, Carrier Transicold, ATO and the Greenery intend to continue their co-operation after the end of the project in follow-up of the project. For this follow-up a number of new partners have been approached. ATO has had frequent contacts with potential end-users of the new technology such as importing and exporting companies like Frugi Venta and Haluco and has discussed their role in a follow-up project. For the development of the monitoring systems R&R Mechatronics will be involved. Their role will be the development of prototype sensors to production types and the actual production of the sensors. The storage division of the Greenery will be involved in the follow-up of the project for investigations of transfer of the developed technology to storage facilities.
Co-operation between partners was visible in meetings and the exchange of information, furthermore in combined activities, such as the full-scale container experiment where The Greenery, P&O Nedlloyd, Carrier Transicold and ATO closely collaborated.

3.4.3 Co-operation and meetings

During the last phase of the project, phase 3 *Integration of all tasks,* there has been a lot of interaction between all partners in the project. The set-up and the results of the full-scale container experiment have been elaborately discussed among the partners.
Furthermore, starting approximately in July 2001 the follow-up of the project has been discussed among the partners of the project in both bilateral meetings among partners and in meetings with all project partners. For this purpose ATO has visited Carrier Transicold in August and a number of times a videoconference was organised to allow participation of Carrier Transicold in the project meetings.

With respect to future co-operation several discussions were held between the existing partners as well as with new partners. New projects partners should be transporting products and act as end-users of the developed technology. An important milestone was the submission of the proposal "Quest: Quality and Energy efficiency in Storage and Transport of agro-materials" (2002T1151) to the E.E.T.-office.

3.4.4 Contribution of co-operation to end-result(s)

The multi-disciplinary nature of the project makes co-operation among partners vital for achieving the project aims. In the course of the project co-operation has greatly improved. In the follow-up of the project the interaction between partners on technological, marketing and logistics aspects will be continued.

3.4.5 Cooperation outside the project

Besides co-operation in the project CEET 2005, there are several other joint projects in which partners of the proposed project co-operate. ATO and The Greenery have a number of joint projects, mainly concerned with quality and storage of agro-products. ATO has a consultancy contract with the business unit "Fruit Storage" of the Greenery. Within this co-operation ATO advises the Greenery about storage conditions and writes protocols for storage, and also advises about new cultivars, product quality checks and knowledge transfer to employees and customers. Another project in which ATO and The Greenery co-operate is the development of the storage concept "DCS" (Dynamic Control System). This system allows adjustment of the proper gas conditions during long-term storage based on ethanol production of the agro-product. The Dynamic Control System has been tested and implemented at storage facilities of the Greenery in the past few years. Another recent co-operation is the project "KwaliCon" in which besides ATO and the Greenery grower corporations and trade companies participate to enhance quality and storage duration of Conference pears. An important aspect of this project is the development and implementation of practical methods for reduction of water loss of pears in long-term storage. Also with companies falling under the umbrella of Frugi Venta ATO has carried several joint projects, mainly related to quality of fruit and vegetables, cooling methods, storage, and packaging and distribution concepts.

P&O Nedlloyd is one of the main customers of Carrier Transicold. For example in September 2001, P&O Nedlloyd awarded an order for 14.500 container refrigeration units to Carrier Transicold. The size of this order approaches one-third of the estimated overall annual market for container refrigeration units.