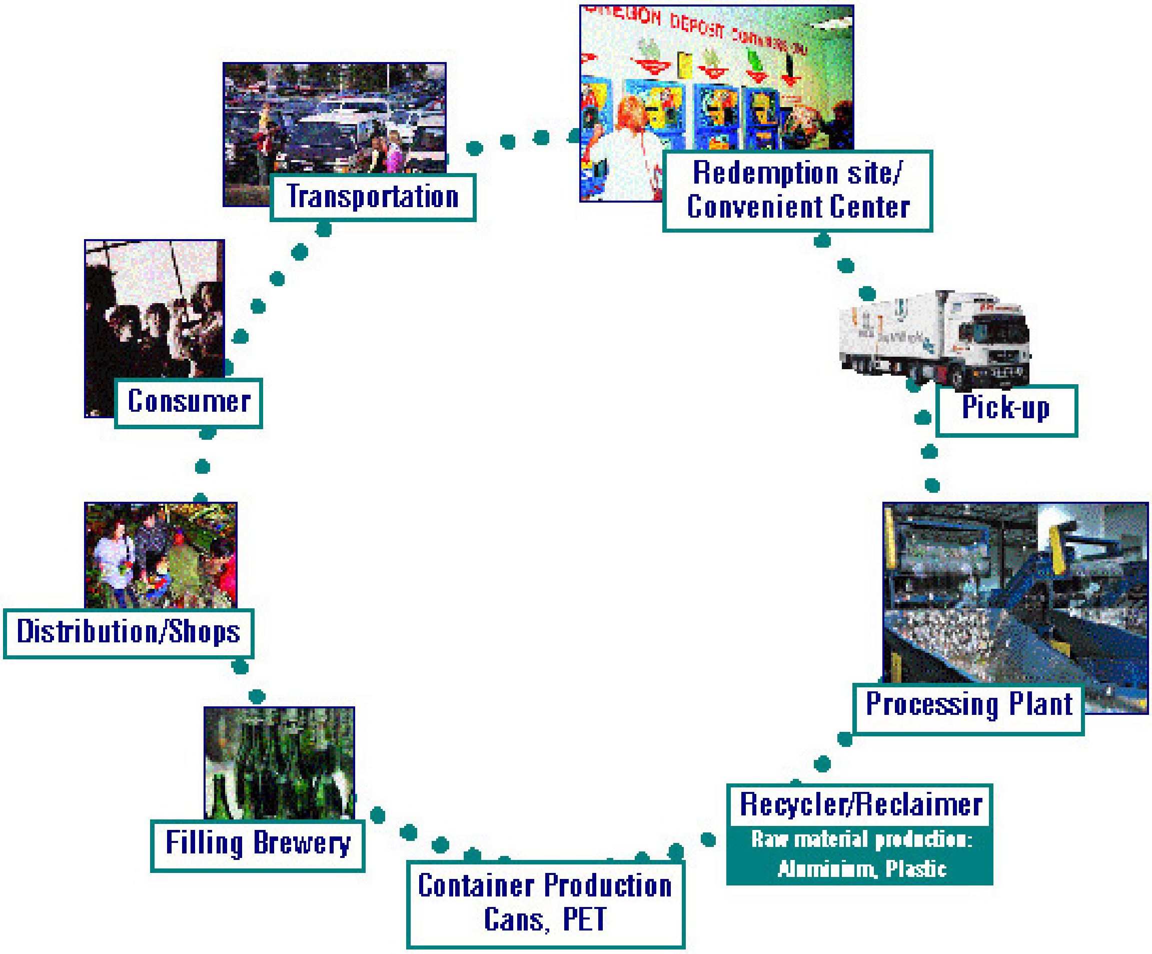
Environmental and economic assessment of Tomra recycling systems in Connecticut and California, and for manufacture and use of the T42 Tomra reverse vending machine



Eco-Efficient Solutions for Recycling Systems for

Tomra Systems ASA

Elin Økstad, Solveig Steinmo, Hanne Lerche Raadal, December 1999 OR 43.99

REPORT OVERVIEW

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Report heading: **Eco-Efficient Solutions for Recycling Systems for Tomra ASA**	**Autor(s):** **Elin Økstad** **Solveig Steinmo** **Hanne Lerche Raadal**
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Report employer: Tomra and The Norwegian Research Council

Employer reference: Bernt Saugen at Tomra and the program board of VARP

Resume:

This report gives the main results and conclusion from the project on Eco-Efficient Solutions for Recycling Systems for Tomra Systems ASA.

The project was organized under the program for Packaging Research set up by Norwegian Research Council and "Samarbeidsrådet for Emballasjeforskning", where improved eco-efficiency of packaging systems are considered.

The study is an important basis for Tomra Systems' participation in the Industrial Ecology program under the P-2005 Research Program.

The main aim of the project was to develop knowledge in systems analysis, LCA methodology and its application in the organization of Tomra Systems.

The environmental and economic properties of Tomra recycling systems for PET and aluminum beverage containers have been studied in two states in the USA, Connecticut and California. Further, the environmental and economic performance of manufacturing and use of the Tomra machine T-42 was analyzed.

On the basis of the results, improvements to both the recycling system as well as the machine have been proposed. Methodological issues are discussed, and further methodological studies are proposed for the P-2005 Research program.

Keywords: ***recycling systems** ***eco-efficiency** ***eco-design**	**Officiality: Open** **This side:** Open **This report: Open**	**Total number of pages:** .

Date:

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Project leader **Director of Institute**

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1 BACKGROUND

1.1 Introduction

This report presents the main results and conclusion from the project on Eco-Efficient Solutions for Recycling Systems for Tomra Systems ASA.
The results are taken from the Tomra internal reports:

- "Environmental and economics assessment of manufacture and use of the T42 Tomra reverse vending machine" and
- "Environmental and economic assessment for Tomra Recycling Systems in California and Connecticut".

In this open report, all general results and conclusions are shown, but Tomra internal background data and results connected to performance, economy and strategy are omitted. More information about the background data these studies are based on can be obtained from Solveig Steinmo at Tomra.

The project was organized under the program for Packaging Research set up by Norwegian Research Council and "Samarbeidsrådet for Emballasjeforskning", where improved eco-efficiency of packaging systems are considered. The study is an important basis for Tomra Systems' participation in the Industrial Ecology program under the P-2005 Research Program.

The project was started in October 1998, and was finished in December 1999.

1.2 Project organization

The project was organized with a project group and a reference group.

The project group had the following participants:

- R&D Processing Group Manager Bernt Saugen, Tomra Systems ASA (Tomra project manager)
- Project Engineer Solveig Steinmo, Tomra Systems ASA
- Research scientist Hanne Lerche Raadal, Østfold Research Foundation
- Section Manager Elin Økstad, Østfold Research Foundation

The reference group had the following participants:

- Professor Helge Brattebø, NTNU
- Senior research scientist/Professor II Ole Jørgen Hanssen, Østfold Research Foundation/NTNU

The working group had frequent meetings and work sessions throughout the project period. The working group met with the reference group 3 times during the project.

The internal project manager reported to Vice President R&D Terje Hanserud as responsible for the project in Tomra Systems' management group.

2 PROJECT OBJECTIVES

The main aim of the project was to develop knowledge in systems analysis, LCA methodology and its application in the organization of Tomra Systems. The results should be given in a form that can be used as:

- Input to Ecodesign strategies for Tomra Systems' manufacture of recycling machines.
- Input to Tomra Systems strategic development process and to the development of the ISO 14001 program.
- Input to the research activities in P-2005 Industrial Ecology program from Tomra Systems.

The life cycles of deposit beverage containers of PET and aluminum have been studied in two states in the USA, Connecticut and California. These states have been selected because of Tomra's high involvement in the material handling of used beverage containers here, and since the two states have different deposit systems, a wider variety of solutions would be covered. In addition, Tomra Metro in Connecticut was assumed to have a large proportion of it's information systematized.

Further, the environmental and economic performance of manufacturing and use of the Tomra machine T-42 was assessed to provide input to Ecodesign strategies for Tomra, as well as input to development of an ISO 14001 program.

The project plan included the following main activities:

1. Data collection and environmental and economic analysis of a Tomra Reverse Vending Machine
2. Data collection and environmental and economic analysis of Tomra recycling systems in California and Connecticut
3. Data collection and environmental and economic analysis of curbside recycling systems
4. Discuss options for improvement of the Tomra systems.
5. Develop reports for application in Tomra Systems own organisation as well as an open report for publication.

3 METHODICAL APPROACHES

3.1 Life Cycle Assessment (LCA)

3.1.1 General method of LCA

Life Cycle analyses can be performed both in environmental and economic terms, LCA and LCC respectively. This study has performed both analyses.

The Life Cycle Assessment was carried out according to the standard ISO 14040-43. The results are meant for internal information and improvement actions only.

Life Cycle Assessment (LCA) is in ISO described as:
"A technique for assessing the environmental aspects and potential impacts associated with a product, by

- *compiling an inventory of relevant inputs and outputs of a product system*
- *evaluating the potential environmental impacts associated with those inputs and outputs*
- *Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.*

An LCA studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle – to –grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health and ecological consequences".

The information from both LCA and LCC is particularly useful to answer the following questions:

- What are the most important environmental and resource problems related to the system?
- Where in the life cycle of the product do they occur?
- What are the most cost efficient solutions to improve the system?

An LCA is divided into four different stages:

1. Goal definition and scooping
2. Inventory analysis
3. Impact assessment
4. Improvement analysis

The ISO Standard 14040 is stating that the depth of detail and time frame of an LCA study may vary to a large extent, depending on the definition of goal and scope. There are specific requirements that apply when LCA is used to make comparative assertion that is disclosed to the public.

Goal definition and scoping
In the goal definition and scooping stage the purpose of the study has to be stated along with a definition of the functional unit and a system description.

Functional Unit
The functional unit shall be chosen to reflect the performance of the studied product. The functional unit will have a key influence on the results of the study. All data will be normalized according to the functional unit.

In order to make comparisons between product systems, these product systems have to fulfil the same function. An example of a functional unit for an LCA analyzing different materials for road surface could thus be formulated as this: *"1 mile of road used and maintained for 10 years"*. By defining the functional unit as such, the materials and energy required for repair, maintenance, lightning and road marking has to be included in the analysis.

Inventory analyses
In the inventory stage all relevant information about energy and resource depletion, emissions and waste generated throughout the life cycle is collected and systemized.

Impact assessment of potential environmental effects
In the impact assessment stage, the environmental impacts of the product system are calculated by classification, characterization and valuation of the impacts.

In the classification step the different emissions and energy demands are assigned to different impact categories based on the expected type of impacts on the environment (i.e. resource depletion, human health impacts and ecological impacts). The main purpose of the activity is to describe which potential environmental effects the inputs and outputs may cause.

In the characterization step the potential contributions from the different inputs and outputs are connected to the different impact categories, and the contributions to the same impact category are added up. Examples of environmental impacts that may be assessed are resource depletion, human health, global warming, acidification, and depletion of stratospheric ozone, eutrophication, photo-oxidant formation and eco-toxic impacts.

In the valuation, the relative importance of different environmental impacts is weighed against each other and an index of the relative importance of the environmental impacts is calculated. Different valuation models are applied to carry out the valuation step. The goal for all models is to set a one-dimensional value on resource use and emissions in order to calculate the total environmental impact of a product in this analysis.

3.1.2 Specific methodological approach: the Tomra Reverse Vending Machine

The functional unit of the Tomra Reverse vending machine was chosen to be
"The manufacture, operation for 10 years, and waste management of the T-42 Tomra Reverse Vending machine".

In this project, the impact categories resource depletion (in terms of primary energy), global warming potential, acidification and eco-toxicity potential were included in impact assessment. However, in this report, only the impact categories primary energy consumption and global warming potential are shown.

A final valuation where the relative importance of different environmental impacts is weighed against each other has not been carried out.

3.1.3 Specific methodological approach: the recycling system

The functional unit of the Tomra recycling systems was chosen to be
"1 ton of reclaimed material after passing through the Tomra recycling system".
Both recycling and reclaiming of PET and aluminum was analyzed in the project.

In the project, the impact categories resource depletion (in terms of primary energy) and global warming potential were used. This choice is made for two reasons:
1) global warming gives a good picture of the environmental impact potential for this particular system and 2) the input data for energy consumption and energy efficiency are of good quality for most parts of the system, thus enabling an aggregation and comparison of results derived from energy use.

Only one of the impact categories, primary energy consumption, is shown in this report. The results given in the Tomra internal report, showed that the energy consumption and releases of climate gases are proportional, since most of the energy is based on fossil fuel. Thus, the conclusions can be drawn on the basis of the primary energy consumption.

3.2 Life Cycle Costs

3.2.1 General method description

Within «Systems Engineering», methods for life cycle cost are given (Blanchard & Fabrycky 1990, Asbjørnsen 1992). Based on structure and life cycle of a product system, it is possible to calculate a product's life cycle costs per functional unit for the customer. Thus, different products, which are to fulfil the same function, can then be compared in economic terms.

The analysis can be a simple cash flow analysis for all costs and income related to the product structure and the functional unit. A simple cash flow analysis can be undertaken if it is possible to assume that inflation and interest rate will balance on a long term basis. Alternatively, the rates for inflation and investments can be included for the calculation of net present value of the cash flow throughout the life cycle.

Most products are the source of environmental impacts when they are produced, used and discharged. These impacts are most often not transferred to economic expressions, maybe except for the cost of cleaning equipment in production. In the future, it is expected that external environmental costs will be internalized in budgets and economic systems, through environmental taxes, financing of recycling systems and waste treatment.

3.2.2 Specific methodological approach: The Tomra Reverse Vending Machine

The life cycle costs for the Tomra reverse vending machine are illustrated with a simple cash flow analysis as well as a calculation of the net present value. The cash flow analysis is meant to illustrate the economic consequences both for the customer and Tomra at a given time.

The net life cycle costs for the Tomra machine includes:

- Purchase price
- Energy cost for the use of the machine
- Operation cost (daily cleaning and maintenance)
- Costs of service and repair (Fixed and variable costs)
- Costs related to disposal

3.2.3 Specific methodological approach: the recycling system

The life cycle costs analysis for the total recycling systems was carried out as a simple cash flow analysis.
The life cycle costs analysis of the machine included the following costs:

- *RVM costs* include machine depreciation (10 years), service, electricity cost, refurbishing, and disposal
- *Store operation* includes daily cleaning and maintenance, emptying bins, and building rent for machine “space”.
- *Convenience Center costs* include 30 hours of labor per week and container (bin) cost
- *Transport costs* include truck operation, labor and fuel
- *Processing costs* include equipment, maintenance, labor and energy
- *PET reclaiming* includes all the connected costs, and is calculated using material prices

Interest rates were not included, and the equipment depreciation is assumed equal for each year. Where possible, the average costs for 1998 was used.

3.3 Tools and databases

LCA Inventory Tool, version 3.0, developed by Chalmers Industriteknik, was used along with Excel to implement and analyze the collected data.

The LCA Inventory Tool is an expert tool for life cycle assessment, systemizing inventory data and calculating the inventory results (see 3.1.1). The inventory results are exported to Excel for impact assessment and graphic presentation.

4 SYSTEM DESCRIPTION AND ALLOCATION METHODS

4.1 System description: the Tomra Reverse Vending Machine

Figure 4.1 illustrates the life cycle of the Tomra machine as it is analyzed in this study.

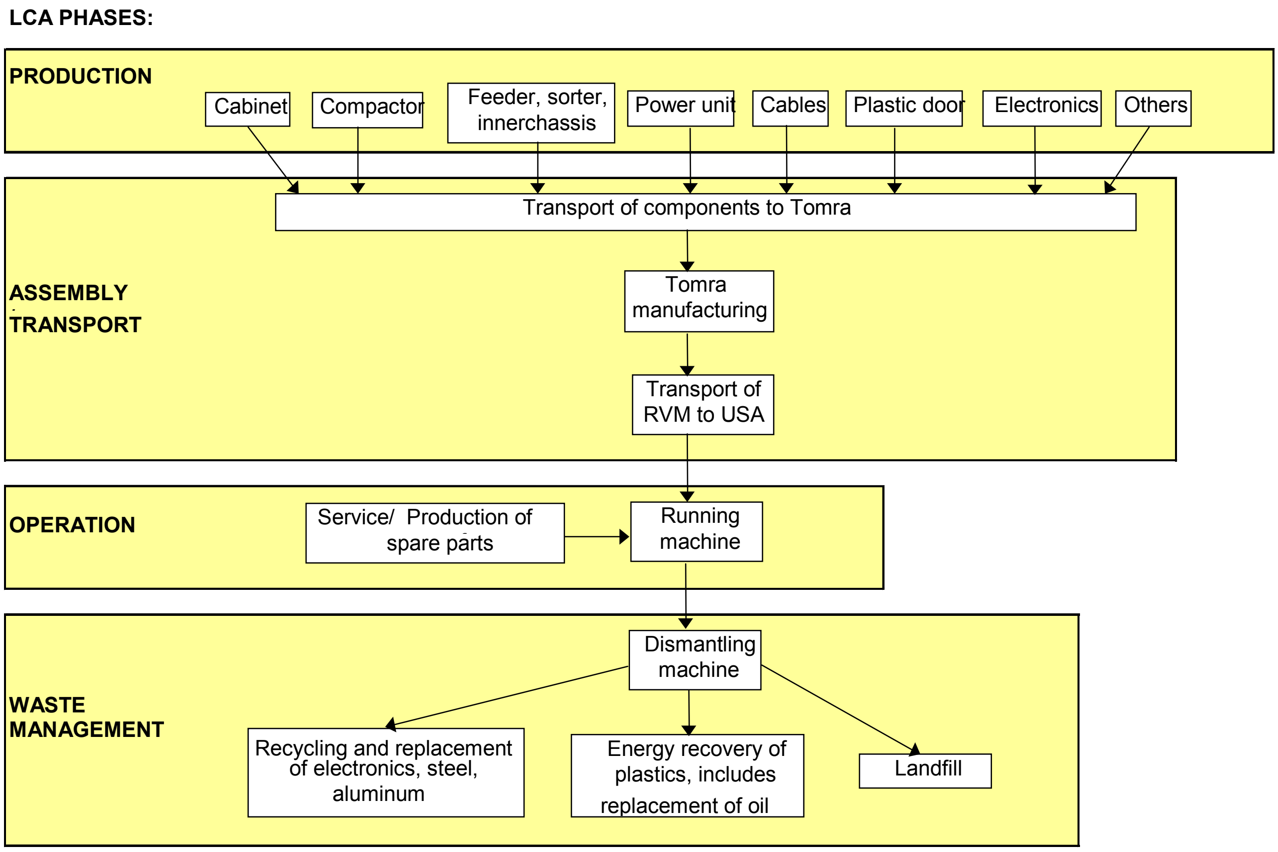

Figure 4.1: Life Cycle System of T42 Tomra reverse vending machine (RVM)

The life cycle for the Tomra reverse vending machine includes the following phases:

- Production: Production of the different machine components (including extraction of raw materials and all associated transports).
- Assembly/transport: Transportation of the components to Tomra (Asker) and assembling the reverse vending machine. Includes further transportation of the RVM T42 from Asker to USA.
- Operation: Running the machine for 10 years, including changing spare parts. During the lifetime the machine flattens approximately 7.850.000 Aluminum cans
- Waste management: Dismantling and waste management of the machine after a lifetime of 10 years.

The ownership of the machines varies: Many machines are sold to shops, but in some markets the machines are rented or leased by the shops. In other markets Tomra owns and runs the machines. Installation, service and some maintenance is undertaken by Tomra Service Personnel, while the shop takes care of day-to-day cleaning and maintenance. In this study, it is assumed that the customer purchases the machine.

4.2 System description: Tomra Recycling Systems in Connecticut & California

The life cycle of a beverage container in this study includes the whole chain of processes from raw material extraction and container production to recycling and reclaiming for use as raw material in a new product. However, focus is on the recycling part of the system. Figure 4.2 gives a general illustration of a recycling system.

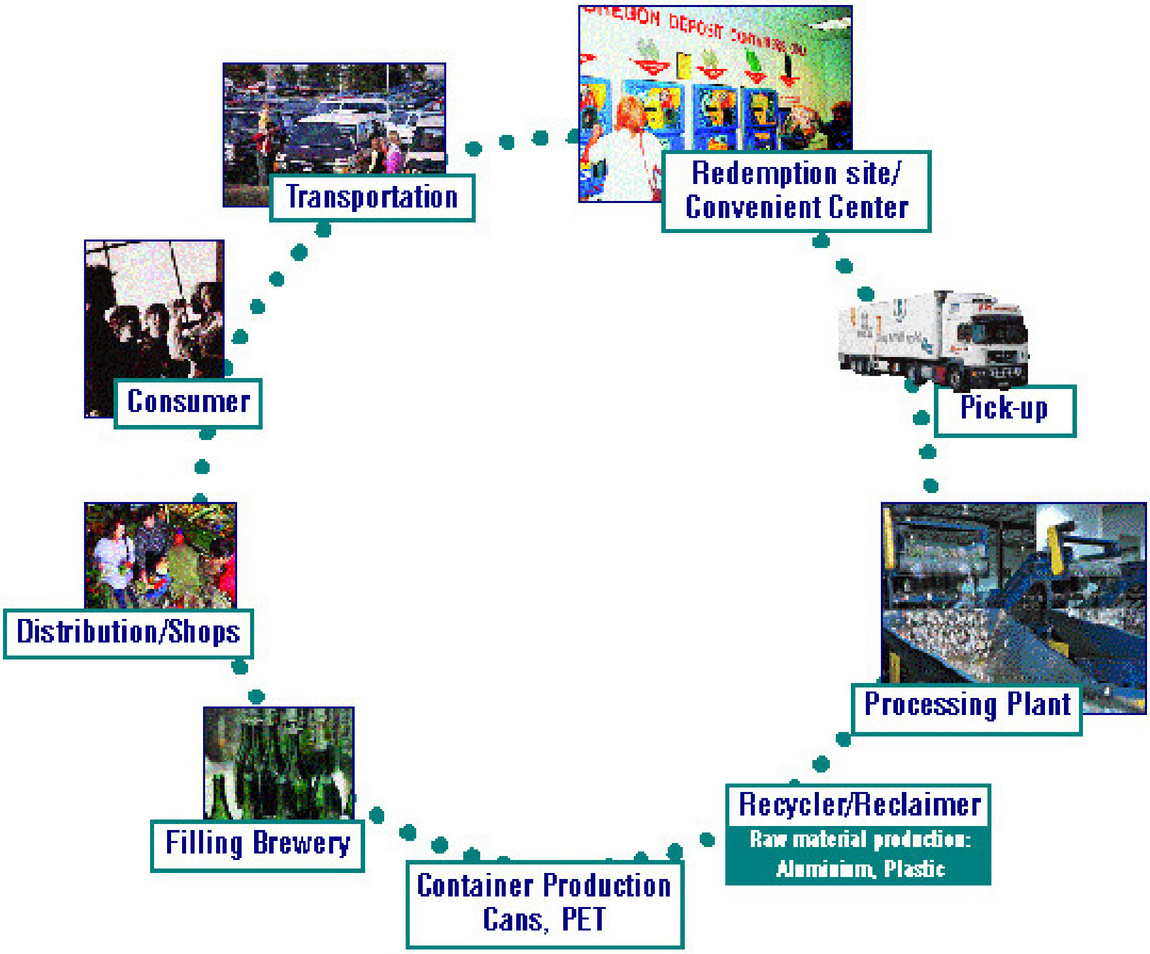

Figure 4.2: Lifecycle of reclamation of container material

The following systems are modeled in Connecticut:

1. PET shredded in Tomra RVMs (Reverse Vending Machines), sorted and chipped at BPRC (Tomra Metro), then transported to reclaimer and "reclaimed" to commercial grade pellets/resin.
2. PET flattened in Tomra RVMs, and bailed (using general data), then transported to reclaimer, chipped and "reclaimed" to commercial grade pellets/resin.
3. Aluminum cans flattened in Tomra RVMs, bailed at BPRC (Tomra Metro) and shipped to Morgan Town, Kentucky (Wise Recycling).

The following systems are modeled in California:

4. Whole PET bottles collected in Convenience Centers.
5. Whole aluminum cans collected in Convenience Centers, shredded at Cucamonga plant and shipped to Reynolds in Alabama

The different parts of the recycling cycle are described as follows:

Raw material and container production
The studied systems include production of raw material and containers for beverages.
Bottling/filling and distribution is not included, due to lack of site specific data, and because it was not considered a focal point of this study (however the model is built with a possibility to include this at a later stage).

Consumer:
In order to understand more of the consumer behavior in recycling, consumer researches has been carried out both in CT and CA (by Audits and Surveys Worldwide, Oct.-99, and Options –Marketing Research, Sept.99).

The Connecticut research was performed by telephone interviews, and showed that:

- 41 % of the consumers recycle beverage bottles and cans in grocery stores. 25% of the interviewed drove 3,7 extra miles to recycle (6km), however this point was difficult to interpret from the research. For this study it is assumed that 20% of the CT volume comes from non-driving "professionals".
- Average refund value $ 3.20 per recycling trip, or each person brings an average of 41 Al cans, 12 PET bottles and 11 bottles in glass. However the people that drive solely to recycle, bring more bottles and get about $ 4.50 in refund.

- 48 % of the consumers recycle beverage bottles and cans by using curbside systems. We assume that a lot of this volume ends up at RVMs through scavengers.

The Californian study was performed by personal interviews of consumers visiting the new Convenience Centers. It showed the following:

- 23% are driving solely to recycle
- They are driving an average of 2 miles (3,2km)
- Average refund value of $8.80 (70 NOK) per recycling trip or each person bring ca. 280 Al cans, 30 PET bottles and 40 Glass bottles (calculated)

It is believed that if the Connecticut research were carried out at an actual RVM site, the survey would have resulted in lower figures as regards to driving distances.

Container collection:
Deposit system description
Each state in the USA has it's own laws for recycling. 10 States have some form of beverage container refund (deposit) law. These laws require beverage retailers to pay the consumers a specified refund value for returning empty containers, and require wholesale distributors to pay refund to retailers. Connecticut has a "typical" deposit system, where distributors keep unclaimed deposits. The redemption value for each container is relatively low (5 cents). In the Californian system the redemption value is even lower (2,5-5 cents), which gives lower incentives for the consumers to recycle. However, here the income from unredeemed containers is used to finance the program and other recycling related initiatives, and is not kept by the distributors.

Redemption site
In CT it is common with reverse vending machines (RVMs) in grocery stores, where consumers redeem their containers combined with shopping. Tomra has about 65% of the RVM market in CT. In California, RVMs are not common, and used beverage containers are handled manually in Convenience Centers situated on parking lots outside some shopping centers. However, much of the aluminum can volume goes to traditional scrap dealers ("old liners"). There is a total of about 2800 Redemption Centers in CA, 1100 are Convenience Centers of which Tomra operate 400.

The Tomra recycling system in CT is based on shredding of PET bottles and flattening of Aluminum cans in the RVMs. This gives relatively high transportation efficiency. However, the average truck utilization rate from retailer to processing plant is only about 50%.

In the Convenience Centers in CA, the bottles and cans are not compacted, but are transported whole in roll-off containers to the processing center. It should be noted that the transport distance in CA is much less than in CT. (RVMs are not included in the CA model, because only a few centers are up and running with RVMs in 1999).

In order to investigate energy consumption by Tomra RVMs in CT, Tomra R&D carried out a test. It showed that approx. 75% of the energy consumption of the machine comes from idle/stand-by. At a low throughput of used beverage containers, the energy consumption per ton containers will increase.

Figure 4.3: New Convenience Center LA, California

Processing plant:
Tomra in Connecticut (Tomra Metro) have one processing plant in Stratford that handles cans, PET and Glass bottles. Shredded PET is chipped in smaller pieces, and whole and flattened PET are sorted and ground. The flattened aluminum cans are bailed. Transportation to reclaimer/ recycler is quite efficient, but the transportation distance is long.

In California, one of the three Tomra Pacific's processing plants, Cucamonga, was chosen to be examined. This plant shredding aluminum cans, and only reloads PET (no processing). The processing plant also treats other material flows such as red metals and newspaper. The transportation of aluminum cans to reclaimer/ recycler is by train.

Reclaiming/recycling
The PET-material is de-bailed, sorted and ground. Ground material is cleaned for contaminants in a multi-step process, the material can then be sold as "flake" or it goes through an extruding process and is sold as "pellet". This pellet is the same form as virgin resin is sold in.

Flattened or whole aluminum cans are transported, re-melted and strip rolled. General data is used for this process.

Replacement of material
Recycled PET goes to production of strapping, engineering resins, bottles (not for beverages or food), sheets/film, and fiber for clothing.

Recycled Aluminum from cans goes into the production of new cans. Approximately 10% of the mass are taken out at each recycling loop, to be replaced by virgin material. The removed 10% go to production of other aluminum products with lower quality requirements.

The data used in the study comes from many different sources. A list of assumptions and data sources is given in Appendix 1.

4.3 System Description of Curbside systems in Connecticut and California

In curbside collection systems recyclable waste is sorted at home and placed outdoors in separate bins or boxes for collection. A collection vehicle, which may have several compartments, drives by the house and picks it up. Some of the trucks compact the material. Further, the material is sorted and bailed at a processing facility, before it is shipped to the reclaimer/recycler.

There are different ways of organizing curbside collection systems:
1. Split stream (paper, glass and plastic/metals are separated)
2. Hybrid (paper separated from the rest)
3. Mixed (all the recyclable together)

In California, the State has set a 50% recycling target for municipal waste by the year 2001. The 50% recycling target does not give any incentive for achieving quality of the output material. The result is that many communities have started collecting commingled (mixed) recyclable, which increases the participation rate, but lowers the quality of output material. For example, broken glass affects the recycling of newspaper.

Curbside systems are usually assumed to have lower recycling rates compared to deposit systems. The costs vary greatly from program to program. Collection crew size (one or two people in the truck) is a particularly important factor.

Figure 4.4 Curbside collection boxes (Norway)

4.4 Allocation rules

4.4.1 System expansion

Allocation in LCA terminology means distributing environmental burdens and benefits between different materials and life cycles.

To avoid allocation, it is possible to expand the system. This approach is illustrated in Figure 4.4.

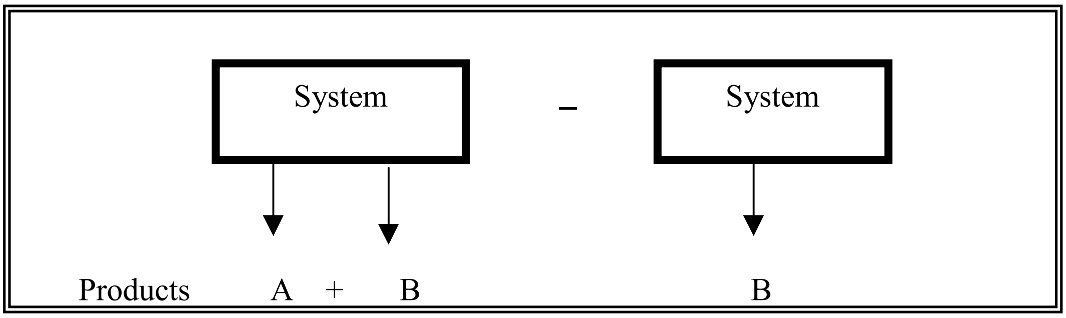

Figure 4.4: An expanded product system where the results are presented as a result of the production of product A+B – B.

A+ B: Production and use of container and recycling of this for new product
-B: The avoided production related to the recycling of material available for new product.

This approach is used for both the aluminum system and the PET system. Environmental <u>burdens</u> connected to production of one ton of beverage containers and the recycling processes are summarized, and the environmental <u>benefits</u> connected to the avoided production of new raw material is subtracted.

4.4.2 Open or closed loop processes

The recycling systems analyzed in this study can be described as open or closed loop processes. An open loop process is where a material goes through a defined number of life cycles, whereas a closed loop is where the material goes into another utilization an unlimited or unknown number of times.
In this project, the aluminum material can be described by closed loop recycling. Aluminum containers are recycled and reclaimed into the same type of product.
Used PET containers are not used for production of new containers. Thus, it is an open loop recycling.

Figure 4.5 describes a closed loop recycling. Material losses in each life cycle are included (thus making it necessary to provide some new primary material for each loop). Though only one loop is analyzed in this study.

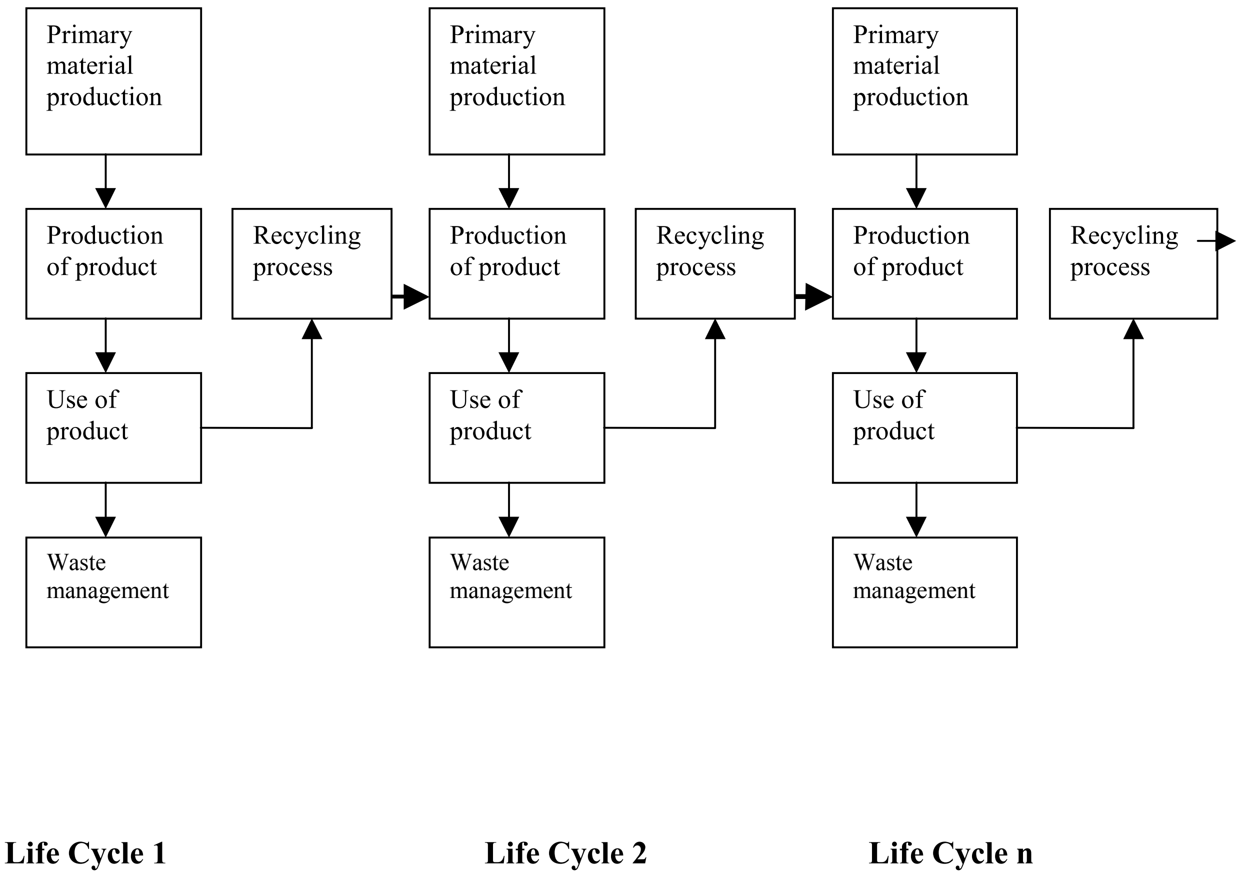

Figure 4.5: Closed loop recycling with material losses (LCA Nordic Technical Reports, 1995)

4.4.3 Allocation rules applied for the aluminum system

To maintain the quality required for can manufacture, means that approximately 10% (Miljøstyrelsen 1999) of the material must be taken out and be replaced by virgin material for each recycling loop. The closed loop recycling of aluminum is thus not a "perfect" closed loop, and this loss of material ("quality loss") has to be accounted for. However, the material "taken out" of the can production is used for other aluminum products, and the 10% are therefore not a total loss of material.

To allocate between the primary loop of can manufacturing and the secondary loop of other aluminum products, it has been assumed that the material taken out of the can manufacturing is recycled another four times. The total quality loss for each recycling step is therefor ¼ of the 10% material loss, making a total of 2,5% "loss of quality" for each recycling loop.

4.4.4 Allocation rules applied for the PET system

Used PET containers are not used for production of new beverage containers, and can be described as an open loop recycling. Reclaimed PET material are used to produce other types of products, such as car parts, clothing, and strapping. These products have replaced the production of similar products, made of different material, but with the same function.

For PET, the allocation rule for dividing the environmental burdens between the PET container and the new product has been set as the economic value for the reclaimed raw material. The economic value for material based on reclaimed PET is approximately 90% of the costs of virgin PET. The environmental savings of the avoided production of new material has thus been set as 90% of the burdens of producing virgin PET.

4.4.5 Allocation between materials at transport

When calculating the environmental and economic burdens connected to transport by the consumer, the burdens are allocated on a weight basis. In the analysis of the PET-system, the burdens are allocated to PET according to the weight fraction of PET. The same approach has been applied to the aluminum systems.

For the transport distances by Tomra from the redemption sites to the processing and further to reclaiming of materials, the burdens are allocated according to both the volume and weight of the material according to best possible estimates.

5 RESULTS

5.1 Tomra Reverse Vending Machine

5.1.1 Environmental profiles of the Tomra Reverse Vending Machine

The results are shown with both American and Norwegian average electricity during the operation phase.

Primary energy consumption

Figure 5.1 shows the primary energy consumption (MJ [1]/ Tomra machine for 10 years) linked to each phase of the life cycle.

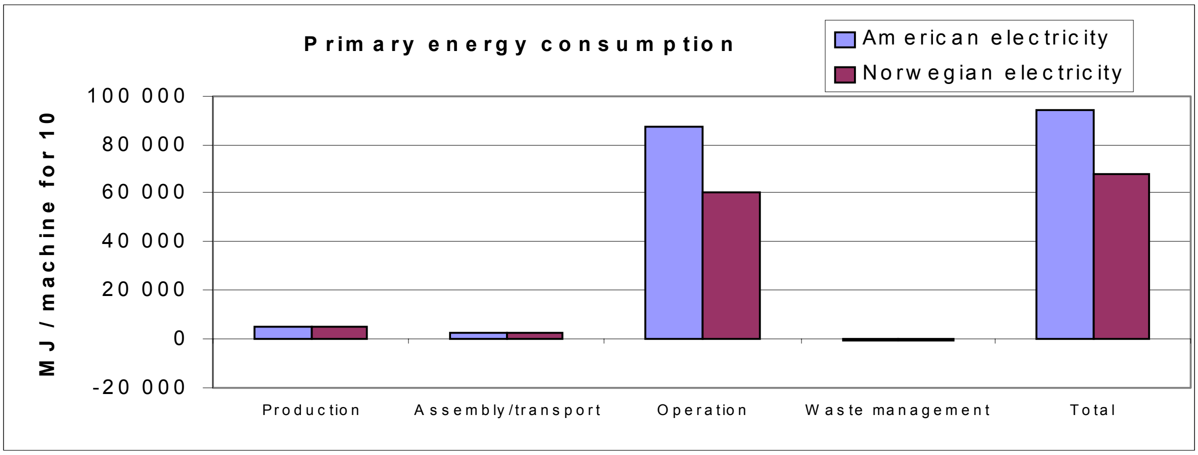

Figure 5.1: Primary energy consumption

As seen in figure 5.1, the operation phase gives the highest contribution to primary energy consumption. Use of American average electricity gives a higher contribution to primary energy consumption during the operation phase. The reason for this is that producing American electricity for running of the machine is mainly based on fossil energy carriers, requires more energy than producing Norwegian electricity (mainly based on hydropower).

Global Warming Potential

Figure 5.2 shows the global warming potential (GWP or g CO_2-equivalents / Tomra machine for 10 years), linked to each phase of the life cycle.

[1] 1MJ=3,6kWh

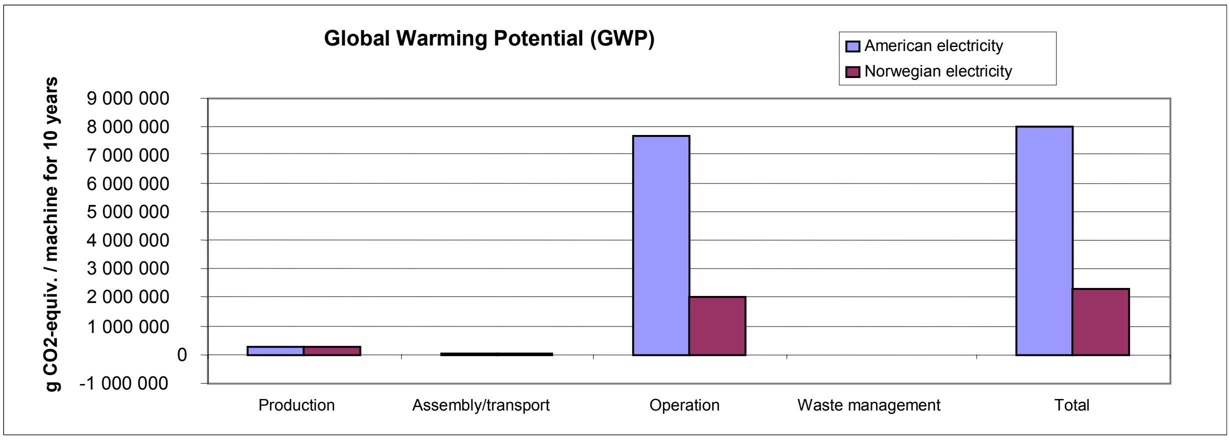

Figure 5.2: Global warming potential

Figure 5.2 shows that the highest contribution to greenhouse gas emissions also comes from the life cycle phase "Operation". As seen in the figure, the use of average American electricity to operate the machine gives a much higher contribution to GWP than using average Norwegian electricity. The reason for this is that 70% of American electricity is based on fossil energy carriers, while Norwegian electricity is mainly (90 %) based on hydropower.

Operation phase

As seen above, the operation phase gives the highest contribution to all the classified environmental burdens. Therefore, the operation phase is divided into four steps to identify the most important activity. Figure 5.3 shows the global warming potential (GWP / Tomra machine for 10 years) linked to the four steps during the operation phase.

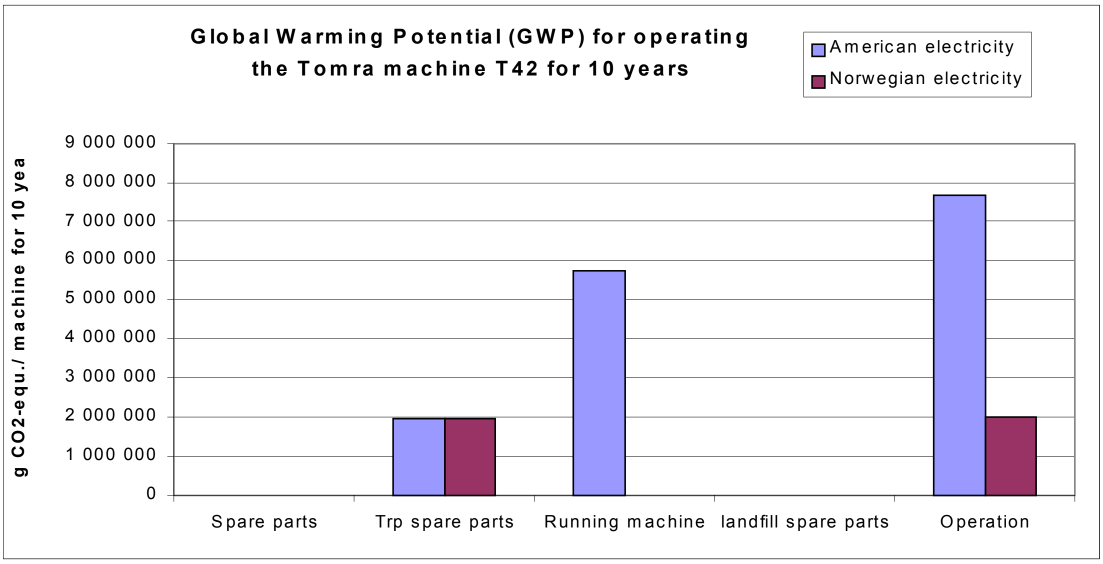

Figure 5.3: Global warming potential for the operation phase

As seen in figure 5.3, by using American electricity the total impacts differ a lot from using Norwegian electricity. When using American electricity, the highest contribution to GWP comes from the step “running machine”, while using Norwegian electricity gives an insignificant potential from the same step.

The step “transport spare parts” also gives a large contribution to GWP, which mainly comes from a “service car transport” of 3550 km for 10 years.

Other categories
The picture for “Acidification“, “Eutrophication” and “Photochemical oxidation” will be similar to those for “Global warming potential”, which means that the operation phase gives the highest contribution to the environmental burdens.

Eco- toxicity and human toxicity
In this study calculation of the eco-toxicity potentials using the USES-LCA model was attempted. Unfortunately, data gaps were discovered (especially regarding the waste management phase), and conclusions about eco-toxicity have been difficult to make. However, the calculations indicated certain focal points:

- Production of raw materials, such as steel and aluminum, are the main contributors to aquatic and sediment eco- toxicity (Cu, Ni, V and Zn).
- Production of raw materials, such as steel and aluminum, are the main contributors to human toxicity, caused by metals (Cr) and aromatics (PAH).
- The chromating process for steel contributes only to a very small degree to “Human toxicity potentials”. According to the supplier, the chromating process for steel gives emissions to water only (no emissions to air). The impact score factor for human toxicity caused by emissions of ChromiumVI to air is a million times greater than the factor for emission of Chromium IV to fresh water (Huijbregts, M.A.J, 1999). Therefore, the emissions from the chromating process for steel have an insignificant potential for human toxicity in relation to processes that give emissions to air. A possible source of uncertainty could be that the emissions of chrome to air from the chromating process have not been possible to measure.

Specific eco-toxicity data
The flame-retardants triphenyl phosphate and bromine derivative are additives of some of the Tomra machine components (plastic door and electronics). Flame retardants are required to get international product approval such as UL (Underwriters Laboratories Inc) in the USA.

The flame-retardant bromine derivative is included in SFT’s[2] list called: “Helse- og miljøskadelige kjemikalier: Prioriterte helse- og miljøfarlige kjemikalier, Tabell B: The list presents toxic substances that shall be substantially reduced within the year 2010. Research by the Swedish research scientist Åke Bergman, University of Stockholm (Natur & Miljø Bulletin 5/99), shows that processes for recycling of electronics (containing bromine derivatives) produce dangerous smoke.

[2] SFT is the Norwegian Pollution Control Authority

5.1.2 Life Cycle Costs of the Reverse Vending Machine

In the project, a life cycle cost analysis was performed. This analysis included costs for the customer (purchase, service, energy consumption, daily operation and disposal) during a lifetime of 10 years.

The analysis included both a cash flow and net present value calculations. The net present value approach included the use of interest rate. Here, the relative importance of costs related to service and operations is lower than for the cash flow approach, because these costs are distributed over several years.

The general findings applying both approaches were:
- the main costs for the customer were purchase, operation and service.
- the lowest costs for the customer were disposal and energy consumption of the machine

The analysis included a break down of service costs: Spare parts, labor, fuel and fixed costs. Labor costs constitute approximately 50% of the total costs.

5.2 Tomra recycling systems

5.2.1 Environmental profiles of Tomra Recycling Systems of PET

In figure 5.4, the total load (given in MJ) of the PET recycling systems are shown up against production and discharge (landfill) of PET. It is chosen to present the results by energy units due to the fact that most emissions to the environment in this system are energy-related. Because the USA has fossil fuel based electricity production the greenhouse gas emissions (CO_2 equivalents) will be proportional to the energy consumption. This applies for transportation energy as well.

The different elements are:
- Raw material production of PET granulate
- PET bottle production
- Environmental impact of recycling, including transportation, loss, processing and reclamation by Tomra.
- Environmental savings, including the reduced production of new raw material due to recovered material
- Total load, a sum of all the above.

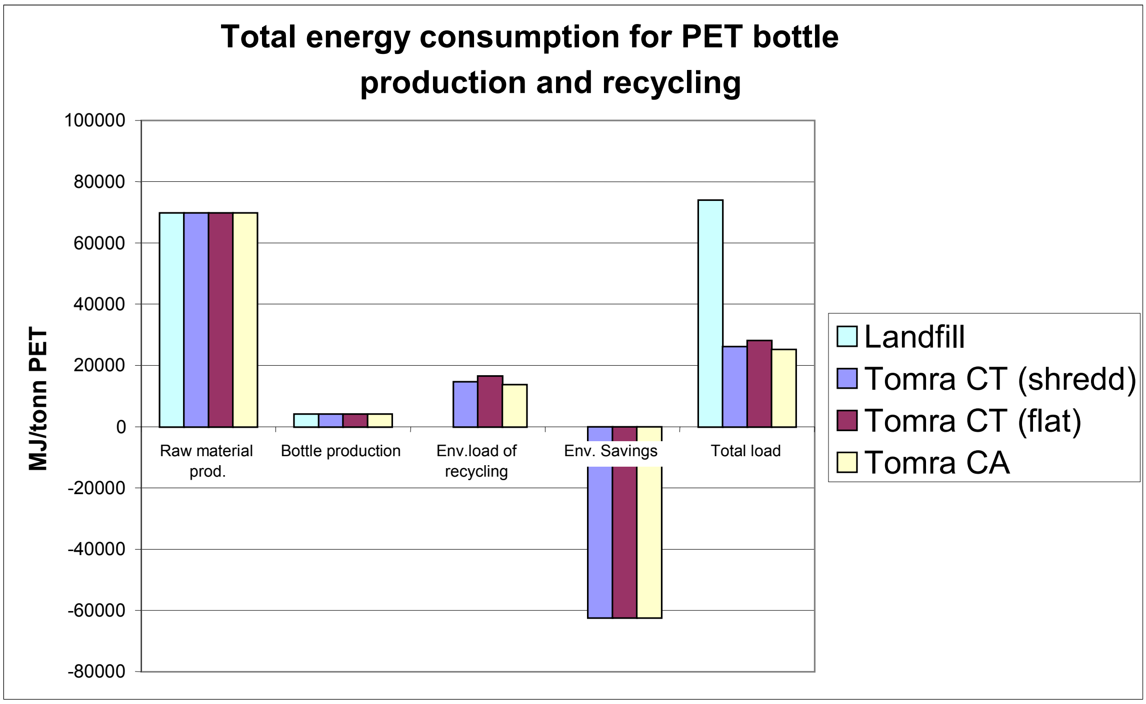

Figure 5.4: Total load of production and recycling of material for the three PET-systems versus landfill

The Landfill alternative means that the production of raw material and PET bottles are included, and the bottles go to landfill after use. In the landfill-alternative it should be noted that emission of greenhouse gases at the landfill is not included.

The figure shows that the total load of the production and recycling of PET bottles in the recycling systems is about 40% of the load for landfill. The bottle production contributes with approximately 30% to the total load, and the environmental load of recycling with 60%. The environmental load of recycling and the environmental savings are adding up to give the total gain of recycling.

Figure 5.5 illustrates the different contributions to the energy use for PET-material recycling. The different elements of the figure are:

- Trp. consumer: Transport of the containers by the customer to redemption site
- Redemption site: Running of the machine at the redemption site
- Trp to processing plant: Transport of the containers from redemption site to processing plant
- Processing plant: In CT: Sorting and grinding of shredded PET, sorting and grinding of flattened PET containers. In CA: Reloading of PET
- Trp to reclaiming plant: Transport of material from processing to reclaiming
- Reclaiming plant: Reclaiming of material to pellets
- Loss of material: The loss of material that has to be replaced by virgin material
- Env.load of recycling: The total of the above

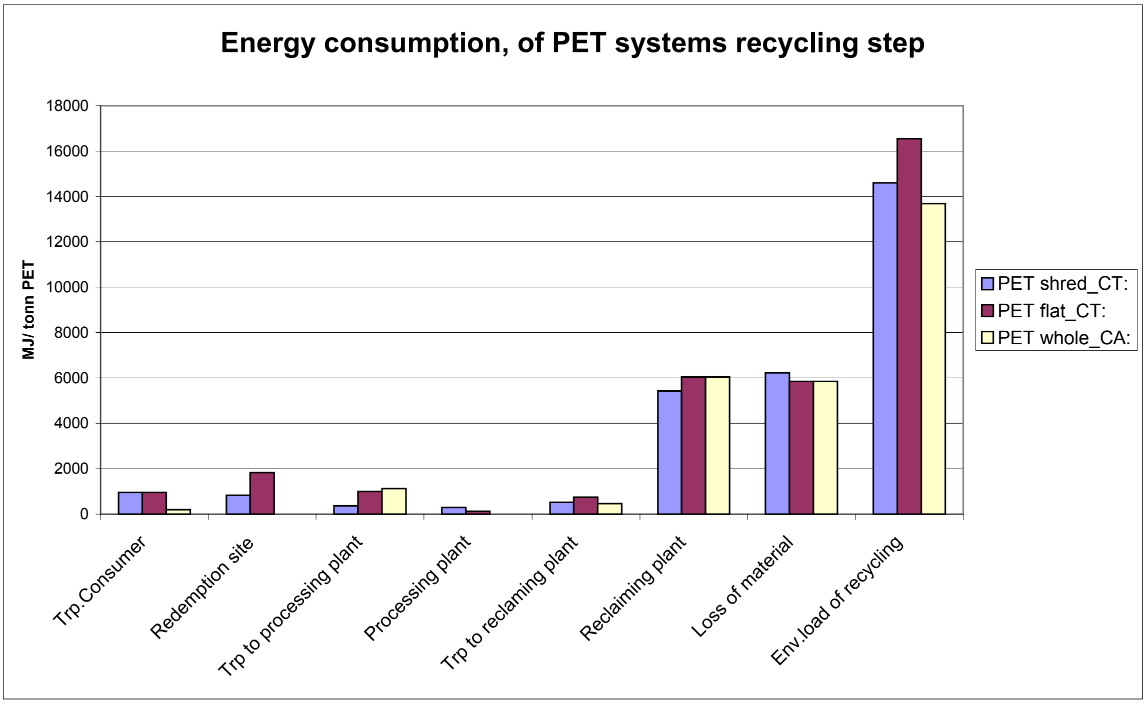

Figure 5.5 Total energy consumption of the recycling step of the three PET - systems

The figure illustrate the following:

- The total energy consumption is the highest for the systems in CT, due to higher degree of transportation by the consumer as well as the use of energy by the Tomra machine. The high energy consumption at redemption site for flattened PET is due to significant lower volume.
- The reclaiming plant gives the highest contribution to energy consumption in the recycling loop, and about 50% of this energy is used in the extruding step. Shredded (ground) PET has the lowest energy consumption at reclaiming, the difference consist in grinding energy for bailed material.
- The loss of material in the different steps of the process has a significant impact. The loss takes place at the redemption site, the processing plant as well as at the reclaiming plant.

5.2.2 Environmental profiles of Tomra Recycling Systems of aluminum

In figure 5.6, the total load (given in MJ) of the aluminum recycling systems are shown up against landfilling of the aluminum cans.

The different elements are:

- Raw material production of aluminum sheets
- Can production
- Environmental load of recycling, including transportation, loss, processing by Tomra and re-melting of material
- Environmental savings, including the reduced production of new raw material due to recovered material
- Total load, a sum of all the above.

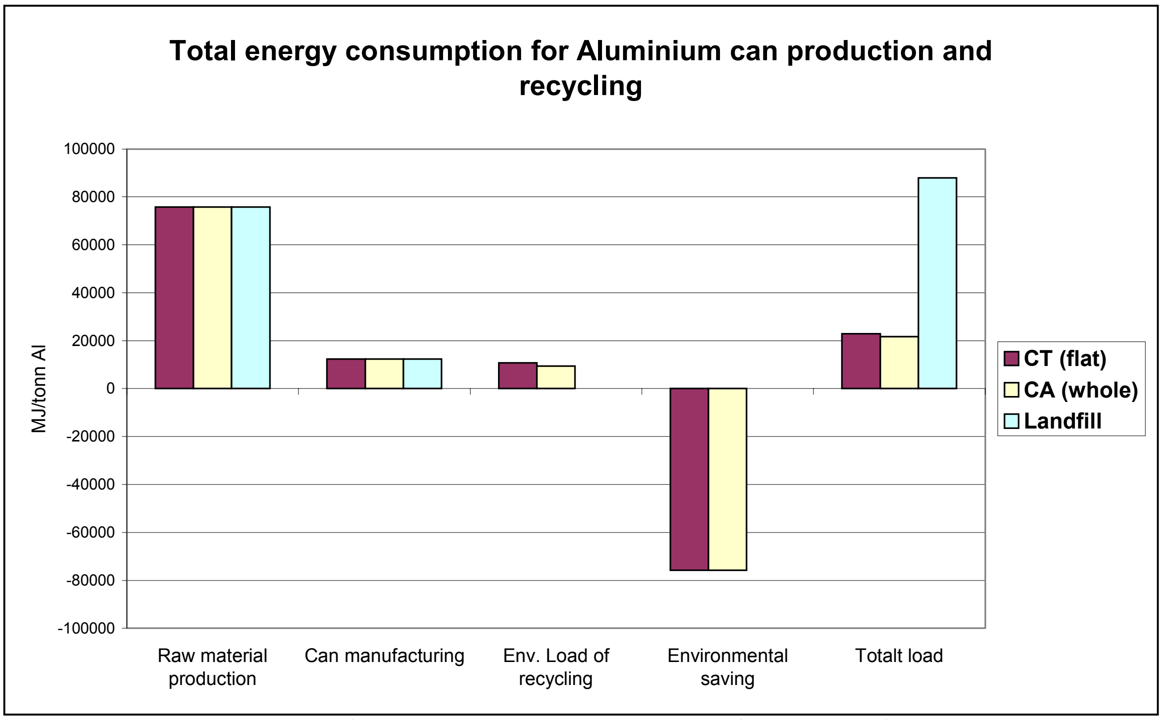

Figure 5.6: Total load of production and recycling of material for the aluminum-systems versus landfill

The figure shows that the total load of the recycling systems is about 25% of the load for landfill. Can manufacturing contribute with approximately half of the total environmental load for the system.

Figure 5.7 illustrates the different contributions to the environmental load of recycling.

The different elements of the figure are:
- Trp. consumer: Transport of the containers by the consumer to redemption site
- Redemption site: Running of the machine at the redemption site. In CA the collection is manual
- Trp to processing plant: Transport of the containers from redemption site to processing plant
- Processing plant: In CT: Bailing of containers. In CA: Shredding of containers
- Trp to reclaiming plant: Transport of material from processing to reclaiming
- Reclaiming plant: Reclaiming of material to pellets
- Loss of material: The loss of material that has to be replaces by virgin material
- Env.load of recycling: The total of the above

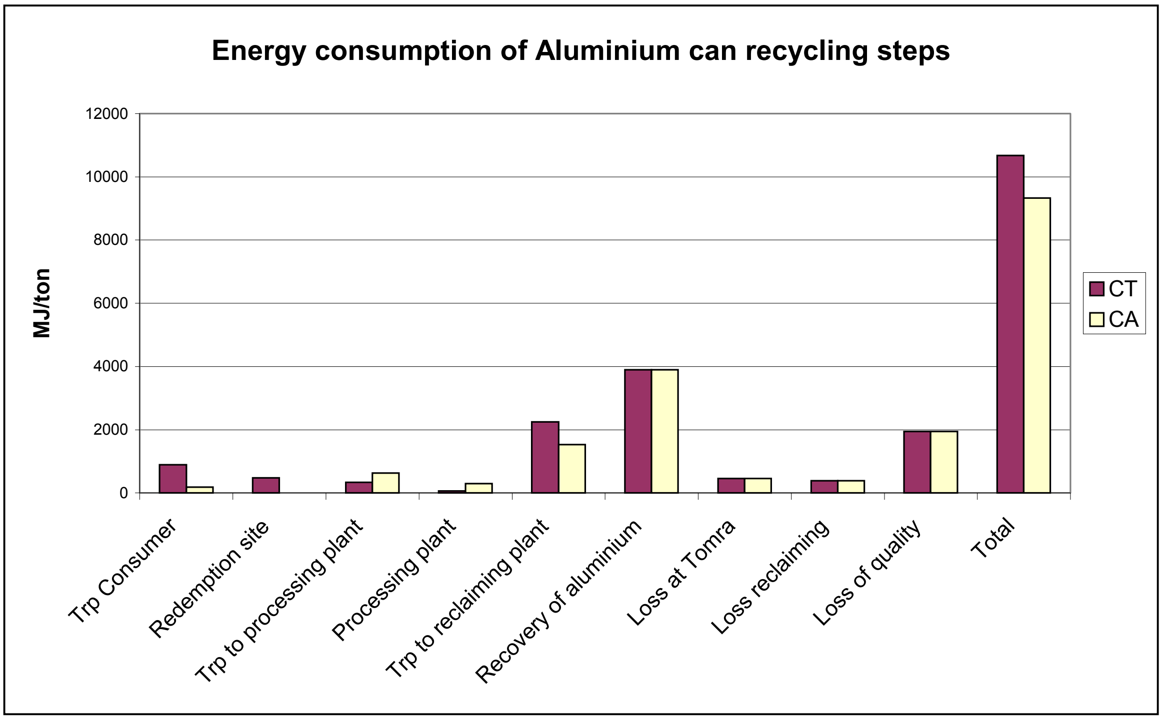

Figure 5.7: Total energy consumption of the recycling step of the aluminum - systems

The figure illustrate the following:
- The total energy consumption is highest for the system in CT, due to higher degree of transportation by the consumer as well as the use of energy by the Tomra machine.
- The recovery plant gives the highest contribution to the energy consumption in recycling.
- Transport to recovery of aluminum has a high impact in both systems due to long transportation distances.
- The loss connected with maintaining quality of recycled material has a significant impact. The losses at Tomra processing have a relative low impact.

5.2.3 Summary of the environmental assessment of the Tomra recycling systems

The analyses of Tomra recycling systems in Connecticut and California gave similar results for both Aluminum and PET containers:

- A high recycling rate is favorable – the environmental gain of recycling is high for all systems.
- Reclaiming of material gives the highest energy consumption of the total recycling loop
- The quality of the reclaimed material and the loss of material in the recycling system are important factors.
- Transport of the containers to redemption-sites by the consumers can give significant negative influence of the energy efficiency of the recycling system.
- The demographics and geography of the analyzed area in Los Angeles resulted in favorable low transportation distances for the Californian case compared to the Connecticut case. Such aspects must be taken into account when comparing results from different areas.

5.2.4 Life Cycle Costs of Recycling Systems in Connecticut and California

The analysis of the life cycle costs of the recycling systems in California and Connecticut systems show the same trends:

- The collection of beverage containers at the redemption site involves the highest costs compared to other costs in the system. This applies for both shredded PET and for aluminum.
- For whole PET bottles, the transportation costs are especially high due to low efficiency.
- For aluminum, the transportation and processing costs are relatively low.
- The reclaiming cost for PET is substantial. This cost is not included for aluminum.

The cost at redemption sites for RVMs (located in stores) is mainly related to machine depreciation and service, and daily operation by store personnel. For the manual Convenience Centers, the labor costs contribute the most. The big difference between the PET and the aluminum system is due to labor cost allocation on a per container basis.

With today's prices, the total cost for PET recycling seems to exceed the material sales price. The aluminum system is profitable with only material revenue. The sales price will be dependent of material quality and area of use. It is here assumed high quality PET pellet and aluminum. These results are based solely on corporate economic analysis. External costs and benefits are not included.

5.3 Curbside systems

5.3.1 Simulation of the Environmental profile

When simulating the curbside systems, the material is assumed to have the same output quality as the Tomra systems. However, the collected curbside material contains more of other types of bottles and waste. So to obtain the high quality output, two extra sorting steps are included, and a higher material loss (3% extra for PET). Similar transport distances as for Tomra are used for the Curbside systems, though higher fuel consumption due to many stops.

The main difference between the curbside systems and Tomra systems is in collection of the containers (transport, extra sorting steps and loss of material). Thus, only the detailed picture giving the environmental load of the recycling is shown.

Figure 5.8 illustrates the energy consumption of the PET system recycling system for the curbside systems in Connecticut and California.

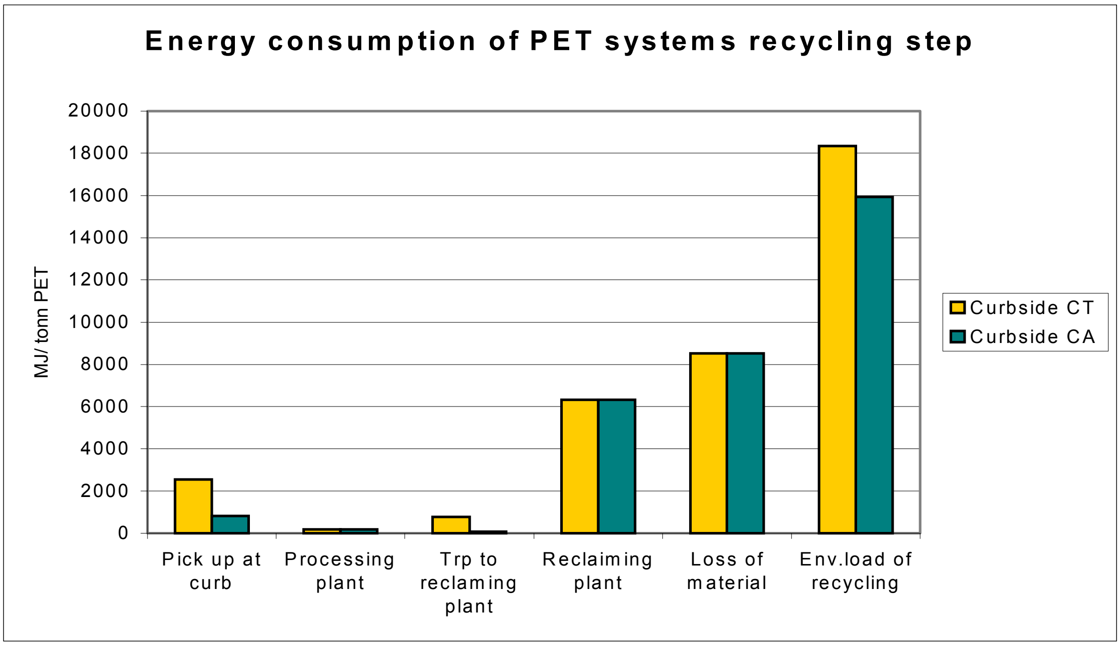

Figure 5.8: Total energy consumption of the recycling step of the two simulated Curbside PET - systems

The figure illustrates the differences in the total energy consumption. The reclaiming plant as well as loss of material contributes the most. The Curbside system in CT has a higher energy consumption related to the collection of materials due to a longer distance to the processing facility.

Figure 5.9 illustrates the energy consumption of the aluminum can production and recycling for the two curbside systems in CT and CA.

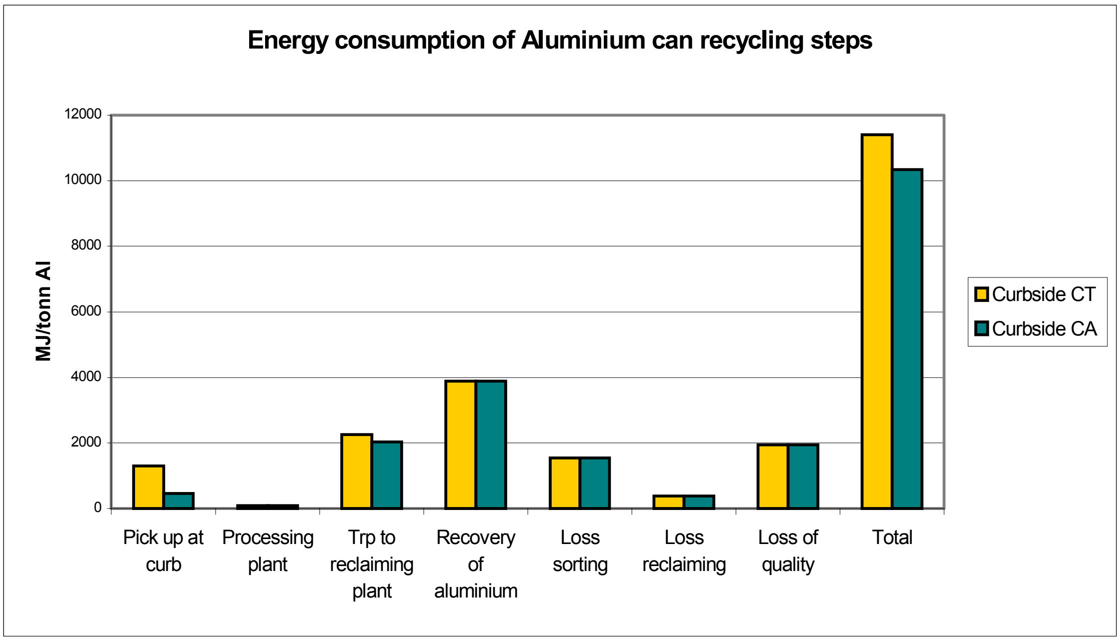

Figure 5.9: Energy consumption of the recycling steps of the simulated curbside aluminum - systems

Figure 5.9 illustrates the total load for aluminum recycling in the curbside system. It illustrates that the transport to the reclaiming plant as well as recovery of aluminum contributes the most to the recycling process. This is in accordance with the results obtained for the Tomra systems.

5.3.2 Simulation of Life Cycle Cost of Curbside Systems

The LCC for Curbside systems is based on information from the Californian program. These data are assumed to have the same preconditions as the Tomra systems. Generally, the overall cost per ton collected by curbside systems is lower than for the Tomra system, because a lot of other materials than PET and aluminum are included. Much of it is newspaper and this material has in addition a higher density than bottles and cans. However, these other materials have a lower material price, and thus the overall material revenues are much less than from a deposit system. Therefor curbside programs need more revenues from other sources, like household fees.

5.3.3 Summary of the Curbside systems

The environmental and economic assessment of the curbside system gave the following results:

- The collection of beverage containers at the curbside involves high costs both for PET and aluminum
- The extra sorting steps to increase quality have relatively small impacts both on the environmental and economic results
- The environmental impacts are very much related to the total loss of materials as well as quality of the material. These losses are difficult to estimate.

6 DISCUSSION OF RESULTS

6.1 Data quality and data gaps

6.1.1 Tomra Reverse Vending Machine

This is the first life cycle assessment of a Tomra machine, and for such situations, data gaps will always be discovered. The suppliers of information (both internally and externally) do not always have the necessary information at hand, and some data are more complicated to compile than others (e.g. where there are long chains of suppliers that must all contribute).

The impact data for “Primary energy consumption”, “Global Warming Potential”, ”Acidification”, “Eutrophication” and “Photochemical oxidation” are of good quality. Regarding the impact category “eco-toxicity”, the analysis especially concluded that data are missing. Further, dialogue with the supplier of plastic doors and electronics is important to improve the knowledge about the flame-retardants triphenylphosphate and bromine derivative. Filling in data gaps and information that is missing is an important contribution to the ISO 14001 process for continual improvement at Tomra.

6.1.2 Recycling Systems

It has been difficult to obtain exactly allocated data for the Tomra system and specific data for curbside systems. The data quality is generally regarded as higher for the Tomra system than for the curbside systems. In this study, best possible estimates for material loss and transport efficiencies related to the different phases of the life cycle are used.

However, certain data gaps are known, and these are related to
- material loss
- bottle mix (at transport)
- transport volumes
- economic data (especially overhead, and detailed transport costs)
- environmental and economic data for curbside systems

This is a first attempt to collect and systemize a combination of both environmental and economic data within Tomra. A lot of data is collected and the most important impacts are identified. However, when the results are to be transformed into improvement activities, the significant data should undergo a critical review and update by relevant parties.

6.2 Transport data

The transport by the consumer to the redemption site in Connecticut has a high impact on the total energy consumption of the recycling system. It is a fact that the distances are higher in Connecticut compared to the California area (Los Angeles) investigated in this study. The data from consumer transportation is taken from the research carried out by Audits & Surveys

Worldwide. However, the data on driving distances and driving "habits" by the consumer were not easy to interpret, and may be questionable. To clarify this, it may be necessary to perform a follow- up consumer research.

An important conclusion is then to investigate this issue further in order to improve the quality of the background data. If the "preliminary" results from this study are proved to be correct, this is an important input to system improvements at Tomra.

6.3 Recycling and Recycling rates

In 1997 75% of the 12.5 billion deposit containers sold in CA where redeemed (population 33.0 million*)*. The number for CT was 88% of 1.66 billion containers (source CRI, Feb.99).

Tomra California was in 1998 handling approximately 400 mill containers through Convenience Centers, which is 4.3% of the total recycled containers in CA. Today though, Tomra has 70% more Convenience Centers and the volumes have correspondingly increased. Curbside systems in California handles less than 10% of the total deposit containers (estimated).

There are several reasons for this relatively low curbside recycling volume. In some areas people place their deposit containers on given days on a "donation" basis. Other areas may have regular visits by "scavengers" or "professionals", who sort out redemption bottles/cans from peoples curbside bins and redeem it at recycling centers and scrap yards.

6.4 Comparison of different recycling systems

Most states in the USA with a deposit/refund system for recycling of beverage containers also have a well developed curbside system. Neither method excludes the use of the other. However, many wish to compare the merits of the two system alternatives. For this study, it has been difficult to obtain up to date and quality- assured curbside system environmental and economic data.

The two systems are not designed to serve exactly the same purposes. In addition to promoting recycling, deposit-refund systems reduce litter generation, make possible the use of refillable beverage containers and cover non-domestic beverage consumption. Curbside programs, on the other hand, can target a wider range of materials than those in a deposit system. Much of the material handled at curbside is newspaper/paper. Another reason for being careful about comparisons is that results can be greatly affected by methodological assumptions.

In general, deposit systems collect more of their target materials than curbside programs, and the materials are of better quality (particularly when curbside materials are co-mingled during collection). However, deposit-refund systems usually cost more to operate on a per ton basis, but they have much higher revenues from product prices. Curbside programs are usually dependent on tax revenues. Research studies[3] suggest that both approaches in combination are likely to increase the amount and quality of the material collected.

The differences in data quality as well as functionality mean that direct comparisons of systems should be avoided. **To make a comparison to promote Tomra solutions, a more thorough study will be necessary. This will require close co-operation with the studied curbside system managers.**

Other systems like Igloo (neighborhood recycling drop-off areas), and waste stream recycling, have not been investigated in this study.

6.5 Allocation methods used

<u>Allocation between different life cycles</u>

This study has chosen to use the price of the recycled material as the basis for environmental credit from the systems, which is a very important assumption. This is done both in the analysis of the PET and Aluminum. As the price for this type of recovered raw material is approximately 90 % of the raw material, the environmental credit is also set as 90% of the initial environmental impacts. A prerequisite for this allocation method is a stable market with no major surplus or underproduction of either virgin or reclaimed material. In the PET case, reclaimed PET material is sometimes used for products that would not have been made if this recovered material was not at hand.

The business concept of Tomra is to create efficient systems for recycling of high quality materials. It is therefor important to establish a scale that takes into account the improvements in efficiency and the quality of the material. In this project, the scale is set by allocating burdens according to the price of the recovered material. However, to investigate the most effective solution including socio-economic terms, the use of different allocation methods should be tested in a broader perspective within the P2005 research program at NTNU.

Another way of addressing this allocation would be to use the “50/50-allocation rule”. This means to credit 50% of the burden to the product bringing the raw material into the technosphere, and 50% to the product sending the material out of the technosphere.

For the PET system, what type of material we replace the recycled material with can also be discussed. The analyzed systems have been credited with the environmental “savings” of using recycled material. These savings are dependent on what type of material is replaced and it is here assumed that we replace virgin PET. When fiber is produced from recycled PET, it would be more correct to use PE or “Nylon” as the replaced material. If we replace other recycled material instead of virgin material, the results would also look different.

<u>Allocation between materials at consumer transport</u>

It can be argued that the main environmental burden connected to transport in private cars is that the transport is taking place, not <u>how much</u> material is transported each time. To follow

[3] Congressional Research Service, report for Congress “Bottle Bills and Curbside recycling: Are They Compatible?” James E. McCarthy, specialist Environment and Natural Resources Policy Division January, 1993, 93-114 ENR

this argumentation, the total energy consumption should be allocated to the transport of each material fraction. In this analysis, the burdens are allocated to the weight of the materials transported. When calculating the environmental and economic impact connected to transport on a weight basis from the customers, lighter materials (PET and aluminum) are get a lower burden than heavier ones. This also means also that if carrying out analysis of all the material fractions, the total energy consumption of this activity will add up to the correct total. It was regarded as important to use the same model for all material fractions, and to avoid accounting for the environmental impact several times.

It is important to note that the basis in this system, that people combine recycling with shopping errands, saves a lot of extra driving in the first place.

<u>Allocation between materials at Tomra transport</u>

Transport of different materials (aluminum, PET, glass) takes place in the same truck. When analyzing one material fraction, the environmental burdens are allocated based on best possible estimates. Glass, a material that is not included in this analysis, is bulky and heavy and difficult to load on top of other materials. Glass is thus given a higher relative portion of the cost of transportation.

6.6 Choice of impact categories for recycling systems

In this study the impact categories resource depletion (in terms of energy) and Global warming potential (CO2 emissions) were used to describe the environmental profile. This means that other potential environmental impacts from the study are not assessed.

The production of raw material as well as reclamation of aluminum is known to give an eco-toxicity potential from the releases of heavy metals and toxic substances (such as dioxins). However, it is known that these burdens from the recovery process are lower than for the production of primary material.

Acidification due to releases of SOx and NOx are a result of the combustion of fossil fuel from processes and transport. This potential is most often proportional with the releases of climate gases. The photo oxidant potential (Volatile Organic Compounds (VOC), NOx) can in this case also be seen as proportional to the climate gas releases from fossil fuel. In the production of cans there are additional releases of VOC other than energy related. These are not accounted for in the results from the analysis.

Resource depletion such as land use has not been accounted for in the analysis, nor have the potential impacts on bio-diversity. The scope of the data collection did not include these parameters. This is also due to the fact that the methods for calculating these impacts are very complicated and based on local aspects. Data for water consumption has been included for the recycling steps, but are not known for the total life cycle. To be able to draw any clear conclusion from an assessment of water consumption, local conditions should be assessed further. The water consumption should thus be an aspect to consider for improvement actions within Tomra.

On the basis of this discussion, the indicators for energy consumption as well as global warming potential should be sufficient indicators in order to draw relevant conclusions as improvement actions for improving environmental efficiency of the recycling systems.

6.7 Discussion of environmental vs. economic results of PET recycling

The results from the environmental assessment indicated clearly that material recycling of PET is environmentally favorable. However, the economic assessment indicated that it is difficult to make this process economically sound for the involved parties. The material price of PET used in the analysis was the average market price from 1998. Variations in prices for recycled material makes it difficult to draw any clear conclusion, but it seems to be important to improve the recycling processes in order to promote an environmentally favorable activity.

Reclaiming energy for PET is high, and the extruding step is the most energy intensive. In addition this step contributes to property loss in the material. So by being able to skip this step, savings can be made both environmentally and economically. A barrier for solving this problem is that that many buyers/producers have designed their processes based on polymer pellets, thus demanding this type of raw material.

It should also be important to investigate the socioeconomic results from the recycling of PET, as input to further policy making within the field of PET packaging.

6.8 Discussion of Improvement actions for recycling systems

The environmental assessment has identified the following general areas as important for improvement actions:

1. To reduce the loss of material in the recycling process steps, in order to minimize the amount of new raw material required.
2. To improve the quality of the recovered PET material, to be able to utilize this material for products with high quality requirements and to secure a high number of recycling loops.
3. To increase the efficiency of transport, from the customers to the redemption site, as well as for Tomra from the redemption site all the way to the recovered product.
4. To decrease energy consumption when running the Tomra RVM machines

These improvement actions will also give a positive economic contribution for both Tomra and the consumers.

The models used for assessing these actions are built on the best available data (see 6.1 and 6.2), and only linear connections between the input data and the results are assumed. Thus, by using the model as it is today, a simulation of reduced material loss will give a positive contribution to the environmental and economic gain. However, to build up more complex models taking into account possible non-linear connections, or to establish the functions describing the results, the improvement actions must be studied at the actual site where the improvements can be implemented. The relevant data and functions must be established for these specific sites.

Increasing product quality may impose investments in new equipment to an extent that the economic results will be less favorable. This new equipment can also be energy intensive so that the environmental gain from the quality improvement is reduced. Therefore, each practical improvement action should be assessed separately, and the results put into the overall model established in this project.

7 MAIN CONCLUSIONS

7.1 Main findings

The environmental assessment gave the following conclusions:

- For both PET and Al containers, the most environmentally "damaging" stage of the life cycle is the raw material production. By using recycled material, the raw material step is skipped and substantial environmental savings are obtained for both material types. Landfill is the absolute least favorable alternative.
- USA electricity is mainly based on fossil fuel, contributing to the greenhouse effect. Thus, by reducing the energy consumption or choosing renewable energy sources, greenhouse gas emissions can be drastically reduced.
- The energy consumption by the Tomra Reverse Vending Machine, and particularly the stand-by power consumption, is a major factor for improvement of the machine.
- Consumer behavior is also an important issue to address. A potentially high rate of consumers driving long distances to recycle may give a high contribution to the environmental load of recycling both for PET and Aluminum cans. Thus, it is important to work on making recycling a natural part of peoples shopping patterns.
- Increasing transport efficiency from store/ Convenience Center may be another improvement target.
- Material loss is an important aspect to consider for improving the total recycling systems.
- Reclaiming energy for PET is high, and the extruding step is the most energy intensive. In addition this step contributes to property loss in the material. So by being able to skip this step, great savings can be made both environmentally and economically.
- The total recovery rate of used materials in a state is very important to the overall environmental effect. It is therefore important to strive for high recovery rates.

The economic assessment gave the following conclusions:

- The collection of beverage containers at the redemption sites involves high costs both for PET and aluminum. For Reverse Vending Machines in stores, these costs are mainly machine depreciation and service and daily operation by store personnel. For manual Convenience Centers the labor cost contributes the most.
- Because of the high costs of daily operation, it will be important to increase the quality and reliability of the Reverse Vending Machines, and possibly make it less dependent on attendance.

Combining environmental results and economic results

- Results from the environmental Life Cycle Assessments (LCA) differ at some points from the results from the Life Cycle Cost (LCC) analysis. Energy use, especially energy made from fossil fuels, has high environmental impacts, but is relatively low in cost.
- Recycling of PET seems to be economically unfavorable but environmentally favorable. Recycling of aluminum is both economically and environmentally favorable. However the PET system can be optimized, and by including socio-economic considerations the result may come out differently.

7.2 Recommendations for further work

Input to Tomra: – system improvements

- By using the results from this project, initiate improvement action projects at the different sites to obtain environmental and economic improvements. It seems to be especially important to improve the economy of the PET system.
- Initiate a cooperation with operators of curbside systems, to establish better knowledge of how to optimize the efficiency of both systems.
- Establish an internal program for improving data quality for the most important parts of the system, such as material loss and transport efficiency. Identify some important indicators to be reported from the different parts of the system, and implement a periodical reporting procedure for these indicators.
- Make regular updates of the life cycle models established in this project, with the regularly updated data and indicators, and the results from the improvement actions. The updates of the models can be used as documentation for the continuous environmental improvement as required by ISO 14001.

Input to Tomra: - Machine improvements

In order to improve it is important to focus on the energy consumption during the operation phase as well as the transport related to service:

- To reduce energy consumption during the operation phase, Tomra can focus on two improvement possibilities:
  - Improve routines for starting, closing and operating the machine during the lifetime
  - Eco-design of the Tomra machine, so that it requires less energy during the operation phase

- To reduce transport related to service, Tomra can focus on routines for service transport, the need for service during the lifetime and increased quality, as well as making it easier to repair by local owners. Expanding the use of online service is another way of reducing service transport.

Another improvement possibility is to eco-design the machine for recycling/reuse. By making the most important machine components (steel, aluminum, plastics) more available for recycling. Materials from these components can replace virgin material. To show the environmental effect of this, different scenarios for increased recycling can be analyzed in a further study.

Input to P-2005 Research Program

- Identify criteria for optimal systems (environmental and economic) for recovery and reuse of beverage packaging in Europe. A project with this scope is proposed for the Program of Industrial Ecology at NTNU, and will probably start up in the beginning of year 2000.

- Evaluate the results from this project by applying different allocation methods.

- Evaluate LCA model sensitivities due to changes in critical input parameters, and if possible evaluate cost efficiency of PET also by macro- economic principles.

➢

8 APPENDIX

8.1 Appendic 1

Background data and sources for the selected beverage recycling systems where Tomra does part of the material handling

Connecticut:

System 1: **PET shredded in Tomra RVM's, sorted and chipped at BPRC (Metro), then transported to reclaimer and "reclaimed" to a commercial grade pellets/resin.**

Process/ element		Preconditions	Data source	Comment
PET production		General data.	Data from APME/PWMI (Eco-profiles of the European plastic industry, report 8: Polyethylene terephthalate,..)	
Transportation of PET raw material		Not included	(Data not found)	
Bottle production		General data (extruding bottles)	Data from PLM Lidkjöping 1995	
Top production		General data	Data from Eco-profile report 3, PWMI, table 26 page 17.	Only for PP raw material production
Filling, distribution		Not included (specific data not obtained)		Not considered as focus in this study
Transportation to consumer		Not included		Mainly transporting the beverage
Transportation from consumer to redemption site		Site specific	Data from survey done for Tomra by Audits & Surveys Worldwide, Oct. 1999	Some assumptions have been made
Redemption site		Site specific on energy consumption, measured (American average el.)	Data from Tomra Metro and Tomra Systems, R&D	Energy consumption found by tests

Transportation to Metro Processing (BPRC)		Site specific	Data from Tomra Metro	Some assumptions are made for differentiating the commodities in the truck
Metro Processing, chipping		Site specific	Data from Tomra Metro	
Transportation to reclaiming		Site specific	Data from D.A.C	Distance from map
Reclaiming		Site specific	Data from wTe	

Simulation of PET system: *PET flattened in Tomra RVMs, and bailed, then transported to reclaimer, chipped, and "reclaimed" to a commercial grade pellets/resin.*

Same as for system 1, except from Metro processing which is replaced with bailing:
The chipping is now done at reclaimer instead of at Tomra Metro.

Process/ element		**Preconditions**	**Data source**	Comment
Bailing		General data.	Data from Report No.405 1998, Ministry of Environment and Energy, Denmark; "LCA of Packaging systems for Beer and Soft Drinks"	

System 3: *Aluminum cans flattened in Tomra RVMs, bailed at BPRC (Metro) and shipped to Kentucky (Wise Recycling).*

Process/ element		Preconditions	Data source	Comment
Primary aluminum production replaces - **lost aluminum (extra aluminum)** - **-loss of quality**		General data.	Miljøstyrelsen no 402/98. based on data from the European Aluminum Industry, European Aluminum Association, 1996.	Include data from the mining stage and throughout foil production
Transportation of Aluminum raw material		Not included		Not considered as focus in this study
Can manufacturing		General data	Miljøstyrelsen no 402/98. Data from Gøte Nylin, PLM in Malmø. American electricity replaces swedish el..	Data is in the same order of magnitude as data used in Norwegian study (STØ 1995).
Filling, distribution		Not included (specific data not obtained)		Not considered as focus in this study
Transportation to consumer		Not included		Mainly transporting the beverage
Transportation from consumer to redemption site		Site specific	Data from survey done for Tomra by Audits & Surveys Worldwide, Oct. 1999	Some assumptions have been made
Redemption site		Site specific on energy consumption, measured (American average electricity)	Data from Tomra Metro and Tomra Systems, R&D	Energy consumption found by tests
Transportation to Metro Processing (BPRC)		Site specific	Data from Tomra Metro	Some assumptions are made for differentiating the commodities in the truck.
Metro Processing, bailing		Site specific	Data from Tomra Metro	
Transportation to re-melting		Site specific	Data from Wise Recycling on distance	
Re-melting		General data	Miljøstyrelsen 402/98. Based in data from EEA.	American electricity is used instead of electricity made from coal.

Strip rolling		General data	Miljøstyrelsen nr 478/99. Data from EEA.	American electricity is used instead of electricity made from coal. .

California

System 4: *Whole PET bottles collected in Convenience centers. Data for reclaiming will be taken from Connecticut.*

Process/ element		Preconditions	Data source	Comment
PET production		General data.	Data from APME/PWMI (Eco-profiles of the European plastic industry, report 8: Polyethylene terephthalate,..)	
Transportation of PET raw material		Not included	(Data not found)	
Bottle production		General data (extruding bottles)	Data from PLM Lidkjöping 1995	
Top production		General data	Data from Eco-profile report 3, PWMI, table 26 page 17.	Only for PP raw material production
Filling, distribution		Not included (specific data not obtained)		Not considered as focus in this study
Transportation to consumer		Not included		Mainly transporting the beverage
Transportation from consumer to redemption site		Site specific	Data from survey done for Tomra by "Options", Sept. 1999	Some assumptions have been made
Redemption site		Site specific	Data from Tomra Pacific	Manual work (no specific environmental impacts)
Transportation to Cucamonga Plant		Site specific	Data from Tomra Pacific	Some assumptions are made for differentiating the commodities in the truck
Cucamonga plant		Site specific	Data from Rancho Cucamonga plant	Only some reloading done, no processing of PET
Transportation to reclaiming		Site specific	Data from D.A.C	Using Connecticut data (the material is actually going to among others PPRC, Plastic Recyclers of California)
Reclaiming		Site specific	Data from wTe	Using Connecticut data

System 5: *Whole aluminum cans collected in Convenient Centers, shredded at Cucamonga plant and shipped to Reynolds in Alabama*

Process/ element		**Preconditions**	**Data source**	**Comment**
Primary aluminum production replaces - **lost aluminum (extra aluminum)** - **-loss of quality**		General data.	Miljøstyrelsen no 402/98. based on data from the European Aluminum Industry, European Aluminum Association, 1996.	Include data from the mining stage and throughout foil production
Transportation of Aluminum raw material		Not included	(Data not found)	
Can manufacturing		General data	Miljøstyrelsen no 402/98. Data from Gøte Nylin, PLM inMalmø. American electricity replaces swedish el..	Data is in the same order of magnitude as data used in Norwegian study (STØ 1995).
Filling, distribution		Not included (specific data not obtained)		Not considered as focus in this study
Transportation to consumer		Not included		Mainly transporting the beverage
Transportation from consumer to redemption site		Site specific	Data from survey done for Tomra by "Options", Sept. 1999	Some assumptions have been made
Redemption site		Site specific	Data from Tomra Pacific	Manual work (no specific environmental impacts)
Transportation to Cucamonga Plant		Site specific	Data from Tomra Pacific	
Cucamonga plant		Site specific	Data from Cucamonga plant	
Transportation to re-melting		Site specific	Data from Cucamonga plant	
Re-melting		General data	Miljøstyrelsen 402/98. Based in data from EEA.	American electricity is used instead of electricity made from coal.
Strip rolling		General data	Miljøstyrelsen nr 478/99. Data from EEA.	American electricity is used instead of electricity made from coal. .