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Energy from waste in Sweden – state of the art and possibilities for the future

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1. Introduction

Energy from waste is an important waste management method in Sweden, especially incineration of waste. In the last 5 year-period, the incineration of municipal solid waste in Sweden has been 2.2 – 2.3 million tonnes annually, which corresponds to approximately 48 – 51% of the municipal waste. The incineration plants also use other waste fuels: the total amount of incinerated waste in "municipal incinerator plants" were about 5.8 million tonnes in 2015, of which 2.3 million tonnes were Swedish municipal waste, about 1.5 million tonnes were imported municipal waste or sorting residues from municipal waste, and the rest were Swedish industrial wastes. The incineration plants produced 14.7 TWh of district heating and 2.3 TWh of electricity. That means that close to 23% of the district heating in Sweden is produced from in municipal waste incineration plants.

Further, there were in 2015 in total 1.6 million tonnes that were anaerobic digested with production of biogas, of this amount about 0.32 million tonnes were food waste collected from households, restaurants and similar, the rest was different kind of biodegradable industrial wastes (from food industry and slaughter-houses) and manure. In 2015 these digestion plants produced more than 0.9 TWh of biogas (of which 0.75 TWh was upgraded to methane mainly used as vehicle fuel).

However, there are different ambitions to reduce the importance of incineration. According to the waste hierarchy in the EU waste directive 2008/98/EC, recycling of waste is prioritized to energy recovery by incineration, and there are several policy initiatives to increase the recycling of waste, for example in the EU circular economy package [COM(2015) 614 final]. In Sweden, also prior to the circular economy package, the recycling goals for packaging waste have been raised, and in the current work with the Swedish National Waste Plan the Swedish EPA is discussing measures for increasing the recycling.

The goal with this report is to shortly discuss the role of energy recovery from waste, especially incineration, in the future in Sweden, and to propose research areas that are relevant to waste incineration in the future.

2. EU circular economy package[1]

2.1 General

The discussions about a circular economy package have gone on for several years. In 2014 there was a first proposal, that were withdrawn in December 2014, as part of the political discontinuity exercise carried out for the first Work Programme of the Juncker Commission.

A year later, on 2 December 2015 the European Commission adopted the ambitious new Circular Economy Package[2] to help European businesses and consumers to make the transition to a stronger and more circular economy where resources are used in a more sustainable way. The proposed actions is expected to contribute to "closing the loop" of product lifecycles through greater recycling and re-use, and bring benefits for both the environment and the economy. The plans will extract the maximum value and use from all raw materials, products and waste, fostering energy savings and reducing greenhouse gas emissions. The proposals cover the full lifecycle: from production and consumption to waste management and the market for secondary raw materials. This transition will be supported financially by ESIF funding, €650 million from Horizon 2020 (the EU funding programme for research and innovation), €5.5 billion from structural funds for waste management, and investments in the circular economy at national level.

The Package has been broken down in the Commission and contributes to broad political priorities by tackling climate change and the environment while boosting job creation, economic growth, investment and social fairness.

The Circular Economy Package aims to give a clear signal to economic operators that the EU is using all the tools available to transform its economy, opening the way to new business opportunities and boosting competitiveness. Innovative and more efficient ways of producing and consuming should increasingly emerge as a result of the incentives we are putting in place. The circular economy has the potential to create many jobs in Europe, while preserving precious and increasingly scarce resources, reducing environmental impacts of resource use and injecting new value into waste products. Sectoral measures are also set out, as well as quality standards for secondary raw materials. Key actions adopted today or to be carried out under the current Commission's mandate include:

- Funding of over €650 million under Horizon 2020 and €5.5 billion under the structural funds;
- Actions to reduce food waste including a common measurement methodology, improved date marking, and tools to meet the global Sustainable Development Goal to halve food waste by 2030;
- Development of quality standards for secondary raw materials to increase the confidence of operators in the single market;
- Measures in the Ecodesign working plan for 2015-2017 to promote reparability, durability and recyclability of products, in addition to energy efficiency;
- A revised Regulation on fertilisers, to facilitate the recognition of organic and waste-based fertilisers in the single market and support the role of bio-nutrients;

[1] http://europa.eu/rapid/press-release_IP-15-6203_en.htm

[2] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Closing the loop - An EU action plan for the Circular Economy. Brussels, 2.12.2015. COM(2015) 614 final.

- A strategy on plastics in the circular economy, addressing issues of recyclability, biodegradability, the presence of hazardous substances in plastics, and the Sustainable Development Goals target for significantly reducing marine litter;
- A series of actions on water reuse including a legislative proposal on minimum requirements for the reuse of wastewater.

The package includes a clear timeline for the actions proposed and a plan for a simple and effective monitoring framework for the circular economy.

The revised legislative proposal on waste sets clear targets for reduction of waste and establishes an ambitious and credible long-term path for waste management and recycling. To ensure effective implementation, the waste reduction targets in the new proposal are accompanied by concrete measures to address obstacles on the ground and the different situations across Member States. Key elements of the revised waste proposal include:

- A common EU target for recycling 65% of municipal waste by 2030;
- A common EU target for recycling 75% of packaging waste by 2030;
- A binding landfill target to reduce landfill to maximum of 10% of municipal waste by 2030;
- A ban on landfilling of separately collected waste;
- Promotion of economic instruments to discourage landfilling ;
- Simplified and improved definitions and harmonised calculation methods for recycling rates throughout the EU;
- Concrete measures to promote re-use and stimulate industrial symbiosis –turning one industry's by-product into another industry's raw material;
- Economic incentives for producers to put greener products on the market and support recovery and recycling schemes (e.g. for packaging, batteries, electric and electronic equipment, vehicles).

The legislative proposal is being processed at the European Parliament. Members of the European Parliament voted in plenary 14 March 2017 to strengthen resource efficiency in the EU by 2030 – a move that signals strong political support for the transition towards a circular economy. The text approved today includes:

- 70% target for the recycling of municipal waste, as opposed to 65 percent – with a five percent of that waste to be prepared for reuse;
- 80% target for the recycling of packaging waste
- A landfill limit of 5%
- Mandatory separate collection for the main waste streams, including biowaste, waste oils and textiles;
- Increasing use of economic instruments such as landfill and incineration taxes and deposit-return schemes, and
- More clarity on the decontamination of hazardous components in waste.

The Council of the European Union is expected to take a position on the Circular Economy strategy in the coming months, before the Parliament, Commission and Council can all agree on the final text.

The Commission will continue to deliver on the Circular Economy Action Plan. During 2017 several topics will be presented: a strategy for plastics in the circular economy, an assessment of options for the improved interface between chemicals, products and waste legislation, a legislative proposal on water reuse and a monitoring framework on circular economy.

2.2 The role of waste-to-energy in circular economy

As a part of the package EU Commission has issued a communication about the role of waste-to-energy in the circular economy[3]. It provides guidance for Member States to achieve a balance of waste-to-energy capacity, highlighting the role of the waste hierarchy which ranks waste management options according to their sustainability and gives top priority to preventing and recycling of waste. It helps optimizing their contribution to the Energy Union and exploiting the opportunities for cross-border partnerships where this is appropriate and in line with our environmental goals.

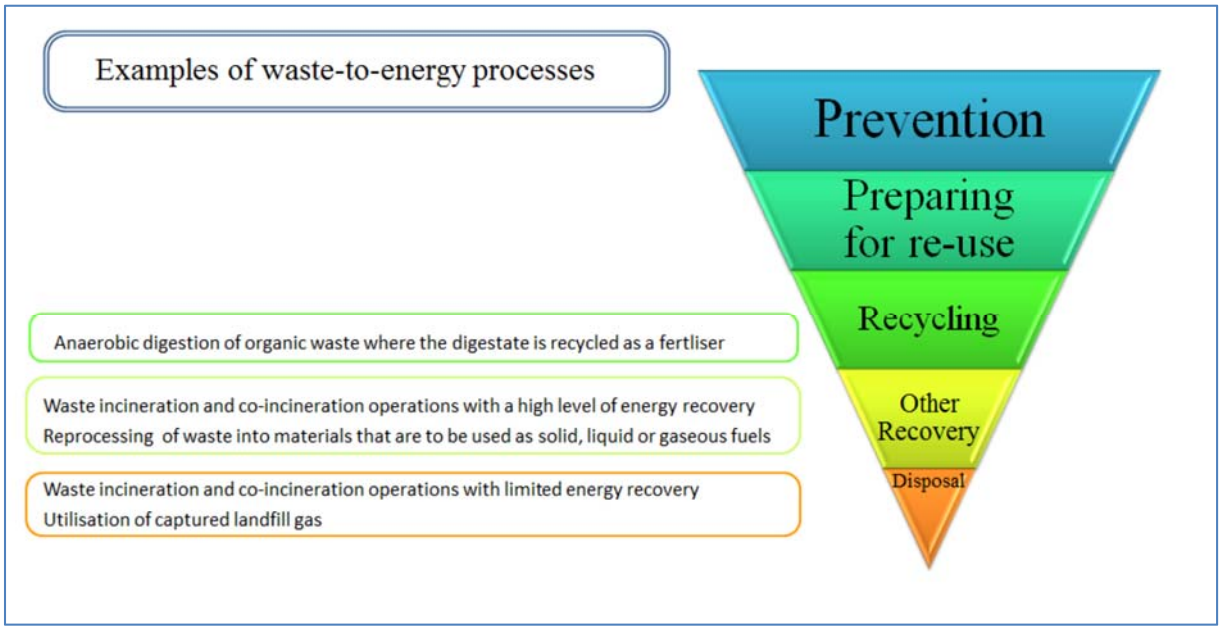


Figure 1. The waste hierarchy and waste-to-energy processes.

Some important or interesting topics from this communication are:

- The communication confirms that dedicated incineration capacity for municipal waste is unevenly spread in the EU. Germany, France, the Netherlands, Sweden, Italy and the UK account for 75% of the EU's incineration capacity. Sweden and Denmark have the highest per capita incineration capacity with 591 kg/cap and 587 kg/cap respectively, followed by the Netherlands, Austria Finland and Belgium. In contrast, the southern and eastern parts of the EU are practically devoid of dedicated incineration capacity and are highly reliant on landfill.

[3] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIALCOMMITTEE AND THE COMMITTEE OF THE REGIONS The role of waste-to-energy in the circular economy. Brussels, 26.1.2017 COM(2017) 34 final

- A study from the European Environment Agency suggests there is currently no incineration overcapacity in the EU as a whole. However, the statistics show that some individual Member States are excessively reliant[4] on incineration of municipal waste. This situation may be partly explained by high demand for heat through district heating networks, the higher efficiency of their waste-to-energy processes and high levels of social acceptance. Nonetheless, such high rates of incineration are inconsistent with more ambitious recycling targets. To address this problem a number of measures can be taken at national level and have already been implemented in some Member States, in particular:
    - introducing or increasing incineration taxes, especially for processes with low energy recovery while ensuring they are paired with higher landfill taxes;
    - phasing out support schemes for waste incineration and, where appropriate, redirecting support to higher-ranking processes in the waste hierarchy; and
    - introducing a moratorium on new facilities and decommissioning older and less efficient ones.

- Waste-to-energy processes can play a role in the transition to a circular economy provided that the EU waste hierarchy is used as a guiding principle and that choices made do not prevent higher levels of prevention, reuse and recycling.

[4] This is the exact wording in the Communication. It can be discussed if "reliant" shall be interpreted as positive or negative. In the communication there is a negative undertone towards incineration, but in reality it also means that the country that is "reliant" on incineration, is not "reliant" on landfilling, which should be positive.

3. Swedish material recycling goals

Sweden is dependent on the requirements in the waste framework directives (2008/98/EC) and other directives concerning waste and waste management. However, these requirements are minimum requirements and member states may decide about higher recycling rates.

The Swedish EPA is currently working with a new waste management plan, including a national waste prevention plan, to be valid for 2018 – 2023. The plan will be decided before the end of 2017. According to the directions from the Government the plan shall contain measures for complying with the recycling and prevention requirements in the EU waste directive. It is expected that the plan will include proposed measures for increased recycling of prioritized waste streams, as well as measures for prevention of prioritized waste streams.

Already in 2014, before the launching of EU's circular economy package, it was decided that the goals for recycling of packaging waste shall be increased from 2020 (Packaging Waste ordinance 2014:1073):

Material	**Current goal for recycling, %**	**Goal for recycling from 2020, %**
All packaging waste, total recycling	55	65
Paper packages	65	85
Plastic packages (excluding beverage packages)	30	50
Plastic beverage packages	90	90
Glass packages	70	90
Metal packages (excluding beverage packages)	70	85
Metal beverage packages	90	90
Wood packages	15	15
Packages of other materials	15	15

Also material recycling of newsprint waste has new material recycling goals from 2020. The current goal is 75% and from 2020 the goal is 90%.

A general conclusion is that these requirements are of low importance in the perspective of incineration in the future. The total amount of packaging and newsprint wastes to recycling are about 1.3 million tonnes per year and a 10% increase of the recycling means 120,000 tonnes less to incineration, to be compared with the 2.2 – 2.3 million tonnes/year of municipal waste that is incinerated today, or 5.8 million tonnes/year total of waste incineration.

4. Other relevant legislation and policy questions

4.1 Classification of bottom ash from incineration

Incineration of waste generates secondary wastes such as fly ash, flue gas cleaning residues and bottom ash. Fly ash and flue gas cleaning residues are classified as hazardous waste. Bottom ash has until now been classified as non-hazardous waste and large quantities are used as construction materials or are landfilled as non-hazardous waste. However, the criteria for hazardous waste (Annex III in the Waste Framework Directive 2008/98/EC) have been under development and have recently been changed. A first change was presented in 2014, but that has not had any influence on the classification of bottom ash. On 8 June 2017 there was a Council Regulation (2017/997) regarding the hazardous property HP 14 Ecotoxicity. This new criteria will have an influence on the classification on bottom ash and it is to expect that parts of the bottom ash will be classified as hazardous waste. This may have an effect on the economy for the incineration plants (remark: fly ash and flue gas cleaning residues will be classified as hazardous waste as earlier).

It is too early to make any more detailed predictions of the consequences of the new classification. Avfall Sverige (Swedish Waste Management Association) has recently started up a project with a more detailed consequence analysis.

4.2 BREF document

The first draft of the reference document for best available techniques (BREF) for Waste Incineration (WI) was published by EU:s Joint Research Center (jrc) on 24th May[5]. Once adopted, this document will have an important impact on the sector as all permits will have to be based on the Best Available Techniques (BAT) Conclusions 4 years after the publication in the Official Journal.

The Best Available Techniques Associated Emission Levels (BATAELs) proposed in the drafts are stricter than the current emission standards for waste-to-energy plants. There are also more far-reaching technical requirements, and requirements on more continuous monitoring of some emissions depending on the size of the incineration plant (for example HCl, SO_2, NO_X, CO, NH_3, dust, TVOC[6] and Hg are mentioned for large size incinerators).

A very preliminary assessment of the consequences for the Swedish incinerators is:

- The Swedish incinerators have a high technical standard and it should be no major problems to meet the new technical requirements, nor should they have problems to comply with the new emission standards.
- The additional requirements on continuous monitoring of certain emissions are a new requirement that will force the Swedish incineration plants to invest in new monitoring equipment and introduce new monitoring routines. This will increase the running costs of the incinerators.

[5] http://eippcb.jrc.ec.europa.eu/reference/BREF/WI/WI_5_24-05-2017_web.pdf
[6] Total Volatile Organic Carbon

5. Waste-to-energy research in Sweden

5.1 Waste Refinery[7]

Waste Refinery started in 2007 as a center of knowledge, hosted by SP Technical Research Institute and continued until the end of 2015. Several research and development projects were initiated by the center, with financing from other research programs. From January 1 2015, Waste Refinery continues as a strong strategic network. During 2007 – 2014 there were 64 projects financed through Waste Refinery. Projects regarding incineration were, for example

- technical research about the incineration process
- technical research about recovery and disposal of ash and slag from incineration
- system analyses of waste treatment options, including incineration
- technical research about waste fuels

There were also several projects about anaerobic digestion and biogas.

5.2 RE:SOURCE[8]

RE:Source is Sweden's leading research and innovation investment within the resource and waste area. It is a national innovation arena and supports the development of innovations that can contribute to a more efficient use of resources in both society and business. RE:Source has been appointed by the Swedish Energy Agency, Vinnova and Formas as a Strategic Innovation Program, which means it has great importance for Sweden's international competitiveness, as well as for creating sustainable solutions to global societal challenges. The program will run for three years from 2016, but it could be extended for a combined period of twelve years. The program is led by RISE Research Institutes of Sweden in collaboration with Chalmers Industriteknik, IVL Swedish Environmental Research Institute and Swerea.

The ongoing projects is mostly focused on circular economy, sustainability and similar. The projects concerning incineration are for example two projects about handling of fly ash from incineration, and one project about co-pyrolysis of plastic waste and biomass.

5.3 Avfall Sverige (Swedish Waste Management Association)[9]

Avfall Sverige (the Swedish Waste Management Association) is the Swedish Waste Management and Recycling association with 400 members from both the public and the private waste management and recycling sectors. It is a stakeholder and trade association in the field of waste management and recycling. Avfall Sverige represents its members in dealings with politicians, other decision makers, authorities and media, both in Sweden and internationally.

Avfall Sverige finances research and development projects about incineration and anaerobic digestion, for example technical R&D about

- use and recovery of slag and fly-ash,
- future capacity of waste incineration
- how import of waste for incineration affects material recycling
- benchmarking of biogas production

[7] http://wasterefinery.se/
[8] http://www.resource-sip.se/
[9] http://avfallsverige.se/

- upgrading of biogas
- measurements of methane slip from biogas production

5.4 International research on waste-to-energy

A fast screening of international research on waste-to-energy gives the following overview:

- Research on waste-to-energy is going on all over the world. A lot of the research is focused on the local/regional applicability and feasibility of waste-to-energy in the country in question.
- There are a number of projects focused on environmental consequences and life cycle assessments of waste-to-energy.
- The environmental problems that are touched is both ash/slag and emissions to air.
- There are several research groups that are interested in thermal gasification as an alternative to incineration.
- Some studies discuss waste-to-energy from a sustainability and renewable perspective.
- Also different business models have been discussed, for example public–private partnership (PPP) and build-own-operate (BOO) and others.

An interesting overview of the research in waste-to-energy and incineration is given by Wang et al[10], who made a bibliometric review of the waste-to-energy research:

"This study aims to provide an up-to-date contemporary bibliometric view of the waste-to-energy incineration literature and a correlative analysis of this field. Based on the bibliometric method, a statistical analysis was undertaken on papers published from 1999 to 2015 in Science Citation Index (SCI) and the Social Science Citation Index (SSCI). There were 4348 publications in the field of waste-to-energy incineration. The number of publications per year has increased steadily since 2009. China produced 15.71% of all pertinent articles followed by Japan with 11.37% and USA with 7.97%. China has played a key role in the collaboration network of 30 most productive countries and regions. In addition, the cooperation within the European countries was notable. However, China ranked first in all aspects except h-index. This means China's impact (number of citations) in this field could be further strengthened though its quantity (number of publications) was the highest. Five clusters were identified from keywords networks, i.e. Central Cluster node ("combustion"), Cluster(I) (central nodes were "fly ash"," heavy metal(s)" and "bottom ash"), Cluster(II) (central nodes were dioxin-related substances), Clusters(III) (central nodes focused on waste management), and Cluster(IV) "chemistry methods". These findings are useful for the future endeavor of waste-to-energy incineration academic research."

5.5 Discussion

The research and development concerning waste-to-energy is to a great part focused on technical issues. Some reports and studies that are of interest are referred in chapter 6.

[10] Yuan Wangab, Nan Laia, Jian Zuocd, Guanyi Chenab, Huibin Dud. Characteristics and trends of research on waste-to-energy incineration: A bibliometric analysis, 1999–2015. Renewable and Sustainable Energy Reviews Volume 66, December 2016, Pages 95-104

6. Some R&D studies of relevance

6.1 Waste management indicators

From 2013 there have been some co-ordinated projects developing a system for waste management indicators in Sweden.

The Waste Refinery and the NEPP project

IVL and PROFU made a study about waste management indicators in 2013[11]. It was conducted within the network of first step of NEPP, and with grants from different research funds. The overall objective of the project was to develop a set of indicators describing the resource-efficiency of the waste management system and comparison of possible development over the years. This means that the indicators:

- will illustrate the achievement of set objectives
- will make it possible to follow up the development of the Swedish waste management system on local/regional and national levels in a simple way.

Although the information and knowledge on waste management has constantly been improved in society, the difficulties in measuring and monitoring the development has increased. The goals of waste management have steadily become more ambitious and this has created an increasingly complex waste management system. This is evident when looking at today's ambitions to develop the upper portions of the waste hierarchy, i.e., waste prevention and material recovery. These parts are much more difficult to describe, measure and follow-up compared to the lower processing steps. Indicators on prevention and decoupling have been an important objective for the indicator project.

In the project, the indicators have been analyzed and tested in five different case studies (three at the municipal level and two at the national level, including one case study for household waste in accordance with Avfall Sverige and one of the national total waste linked to the official waste statistics).

The following criteria have been applied and are achieved:

- Relevance
- Data access
- Quality
- Communicability and Usability

The indicators that have been developed:

- Are neutral and useful at the level they relate to, i.e. at the municipal/regional and/or national level.
- Are designed to measure change and/or the rate of annual change
- Covers every step of the waste hierarchy (they give an indication of the resource efficiency of each step and of the total system).
- Measures the change in the resource efficiency of the entire system over time (i.e., describes a position in the waste hierarchy).

The indicators can be used at the municipal level or at national level. The indicators are intended to support policy makers, municipalities and municipal waste companies in planning and monitoring of municipal waste management.

[11] Indikatorer för en resurseffektiv avfallshantering. Indicators for a resource efficient waste handling. Waste Refinery project WR53. 2013. http://wasterefinery.se/media/2016/02/WR53-slutrapport-140113.pdf

Three types of indicators are developed:

- Indicators measuring the climbing in the waste hierarchy - mirrors the level and development of the total waste management system.
- Indicators describing each level of the waste hierarchy - describes and measures the performance of each step in the waste hierarchy minus the rejected amounts of waste arising prior to the treatment (for example, sorting residues from recycling).
- Background Indicators - takes into account all treated waste in every particular step of the waste hierarchy, also waste generated by other treatment (such as ash from incineration).

The objective is that the derived indicators will be integrated with existing waste reporting in local government, e.g. in AvfallWeb (the Swedish Waste Web)[12] and in national monitoring that the Swedish EPA implements.

A user guide has also been produced within the project to provide a view of the indicators and how they can be used.

Follow-up project by SMED

In 2015 SMED[13] made a follow-up study on the indicator project mentioned above. The study was financed by Swedish EPA. The aim was to study how the national statistics (both for waste from households and waste from business and industry) can be developed to indicate how the waste management is developed (Swedish EPA is responsible for the waste statistics in Sweden).

As a result of the project, the production of waste statistics have been developed so the waste statistic data can be used as input in the indicator system. In addition, some changes to the indicator system have been suggested in order to make it easier to use available statistic data.

Avfall Web[14]

Avfall Web *("Waste Web")* is and Internet-based tool for municipalities and municipal waste treatment plants to follow up and benchmark the waste management in municipalities. It was initiated and is administrated and operated by Avfall Sverige (Swedish Waste Management Association)[15], a stakeholder and trade association in the field of waste management and recycling. Avfall Sverige was co-funding the first indicator project (see above) and was involved in some case studies where municipal waste data was used to analyze the waste management in some municipalities with the indicator system. From 2014 it is possible for the

[12] Avfall Web (Waste Web) is and Internet-based tool for municipalities and municipal waste treatment plants to follow up and benchmark the waste management in municipalities. It was initiated and is administrated and operated by Avfall Sverige (Swedish Waste Management Association). http://www.avfallsverige.se/en/statistik-index/avfall-web/

[13] SMED means "Swedish Environmental Emissions Data", which is a collaborative consortium involving the four organizations IVL Swedish Environmental Research Institute, Statistics Sweden, Swedish University of Agricultural Sciences and Swedish Meteorological and Hydrological Institute. Only IVL Swedish Environmental Institute and Statistics Sweden have been involved in the follow-up project on the waste indicators .

[14] http://www.avfallsverige.se/en/statistik-index/avfall-web/

[15] http://www.avfallsverige.se/

municipalities to enter data in the Avfall Web and get waste indicators as output. In 2015 there were 171 municipalities that entered data in the indicator section of the Avfall Web.

6.2 Import of waste and material recycling[16]

The aim of the project was to investigate how recycling of waste is affected by waste imports to energy recovery in Sweden. The study covered both recycling in Sweden and in the countries where most of the imported waste is derived.

Roughly 5.8 million tonnes of waste was used for energy recovery at incineration plants in Sweden in 2015 of which 1.6 million tonnes were imported waste. The Swedish waste-to-energy plants are paid to treat the imported waste, which came primarily from the UK, Norway and Ireland in 2015.

Sweden has a relatively cold climate requiring heating of dwellings and premises. This is one of the reasons why district heating systems are well-established in Sweden; with the fuels coming from a number of sources. In these systems, biofuels represent around 40 percent of the total energy supply to district heating and waste more than 20 percent.

The Swedish waste incineration capacity is increasing. Today there are 34 incineration plants plants in Sweden with permission to recover energy from incineration of household waste, and one additional plant is planned. The capacity in Sweden is around 6.65 million tonnes of waste per year meaning that the capacity is exceeding the current demand for energy recovery for domestic residual waste from households and businesses with around 1.6 million tonnes. At the same time as the Swedish capacity is increasing, the EU has strengthened efforts to decrease landfilling of waste in the EU. As a result large quantities of waste need to be taken care of by other treatment methods than disposal. As an example, the UK and Ireland have in response to policy intervention, implemented landfill taxes, which have increased continuously. Norway has also implemented a landfill ban on biodegradable waste. Swedish waste-to-energy plants can offer competitive gate fees for this waste as the energy in the waste can be efficiently used, and due to Swedish taxes on fossil fuels, waste becomes competitive with the relatively expensive biofuel alternatives. For Swedish waste-to-energy plants, the choice of fuel is dependent on the market conditions. Imported waste for energy recovery has in many cases shown to give lower heat production costs compared to alternative fuels. In addition, the imported waste is often of higher fuel quality compared to domestic waste to energy recovery due to higher heating value, and lower ash and moisture content.

In recent years, the import of waste has received increased attention from Swedish media. Questions have been raised whether recycling of waste in Sweden and in the exporting countries are influenced by the waste imports to Sweden, but few facts have been put forward in the debate. In this context it is important to highlight why waste is recycled. Recycling of waste occurs due to two main reasons; 1) market conditions, i.e. it is economically profitable to recycle waste due to the economic value of the waste and/or compared to other treatment options, or 2) due to national or EU targets as well as other policy instruments. For recycling under economically advantageous basis, the value of the waste must cover the extra costs of collection, sorting, transport and other activities surrounding recycling compared to other treatment methods. The secondary material must also be of sufficiently high quality in order to compete with virgin materials. Profitability in sorting out more material for recycling also

[16] Avfallsimport och materialåtervinning. IVL Rapport B2236, http://www.ivl.se/sidor/publikationer/publikation.html?id=5313n

depends on the composition of the waste and thus on the degree of source-separation of the incoming waste and on the available collection systems.

National or EU targets or other policy instruments indirectly affect the amount of waste that is recycled, for example, targets for recycling of certain product groups and producer responsibility obligations. Policy instruments may lead to recycling even though it is not economically advantageous for the actors involved.

The project was conducted based on available literature and interviews with actors directly or indirectly involved in the waste trade. This included representatives from government agencies, municipalities, waste contractors and facility owners. The findings were analyzed and used to present and discuss possible connections / hypotheses on the import of waste and recycling. The study has been limited to Ireland, Norway, UK and Sweden.
One clear conclusion is that the waste exported to Sweden has different origins and has undergone various types of processing before export. The waste comes both from households and from businesses, and has been separated at source in varying degree. In addition to source-separation the waste can have undergone other types of sorting in a simple or more advanced manner. The waste exported is thus not a homogeneous stream, but a complex mixture of waste handled in different ways.

Of the countries studied only the UK requires that waste to energy recovery must be pre-treated prior to export. However, there are no specific requirements on how pre-treatment should be designed. In practice this means that waste from households and businesses may have gone through everything from very simple sorting and processing, where some types of materials are separated, to advanced sorting and processing. Source-separation is not considered pre-treatment.

The main waste streams exported from Ireland, Norway and the UK are rejects from MRF facilities (Materials Recovery Facilities), rejects from MBT plants (Mechanical Biological Treatment) as well as waste from households and businesses that have undergone varying degrees of source-separation and sorting after collection. MRF facilities located in Ireland and in the UK, primarily sort mixed packaging waste into numerous material fractions that are sent further to recycling. MBT plants in the UK can be constructed in different ways and be built with different purposes. Common to these facilities are the inputs, i.e. they all receive municipal waste that has been source-separated to a varying extent, but where food waste is part of the incoming fraction. They contain both mechanical steps and steps for biological treatment. Contaminants, dirt and liquid as well as waste that potentially could be recycled, but not under prevailing economic conditions, form a reject when sorted that needs to be treated by energy recovery or disposal. There remains thus a potential to sort out more waste for recycling from both MBT and MRF facilities and through other types of sorting procedures. The reason why the waste remains in the exported waste fractions is primarily due insufficient economic value of the secondary materials, which does not compensate for the extra costs of sorting, and due to lack of market possibilities for some of the material.
The level of sorting at MRF and MBT plants and for other types of sorting is to a greater extent determined by the marketability and price of the sorted material than the cost for treatment of the reject fractions. It is thus the market for secondary materials, the degree of sorting and the quality of the sorted material that primarily determine whether the waste will be recycled or turned into a reject to energy recovery or disposal.

The cost difference between recycling more waste, or instead send the waste to other treatment; energy recovery or disposal, can affect how the waste is finally treated. From a market perspective, it can theoretically be argued that the more expensive disposal or energy recovery, the greater is the economic incentive for recycling to become the most economical option compared to other options. This may in turn lead to stronger incentives to recycle waste. If, instead, the opposite would apply, that it is cheaper to send the waste to energy recovery or disposal, recycling is hampered. The relatively low Swedish gate fees to energy recovery result in more economic incentive for Norwegian, British and Irish actors to send the waste to Sweden than to treat the waste in their own countries. This can theoretically inhibit recycling of waste in the exporting countries. Imports to Sweden, however, has limited effect on the cost for these players because the gate fees for energy recovery in Sweden are determined with respect to the alternative costs reflecting the willingness to pay of the waste exporter/generator. The waste imports can increase the gate fees in Sweden due to the fact that the gate fees are affected by the cost of the more expensive treatment options in the exporting countries. By contributing to higher gate fees for energy recovery, imports of waste can in theory actually stimulate recycling in Sweden.

If the capacity for energy recovery in the future is expanded in northern Europe there may eventually be competition for waste between waste-to-energy plants. If that happens, the gate fees might generally decrease, which theoretically could hamper recycling of waste. The gate fees for energy recovery, both in Sweden and in the market actors in the UK, Ireland, Norway and Sweden operate in have thus risen over the past 1-2 years. **This indicates that the economic incentive for when recycling, theoretically, becomes the most economically feasible option compared with other options does not shrink, but has rather increased in recent times**. The results from the project also indicate that a limited possibility to export waste to energy recovery did not necessarily lead to increased sorting to recycling. The most cost-efficient way of treating the waste had likely been used, domestic energy recovery or disposal. If only Sweden had put restrictions on the waste imports, increased export to other countries would have also been the likely option.

What actually happens to recycling if energy recovery in comparison becomes more or less expensive is difficult to assess. This is due to the fact that many other factors in the society influence the outcome. Previous knowledge indicates that recycling of waste is likely to be fairly insensitive to changes in the cost difference between recycling and energy recovery as long as the recycling is mainly dependent on source-separation.
In Norway, the project team found one concrete example where the Swedish gate fees for energy recovery have contributed to hampering biological treatment of food waste. The basis for the decision to send food waste with residual waste for energy recovery in Sweden instead of sorting out the food waste to biological treatment was justified both for environmental and for economic reasons. Imported waste for energy recovery in Sweden could hypothetically have a psychological effect on households' source-separation behaviour in Sweden and / or in the exporting countries. This is an unexplored area where more knowledge is needed. The project has only found one behavioral study concerning the subject, which is not considered enough to draw general conclusions. Results from the study in question indicated, however, that the effect on households' source-separation is small. Behavioral studies of this kind have neither been possible to identify in the UK, Ireland and Norway. Reliable behavioral studies can be challenging to carry out as the questions posed easily become leading.

The possibility to export waste to energy recovery in Sweden could affect policy instruments to increase recycling in the exporting countries. No connection between objectives and

measures and the possibility to export waste to countries such as Sweden has thus been identified. The exporting countries have equally high ambitions recycling of waste compared to Sweden. The EU common objectives are valid in all studied countries. Parts of the UK (Wales, Scotland and Northern Ireland) have higher targets for preparation for reuse and recycling of waste from households and from similar sources than Sweden. In all of the studied exporting countries, and in Sweden, there are producer responsibility obligations for packaging, although the responsibilities' are designed differently. In all of the countries studied there are higher recycling targets for recycling of packaging than the EU minimum targets, either in the form of requirements on individual producer responsibility schemes or according to national legislation. In Ireland, weight-based waste tariffs are introduced for areas with more than 500 people as a way to increase the share of waste going to recycling. The Norwegian EPA (Miljødirektoratet) has examined possibilities of introducing mandatory food waste and plastic waste collection in municipalities.

The possibility to export waste for energy recovery in Sweden can also affect investments in waste-to-energy in the exporting countries. The capacity is expanding in the UK and Ireland, and to a limited extent in Norway. The export from Norway is more highly driven by the price difference between energy recovery in Norway compared to Sweden, and not to the same extent by the insufficient waste incineration capacity. Exports of waste for energy recovery in countries like Sweden, with relatively low gate fees to energy recovery, result in reluctance to invest in new waste-to-energy plants, which inhibits the development of domestic waste incineration capacity. Waste imports to Sweden therefore reduce energy recovery in the exporting countries in the short term and, possibly even more in the long term. Expansion of own recycling capacity, in addition to MBT and MRF facilities are governed primarily by the secondary raw materials market in the studied exported countries. The UK, Ireland and Norway are dependent on exports for final recycling of waste generated.

In summary, the study concludes that waste imports for energy recovery in Sweden may lead to a combination of reduced landfilling of both treated and untreated waste in the studied exported countries as well as reduced domestic energy recovery and incineration without energy recovery. The knowledge developed in this study and in previous studies suggests that the effects the waste imports to Sweden have on recycling are small in practice, but more knowledge is encouraged.

6.3 Waste amounts and waste treatment capacities in the future[17]

This project was carried out by the consortium SMED in 2016 at the request of Swedish EPA, and was a study made within the framework of the new national waste plan.

The aims with the project were to

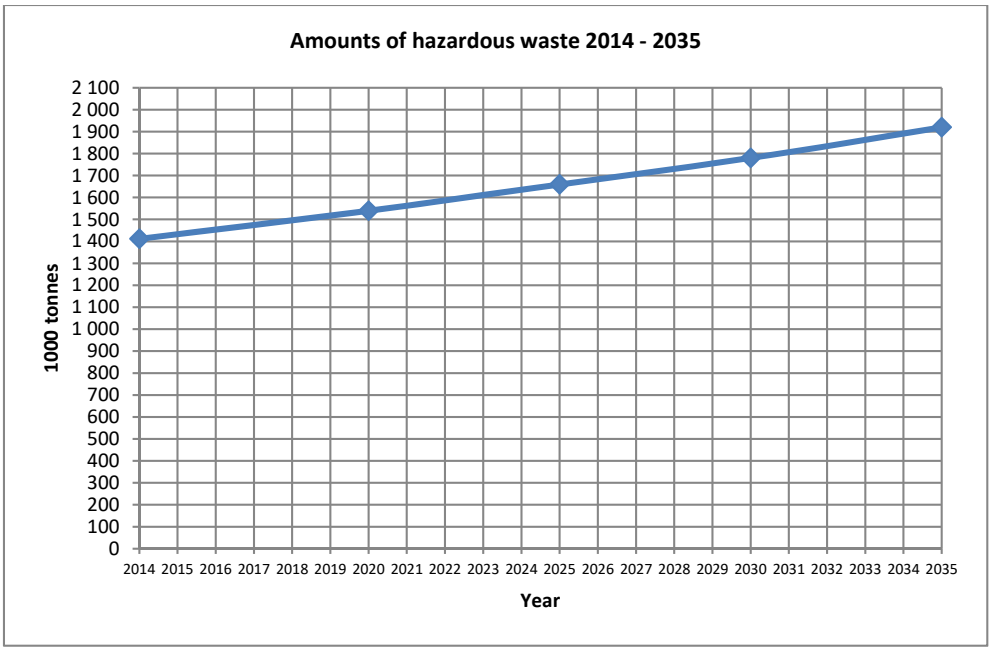
- Estimate amounts of generated waste for the period 2020 – 2030 based on earlier published studies.
- Survey current treatment capacity and planned treatment capacity
- Discuss how the waste will be treated in Sweden 2020 – 2030.

In 2016 Konjunkturinstitutet (the National Institute of Economic Research) conducted a study where future waste amounts were estimated[18]. The model calculation was based on the EMEC

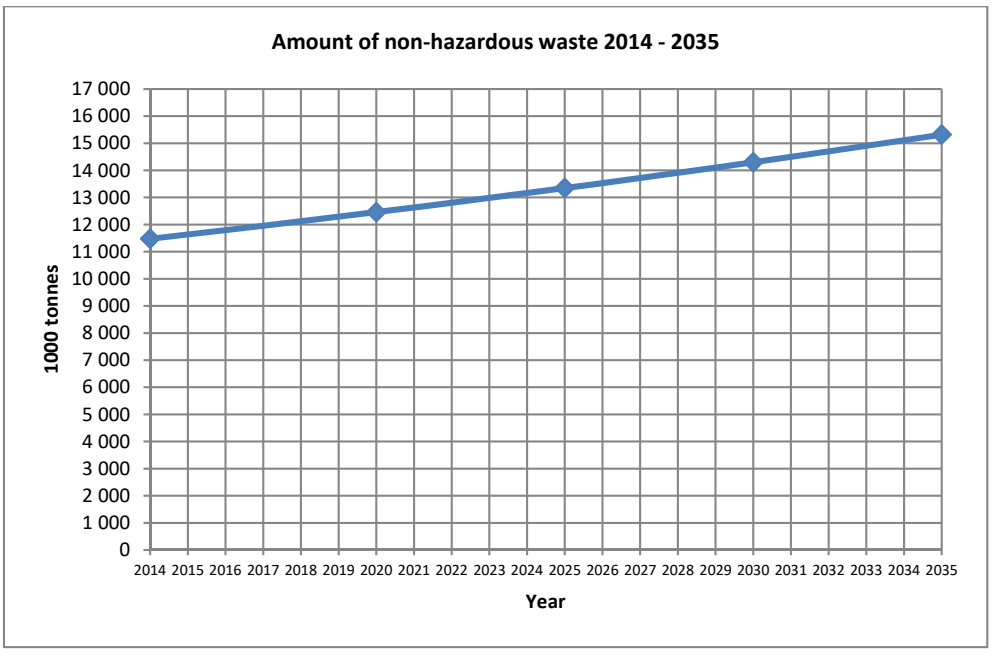
[17] http://www.smed.se/avfall/rapporter/rapportserie-smed/4060
[18] Miljö, ekonomi och politik 2016. Konjunkturinstitutes miljöekonomiska rapport 2016. http://konj.se/download/18.1910291f158b9b08e365eebe/1480941421501/Miljo-ekonomi-politik-2016.pdf

which is a computable general equilibrium (CGE) model of the Swedish economy developed and maintained by the National Institute of Economic Research for analysis of the interaction between the economy and the environment. There is a special module calculating waste amounts. The amounts of waste, divided into 40 different waste types were, for each industrial branch plus private households.

The data from Konjunkturinstitutet was further developed in the study to estimate the expected amounts at different years between 2014 and 2035.



Figur 1. Estimated amounts of hazardous waste 2014 – 2035.



Figur 2. Estimated amount of non-hazardous waste 2014 – 2035.

It can be observed that the growth of waste is lower than the growth in economy. In the study by Konjunkturinstitutet, the increase of the GDP was assumed to be 64% between 2014 and 2035 (about 3.2% per year as an average), while the growth of the amount of hazardous waste was estimated to 36% and the growth of non-hazardous waste was estimated to 33% during the same period. This depends on structural changes in the industry, where waste intensive sectors (for example pulp and paper, metal, and mechanical industry) is growing slower than the less waste intensive sectors (for example Services)

Regarding incineration of waste the SMED study concluded that:

- Capacity of waste incineration in municipal waste incinerators is about 6.6 million tonnes/year in 2016, and is expected to rise to 6.7 – 7.0 million tonnes/year in 2020.
- During the period 2016 – 2020 the capacity is higher than the available amount of Swedish combustible waste. The surplus is expected to be 1.1 – 2.0 million tonnes/year in 2020, and have to be filled up with imported waste if full capacity shall be accounted.

Regarding the waste to incineration the SMED study also made the following compilation of possible development in the future.

Tabell 1. Estimated amounts to incineration in the future (according to a business-as-usual-scenario).

	To incineration 2014 *Mtonnes*	To incineration 2020 *Mtonnes*	To incineration 2025 *Mtonnes*	To incineration 2030 *Mtonnes*	To incineration 2035 *Mtonnes*
Waste to incineration (business-as-usual)					
Household waste	2,16**	2,45	2,72	3,02	3,35
Mixed Swedish business waste	1, 67**	1,7	1,75	1,8	1,84
Wood waste, non-hazardous	1,56**	1,7	1,87	2,04	2,22
Wood waste, hazardous	0,10**	0,11	0,12	0,13	0,14
Sludges, non-hazardous	0,08**	0,09	0,095	0,1	0,11
Other wastes	0,25**	0,28	0,29	0,32	0,34
Total Swedish waste to incineration (rounded)	**5,8**	**6,4**	**6,9**	**7,4**	**8,0**

* Avfall Sverige (2015). Kapacitetsutredning 2016 – Avfallsförbränning och avfallsmängder till år 2020. Avfall Sverige Rapport 2016:1 (in Swedish)

**Based on official waste statistics from Swedish EPA Avfall i Sverige (2014), Naturvårdsverket Rapport 6727, Juni 2016, and Statistics Sweden's statistc database: http://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__MI__MI0305/MI0305T02/?rxid=47754f24-c3b9-4d1d-b2b1-8af336124a2c

These figures are based on a business-as-usual scenario, where the recycling rate (% collected for recycling) is the same during the period to 2035. It is to expect that the recycling rates will increase. However, the increased amount of recycled packages and newspaper is expected to be about 0.12 million tonnes in 2020 and 0.16 million tonnes in 2035 (corresponding to a total increase of 10% of recycling of packages and newsprint).

7. Attitudes to waste-to-energy

Attitude studies have been rather common in the Swedish waste management. For example several municipalities, producer responsibility organizations and Swedish EPA are doing attitude studies on a regularly basis. The aims are usually to identify weaknesses what users and customers experience as difficulties in the waste system, and to benchmark themselves. The studies are often rather rudimentary and lack deeper analyses.

A study focused on attitudes to incineration was made in Helsingborg 2010. During the planning of the new incinerator plant 205 citizens in Helsingborg were questioned about their opinion on a waste incineration plant in the city[19]. The result showed that more than 25% answered they were "Very positive", and further 59% answered "Positive". 14% were "Negative" and 1% was "Very negative".

There are also examples of more scientific studies. In the research program "Towards a sustainable waste management"[20] which was run between 2006 and 2012, there were two projects focusing on attitudes, habits and behavior. The two projects were:

- **Evaluating design and impact of environmental information**[21]. This project investigated how environmental information can be developed and designed in order to increase people´s readiness to take part in source separation schemes. By applying quantitative methods of environmental psychology, it was examined how individuals perceived information on waste sorting and waste prevention. What is acceptable waste management information that can be laid upon consumers? How can new environmental information be designed to target the vast variation among individuals in different surroundings?
- **Sorting things out: considering cultural categories of waste**[22]. The aim of the project was to investigate how efficient source-separation systems can be designed from a user perspective. People are generally positive to source separation, but there is a difference between what they think and what they actually do. Perceptions of waste heavily rely on widespread and culturally grounded values and habits of daily life. To be efficient, source separation systems and policy instruments, often created by experts and professional actors in the waste-collection market, should not contradict such values and habits.

These two projects did not include waste incineration and other waste-to-energy issues, but the methods could be used to highlight people's perception of incineration and waste-to-energy.

[19] https://www.hd.se/2010-11-05/manga-ser-fram-emot-sopforbranning
[20] http://www.hallbaravfallshantering.se/ , http://www.sustainablewaste.info/
[21] http://www.sustainablewaste.info/innehall/om/theresearchprogramme/researchprojects/5evaluatingdesignandimpactofenvironmentalinformation.4.712fb31f12497ed09a580002808.html
[22] http://www.sustainablewaste.info/innehall/om/theresearchprogramme/researchprojects/6sortingthingsoutconsideringculturalcategoriesofwaste.4.712fb31f12497ed09a580002821.html

8. Conclusions

8.1 Possibilities for waste-to-energy by incineration in the future

When discussing incineration in a European perspective, there are several waste management strategies that have to be considered:

1. **Material recycling**. Recycling is preferable prior to incineration according to the waste hierarchy, and according to the circular economy principles, see above. However, in practice there are some problems connected with recycling:
   - The market for plastic is limited. There have been plastic wastes from Europe that have been exported to recycling in India and China where there is no control of the quality of recycling. Plastics can also be recycled only a limited number of times, the polymer molecules are degraded after some recycling rounds.
   - There is hardly any material recycling of wood.
   - Paper can be recycled a limited number of times. When a paper fibre has been recycled 5 – 7 times, it is worn out and has to be rejected from the recycle process.

2. **High performance incineration, with controlled emissions to air and water, and high energy recovery rate**. Incineration in Sweden is an example of this. The emissions (per ton waste, or per m3 emitted flue gas) are low, and well below the standards in the waste incineration directive (2000/76/EC) and industrial emissions directive (2010/75/EU) and also below the standards proposed in the new BREF document about waste incineration[23]. The high energy recovery is favorable for the economy since both electricity and heat is sold. A prerequisite is that there is an existing infra-structure for distribution of heat (district heating).

3. **Medium and low performance incineration, with controlled emissions to air and water, and lower energy recovery rate**. The emissions (per ton waste, or per m3 emitted flue gas) are low, and well below the standards in the waste incineration directive (2000/76/EC)) and industrial emissions directive (2010/75/EU) and also below the standards proposed in the new BREF document about waste incineration[24], but there are limited market for heat, since the district heating grids are not developed as in Sweden.

4. **Landfilling.** Landfilling is the least desirable option according to the waste hierarchy. In Sweden there is practically no municipal waste that is landfilled. In some countries in southern and eastern parts of Europe landfilling is the dominating waste management method.

The expected requirements on increased recycling will decrease the amount available for incineration. However, as mentioned above, the expected increase in recycling in Sweden is relatively small compared to the amounts that actually are incinerated.

Today the capacity of incineration is higher than the available Swedish waste, and import of waste is a way of filling up the surplus. This is expected to be the situation for several years

[23] http://eippcb.jrc.ec.europa.eu/reference/BREF/NFM/JRC107041_NFM_Bref_2017.pdf
[24] http://eippcb.jrc.ec.europa.eu/reference/BREF/NFM/JRC107041_NFM_Bref_2017.pdf

ahead. In many European countries landfilling of organic waste is still of importance, and may be of importance for several years ahead.

Swedish waste incineration is competitive in an international perspective, to a large part depending on effective district heating systems. For many countries it will be less expensive to export combustible waste to Sweden, than to implement own incineration facilities. There are municipalities and cities in, for example Norway and England, that prefer to export their waste to Sweden, instead of sending it to domestic incineration plants.

Several life cycle assessments have shown that incineration with high energy recovery is advantageous to landfilling (even modern high technology landfills with high landfill gas recovery).

From a European perspective it may be advantageous, from both an economic and environmental point of view, if Sweden develop the waste incineration so ”landfilling countries” export their combustible waste to Sweden, instead of continuing landfilling or building own incineration plants with lower energy recovery efficiency.

There will be some kind of competition between incineration and material recycling, also in the future, and it is important to find practical rules and criteria for when incineration is preferred and when material recycling is preferred. According to the circular economy package recycling shall be chosen prior to incineration, but according to the waste framework directive it is possible to make exceptions from the waste hierarchy:

- “*When applying the waste hierarchy referred to in paragraph 1, Member States shall take measures to encourage the options that deliver the best overall environmental outcome. This may require specific waste streams departing from the hierarchy where this is justified by life-cycle thinking on the overall impacts of the generation and management of such waste*.” (Article 4.2 in the Waste Framework Directive 2008/98/EC)

8.2 Discussion of research needs (in the perspective of the NEPP2 project)

- Putting requirements on imported waste, for example requirements on prior source sorting or presorting and control of waste quality.
- Development of the earlier mentioned indicator system, and dissemination of the system and the results.
- Finding the balance between incineration and material recycling:
    - LCA of waste management in a circular perspective. Earlier LCA have usually been based on linear systems (“from the cradle to the grave”), but in circular systems the results may be different. For example in the linear system the question of issue is often “shall we incinerate or recycle”. In a circular perspective other issues with combinations of recycling and incineration of reject from recycling may be possible.
    - Also quality questions are of importance when discussing the balance. The quality of the plastic waste from source separation is usually of higher quality (higher price, easier to market, possible to substituting virgin plastic, and so on) if the source separation is low, for example 30%, than if the separation is high, for example 80%.

- Attitudes to waste-to-energy and incineration – both the public opinion and the official attitude from EU, government and parliament can be discussed and analysed from several different perspectives.
- System analyses: European or North European perspective on the balance between material recycling, incineration in Sweden, incineration in other countries and landfilling.