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Circular Economy: Global Perspective

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Circular Economy Initiatives in Norway

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1 Introduction

Circular economy is a principle of economic activity that aims to ensure that resources remain in the economy for as long as possible. This may be achieved by reducing raw material consumption, waste generation, emissions and energy consumption. The waste and recycling industry represent the largest part of the circular economy today, and it is estimated that more than 600 million tons of wastes can be recycled or reused in Europe (EC 2015).

The European Waste Framework Directive (WFD 2008) issued by the European Commission lays out common recycling targets and strategies for the EU Member States. The objective is to achieve a level playing field and improved resource efficiency in waste management. Six Member States landfilled less than 3% of their municipal waste in 2011, while 18 States landfilled over 50%, with some exceeding 90% (EC 2015).

Circular economy has a significant growth potential in Europe and in Norway. On average, recycled materials only meet less than 12% of the EU demand for materials (EC 2019). EU alone may save 600 billion US dollars annually after 2025 if industrial companies are able to turn their business around a circular economy (MacArthur and McKinsey 2015). In addition, such a transformation can create more than two million jobs by 2030, according to the EU Commission.

Norway is not a member of the European Union but have access to trade and other forms of relationship through a European Economic Area Agreement, which also means that Norway needs to comply with various EU directives, as the WFD. The waste hierarchy, i.e. prevention, recycling, material recycling, energy utilization and final processing in order of priority, constitutes the framework for the regulatory development in the EU and Norway.

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In Norway, the total material recycling level in 2017 was around 45%, which indicates a huge potential for circular economy initiatives (SSB 2019). Norwegian recycling companies must have access to international markets, on the same basis as other importers and exporters of raw materials. Harmonized and open waste markets, across national borders, strengthen the willingness to invest in the industry. Furthermore, a level playing field is crucial for the ability to invest in profitable, innovative and resource-efficient waste and recycling facilities.

Norway has a mixed economy with state and private ownership in, for example, the petroleum sector (Equinor), hydroelectric energy production (Statkraft) and aluminium production (Norsk Hydro). This provides a sound basis for growth in Norwegian circular economy which involves both private industry and the government.

2 Minimizing Resource Consumption and Rationalizing Resource Utilization Based on 3Rs (Reduce, Reuse and Recycle)

The linear economy of "take-make-dispose" is not sustainable in the long run, given the volatile resource prices, supply disruptions, economic losses and environmental strain. A circular economy is a regenerative system in which resource input and waste, emission and energy leakage are minimized through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, recycling and upcycling. The aim is to keep the value and utility of products, materials and components as high as possible for as long as possible. A circular economy will contribute to reduce future resource scarcity, help reduce climate impact, provide opportunities for innovative services and deliver new levels of economic efficiency and resource productivity.

The total generation of all non-hazardous and hazardous waste in Norway was 11.7 million tons in 2017. Around 21% of the waste was placed at landfills which indicate that there is still a significant potential to contribute to the circular economy. In particular, about the inorganic waste types like concrete, masonry, various types of slag, fly ash and dust which constitute 50% of the landfilled materials. However, for other waste streams, for example municipal solid waste, organic hazardous waste and EE waste, a sound waste management system is implemented for high recovery rates.

Innovation in the waste sector in Norway is guided by the waste hierarchy and the circular economy principles. Valorization of these waste streams is possible due to ambitious policy, well-functioning waste management systems, innovative technology and good communication between the different stakeholders in the region.

3 Legislative Framework and Government Support Towards Implementing 3Rs and Circular Economy Initiatives

3.1 Government Strategy

In 2015, the Norwegian government appointed an Expert Committee to propose a national strategy to promote "green competitiveness" towards 2030 and the low-emission-society in 2050 (Regjeringen 2015). Norway and the EU are prioritizing a circular economy agenda to deliver the next generation of jobs, growth and investment. Research funds, innovation support, consumer demands and legislative requirements will provide opportunities for those businesses using resources more productively.

The Norwegian government presented a White Paper to Parliament on waste policies in a circular economy with an emphasis on increasing reuse and recycling on 21 June 2017. The White Paper also outlines Norway's strategy to strengthen international commitment to combat marine litter through cooperation in the Nordic region, the EU, other regional fora and through the UN (NMCE 2017).

Long-term goals on waste reduction in different industries are also in the pipeline. Recently, an agreement with the food industry was established aiming to reduce food waste by 50% by 2030. The Norwegian Ministry of Climate and Environment announced that a similar type of collaboration will be established with the textile industry.

Norway has a tradition of using national policy targets combined with regulations, economic incentives, information and extended producer responsibility (EPR) schemes. Agreements between the branch/trade and the government on producer responsibility have promoted efficient waste management and product optimization for packaging, waste electrical and electronic equipment (WEEE) and PCB-containing glazing units, and taxes/fees have encouraged recycling and established a market for waste. At the regional level, counties are free to set their own targets and develop local/regional plans. This has been important for optimal and adapted resource efficiency in Norway (EEA 2016).

3.2 Extended Producer Responsibilities

The fundamental idea behind EPR is to place a responsibility for the post-consumer phase of certain goods on the producers. According to OECD, EPR is a policy approach under which producers are given a significant responsibility—financial and/or physical—for the treatment or disposal of post-consumer products. Assigning such responsibility could in principle provide incentives to prevent wastes at the source, promote product design for the environment and support the achievement of public recycling and materials management goals. In Norway, the EPR is implemented for products that contain dangerous substances and materials that are important to recycle (NMCE 2004):

- Electrical and electronic (EE) products
- Batteries
- Packaging
- Vehicles
- Tyres
- Double-glazed glass containing PCB.

3.2.1 Electrical and Electronic Products

Electrical and electronic products may contain health and environmental harmful substances. The collection, sorting and treatment of the waste derived from these products are regulated in the directive of waste electrical and electronic equipment (WEEE) (Directive 2012/19/EU), which is implemented in Norway.

All producers and importers in Norway are required to be a member of a compliance scheme for WEEE. An environmental fee is added to the price of goods coming out on the market. The amount of the fee is determined by the costs associated with collection and recycling of the product. In order to follow up producers and importers of EE products and resourced companies, the Norwegian Environment Agency has established the EE register. The EE register has an overview of all manufacturers and importers of EE products and informs them of what duties the waste regulations impose on them.

All municipal recycling stations are obliged to receive EE waste from consumers—completely free of charge. The same applies to retailers selling the same type of product that the consumer wishes to discard, regardless of brand. Therefore, municipalities and retailers must also be affiliated with an approved compliance scheme for handling the EE waste.

3.2.2 Batteries

The battery directive (Directive 2006/66/EC) has the objective of improving the environmental performance of batteries by regulating the use of certain substances in the manufacture of batteries (lead, mercury, cadmium, etc.) and setting standards for the waste management of these batteries. The interpretation and implementation of this directive in Norway has put the responsibility of a safe and sound management of waste batteries on the battery producer. This means that the entity that puts the battery product on the market is considered as a producer. The producer may transfer the EPR tasks to an authorized third party (compliance organization).

Table 1 New recycling targets of packaging waste laid down by EU (Directive (EU) 2018/852) and the recycling level in Norway in 2016

Material fraction	Recycling target 2025 (%)	Recycling target 2030 (%)	Recycling Norway 2016[a] (%)
All packaging waste	65	70	50
Plastic	50	55	45
Wood	25	30	4
Ferrous metal	70	80	Not given
Aluminium	50	60	Not given
Metal total	Not given	Not given	83
Glass	70	75	90
Paper and cardboard	75	85	80

[a]SOE Norway (2019)

3.2.3 Packaging and Packaging Waste

In 2017, the Norwegian waste regulation (NMCE 2004) was revised, and the producer responsibility for packaging was added. This implies that all entities that annually import or produce more than 1,000 kg of packaging wastes must finance collection, segregation and material recycling.

The financing is conducted by membership of a compliance organization authorized by the Norwegian Environment Agency. In the directive amendment (Directive (EU) 2018/852) to directive on packaging and packaging waste (Directive 1994/62/EC), new material recycling targets for packaging waste are provided; see Table 1. The recycling level in Norway is also shown in the same table, and it can be seen that the Norwegian level is roughly close to the EU target for 2030. Recycling of wood is an exception, as around 96% is energy-recovered in Norway.

3.2.4 Vehicles

Manufacturers and importers are responsible for the collection and recycling of discarded vehicles in Norway, so-called full producer responsibility. According to the directive on end-of-life vehicles (Directive 2000/53EC), the reuse and recovery for all end-of-life vehicles, by 2015, should have been minimum of 95% by an average weight per vehicle and year. Within this target, the reuse and recycling shall be a minimum of 85%. The same target is also implemented in the Norwegian waste regulations (NMCE 2004).

Around 140,000 car wrecks are collected in Norway annually. This represents 95% of the total scrapped cars. The recycling of car wrecks is mainly about the recycling of parts, material recycling of metal and other materials such as plastic and glass, as well as energy recovery. The rest goes to final disposal.

The company Autoretur AS has been responsible for collecting and recovering discarded vehicles. The company has good geographical coverage in Norway. The recycling and reuse level of car wrecks was 87.7% in 2018 (Autoretur 2019).

3.2.5 Tyres

The tyre industry is responsible for the collection and recycling of car tyres. Consumers have the right to deliver discarded tyres for free at the tyre dealers. Between 45,000 and 50,000 tonnes of car tyres are collected, which make up about 4 million discarded tyres a year.

It is prohibited to place tyres on a landfill, and Norsk Dekkretur AS is responsible for collecting, storing and processing discarded car tyres. In 2018, the 60,411 tonnes of used tyres were collected in Norway (Norsk Dekkretur 2019).

The following treatment and disposal methods were used: co-processing in cement industry (75%), material recycling (20%), reuse (2%) and the rest fraction of water, metals and residual waste (3%). Hence, none of the collected tyres were placed on a landfill.

3.2.6 Double-Glazed Glass Containing PCB

Manufacturers are obliged to ensure that any waste holder can deliver PCB-containing insulating glass for proper handling against a consideration that does not exceed the normal price for the delivery of insulating glass panes without PCBs to ordinary waste recycling plant. The manufacturer must cover the additional costs beyond this. The Norwegian Environment Agency determines for three years at a time what is considered the maximum normal price for the delivery of insulating glass routes without PCB.

The Norwegian company Ruteretur AS was established in 2002, after an agreement was signed between the Ministry of the Environment and the owners of Ruteretur. The company is a non-profit company that collects discarded PCB glass panes throughout the country and ensures that these are handled safely. Ruteretur is owned by the industry itself, via branch organizations in the building and construction industry.

4 Future Plans and Targets in the Country/a Particular State/Localized Initiatives

4.1 Circular Bio-economy

Around 651,000 tonnes of waste were processed at biogas and composting plants in 2017, and 56% was used for biogas production (SSB 2019). This is a significant increase in the last 5 years. Some of the reasons may be the prohibition to dispose biodegradable waste in landfill from 2009.

Biogas is a common term for the gases methane (CH_4) and carbon dioxide (CO_2) that occur when organic materials (e.g. food waste) decompose. If the waste decomposes without access to oxygen, it is left with about 60% CH_4 and 40% CO_2. These gasses are suitable for different purposes and are today mainly used for transport and food production.

Around 350 buses were running on biomethane in 2016. Given that they run a total of 70,000 km each year, this alone gives a climate gain of more than 30,000 tonnes of CO_2. Unlike diesel, biomethane also releases very little soot particles and does not impact the local air quality with particles that are harmful to the lungs. It is, therefore, ideally suited for high-traffic roads located in densely built-up areas.

In addition, one can utilize CO_2 from the biogas in greenhouses. Plants need CO_2 and sunlight to grow (i.e. photosynthesis). If the carbon dioxide in the greenhouse is made from food waste, it is an excellent example of how we can use the resources we already have around us to form circular value chains, rather than resorting to fossil sources.

In addition to the biogases produced from the waste, the "left-over" is biofertilizer which has similar properties like other manure. Biofertilizer can be used in organic farming. It adds important nutrients to the soil and thus reduces the need for fertilizers. In addition, carbon is stored in the soil. If the biogas plants are utilized fully in Norway, they can produce 600,000 tonnes of liquid biofertilizer directly to agriculture or as input goods in commercial fertilizer, compost, garden soil or growth soil. When biofertilizer is used for new food production, this is in practice circular economy, i.e. the resources in the waste (nutrients) are used over and over again. In addition, soil is supplied with carbon that prevents erosion and depletion. Biogas is, therefore, an important instrument in order for Norway to be able to achieve the EU's goal of material recycling.

4.2 Norway's Programme to Combat Marine Litter and Microplastics

Approximately 80% of the litter that ends up in our oceans comes from land-based sources. The problem is in the oceans, but important solutions are on land. Improvements in waste management should, therefore, be a key priority. Sixteen of the top 20 producers are middle-income countries (majorly in Asia), where fast economic growth is occurring, but waste management infrastructure is lacking. Assuming no waste management infrastructure improvements, the cumulative quantity of plastic waste available to enter the marine environment from land is predicted to double by 2025 (Jambeck et al. 2015).

Norway has established a programme to combat marine litter and microplastics in developing countries. The impact of the assistance programme will be to "Prevent and significantly reduce marine litter and microplastics from sources in partner countries". Activities to be supported by this programme are to be implemented exclusively in countries that are major sources of marine litter, as, for example, in Asia. Norway wants to enhance international cooperation to prevent marine littering within the framework of the UN Environment Assembly.

The government has allocated around 35 million USD in 2018. Norway has also taken the initiative to make improved waste management and prevention of marine litter focus areas of the World Bank's fund PROBLUE. Combatting marine plastic pollution is a long-term commitment; Norway intends to spend 200 million USD to assist developing countries combatting marine litter and microplastics over the next four-year period (State Secretary Jens Frølich Holte's addresses at the seminar Stepping Up to Stop Marine Plastic Pollution in Washington, DC, USA).

The Norwegian Government also intends to reduce emissions of microplastics from key land-based sources in Norway and strengthen the clean-up efforts of plastics from along the Norwegian coastline. It has recently been decided to establish a National Centre in Lofoten/Vesterålen that will hold a central role in the clean-up effort. A grant scheme will also be introduced for local authorities that want to implement measures to reduce marine litter and microplastics as local authorities are key players in carrying out measures against marine litter and microplastics.

5 Examples of Research Projects

5.1 OPTOCE

International action is a key to tackle the most significant sources of plastics litter in the oceans, i.e. insufficient waste management infrastructure in developing countries and emerging economies. The project "Ocean Plastic Turned into an Opportunity in Circular Economy (OPTOCE)" aims to demonstrate the feasibility of using public–private partnerships to collect wastes from polluted hot spots, major river basins and beachfront areas and to treat the wastes in local industries (https://optoce.no). Pilot demonstrations will be conducted where non-recyclable plastic wastes will be energy-recovered in local energy-intensive industry, constituting a win-win concept and a fundamental pillar in circular economy. Such practice will increase the treatment capacity for wastes significantly, reduce the need for landfilling and incineration, reduce the consumption of non-renewable fossil fuels and virgin raw materials in energy-intensive industries, and finally reduce the release of greenhouse gases. Recyclable fractions will be sent to recyclers.

Lessons learned will be shared through a regional multi-stakeholder forum enabling awareness raising, capacity building and efficient replication across the continent. The forum will bring together relevant stakeholders to demonstrate cost-efficient and sustainable solutions to urgent local problems with global impacts. Initial partner countries are China, India, Thailand, Vietnam and Myanmar, but the final selection will be subject to their baseline situation and their willingness to engage in the project with own resources. Other countries might be considered. Opportunities and challenges linked to plastics are increasingly global, and addressing them will significantly contribute to achieving the 2030 Sustainable Development Goals. SINTEF has been implementing several waste recovery projects in Asia the last twenty years.

5.2 SFI Circular

The project, SFI Circular, aims to create new business opportunities that increase value creation and competitiveness in the Norwegian industry (SINTEF 2018). At SFI Circular's core are the academic partners SINTEF, NTNU and Nord University together with industrial enterprises in Norway committed to making a transition to a circular economy. SFI Circular will focus on identifying, evaluating and implementing innovative opportunities for value creation from adapting circular economy principles within and across different sectors. SFI Circular creates value by pooling resources from many industries and sectors.

5.3 PlastiCircle

The project, under the European Union's Horizon 2020 research and innovation programme, aims to develop and implement a holistic process to increase recycling rates of packaging waste in Europe including improvement of the plastic packaging waste chain from a circular economy approach (http://plasticircle.eu).

The target is to increase collection of plastic waste by 10%, and thus, the implementation of PlastiCircle approach in Europe has the potential to increase collected plastic by 860,000 tonnes, create 500–1,400 new companies and generate 12,000–33,000 new jobs. There are multiple partners in the project from Norway, Spain, UK, Italy, Netherlands, Romania, Slovenia, Belgium and Germany. SINTEF is the only partner from Norway, and its main contribution will be the integration and validation of the results on collection, transport, sorting and recycling. SINTEF also contributes to transport optimization, recycling and life cost analyses.

5.4 Construction, Demolition and Surplus Material Projects

The WFD includes a target for recovery of construction and demolition waste (C&D waste). Within 2020, the preparing for reuse, recycling and other material recovery of non-hazardous construction and demolition waste (excluding naturally occurring material) shall be increased to a minimum of 70% by weight.

The target was added during the final negotiations of the Directive text, and instructions for verifying compliance were established in 2011 (Arm et al. 2017). Norway has implemented the WFD and must comply with this target through the partnership of the European Economic Area. The directive is intended to be an overall key driver for circular-driven economy for C&D waste.

Although most of the C&D waste material recovery in Norway is by unbound use like road constructions and backfilling operations, there are ongoing initiatives that focus on recycling the waste entirely into new building products (e.g. concrete and paving blocks). Some of the ongoing circular economy-based C&D waste initiatives are mentioned below:

- Recycled aggregates from excavation materials are used in road construction and concrete production (RESGRAM) 2016–2020. The overall objective for the treatment and recycling plant is to convert more than 90% of the incoming excavation materials into commercial products, supported by Research Council of Norway (RCN 2016a, b).
- Use of local materials (Kortreist Stein) 2016–2019. The main objective of the project is to develop new technological solutions and tools, smart business models and good regulation processes to be able to utilize rock materials from infrastructure projects and local quarries in a superior and sustainable manner, supported by Research Council of Norway (RCN 2016a, b).

5.5 SINTEF Priority Programme on Circular Economy

SINTEF group priority programme on circular economy is a holistic approach through the focus on circular economy (SINTEF 2019). SINTEF combines technological expertise with economic and environmental expertise to provide our customers with multidisciplinary solutions. Important topics are development of optimization models combining technological possibilities with economic and environmental effects, development of innovative business models and new forms of cooperation as well as developing the materials and technology of tomorrow.

5.6 Lessons Learned

A study of the 15 companies in Norway concluded that collaboration is essential for how businesses transition to, and operate, circular business models. Moreover, Norwegian industry's characteristics of trust and reciprocity generate favourable conditions for close collaborations. Collaborating in clusters and industrial parks further enhances the strategic benefits, as it is proposed to facilitate for specialization, knowledge-sharing, relation-specific investments and utilization of complementarities (Zagragja and Rydningen 2016).

Deloitte has studied the circular economy practices of the 50 largest Norwegian companies and compared them with the global pioneers. Some of the important findings of a study by Deloitte on Norwegian circular economy benchmark (2018) are the following:

- Successful innovators that look beyond product performance and CE principles can provide valuable input as a source of innovation.
- Circular economy allows economic growth while optimizing the use of resources and transformed patterns of production and consumption chains.
- Norwegian firms innovate primarily within the network, process and product performance and focus the least on channel for distribution.
- Compared to the global benchmark, there is untapped potential for Norwegian companies to leverage opportunities related to the circular economy business development; consumer goods industry in Norway outperforms the global players.

Integrated waste treatment practice is a win-win concept and a fundamental pillar in circular economy; waste and discharges in one industry are used as inputs and resources in other industries. This waste management practice will increase the treatment capacity for wastes significantly, reduce the need for landfilling and incineration, and reduce the consumption of coal and raw materials in energy-intensive industries, like cement manufacturing, and finally reduce the release of greenhouse gases.

The winners of tomorrow will be the companies that are able to create more value out of less resources. This demands an innovative mindset, a long-term perspective, new business models and willingness to collaborate.

5.7 National Recycling Initiatives Contributing to a Circular Economy

5.7.1 Waste Sorting and Treatment for Household Wastes Generated in Oslo

The Oslo Energy Recycling Agency's (EGE) main task is to sort household waste from the municipality of Oslo, produce district heating and make biogas and biofertilizer (Oslo Municipality 2017).

The lifecycle-based waste management system in Oslo plays an important role in helping the city to reach the climate goals like material for recycling of 50% by 2018, reduce greenhouse gas emissions by 95% by 2030 and achieve climate neutrality by 2050. An important contribution is EGE's two optical sorting plants at Haraldrud and Klemetsrud, where source-separated household waste is sorted, as shown in Fig. 1. Expanded source separation of food waste and plastic packaging helps reduce greenhouse gas emissions and improve local air quality. It also aids in the recovery of valuable resources found in waste products.

Waste sorting is done with the aid of a fully automated optical sorting process for source-separated household waste, separated into bags with specific colours. The optical sorting plants are equipped with cameras that can identify the colours of the bags with about 98% accuracy.

The three lines at Haraldrud and Klemetsrud can sort 150,000 tonnes of household waste per year; the Haraldrud sorting plant is currently the world's largest, as per

Fig. 1 Optical sorting of waste at Haraldrud

June 2017. The various stages of the sorting process are briefly described in the following.

Households in Oslo city sort their waste into three categories: food is sorted in green bags; plastic packaging in blue bags and residual waste in regular shopping bags. This type of waste separation is an addition to existing systems for sorting paper and cardboard, glass, metal and hazardous waste. A major advantage of this system is that the bags can all be placed into the same bin and transported in the same vehicle to the waste management plant.

- Pre-sorting: During the first sorting stage, larger unwanted elements and loose waste are sifted through a robotic pre-sorting process at the plant, where only blue, green and common plastic bags are allowed through. Unwanted waste of all sizes is removed and sent off for incineration, while the rest of the bags continue to the next step in the sorting process.
- Preparation for optical detection: When the robotic pre-sorting stage is complete, household wastes in the bags are distributed onto three conveyer belts equipped with robotic arms. The robotic arms rearrange the bags into a line, getting them ready for optical reading and sorting. The distance between the bags makes it easier for the optical cameras to read the colour and prevent the bags from being on top of each other.
- Optical sorting: When the bags arrive for optical reading, the cameras detect the colour of the bags with 98% accuracy. There are two sensors that detect green bags, one sensor that detects blue bags, and one sensor that detects both. Blue and green bags are removed with the aid of robotic arms, while those bags that are neither blue nor green continue further for recycling. The blue and green bags are transferred onto separate belts, where the colour codes are detected a second time through what is known as negative sorting. This process discards bags and elements which are neither blue nor green, but which may have been removed in error in the previous stage. The bags are then sent to separate containers. These optical sorters have a 98% detection rate.
- Blower: The blue bags undergo yet another quality control. To weed out the blue bags that contain waste other than pure plastic packaging, a blower or negative sorter has been installed on the blue belts. Lightweight bags can pass, but bags that are too heavy (more than about 600 g) are sent off for recycling. These are bags that contain waste other than plastic. The blue bags which are light and accepted by the blower continue to the compactor container. Plastic waste in the blue bags is sent to treatment plants in Germany and Sweden, where it is sorted into 5–7 categories. The plastic is melted into granules and then used as raw material in making new plastic products.
- The energy of the residual waste is recovered in Haraldrud and Klemetsrud waste-to-energy plants. The recovered energy is utilized for district heating and electricity production.

5.7.2 Advanced Plastic Sorting Facility for Household Waste

Romerike Waste Processing IKS (ROAF) works with the collection, sorting, recycling and recycling of waste. ROAF owns and operates the most modern household waste sorting plant in Europe and have an extensive responsibility to manage the resources in the waste in a responsible manner. They work continuously to reduce the ecological footprint of our operations and consider the environment in everything we do. The household wastes from 200,000 citizens in the suburbs of Oslo are collected. The sorting facility commenced operation in 2014, built at a budget of 25 million euros. The sorted materials are then sent to recycling.

ROAF has developed one of the most advanced sorting facilities in the world utilizing near-infrared (NIR) technology to sort out five different plastic qualities, metals and even paper from the residual waste stream. ROAF also administers several closed landfills as well as a landfill on the same site as the sorting facility. This list of equipment includes conveyors, NIR machines, drum screens, vibrating screens, shredder, bag openers, ballistic separator, Eddy current separator, magnetic separators, wind sifter and star screen. Dry, clean plastic can be recycled as many as ten times, and one kilo of recycled plastic saves the environment for two kilos of oil, which would otherwise have been used in the production of new products. It is more energy demanding to produce new plastic, than to reuse what already exists.

The advanced plastic sorting facility has resulted in the need for only two waste bins inside each household for the residual waste, i.e. one bin for food waste and one bin for other non-recyclable residual waste including plastics. This makes it easier for the consumers to focus on the household segregation (metal, paper, glass in addition to food and residual waste). The ROAF facility is sorting out around 2,500 tonnes per year for plastic material recycling.

5.7.3 Co-processing of Wastes in Norway

Co-processing is defined as use of a waste in an industrial process as an input material, additionally or in substitution of standard (primary, natural) input materials. Co-processing implies that there is a substitution effect together with the use of the waste, i.e. that the waste substitutes a fuel, a raw material, an auxiliary material or any combination of these in the process. Co-processing is widely used in the cement production. The co-processed wastes in cement industry substitute very often both the fuel and raw materials. In the cement clinker production, material temperature of up to 1,450 °C is needed to ensure the sintering reactions. Furthermore, the clinker needs to be burned in the excess of 2–4% oxygen. Hence, the cement kiln has many inherent features, which makes it ideal for hazardous and non-hazardous waste treatment (e.g. high temperatures, long residence time, surplus oxygen, dry scrubbing of the exit gas by alkaline raw material).

In Norway, two cement kilns are operated by Norcem AS. Both plants practise installed co-processing. It is emphasized that a dedicated incinerator for hazardous waste has never been built in Norway. A political decision was taken in the early

1990s to use the Norcem cement plants to destroy the organic hazardous liquid wastes. These plants substitute today approximately 70% of its coal need with waste-derived fuel, both hazardous and non-hazardous wastes. This strategy increases the waste treatment capacity significantly, reduces the need for landfilling and incineration, reduces the coal and raw material consumption in the cement industry and contributes to reduce greenhouse gases. The waste-derived fuel in the Norcem Brevik cement plant is from the following sources; 20% from municipal solid waste, 21% hazardous wastes, 9% from anode carbon, 5% from animal meal and 2% from waste oil.

The use of alternative fuels replacing fossil fuel is one of the key factors for the cement industry in western Europe in becoming sustainable. In addition to higher competitiveness, the use of more alternative fuels will also contribute to lower direct CO_2-emissions due to the use of biomass-based fuels and indirectly by avoiding landfilling and incineration of other waste types. The Brevik plant is a modern cement manufacturing process using the latest BAT/BEP technology, i.e. dry process with pre-heating and pre-calcination, advanced exit gas quenching and cleaning, and online exit gas monitoring.

5.7.4 Carbon Capture Projects in Norway

The Norwegian Government has initiated a full-scale carbon capture and storage (CCS) project in Norway. There are two capture projects that are part of the pre-engineering project: Fortum Oslo Varme waste-to-energy plant in Oslo (i.e. Klemetsrud plant) and Norcem cement plant in Brevik (Fortum 2019). Both facilities plan to capture around 400,000 tons of CO_2. This amount is equivalent to removing 60,000 cars from the road for a year.

The CO_2 will be transported by ship from the capture plant to an onshore facility on Norway's west coast for temporary storage. The CO_2 will then be transported via a pipeline to a subsea reservoir in the North Sea for storage. Equinor, with its partners Shell and Total, are responsible for the planning of the storage facility. The storage concept study will be completed during the course of 2019 followed by an advanced planning study. Once these studies are completed for all stages of the CCS chain, the basis for an investment decision will be in place. The projects are considered to be pioneering at an international level.

The Klemetsrud plant is a large source of emissions with annual emissions of more than 400,000 tons of CO_2. By capturing the emitted greenhouse gas, and subsequently storing it, it will be possible to reduce the fossil CO_2 emissions by around 12% per year. In 2016, Aker Solutions set up a test facility for carbon capture at Klemetsrud incineration plant. The pilot project lasted five months and captured successfully 90% of the carbon from the waste incineration. If approved, the carbon capture technology can be spread to Norway's 17 waste incineration plants, and even to the approximately 450 others in Europe. The Norwegian Parliament is expected to make an investment decision for the project in 2020/2021. The project will then be able to commence operations in 2023/2024.

Norcem and Heidelberg Cement Northern Europe have a vision of zero emissions of CO_2 from concrete products as seen over its lifecycle in 2030. To achieve this vision, it is necessary to capture CO_2 from cement production. In 2013, Norcem started a capture project to test different technologies in the plant in Brevik. The projected was finalized in 2017 which included a feasibility study for use of the amine technology from Aker Solutions. Furthermore, funding was assigned in the Norwegian state budget for 2018 for the last stage (FEED study) before the final construction. The aim of the ongoing FEED study is a detailed review of the project to provide a basis for an investment decision. The study will be ready by the end of 2019. After a third-party review, the Norwegian Government will submit a proposal to the Parliament to realize the project. If a decision to invest is made, the project will then enter a three-year construction phase. The cement clinker plant with full-scale carbon capture may thus be in operation in 2024.

6 Concluding Remarks

A circular economy is a regenerative system in which resource input and waste, emission and energy leakage are minimized through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, recycling and upcycling. An ultimate result of circular economy is that the term "waste" should disappear from our vocabulary. Hence, waste materials play a key role in the implementation of initiatives that contribute to circular economy.

The legislative framework for circular economy in Norway is based on the European directives that need to be implemented through the European Economic Area agreement between EU and Norway. The directives and the Norwegian legislation impose an increasing responsibility on the producer of consuming products, i.e. extended producer responsibility. This has been implemented for a number of large product groups (e.g. electrical and electronic equipment) which results in large waste streams. The producer responsibility is to a large extent successful and contributes to a safe and sound waste management which results in increased reuse, material recycling and energy recovery.

Many national and international circular economy projects are initiated in Norway. They are developed from the common sustainability perspective which focuses on the circular economy in particular. The R&D projects have different funding instruments and comprise research on different smart materials, design solutions, separation processes, carbon capture, legislative enablers, economic models, social factors, etc.

The focus on ocean plastic is high in Norway, and a strategy is decided by the government. This is also reflected in newly started projects that focus on reducing plastic and microplastic to enter the oceans (e.g. OPTOCE). Furthermore, the ongoing initiatives also have high international collaboration which is decisive to implement circular economy on a global scale. Furthermore, the governmental participation in the further development is important as both political and economic incentives are some of the cornerstones in circular economy.

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