New Plastics Economy

A RESEARCH, INNOVATION AND BUSINESS OPPORTUNITY FOR DENMARK

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McKinsey&Company

Innovation Fund Denmark

Content overview

New Plastics Economy – A Research, Innovation, and Business opportunity for Denmark

1. **Human beings throw away more than half their own weight in plastic every year – 260 million tons of it. The figure will probably reach 500 million tons by 2030. 8 million tons of this waste ends up in the sea, killing wildlife, and disrupting ecosystems. To deal with this pressing challenge, we have to define a New Plastics Economy. In Denmark, we also see the harm that waste plastics can cause at first hand**
    1. Every year, Denmark collects 1,000 tons of waste on its western coastline
    2. The Arctic Ocean is a global sink for microplastics with an estimated 300 billion plastic items floating in the ice-free waters
    3. Danes want action: 99% of Danes say it is important to act on the challenge of plastics
2. **Denmark can capitalize on the commitment of its citizens to become a frontrunner in the New Plastics Economy. It can help capture the full value of plastics through research and innovation aimed at smarter use with reduced consumption, full recycling of all consumer and industrial plastics, development of sustainable plastics, and the elimination of pollution from plastics in use**
    1. Doing so offers economic benefits: Denmark loses DKK 1.6 billion a year by importing virgin plastics rather than recycling domestic plastics waste
    2. Denmark will also benefit economically from cutting the environmental costs of pollution and by creating value from new technology and jobs
3. **In the short term, academia, industry, and regulators can together define a research and innovation agenda that will close gaps in our knowledge and help identify necessary technologies, regulatory changes, and societal tools**
    1. Towards 2025, specific milestones could include support for research and innovation from both public and private stakeholders
    2. We cannot solve the plastics challenge alone. Denmark could take the lead on implementing the EU Directive on single-use plastics and fishing gear and lead international forums to set more ambitious targets for reducing plastics pollution
4. **In the medium term, Denmark has to meet the EU 2030 targets and could drive innovation in waste collection along with consumption reduction**
    1. The EU's target for recycling plastic packaging is 55% by 2030. Denmark currently achieves less than a third of this. A first step to reaching it can be for municipalities to align their criteria for collecting waste, to eliminate today's inefficiency. Meeting the target also requires decreasing consumption and creation of waste, specifically of plastics that are difficult to recycle. This can, for example, include scaling up pilot projects that can successfully increase reuse of plastics
    2. There is great scope for innovation. For example, we could improve collection and sorting by using AI and advanced sensors, as well as continue to improve on recycling technologies. Additional innovation potential lies in developing new products and materials that can be reused and repaired, or new business models that enables using less plastic
5. **In the long term, a working market for recycled plastics and sustainable plastics must be established**
    1. This will need measures to build the demand and supply for recycled plastics. One example to build reliable supply is to promote recyclability as part of implementing Extended Producer Responsibility, which is required for various plastic items across the EU towards 2025
    2. In Denmark, we have an opportunity to develop niche applications of sustainable plastics for high-value products based on local industries
6. **By realizing this vision, Denmark could capture research, innovation and business opportunities by helping to set the world on a new, less wasteful course, in which plastics can again become a solution to problems, and not a cause of them**

NOTE: In this document, "plastics" is used as a general term (unless otherwise specified), while we recognize this covers a wide field of plastic and product types. Initiatives on plastics will have to consider the specific use of different plastic types and products.

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Thanks to Plastic Change for providing case examples for plastic consumption reduction as well as input on potential Danish implementation

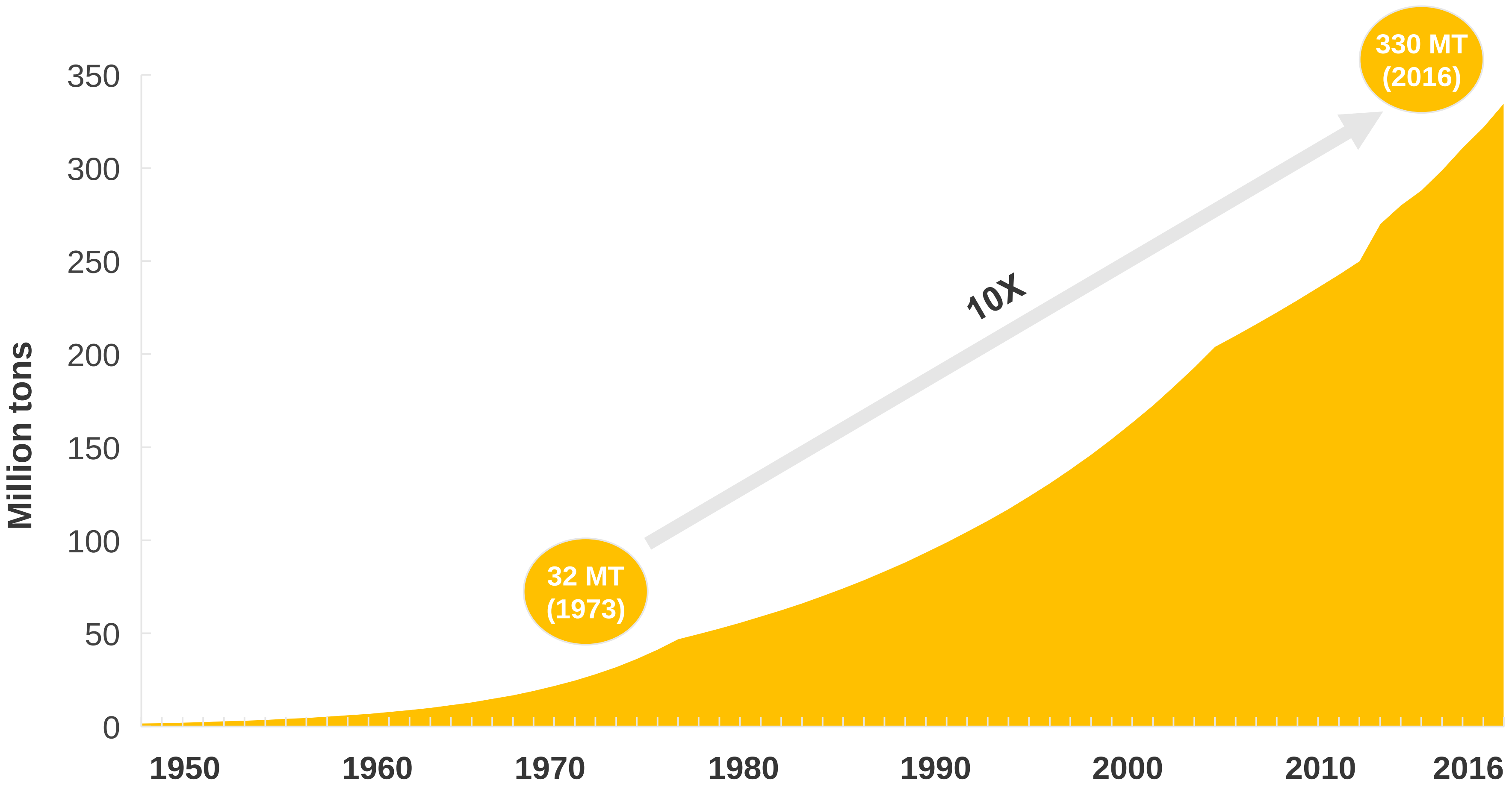
one

Human beings throw away more than half their own weight in plastic every year – 260 million tons of it. The figure will probably reach 500 million tons by 2030. 8 million tons of this waste ends up in the sea, killing wildlife, and disrupting ecosystems. To deal with this pressing challenge, we have to define a New Plastics Economy. In Denmark, we also see the harm that waste plastics can cause at first hand

1. Every year, Denmark collects 1,000 tons of waste on its western coastline
2. The Arctic Ocean is a global sink for microplastics with an estimated 300 billion plastic items floating in the ice-free waters
3. Danes want action: 99% of Danes say it is important to act on the challenge of plastics

1.0 In the past 40 years, global plastics production has increased tenfold

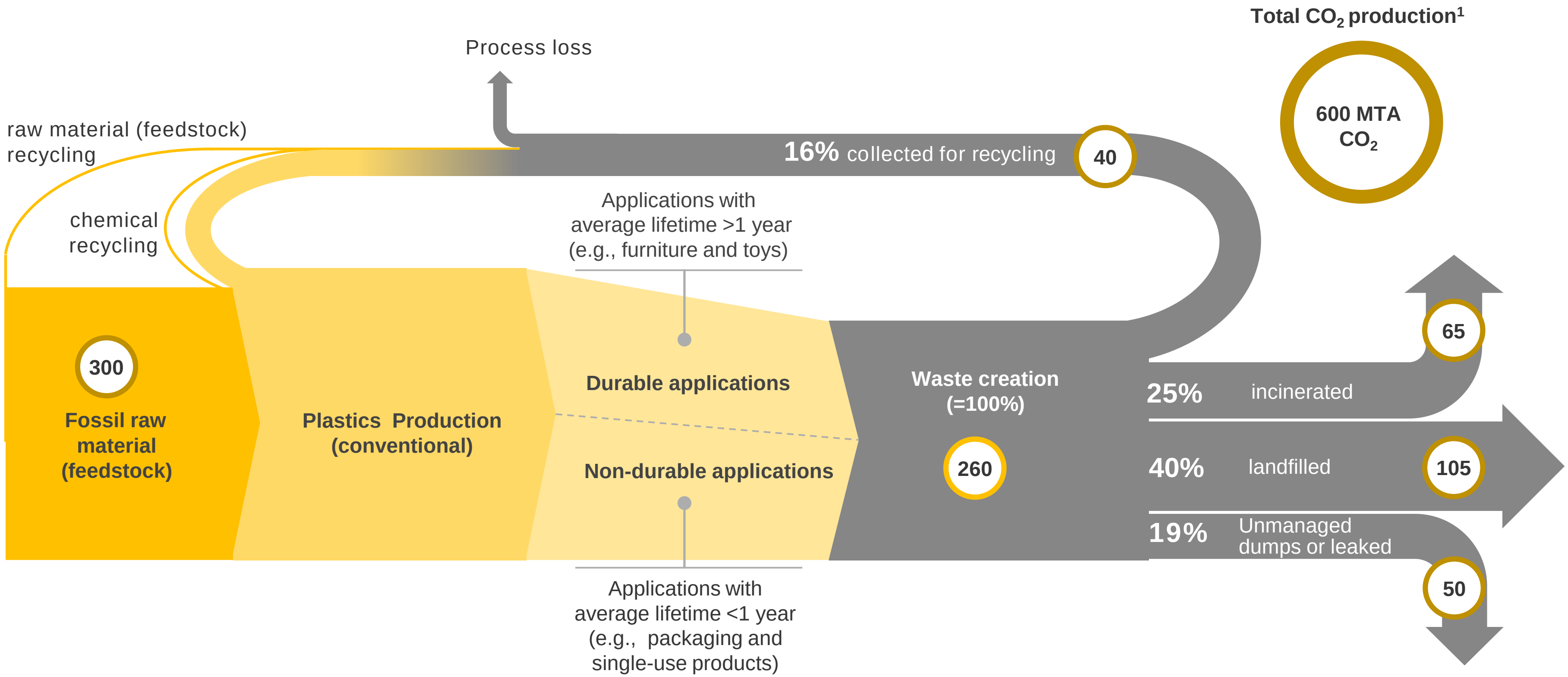
Growth in global plastics production 1950-2016, Million tons annually



SOURCE: Ellen MacArthur Foundation and McKinsey & Company “New Plastics Economy” (2016); Plastics Europe “Plastics -The Facts 2013” (2013); Plastics Europe “Plastics -The Facts 2015” (2015); McKinsey plastic waste stream model

1.0 Today we create 260 million tons of plastic waste – the vast majority is not recycled

Global plastics flows 2016, million tons annually (MTA)



1 Total CO_2 production annually, including virgin plastics production but excluding plastic processing

SOURCE: McKinsey plastic waste stream model

1.0 ~8 million tons of plastics leak into the ocean annually, mainly because of waste mismanagement, littering behavior, and poor design

Geographical sources of plastic in the ocean, thousand tons annually (TTA)

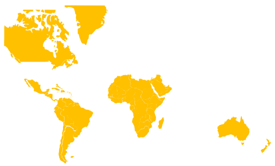
The US and Europe

2% = 160 TTA

Asia

82% = 6,560 TTA

Rest of the world



16% = 1,280 TTA

Total: 8,000 TTA

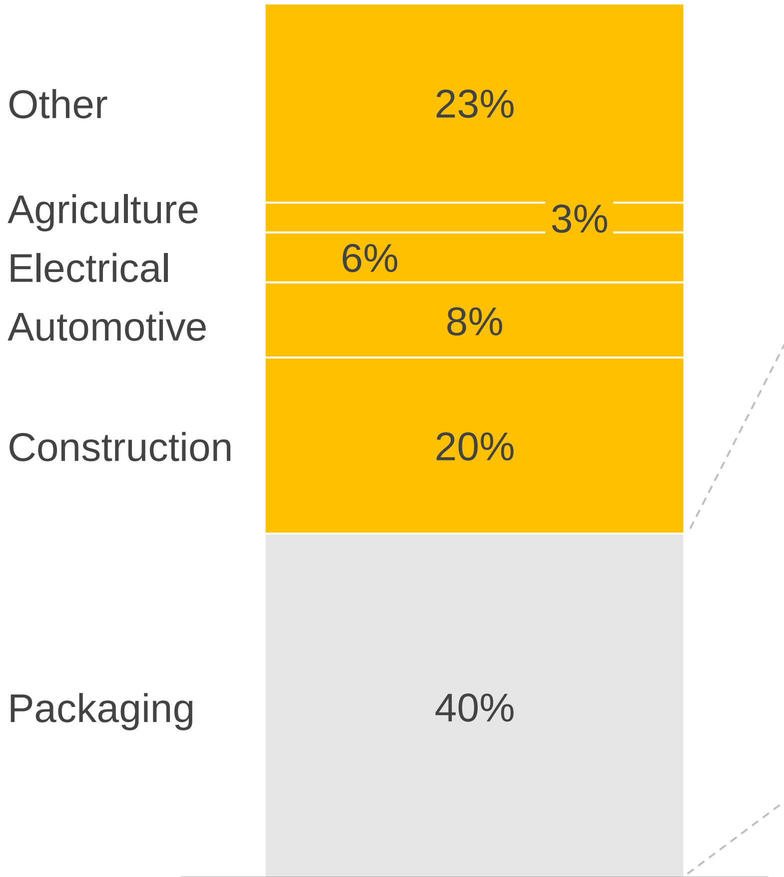
Plastic pollution sources	Description
Mismanagement 	▪ Plastics that have **successfully been collected** still end up as pollution due to **unmanaged landfills or mismanaged waste handling**
Marine-based waste 	▪ **Dumping of waste at sea,** e.g., fishing boats dumping damaged fishing nets or waste from oil rigs ▪ Plastics with **a design to leak into the ocean,** e.g., dolly ropes
Littering and dumping 	▪ **Uncollected waste** from littering/dumping by both citizens and organizations, e.g., due to insufficient infrastructure or lack of education
Intentional waste 	▪ Plastic with a **use pattern or design that is unsuitable for collection systems,** causing high likelihood of leakage into the environment, e.g., toy gun cartridges, particles from tires, and small detached packaging items

SOURCE: Expert interviews; World Bank "What a Waste 2.0" (2018); Ellen MacArthur Foundation and McKinsey & Company "New Plastics Economy" (2016)

1.0 Packaging accounts for the largest application of plastic and is especially prone to leaking into nature

Plastics by global application[1]

100% = 3300 million tons



High risk of leakage into the environment due to small size, complex design, low residual value and short usage periods

- Plastic packaging constitutes **+60% of all coastal waste**
- **All 10 brands with highest amount of leaked plastic waste are within packaging, notably food and beverages,** according to latest report from Greenpeace

1 Other sources have previously stated different numbers for the application rate of plastic for packaging, e.g., The New Plastics Economy (2016) by Ellen MacArthur Foundation and McKinsey & Company estimates total application for packaging to be 26%; McKinsey plastic waste stream model

SOURCE: R. Geyer et al. “Production, use, and fate of all plastics ever made” (2017); Greenpeace “Branded” (2018)

1.0 Plastics pollution also occurs through microplastics, from decomposed plastic waste as well as car tires and textiles, and other sources

Sources of microplastics

Secondary micro-plastics

Decom-posed macro-plastics

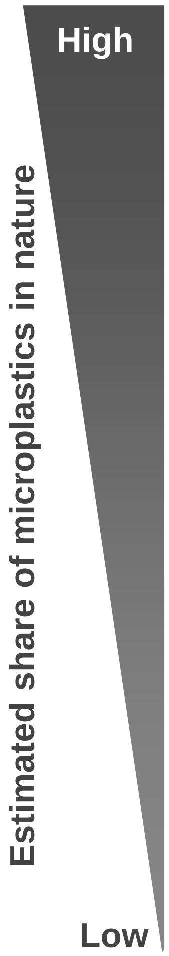
- Exposure of plastic objects on surface waters to solar radiation results in **photo-degradation, embrittlement, and fragmentation**
- The degradation process **depends on the type of plastic,** as different types will have different reactions to the environment

Worn-off plastics

- Particles **torn off from larger plastic objects,** which can be tires, textiles, and footwear (still to be proven)
- **Some sources estimate tires to be the largest source of secondary microplastics,** contributing with 4x more microplastic than textiles, which has otherwise received more public attention

Primary micro plastics

- Microplastic particles smaller than 5 mm **intentionally produced for use in industry or commercial products,** e.g., in personal care products and raw materials for plastic production
- The **primary environmental pathways are through sewages;** in Denmark, most microplastics are collected in the sludge through a wastewater plant to then be incinerated or used as fertilizer

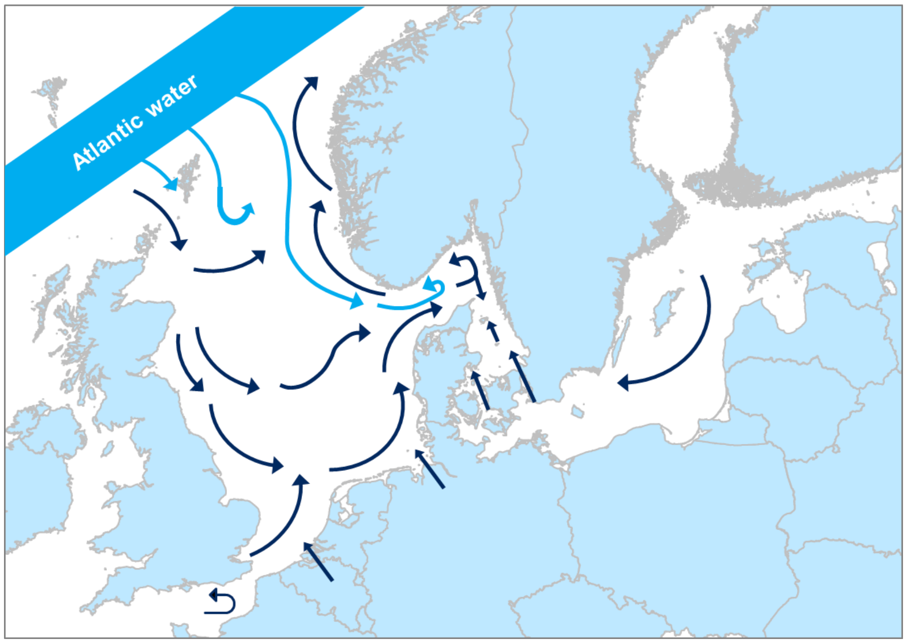


SOURCE: Andrady "Microplastics in marine environment" (2011); Expert interviews; The Danish Environmental Protection Agency "Microplastics – Occurrence, effects, and sources of releases to the environment in Denmark" (2017); The Danish Environmental Protection Agency "Microplastics – Occurrence, effects, and sources of releases to the environment in Denmark" (2015); Eunomia "Investigating options reducing releases in the aquatic environment of microplastics emitted by (but not intentionally added in) products" (2018); Eunomia "Plastics in the Marine Environment" (2016)

1.1 While Danish pollution is low, Denmark is still exposed to marine waste from elsewhere - 1000 tons per year on the Danish West Coast

Transport via ocean currents and local circulation cause waste accumulation in Skagerrak

Circulation of ocean currents in the North Sea and Skagerrak



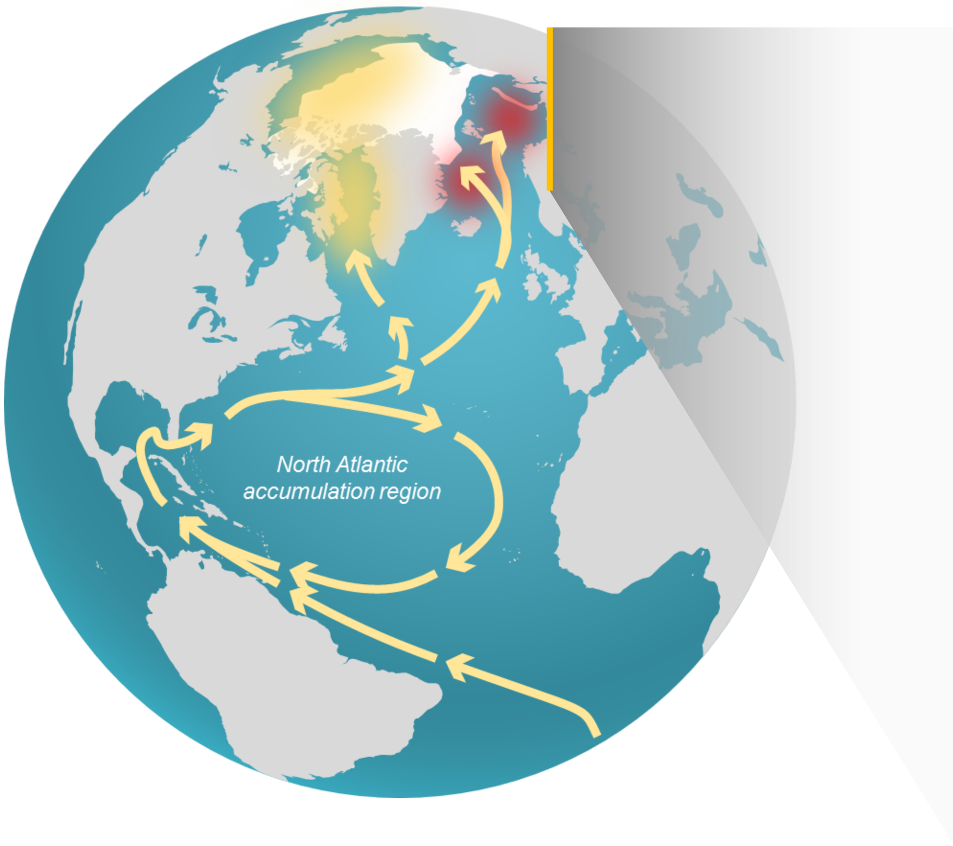
- **1000 tons of waste – mostly plastics - washes onto the Danish West Coast annually**
- The ocean currents create **a local circulation in the Skagerrak region that functions as an accumulation area for marine litter**
- Coastal areas in **Skagerrak receive ~10% of all marine litter in the North Sea**, despite only covering about 2% of the total coastline

1 Based on OSPAR + MARLIN data 2002-2012

SOURCE: Nordic Council of Ministers “Marine Litter in Nordic Waters” (2015); UNEP “Marine Litter - An analytical overview” (2005); KIMO via Danish EPA press release (March 2018); Strand, J., Tairova, Z. & Metcalfe, R. d’A “Status on beach litter monitoring in Denmark” (2015)

1.2 The Arctic Ocean is a global sink for microplastics as plastic waste decompose and is transported below the surface

Plastics concentration in the Arctic Ocean



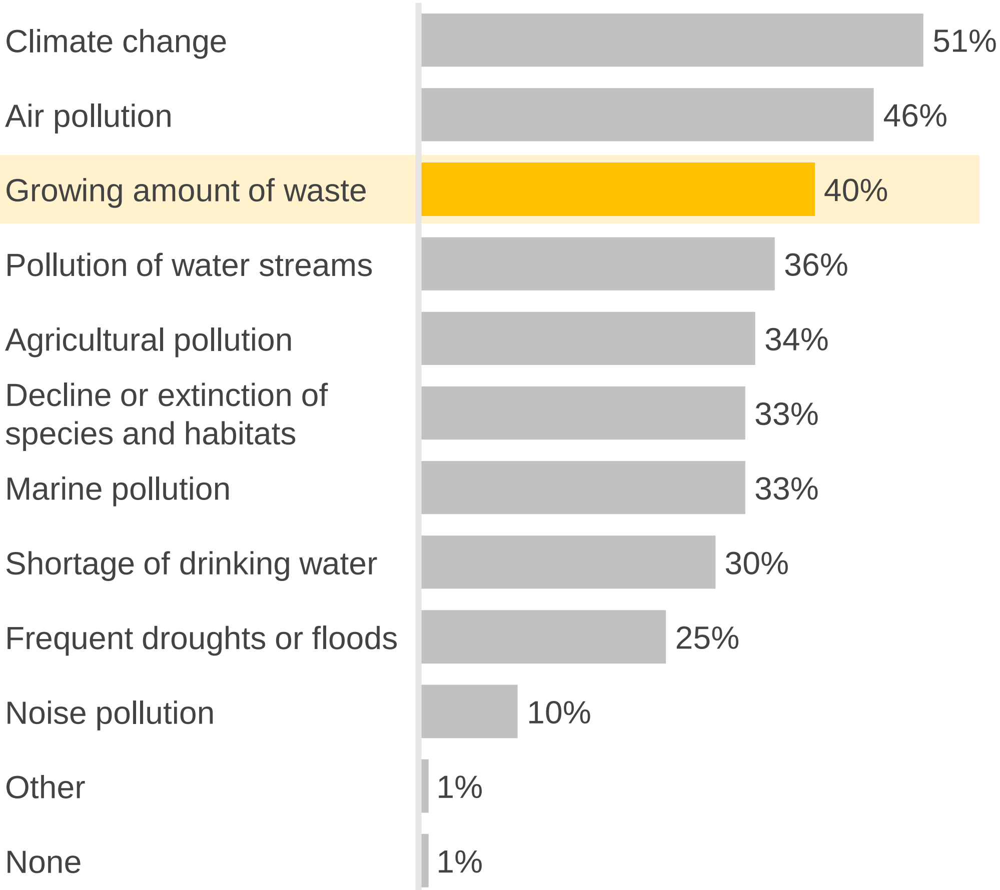
- The Arctic Ocean **constitutes a global sink for plastic debris** as it transfers plastics to the ocean interior
- A significant fraction of plastics in the Arctic come from far away, as **Nordic ocean currents provide long-range transport for plastics waste**
- **Surface ice-free waters in the Arctic Polar Circle were slightly polluted with plastic debris,** despite extremely low population density
- **The uniqueness of the Arctic ecosystem** makes the potential ecological implications of exposure to plastic debris a special concern

SOURCE: Cozar et al. "The Arctic Ocean as a dead end for floating plastics in the North Atlantic branch of the Thermohaline Circulation" in Science Advances vol. 3, no. 4 (2017); Nordic Council of Ministers "Marine Litter in Nordic Waters" (2015)

1.3 Danes want action on the plastics pollution challenge

Most important environmental issues among Europeans

Share of respondents who chose the option (max 4 answers)



Addressing plastics waste is also high on the Danish agenda

99% find it important or very important to **do something about the amount of plastics in nature**

85% worry about the amount of **waste in the ocean**

52% think supermarkets should **focus on environmentally friendly plastic/packaging**

SOURCE: Eurobarometer poll, European Commission Special Eurobarometer 468 "Attitudes of European citizens towards the environment“ (2017); COOP “Forbrugerne til supermarkederne: Plastik og madspild er vigtigst” (2018); Ministry of Environment and Food of Denmark ”Danskerne går sammen om at rydde op på stranden” (2018); Plastic Change “Danskerne vil bekæmpe plastikspild i naturen” (Accessed 2018)

1.3 Brand owners are also reacting, as they make bold commitments targeted at managing waste from packaging

Focus area	Description	Example	Potential impact on recycled plastic demand
Increase recycled content	Increasing share of recycled material in products	P&G, Renault, Electrolux ▪ Electrolux Green products with up to 85% recycled plastics ▪ Renault eco car line with 17% recycled plastic (Laguna 3) ▪ Ford underbody and hood plastic parts are made from 75% recycled batteries and 8% recycled HDPE bottles ▪ 60/40 PP/PE raw material recovered and reused in P&G products (e.g., caps for cleaners)	↑
Establish deposit and return systems	Establishment of collection, sorting, and reprocessing infrastructure	Pampers, PepsiCo, Unilever ▪ Pampers diaper recycling process with 10 thousand tons pilot plant set up; separated raw material sold into new applications; aim is to eliminate landfill entirely ▪ Project CEFLEX initiated by producers and brand owners to build collection/sorting/reprocessing infrastructure by 2025	↑
Design for recyclability/ reusability	Improving packaging design for easy recovery/recycling, by standardizing plastic types and characteristics	Coca-Cola ▪ Coca-Cola's initiative to design for recyclability to enable 100% recycling chain by 2030 (including road map with producers to solve challenge with PP caps and closures)	↑
Eliminate specific types of plastic	Promise to eliminate/reduce use of certain types of plastic	Dunkin' Donuts, Target ▪ Dunkin' Donuts' commitment to eliminate polystyrene cups by 2020 ▪ Target's commitment to eliminate expanded polystyrene from its brand packaging by 2022 ▪ Push for phthalate-free PP for non woven fabrics in personal care/hygiene in general	*Uncertain*
Reduce volume/ weight	Reduction of volume/weight of products	BMW, amcor, Constantia ▪ BMW Countryman instrument carrier Panel Carrier achieving 15% lighter structure using foaming technology ▪ 3D printing of car components (3D-printed cars projected to be mass produced within 8-10 years)	*Uncertain*

SOURCE: Brand owner websites; Press search; IHS PEPP conference New Plastics Future; McKinsey analysis

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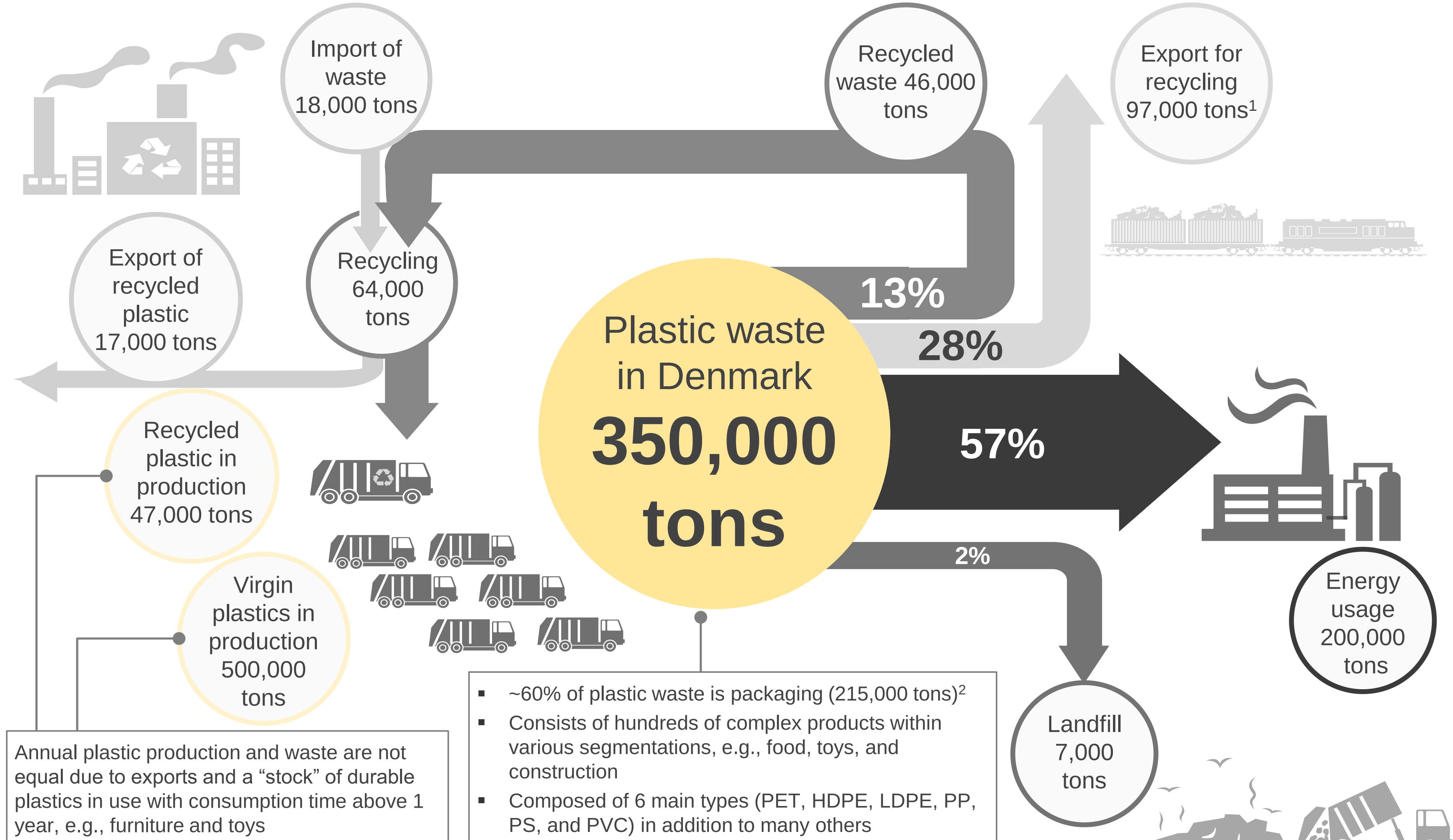
Denmark can capitalize on the commitment of its citizens to become a frontrunner in the New Plastics Economy. It can help capture the full value of plastics through research and innovation aimed at smarter use with reduced consumption, full recycling of all consumer and industrial plastics, development of sustainable plastics, and the elimination of pollution from plastics in use

1. Doing so offers economic benefits: Denmark loses DKK 1.6 billion a year by importing virgin plastics rather than recycling domestic plastics waste
2. Denmark will also benefit economically from cutting the environmental costs of pollution and by creating value from new technology and jobs

2.0 Most of the Danish plastic waste is incinerated – leaving significant potential for increased recycling

Estimate of current Danish plastic production, waste, and waste treatment



1 Data on recycling rate of exported plastics waste is poor, while expert interviews indicate that ~50% of the exported plastic waste is recycled
2 Includes primary, secondary, and tertiary packaging

SOURCE: Ministry of Environment and Food "Statistik for emballageforsyning og indsamling af affald 2016" (2018); Expert interviews; McKinsey analysis

2.1 A New Plastics Economy is part of realizing the circular economy opportunity

The circular economy opportunity in Denmark

- Upwards of **DKK 45 billion in estimated annual value potential** for Danish GDP if transforming into a circular economy by 2035
- Circular economy strategy for Denmark already in place
- Separate strategy for plastics, “Plastik uden spild - Regeringens Plastikhandlingsplanen” published in December 2018

The circular economy opportunity in Europe

- Increase in **resource productivity** by up to 3% annually
- A **primary resource** benefit to Europe’s economies of as much as EUR 0.6 trillion per year by 2030
- EUR 1.2 trillion in **non resource and externality benefits**
- A **GDP increase of as much as 7 percentage points** relative to the current development scenario, with additional positive impacts on employment
- EUR 45 billion in potential **value creation from recycling plastics** during 2016-2030

NOTE: See appendix for overview of the EU Circular Economy package including details on plastic-relevant elements

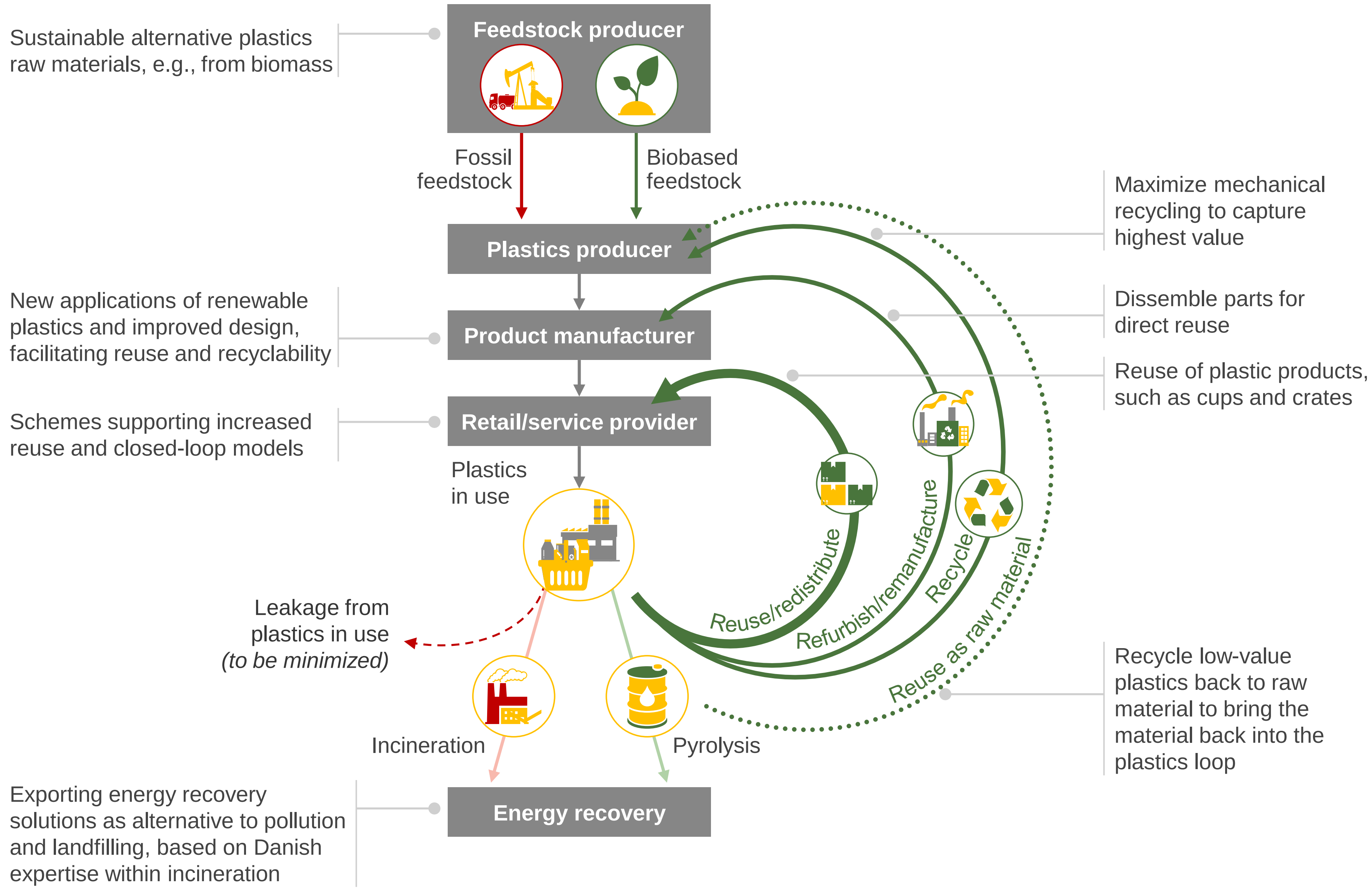
SOURCE: Ellen MacArthur Foundation and McKinsey & Company in “Potential for Denmark as a Circular Economy” (2015); The Danish Ministry for Environment and Food and Ministry of Industry, Business, and Financial Affairs “Strategi for Cirkulær Økonomi” (2018); McKinsey & Company, Ellen MacArthur Foundation, SUN Foundation Analysis “Growth within: A circular economy vision for a competitive Europe” (2015); McKinsey recycling economics model

2.0 Denmark can aspire to become a front runner in the New Plastics Economy and capture the value of plastics through research and innovation

Elements of a vision for Denmark

1. 100% recycling of plastics with a view to capture the full value of our waste streams - for both household and industrial plastics –enabled by a functioning market for reused and recycled plastics
2. Minimize or phase out plastics that are difficult to recycle and/or collect
3. Find alternatives for plastics where intended use result in direct pollution (e.g., textiles and artificial turf)
4. Eliminate need for new fossil based plastics by reducing consumption, a high level of recycling and development of new sustainable bio-based plastics
5. Drive policies to stop plastics pollution of the oceans through the EU and global forums, as Denmark cannot solve the plastics challenge alone

2.0 Vision for a circular New Plastics Economy in Denmark



2.0 A set of aspirational targets on short, medium, and long term can guide efforts needed today and in the future

Potential targets on short, medium, and long term

Short term:

Prioritize research and development on plastics

Bring academia, industry and regulators together to define a research and innovation agenda to close key knowledge gaps

Identify necessary **technologies, regulatory changes, and societal tools**

Medium term:

Meet EU targets and drive innovation

Align collection criteria across municipalities and **reduce plastics consumption and waste creation,** specifically in plastics that are difficult to recycle

Innovation in necessary **recycling technologies, and supporting technologies for sorting and collection** (e.g., traceability, use of AI, and robotics) as well as innovations for **reuse and repair**, **and new business models**

Long term:

Establish a viable market for renewable plastics and new sustainable plastics

Define and implement **a viable market for recycled plastics** via a combination of demand and supply measures

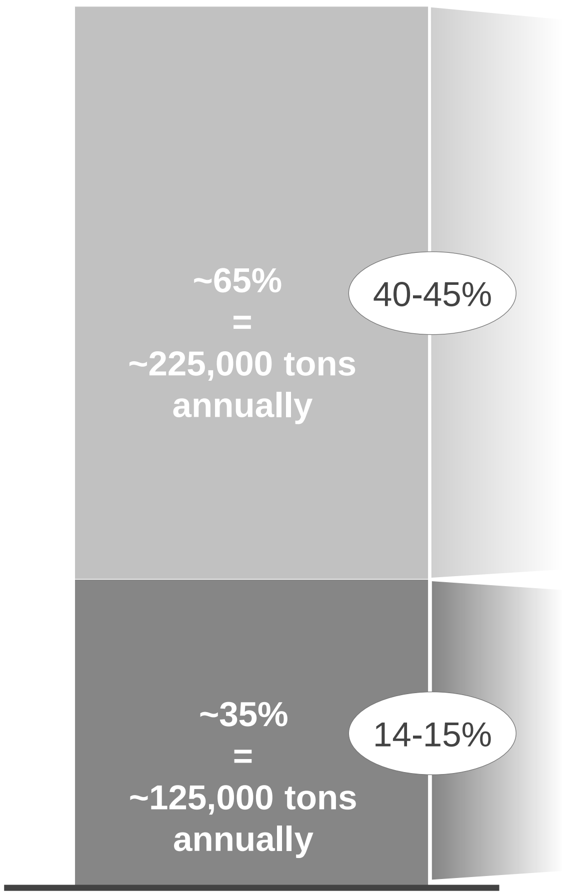
Lead **development of niche applications of bio-based plastics** for high-value products based on existing industry in Denmark

2.0 Solving the plastics challenge requires focusing both on industrial and household plastics

Share between industrial and household plastics in Denmark

X Share collected for recycling

100% = 350,000 tons



Industrial plastic waste[1]

- Handled by private waste managers, not allowed to be handled by municipal waste management
- Consists of production waste e.g., scraps, secondary, and tertiary packaging, discarded construction parts, as well as “household- like” waste
- The manufacturing industry is the largest contributor, making up ~30% of total plastic waste
- Experiences higher recycling rates due to
  - Cleaner waste streams
  - Availability from small number of sources with relatively high volume

Household plastic waste[2]

- Handled by public waste management through utility companies
- Collected at households or local collection sites
- High risk of contamination between materials
- Low volume per source cause high cost of collection

- While household plastic waste receives more attention, **industrial plastic waste makes up the majority of plastic waste**
- Solving the plastics challenge therefore **requires focus on both household and industrial plastic waste**

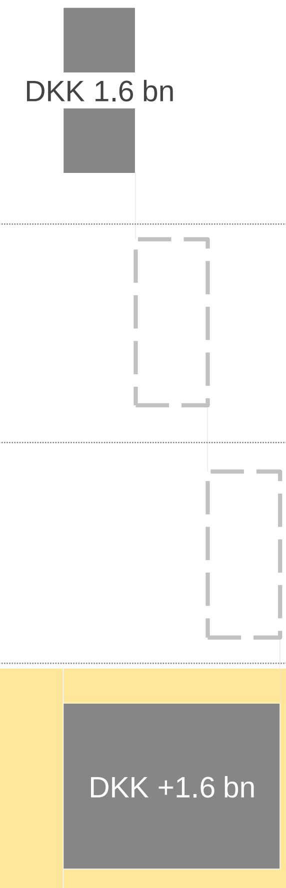
1 Includes waste from industry (manufacturing), service, construction, agriculture, forestry, and hunting sectors

2 Includes waste from permanent and secondary residences, including residents in institutions (e.g., elderly homes)

SOURCE: Plastindustrien “Plastaffaldskilder I Danmark”; Ellen MacArthur Foundation and McKinsey & Company “Potential for Denmark as a Circular Economy: A Case Study From: Delivering The Circular Economy – A Toolkit for Policy Makers” (2015); Danish Environmental Agency “Affaldsstatistikken 2016” (2018)

2.1 The economic upside is substantial, with at least DKK ~1.6 billion annual savings from reduced use of virgin plastics

		Estimated annual value of a circular plastics economy, DKK
Value of saved costs from virgin plastics	▪ The Danish companies and consumers are **currently foregoing a potential of DKK 1.4 billion**[1] by importing virgin plastics rather than recycling domestic plastics (based on current prices of imported virgin plastics and Danish recycled plastics) ▪ Another **DKK ~200 million can be saved on costs of exporting plastics waste** for recycling[2] (adding to DKK 1.6 billion in total saved costs)	Saved costs from virgin plastics and avoided costs of waste export
Value of innovation and export of technologies	▪ Recycling industry generates **more jobs at higher income levels** than landfilling or incineration of waste ▪ **Export of new technologies and innovations,** e.g., recycling, sorting, new materials, product designs ▪ **Strengthen existing export** within energy recovery	Additional economic value
Value of avoided natural capital loss	▪ **Environmental and social impacts** can be expressed in monetary terms, e.g., by using concept of natural capital ▪ Potential impacts from plastics include animal and human health, clean up costs, and effects of CO_2 emissions	Avoided natural capital value loss
Annual benefit of a circular plastics economy in Denmark	▪ A significant value potential can be realized from improved plastics recycling and usage ▪ **More research is needed on the potential economic value creation of plastics recycling** to create an economic rationale for undertakings within the plastics industry ▪ **Full investment in required infrastructure is not reflected** in savings estimate	Total economic potential of a new plastics economy



1 Assuming that savings per kg of recycling Danish plastics waste rather than importing virgin plastics amount to DKK 4 per kg, based on the price difference between Danish recycled plastic and imported virgin plastics. Considering the full potential for Danish plastics as equal to total Danish plastic waste, this amounts to 350,00 tons with a derived savings potential of 1.4 billion DKK

2 Assuming costs of DKK 2,000 per ton exported for recycling and total amount of plastics waste exported to be 97,000 tons

SOURCE: European Environment Agency "Earnings, jobs and innovation: the role of recycling in a green economy" (2011); UNEP and Trucost "Valuing Plastic – The Business Case for Measuring, Managing and Disclosing Plastics Use in the Consumer Goods Industry" (2014); Expert interviews; McKinsey analysis

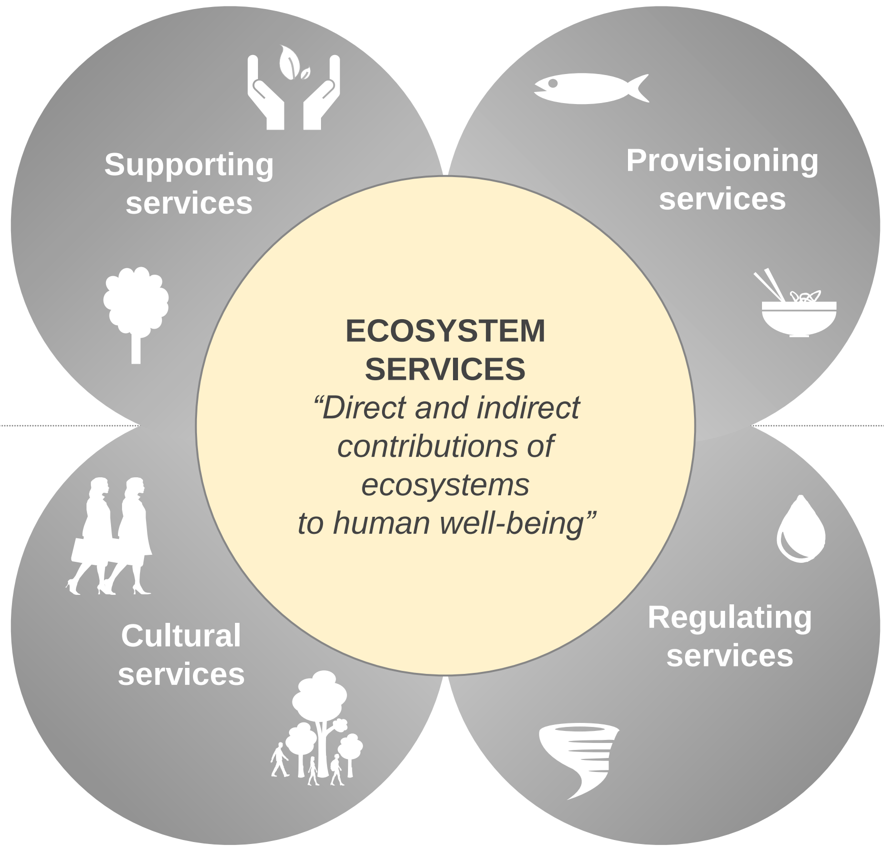
2.2 Limiting plastic pollution also prevents costs incurred by society through a decreased value of ecosystems

Potential effects of plastic pollution on ecosystem services

XX Effected by plastic pollution

- **Habitat for species**
- Maintenance of genetic diversity

- **Food**
- Raw materials
- **Fresh water**
- Medicinal resources



- **Recreation and mental and physical health**
- **Tourism**
- **Aesthetic appreciation and inspiration for culture, art, and design**
- **Spiritual experience and sense of place**

- **Local climate and air quality**
- Carbon sequestration and storage
- Moderation of extreme events
- Waste water treatment
- Erosion prevention and maintenance of soil fertility
- Pollination
- Biological control
- Regulation of water flow

SOURCE: Food and Agriculture Organization of the United Nations “Ecosystem Services & Biodiversity (ESB)” (Accessed November 2018); Biodiversity Information System Europe “Ecosystem services” (Accessed November 2018)

2.2 Current plastic waste management could be reconsidered when transforming into a low-emission economy by 2050

	Today[1]	By 2020	By 2030	By 2050
Danish CO_2 reduction commit-ments	▪ 27% reduction compared to 1990 levels	▪ 20%[2] reduction compared to 1990 levels	▪ 40% reduction compared to 1990 levels	▪ 80-95% reduction compared to 1990 levels ▪ Low-emission society independent from fossil fuels

Current view on plastics incineration in a low-emission society

Circular scenario	▪ No plastics incineration due to CO_2 emission; all plastic waste is recycled
Linear scenario	▪ Some plastics incineration continues, supported by carbon-capture technologies

1 2015 emission level 2 Only on CO_2 reductions from buildings, transport, and farming
NOTE: See appendix for an overview of the CO2 balance between recycling, incineration, and landfill

SOURCE: Danish Energy Agency website "Dansk Klimapolitik" (accessed November 2018); Danish Energy Agency "Denmark's Energy and Climate Outlook" (2017)

three

In the short term, academia, industry, and regulators can together define a research and innovation agenda that will close gaps in our knowledge and help identify necessary technologies, regulatory changes, and societal tools

1. Towards 2025, specific milestones could include support for research and innovation from both public and private stakeholders
2. We cannot solve the plastics challenge alone. Denmark could take the lead on implementing the EU Directive on single-use plastics and fishing gear and lead international forums to set more ambitious targets for reducing plastics pollution

3.0 Academia, industry, and regulators can together define a research and innovation agenda, and define regulatory changes

Traditional role in shaping key elements[1]: ✓ In the lead (✓) Contributing ✗ Not actively involved

Responsible party	Integrated portfolio of technologies	Guidance for design and use	Collection, sorting, and aggregation	Responsibilities
Policy makers	✗	✓	✓	▪ Enable market mechanisms by introducing tax incentivization and direct investments ▪ Introduce regulations to enforce recycling
Plastics supply chain	✓	(✓)	✗	▪ Invest in recycling technologies ▪ Partner with waste managers to enable recycling throughout the value chain
OEMs/brand owners	✗	✓	(✓)	▪ Introduce recycling-friendly packaging and optimize for demand reduction ▪ Establish collection schemes for reusable parts
Waste managers	✓	✗	✓	▪ Invest in sorting technologies ▪ Partner with plastics supply chain to close loop in value chain
Academia	(✓)	(✓)	(✓)	▪ Conduct research and develop technology ▪ Create necessary data pool on consumers, market, and waste production

1 Roles of the plastics ecosystem stakeholders may change over time, e.g., as waste managers are increasingly included in product design

SOURCE: McKinsey analysis

3.1 Danish plastic companies are already active throughout the value chain, including many SMEs and public utility companies

A new industry is developing that works to change consumer behavior, e.g., improving household sorting

Examples of companies within the Danish plastics value chain

Plastics-producers *(bio and conventional)*
- BASF
- Controlled polymers
- DuPont
- Erteco[1]
- Haldor Topsøe
- Master Batones
- Polykemi

Plastic converters
- AVK Plast
- Coloplast
- Dansk Dekor-Laminat
- Færch
- Løgstør Rør
- Radisurf
- Schoeller Plast
- Sundolitt
- Tempur
- Uponor
- VELUX

Packaging companies
- BEWi-Synbra
- Danapak
- Gerresheimer
- Pack Tech
- Plus Pack
- RPC Promens
- RPC Superfos
- Trioplast

Retailers and brand owners
- Aqua D'Or
- Arla
- Carlsberg
- COOP
- De Samvirkende Købmænd
- IKEA
- Salling Group

Consumers (communication and behavior)
- Circle Development
- Katzenmark
- Lundhus Event & Udvikling
- Open Experience
- Tanke-gang
- World-Perfect

Collection
- Dansk Retur-system
- H.J. Hansen
- HCS
- M. Larsen
- Marius Pedersen
- Meldgaard
- Stena Recycling

Sorting
- Dansk Affald
- Envac optibag
- Eldan
- Erema
- Flexo-waste
- Metso
- Steinert
- TREBO[2]

Recycling
- A.V. Pehrsson
- Aage Vestergaard Larsen
- Dansk Affalds-minimering
- EPS-Recycle
- GENplast
- Letbæk Plast
- Plastix
- RC Plast
- Re-Match
- Trioplast

Incineration (including cement kilns)
- Aalborg Portland
- B&W Vølund[3]
- FLSmidth[3]

Local utility companies, e.g., Amager Ressourcecenter, Vestforbrænding, Affald Randers, Reno Nord, Nomi4s

- Large share of SMVs with a few large players
- Plastic producers are experiencing export-based revenue growth
- Primarily based outside the capital region
- Plastic production recipients include the food, furniture, and construction industries, amongst others

1 Supplier of plastic raw materials, not producers 2 Still at pilot scale 3 Technology and equipment suppliers

NOTE: The overview does not include NGOs and industry associations active within the Danish plastics value chain

SOURCE: Expert interviews; DAKOFA; Danish Plastics Federation; Plastindustrien, "Tal og Tendenser – Plastindustriens bidrag til vækst og beskæftigelse i Danmark 2018" (2018)

3.1 Towards 2025, specific milestones could include support for research and innovation from both public and private stakeholders

Milestones (examples)

- **Establish plastics research center supporting innovation**
- **Set up innovative method for aligning collection guidelines**
- **Ensure that Extended Producer Responsibility (EPR) is implemented “smart”**
- **Set up funding for innovative business models that increases re-use of plastics**
- **Set up a structured set of funds for innovation across recycling technologies**
- **Set up integrated network to develop sustainable plastics and alternative materials**

3.1 Milestones should be based on relevant context and with an output that supports the Danish vision

Milestone (example)	Key actions	Context	Output
1 **Establish plastics research center supporting innovation**	▪ Identify feasible focus based on Danish capabilities ▪ Include stakeholders outside academia to challenge agenda ▪ Include financing from private companies to ensure all participants have a stake in ensuring a good outcome	▪ A national plastics center is part of 2018 Danish plastics strategy ▪ Acknowledgement of lacking data on plastics in Denmark	▪ Danish research, data, and knowledge on plastics have significantly improved by 2022
2 **Set up innovative method for aligning collection guidelines**	▪ Set up cross-municipal agile team to identify relevant set-up ▪ Include and develop digital methods for feasibility analysis ▪ Create depreciation timeline for existing facilities	▪ Alignment of collection criteria and system is part of the 2018 Danish plastics strategy	▪ Innovative method for identifying feasible collection guidelines and system ▪ Clear timeline towards a national collection guidelines and system
3 **Ensure that Extended Producer Responsibility (EPR) is implemented "smart"**	▪ Identify areas where regulation will have most impact in terms of pollution, consumption, and recycling, respectively ▪ Set up framework to weigh business impact against environmental impact	▪ EPR be implemented across the EU for packaging and cigarette butts	▪ Develop state-of-the-art method for implementing EPR ▪ Increased recycling rate
4 **Set up funding for innovative business models that increase re-use of plastics**	▪ Set up funding committee including external investors from the industry ▪ Support scaling of pilot projects that have proved successful in "closing loop" ▪ Include financing from private companies	▪ Increased reuse of plastics decreases plastics waste, a necessary part of meeting EU 2025 and 2030 recycling targets	▪ Decrease in plastics waste ▪ Decrease in resource demand ▪ Recycling at highest value point ▪ Export potential from innovative business models
5 **Set up a structured set of funds for innovation across recycling technologies**	▪ Set up funding committee including external investors from the industry ▪ Aim to develop technologies across recycling portfolio at various maturity levels ▪ Include financing from private companies	▪ Full recycling of plastics in Denmark require a development across the portfolio of recycling technologies	▪ Increased recycling rate ▪ Improved outcome of recycling process ▪ Export potential from technology development
6 **Set up integrated network to develop sustainable plastics and alternative materials**	▪ Identify network partners across established companies, startups, public organizations, and academia ▪ Partners must pledge to provide expertise, facilities, and funding for projects	▪ Based on existing industry, Denmark can develop high-value niche applications of sustainable plastics to curb CO_2 emissions from plastics	▪ New innovation areas for the Danish industry ▪ Industry leadership in sustainable plastics and alternative materials

See next page for examples of research areas, e.g, as focus areas under milestone 3,4, and 5

NOTE: See appendix for a more detailed description of Extended Producer Responsibility

3.1 Potential research areas for Denmark in the circular plastics economy

Research areas (examples)

Smart use of plastics

- Product design enabling increased reuse
- New circular business models for plastics
- Alternative materials for food packaging

Long term health and biosystem effects of plastics

- Definition and measurement technologies for micro- and nanoplastics
- Biosystem and human health effects of microplastics exposure incl. critical thresholds and most critical exposure pathways
- Technologies to avoid or reduce micro- and nanoplastics in nature

Recycling of plastics

- Assessment of potential of mechanical recycling of consumer and industrial plastics
- Technologies for improved sorting and collection incl. AI, robotics, advanced sensors as well as potential implementation roadmap
- Technologies to detect, measure, and remove substances of concern from plastics
- Technologies for recycling of complex plastic waste, e.g., chemical recycling

New sources of plastics

- Technology and cost roadmaps for sustainable bio-based plastics
- “Power to X” and other options for fossil free plastics incl. cost and environmental comparisons

3.1 Additional critical knowledge gaps remain regarding plastics, that also requires further research

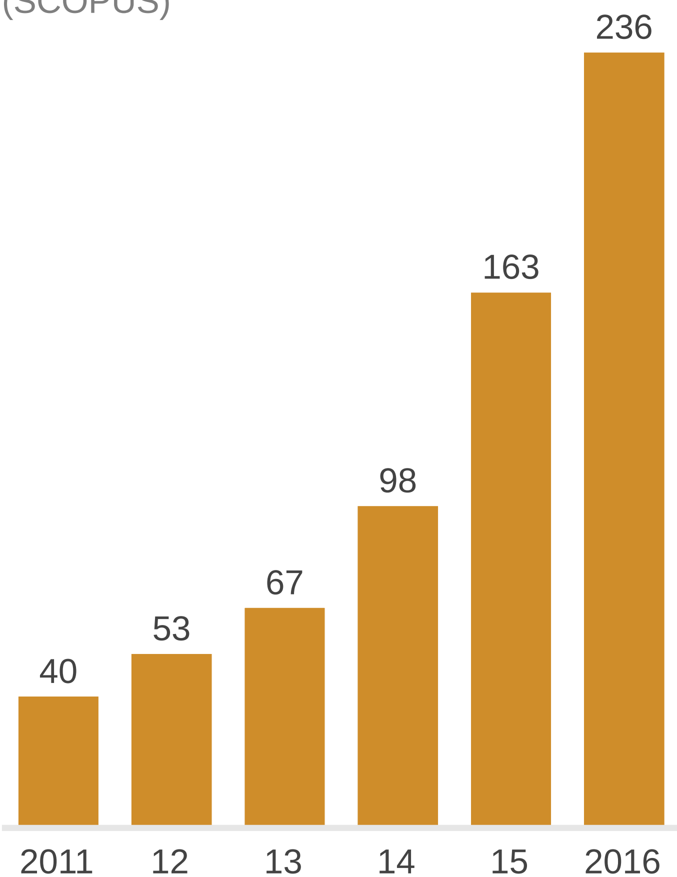
	Source and distribution of plastic in nature	Microplastics	Recycling and recycling-enabling technologies	Health and ecosystem impact of macroplastics	Socio economic analysis and impact of plastic pollution
EXAMPLES OF KNOWLEDGE GAPS	▪ Decomposition time and process in different ecosystems ▪ Insight on non domestic plastics flowing onto Danish shores ▪ Detailed data on sector generation and treatment of plastics in Denmark ▪ Quantity of plastic waste from ocean-based activities in global and Danish oceans, e.g., ghost nets	▪ Definition and analytical methods for measurement of micro- and nanoplastics ▪ Transport in biological systems, e.g., membranes ▪ Toxicity and other health effects of microplastics, e.g., as vector for bacteria and chemicals ▪ Transport and accumulation in ecosystems, e.g., soil ▪ Adverse impact of microplastics particles compared to other pollution particles, e.g., soot ▪ Main sources of microplastics in Denmark	▪ Opportunities and feasibility of design and citizen-based innovation to reduce consumption and improve recycling ▪ Economics, energy requirements, and relation to substances of concern for recycling technologies, e.g., pyrolysis, monomer, and mechanical recycling ▪ Minimum and optimal scale for full plastic recycling, e.g., is Denmark a big enough market? ▪ Develop sustainable bio-based plastics that are degradable in natural environment ▪ Total economics of sorting and collection technologies ▪ Development pipeline and economics of plastics traceability technologies ▪ Technologies for separation and detection of Substances of Concern (SoC) from plastics for recycling ▪ Wider value chain requirements to accommodate a circular economy	▪ Routes of exposure and quantification of animal impact ▪ Effects of ingesting plastic for larger animals ▪ Reach and impact of SoC from additives on ecosystems, humans, and animals ▪ Toxicology of plastic and its associated substances and effect on food chain, including humans ▪ Quantification of the risk of recirculating older plastic generations with SoC, e.g., for Denmark specifically	▪ Impact of plastic leakage to ecosystem services such as natural systems (e.g., forests and waterways) and urban infrastructure (e.g., sewers) ▪ Detailed socio economic consequences of plastic pollution, e.g., jobs lost, exported ▪ Resources spent now and in the future on plastic clean up globally and in Denmark ▪ General inclusion of social sciences within plastics research needed, e.g., in terms of changing culture on plastics pollution ▪ Comparative effect of regulatory tools on consumption ▪ Barriers to a circular economy in existing regulatory setups
EMERGING CONSENSUS	▪ ~8 million tons of plastic annually leak into the ocean, with Asia as biggest contributor ▪ ~160 TTA of plastic waste leaked into the ocean in the US and Europe ▪ Packaging accounts for majority of global plastics application and constitutes >60% of all coastal waste ▪ Denmark incinerates more than half of its plastics	▪ Main source is decomposed macroplastics ▪ Present within organisms, including humans and food products as well as in nature ▪ Detrimental to small organisms at high levels of concentration	▪ To sustain value, recycling should take place as high in the recycling hierarchy as possible – starting with reduction of usage ▪ Mechanical recycling saves more CO_2 per kg of plastic than other recycling technologies today ▪ Incineration has a negative CO_2 balance compared to recycling plastic and is not considered circular	▪ >500 animal species are affected by plastic pollution ▪ Some plastic additives regulated as SoC, e.g., phthalates and styrene monomer ▪ Most animals and humans have varying amounts of plastics in intestines, e.g., ~90% of seabirds have plastics in their intestines	▪ First estimation on global natural capital cost of plastics at EUR 65 billion per year ▪ Local estimations on potential effect of marine litter from plastics, e.g., EUR ~1 million at the Shetland Islands ▪ Significant lost value from plastics only used once, estimated to be EUR 70-105 billion for plastic packaging globally

SOURCE: World Bank “What a Waste 2.0” (2018); R. Geyer et al. “Production, use, and fate of all plastics ever made” (2017); Greenpeace “Branded” (2018); The Danish Environmental Protection Agency “Microplastics – Occurrence, effects and sources of releases to the environment in Denmark” (2015); European Commission “Factsheet, Microplastics – focus on food and health” (2017); Lenz, Enders, Nielsen “Microplastic exposure studies should be environmentally realistic” (2016); Gall and Thompson “The impact of debris on marine life” (2015); Wilcox, Sebille, and Hardesty “Threat of Plastic Pollution to seabirds is global, pervasive and increasing” (2015); UNEP “Valuing Plastic” (2014); The Scottish Government “Marine Litter Issues, Impacts and Actions” (2012); Ellen MacArthur Foundation and McKinsey & Company “New Plastics Economy” (2016); Ocean Conservancy and McKinsey & Company “Stemming the Tide” (2016) McKinsey analysis

3.1 Microplastics have gained public attention over the past years, but still constitutes a new research area with significant unknowns

Microplastics have received increasing public and academic attention

Scientific publications on microplastics (SCOPUS)



… still, various areas remain unclear (examples)

Emerging consensus

- Standard size microplastics is **less than 5 mm,** with some definitions including lower threshold of 1 mm in size
- Microplastics are **ingested by wildlife in the ocean,** e.g., fish, whales, and plankton

Open questions

- **Microplastics' ability to spread from the digestive system,** e.g., ability of microplastics to transfer through membranes due to their small size
- Dissemination of **microplastics in food and beverage products,** e.g., source or origin of microplastics measured in honey
- Degree to which **microplastics act as a vector,** e.g., for chemicals and bacteria, resulting in contamination of host organisms
- **Largest sources** of primary and secondary microplastics

SOURCE: The Danish Environmental Protection Agency "Microplastics – Occurrence, effects and sources of releases to the environment in Denmark" (2015); European Commission "Factsheet, Microplastics – focus on food and health" (2017); Eunomia "Investigating options for reducing releases in the aquatic environment of microplastics emitted by (but not intentionally added in) products" (2018)

3.2 Beyond research, Denmark could facilitate necessary international collaboration to set ambitious targets for reducing plastics pollution

Forums for reducing plastics in the oceans (examples)

- **EU: The Marine Strategy Framework Directive**
  - First comprehensive piece of EU legislation aiming to protect marine environment and natural resources
- **Regional sea conventions, OSPAR and HELCOM**
  - Both OSPAR and Helcom have adopted regional action plans for marine litter
  - Denmark has taken leading role on initiative regarding EPS[1] in the Baltic Sea within HELCOM

Geographical coverage of OSPAR[2] and HELCOM[3]

Policy arenas for action on plastics use and recycling (examples)

- **UN Environment Programme's Clean Seas campaign**
  - Aims to engage governments, the general public, and the private sector in the fight against marine plastic pollution
  - Addresses root causes of marine through public commitments and initiating a public debate
- **EU circular economy package**
  - Aims - amongst other - to increase industry demand for recycled plastic and encourage design for recycling
  - Applies legislative measures targeting producers to reduce single-use plastics
- **Nordic Council of Ministers**
  - Facilitates projects concerning optimization of design of plastic products and waste management and microplastics' impact on the ocean

1 Expanded Polystyrene
2 Contracting parties include Belgium, Denmark, the EU, Finland, France, Germany, Iceland, Ireland, Luxembourg, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom
3 Contracting parties include Denmark, Estonia, the EU, Germany, Finland, Latvia, Lithuania, Poland, Russia,, and Sweden

SOURCE: Ministry of Environment and Food "Plastik uden spild – Regeringens plastikhandlingsplan" (2018); UNEP website; Clean Seas website

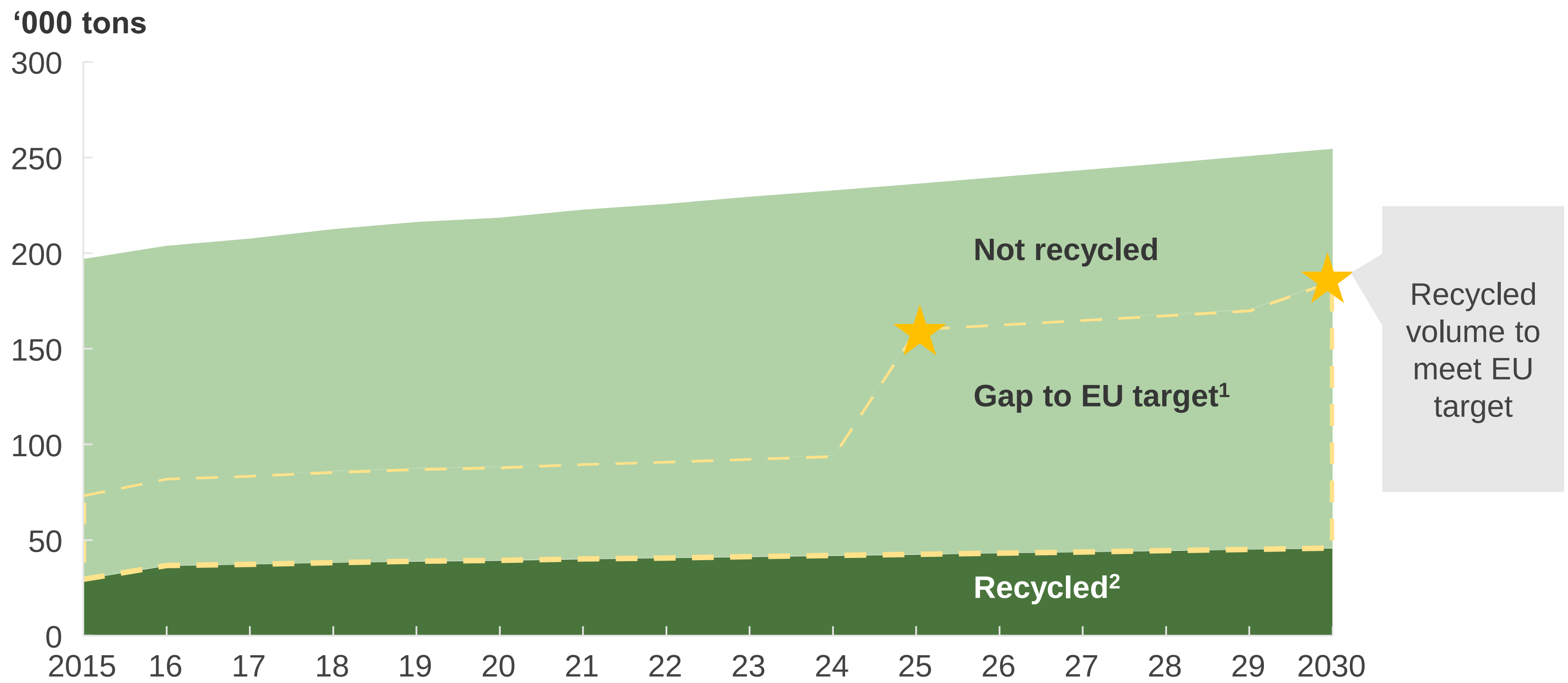
four

In the medium term, Denmark has to meet the EU 2030 targets and could drive innovation in waste collection along with consumption reduction

1. The EU’s target for recycling plastic packaging is 55% by 2030. Denmark currently achieves less than a third of this. A first step to reaching it can be for municipalities to align their criteria for collecting waste, to eliminate today’s inefficiency. Meeting the target also requires decreasing consumption and creation of waste, specifically of plastics that are difficult to recycle. This can, for example, include scaling up pilot projects that can successfully increase reuse of plastics
2. There is great scope for innovation. For example, we could improve collection and sorting by using AI and advanced sensors, as well as continue to improve on recycling technologies. Additional innovation potential lies in developing new products and materials that can be reused and repaired, or new business models that enables using less plastic

4.1 To meet EU 2030 target of 55%, the Danish recycling for plastics packaging is required to triple

Recycling rate and volumes for plastics packaging, thousand tons



1 New EU legislation from 2018 obliges member states to recycle 50% of plastics packaging waste in 2025 and 55% in 2030

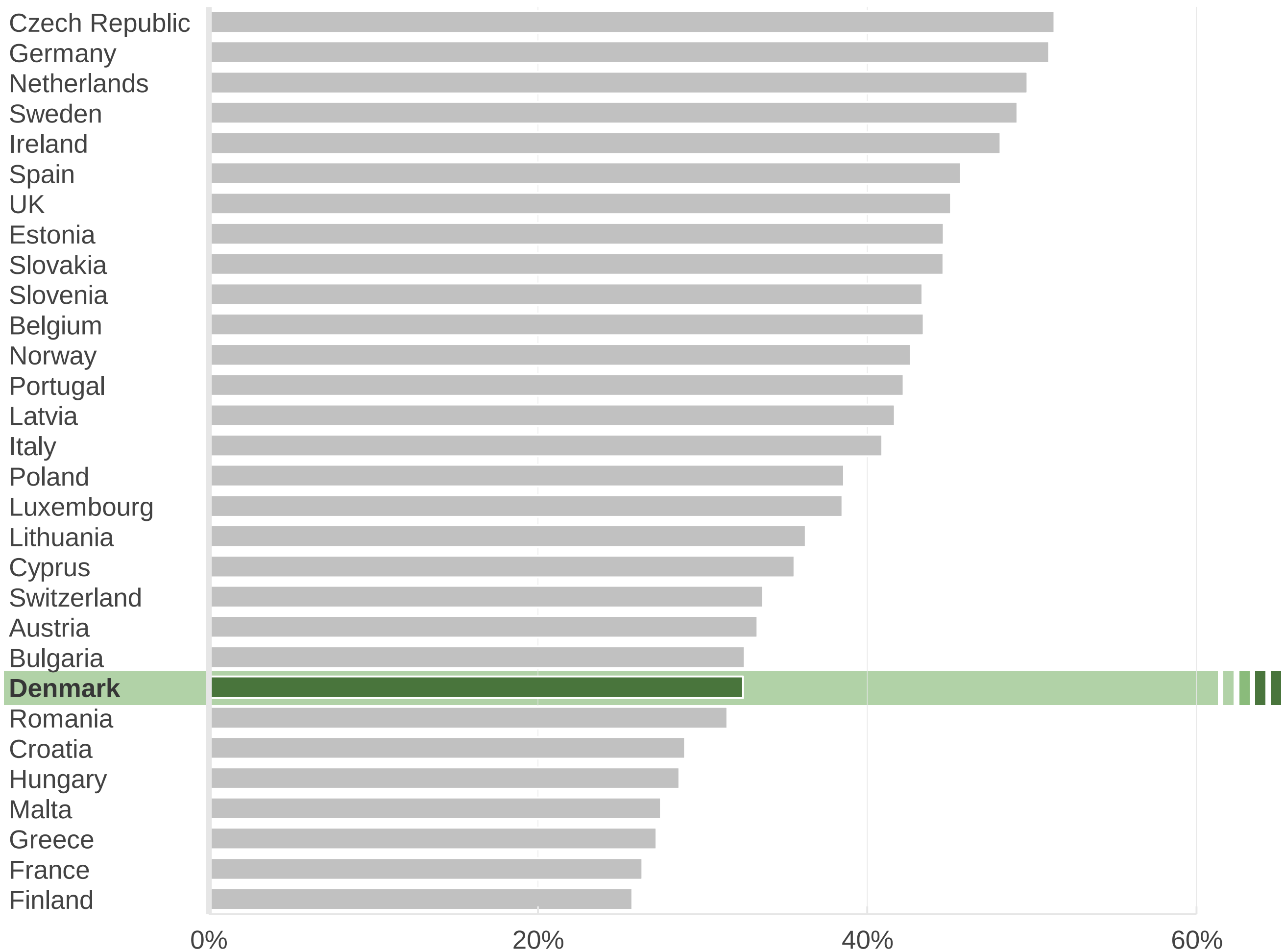
2 Plastics packaging collected for recycling projected by current FRIDA estimation to increase up to 36% towards 2025 after which current municipal waste plans will be fully implemented (does not include political initiatives after 2015 and technology development). This rate was already achieved in 2016, while the recycling rate in 2015 was 30.5%. Based on expert interviews, the rate of actual recycled plastics is assumed to be 50% of plastics collected for recycling, i.e. ~15% for 2015 and ~18% for 2016 towards 2025

NOTE: Total volume for plastics packaging projected from DEA estimation of total plastic packaging consumption in Denmark for 2015, growth rate estimated by ICIS for all plastics applied towards 2025. Growth rate of 1.5% is assumed from 2025-2030

SOURCE: Danish Environmental Agency ”Statistik for emballageforsyning og indsamling af emballageaffald 2015” (2015); Danish Environmental Agency ”Statistik for emballageforsyning og indsamling af emballageaffald 2016” (2016)ICIS data; Expert interviews

4.1 Compared to European peers, Denmark ranks low for plastics packaging collected for recycling

Proportion of plastic packaging waste collected for recycling per European country (2016), percent



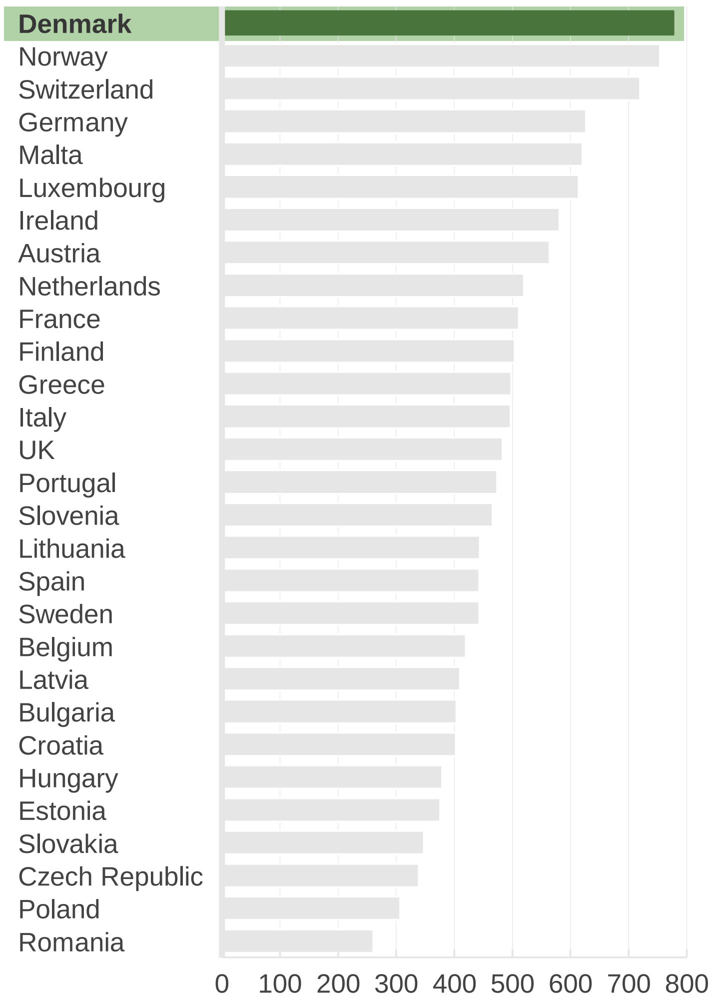
Denmark collects less plastic packaging waste for recycling than European peers

- Large waste incineration overcapacity has limited the incentive to switch waste volumes to recycling
- Industry is the main contributor to plastics packaging recycling and collects ~64% for recycling, compared to households that recycle ~15%

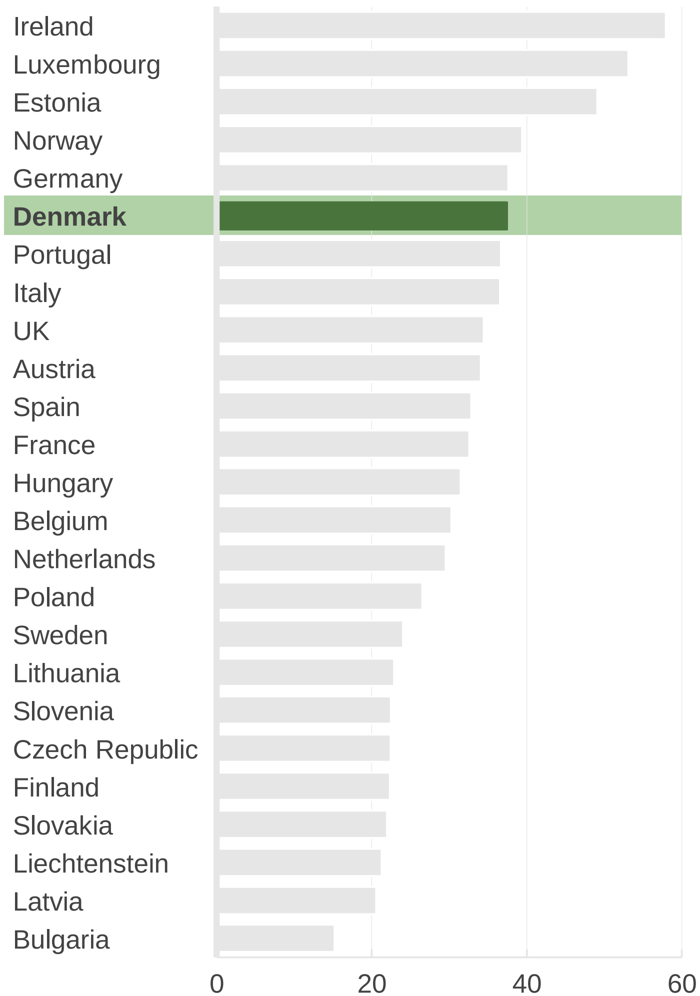
SOURCE: PlasticsEurope: Plastics – the Facts (2017); Plastindustrien, "Så meget plastik genbruges i Danmark" (2018); Ellen MacArthur Foundation and McKinsey & Company "Potential for Denmark as a Circular Economy, Case Study from: Delivering The Circular Economy – A Toolkit For Policy Makers" (2015)

4.1 Denmark is also amongst the largest waste producers per citizen in Europe

Waste per citizen, 2016[1], Kg per capita



Plastics packaging waste per citizen, 2016[2], Kg per capita



Several potential drivers of relatively high waste production in Denmark

- High-income countries generally produce more waste
- Waste generation increases with urbanization
- Waste management system has not created incentive to reduce waste
- Retail dominated by supermarkets rather than open air markets with less packaging

Note that data on waste generation can be difficult to compare as varying methods to measure waste production are used in different countries

1 Includes only household waste
2 Includes both industrial and household waste

SOURCE: Eurostat; World Bank "What a Waste 2.0" (2018)

4.1 Germany has developed an exemplary system with 45% of plastics waste collected for recycling

Key take-aways

- Recycling differences are **driven by regulation**
- **Plastics players** have taken **little initiative** to reshape recycling
- There is a **lack of economic consequences** for producers and suitable business cases
- **Brand owners only** step up **where consumers are aware** of plastic-related problems

Key initiatives to push plastics recycling	Policy makers	Plastics value chain	Brand owners	Consumers	Waste managers
	▪ Regulate ▪ Educate	▪ Innovate ▪ Integrate ▪ Influence	▪ Design for recyclability ▪ Increase recycled content	▪ Purchase recyclables ▪ Separate waste	▪ Consolidate ▪ Integrate ▪ Innovate

1 Includes waste management players, pure recyclers and compounders, and virgin plastic producers
2 2015 figures for Germany, 2014 for France
3 Mechanical recycling could include recycling outside of Germany (export)

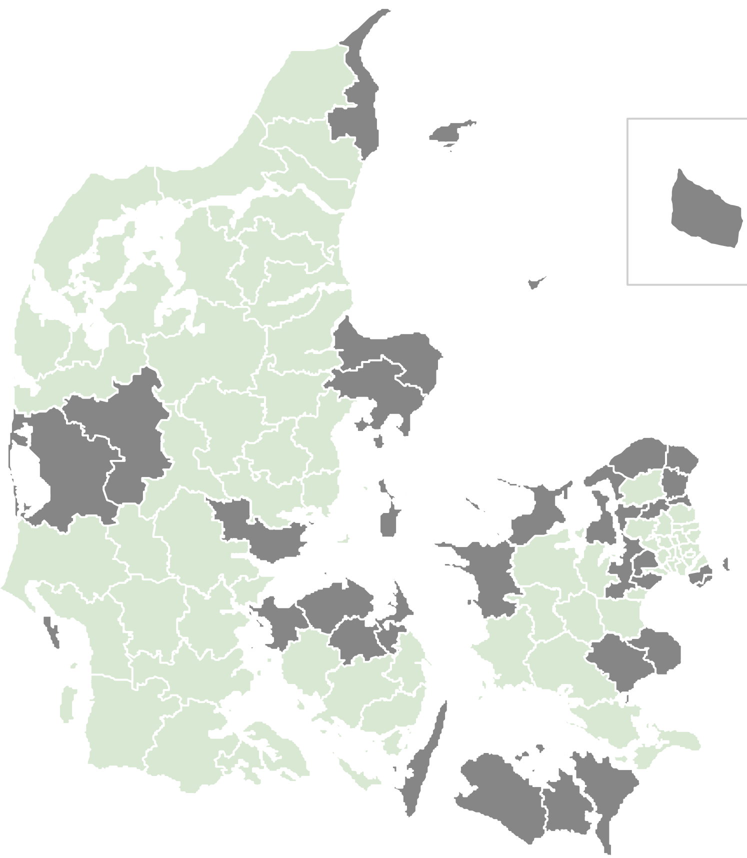
SOURCE: IHS Chemical Economics Handbook (2016); Plastic Europe (2017); US Environmental Protection Agency (2016); Conversio (2016); Consultic, Umweltbundesamt; CPCB India – PWM Report; web search; McKinsey analysis

4.1 Standardizing collection criteria can create a better business case and help increase the Danish recycling rate for waste

Not all municipalities collect plastics waste at household level

Collects plastic waste at source (households)[1]

Does not collect plastic waste at source (household)



No standards for collection criteria cause inefficiencies

- Every municipality **defines its own collection criteria**
- Multiple plastic waste collection setups make it **difficult to gain economies of scale and thereby set up good business case** for collection and recycling of the waste

Standards for collection criteria to be defined

- Ensure that **all municipalities collect plastics separately at household** (not mixed with other materials, e.g., glass)
- Makes it attractive for companies to **source plastic waste from multiple waste facilities**
- Ensure flexibility in standards to **enable innovation and accommodate existing municipal facilities**
- **Allow for some regional variety** in terms of population density and different housing types
- Over time consider **required standards for industrial waste**

1 Only includes municipalities where plastics waste is collected at household level, thereby excluding municipalities where residents are required to deliver the plastic waste at recycling stations or local collection points. Does include municipalities with alternative curb-side collection, e.g., weekly pick-up at household

NOTE: Municipality overview does not include municipalities with plans to collect plastics waste at household level within the coming years

SOURCE: Ministry of Environment and Food of Denmark; European Commission; PlasticsEurope "Plastics – the Facts" (2017); Incentive for the Danish Environmental Agency "Effektiviseringspotentiale ved kommunal affaldsindsamling" (2017)

4.1 Source separation allows for consistently high recycling rates compared to other sorting approaches

Curbside collection

Plastics collection and sorting	Description	Evaluation	Example countries	Recycling rates[1]
Source/ curbside sorting	▪ Source separation and collection of plastics at curbside ▪ Collection vehicle has different compartments	▪ Allows for contamination to be filtered out at the point of collection ▪ Lowest sorting effort in MRF		▪ 27-33%
Multiple streams comingled	▪ Partial sorting of materials into multiple containers ▪ Subsequent sorting of materials at materials recovery facility (MRF)	▪ Easier separation at MRF (reduced potential for materials to bind together) ▪ Increased collection efficiency		▪ 13-37%
Single stream comingled	▪ Collection of comingled materials in a single compartment vehicle ▪ Sorting of materials at materials recovery facility	▪ Quality dependent on capacity and capability of MRF ▪ Lowest dependency on residents' behavior		▪ 20-37%
Collection sites	▪ Residents are required to deliver the waste to collection sites ▪ Can be sorted or comingled	▪ Reduced collection effort ▪ Higher acceptance by residents required		▪ 37% (sorted) ▪ 24-33% (2 fractions)

- With regard to recycling rates, source separation seems to be a promising approach
- When deriving the ideal collection and sorting approach, acceptance from citizens for separation and drop-off as well as a minimum waste stream size for collection efficiency needs to be considered

1 2014 figures

SOURCE: European Commission DG ENV, Brussels; Waste & Resources Action Programme; Consultic; McKinsey analysis

4.1 Meeting the EU targets also requires phasing out plastics that are difficult to collect and thereby recycle

Examples of initiatives to reduce consumption of single-use plastics

Voluntary initiatives

- **The Freiburg Cup** seeks to tackle the issue of single-use, to-go coffee cups, as 2.8 billion cups are used every year with an average use time of 13 minutes
- The cup is made from dishwasher-proof plastic and **can be reused hundreds of times or returned to recycling**
- It can be obtained for a deposit of EUR 1 at the **more than 100 cafés and bakeries in Freiburg** that have signed up to the program, who wash and redistribute the cup

Regulatory initiatives

- In England, large retailers are required to **charge a 5p fee on carrier bags as of October 2015** to combat the 7.6 billion single-use plastic bags issued in 2014
- Consumption at the large retailers has **decreased by 87% to 1 billion bags in 2017**
- The UK government is currently considering **expanding the fee to all shops**
- A recent study found a **drop of ~30% in plastic bags on the seabed**

SOURCE: World Economic Forum "Germany has come up with the best solution to single-use coffee cups" (2017); Maes et al. "Below the surface: Twenty-five years of seafloor litter monitoring in coastal seas of North West Europe (1992–2017)" (2018); UK Department for Environment, Food & Rural Affairs "Single-use plastic carrier bags charge: data in England for 2017 to 2018" (2018)

4.1 Plastic consumption can be further decreased by scaling up pilot projects that aim to increase re-use of plastic products

Potential of local pilot projects

- Local pilot projects enable testing new concepts, e.g., new product designs, new infrastructure, deposit incentives, and value chain collaborations
- Larger events - such as festivals - with large food and beverage demand provide a setup for pilots to reduce single-use packaging
- Other setups can be shaped around geographical areas or institutions, e.g., universities

Examples of successful local pilot projects

Closed loop for plastic cups and crates at NorthSide Festival

- Closed loop setup for plastics packaging, e.g., by using reusable cups and crates for beverages
- Plastic cups were recycled to be used at the festival the following year as plates for food, which was well received by the festival audience
- Funded by the Ministry of Food and Environment

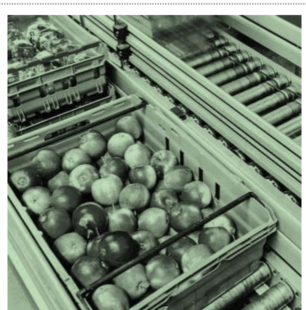
Reusable cups in Tivoli

- Deposit system for all plastic cups and mugs that uses “reverse” vending machines, that gives the deposit back to the consumers
- All returned cups and mugs are washed in Tivoli’s own facilities to quickly get them back into circulation
- Through its reusable cup system, Tivoli has saved 1.2 million single-use cups and mugs

SOURCE: Plastic Change; Company websites

4.1 Alternatives to current use of plastics can be driven by new business models that enable a lower plastics footprint

Examples of innovation that helps reduce plastic packaging consumption

Initiative/company		Actor type	Description	Tools for reduction
Algramo		Start-up	▪ Sells food and hygiene products through vending machines ▪ Customers use reusable plastic containers for the machines, replacing single-use packaging	▪ Reusable packaging design ▪ Technology ▪ Economic incentive for customer
MIWA		Start-up	▪ Combines digital technology with waste-free shopping solution ▪ Food producers deliver products in reusable containers ▪ Customers only buy desired amount of given products using an app on their phone and can use their own reusable packaging	▪ Product and packaging design for reuse ▪ Context design for reduce and design thinking ▪ New technology ▪ Economic incentive for customer
Svenska Retur-system		Industry	▪ Operates deposit-based system for crates and pallets, used in B2B handling of goods ▪ Nonprofit and run by special interest organizations representing grocery manufacturers and wholesalers	▪ Reusable product design ▪ Valuechain alignment/ standardization ▪ Economic incentives ▪ EPR-driven business model

SOURCE: Plastic Change; Company websites

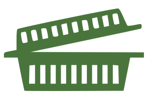
4.2 There is innovation potential all along the value chain, both in production, use, and waste management of plastics (incl. recycling)

Potential areas of innovation for plastics

Production

- Design for increased reuse and recyclability
- Design to avoid product itself or parts of it ending up in nature
- Sustainable alternative plastics materials, e.g., from biomass
- Application of renewable plastics in niche applications

Use



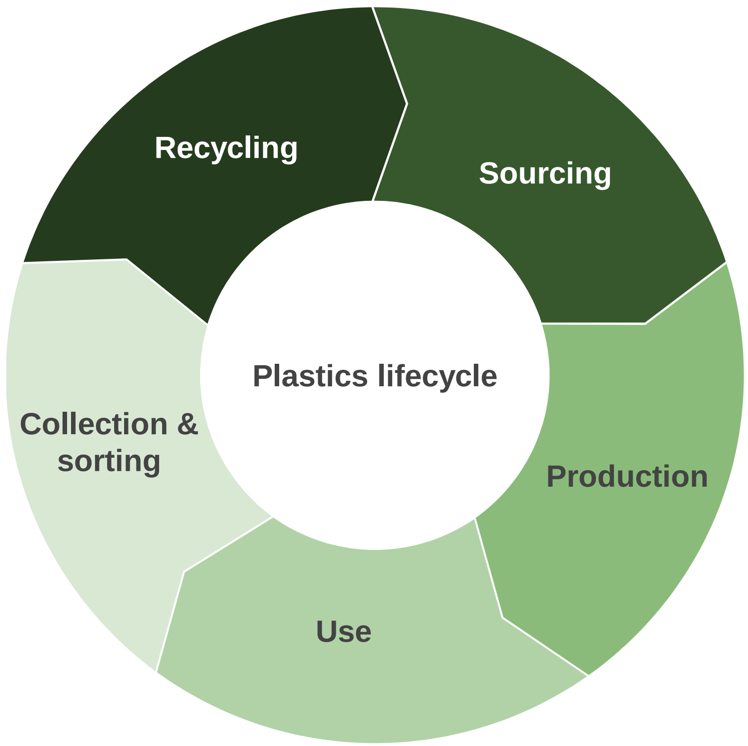
- Business models to incentivize use of reusable packaging
- Closed-loop models for reuse, e.g., cups and pallets

Waste management

- Mechanical recycling technologies
- Chemical recycling for specific low-value plastics
- Recognition ability of sorting technologies, e.g., optical sorting or AI
- Sorting for difficult waste streams, e.g., through robotics
- Methods for traceability of plastics, e.g., chemical markers
- Biological methods for degradation of plastics
- Technologies for tracking and removing additives

4.2 There are several points of innovation within design to be leveraged based on the strong Danish design tradition

Innovation within design can improve sustainability in each phase of the plastics lifecycle



- **Design choices enable high value recycling**
  - Capabilities in making smarter design and material choices are in demand, as companies look to decrease risk of negative environmental impact
  - **Materials and design prolongs lifetime of plastic products**
  - The Danish design tradition is characterized by a focus on quality and long-term sustainability, e.g., in furniture design
- **System design enables innovative solutions**
  - Collaboration across the value chain enables new solutions but can be difficult, especially in countries with no or little tradition for cross-sector collaboration
  - In Denmark, **we have experience with efficient system design historically** (e.g., district heating) which we can apply to new systems as well as export for other economies
- **Application generates increased value**
  - Untapped potential **in applying recycled high-quality plastics to new applications**, where high-quality plastics would otherwise be too expensive, e.g., construction products
  - Some consumers are **willing to pay more for a sustainable product**, which can be utilized through designing high-value products from recycled plastics, e.g., design chairs from recycled plastics

SOURCE: Expert interviews; State of Green "Circular Economy – Denmark as a Circular Economy hub" (2016); Ministry of Environment and Food, and Ministry of Industry, Business, and Financial Affairs "Strategi for Cirkulær Økonomi" (2018)

4.2 Find alternatives for plastics where intended use results in direct pollution (e.g., shotgun cartridges and artificial turf)

Examples of plastics usage with direct pollution - and where alternatives are needed

	Description of issues	Potential alternatives
Artificial turf	▪ 300 fields across Denmark each lose ~5 tons of rubber granules each year ▪ Up to **1500 tons of rubber granules leak** into the surroundings and nature every year	▪ Granules from cork ▪ Coir
Dolly ropes	▪ Used to buffer and protect fishing nets from wear and tear ▪ The net is dragged along the seabed, with 10-25% of the dolly ropes tearing off ▪ Early analysis suggests **25 tons of dolly rope threads end up in the North Sea and 65 tons in Europe overall**	▪ Natural based materials such as wood, hemp, and leather ▪ Alternative design in other form than string
Textiles	▪ The washing of textiles made of non natural products, e.g., nylon, polyester, and rayon ▪ Washing leads to microplastics being released along with waste water ▪ Textiles are responsible for **2% of microplastics leakage in Denmark,** leaking 200-1,000 tons annually	▪ Natural based textiles from wool, bamboo, linen, and cotton

SOURCE: Ministry of Environment and Food “Plastik uden spild – Regeringens plastikhandlingsplan” (2018); DHI “Koncept for regulering af drænvand fra nye kunstgræsbaner” (2017); DollyRopeFree; Ministry of Environment and Food “Microplastics. Occurrence, effects and sources of releases to the environment in Denmark” (2015)

4.2 Optimized recycling requires a portfolio of recycling technologies

Overview of recovery technologies throughout the plastics value chain

Recovery type	Energy recovery	Feedstock recovery	Monomer recycling	Plastics recycling		Refurbish/re-manufacture	Demand reduction	
Process type	Incineration	Thermal (pyrolysis/ gasification)	Chemical (hydrolysis/ hydrocracking)	Mechanical or chemical (solvent-based)		Disassembly/ reassembly		
Product chain	Energy	Feedstock	Monomer	Plastics (polymers)	Com-pounds	End product	USAGE	Disposed product
Description	▪ Typically, in mix with municipal solid waste (~15% of plastic share)	▪ Suitable for oxygen-free plastics (e.g., polystyrene that is for example for disposable cutlery)	▪ Suitable for polyconden-sates (e.g., PET and many engineering plastics)	▪ Plastics recovery through direct mechanical processes and remolding or a chemical process		▪ Direct re-use of finished products (e.g., spare parts aftermarket) after beautification and repair	▪ Consumer- or Brand Owner-driven demand reduction of plastics	

Low ← **Value conservation** → High

- **Today, Denmark primarily recovers value of plastics at its lowest value point;** energy recovery through incineration
- **Recycling should take place at the highest value recovery point** as possible to gain highest value recovery
- **Mechanical recycling can be maximized for recycling,** as it is the recycling technology with the highest value recovery

NOTE: See appendix for detailed overview of plastic waste recovery technologies

SOURCE: McKinsey analysis

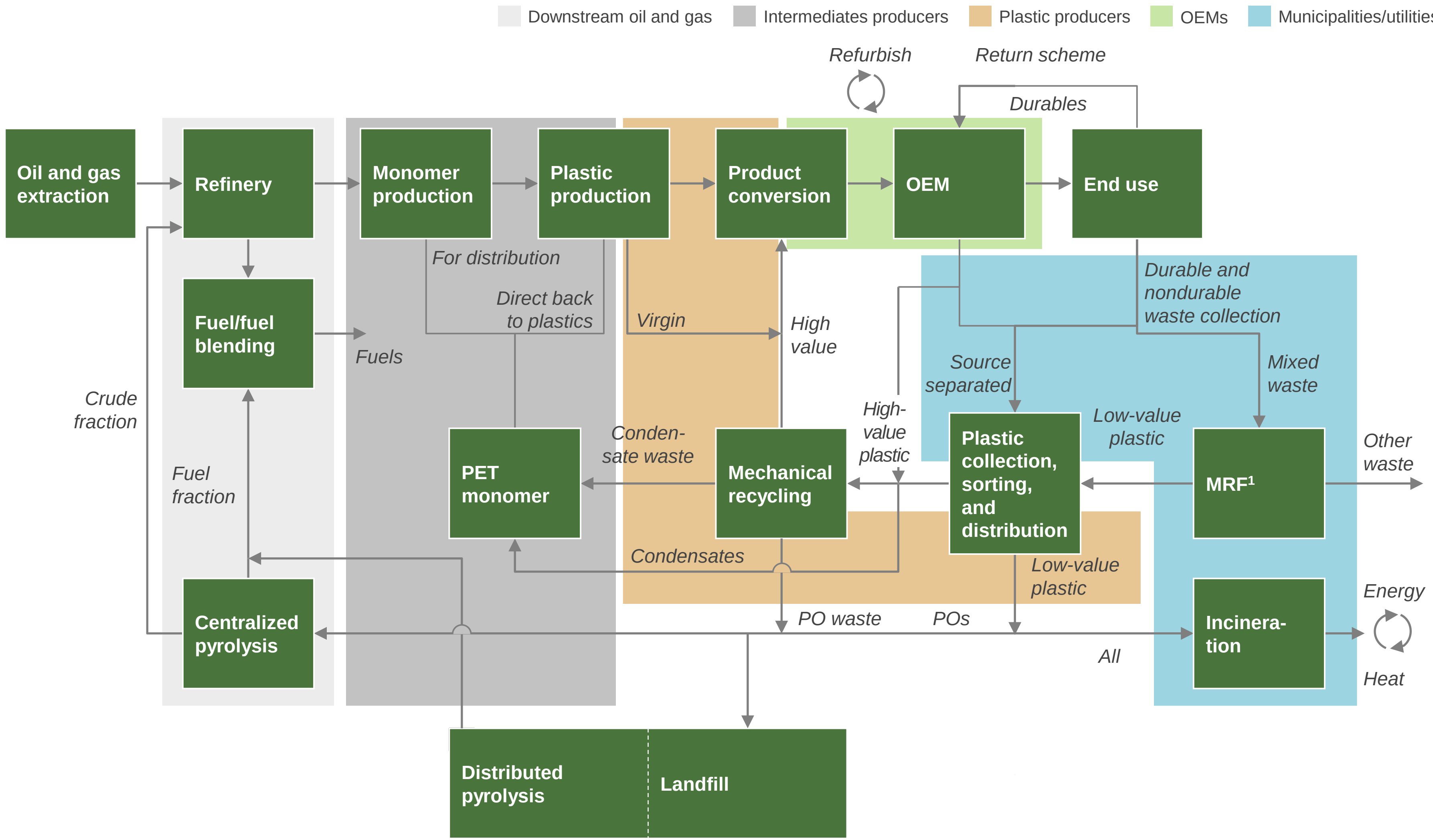
4.2 Different technologies is required to cover the various types of plastics available

Type of plastic	Full name	Global demand (MTA, 2015)	Major applications (examples)	Recycling technology: Mechanical	Chemical	Pyrolysis	Incineration
PET	Polyethylene terephthalate	19.7	Fibers (~64%), bottles (~25%)	✓	✓	✗	✓
HDPE	High-density polyethylene	41.0	Blow molding (26%), film/sheet (19%), injection molding (19%)	✓	✗	✓	✓
PVC	Polyvinyl chloride	43.4	Pipe/fitting (43%), profile/tube (18%), film/sheet (17%)	✓	✗	(✓)	✓
LDPE LLDPE	Low-density polyethylene	48.6	Film/sheet (67%), extrusion coating (10%), injection molding (7%)	✓	✗	✓	✓
PP	Poly-propylene	62.1	Fibers and filaments (32%), injection molding (31%)	✓	✗	✓	✓
PS EPS	Polystyrene	18.5	Foam peanuts, food containers, disposable cups	(✓)	✗	(✓)	✓
Others		36.7	n/a	✗	(✓)	✗	✓

SOURCE: EPA; HIS; McKinsey plastic waste stream model; McKinsey analysis

4.2 A portfolio of recycling technologies could be implemented and integrated by current participants within the plastics value chain

A fully integrated recycling system, bringing together all relevant technologies



1 Material recovery facility

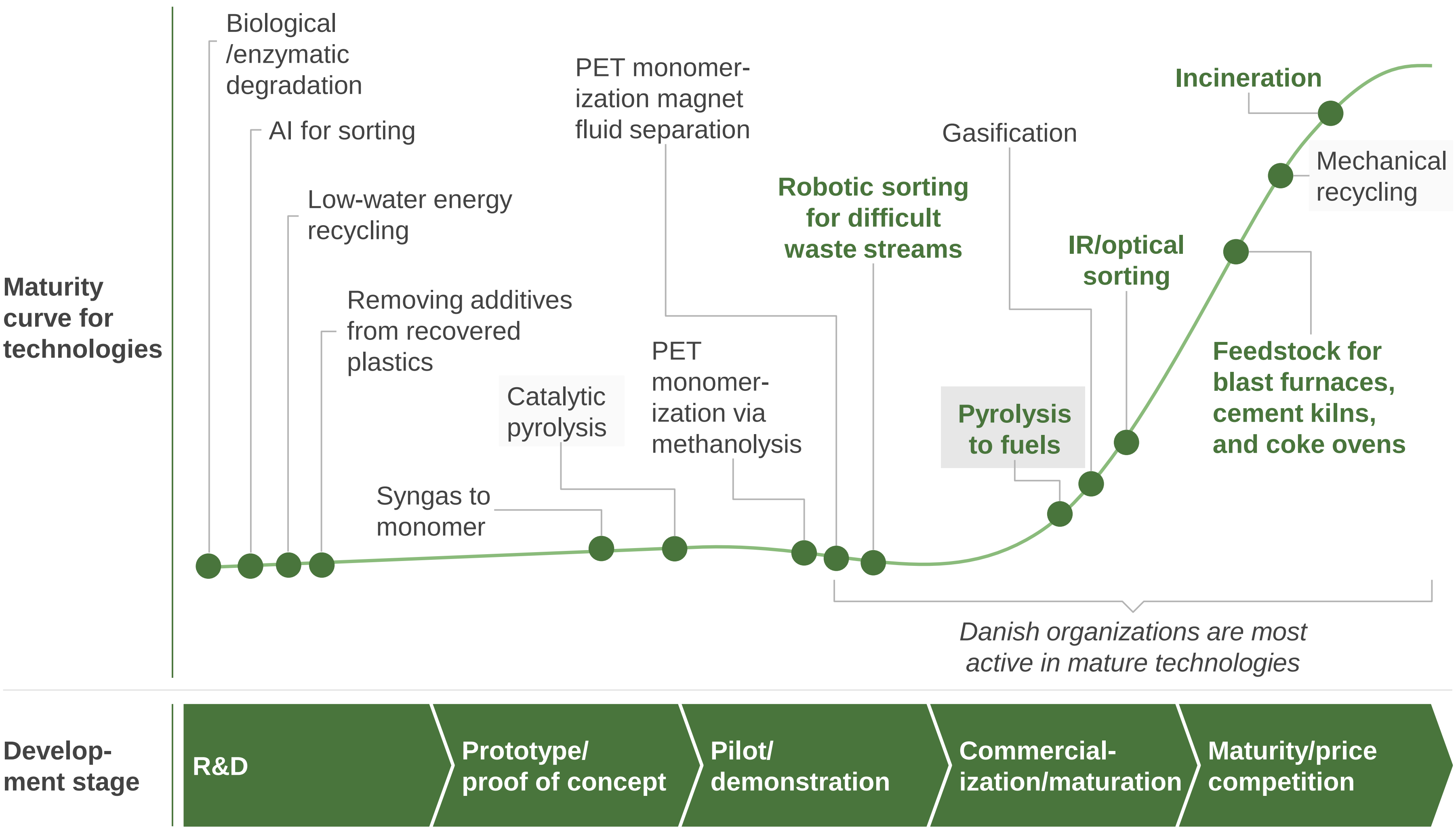
NOTE: See appendix for an example of key elements in an integrated portfolio of technologies

SOURCE: McKinsey analysis

4.2 Danish actors can capture the technology development from increased demand for improved plastic use and waste handling

XXX Technologies applied in Denmark
Deep-dive on following pages

Plastic recovery technologies and their maturity (examples)



SOURCE: Press releases; web search; PlasticEnergy; Ioniqa; expert interviews; McKinsey analysis

4.2 Pyrolysis could complement mechanical recycling in Denmark by utilizing the decentralized waste system and existing know-how

Benefits and disadvantages of pyrolysis

- (+) Suitable for low-value plastic waste that cannot be mechanically recycled
- (+) More CO_2-effective than incineration[1]
- (+) Danish know-how in place from both industry (e.g., Haldor Topsøe) and academia (e.g., DTU)
- (+) Suitable for small scale

- (–) Energy-intensive compared to other recycling technologies
- (–) Cannot handle plastics that can oxygen efficiently
- (–) Value creation realized abroad as reprocessing will take place at producer

Potential set-up

- **Optimize waste streams through sorting to maximize mechanical recycling share**
  - Maximize share of plastics waste going to mechanical recycling through improved sorting technologies and better waste streams
  - Focus on PET and PVC, as these plastics cannot be pyrolyzed
  - Mechanical recycling to take place at regionally based, smaller facilities
  - Potential continuation of additional export dependent on market development
- **Set up decentralized pyrolysis facilities**
  - Regional pyrolysis facilities to confine cost of transporting low-value waste
  - Connect to district heating system to utilize excess heat
  - Output (naphtha oil) sold to plastic producers – likely abroad – who will have steam crackers on production site

Innovation opportunities

- Denmark could **develop edge on specific points of the pyrolysis value chain**
- **Several unsolved processing issues** (e.g., feedstock variability, contamination) impacting yield and pyrolysis economics
- Pyrolysis facilities could help **drive demand for improved sorting technologies**
- **Potential to become proprietary system for low-density areas** that can be exported

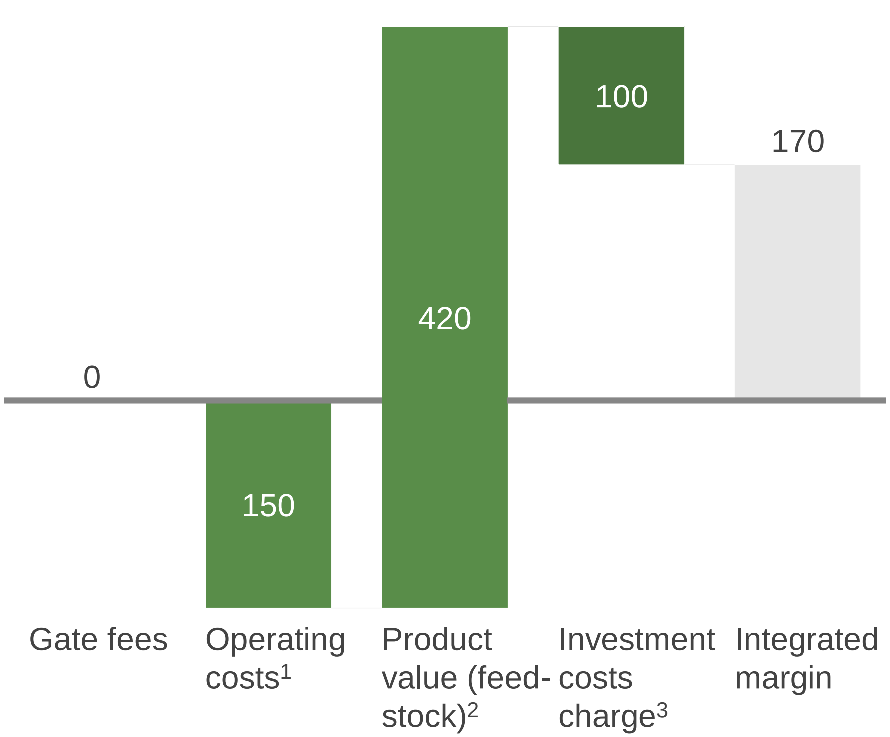
1 Provided that feedstock is used for producing new plastics and not as fuel

SOURCE: Expert interviews

4.2 Pyrolysis is likely already economically viable today

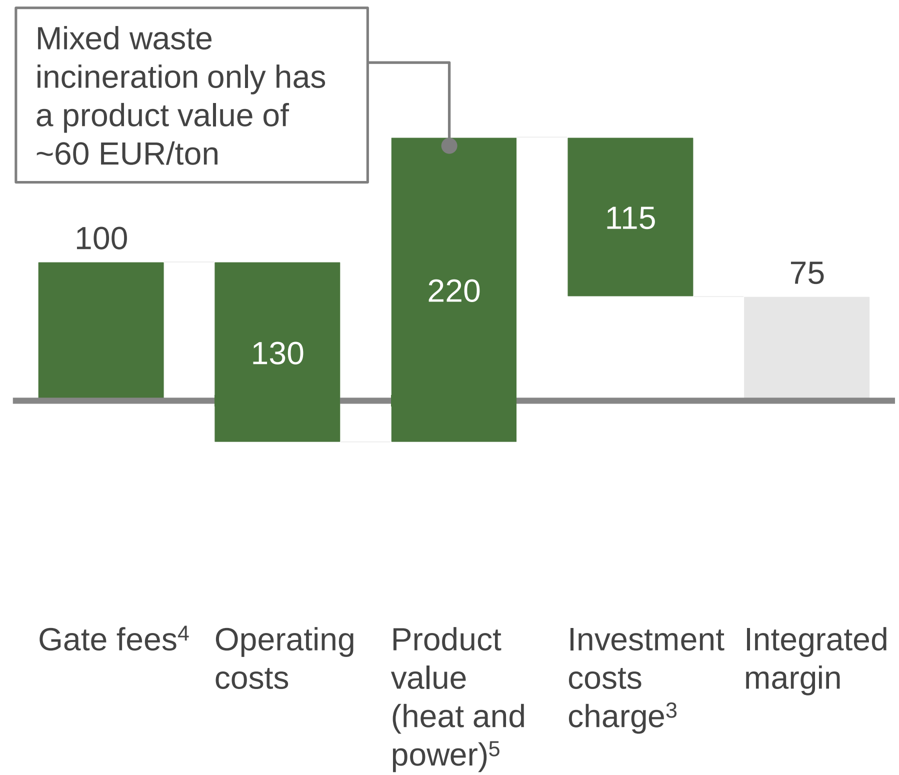
Process economics comparison, EUR/ton input material (estimate)

Pyrolysis



Pyrolysis could operate profitably without additional incentives – large uncertainty remains in terms of product yields, true operational costs, and oil price

Incineration of pure plastic waste



Incineration requires gate fee to recoup operational costs (incl. investments) and generate a profit

1 Operating costs will be tightly linked to input material consistency and quality (determines the number of cleaning cycles of the reactor) and degree of automation of potentially highly variable process conditions 2 Assumes majority fraction of direct fuel cuts of 50-60% and ~20% syncrude output, i.e., 80% average yield at USD 75 billion oil price 3 Assuming 10-year write-off (can also be taken as required maintenance capex) 4 Typical European gate fee for landfill and incineration units 5 Assumes average energy content of mixed plastic waste of ~10,000 kWh/ton turned into 75% electricity and 25% heat; electricity conversion efficiency assumed at ~40% and heat conversion efficiency of 90%

SOURCE: Expert interviews; McKinsey analysis

five

In the long term, a working market for recycled plastics and sustainable plastics must be established

1. This will need measures to build the demand and supply for recycled plastics. One example to build reliable supply is to promote recyclability as part of implementing Extended Producer Responsibility, which is required for various plastic items across the EU towards 2025
2. In Denmark, we have an opportunity to develop niche applications of sustainable plastics for high-value products based on local industries

5.1 The market for recycled plastics can be vastly improved to enable the economic incentive for investment into research and development

- The current market suffers from **a coordination failure that slows down technology development**. Volatile prices hamper investments in technology development that can increase supply, while limited supply predictability hinders demand growth
- **A market for recycled plastics could be established** to set the value of recycled plastics at a level that makes exhaustive waste collection, technological development, and higher requirements for design economically viable
- This is **especially the case for recycled PET,** where the technology for recycling and sorting is developed but demand is still lacking to be able to unlock the remaining potential for recycling[1]

Potential supply measures

- **Extended Producer Responsibility requirements**
  - Incentivize design for recycling, e.g., by levying fees according to official design manual (EPR on plastics packaging to be implemented throughout the EU by 2025)
- **Certification standards for recycled plastics**
  - Encourage transparency and high quality to decrease uncertainty about presence of additives in plastics waste

Potential demand measures

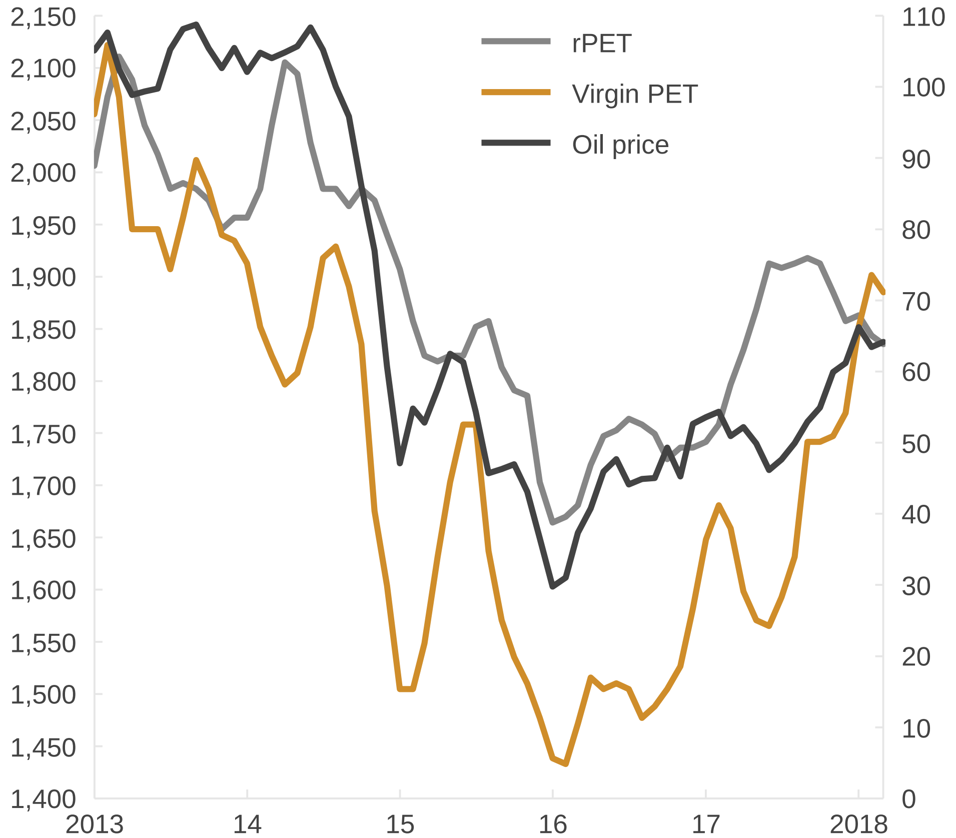
- **Minimum requirements on recycled plastics share**
  - Create separate demand for recycled plastics suppliers, as they currently compete against virgin plastics suppliers
- **Consumer education and awareness campaigns**
  - Stimulate consumer demand for products containing recycled plastics
- **Green Criteria for Public procurement**
  - Set requirements for recycled plastics content in certain product groups purchased with public funds
- **Tax virgin plastics**
  - Incentivize plastics producers to use more recycled raw materials

1 See example on next page

SOURCE: Expert interviews; OECD “Improving Markets for Recycled Plastics” (2018)

5.1 Recycled PET exemplifies the current difficult market for recycled plastics, deriving from fixed cost structures and volatile prices

North America PET virgin, recycled resin, and oil prices, USD per metric ton, USD/barrel



- **Stable supply of recycled PET (rPET),** due to
  - High **system automation** and **technology maturity**
  - Existing **high recycling rates** (in mature markets)
- However, rPET prices trail virgin plastics prices, causing **unstable supplier profitability**
  - Recycled PET production is **profitable when oil prices are high**
  - **Profits easily plummet** due to relatively fixed manufacturing costs (~70% of total costs)
- **Volatility has caused multiple players to drop out of business**, which again creates difficulties for steady supply of rPET

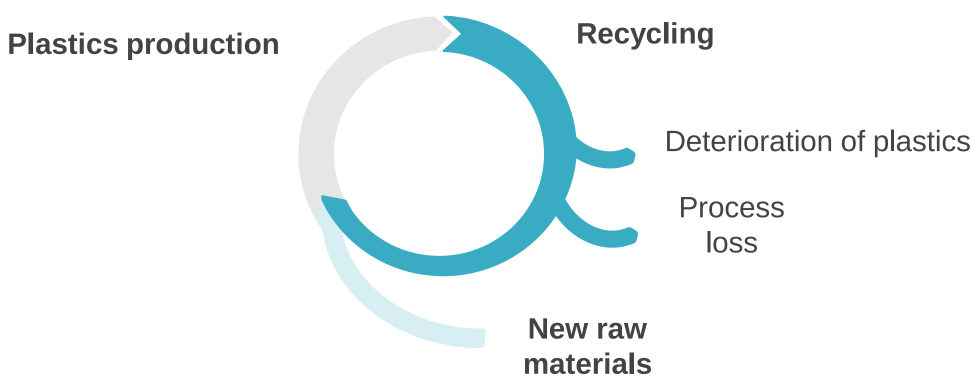
SOURCE: IHS; World Bank; Expert interviews

5.2 Denmark has potential to lead development of niche applications of sustainable bio-based plastics for high-value products

Demand for new plastics raw material should be met with sustainable bio-based plastics

- Plastics deteriorate as they are used and recycled over and over, creating a need to add new raw materials
- Process loss occurs during recycling, meaning that even if plastics demand stabilized, there would still be a need for new raw materials
- Current raw material for plastics primarily come from fossil fuels, which must be replaced for future raw material production to avoid CO_2 emissions
- Bio-based plastics should still be kept to a minimum due to competition with food sources, risk of land grabbing, and loss of biodiversity
- Applying sustainable bio-based plastics for niche applications can help keep production under control, while Denmark has several industries where innovation within bioplastics is relevant

New raw materials for plastics are necessary, as process loss occurs and materials deteriorate through recycling



- Sustainable bio-based plastics are especially attractive for **companies looking to become completely free of fossil fuels**
- A **profit margin high enough to carry additional costs** of sustainable bio-based plastics is required
- Examples of **companies looking into bio-based plastic applications** of high-end products:

LEGO® botanical elements will all be made from bio-based plastics in the future

Bio-based plastics to be used in numerous Apple components in the future, e.g., in iPhone cover glass and speaker enclosures

NOTE: To remain sustainable, bio-based plastics should take part of the circular system similar to other plastics through recycling

SOURCE: Expert interviews; company websites

5.2 Bio-based plastics still face a number of challenges to become a scalable and sustainable alternative to plastics from fossil fuels

Benefits and challenges for biodegradable and nonbiodegradable bio-based plastics

	Benefits	Challenges	Examples of niche applications
Non-biodegradable	▪ Made from **bio-based feedstock** (e.g., sugarcane) and not fossil fuels ▪ Creates lower CO_2 emissions than plastics based on fossil fuels	▪ Bio-based plastics might **appear sustainable, but they do still create CO_2 emissions** ▪ Growing demand generates **increased competition for biomass, incl. food sources, as well as risk of land grabbing and decreased biodiversity**	▪ High-value plastic products from companies looking to become completely fossil-free
Bio-degradable[1]	▪ Potential for **decomposition** under the right conditions (composting facility) ▪ Made from **bio-based feedstock** (e.g., sugar cane), can also in some cases be based on fossil fuels	▪ Current development can **degrade only under very specific conditions** (e.g., presence of water, light, oxygen, temperature) ▪ **Biodegradable plastics contaminate** regular plastic recycling streams due to composition ▪ Bio-based plastics **but they do still create CO_2 emissions** ▪ Growing demand generates **increased competition for biomass, incl. food sources, as well as risk of land grabbing and decreased biodiversity**	▪ Plastic products prone to leakage, e.g., wrappers ▪ Items where usage causes tearing, e.g., fishing equipment (such as dolly ropes) ▪ Smaller plastic pieces that are difficult to collect upon usage, e.g., shot shells and soft gun bullets *Only relevant if bio-based plastics are fully compostable under natural conditions*

1 Decomposes under specific conditions and contains at least 50% organic matter

SOURCE: Bioplastics Guide; Wageningen University & Research; Ellen MacArthur Foundation “The New Plastics Economy” (2016); McKinsey analysis

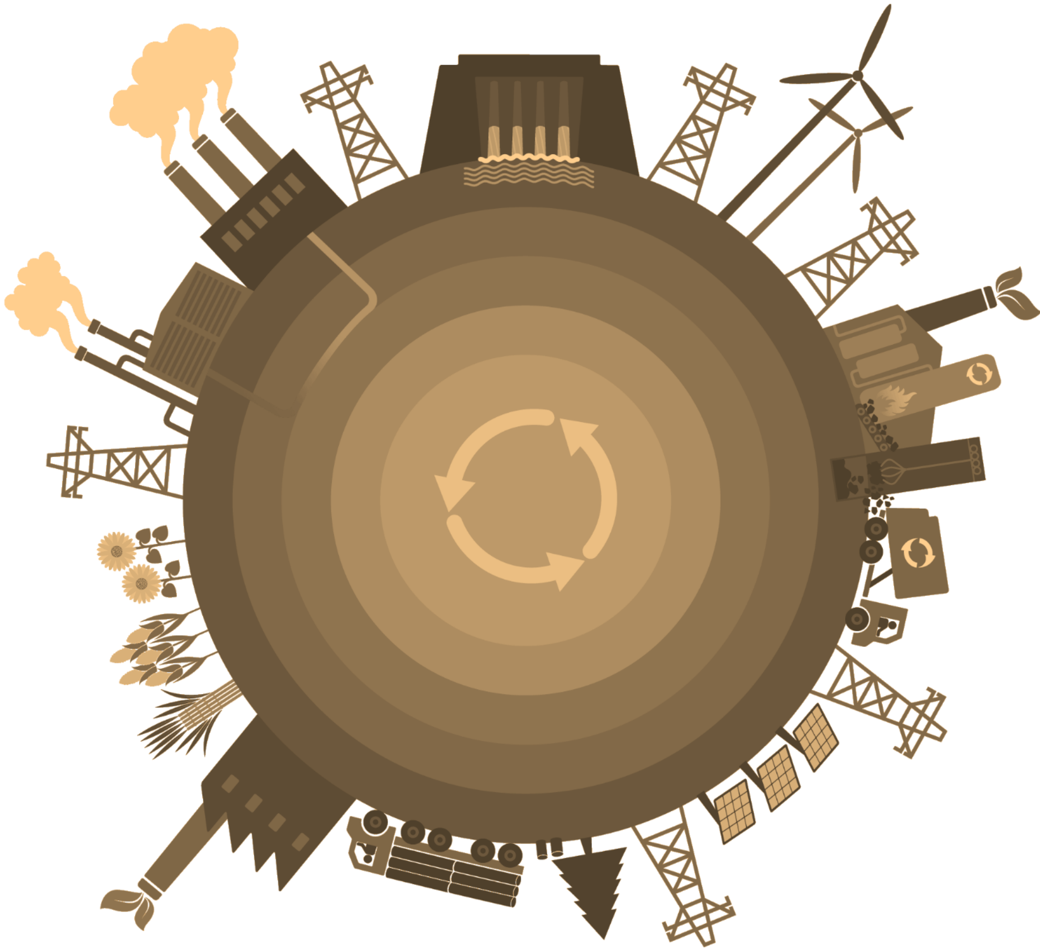
A Danish perspective on the New Plastic Economy

For more than a decade, McKinsey has been involved in shaping the approach on how to solve the equation of growth and sustainability by providing a fact base and platform that enables sound decision making and concrete plans of action

The Circular Economy concept is one that provides an opportunity to combine sustainability and growth, such as using and reusing natural capital as efficiently as possible, and finding value throughout the lifecycles of finished products, which can boost company profitability and national resource productivity

This report has explored the Circular Economy within plastics for Denmark, a New Plastics Economy. Firstly, it considered the “Plastics Challenge” from international and domestic plastics consumption and waste management to remaining knowledge gaps. The second part defined a potential vision, targets, and areas of action to tackle the plastics challenge to thereby capture the research, innovation, and business opportunities that it offers.

We hope this report and the supporting fact base will inspire action to address the challenge and capture the opportunity.



APPENDIX

China, previously a main importer of plastics waste, banned all imports waste as of January 2018 causing countries to struggle with managing low-value plastics waste

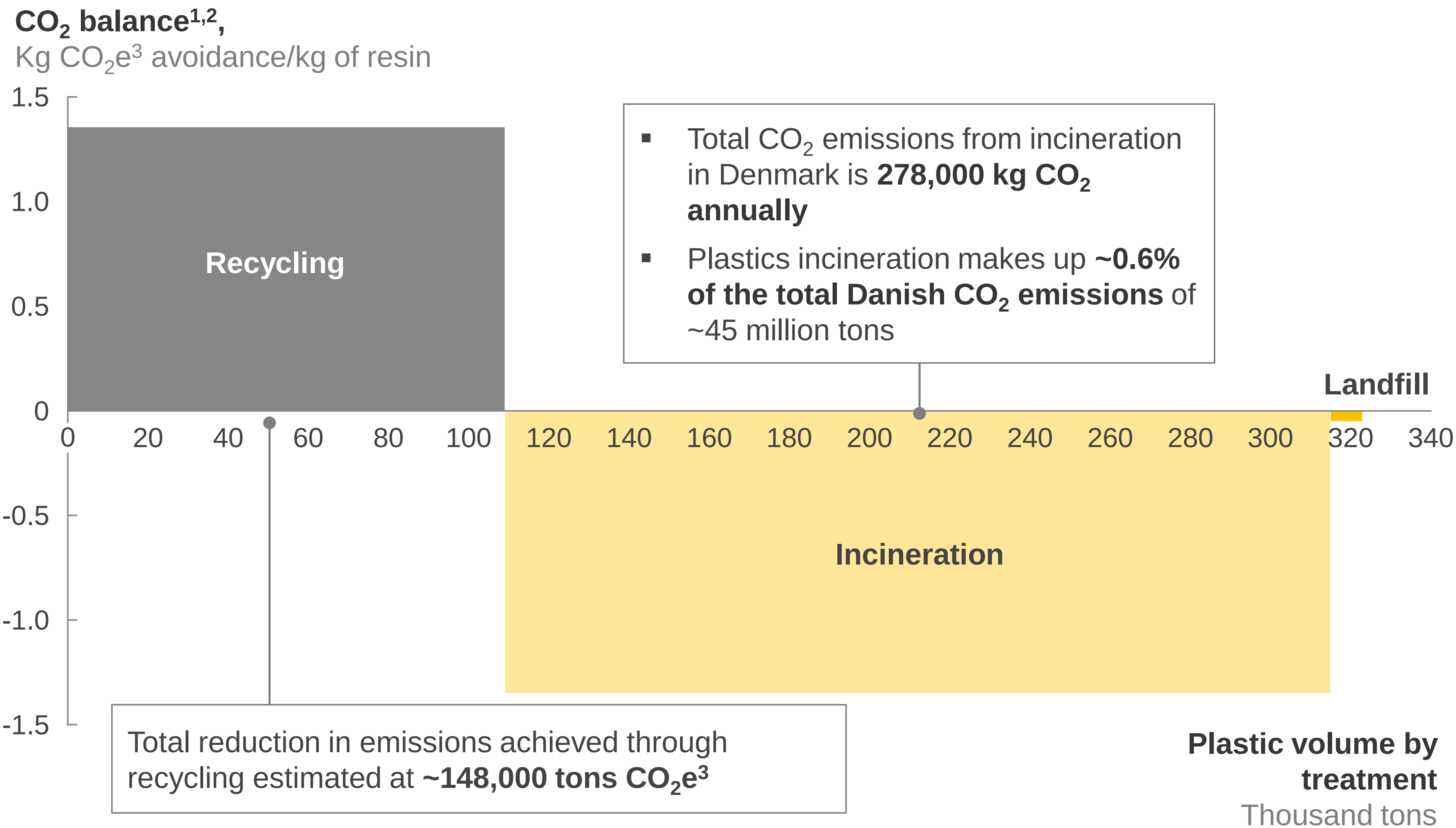
Context

- Until 2018, China imported about **70% of world's traded plastic waste,** amounting to **8.9 MT** in 2012
- **40% of total plastics waste collected in Europe** (EU-27), or 87% of plastic waste exported, was in 2012 sold to China and Hong Kong, amounting to **USD 767 million** in trade
- Chinas has **increasingly implemented waste import policies, e.g., "Green Fence" of 2013** to increase the waste quality that China is receiving while reducing illegal smuggling and trading

	National Sword – campaign	National sword – full ban
Year	2017 Feb	2017 July
What it is	▪ One-year campaign consisting of focused **crackdown on smuggling and illicit activities** related to recyclable and waste materials (i.e. illegal imports, improper recycling operations)	▪ Permanent ban on plastics and mixed paper (amongst other waste) to **clean the Chinese industry of contaminated waste** effective from January 1st 2018
Impact on industry	▪ 15 smuggling operations were exposed, **22,100 tons** of foreign waste confiscated ▪ 100% custom checks on imported materials **increase lead time by up to 4 times** and increase **demurrage cost** for exporters ▪ Recycling in China is encouraged from own commercial and domestic waste streams	▪ Economies such as the EU, US and Japan now face the **challenge of managing the waste previously shipped off to China** as existing capacity cannot cope with increased domestic recycling ▪ This may lead to **increased landfilling and incineration** until a long-term solution is identified ▪ It has been estimated that **111 million metric tons of plastic waste will be stranded by 2030** as a result ▪ Risk of **plastic waste export moving to other developing countries** with sub-par environmental standards

SOURCE : ISWA, UN CoMTrade press search; Agricultural Plastic Recycling Conference "Science Advances" (June, 2018)

Plastics incineration adds to the Danish CO_2 emission, while only making up a small part of the total emissions



1 CO_2 emission balance assumed to correspond to average balance of mechanical recycling for PE, PP and PET, PVC, PS+other, and Pyrolisis
2 CO_2 balance calculated based on simplified approach with polyethylene as proxy for CO2 balance of all polymers
3 CO_{2e} describes different greenhouse gases according to the amount of CO2 that would have the equivalent global warming impact

SOURCE: Ecoprofiles Plastics Europe, EPA WARM model v14; Aage Vestergaard Larsen, "Plastens vej i Danmark" (2014); Danish Ministry of Energy, Utilities and Climate "Klimapolitisk Redegørelse 2017" (2017); McKinsey analysis

The EU Circular Economy package has significant consequences for Danish plastics consumption and waste management going forward

The EU Circular Economy package

- *Revision of 6 pieces of EU waste legislation*
  - **Waste Framework Directive**
  - Landfill Directive
  - **Packaging Directive**
  - 3 other directives on end-of-life vehicles, batteries and accumulators, and waste electrical and electronic equipment (WEEE)
- *A communication aiming to "close the loop" ("Action Plan for the Circular Economy – Closing the loop"), through 54 key actions incl.*
  - **A strategy on plastics in the circular economy**
  - **Measures in the Ecodesign Working Plan for 2015-2017**
- *A new Directive to tackle the 10 single-use plastic products most often found on Europe's beaches and seas*[1]
  - **Directive on Single-Use plastics**

Details on plastic-relevant elements

Waste Framework Directive
- A common EU target for recycling 65% of municipal waste by 2030
- Updated point of measuring recycling rates from waste collected to final waste recycled
- Prevention, reuse, and recycling clearly placed above landfilling and incineration

Packaging Directive
- Common recycling targets for all packaging is 65% in 2025 and 75% in 2030
- Common EU recycling targets for plastic packaging is 50% in 2025 and 55% in 2030
- Updated point of measuring recycling rates from packaging waste collected to final waste recycled

A strategy on plastics in the circular economy
- By 2030, all plastic packaging is re-useable or recyclable in cost-effective manner
- By 2030, sorting and recycling capacity has increased fourfold since 2015
- Highlights the need for specific measures, possibly a legislative instrument to reduce the impact of single-use plastics
- Need for restricting use of oxo-plastics and intentionally added microplastics in the EU
- EU-wide pledging campaign targeting industry and public authorities to boost recycled plastics content

Measures in the Ecodesign Working Plan for 2015-17
- No measures on plastics currently, but indications of extending the Ecodesign Directive to include measures on environmental impact beyond energy use, e.g., potential for reuse and recyclability

Directive on single-use plastics
- Ban on certain products with readily available alternatives, e.g., cutlery and straws
- Establishing Extended Producer Responsibility schemes to cover the costs of prevention of littering and waste management for food containers, packets and wrappers, drink containers and cups, tobacco products with filters, wet wipes, balloons, and lightweight plastic bags
- Establishes Extended Producer Responsibility on plastics packaging to be implemented by 2025 in Denmark
- Obligation of member states to collect 90% of single-use plastic bottles by 2029
- All new plastic bottles have to contain a minimum of 30% recycled content in 2030
- All plastic drink containers must have caps/lids attached to containers by 2024

1 Added to the Circular Economy package after its initial presentation in 2015 as part of the strategy on plastic

SOURCE: European Commission; EIB "The EIB Circular Economy Guide" (2018); EU Legislative Train Schedule

Extended Producer Responsibility(EPR) to be implemented across the EU for plastics packaging by 2025

EPR for plastics packaging

- Make **producers bear the costs and responsibility of negative environmental effects** of their products
- Can be applied to both industrial and household waste
- May imply covering the **costs of sorting and recycling plastics packaging as well as means for use reduction**
- 26 of the 28 EU member states have some form of EPR in place for packaging waste today

Most common approaches to EPR implementation

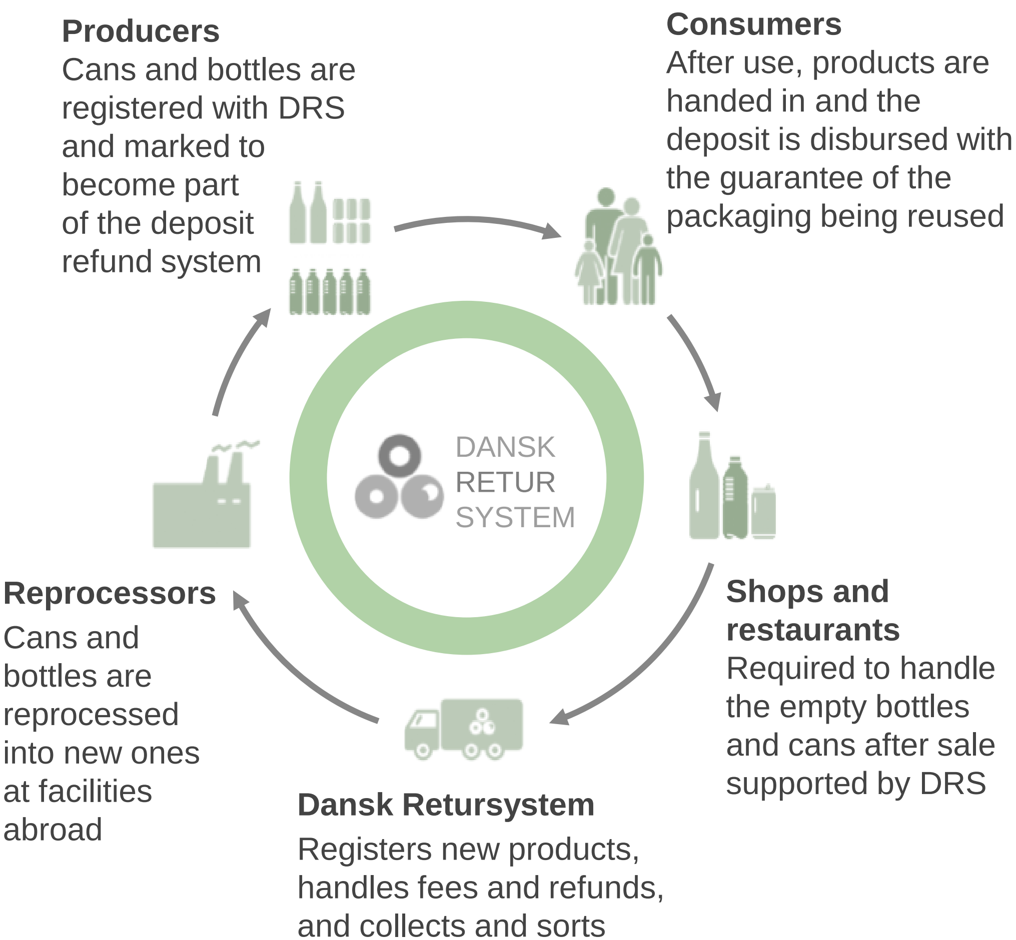
Product return require-ments	▪ Mandatory or voluntary recycling and collection targets for specific products or materials ▪ Responsibility to achieve these targets assigned to producers or retailers
Advanced disposal fees	▪ Fees on products at point of purchase, based on estimated costs of collection and treatment ▪ Finances end-of-life management of products
Deposit refund systems	▪ Surcharge on individual products at point of purchase (voluntary or legislative) ▪ Aims to increase return of used products rather than covering costs

The extent to which the EPR[1] system will be carried out by municipalities or private companies in Denmark is still to be decided. A final setup is not expected before January 2023

SOURCE: Institute for European Environmental Policy "EPR in the EU Plastics Strategy and the Circular Economy: A focus on plastic packaging" (2017); Material from DAKOFA seminar November 1st by Anne Harborg Larsen, Ministry of Environment and Food "Udvidet producentansvar på emballage" (2018)

The Danish deposit refund system is highly successful and could be applied to more areas as part of implementing EPR[1] in Denmark

Dansk Retursystem (DRS) has been highly successful in providing a closed loop for cans and bottles



16,000 tons of plastics are handled by DRS, **equal to ~5% of Danish plastics waste,** leaving a lot of potential for the refund system[2]

1.2 billion packaging products were returned in 2017

9 out of 10 single-use bottles or cans are returned

How can we utilize the well-functioning DRS to get equally impressive rates on other plastic waste streams?

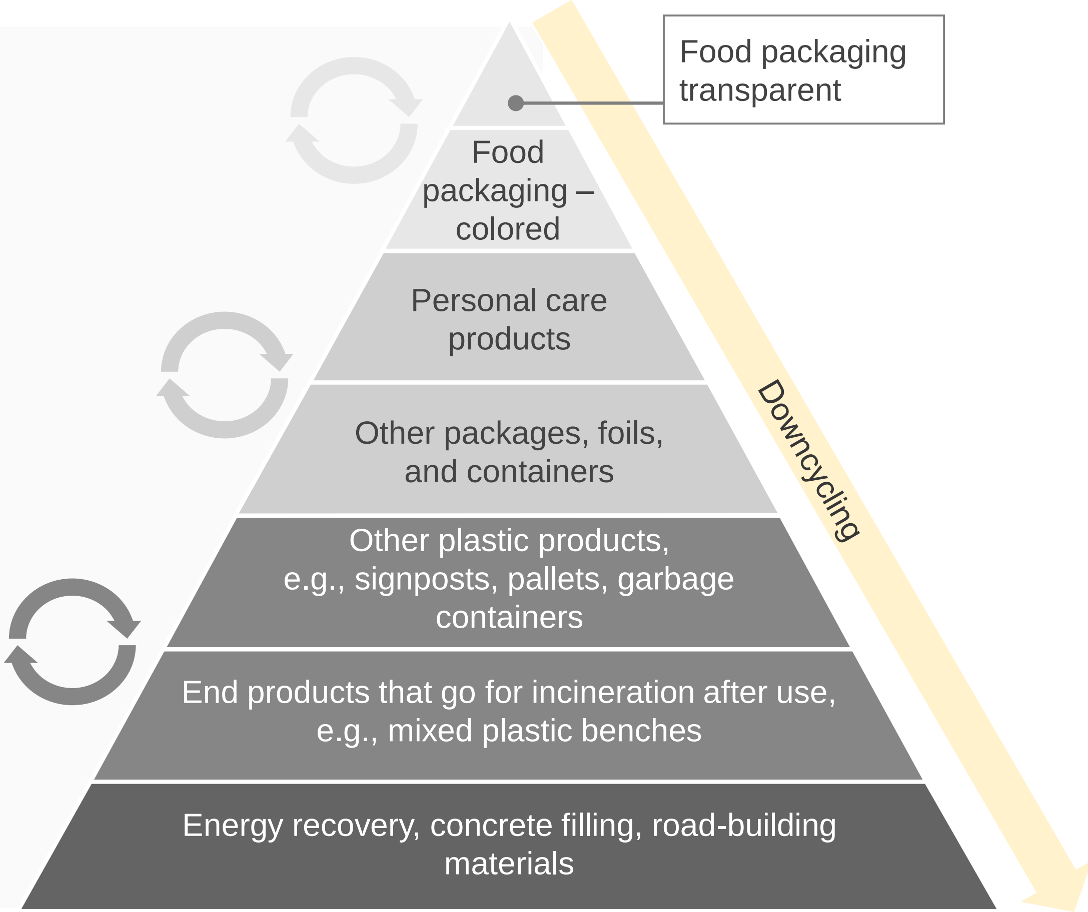
1 Extended Producer Responsibility
2 Juice bottles will be included in the deposit refund system by 2020, which is expected to add 6,000 tons of packaging to the system with majority being plastics

SOURCE: Dansk Retursystem website; Dansk Retursystem 2017 annual report; Ministry of Environment and Food

Conscious design choices facilitate increased reuse as well as recycling at the highest levels of the recycling hierarchy

Key design choices identified by the Forum for Circular Plastic Packaging

- The **main plastic types PET, PE, and PP** should be chosen for the packaging (including sub-components)
- Entire packaging should be composed of **1 material** (including sub-components)
- **Uncolored or clear plastics** are preferred
- **Monolayer** products prevent contamination of different types of plastic
- Seals, labels, and covers of other materials should be **removeable**
- **Maximum emptying and washing** should be enabled by design



Chemical recycling, pyrolysis, and feedstock recovery can **upcycle plastics** back through the value chain

SOURCE: Forum for Circular Plastic Packaging under the Danish Plastics Federation “Reuse and recycling of plastic packaging for private use” (2018)

Critical design choices to maintain value

- Can become new raw materials of high quality
- Can become new raw materials of lower quality
- Used for energy recovery or as filling in concrete

Design manual for plastic packaging for private use by the Danish Plastics Federation

Criteria / Quality	**Main component** (container, bucket, tray, bottle, foil)	**Sub-component** (closures, lid, inserts, seals)	**Decoration** (cover, print, glue and labels)	**Emptying** (by consumer)	**Examples**
High	Main component is in mono-material: PET, PE or PP Shall tolerate washing to a suitable degree	Sub-components are in the same material as the container or completely separated from the container in use	Cover and labels are entirely removed in use or simple dismantling There is no colored print on the container, only on the cover or labels	The packaging can easily be entirely emptied of residues after normal use. Only needs a light rinse with water (e.g., meat tray)	rPET can, for example, be used for new bottles, food trays, and food tubs rPE and rPP can, for example, become pipes, buckets or containers for non-food products
Moderate	Main component is of mono material: PET, PE or PP Or a minimum content of compatible material Main component is colored	Sub-components are not separated in use but are of materials that are compatible with the main component Sub-components are colored	Cover and labels are not separated from the container but are of the same material as the container or compatible There may be printing on the cover, labels or container	The packaging is only partly emptied of residues after normal use However, sub-components are easily separated so that the consumer can rinse the packaging (e.g., ketchup bottle)	rPET can, for example, be used for fibers for textiles Can also be used for fleece sweaters, blankets, etc. rPE and rPP can, for example, become pipes, buckets or containers for non-food products
Low	Main components consists of laminated materials that are not compatible (cf. Appendix A)	Sub-components contain incompatible plastic types, metal, paper, etc. Sub-components are not separated in use	Labels and cover are incompatible with the main components and cannot be removed. There is a great deal of ink printing on the packaging	The packaging cannot be emptied of residues after normal use (e.g., toothpaste tube)	Mixed plastic can, for example, be used for concrete filling, RDF, and plastic to diesel

SOURCE: Forum for Circular Plastic Packaging "Reuse and recycling of plastic packaging for private use" (2018)

Overview of plastic waste recovery technologies

	Applicability window	Output	Economic drivers	Technological challenges
Demand reduction	▪ Low to medium ▪ All plastics	▪ N/A	▪ Consumer behavior (GDP growth, urbanization, lifestyle preferences, etc. ▪ Substitution	▪ N/A
Refurbish- ment	▪ Low ▪ Durable goods	▪ Durable goods	▪ Industry standardization	▪ Plastics deterioration (limited lifetime)
Mechanical recycling	▪ Low to medium ▪ Estimate: 30-50% ▪ Mostly PET, polyolefins	▪ Plastics	▪ Plastics price ▪ Waste acquisition cost	▪ Clean collection and sorting (pure plastic waste streams) ▪ Contaminations ▪ Downcycling
Monomer	▪ Low (<10%) ▪ Limited to polyesters and polyamides (condensates)	▪ Monomer (plastics)	▪ Monomer price ▪ Waste acquisition cost	▪ Clean collection ▪ Process sensitivity to impurities
Feedstock recycling/ pyrolysis	▪ Medium to high ▪ Most and mixed plastics (excl. Polystyrene, PVC)	▪ Fuel ▪ Oil/naphtha ▪ Gas ▪ Wax	▪ Oil/fuel price	▪ Integration with downstream users ▪ Process costs and CapEx investments ▪ Disposal of byproducts
Energy recovery/ incineration	▪ All plastics ▪ Mixed waste streams	▪ Energy ▪ Electricity	▪ Oil/fuel price ▪ Landfill cost ▪ Waste acquisition cost	▪ Integration with broader MSW stream ▪ Legal emissions requirements (GHG, toxicity)

SOURCE: McKinsey analysis

An integrated portfolio of technologies can be composed out of main 4 elements with high interdependence

	Virgin plastic technology	Sorting	Recycling technology	Applications
Description	▪ Plastic technology to **enable efficient recycling**, while maintaining material benefits ▪ Technology levers – Resins technology (e.g., multi modal resins) – Additives (e.g., recoverable) – Processing technology	▪ Sorting technology to **enable increasing yields of recycling** processes ▪ Technology levers – Automation – Improved material separation – Increased throughput	▪ New technologies are required to **enable higher quality of recycled materials,** including monomer and feedstock recycling for lower value plastics ▪ Non-mechanical recycling technologies required to **deal with material degradation** through multiple cycles	▪ Application technology for **value-added products from recycled plastics** ▪ Applications to be designed that have a high share of recycled content, while not be discounted vs. virgin materials
Examples	▪ **Mono material PE laminate** solution for flexible packaging materials, designed by industry consortium	▪ Molded or micro-engraved diffraction gratings for optical sorting ▪ Near infrared optical sorting ▪ Additive-aided optical sorting (tracers)	▪ **Monomer and feedstock recycling** enables virgin quality with reduced CO_2 emission compared to feedstock recycling	▪ **Food contact approval** requires high quality and purity of material

SOURCE: Borealis website; McKinsey analysis