MSG Sustainable Strategies

# PLASTIC RECYCLING

## Een internationale vergelijking

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ChemistryNL

# INHOUD

# INLEIDING

Dit onderzoek bouwt voort op de uitkomsten van een analyse van het innovatieportfolio van de chemische sector. In die studie zijn alle technologieën in kaart gebracht die kunnen bijdragen aan de klimaatdoelen en is zichtbaar gemaakt welke R&D-inspanningen in Nederland geleverd moeten worden.

De resultaten van deze analyse zijn beschikbaar via: https://chemistrynl.com/theme/climate/

De chemiesector opereert internationaal en is daarom ook geïnteresseerd in de ontwikkeling van technologieën in andere landen. Dit is aanleiding geweest voor de huidige studie. Men heeft er voor gekozen om zich daarbij te concentreren op innovatieve technologieën voor plastic recycling.

**Onderzoeksvraag**

Wat zijn de overeenkomsten en verschillen in het afval- en innovatiebeleid op het gebied van plastic recycling voor China, VS, Japan en Duitsland in vergelijking tot Nederland?

Dit slidedeck vat de resultaten samen voor drie deelvragen:

1. Welke drivers en dynamiek bepalen het afval- en innovatiebeleid?
2. Wat zijn de uitdagingen in het afvalbeleid?
3. Hoe stimuleren lokale en landelijke overheden de oplossingsrichtingen?

Per land is aanvullend informatie beschikbaar over:

- Waste management
- Policies
- Innovation landscape

Deze landenbijlagen zijn beschikbaar via: link

# AANPAK

Op basis van openbare literatuur en in samenwerking met de ambassade zijn feiten en cijfers over plastic recycling bijeengebracht.

Per land is een dossier gemaakt, dat gebruikt is als input voor een innovatiemissie van het Topteam Chemie.

In overleg met EZK en de TKI Chemie is bepaald wat de belangrijkste deelvragen zijn.

De resultaten van de deskresearch en de resultaten van de missies zijn gezamenlijk geanalyseerd om op hoofdlijnen antwoord te geven op de drie deelvragen.

De resultaten van de landenvergelijking is gedeeld met de ambassades in de betreffende landen voor commentaar en aanvulling.

Nota bene

1. *Voor de VS is de missie geannuleerd vanwege Corona en zijn de resultaten van dit onderzoek uitsluitend gebaseerd op openbare literatuur.*

2. *Dit onderzoek is uitgevoerd voor dat de COVID-19 pandemie uitbrak. Door de pandemie is de afvalproblematiek in veel landen verergerd. Door lock-downs zijn consumenten meer online gaan kopen, wat meer verpakkingsafval genereert en uit hygiëneoverwegingen is het gebruik van wegwerpproducten toegenomen. Ondertussen wordt inzameling, scheiding en export van afval door COVID-19-maatregelen bemoeilijkt.*

# VERGELIJKING

## 1. Welke drivers en dynamiek bepalen het afval- en innovatiebeleid?

| Nederland | Duitsland | China | Japan | Verenigde Staten |
|---|---|---|---|---|
| Nationaal: klimaatakkoord, grondstoffenakkoord. Importafhankelijkheid m.b.t. grondstoffen.<br><br>Gebrek aan ruimte voor stortplaatsen.<br><br>Behoud van werkgelegenheid; ontwikkeling hoogkwalitatieve recycling als kans voor de kenniseconomie.<br><br>Sterke, innovatieve chemische industrie.<br><br>Reductie GHG en verbetering luchtkwaliteit e.a. milieu-indicatoren | Individuele staten (Länder) ontwikkelen programma's binnen nationaal raamwerk.<br><br>Importafhankelijkheid m.b.t. grondstoffen.<br><br>Dringend behoefte aan CO2-arme energie met back-up-functie voor wind en zon.<br><br>Behoud van werkgelegenheid en economische groei.<br><br>Ontkoppeling van economische groei en grondstoffenverbruik.<br><br>Sterke chemische industrie.<br>Reductie GHG en verbetering luchtkwaliteit e.a. milieu-indicatoren | Nationale 5-jarenplannen om circulaire economie te bevorderen<br><br>Grondstoffenschaarste (vooral m.b.t. metalen, olie en vruchtbare grond) als mogelijke rem op economische groei.<br><br>Toegenomen welvaart en verstedelijking leidt tot sterke stijging van (plastic) afval.<br>Behoud van politieke stabiliteit.<br><br>Sterke inzet op kunstmatige intelligentie als kans voor innovatie en ontwikkeling.<br>Reductie vervuiling van vruchtbare grond, water en lucht. | Importafhankelijkheid m.b.t. grondstoffen, incl. fossiele brandstoffen.<br><br>Beperkte beschikbaarheid van hernieuwbare energie (bv. wind).<br><br>Gebrek aan ruimte voor stortplaatsen.<br><br>Wegvallen export naar China geeft meer investeringen in binnenlandse recycling.<br><br>Behoud van werkgelegenheid en nationale zelfstandigheid.<br><br>Ontkoppeling van economische groei en grondstoffenverbruik.<br>Sterke chemische industrie.<br><br>Circulaire economie past bij traditionele Japanse waarden: eenvoud & 'zonde om te verspillen'.<br><br>De private sector is de belangrijkste investeerder in R&D.<br>De chemische industrie werkt actief samen met academia | Veel beleid en wetgeving op niveau staten. Grote verschillen per staat, afhankelijk van politieke kleur.<br><br>Weerstand tegen nieuwe stortplaatsen & inperking van mogelijkheden om afval te exporteren.<br><br>Groei potentieel van recycling sector.<br><br>Sterke fossiele industrie.<br><br>Publieke zorg over plastic in de zee.<br><br>Voor steden/staten: oplopende kosten van afval verwerking. |

# VERGELIJKING

## 2. Wat zijn de uitdagingen in het afvalbeleid?

| Nederland | Duitsland | China | Japan | Verenigde Staten |
|---|---|---|---|---|
| Mechanische recycling loopt tegen grenzen aan.<br><br>Vervuiling afvalstromen veroorzaakt kwaliteitsverlies bij recycling.<br><br>Verwerking GHG-emissies recycling vs. verbranding met energieopwekking in nationale klimaatcijfers.<br><br>Kosten gerecyclede producten en reparaties zijn hoger dan nieuwe producten.<br><br>Belangen van en effectiviteit van bestaande afvalverwerkings-systeem staat mogelijk hergebruik en afval-preventie in de weg. | Grootste hoeveelheid afvalproductie en plastic-consumptie per capita van Europa.<br><br>Vervuiling afvalstromen veroorzaakt kwaliteitsverlies bij recycling.<br><br>Verschillen in economische belangen en cultuur per deelstaat.<br><br>Kosten gerecyclede producten en reparaties zijn hoger dan nieuwe producten.<br><br>Belangen van en effectiviteit van bestaande afvalverwerkings-systeem staat mogelijk hergebruik en afval-preventie in de weg. | Toenemende hoeveelheid afvalproductie per capita, met name aan plastic. Belangrijke rol e-commerce<br><br>Onvoldoende scheiding van afvalstromen, lage kwaliteit plastic en chemische toevoegingen bemoeilijken recycling.<br><br>Transitie van informele afvalinzameling en recycling naar formele sector, die voldoet aan acceptabele milieunormen.<br><br>Slechte afstemming en gebrek aan samenwerking tussen verschillende overheidsinstanties. | Verbeterd gebruik van afval via energy recovery en/of chemische recycling.<br><br>Transparantie in afvalketen, met name m.b.t. hoe de verwerking plaatsvindt.<br><br>Verwerking van plastic afval binnen de eigen landsgrenzen.<br><br>Lokale afvalverwerking staat schaalvergroting in de weg. Belemmering voor innovatie.<br><br>Circulaire concept is goed ontwikkeld, maar spelers focussen sterk op eigen rol. Integratie vormt een uitdaging.<br><br>Overheidsbeleid is reactief en worstelt met stimulering industrie voor R&D richting circulaire economie.<br><br>Sterke nationale oriëntatie geeft fundamentele dilemma's bij vinden van oplossingen. | Grootste hoeveelheid afvalproductie per capita in de wereld.<br><br>Lage olieprijzen zorgen voor lage prijzen van virgin plastic.<br><br>Afvalinzameling en –scheiding hapert. Staten hebben verschillende regels voor scheiding en inzameling, wat leidt tot verwarring. Inzameling gebeurt vaak door verschillende bedrijven, met matige coördinatie.<br><br>Tot importbeperkingen van China was de recycling sector vooral gericht op afval-export. Eigen recycling faciliteiten zijn schaars. |

# VERGELIJKING

## 3. Hoe stimuleren lokale en landelijke overheden de oplossingsrichtingen?

| Nederland | Duitsland | China | Japan | Verenigde Staten |
|---|---|---|---|---|
| Uitbreiding statiegeld op plastic flessen.<br>Verminderen plastic verpakkingen e.a. 'single use plastic'.<br>Convenanten.<br><br>Voorlichting en communicatie om recycling te bevorderen. Stimulering hergebruik & reparatie.<br><br>Duurzaam inkopen door de overheid.<br><br>Subsidies voor onderzoek en verbetering samenwerking binnen het bedrijfsleven en met de overheid. | Investeren in efficiëntere productie processen om behoefte aan grondstoffen te verminderen.<br><br>Educatie en voorlichting bij het publiek om plastic gebruik te verminderen.<br><br>Gekozen oplossingsrichtingen blijven erg op efficiency hangen en blijven weg bij fundamentele herziening.<br><br>Relatief grote budgetten voor onderzoek en innovatie: zowel in fundamenteel als toegepast onderzoek en ook in innovatieprogramma's voor het MKB (oa regelingen gericht op efficiënt gebruik van energie en grondstoffen). | Waste collection en recycling formaliseren en reguleren. Aanpak corruptie.<br><br>Afvalheffing voor huishoudens.<br><br>Investeren in artificial Intelligence oplossingen voor afvalscheiding.<br><br>Recycle doelen stellen voor bedrijven.<br><br>'Resource tax': belasting op extractie van grondstoffen en gebruik van grond voor niet-landbouw-doeleinden. | Intensieve monitoring van en regelmatige rapportage over 'material flows'.<br><br>Publiek-private samenwerking met name om 'reduce' and 'reuse' te bevorderen.<br>Extended Producer Responsibility voor bijna alle consumentenproducten.<br><br>Verbod op export van afval zodat het lokaal als grondstof gebruikt kan worden. | Verminderen van afval productie door verbod op single use plastics zoals tasjes, rietjes, etc. in sommige staten.<br><br>Voorlichting en communicatie om recycling te bevorderen en vervuiling van afvalsstromen te verminderen.<br><br>Duurzaam inkopen door overheid (Californië).<br>Keurmerk 'made in California'.<br>Fondsen en advies aan circulaire bedrijven (Californië). |

# OBSERVATIES
## Uitdagingen

De vijf landen hebben doorgaans hetzelfde doel met plastic recycling: beter gebruik van grondstoffen. De ideeën om dat doel te bereiken verschillen echter, evenals de uitdagingen en drijfveren.

Japan, Duitsland en Nederland hebben een betrouwbaar afvalinzamelingssysteem en een verwerkende industrie die zich in de afgelopen decennia heeft ontwikkeld. Wat deze landen gemeen hebben, is een gebrek aan grondstoffen en een gebrek aan beschikbare ruimte. Dit maakte dat afval storten geen geschikte optie is en bracht deze landen ertoe te investeren in oplossingen zoals afvalverbranding en recycling. Dit wordt versterkt door sterke nationale wetten inzake milieubescherming.

China en de VS delen deze uitdagingen niet. Hun afvalverwerkings- en recyclingsystemen zijn minder ontwikkeld. Beide landen zijn nog steeds sterk afhankelijk van het storten van afval. China wordt nu geconfronteerd met de gevolgen van een snelgroeiende economie, maar een onderontwikkeld afvalverwerkingssysteem. De informele sector speelt een belangrijke rol bij de inzameling en recycling van afval. Het land begint nu een inhaalslag te maken door deze industrie te formaliseren en erin te investeren.

In de VS beweegt de federale overheid zich in een andere richting en verzwakt of schaft ze de milieubeschermingswetten af. Sommige staten investeren in recycling en afvalverwerking, maar nationale coördinatie ontbreekt. De VS hebben sterk geleden onder het Chinese importverbod van gebruikte kunststoffen, waardoor de recyclingsector onder grote druk kwam te staan.

# OBSERVATIES
## Drivers

Japan en Duitsland hebben een specifiek belang bij het verhogen van de productiviteit van hulpbronnen om het economische concurrentievermogen te vergroten. Dit is niet gericht op het verwerken van afval, maar op het gebruik van minder grondstoffen en het creëren van economische groei. Dit is niet alleen goed voor het milieu, maar het gebruik van minder grondstoffen is ook goedkoper, waardoor ze een comparatief voordeel hebben.

Een probleem voor Japan is het gebrek aan energiebronnen. Afval naar energie wordt gezien als een vorm van recycling, terwijl andere landen het zien als een laagwaardige oplossing.

Nederland wil koploper worden in (chemische) recycling en daarmee banen in de industrie en banen in de kenniseconomie realiseren. Deze technologieën kunnen ook worden geëxporteerd, waardoor er nog een economische kans ontstaat.

In de VS zijn er grote verschillen tussen staten. Het (lokale) beleid wordt sterk bepaald door de mogelijkheden om verontreinigingen van stortplaatsen te beheersen, ruimte voor stortplaatsen en toenemende kosten voor afvalverwerking en recycling.

# OBSERVATIES

## Chemische recycling als oplossingsrichting

Van alle landen in deze benchmark is Nederland het enige land dat duidelijke doelstellingen heeft geformuleerd over hoe chemische recycling onderdeel gaat worden van de afvalverwerkende industrie. De andere landen tonen interesse in de techniek, maar er is geen specifiek beleid uitgestippeld.

Een gelijkenis die is gevonden is dat het bedrijfsleven een leidende rol speelt bij de ontwikkeling van chemische recycling en voorloopt op het overheidsbeleid. Landen ondersteunen innovatie op het gebied van afvalbeheer die zou kunnen worden gebruikt, maar die niet specifiek is gekoppeld aan chemische recycling.

Geen van de landen heeft op grote schaal chemische recycling van plastic toegepast. Er zijn proefprojecten die de mogelijkheden van chemische recycling demonstreren, met name in Japan en de VS. Duitsland, China en Nederland kennen enkele pilotprojecten.

De stap van proefprojecten naar grootschalige economisch haalbare recyclinginstallaties is groot. Deze stap wordt gecombineerd met hoge investeringen op lange termijn. Om te slagen moeten de chemische industrie, de afvalverwerkende industrie en de overheid samenwerken. De belangrijkste randvoorwaarde daarvoor is dat de businesscase van gerecyclede kunststoffen moet worden verbeterd.

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# RECYCLING IN CHINA

waste management, policies and innovation

# Contents



**Cover photos**
Landfill in the outskirts of Beijing. Photo: Liwen Chen
Waste incinerator in the outskirts of Beijing. Photo credit: Liwen Chen
Informal collectors collect valuable recyclable material for a living. Photo: Judy Li
Residents use a waste sorting bin of Xiaohuanggou in a community in Shenzhen. (Photo courtesy of Xiaohuanggou)

# 1 Introduction

The Ministry of Economic Affairs & Climate Policy and the Topsector Chemistry have visited China in March 2019. The goals of the mission were: learning from each other and exploring opportunities for Sino-Dutch co-operation for recycling.

As a preparation for the mission, this fact sheet was prepared. It summarizes the available knowledge on Chinese waste management, waste and recycling policies, and the innovation landscape. Most information is on the national level. Where available, information on Beijing and Shanghai has been included.

The focus lies on the policies for waste and recycling with reference to the wider areas of resource efficiency and circular economy where appropriate. The fact finding is limited to building materials and plastics.

The information in this document is based on desk research of public documents (see 6.1) complemented with input from stakeholders and experts (see 6.2). The information that was gathered, typically is coarse-grained and not always up-to-date, and should be considered as a guide for further fact finding.

# 2 How to read the document

The information in this fact sheet is divided in three broad themes: general information on waste management in China (Chapter 3), an overview of the relevant policies (Chapter 4) and information on the innovation landscape (Chapter 5). The latter ranges from the universities and their research programs to the economic actors and their investments in technology. These chapters contain the information in summarized format and refer to specific sections in the Annex (Chapter 6) for a more complete overview.

# 3 Waste management in China

## 3.1 Facts and figures

**Waste generation has been growing in line with economic activity and material consumption, but the growth rate has significantly decreased in recent years.**
The waste generation intensity per unit of industrial value added, declined by almost 60% during the 1990s and remained stable throughout the 2000s. In 2014, the waste generation intensity per unit of GDP (2010 prices) was 600 kg per USD1000. (OECD, 2018)

*Table 1. Selected data on consumption waste handling (2017). Source: China Bureau of Notional Statistics, table 8-17 & 8-14*

| | China | Beijing | Shanghai |
|---|---|---|---|
| **Consumption waste (1.000 tons)** | 215.209 | 9.248 | 7.431 |
| **Total number of facilities** | 1.013 | 24 | 15 |
| **Landfill facilities** | 654 | 13 | 4 |
| **Incineration facilities** | 286 | 5 | 9 |
| **Other facilities** | 73 | 6 | 2 |
| **Destination** | | | |
| **Fraction landfilled** | 57% | 47% | 50% |
| **Fraction incinerated** | 40% | 35% | 49% |
| **Fraction other** | 3% | 17% | 2% |
| | | | |
| **Industrial solid waste** | | | |
| **Produced (1.000 tons)** | 3.315.920 | 6.300 | 16.300 |
| **Disposed (1.000 tons)** | 797.980 | 1.640 | 1.000 |

**Though landfilling is still the most common form of waste management (table 1), an increasing share of waste is being incinerated, recovered for recycling or reuse.**
The fraction of waste that is incinerated, more than doubled from 15% to 33% between 2006 and 2014 (Li, 2016). New policies specify that the nationwide average for incineration of consumption waste reach 50 percent by 2020.

55% of common industrial solid waste generated in 2017 was "utilized" (National Bureau of Statistics), compared to about 45% in 2000 and 30% in 1990. (OECD, 2018)

**Construction & Demolition waste (CDW) accounts for 30% to 40% of the total amount of waste in China.**
The volume has reached 2 billion tonnes per year and is increasing by 10% annually. (Ellen MacArthur Foundation, 2018). Major wasted building materials encompass concrete (60%), mortar (14-16%), brick (8-11%), metal (5%) and other mixed building materials. (Hongping Yuan, 2017). More than half of CDW is being generated in East China (Lina Zheng et al. 2017). The recycling volume of concrete and asphalt in Shanghai has increased from 100 megatons to 400 megatons per year.

**Only 5% of CDW is being recycled**
Most recycled CDW is reused for road gravel rather than reentering the construction industry. For comparison: The CDW recycling rate in Japan is 95% and 94% in the Netherlands. (Ellen MacArthur Foundation, 2018)

**In 2010 China contributed an estimated 1.50-3.53 million tonnes per year of mismanaged plastic wastes and is the number one contributor of the plastic inputs of the plastic soup (Crippa, 2019).**
The scale of the Chinese waste flows is enormous. For example, every 10,000 $m^2$ of demolished buildings generates 600 tons of construction waste - an important statistic given the planned 30 billion $m^2$ of newly built buildings between now and the end of 2020. And China's production of plastics has doubled between 2010 and 2017 to a level that is good for a quarter of global production.

## 3.2 Waste management system

**China's current waste management system has two parts: Government-run and private/informal (**Morris & Schonberg, 2017)**:**
The government-run system includes large contracted companies that manage collection, incineration, landfill disposal, and composting.

A significant part of the waste management system includes private businesses and involves millions of "informal" workers who collect, store, and sell waste to recycling plants, factories, and reprocessing centers, thereby diverting waste from landfill in the process. The private, informal sector rarely works with the formal sector and face increasing pressure to close private facilities as the system formalizes and environmental regulations tighten. As an example, the informal sector includes up to an estimated 200,000 active waste pickers in Beijing alone (World Bank). Thus, in China, most recycling takes place "under the radar" and without or outside of the regulations.

Since Operation Sword dramatically reduced the import of foreign waste, large parts of the private, informal collection and recycling infrastructure has entered a crisis. For the future, it seems that China is primarily focusing on the development of AI solutions matching the government-run, large scale waste-management structure.

# 4 Policies

## 4.1 Policy drivers and priorities

**Since 2008, Chinese policies promote a Circular Economy (see 5.2. for an overview of policy development).[*] The key driver for this policy is resource scarcity as a potential limitation to economic growth.**
Especially *rare earth metals* are seen as a scarce resource that therefore has to be recovered and recycled, e.g. from electronic waste and batteries, but also *fertile land*, which is a key resource needed to feed the population. Pollution, land use and degradation of fertile land resulting from illegal dumping of waste, landfilling and poorly regulated recycling activities are growing problems. Landfill capacity is being exceeded, especially as a result of the growing amount of construction and demolition waste (CDW), which leads to illegal dumping of waste. (Jin,2017). Large-scale, low-tech recycling of plastics by the private sector has led to extensive pollution of soil and surface water in certain regions, e.g. Guangdong.

Recycling is a high priority in China, not only from a climate point of view, but also in light of access to raw material and resource efficiency.

**The key priorities for Chinas Circular Economy policies are**:

- Recycling of electrical and electronic products, automobiles, rubber, metal, and batteries, incl. the recovery of rare earth metals;
- Development and manufacturing of recyclable construction materials;
- Recycling of construction and demolition waste;
- Manufacturing of recycling equipment for plastic, electrical appliances, rubber, batteries and textile;
- Development of unconventional water treatment and recycling equipment.

These priorities are being pursued through embedding circular economy principles (reduce, reuse and recycle) into all production processes within companies – e.g. by widening the product range of a company to enable the use of internal waste streams -; creating circular systems of industry, agriculture and services (industrial parks making use of resources available in the region), stimulating growth of the recycling industry and guiding citizens towards smart, healthy and safe consumption ('circular values'). Implementation takes place at company level, at regional levels (regions and cities) and at the level of industrial parks.

[*] From the 13th Five Year Plan: **"***We will implement a plan for guiding circular development, encourage the circular use of resources between production and society, and accelerate efforts to recycle resources from refuse. We will make coordinated plans for industrial layouts based on material flow and industrial linkage, encourage industrial parks to adopt a more circular operational flow, establish hybrid industry-agriculture circular economy demonstration zones, and promote the coupled growth of enterprises, industrial parks, and industries. We will facilitate the recovery and utilization of mineral resources from urban waste, ensure that resources from industrial solid waste and other types of mass refuse are recycled and reused, accelerate the establishment of systems for the recycling or safe disposal of urban kitchen waste, construction refuse, and textile waste, and develop remanufacturing in line with standards. We will put into effect an extended producer responsibility system. We will improve recycling networks for renewable resources and strengthen coordination between the recycling of sorted household waste and the recycling of renewable resources."*

## 4.2 Overview of policies

**The concept of a Circular Economy was officially introduced into Chinese policies already in 1998 and has since then been further researched and developed. In 2008 the decision to proceed Chinas development towards a circular economy was cemented in the Circular Economy Promotion Law laying the legal basis for further regulations and policies.**

In Annex 7.3, we provide a chronological overview of key policy developments and documents regarding recycling and the circular economy from 2008 and onwards.

Policies related to recycling and waste management are mostly developed by the following government bodies:

- The State Council
- National Development and Reform Commission (NDRC)
- Ministry of Education (MoE)
- Ministry of Housing and Urban-Rural Development (MoHURD)
- Ministry of Environmental Protection (MEP)

China’s environmental policies have long been characterized by a broad use of command-and-control measures, but in the past 10 to 15 years, the use of environmentally related taxes and other financial instruments has been growing. In many provinces a resource tax now applies to the extraction of natural resources (metal ores, fossil energy, industrial minerals) and to the non-agricultural use of farmland and by 2020 households across the nation will, for the first time, have to pay for garbage disposal.

There is little mutual contact and cooperation between ministries; government agencies act strictly separately from each other.

**National and local policies regarding recycling**

National:

- In the most recent Five-Year Plan, the circular use of asphalt and concrete has become a top priority.
- In China, tax breaks are provided to companies that recycle construction waste, but opinions are not unanimous about the quality / safety of the recycled construction material.
- In China, a single-use plastic bag ban has been in place since June 2008.
  There is little legislation in China regarding the separation of construction waste.

Shanghai:

- In Shanghai, all asphalt waste must be collected and processed; dumping is not allowed. If a construction project does not meet this requirement, the building permit will be withdrawn.
- 15% of the base layers of asphalt roads must consist of RAP, reclaimed asphalt. In some smaller roads this percentage is now 100%. Over three years, this percentage should also cover at least 30% in larger roads.

Project "Zero Waste Cities":

The concept of Circular Economy has different interpretations in different Chinese cities. To counter this, the Chinese government has created "Zero Waste Cities", a national program at the local level. The program rewards cities according to their processing volume of waste streams. China hopes that in the near future, partly due to this project, 90% of all 'solid waste' will be recycled and processed into re-usable materials.

# 5 Innovation landscape

An overview of recycling technologies is provided in Annex 7.5.

## 5.1 International aspects

**The state of plastic recycling technology is difficult to assess in detail. Based on expert opinion, China is at least as far and maybe even further advanced in plastic recycling technology.**

Differences in adopted technologies are not so much the consequence of a lack of R&D, but more a result of policy choices, the availability of (high-quality) waste streams, and the markets for recycled material.

**For both asphalt and concrete recycling, the EU lies ahead of China.**

Both asphalt and concrete recycling in The Netherlands are at commercial scale. The further developments lie in lowering the energy usage an in the processing of more types of rest streams with different additives.

**International exchange of knowledge occurs bilaterally between universities and knowledge institutes, and via direct foreign investments.**

Universities exchange knowledge through exchange of PhDs and international conferences. TNO has a collaboration in the Guandong Province. A number of waste companies in the Netherlands are part of a Chinese holding, e.g. AVR. Innovation and engineering are readily transferred to China.

## 5.2 Universities

**China is the biggest scientific contributor to the field of recycling of building materials.**

China takes up about a quarter of the world's scientific publication that contain building materials recycling related terms in abstract, title or user provided keywords. Especially recycling of concrete is a hot topic, with Recycled Aggregate Concrete and similar keywords being 2 times overrepresented. Asphalts are slightly underrepresented.

**Universities most active in research of building materials are: Tongji University (Shanghai), Hong Kong Polytechnical University, South East University (Nanjing), Beijing University of Technology, and Shenzhen University.**

Tongji University is involved in the recycling pilot project with CABR. Therefore, it is no surprise that it is also prominent in terms of research. The focus is mostly on recycled aggregate concretes.

Hong Kong Polytechnical University is the highest ranked within Civil Engineering within China (10 in the world) and has a strong collaboration with TU Delft in the area. Compared to Tongji University, the focus is more on new building materials, making them sustainable and durable, and doing life cycle analyses.

South East University is mostly focusing on asphalts. This involves reclaimed pavements and their performance, but also rejuvenation, such as Hot In-Place Recycling and Cold In-Place Recycling. Research takes place to find optimal rejuvenation agents and rejuvenation methods.

Beijing University of Technology is also focused on concretes. It is smaller than Tongji University, and compared to Tongji, there is more focus on High Strength Recycled Concrete and metal bar reinforced concrete, with research taking place on bearing strength and load capacities of these kind of concretes.

Shenzhen University has a strong focus on construction management and reduction/recycling of CDW. There used to be a 'Smart Cities Research Institute' but this seems to have been replaced by an Urban Planning & Design Institute and the Research Institute of Construction Management, both of them served by several laboratories also serving projects in the Guangdong province.

**Compared to recycling of concretes, recycling of plastic is less of a scientific theme in China. It is the biggest worldwide contributor in the development of underlying technologies.**
China develops technologies such as depolymerization, pyrolysis, solvolysis, gasification, magnetic separation and image recognition on conveyer belts. However, these technologies are used mostly in a variety of different applications, such as paper making and production of chemical building blocks. For use of these technologies for plastic recycling, the USA and Europe are more prominent.

**The two most important universities for plastic recycling are Tsinghua University (Beijing) and Shanghai Jiaotong University.**
At Tsinghua University, at a variety of departments, research is done on retrieval of plastics from municipal waste, behavior of micro- and nanoplastics, as well as e-waste. Pyrolysis is the technique most often used, sometimes as co-pyrolysis with organic waste such as potato starch, or with microalgae.

At Shanghai Jiaotong, similar research is being done, sometimes in collaboration with Tsinghua. Next to that, at the department of polymer science and engineering, there is a focus on recycling rubber from old tires, through light pyrolysis.

Universities that could be of further interest are: Zhejiang University (Hangzhou) with research towards Co-pyrolysis; the school of Energy and Environment, Southeast University (Nanjing) with a program towards MSW pyrolysis and gasification as part of the 973 program; The Insititute of Process Engineering, Chinese Academy of Sciences (Beijing) which contains a research center of circular economy technology and the Nanjing/Tongji University (Shanghai) where the state key laboratory of pollution control and resource reuse is active in fields as advanced treatment of municipal wastewater, industrial wastewater management and reuse, household refuse disposal and reuse, environment restoration and watershed pollution control.

## 5.3 Research programs

**At National level, Chinese research is funded through g**eneral science and technology programs
The following programs are not specific for waste & recycling, and date from 2012 or earlier. A short description is provided in Annex 7.6.

- National High-tech R&D Program (863 Program)
- National Key Technologies R&D Program
- National Basic Research Program of China

- National Science and Technology Infrastructure Program
- Environment Building for S&T Industries
- Mega-projects of Science Research for the 10th Five-year Plan

## 5.4 Companies

**China has about 50 publicly traded waste-management companies, more than a dozen with market values exceeding $1 billion, led by Tus-Sound, GEM Co. and Dynagreen.**
A selection of waste and recycling companies is listed in Annex 6.4. Basic information on the a few selected companies is provided below:

SUS Environment (www.shsus.cn), is the leading waste-2-energy company in China.

Tus-Sound Environment Resources Co. provides environmental engineering designing, waste recycling, environmental resources development, and other services. Main businesses include solid waste treatment system integration, R&D, environmental protection equipment and sanitation vehicles, urban and rural sanitation integration, renewable resources recovery and utilization, municipal water supply to specific regions and investment operation services of sewage treatment project.

GEM Co. GEM recycles over 3 million tons of waste resources annually, especially WEEE waste (15% of total WEEE recycling in China) with a focus on recovery of rare earth metals. Also, some plastics recycling takes place, but this is not the core business.

Dynagreen Environment Protection Group. Collects, stores and incinerates garbage. Sixth nationally in incineration volume. State-controlled fund is the company's biggest shareholder. No recycling takes place, only incineration of waste with energy recovery.

China Strategic Alliance of Technological Innovations for the Construction Waste Recycling Industry

Circular Economy Association of China

GreenUnited Technologies

## 5.5 Investments in waste management

**The waste disposal and recycling market is large and growing rapidly**
Fixed-asset investment in recycling and disposal of waste rose 23 percent from 2016 to 2017, to 169 billion yuan. About 100 billion yuan ($14.6 billion) of sanitation and classification contracts were signed in the first half of 2018.

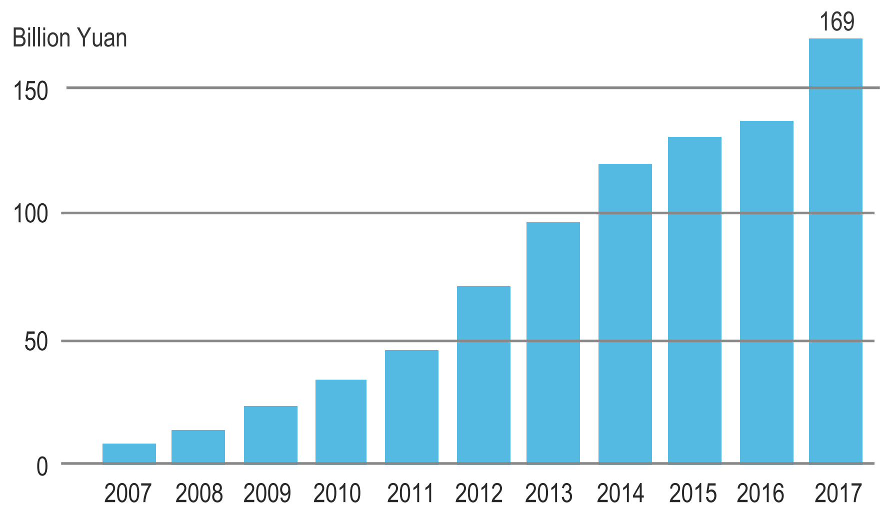

*Figure 1.China fixed asset Investment in recycling/waste disposal (Billion Yuan). Source: National Bureau of Statistics China*

Investments especially focus on:

- **Incineration with energy recovery (Energy from Waste):** EfW capacity in China has grown with 26% per year over the past five years and China now has the largest installed EfW capacity in the world (7.3GW).
- **Waste to fuel techniques (pyrolysis):** There is a huge amount of Chinese companies specialized in (equipment for) pyrolysis of especially tires and - upcoming – biomass into fuel oil.
- **Improved waste collection and recycling methods:** In contrast to Europe, China's recycling industry is more developed than its system for waste collection. The recycling industry - primarily based on relatively small family-owned enterprises, performing mechanical recycling - has largely developed on the basis of waste imports rather than local waste. For improved waste collection and sorting the focus seems to be on high-tech solutions – intelligent waste bins, mobile phone apps rewarding citizens for good behavior, post-collection-sorting of waste using AI– rather than on formalizing the existing informal system of waste collection. Also, investments are being made in more environmentally friendly and higher quality forms of recycling.

## 5.6 Demos and pilots

**A list of demos and pilots was compiled (Annex 7.7). Those in Beijing and Shanghai are provided below.**

Beijing Yuantaida Construction Waste Recycle and reuse Integration Technology Upgrade Project

Beijing Royco pyrolysis. Stirred tank reactor (6kt/d). *Unknown status*

Shanghai Construction Waste Green Disposal Demonstration Project

# 6 Appendices

## 6.1 Literature sources


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* Lina Zheng, Huanyu Wu, Hui Zhang, Huabo Duan, Jiayuan Wang, Weiping Jiang, Biqin Dong, Gang Liu, Jian Zuo, Qingbin Song. 2017. *Characterizing the generation and flows of construction and demolition waste in China.* In Construction and Building Materials.

## 6.2 Consulted stakeholders and experts

The following people where consulted in preparation of this fact sheet

| Name | Organization |
|---|---|
| Ardi Dortmans | TNO/TKI |
| Bert Jan Lommerts | Topteam Chemistry, Latexfalt |
| Bert Weckhuysen | UU |
| Caroli Buitenhuis | Green Serendipity |
| Christiaan Bolck | WUR |
| Eric de Ruijter | NRK |
| Freek van Eijk | Holland Circular Hotpot |
| Monique de Moel | Port of Rotterdam |
| Rob de Ruiter | TNO Senior Business developer |
| Unico van Kooten | Vereniging van Afvalbedrijven |
| Jan Henk Welink | TU Delft |
| Adrienna Zsakay | Circular Economy Asia |

## 6.3 Chinese policy overview regarding recycling and circular economy

*Table 2. Overview of developments and policy documents regarding recycling and the circular economy*

| Year | Policy document | Policy maker | Key contents |
|---|---|---|---|
| **2008** | Circular Economy Promotion Law | National People's Congress | The law marked that China had set its foot on the track of developing the circular economy according to laws. It focuses on the "3R" principles (reduction, reuse and recycling), defines the circular economy, and clarifies the objectives, details, guidelines and principles of circular economy development. It also stipulates clauses on penalty and liabilities for various categories of economies failing to fulfill the legal duties. |
| **2012** | Notice on administration of Special Fund of CE | MoF, NDRC | Fiscal and taxation policy to support the development of a circular economy |
| **2013** | Notice on strategy and action plan for the development of CE | State Council | The Action Plan set goals for the CE in different stages. For 2015, some of the goals were: wide application of advanced resource recycling technologies featuring the 3Rs; > 72 % of industrial solid wastes are disposed of for utilization; a modern waste recovery system is taking shape; 70 % of waste products are recovered by virtue of advanced technologies.<br><br>By 2020: an industrial technology innovation system should have been built for reuse and recycling; a competitive group of manufacturers of technical equipment and products for resource recycling should have emerged and a technologically advanced industrial system for resource recovery and recycling, covering urban and rural areas, should be in place. |
| **2016** | Notice on Development of Green Building Materials Industry | MIIT | Focuses on sustainable building materials, less on recycling |
| **2016-2020** | 13th Five-year Plan of the People's Republic of China | National People's Congress | Confirmation and intensification of circular economy goals. 35% of urban household waste to be recycled in 2020. |
| **December 2016** | Notice on the CE Development Evaluation Indicator System (2017 Edition) | NDRC, MEP and the National Bureau of Statistics (NBS) | The CE indicators are based on the Material Flow Analysis (MFA) method and have been designed to assess circularity on macro and meso levels in line with the 3R principles.<br><br>The 2017 system is made up of three main interconnected categories:<br><br>• Comprehensive indicators: measure the overall productivity of main resources, such as fossil fuels, metals, minerals, and biological resources. They also measure the recycling rate of the main waste streams.<br>• Specialized indicators: measure specific |

| | | | |
|---|---|---|---|
| | | | streams of resource productivity, waste recycling rates, and the value added by recycling industries.<br>• Supplemental indicators: focus on the end-of-pipe treatment of waste, such as industrial, solid, and wastewater municipal waste, and the emission of main pollutants.<br>These indicator categories jointly form one composite indicator – the circular economy development indicator – which measures and tracks the overall progress towards a circular economy. |
| **March 2017** | 46 cities to implement mandatory garbage sorting by the end of 2020 | Ministry of Housing and Urban-Rural Development | By the end of 2017, 12 cities had adopted laws and regulations on garbage sorting, while 24 had introduced work programs related to the issue<br>>4 million households in Shanghai had registered to get reward credits for good garbage sorting/recycling.<br>Taiyuan in Shanxi province has introduced intelligent waste recycling bins allowing people to earn points for corresponding items by throwing a waste item into the right bin. |
| **July 2017** | Notification to WTO on ban of waste imports followed by internal campaign to crack down on illegal waste imports. | State Council and Ministry of Environmental Protection | As part of Operation Sword, an Import ban on 24 types of solid waste, including waste plastics and phase out of imports of all solid waste that can be replaced by domestic resources by the end of 2019. This is motivated by a need to focus on managing China's own waste instead of waste from other countries.<br>Ban has led to a (temporary) crisis in the Chinese plastics recycling industry. |
| **2018** | Construction Waste Management Pilot Projects | MoHURD | Defines specific CDW management pilots in 35 cities – see the list of pilot projects. |
| **2018** | China and EU sign a Memorandum of Understanding on Circular Economy Cooperation* | EU- NDRC | The MoU seeks to promote cooperation through joint meetings, knowledge exchange and capacity building. There are no financial tools connected to the MoU. |
| **Jan. 2019** | Selection of 10 Cities as Zero-Waste Demonstration Cities | State Council | 10 Cities expected to promote green lifestyles, minimize amount of waste produced, strengthen recycling programs and ensure that waste released into the environment is harmless.<br>By 2020 they should have established a comprehensive management system for waste and be demonstration models for zero-waste cities. Building material recycle and reuse is led by MoHURD, MIIT and NDRC |

## 6.4 Waste and recycling companies in China

A selection of waste and recycling companies. Source: https://www.environmental-expert.com.

| Company name | Focus areas | Location | Details |
|---|---|---|---|
| Careddi Technology Co. Ltd | Tyre and rubber recycling equipment | Nanjing | Specializes in manufacturing waste tyre recycling machines and pyrolysis oil systems (tyre crusher, tyre pyrolysis equipment ,tyre shredder, Carbon black Milling, Carbon black pelletizing). >20 experience. |
| FUKUTOMI (SHANTOU) INDUSTRIAL LIMITED | Plastic recycling | Shantou | Founded 1984. $10-100 mio. Initial phase production lines include production of multimedia packaging products, blister used for packaging purpose, plastic pallets for industrial use by using prime and recycled materials; compounding of engineering plastics; and production of biodegradable Polylactic Acid products. Partially based on recycled plastic. |
| G.E.T. Recycling | Plastic recycling | Wuxi City, Jiangsu, | Founded in 2002, with Dutch background. Recycling of LDPE film, PET, HDPE/PP, PS/ABS, EPS-LDPE and WEEE. |
| Henan Doing Mechanical Equipment Co.,Ltd | Waste to energy - waste to fuel equipment | Zhengzhou , Henan | Specializes in tire recycling pyrolysis machine and plastic recycling pyrolysis machine to get fuel oil, waste oil/black oil refinery machine to get diesel oil, cooking oil production line as well as biodiesel plant |
| Henan Zhongying Rubber Technology Limited Company | Tyre and rubber recycling | Sanmenxia, Henan | Recycling at room temperature. Waste rubber crushed into ultra-fine rubber powder (30-200 mesh). Separation of rubber, steel wire and fiber and 100% recycling. |
| Huanchuang (Xiamen) technology Co., Ltd. | Shredding equipment and recycling solutions solid waste | xiamen , fujian | Products include: wastewater grinder(sewage grinder), household garbage crusher, shredders, high-speed pulverizer/granulator and waste recycling solutions such as MSW crushing & sorting +RDF system, waste plastic (PET, PP, HDPE, LDPE) recycling system, scrap tire recycling system, WEEE recycling systems, etc. |
| Jiangsu LVHE Environmental Technology | Environmental technology | Changzhou | State-owned holding enterprise under the Ministry of Housing and Urban-Rural Development and Wujin Green Building Industrial Agglomeration Demonstration Zone. Together with Finnish ZenRobotics, they introduced a world leading artificial intelligence sorting technology for construction waste recycling. It can identify the type of construction waste through composite sensors, and sort out 13 to 15 categories according to the nature and size of the materials, so that it can be re-used. |
| Jiangyin Xinda Machinery Co., Ltd. | Tyre and rubber recycling equipment | jiangyin City, Jiangsu | Founded in 1996. Specializes in high-tech waste rubber recycling machines. EU certificates for machinery and several patented technologies. |
| Leshan Shengxing Machine Co.,Ltd | Tyre and rubber recycling equipment | Leshan | Founded 1998. Turnover: $1-10 mio. Products covering equipment for the whole process of waste tyre recycling, from tyre disassembling, shredding, crushing to rubber powder pulverization. |
| LESHAN YALUN MOLD CO.,LTD | Tyre and rubber recycling equipment | Leshan, Sichuan | Founded 1979. China's largest tyre recycling equipment manufacturer with more than 200 employees. |
| Suzhou Yagque Environmental Protection Technology Co., Ltd | Tyre and rubber recycling equipment | Suzhou, Anhui | Founded 1993. Specializes in complete equipment applied to crush pulverize and grind waste tires and rubber products. Maintaining technical collaboration with several universities such as China University of Mining and Technology, Xi'an Jiaotong University, and Guangxi Transportation Research Institute |
| Taizhou Zhonghong Waste Rubber Comprehensive Utilization | Tyre and rubber recycling equipment | BinGang Industrial Zone, Zhejiang | Founded 2003. Specialised in rubber recycling machinery. In the year of 2012 the company was appraised as national top ten technological innovation enterprise. |
| Tongli Plastic Recycling machinery Co ltd | Plastic recycling machinery | jiangyin city | Founded 1985. $10-100 mio. Specialised in plastic extrusion, granulation and recycling machinery (PE, PP, PA, PC, PS, ABS, EVA, Nylon, PVC, PET. |
| Vihoo Pyrolysis Plant | Plastic recycling machinery - Waste to energy/fuel | Zhengzhou , Henan | Founded 2000. Turnover: $1-10 mio. VIHOO products mainly include waste tyre and rubber, plastic pyrolysis equipment; crude oil, fuel oil, waste oil and lubricating oil distilation equipment; carbon black deep processing machine and tires crushing equipment. |
| WinSun-Yingchuang | 3D-printing for construction | Shanghai | Founded 2003. Leader in 3D printing techniques for construction industry, based on 100% recycled material. Materials: GRG, SRC, Crazy Magic Stone, FRP, construction printing ink and 3D printing architecture |
| Wuhan Green world Technology Co., Ltd | Tyre and rubber recycling | Wuhan, Hubei | Turnover: $1-10 mio. Entire production line of tyre powder treatment - recycling at room temperature. |
| XDPC (Zhejiang Xinding Plastic Co.), Ltd. | Plastic manufacturer | Taizhou, Zheijan | Founded 1995. More than 1000 employees. Manufactures plastic products: plastic waste containers , plastic pallets , plastic furniture and plastic pet and garden products. Unclear to what extent plastics used are recycled, but probably they partially are. |
| xinxiang xinyutian rubber&plastic machinery co.,lt | Tyre and rubber recycling equipment | Xinxiang City, Henan | Founded 2010. Turnover: $1-10 mio. Specializes in machinery for waste tyre recycling, processing, crushing and cutting and waste tyre rubber powder production lines. |
| Zhangjiagang Huadian Power Equipment Co., Ltd. | Boilers, waste to energy a.o. | Zhangjiagang City | Founden 1998. R&D center of Xi'an Jiaotong University and the manufacture base of The First Electric Power Construction Company of Jiangsu Province |
| Zhangjiagang Yueshun Machinery Co,.Ltd | Plastic recycling machinery | Zhangjiagang , Jiangsu | Founded 2010. $10-100 mio. Specialised in plastic extrusion, granulation and recycling machinery (PE, PP, PA, PC, PS, ABS, EVA, Nylon, PVC, PET. |
| Zhengzhou Dayu hot mix plant Co., Ltd. | Asphalt mixing plants and equipment | Zhengzhou | Founded 1990. $100-1000 mio. All plants are equipped to recycle asphalt, which can lower the need for virgin materials by up to 30 percent. |
| Zhengzhou Zoonyee Mining Machinery Co. | Construction waste crushing & recycling equipment | Zhengzhou | Specialized in the research, production and sale of mining crushing equipment, sand making equipment and construction waste recycling equipment |
| Zibo United Tech Machinery Co.,Ltd. | Recycling, waste to energy | Zibo, Shandong | Founded 1999. Turnover: $1-10 mio. Specialized in environmental and recycling technology different types of waste. |

## 6.5 Recycling technologies

An overview of recycling technologies for solid plastic waste is provided below

| | | Technique | Advantages | Challenges |
|---|---|---|---|---|
| Mechanical recycling | sorting | Flotation (sink-float) | Well-known technology | Efficiency determined by density differences plastics |
| | | | Cost-effective | Mainly limited to binary mixtures |
| | | | Particle size | |
| | | Melt filtration | Useful to remove non-melting contaminants | Potential pressure fluctuations in production |
| | | | Additional melt pressure | |
| | | FT-NIR | Post-drying not required | Black undetectable |
| | | | Well-known | Plastic should be dry |
| | | Tribo-electric (electrostatic) separation | Efficient for various plastics | Pre-treatment |
| | | | Small particle sizes allowed | |
| | | Froth flotation | Efficiency | Precursor step required |
| | | | | In development for recycled plastics |
| | | Magnetic density separation | Improved density-based technique | Density overlaps remain |
| | | | Multiple polymer fractions in a single step | |
| | | X-ray detection | Accuracy | Cost-effectiveness |
| | | | Useful for PVC | |
| | Reprocessing | | High value recycling | Thermal-mechanical degradation |
| | | | Well-known technology | Challenging for complex mixtures |
| | | | Straightforward | Miscibility of polymer blends |
| Chemical recycling | Chemolysis | | Generates pure value-added products | Requires high volumes to be cost-effective |
| | | | Operational for PET | Mainly limited to condensation polymers |
| | Pyrolysis | | Suitable for highly heterogeneous mixtures of plastics | Complexity of reactions |
| | | | Simple technology | Requires high volumes to be cost-effective |
| | | | | Low tolerance for PVC |
| | | | | Stable waste supply |
| | Fluid Catalytic cracking | | Narrow product outcome | Deactivation of catalyst |
| | | | Less stringent reaction conditions leads to favourable economics | Absence of suitable reactor technology |
| | | | | Presence of inorganics |
| | Hydrogen technologies | Hydrocracking | Quality of produced naphta | High cost of hydrogen |
| | | | Suitable for mixtures of plastics | High investment and operational costs |
| | | $IH^2$ process | Promising technology for the production of liquid fuels out of biomass | Further research required |
| | | | Different elements already commercialized | |
| | KDV process | | Also suitable for oxygen and halogenated compounds | Chemistry still unknown |
| | | | | Lack of technical information |
| | Gasification | | Syngas is a valuable intermediate | Amount of noxious $NO_x$ |
| | | | Cost of air | Specific drawbacks of air |
| | | | Well-known technology | |

Source: Kim Ragaert, Laurens Delva, Kevin Van Geem, Mechanical and chemical recycling of solid plastic waste, Waste Management, Volume 69, 2017, Pages 24-58, https://doi.org/10.1016/j.wasman.2017.07.044.

There are four main types of chemical recycling: pyrolysis, gasification, solvolysis and depolymerization. The chemistry of thermal gasification and pyrolysis (or cracking) is reasonably well understood. Challenges lie in the engineering, the lowering of the energy usage and the quality of inputs and outputs. For both techniques, pilots are being developed in the Netherlands. Catalytic cracking is demonstrated for oil industry but is not well suited for plastic streams. Developments in this direction are very much in the academic stage. Solvolysis and depolymerization have a lower technology readiness. They require more pure input streams but can deliver higher quality products.

## 6.6 Research Programs in China

Source: http://www.most.gov.cn/eng/programmes1/200610/t20061009_36225.htm

**The Key Technologies R&D Program**
Launched in 1982, the Key Technologies R&D program was the biggest scientific and technological program in China of the 20th century. Oriented toward national economic construction, it aims to solve critical, direction-related and comprehensive problems in national economic and social development, covering agriculture, electronic information, energy resources, transportation, materials, resources exploration, environmental protection, medical and health care, and other fields. This program, engaging tens of thousands of researchers in over 1,000 scientific research institutions nationwide, has had the largest funding, employed the most people, and had the greatest impact on the national economy of any plan to date.

**National Key R&D Programmes (NKPs)**
http://chinainnovationfunding.eu/national-key-rd-programmes/

China's National Key R&D Programmes (NKPs) are a new category of projects created after the 2014 reform of the national STI funding system. They have incorporated numerous previously-existing programmes such as MOST's "863 Programme" for R&D, "Programme 973" for basic research, Key Technologies R&D Programme, and International S&T Cooperation Programme; and NDRC and MIIT's Industrial Technology R&D Fund.

The NKP's support R&D in areas of social welfare and people's livelihood, such as agriculture, energy and resources, environment, and health. They focus in particular on key and strategic technologies, featuring several well-targeted and defined objectives and deliverables to be achieved in a period ranging from three to five years, and reflecting a top-down and industry-university-research cooperation design which integrates basic research, technology application, demonstration and commercialisation.

**Torch Program**
Launched in August 1988, the Torch Program is China's most important hi-tech industry program and a national guideline program. It includes: organizing and actioning development projects for hi-tech products with advanced technology levels and good economic benefits in domestic and foreign markets; establishing hi-tech industrial development zones throughout the country; and, exploring management systems and operation mechanisms suitable for the development of hi-tech industry. The program mainly involves projects in new technology fields, such as new materials, biotechnology, electronic information, integrated mechanical-electrical technology, and advanced and energy-saving technology.

## 6.7 Waste and recycling demos and pilots in China

*Table 3 Construction waste recycling: demos and pilots*

| | |
|---|---|
| Construction Waste Recycling and Application Promotion Project | Henan |
| Annual treatment and reuse of 2 million tons of construction waste projects | Shaanxi |
| Demonstration project: recycling of construction waste using coal mine cementation technology | Inner Mongolia |
| Construction Waste Green Disposal Demonstration Project | Shanghai |
| Production of lightweight wallboard projects using construction waste | Shenzhen |
| Construction waste recycling and reuse project | Xinjiang |
| Research and Demonstration Project: Waste Plastics and Construction Waste recycling and reuse in New Urban Construction | Shenzhen[†] |
| Beijing Yuantaida Construction Waste Recycle and reuse Integration Technology Upgrade Project | Beijing |
| Construction Waste Comprehensive Utilization Technology and Demonstration Project | Jilin |

*Table 4 Plastic recycling: demo and pilot projects*

| | |
|---|---|
| Demonstration project : high value recycling of waste plastics | Guangdong |
| Demonstration project : recycling and utilization of waste plastic resources | Dalian |
| Waste plastic high value utilization project | Shandong |
| Guangdong Tianbao Waste Plastics Comprehensive Utilization Project | Guangdong |
| Demonstration Project: Annual production of 300,000 tons of new plastic composite building materials | Jiangxi |
| 100,000 tons of waste plastic recycling project | Xinjiang |
| Demonstration project: production of 100,000 tons polyester staple fiber from polyester flakes | Xinjiang |
| Production of HB composite panels from waste paper, plastic and aluminum composite packaging materials | Shenzhen |
| Waste plastic recycling, processing and utilization project | Inner Mongolia |
| Tongjiang Fenglinda waste plastics processing and warehousing logistics | Heilongjiang |
| Recycling of waste plastics & production of new chemical building materials | Hunan |

*Table 5 Pilots and demos for pyrolysis (Arvi 2017)*

| | |
|---|---|
| Royco. Stirred tank reactor (6kt/d) Unknown status | Beijing |
| Hitachi Zosen. Stirred tank reactor | Chiyoda |
| Tech Supplier: PARC (Catalytic depolymerization, continuous feed). | |
| Commercial scale (60 mtpd) pyrolysis system. Not operational (relocating equipment) | Huaian |
| Demonstration (15 mtpd) continuous operations; | Xinghua, Jiangsu |
| Demonstration (20 mtpd); discontinuous operations | Nantong, Jiangsu |

[†] **Shenzhen** (Guangdong province) was the first city to implement a mandatory recycling program for large household waste such as furniture and home appliances. optional pick-up service for large waste since 2015, and it currently has 21 large-scale garbage-processing facilities operating at 70 percent capacity. In 2016, Shenzhen began construction of the world's largest waste incinerator. Won City Climate Leadership Award in 2014 (international award), for green/electric transportation policies. http://english.mee.gov.cn/News_service/media_news/201409/t20140923_289434.shtml

# RECYCLING IN JAPAN

waste management, policies and innovation

# Contents



**Cover image**
3R promotion poster (2014)
http://www.3r-suishinkyogikai.jp/poster/guide/

# 1 Introduction

The Ministry of Economic Affairs & Climate Policy and the Topsector Chemistry visited Japan in May 2019. The goals of the mission were: learning from each other and exploring opportunities for Japanese-Dutch co-operation for recycling.

As a preparation for the mission, this fact sheet was prepared. It summarizes the available knowledge on Japanese waste management, waste and recycling policies, and the innovation landscape. Most information is on the national level. Where available, information on Tokyo has been included.

The focus lies on the policies for waste and recycling with reference to the wider areas of resource efficiency and circular economy where appropriate. The fact finding is limited to building materials and plastics.

The information in this document is based on desk research of public documents complemented with input from stakeholders and experts. The information that was gathered, typically is coarse-grained and not always up-to-date, and should be considered as a guide for further fact finding.

# 2 How to read the document

The information in this fact sheet is divided in three broad themes: general information on waste management in Japan (Chapter 3), an overview of the relevant policies (Chapter 4) and information on the innovation landscape (Chapter 5). The latter ranges from the universities and their research programs to the economic actors and their investments in technology. These chapters contain the information in summarized format and refer to specific sections in the Annex (Chapter 6) for a more complete overview.

# 3 Waste management in Japan

## 3.1 Facts and figures: waste management

Total amount of waste generated in 2014 is 44,3 mln tons of which 70% is generated by households. The total amount of waste peaked around the year 2000 with approximately 55 mln tons of waste and has been declining since then (MoE, 2017a, Table 4.04). The waste collection rate is close to 100% and waste is being extensively sorted in different recyclable and non-recyclable fractions, by consumers as well as industry.

Japan monitors material flows to understand the extent of material extraction, consumption and disposal (Figure 1).

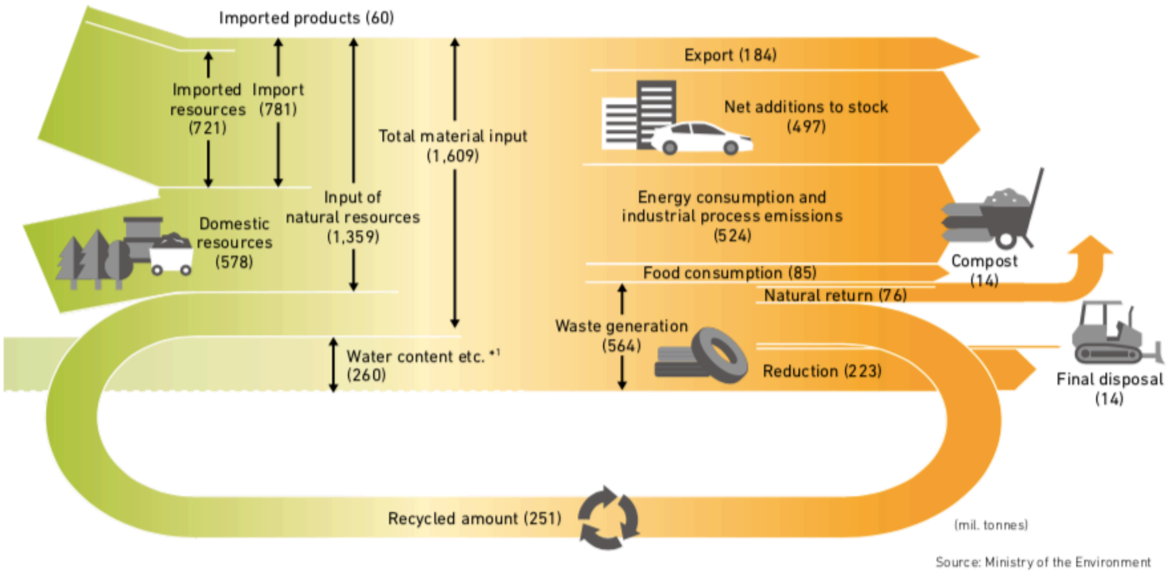



*Figure 1. Material flow in Japan in FY2015 (MoE 2018a, p.30)*

The material flows analysis aids in goal setting as part of the Third and Fourth Fundamental Plan for Establishing a Sound Material-Cycle Society. The main indicators and targets are shown in Figure 2.

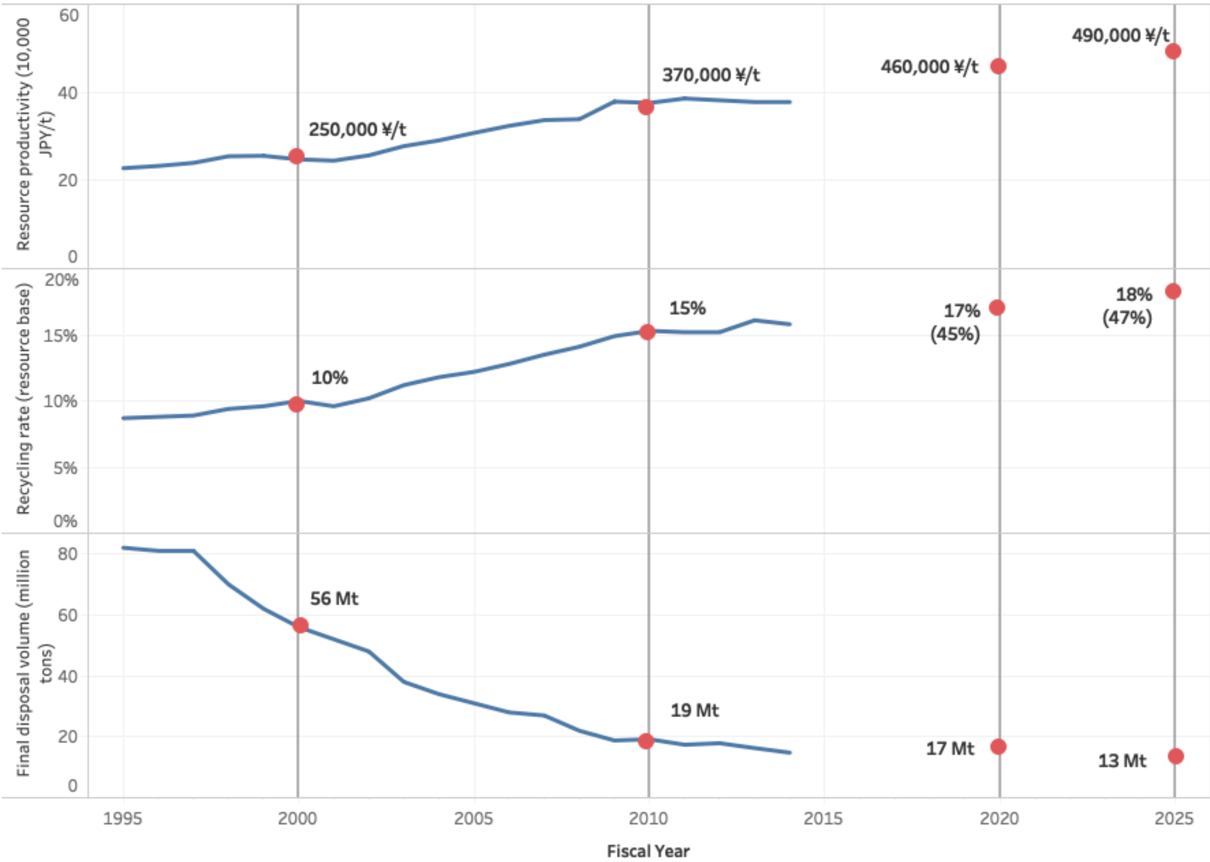



*Figure 2 Changes in main material flow indicators (MoE, 2017a, table4.02). Red dots indicate the targets set in the 3rd and 4th plan for a sound material-cycle society (MoE, 2018b).*

For waste management, Japan relies strongly on waste incineration: In 2014, there was 42 Mt collected waste of which approximately 35 Mt of waste ended up in an incinerator. The total amount of recycling is 9 Mt. 4 Mt ends in a landfill (MoE, 2017a, 4.03).[1]

Between 1977 and 2014 the total operating capacity of incinerators increased from 129 to 183 kt/d. Increasingly the waste incinerators are generating power: growing from 5.5 to 8.0 TWh between 2001 and 2014. There is roughly an equal amount of recycling facilities as there are incinerators (approximately 1,000 of each). The recycling facilities, however, are much smaller, having a total reprocessing capacity of 29 kt/d (MoE 2018b).

The Ministry of Environment collects detailed statistics on every aspect of the waste management system down to the level of detail for prefecture, specific items and materials (MoE 2018b).

## 3.2 Facts and figures: plastics

The Plastic Waste Management Institute (PWMI) surveys and researches data on the generation, recycling, and disposal of plastic waste. With this data, an annual flow chart is constructed. This flowchart is included in Annex 6.2, and the reader is referred to the original publication for a further breakdown in product segments and polymer types (PWMI, 2019, February).

[1] The numbers do not add up, because of other post than 'collected waste' in the flow chart.

Plastics - with circa 9 Mt/a – comprise approximately a quarter of the entire waste stream. Plastic waste originates in roughly equal parts from industry and households. Plastic waste production grew rapidly between the 1970s and 2000 but has decreased since then by circa 10% (MoE 2018b). In 2017, most (86%) of the plastic waste was utilized. Mainly through incineration with energy recovery. The changing trends in plastic waste treatment are shown in Figure 3.

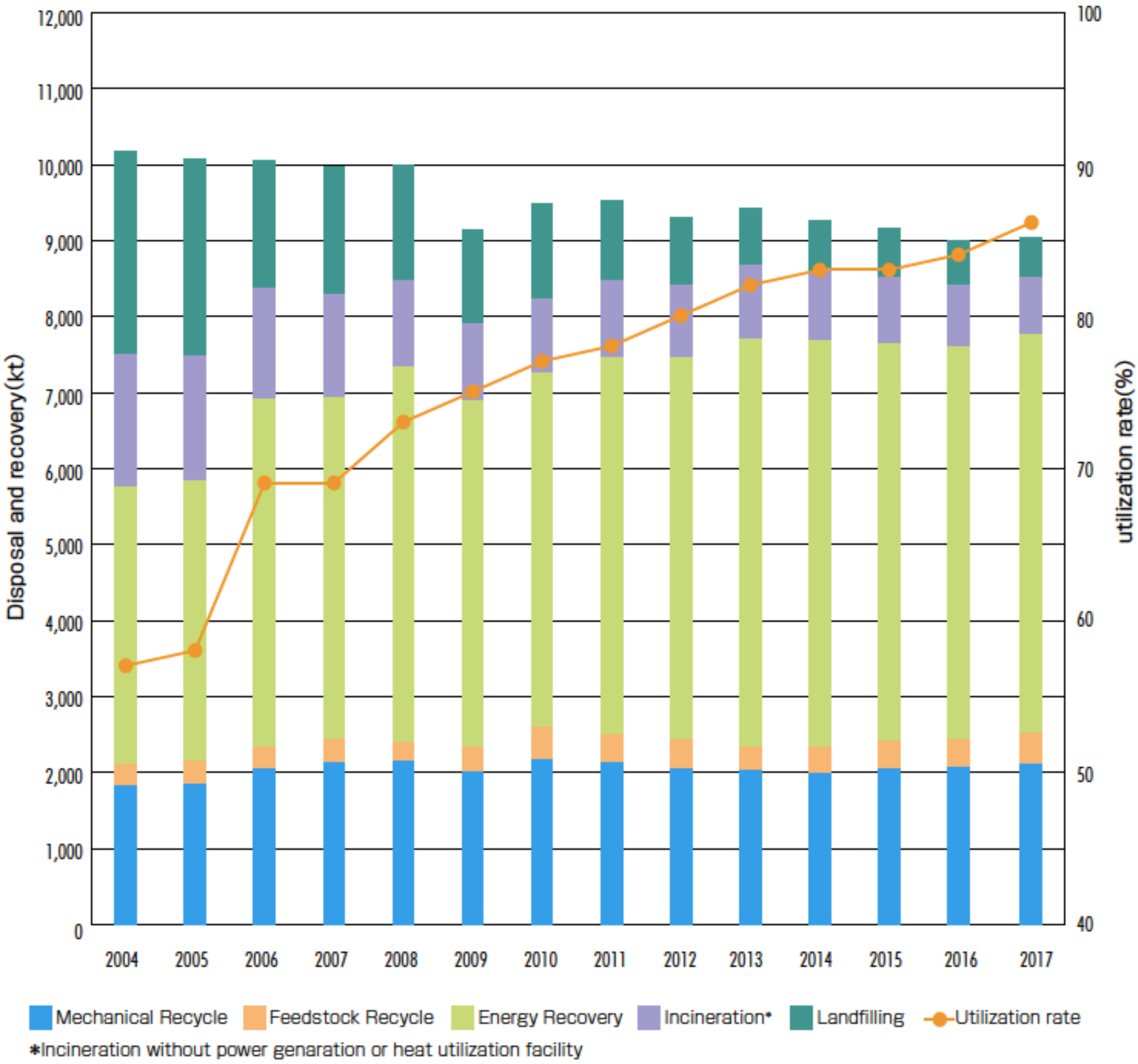



*Figure 3 Changes in plastic waste handling between 2004-2017 (PWMI, 2019, February)*

Feedstock recycling (chemical recycling) forms a small part of the plastic waste handling, approx. 3% of all plastic wastes. For packaging materials, the output is 60% as chemical recycling and 40% as material recycling (Figure 4).

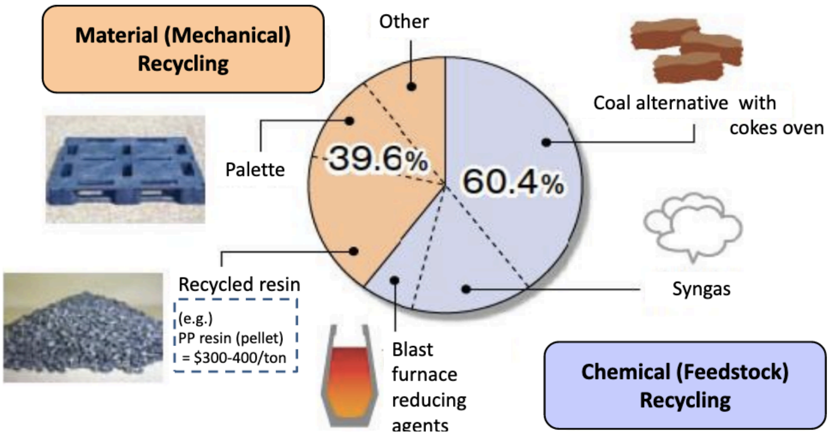


*Figure 4 Recycling of plastic packaging (Innoue, 218)*

## 3.3 Facts and figures: construction and demolition waste (CDW)

With a total amount of 81.61 Mt/a, CDW in 2014 amounted to some 20% of the total amount of industrial waste generated. 2.9 Mt/a was finally disposed of, which amounts to circa 25% of the industrial waste disposed of (MLIT, 2015). Under the Construction Material Recycling Act, construction contractors of a certain scale are required to sort and recycle specific CDW. This requirement has resulted in very high recycling rates for CDW: 85-99% depending on the material. For example, more than 99% of asphalt and concrete waste is being recycled, more than 95% of wood and more than 90% of construction sludge and soil used for construction work. Recycling of mixed CDW remains a challenge, but even for this category, more than 60% is being recycled (MLIT,2015). Most recycled material is used as road sub-base and other forms of 'filler'. The achievement of almost 100% recycling poses the Japanese government with the challenge of setting new targets and identifying new indicators for a 'sound construction material cycle'. Various companies and projects are working on developing new types of high-quality recycled construction materials (see 5.5).

## 3.4 Waste management system

**Japan manages its waste through comprehensive governance and advanced technologies. Almost 100% of waste is collected and sorted into a large range of fractions in order to facilitate recycling. Local governments are responsible for collecting and managing consumer waste, whereas industries themselves are responsible for collecting and managing industrial waste. Despite domestic availability of recycling and waste-to-energy facilities for e.g. metals, plastic, paper and other popular recyclable resources and a reuse market for various products, a significant amount of waste is exported to low-cost countries after sorting.**

Japan's efficient solid waste management practices can be largely attributed to effective cooperation between its national and local governments. The central and urban public authorities coordinate along several dimensions, from data collection to financing.

All local governments in Japan are required to develop a local solid waste management plan for the next 10 years. The plans are developed according to guidelines published by the national government and provide detailed information on intended initiatives to sustainably treat waste and promote waste reduction, reuse, and recycling.

The Japanese national government provides subsidies to municipalities to develop and improve waste treatment facilities based on the submitted waste management plans.

Subsidies cover up to one-third of the cost of basic infrastructure projects, and half of the costs for advanced facilities, such as high-efficiency waste-to-energy facilities. The remaining capital costs are the responsibility of local governments. Operational costs for facilities are fully and directly covered by local governments. The two main revenue sources are the sale of designated plastic bags (a form of user fees in Japan) and general tax revenue.

# 4 Policies

**The concept of a Circular Economy - or 'the sound material-cycle society' - was officially introduced into Japanese policies already in 1991. Since then it has formed the foundation for national policies for industrial development, resource productivity, waste management and sustainable development in general. In 2018, the 'sound material-cycle society' policy has been further cemented in the 5th Basic Environment Plan, integrating climate goals in line with Paris agreement and building on the UN Sustainable Development Goals (SDG) framework.**

In Annex 6.3, we provide a chronological overview of key policy developments and documents regarding recycling and the circular economy from 1991 and onwards.

**Policies related to recycling and waste management are mostly developed by the following government bodies:**

- Ministry of Environment (MoE) - Major coordinating ministry in relation to sound material cycle society policy.
- Ministry of Economy, Trade and Industry (METI)
- Ministry of Land, Infrastructure, Transport and Tourism (MLIT) – especially important for CDW management.
- Ministry of Agriculture, Forestry and Fisheries
- Consumer Affairs Agency
- Other relevant ministries include Ministry of Foreign Affairs; Ministry of Education, Culture, Sports, Science and Technology and Ministry of Health, Labor and Welfare.

**The key drivers for 'sound material-cycle society' policies are high population density, limited (landfill) space and a lack of domestic raw materials, incl. fossil fuels, while being a major industrial manufacturing economy. The disaster with the Fukushima nuclear power plant seems to have further strengthened the emphasis on waste as a source of energy.**

In traditional Japanese society, values relating to simplicity ('shisso kenyaku') and avoiding waste ('mottainai', meaning that it is a shame for something to go to waste without having made use of its full potential) were strongly integrated and major samurai castles like the Hikone Castle were largely constructed from recycled materials. With the opening up of the Japanese economy, rapid industrialization and economic growth after WW2, Japan was confronted with a growing lack of space for the huge amounts of waste generated and at the same time with a lack of material resources for further growth. Reference to traditional culture is extensively used in public communication material.

**Current priorities are to further reduce the total amount of waste (focus on reduce and reuse) and to improve the quality of material recycling in order to keep materials permanently in the production cycle. Particular focus is on recycling/utilization of organic (food) waste and plastics (packaging).** (Country 3R Progress Report, 2019)
Japan has implemented extended producer responsibility (EPR) in almost all consumer goods sectors, making producers responsible for collecting and managing waste at the end of the life cycle. Major challenges in further implementation of EPR is to further increase in collection rate, improve transparency in how recyclers and waste treatment businesses are actually treating recyclables, regulation of informal collectors and how to increase the quality of material recycling.
**Specific goals relating to plastics** are to

- reduce 25% of the accumulated volume of one-way plastics by 2030
- develop reuse / recyclable designs by 2025
- have 60% of packages / containers to be recycled or reused by 2030
- achieve 100% utilization of used plastics by 2035
- double the volume of recycled plastics used by 2030
- introduce 2 million tons of bioplastics by 2030

**The Japanese policy approach has a strong regional character, trying to maximize regional self-sufficiency and minimize imports. The regional focus was especially expressed in the Eco-Town program that ran from 1997 to 2007 and supported 26 areas in developing a strong waste management and recycling infrastructure. In 2018, the concept of 'Regional Circular and Ecological Spheres' has been introduced aimed at strengthening self-reliance of regions.**
Japanese regional and local authorities play a key role in waste management and recycling (see 3.4). Both national and local authorities play a major role in educating the general public in sustainable consumption and proper waste handling. All policy measures are based on a strong cooperation between national government, industry and local communities. From 1997 to 2007, the **Eco-town program** received about 94.75 billion yen in total government support (subsides, tax reductions & policy finance) to generate an increase of 20% per year in recycling capacity - 5.89 million tons in total. With the introduction of **"Regional Circular and Ecological Spheres (Regional CES)"** in the $5^{th}$ Basic Plan, the focus is widened to facilitate energy and resource efficiency, industrial symbiosis, improved interaction between countryside and cities, green consumption and waste reduction and reuse, rather than 'only' recycling/energy recovery. (Country 3R Progress Report, 2019)

**Progress towards a 'sound material-cycle society' is monitored and reported in annual progress reports, including the following key indicators (see 3.1. for specific figures):**

- A **resource productivity indicator** measuring material use as a proportion of GDP;
- An indicator for **cyclical use rate of materials** in the economy, measured by the material reused as a proportion of total material used by the economy; and
- An **output indicator, measuring how much waste is ultimately landfilled**.

These indicators have associated targets, which are supplemented with a host of sector-specific measurements and targets. Japan also measures indicators of societal effort towards a circular economy, looking at the size of the market for rental and leasing of goods, the amount of reusable packaging sold, the number of local authorities that charge for residual waste collection, and even the sales of disposable chopsticks as a proxy for the proportion of the population that uses reusable chopsticks. (https://www.the-ies.org/analysis/circular-economy-japan).


*Figure 4. As a means to address public resistance, Japanese authorities invest a lot in minimizing negative impacts from waste management facilities on local communities, incl.an attractive architecture. Below: Osaka Waste Incineration Plant.*

**A *specific* strategy for feedstock recycling technologies (chemical recycling) has not been found.** Chemical recycling is already used for reusing post-use plastic as plastic products, as fuels for use in the chemical industry, etc. (see also 3.2). Priorities for waste management have been formulated in the Third Fundamental Plan for Establishing a Sound Material-Cycle Society: (1) reduce waste generation (2) reuse (3) recycle (4) heat recovery (5) appropriate disposal. However, it also states "a more appropriate method shall be selected without regard to this priority if environmental loads can be reduced by doing so, and measures shall place importance on Life Cycle Assessment (LCA). (PWMI, 2016). That would allow for a growth of chemical recycling.

A planned measure of the 4$^{th}$ Fundamental Plan is the Establishment of a Plastic strategy and promotion of accompanying measures (MOE, 2018). According to Innoue (2018, p13) three concrete measures are under proposal: (1) Reduction in the use of plastics
(2) Collection and recycling in radical, effective and efficient manners, and (3) Improvement in the practicality of bio-plastics and replacement of fossil-fuel based plastics with bio-Plastics.

# 5 Innovation landscape

## 5.1 International aspects

**Japan sees itself as a global leader in terms of environmental technologies and infrastructure, as well as supporting ideas, systems, and human resources related to sustainability and a circular economy. Therefore, 'international contributions and strategic partnerships' are explicitly mentioned as a key strategy in the 5th Basic Environmental Plan.** In particular, Japan aims to export its waste-management and circular economy know-how, to developing countries and to other countries in Asia. The underlying motive for sharing know-how, clearly is to create new opportunities for Japanese companies and hence for continuous growth of the Japanese economy (MoE, 2018c).

**Japan participates in a number of international collaborations related to a circular economy. A list of ongoing cooperations is provided (Country 3R Progress Report, 2019):**

- Regional 3R Forum in Asia and the Pacific
- African Clean City Platform (ACCP)
- Contributing to Climate and Clean Air Coalition/Municipal Solid Waste Initiative
- Contributing to G7 Alliance on Resource Efficiency
- Contributing to G20 Resource Efficiency Dialogue
- Contributing to OECD Working Party on Resource Productivity and Waste
- Contributing to UNEP International Resource Panel
- World Circular Economy Forum (October 2018)
- 3R Conference for Asian Local Governments
- Support in development of Waste to Energy guideline
- International Promotion of Circular Business

***EU-Japan relationship***

**Japan strives for close cooperation with the EU. In 2018, this cooperation was formalized in a bilateral framework agreement "The new Strategic Partnership Agreement" between the EU and Japan.** The Agreement's primary role will be to serve as the charter defining and undergirding the overall relationship and sets out an overarching framework for enhanced political and sectoral cooperation as well as joint actions on issues of common interest, including on regional and global challenges. The first Joint Committee under the EU-Japan Strategic Partnership Agreement (SPA) was held on March 25th in Tokyo. This launched the implementation of the new agreement and defined the promotion of a circular economy as one of the key priorities to focus on.

**The EU-Japan Centre for Industrial Cooperation** (https://www.eu-japan.eu/) aims to facilitate the exchange of experience and know-how between EU and Japanese businesses. In October 2018, the European Commission organized a Circular Economy Mission to Japan and in May this year, the EU-Japan Centre together with European Demolition Association and Japan Demolition Contractors Association (JDCA) are organizing a conference on 'Enabling Change and a Circular Economy'. Part of the EU-Japan Centre is also a **National Contact Point for Horizon 2020** in Japan. The contact point is appointed by the Japanese government to provide local support towards Japanese participation in Horizon 2020. http://www.ncp-japan.jp/

Cooperation between the EU and Japan in research and innovation is governed by the **Agreement on S&T Cooperation**, which came into force in 2011. On the basis of the 4th

EU-Japan Joint S&T Committee (JSTC) in November 2017 Climate action, environment and resource efficiency are considered to be priority areas for cooperation. Cooperation takes place through multilateral initiatives (Group on Earth Observations, Belmont Forum, Future Earth). (European Commission, 2017) Japanese companies are also applicable for participation in Horizon2020 projects.

## 5.2 Universities

There are many research institutes and research universities in Japan active in this area. The followings are the examples of such research institutes/coordination bodies.

- Japan Society of material Cycles and Waste Management (https://jsmcwm.or.jp/international/)
- Center for Material Cycles and Waste Management Research, National Institute of Environmental Studies (NIES) (https://www.nies.go.jp/sosiki/cycle-e.html)
- Institute for Global Environmental Strategies: 1) Sustainable Consumption and Production Area, 2) Center Collaborating UNEP on Environmental Technologies (https://www.iges.or.jp/en/scp/index.html)
- National Institute of Advanced Industrial Science and Technology (AIST) https://www.aist.go.jp/aist_e/dept/en_dmc.html
- Japan Waste Research Foundation
- Japan Environmental Sanitation Centre (JESC) https://www.ctc-n.org/network/network-members/japan-environmental-and-sanitation-centre

## 5.3 Research programs

**Relevant Japanese research is funded through (Country 3R Progress Report, 2019):**

1. There is a specific category of research and development in relation to the 3Rs and waste management under research grant program called Environment Research and Technology Development Fund as R&D budget managed by Ministry of the Environment (about 800 million JPY a year). Through this fund, 39 research projects are supported in the Sound-Material Cycle field (MoE, 2017b). A list of these projects is provided in Annex 6.4.
2. NEDO's R&D for Recycling Technology Development for Highly Efficient Resource Circulation System (About 700 million JPY a year) (NEDO, 2018)
3. State of the 3Rs in Asia and the Pacific project to develop assessment report of 3R policy progress in the region, coordinated by UNCRD and Institute for Global Environmental Strategies (IGES), and financially supported by Ministry of the Environment of Japan.

## 5.4 Companies

Japan's reuse and recycling economy was worth £163 billion in 2007 (7.6 per cent of GDP) and employed 650,000 people (MoE, 2010). Some key indicators are shown in Table 1.

*Table 1 Sound material cycle society business: market scale in Japan (MoE, 2010, Table 4-1)*

| | | Supply of machinery, equipment and plants | Supply of services | Supply of materials, final consumer goods | |
|---|---|---|---|---|---|
| Business examples | | • Intermediate treatment plants<br>• Melting equipment<br>• RDF manufacturing/using facilities<br>• Oil manufacturing facilities from plastics<br>• Composting equipment from kitchen waste<br>• Plant construction<br>• Construction of final disposal sites | • Waste treatment<br>• Resource recovery<br>• Recycling | • Reclaimed oil from plastics<br>• PET-recycled fiber<br>• Products made of timber from forestthinning<br>• Recycled products (e.g. scrap metals)<br>• Products made from reclaimed items (e.g. recycled paper)<br>• Refillable products<br>• Repairs of machinery, furniture<br>• Housing improvement, repairs | Total |
| Market and employment scale | | • Manufacture of equipment and materials for preventing pollution (waste-related)<br>• Construction and installation of machinery and equipment (waste-related) | • Supply of services (waste-related) | • Recycled materials<br>• Repairs | |
| | 2000 | 806.5 billion yen | 2753.6 billion yen | 26025.4 billion yen | 29585.5 billion yen |
| | 2007 | 456.2 billion yen | 3007.7 billion yen | 34600.5 billion yen | 38064.4 billion yen |
| | 2000 | 1,872 people | 195,292 people | 331,513 people | 528,677 people |
| | 2007 | 8,275 people | 130,392 people | 511,736 people | 650,403 people |

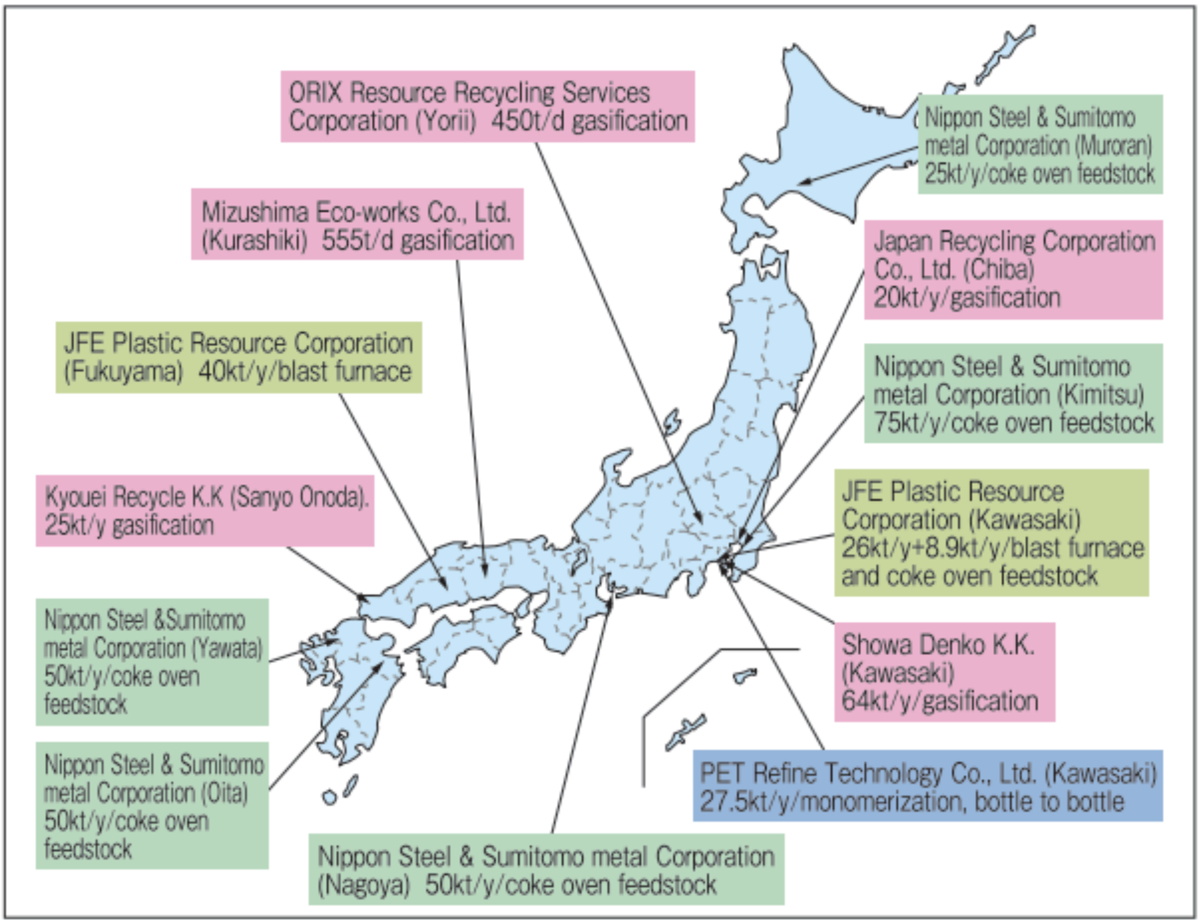
A directory of 113 plastic recycling plants can be found here:
https://www.enfrecycling.com/directory/plastic-plant/Japan
Japanese material recovery facilities receive, separate and prepare recyclable materials. A listing is provided here: https://www.enfrecycling.com/directory/mrf/Japan

Yolin (2015) is a relevant resource for (SME) companies that seek business opportunities in waste management and recycling in Japan. The reader is referred to sections B of this report for details on the opportunities and challenges in this market.

## 5.5 Demos and pilots

**Plastic recycling**

Examples of new technologies for plastic recycling were collected from PWMI (2016, p.19-23) and are listed in annex 6.1. In Japan, there are many facilities applying the chemical recycling technology. Figure 5 shows that the facilities of chemical recycling using the collected plastics under the containers and packaging recycling law. In 2015, there are 13 facilities of monomerization, blast furnace feedstock recycling, coke oven chemical feedstock recycling and gasification in Japan.




Note : The numeric shows treatment capacity kt = thousand tons

*Figure 5 Large scale feedstock recycling facilities (PWMI, 2016, p.23)*

**CDW recycling**

- **Ishizaka Sangyo** (https://ishizaka-group.co.jp/en/idea.php) is one of the leading companies recycling CDW into high-quality construction materials. In the factory near Tokyo CDW is sorted in great detail and recycled into products like building blocks, tiles, sand, crushed stone, wood chips and bedding material. The factory is fully covered by a roof, in order to minimize dust and noise in the surroundings and runs on renewable energy. It prides itself of its connection with the local community, in which it contributes to the maintenance of housing, a theater, large green areas and a theme park.
- The Tokyo Tama Regional Association for Waste Management and Resource Recycling is working with the Hinode-machi Town on the **Eco-Cement Project**. Eco-cement is a new type of cement produced from incineration ash resulting from waste incineration. Incineration ash has a high content of substances essential to cement, and a new technology was invented for using it as a material for cement. In July 2002, the Japanese Industrial Standard recognized it under the name eco-cement. Comparable with ordinary cement in terms of quality, eco-cement can be broadly used in civil engineering projects and various concrete products. https://www.tokyokankyo.jp/tokyoprogram/en/recycling-technologies/eco-cement/
- The Clean Association of TOKYO 23 runs an extensive **project on ash melting**, incl. the development of construction material based on the resulting slag. In various types of furnaces, bottom ash from combustible waste is melted at a temperature of over

1,200°C and rapidly cooled. The result is a sandy slag. As slag, the volume is almost half of that of ash and approximately one-fortieth of its original state as waste. The melting process decomposes dioxins within the ash and traps in the heavy metals, which make it safe to be used for construction material. The resulting slag has properties that resemble sand and can be used widely as a construction material such as skeletal material or backfilling of asphalt pavements or secondary concrete products. https://www.tokyokankyo.jp/tokyoprogram/en/recycling-technologies/ash-melting/

# 6 Annex

## 6.1 Plastic recycling technology development

Examples cited from (PWMI, 2016)

*Monomerization; from PET bottles to PET bottles*

- **Teijin Ltd**. uses its own proprietary decomposition method, combining ethylene glycol (EG) and methanol to break waste PET resin down into DMT (dimethyl terephthalate) to turn it the raw material used to make textiles and film. This technique was improved upon to break PET bottles down further from DMT to PTA (purified terephthalic acid) to make PET resin, and Teijin Fiber Ltd. commenced operation of a facility with the capacity to process around 62 kt a year in 2003. The resin produced was judged suitable for use in food containers by the Japanese Food Safety Commission in 2004, and bottle-to-bottle production started in April with the approval of the Ministry of Health, Labor and Welfare. Aies
- **Aies Co., Ltd**. has also developed a technique for manufacturing resin by breaking it down into high-purity BHET (bis hydroxyethyl-terephthalate) monomer using a new method of de-polymerization using EG. It established a new company, **PET Reverse Co**., Ltd. in 2004 which can process around 27.5 kt per year. However, a shortage in raw materials due to a dramatic increase in the export of waste PET bottles gave Teijin Fiber no alternative but to withdraw from bottle-to-bottle production. PET Reverse, meanwhile, has had to undergo a restructuring, and their bottle-to-bottle business is being carried on by PET Refine Technology Co., Ltd., a member of the Toyo Seikan Co., Ltd. group.

*Plastics used as a reduction agent*

The process by which plastics are used as a reducing agent is as follows. Plastic waste collected from factories and households is cleansed of non-combustible matter and other impurities such as metals, then finely pulverized and packed to reduce its volume. Plastics that do not contain PVC are granulated, then fed into the blast furnace with coke. Plastics that contain PVC are fed into the blast furnace after first separating the hydrogen chloride at a high temperature of around 350°C in the absence of oxygen, as the emission of hydrogen chloride can damage a furnace. The hydrogen chloride thus extracted is recovered as hydrochloric acid and put to other uses, such as acid scrubbing lines for hot rolling at steel mills. This dehydrochlorination method was developed by the **Plastic Waste Management Institute (PWMI), Japan PVC Environmental Affairs Council, Vinyl Environmental Council and JFE Steel Corporation (formerly NKK)** at the request of the **New Energy and Industrial Technology Development Organization (NEDO). JFE Plastic Resource Corporation** (founded in November 2005) has been applying this process in full-scale operations.

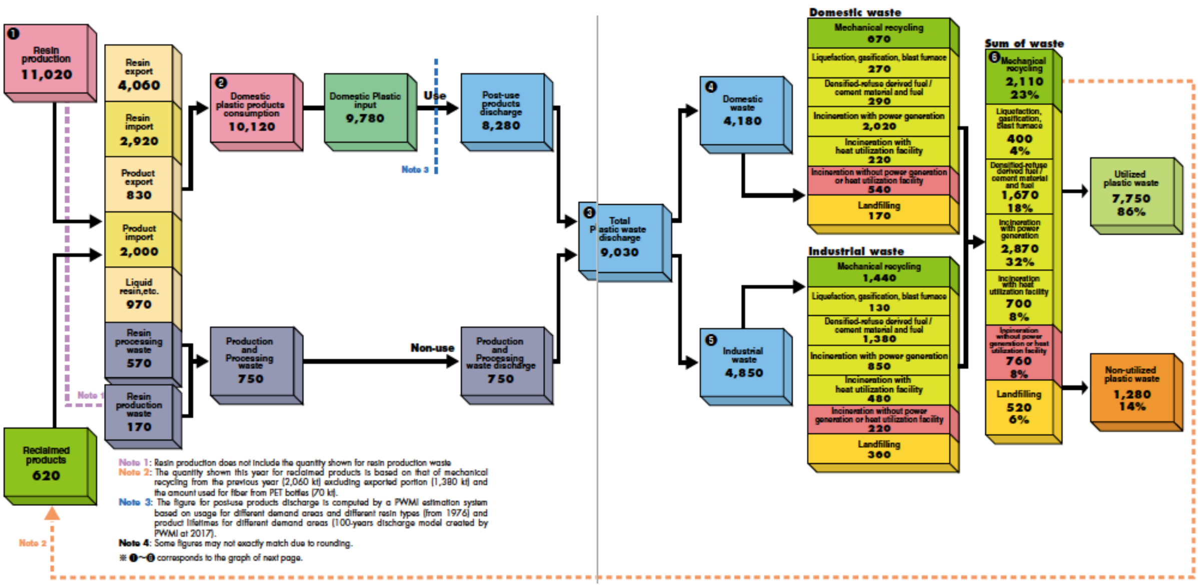
*Plastics waste reused in coke ovens*

Coke is made by baking coal, and the process also generates volatile compounds which produce hydrocarbon oil and coke oven gas. However, coke, hydrocarbon oil and coke oven gas can also be produced from plastic waste. **Nippon Steel & Sumitomo Metal Corporation** has developed facilities at most of its steel mills to use plastic waste as cokes, chemical feedstock and fuel, and it is now in use in its **Nagoya, Kimitsu, Muroran, Yawata and Oita sites**.

*Plastic waste converted to gas for use as a raw material in the chemical industry*
The Plastic Waste Management Institute (**PWMI**) was commissioned by New Energy and Industrial Technology Development Organization (**NEDO**) to conduct trials of this technology, which were performed with the cooperation of **Ebara Corporation and Ube Industries, Ltd. EUP Co., Ltd**. had a plastic gasification plant in full operation in Ube city in January 2001. Although EUP began full operation of this gasification process in 2001, difficulties in procuring raw plastic waste forced the company to withdraw from this business in May 2010. **Showa Denko K.K.** opened a facility in Kawasaki in 2003 using the same technology. Additionally, Japan Recycling Corporation Co., Ltd. implemented the JFE Thermoselect process in 2000 with the aim of using plastic waste as clean fuel gas. The same process was adopted in the form of a private financial initiative (PFI) waste business by **Mizushima Eco-works Co., Ltd** in 2005 and by **ORIX Environmental Resources Management Corporation** in 2006.

*Plastic waste converted back to oil*
**Sapporo Plastic Recycling Co., Ltd.** had been working to establish a liquefaction business with large-scale facilities, but they withdrew from the business in 2010. The research and development of plastic-waste liquefaction technology has had some achievements, but many issues remain, such as how to achieve a scale of business that is commercially viable and how to reduce costs. At present, any new ventures in the liquefaction business face difficult conditions. The above problems and issues must be thoroughly studied by any enterprise looking to adopt this technology.

## 6.2 Flowchart of plastic products, plastic waste and resource recovery



## 6.3 Summary of relevant policies

*Table 1. Overview of developments and policy documents regarding recycling and the circular economy*

| Year | Policy document | Key contents |
|---|---|---|
| **1971 – revised 2006** | **Waste Management and Public Cleansing Act** and **Act for Promotion of Effective Utilization of Resources** | The **Waste Management and Public Cleansing Act** is at the core of the waste management policy and regulations. The 2006 revised law regulates proper treatment of two basic categories of wastes in Japan: municipal solid waste and industrial waste. In both categories of wastes, it provides basic regulation on 1) reduction of waste generation as a basic principle, 2) promotion of proper treatment of waste (including recycling), 3) clarification of the responsibilities for waste management (municipalities for municipal waste and industry for industrial waste), 4) regulation for establishment of waste treatment facilities, 5) regulation for waste treatment operators, and 6) establishment of waste treatment standards.<br><br>The **Act for Promotion of Effective Utilization of Resources** is to promote recycling as well as other 2Rs (reduce and reuse). It defines actual implementation of the 3Rs in specific industrial sectors as well as in the specific products and recyclables. It demands promotion of the 3Rs to 10 different industrial sectors (such as pulp and paper industry, chemical industries, steel industries, non-ferrous metal industries, auto-mobile manufacturers) and 69 specific items (such as personal computers, small secondary batteries). |
| **1991** | **Recycling Promotion Law** | Introduction of planned recycling activities based on legal obligations. |
| **1995** | **Containers & Packaging recycling law** | The oldest of the individual laws setting standards for recycling of glass bottles, PET bottles, paper and plastic containers and other packaging materials. |
| **1993-1994** | **The Basic Environmental Act** (1993) and **Basic Environmental Plan** (1994, revised in 2000, 2006, 2012 and 2018) | The **Basic Environment Act** provides the overall framework for environmental policy including waste management and recycling. Some of the key principles of waste management such as Extended Producer Responsibility as well as Polluter Pays Principle are mentioned in the Basic Act as a responsibility of producers and businesses.<br><br>The **Basic Environment Plan** shows the basic direction of environmental policy, incl. targets, and is revised every six years. |
| **1997-2007** | The **Eco-town program** | The **Eco-town program** was established to create synergies between urban waste management and the promotion of recycling industries. Its key objectives were:<br>• to realize "zero waste", i.e. to minimize waste by recycling all waste and by-products into materials and using those in other industries.<br>• to help to revitalize the economies of local areas.<br><br>Aiming at environmentally-sustainable local development, the Ministry of Economy, Trade and Industry (METI) claimed that this program would promote environmental industry, industrial and technological accumulation, and an environmentally-harmonized social system. The eco-town program sought to promote competition among local governments to promote environmental management projects. Under the plan, local |

| | | |
|---|---|---|
| | | governments would develop plans in conjunction with other stakeholders and apply for recognition as an eco-town. The accepted plans would be subsidized jointly by METI and MOEJ. The eco-town program subsidized both "hardware" projects, such as product recycling or renewable energy facilities, and "software" projects, such as feasibility studies and awareness building. Although the applicant should be a local government, the project proposals would not be approved unless they included cooperative efforts of both business and local government.<br><br>The 26 eco-town projects (1997 to 2007) include Kawasaki City and Kita-Kyushu City. Also Tokyo is a 'super-eco-town'. |
| **2000 - 2003** | The **Fundamental Act and Plan for Establishing Sound Material Cycle Society** (2003, revised in 2008, 2013, 2018)<br><br>The Fundamental Act has been further developed into **specific regulations per product group**:<br>• Revised Containers and Packaging Recycling Act (2006)<br>• Home Appliance Recycling Act (1998)<br>• Food Recycling Act (2000)<br>• Construction Materials Recycling Act (2000)<br>• Act on Recycling of End-of-Life Vehicles (2002)<br>• Small Home Appliances Recycling Act (2008 and 2012/13) | The **Fundamental Act for Establishing Sound Material Cycle Society** is positioned as a law to supplement the realization of the idea expressed in Basic Environmental Act in the area of waste management and recycling and resource-efficient society. It defines the move from a '1R' to a '3R' policy. A 'Sound material-cycle society is defined as "a society in which the consumption of natural resources is minimized and the environmental load is reduced as much as possible by preventing products, etc., from becoming wastes, etc., promoting appropriate recycling of products, etc., when they have become recyclable resources, and securing appropriate disposal (as wastes) those recyclable resources that are not recycled."<br><br>The basic principles of a sound-material-cycle society and the order of preference for 'waste' management is defined as:<br>1. Reduce 'waste' generation (reduce)<br>2. Reuse 'waste' material<br>3. Recycle 'waste' materials<br>4. Incineration with energy recovery<br>5. Appropriate disposal<br><br>A variety of existing and new measures were placed within the framework of the Fundamental Act.<br><br>The **Fundamental Plan for Establishing a Sound Material-Cycle Society** establishes numerical targets based on material flow accounting (MFA)-based indicators, designates particular roles for stakeholders, and provides directions so that individual efforts will be consistent with the national goal of establishing a "sound material-cycle society". Three major indicators and targets set by the Fundamental Plan are:<br>• resource productivity (GDP/resource input),<br>• cyclical use rate [cyclical use amount/ (cyclical use amount+ natural resource input)], and<br>• amount of final treatment.<br><br>To realize the idea of Sound Material Cycle Society and to minimize waste generation, a **series of specific recycling laws** were introduced, targeting specific product categories. |
| **2000** | **Act on Promoting Green Purchasing** | The Original purpose of the **Green Purchasing Act** was to generate demands for products using recyclables. With specific recycling-related laws, Japan tried to establish collection and treatment systems for specific recyclables. However, without a market for recycled products, this didn't work. Hence the Green Purchasing Act was developed to build up a market for green |

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| | | products to close the loop. This law requires the national government, local governments, national institutes and agencies to promote the procurement of recycled products. |
| **2013** | **3rd B.P. on a sound material-cycle society** | The 3rd B.P. put more emphasis on promoting 2R (Reduce and Reuse) which has higher priority than Recycling. Also, it emphasizes the promotion of high-tech "horizontal (same product) recycling and international corporation for 3Rs in order to share Japan's long-standing experience and technologies. |
| **2018** | **5th Basic Environmental Plan** | Holds on to the principles of a sound-material-cycle society, but adds goals for 2030 and 2050 in line with the Paris Agreement and introduces the UN Sustainable Development Goals (SDGs) approach to address multiple challenges in an integrated manner. There is a strongly regional focus, introducing ***"Regional Circular and Ecological Spheres (Regional CES)"*** where each region is meant to demonstrate its strengths by utilizing its unique characteristics, building a self-reliant and decentralized society where different resources are circulated within each region and between regions, depending on their needs.<br>The plan sets 6 priority strategies (aspects of special relevance to recycling of plastics and CDW & a circular chemicals industry highlighted in **bold**:<br>1. ***Formulation of a Green Economic System for Realizing Sustainable Production and Consumption*** (Expand ESG investment and green bonds, Greening of the tax system, Service and sharing economy, Hydrogen derived from renewable energy, low-carbon hydrogen supply chain, **Use of urban mine**).<br>2. ***Improvement of Value of National Land as Stock*** (Resilient society including climate change adaptation, Ecosystem-based disaster risk reduction (Eco-DRR), Forest maintenance and conservation including use of special taxation, Compact cities, small hubs & renewable energy/energy saving, **Marine litter issues including microplastics**).<br>3. ***Sustainable Community Development Using Local Resources*** (Regional human capital, Expanding regional environmental finances, Improved balance of payments making use of resources and energy, Local revitalization centering on national parks, Conservation, regeneration and use of forests, the countryside, rivers and the sea involving cities, incl. coexistence and exchange<br>4. ***Realization of a Healthy and Prosperous Life*** (Switching to a **sustainable lifestyle and consumption** (ethical consumption, COOL CHOICE), Reduction of food waste, **appropriate treatment of waste**, Low carbon and healthy housing, Promotion of rural migration and dual-residence lifestyle & management of forests, the countryside, rivers and the sea, Conservation of a good living environment).<br>5. ***Development and Dissemination of Technologies Supporting Sustainability*** (Fukushima Innovation Coast concept (hydrogen production from renewable energy and floating offshore wind power generation), Logistics Revolution using unmanned autos and drones, **Production of high-value-added chemical products from biomass (cellulose nanofiber),** Productivity optimization with AI).<br>6. ***Demonstrate Japan's Leadership through International Contributions and Build Strategic Partnerships*** (**Exporting** |

| | | |
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| | | **environmental infrastructure**, Adaptation support through Adaptation Platform, Greenhouse gas observation satellite "IBUKI" (GOSAT) series, Support for building overseas sustainable society as a developed country facing various social and other challenges). |

## 6.4 Research projects Environment Research and technology Development Fund FY2017

Sound Material-Cycle Field total 39 research projects (MoE, 2017b):

- 3K153001 / Waste Prevention-System Analysis and Application
- 3K153002 / Study on Sustainability Assessment and Strategy for Improvement of Solid Waste Management System
- 3K153003 / Estimation of Substance Flows and Environmental Emissions of Chemicals Associated with Waste Incineration
- 3K153004 / Proposal of Disposal Standard for Long-term Environmentally-Sound Management of Mercury Waste
- 3K153006 / Application of Used Reverse Osmosis Membrane to Reclamation of Industrial Wastewater in Emerging Countries
- 3K153008 / Assessment of Sustainable Adaptation Measures to Manage Disaster Waste from Great Earthquake against Related Social Risks
- 3K153009 / Organization of Comminution and Separation Technologies for More Efficient Recycling System
- 3K153010 / Development of Anhydride-modified Resins Using the Properties of Recycled Plastic Containers and Packaging
- 3K153011 / A Trash Bin as a Gateway of Used Products to Waste Management System: Serviceability Analysis and Design Effect on Waste Disposal Behaviors
- 3K153012 / Development of a Dry Process for Refining Gallium Compound from Used LED Devices
- 3K153014 / Development of Novel Biofuel Production Process and Design Tools for its Sustainable Implementation
- 3K153015 / Study on the Accumulation Mechanism of Cesium in the Amorphous Phase around Mineral Particle in Incineration Bottom Ash and its Application
- 3J153001 / A Study for Reinforced Clinker-free Concrete Elements Comprising By-product Additives and Recycled Cement Produced from Wasted Fresh Ready-mixed Concrete
- 3K163001 / New Assessment Indicators and Indicator Framework for Establishing a Sound Material-Cycle Society
- 3K162002 / Development of Processes for Efficient Biogas Production from Organic Wastes by Induction of Electric Syntrophy
- 3K163003 / Development of the Utilization System for Captured Animals "Wild boar and Sika deer" by Appropriate and Efficient Processing
- 3K162004 / Selective Fragmentation of Photovoltaic Panels by High Voltage Pulse and Subsequent Physical Separation
- 3K163005 / Study on the Environmentally Sound Management of Wastes Containing Newly Listed POPs
- 3K163006 / Development of Quantitative Estimation Procedure for Disaster Debris in the Catastrophic Disasters in Collaboration with Disaster Prevention Research

- 3K163007 / Development of New Treatment Technology for Exhaust Gas Generated by Waste Incineration Using Carbonate Type Mg-Al Layered Double Hydroxides
- 3K162008 / Development of a Novel Recycling System for Precious Metals and Rare Metals Using Organic Aqua Regius
- 3K163009 / Study on Policy, Consciousness and Behavior to Improve the Effectiveness, Safety and Reliability of Disaster Waste Management
- 3K163010 / Development of PGM Recycling Processes without Emissions of Toxic Substances Including Nitrate-Nitrogen 3
- K163011 / Large-scale Disaster Waste Treatment and Management System Considering Disaster and Region Characteristics
- 3K162012 / Establishment of Appropriate and Efficient Disposal System for Captured Wildlife
- 3-1701 / Long-term Environmentally-sound Management of Treated Waste Consisting of Elemental Mercury in an Aboveground Facility
- 3-1702 / Principles and Practical Implementation of Quality Control for Recycling Waste Gypsum Board
- 3-1703 / Development of Advanced Recycling Technology for Fly Ash to Enable Cement-free Concrete
- 3-1704 / Material Flow Analysis of Prefectures to Promote Sound Material Cycles by Use of Data in Official Reports Collected for Waste Management
- 3-1705 / Research of Creation and Practice of High Value-added Recycling Technology on Waste Plastics
- 3-1706 / Modification of Recycled Resin Using Nanocellulose-based Waste Materials
- 3-1707 / Test and Design Methods for Safe and Sustainable Inert Waste Landfills
- 3-1708 / Development of Rational Recycling Technology for Laminated Hard-to-Handle Panels such as PV and LC 3-1709 / Study on Technologies and Social Systems for Efficient Utilization of Heat Recovered from Waste
- 3-1710 / Development of Organic Solvent Free Separation Techniques to Create High Efficiency Recycle Systems for Critical Metals
- 3-1711 / Recovery of Carbon Fiber from CFRP by Two Stage Low Temperature Gasification
- 3RF-1701 / Separation Process Development for Poly (Vinyl Chloride) and Copper Recovery from Wire Harness
- 3J173001 / Practical Development of Resilient Landfill for Prompt Recovery Restoration from Earthquake
- 3J173002 / Development of Surface Treated Wood Powder for WPC Using
- Harmony

## 6.5 Plastic to fuels technology companies

Based on the table of contents of market research reports[2,3] and Ricardo (2017), global key players in plastics to fuel technology have been identified:

**China**

Shangqiu Sihai Machinery Equipment Manufacturing Co., Ltd. is a professional manufacturing enterprise with over 10 years experience in waste tire/rubber/plastic recycling production line.

Beston (Henan) Machinery Co., Ltd. researches, develops, updates and manufactures waste recycling plants to improve the environment and create profits. Their waste tire pyrolysis plant has been exported to 20+ countries. They also developed a waste rubber pyrolysis plant, which can also deal with many other waste materials, such as tires, plastics, medical waste, oil sludge, etc.

**US**

Agilyx – has sold their technology to three customers in the United States who operate on a commercial scale.

Vadaxx energy recovery technology converts plastic waste into a valuable commodity and creates a source of renewable energy from a plentiful feedstock. They have a first plant in operation in Akron (Ohio)

Plastic2Oil has 3 small operational facilities in the USA that use a feedstock that of unwashed, unsorted waste plastics

Green Envirotec Holdings LLC developed an environmentally sustainable pyrolysis technology that converts scrap tires and waste plastics into valuable commodities; carbon black, steel and oil.

Plastic Advanced Recycling Corporation (P.A.R.C) is an Illinois corporation formed in June 1996 as a research and development company specializing in pyrolysis technology that converts waste plastics to fuel oil.

Gingery is a global manufacturer of waste-to-energy equipment. Our mission is to deliver innovative, efficient, profitable and environmentally responsible solutions that convert Waste into Fuel and Energy and achieve Zero Waste. GGI has one plant in Japan.

**Canada / Japan**

Klean Industries is specialized in the design, manufacture, and installation of advanced thermal treatment facilities using carbonization, liquefaction, pyrolysis, and gasification technologies to produce clean energy products. Klean Industries utilizes the combined technologies and expertise of several different and unique Japanese engineering companies which previously specialized in quite different market sectors - namely thermal structural engineering, waste management and oil refining. This combined, multi-industry

[2] https://www.grandviewresearch.com/industry-analysis/plastic-to-fuel-market

[3] https://www.prnewswire.com/news-releases/the-plastic-to-fuel-technologies-market-forecast-2019-2029-300810348.html

background has allowed Klean Industries to develop a technologically unique range of waste recycling products and systems.

Klean Industries has 3 small scale facilities in operation in Japan, Germany and Canada. Klean Industries established a fully commercial plastic liquefaction facility in 2000 in Japan, with the capacity to recycle over 50 tons a day of mixed plastic waste. A 50tpd facility is expected to recover 90% of total plastic input (15,000tpa), produce 4 MWe of electricity, 8.75 million liters of high liquid fuel and 4 MWe of thermal energy and 3,000 tpa of solid residue.

In Japan, Sapporo Plastic Recycling ("SPR"), utilizing Klean Industries Technology, established a fully commercial plastic to fuel facility on the island of Hokkaido in 2000 (as shown in Figure 3-12) that has the capacity to recycle over 50 t/day of mixed plastic waste (Ricardo, 2017).

**UK**

Recycling Technologies has engineered a modular and scalable machine – the RT7000 - to chemically convert plastic waste, which currently cannot be recycled, into Plaxx® - a valuable hydrocarbon product. The machine is sized to be installed at existing waste sites and recycling centers, diverting residual plastic waste from ending up landfilled, incinerated or exported overseas. Recycling Technologies is engineering the RT7000 and developing the required technologies at its Facility in Swindon, UK.

**India**

Rudra environmental solution Ltd. has been involved in research of converting waste plastic into fuel technology through TCD i.e. Thermo Catalytic Depolymerisation Process. The first pilot plant was established in March 2010, second-generation plant in 2013 and now its patented third generation plant is running successfully in company's own factory situated in Jejuri M.I.D.C. area.

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**Factsheet**
September 4, 2019

# RECYCLING IN GERMANY

Information and knowledge gaps on waste management, policies and innovation

# Contents

# 1 Introduction

The Ministry of Economic Affairs & Climate Policy and the Topsector Chemistry will visit Germany on 9-11 September 2019. The goals of the mission are: learning from each other and exploring opportunities for German-Dutch co-operation for recycling and electrochemical conversion and materials (ECCM).

As a preparation for the mission, this fact sheet was prepared. It summarizes the available knowledge on German waste management, waste, recycling and energy policies, and the innovation landscape. Most information is on the national level. Where available, information on the state Nordrhein-Westfalen – bordering on the Netherlands and the largest industrial employer in Germany – has been included.

The focus lies on the policies for waste, recycling and energy with reference to the wider areas of resource efficiency and circular economy where appropriate. The fact finding is limited to building materials and plastics, as these have been selected by the Topsector as the focus for the mission.

The information in this document is based on desk research of public documents only (see 7.1). The information that was gathered, typically is coarse-grained and not always up-to-date. Therefore, as a guide for further fact finding, some questions and talking points for the discussion partners have been included.

## 1.1 How to read the document

The information in this fact sheet is divided in three broad themes: general information on waste management in Germany (Chapter 3), an overview of the relevant policies (Chapter 4) and information on the innovation landscape (Chapter 5).

# 2 Questions and talking points

In this section, possible questions and talking points for the discussion partners are listed, based on the knowledge gaps that were identified in the desk research. The questions are briefly introduced with a reference to the section where more details can be found.

## 2.1 Questions on waste management

**Germany has a new law on packaging since January 1st. One of the goals is more and better recycling.**

- *Can you tell us more about the governance of recycling system in Germany and how Bund and Länder work together in your national ambitions?*
- *What are your specific instruments in this and how do you monitor progress?*
- *How do you use statistics on material flows and waste handling in in target setting and improving policies?*
- *Are you planning in introducing more specific recycling rates for subcategories of waste e.g. plastics and polymers?*
- *For construction and demolition waste recycling rates are as high as 89% on a general level. In what direction should future efforts be heading for these materials?*
- *What role can R&D play reaching the targets of the new law?*

**Germany appears to export around the same amount of waste as it processes in-country (~20 million tonnes), and also imports around the same amount.**

- *What are the reasons for trading such large amounts?*
- *Is the German waste management sector specializing in processing certain types of waste?*

## 2.2 Questions on policies

**German policies are guided by the concept of a circular economy ("Kreislaufwirtschaft", see section 5).**

- *What are your principles in this concept of CE?*
- *Is this concept confined to resource efficiency / resource protection only?*
- *Do you feel this tackles the problem effectively and efficiently, as in the NL we focus more on the whole value chain and product cycle to reach our goals?*
- *Do you use aspects of eco-design or design-for-recycling when introducing new policies on CE?*
- *What role does design play in the overall CE strategy and how is this implemented?*
- *Is Germany considering to broaden the concept of CE to cover the entire production and value chain so that companies are better involved and recycling initiatives of innovative entrepreneurs are better (earlier) valued and deployed?*
- *What is the political support in Germany for the different concepts of CE? Do you use aspects of eco-design or design-for-recycling when introducing new policies on CE?*
- *There are several ways to make plastics better suited for recycling. Another aspect is that of additives, such as colorants, weakeners, fire retardants. These (often) hazardous substances, also complicate the recycling process. What policies are developed to improve recyclability of plastics? How is producer responsibility implemented?*

## 2.3 Questions on innovation landscape

- Germany has a new law on packaging since January 1st. One of the goals is more and better recycling. At this point we are aware of several specific research programmes of the BMBF (Plastik in der Umwelt) and the BMWi (on CO2 reduction). Are you considering to support the new law on packaging with a broad research programme to strengthen and improve the recycling effort?
- Recently, several universities (including Karlsruhe Institute für Technologie, which we have visited on Monday) have been awarded the status of "Exzellenz-Uni". Has the relevance of their research for addressing societal challenges, such as Circular Economy or Climate, played a role in the decision to award this status?
- Do you see a need for an EU research and innovation programme on recycling?
- With which (EU and other) countries could Germany and The Netherlands collaborate in taking the lead to create a circular economy?

# 3 Waste management in Germany

## 3.1 Facts and figures: waste management

Germany has high the highest recycling rates in the world*: 67 per cent for household waste, around 70 per cent for production and commercial waste, and almost 90 per cent for construction and demolition waste. Waste management in Germany has evolved into a large economic sector. There are more than 270,000 people working in some 11,000 companies with an annual turnover of around 70 billion euros. More than 15,500 waste management facilities help to conserve resources through recycling and other recovery operations. (BMU, 2018).

Germany also has the highest waste production worldwide. Total amount of waste generated in 2015 is 351.2 mln tons, 60% of which is construction and demolition waste. The total amount of waste has dropped since the year 2000, which saw 406.7 mln tons of waste (BMU, 2018, Figure 1).

Fig. 1: Waste generation in Germany 2000 – 2015

Including hazardous waste


* These high numbers have been challenged in a critical study by Eunomia and the European Environmental Bureau, who have recalculated actual recycling rates reported by leading recycling countries. But even after correcting the numbers to what these environmental analysts consider the real recycling rates, Germany still comes out on top of the world, at a 56% recycling rate. See https://www.eunomia.co.uk/countries-reporting-highest-recycling-rates-challenged-by-new-research/

The waste collection rate varies between types of waste. Packaging waste for example is being extensively sorted in different recyclable and non-recyclable fractions, with a collection rate of close to 100% (BMU, 2018, Figure 8).

The concept and implementation of the 1991 Packaging Ordinance have earned a great deal of attention internationally. The German Ordinance gave rise to the implementation of national measures in neighbouring states such as Austria, the Netherlands, Belgium and France, which in turn inspired the adoption of the European Directive 94/62/EC on Packaging and Packaging Waste of 20 December 1994 that is now legally binding for all EU member states. (BMU website a, accessed 1 September 2019).

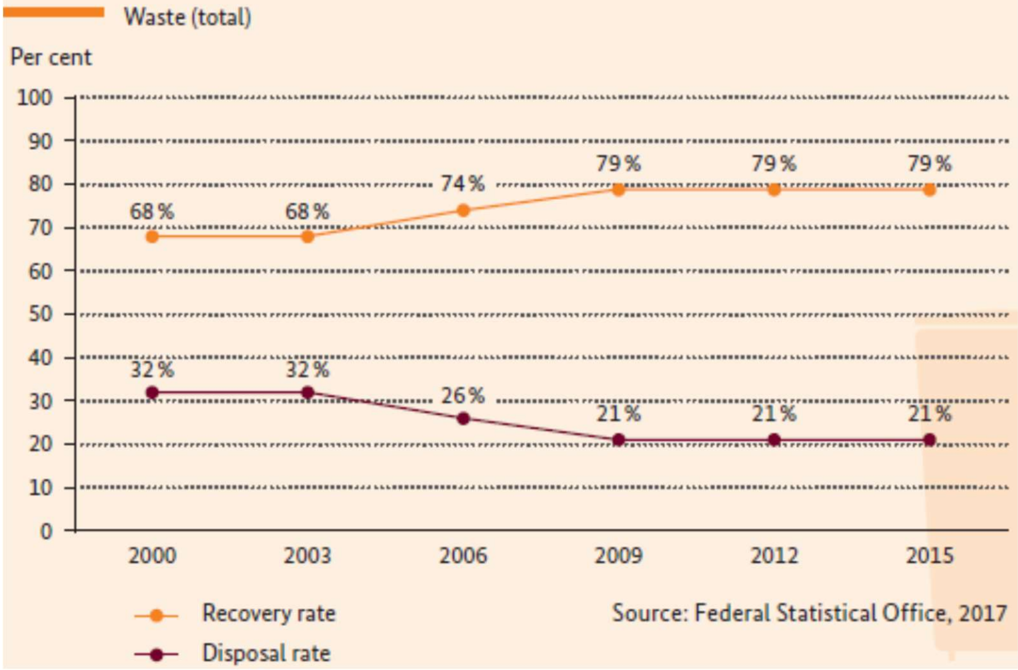
The effect of the 1991 Packaging Ordinance on recovery rates of different types of packaging materials is clearly visible in the figure below.

**Fig. 8: Development of recovery rates of packaging waste 1991 – 2015**


Source: Gesellschaft für Verpackungsmarktforschung mbH (GVM), 2017

When waste is recycled or otherwise productively applied, the German federal government refers to it as "recovery". The overall waste recovery rate was 79% in 2015 (BMU, 2018, Figure 3).

Fig. 3: Recovery and disposal rates 2000 – 2015




Non-recoverable waste must be disposed of safely in Germany. Before being landfilled, organic waste undergoes mechanical-biological or thermal treatment to render it inert and minimise the release of leachate and landfill gas. The landfilling of untreated organic waste has been banned since mid-2005.

In 2017, there were 68 waste incineration plants operational in Germany with a capacity of around 20 million tons (or 54.8 kt/d), as well as 32 substitute fuel plants with a combustion capacity of around 5 million tons (13.7 kt/d). In 2017, 45 bio-mechanical waste treatment plants with a capacity of around 5 million tons (which equals 13.7 kt/d) treated some 4.5 million tons of waste, only around 0.5 million tons of which ended up in landfill. (BMU, 2018)

According to BMU (2018), up to 68 per cent of typical household waste is already recycled. The new calculation method under EU regulations will result in numerically lower recycling rates. Germany is committed to increasing recycling rates in the future.

Germany both imports and exports substantial amounts of waste in comparison to its own waste processing capacity. In 2015, over 22 million tons of waste were imported into the country, of which a little over 6 million tons required a permit. In the same year, around 23.5 million tons of waste were exported, of which 2.5 million tons required a permit. (Federal Statistics Agency 2017, downloaded from BMU website b on 1 September 2019)

## 3.2 Facts and figures: plastics

More than 5.68 million tons of plastic waste were generated in Germany in 2013, over 4.75 million tons of it household or commercial waste. The remaining 0.93 million tons were production and processing waste. The lion's share of plastic waste (1.4 million tons) was attributable to packaging. (Umweltbundesamt website a) The website Environmental Expert lists 50 companies in Germany in the field of plastic recycling.

The figure below (CONSULTIC Marketing & Industrieberatung GmbH 2014, downloaded from Umweltbundesamt website a) shows that of all the plastic waste flows generated in Germany in 2013, 99.2% was recovered and only 0.8% was disposed of.

**Generation and treatment of plastic waste in Germany in 2013, classified by its origin in thousand t**

| Origin | Waste generation | Recovery | Disposal |
|---|---|---|---|
| Commercial waste collected by private waste management companies | 1.103 | 1.088 | 15 |
| Sales packaging (DSD and other Systems) [1] | 1.455 | 1.455 | 0 |
| Household residual waste | 917 | 903 | 14 |
| Household-type commercial waste collected by companies responsible for public waste management | 197 | 193 | 4 |
| Houselhold bulky waste [2] | 201 | 200 | 1 |
| Recyclable materials collected by companies responsible for public waste management [3] | 56 | 56 | 0 |
| Shredder facilities (only end-of-live vehicle bodies) incl. automotive recovery and repair companies | 183 | 177 | 6 |
| Recyclable materials: electric-/electronic scrap from private households, commerce and industrie (take-back by companies responsible for public waste management, by commerce and by private waste management companies) | 175 | 175 | 0 |
| Collection and recovery systems for commercial packaging (incl. transport and secondary packaging) | 357 | 357 | 0 |
| Other collection and recovery systems (AGPR, Plastic Pipe Association, roofing, sheets, Rewindo, etc.) | 103 | 103 | 0 |
| Plastics Production | 74 | 72 | 2 |
| Plastics Processing [4] | 858 | 856 | 2 |
| **Total** | **5.679** | **5.635** | **44** |

Source: CONSULTIC Marketing & Industrieberatung GmbH - Produktion, Verarbeitung und Verwertung von Kunststoffen in Deutschland 2013 (status as of September 2014)

[1] including sorting residues for thermal recovery

[2] for example furniture, carpets, "white goods", "brown goods" etc.

[3] diverse plastic products (like pipes, containers, foils from households and commerce)

[4] waste from plastic processors (for example extrusion, injection moulding) and from further processing (for example window construction)

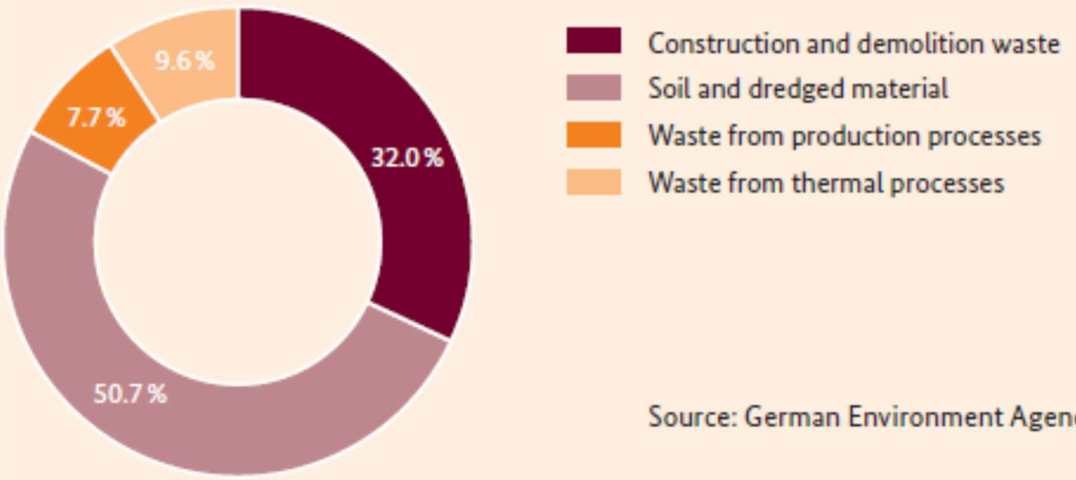
## 3.3 Facts and figures: construction and demolition waste (CDW)

Mineral wastes are the largest waste stream in Germany, with an annual volume of more than 275 million tons. They include construction and demolition wastes (32%, BMU, 2018, Figure 17) and excavated soils, as well as slags and ashes from incineration processes in energy and metal producing industries. A significant fraction of mineral wastes is used by the construction industry, where they substitute primary construction materials, for example as recycled grit in construction materials, as a substitute for landfill construction materials or as backfill material in open pit mining.

Currently, there is no federal regulation on the production and use of mineral wastes as substitute construction material in Germany. The Federal Government is planning to introduce the Substitute Construction Materials Ordinance, designed to promote the use of secondary raw materials, thereby strengthening the circular economy and preserving valuable primary raw materials. The secondary raw materials used for construction are strictly controlled in order to protect valuable soil and groundwater resources, and to prevent the unintentional release of environmentally hazardous substances.

**Fig. 17: Distribution of mineral waste**

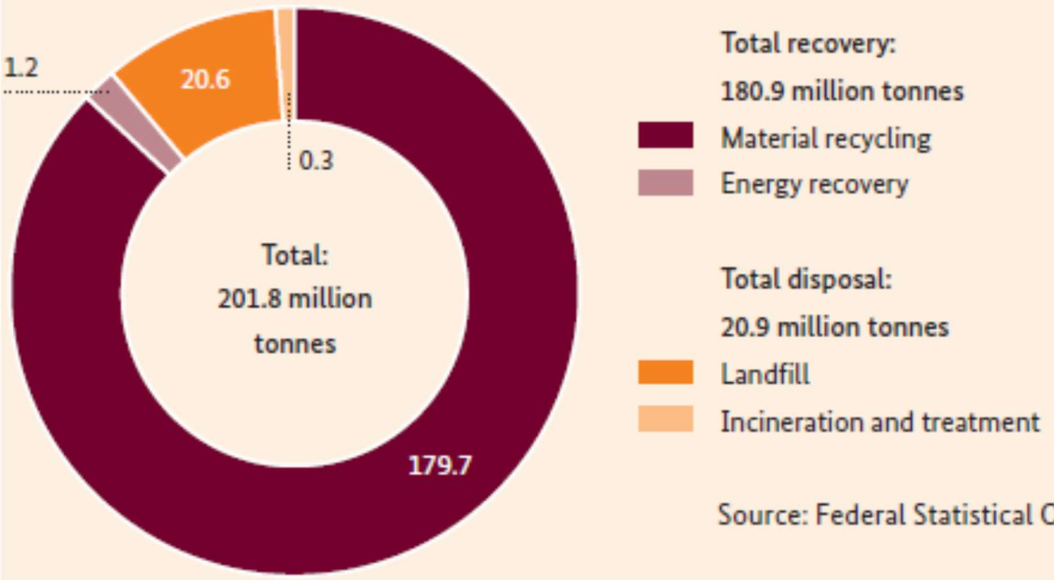
As a percentage




Source: German Environment Agency, 2017

**Fig. 6: Construction and demolition waste 2015**

Including non-hazardous road construction waste, in million tonnes




Source: Federal Statistical Office, 2017

## 3.4 Waste management system

**Germany's waste management industry is booming (see 3.1). Some of these are municipal companies, others are privately owned. This dual public-private system is based on Germany's 1991 packaging law (the "Verpackungsordnung"), and the industry-funded Green Dot recycling scheme. This means that German municipalities and companies jointly recycle German waste. Companies add the Green Dot logo to packaging they promise to collect and then recycle.**

No national visions are developed in Germany. The highest level op cooperation exists at the level of the individual states (Länder). The federal government typically sets a framework, within which the states and municipalities come up with their own programmes. An example of this is the programme for resource efficiency ProGress (see Ressourcen Effizienz Programm). The states have now been asked to come up with their own programmes for this.

Municipalities are supported with information by the German Federal Government, such as the report "Regional and local optimisation of material flows and cycles" by the Umweltbundesamt published in July 2019.[†] The UBA also regularly publishes environmental monitoring information, such as the study "Kunststoffe in der Umwelt" in June 2019.[‡]

[†] https://www.umweltbundesamt.de/en/publikationen/regional-local-optimisation-of-material-flows

[‡] https://www.umweltbundesamt.de/en/publikationen/kunststoffe-in-der-umwelt

# 4 Policies

Germany has a hierarchical structure of regulations regarding waste management, with EU regulations at the top of the hierarchy and municipal regulations at the bottom. According to the Bundesumweltamt (website b), the following laws apply:

## 4.1 European laws

Waste disposal is governed by a number of European regulations and directives, whereby the former automatically apply to each of the member states, while the latter must be separately transposed into national law by each member state. The basis of this legal framework is the Waste Framework Directive (2008/98/EC), which defines the main waste-related terms, lays down a five-step waste hierarchy (see figure below[§]), and contains key provisions for German waste disposal law.


## 4.2 German Federal law

Germany's first uniform national waste disposal act, the Abfallbeseitigungsgesetz (AbfG), was adopted in 1972. Producer responsibility was first laid down in 1991 in the Packaging Ordinance. It includes the obligation to take back packaging after use. The Closed Substance Cycle and Waste Management Act of 1996 comprehensively extended these policies. The Law on Closed Cycle Management and Waste (in German: "Kreislaufwirtschaftsgesetz", or KrWG for short) is today Germany's main waste disposal statute (and the successor to the AbfG act).

**The KrWG, also referred to as the Circular Economy Act, entered into force on 1 June 2012 and explicitly includes the ambition to develop a circular economy. Its first article states "The purpose of this Act is to promote circular economy in order to conserve natural resources and to ensure the protection of human health and the environment in the generation and management of waste."**

**One of the core provisions of the KrWG is the five-step (previously three step) hierarchy pursuant to Article 6, which copies essentially the hierarchy laid down in the EU Waste Framework Directive presented in the figure above.**

**As of 1 January 2015, sorting is mandatory for organic waste, as well as for paper, metal, plastic and glass. With a view to promoting recycling, Article 14 of the KrWG sets so-called recovery rates that will become mandatory in 2020: 65% for municipal waste and 70% for construction and demolition waste (CDW).**

The German federal government has not set specific goals, except the goal to increase the recycling of packaging from 36% to 63%. The Umweltbundesamt has published an advice about substitution quotes (Umweltbundesamt, 2019).

The Waste Management Act (KrWG) is supplemented and fleshed out by a number of other regulations such as the Abfallverzeichnis-Verordnung regulation which lists the types of waste that are classified as hazardous, and those that are classified as non-hazardous. Hence this regulation fleshes out the monitoring provisions of Article 47 ff. of the Waste Management Act (KrWG). Disposal of specific types of product waste (respectively end-of-life vehicles, used batteries and

[§] Figure copied from https://ec.europa.eu/environment/waste/framework/

end-of-life electronic and electrical devices) is governed by the ELV regulation (AltfahrzeugV), Batteriegesetz (BatterieG) and Elektro- und Elektronikgerätegesetz (ElektroG).

### 4.3 State law of German regions (Bundesländer)

The Waste Management Act (KrWG) is further differentiated by the waste management acts of the Bundesländer. However, due to the fact that, under the German Constitution, the federal government is charged with regulating waste disposal related matters (Article 74(1)(24)), the regional states only have jurisdiction over those aspects of waste disposal that are not already regulated by federal law. Hence legal prescriptions in the states' laws tend to address implementation-related matters such as the following: determining which entities are subject to waste disposal obligations; the authorizing bodies for waste disposal matters; and municipal waste disposal ordinances.

### 4.4 Municipal waste disposal ordinances

The collection and recovery of household waste at the municipal level are governed by municipal ordinances concerning matters such as usage and integration into the public system, as well as municipal garbage collection charges.

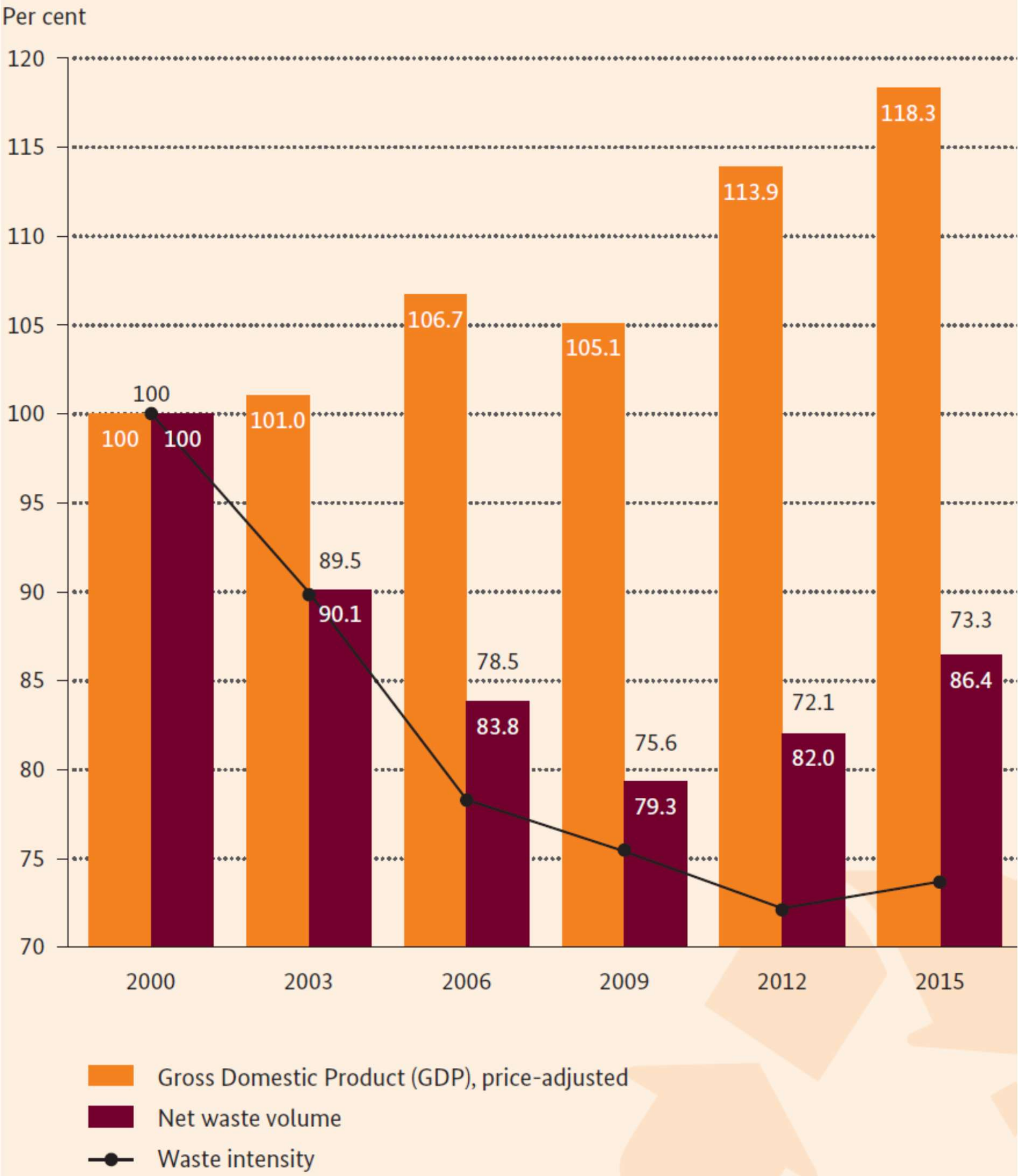
Since 2000, the ratio of waste generated to GDP is been significantly reduced (see BMU, 2018, Figure 2 on the next page). As the figure shows, the drop in absolute waste volumes since 2000 presented in Chapter 4 of this factsheet, is connected to an even strong reduction in the "waste intensity" measured by Germany's Federal Statistics Office. Prevention of waste is a key objective of the federal government and thus also measure with a concrete indicator.

In 2013, the German government and the Federal States (Länder) adopted a programme of public-sector measures designed to reduce waste volumes, as required by Article 33 of the KrWG. The Waste Prevention Programme will be revised and updated in 2019. Raising awareness and sensitising the general public to effective waste prevention is a key part of the waste prevention policy. Each year in November, Germany stages its own series of events to mark the European Week for Waste Reduction, highlighting what can be achieved through individual activities, ideas and commitment. As an example, many retailers have voluntarily introduced a plastic bag charge, reducing Germany's consumption of plastic bags from around 72 bags per person, per year to around 38 bags.

**Policies related to recycling and waste management are mostly developed by the following government bodies:**

- Ministry of Environment (BMU) - Major coordinating ministry
- Ministery of Economic Affairs and Innovation (BMWi) - Technology development and enterprise support
- Ministry of Education and Research (BMBF): R&D&I supporting BMU and BMWi policies
- German states (Bundesländer) and municipalities

**Fig. 2: Severing the link between waste volumes and economic output 2000 – 2015**



# 5 Innovation landscape

## 5.1 International aspects

As an EU Member State, Germany's legal framework for waste management follows the EU's Waste Framework Directive (2008/98/EC) and other applicable EU legislation. Its innovation landscape also benefits from the EU programmes for innovation, most prominently Horizon2020 and its successor as of 1 January 2020, Horizon Europe. 28.6% of all approved Horizon2020 projects has at least one German partner. Of these 6,389 projects, there are 2,117 (or 33%) that have also a Dutch partner. Specifically on the theme ***Climate action, environment, resource efficiency and raw materials*** there are 245 approved projects with at least one German partner, of which a small majority (133 projects) also feature at least one Dutch partner. Also, one approved project exists in which German and Dutch partners collaborate on the theme ***Anticipating and assessing potential environmental, health and safety impacts (IMPACT)***.

Germany also participates in a number of international collaborations related to the theme of waste management and recycling, including, but not limited to:

- Climate and Clean Air Coalition/Municipal Solid Waste Initiative
- G7 Alliance on Resource Efficiency
- G20 Resource Efficiency Dialogue
- OECD Working Party on Resource Productivity and Waste
- UNEP International Resource Panel
- World Circular Economy Forum (October 2018)

## 5.2 Universities

There are many research institutes and research universities in Germany that have activities in the area of recycling. The followings are the examples of such research institutes/coordination bodies.

- Forschungszentrum Jülich GmbH, Ressourcen und Nachhaltigkeit – https://www.fz-juelich.de/portal/EN/Home/home_node.html
- Fraunhofer-Institut für Chemische Technologie ICT – https://www.ict.fraunhofer.de/en.html
- Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik (UMSICHT) – https://www.umsicht.fraunhofer.de/
- Karlsruhe Institut für Technologie - https://www.kit.edu
- Max Planck Institute for Polymer Research – http://www.mpip-mainz.mpg.de/home/en
- Nova Institute: a partner in various research projects within the field of bio-based chemistry, materials and biotechnology – http://nova-institute.eu/
- DWI - Leibniz-Institut für Interaktive Materialien – https://www.dwi.rwth-aachen.de/
- RWTH Aachen, Department for Processing and Recycling – http://www.iar.rwth-aachen.de/go/id/eeby/?lidx=1
- VDZ Research Institute for the Cement Industry – https://www.vdz-online.de/en/vdz/research-institute/

## 5.3 Research programs

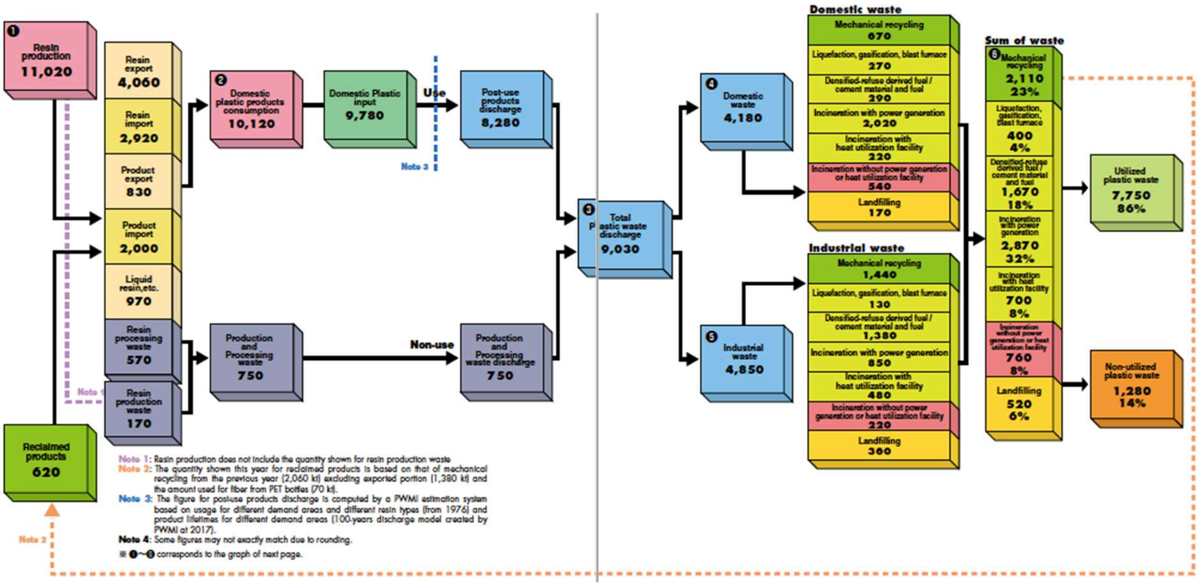
**Relevant German research is funded through:**

- BMBF:
    - CO2 als nachhaltige Kohlenstoffquelle – Wege zur industriellen Nutzung (CO2-WIN): https://www.bmbf.de/foerderungen/bekanntmachung-1875.html
    - Plastik in der Umwelt: https://bmbf-plastik.de/ en https://bmbf-plastik.de/de/querschnittsthema-6

- BMWi:
    - https://www.bmwi.de/Redaktion/DE/Artikel/Industrie/weitere-entwicklung-ccs-technologien.html

# 6 Annex

## 6.1 Flowchart of plastic products, plastic waste and resource recovery

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BMU website b (no date). https://www.bmu.de/en/topics/water-waste-soil/waste-management/waste-management-statistics/general-waste-management/transboundary-shipment-of-waste/ Accessed on 1 September 2019

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# RECYCLING IN THE USA

waste management, policies and innovation


# Contents



**Cover photos**

Nexus Fuels
Digestor eggs of the Newtown Creek wastewater treatment plant
Recyclables make their way through the Sims Municipal Recycling Facility | Photo by Varick Shute

# 1 Introduction

The Ministry of Economic Affairs & Climate Policy, Ministry of Infrastructure and Water Management, and the Topsector Chemistry planned to visit the USA in March 2020. The goals of the mission are learning from each other and exploring opportunities for American-Dutch co-operation for recycling. Due to the Corona crisis, this mission was cancelled.

As a preparation for the mission, this fact sheet was prepared. It summarizes the available knowledge on American waste management, waste and recycling policies, and the innovation landscape with a focus on (advanced) plastic recycling[1]. Most information is on the Federal level. Where available, also specific information on California, Washington D.C. and New York City has been included.

The information in this document is based on desk research of public documents (see 7.1). The information that was gathered typically is coarse-grained and not always up-to-date, and should be considered as a guide for further fact finding.

# 2 How to read the document

The information in this fact sheet is divided into three broad themes: general information on waste management in the USA (Chapter 3), an overview of the relevant policies (Chapter 4) and information on the innovation landscape (Chapter 5). The latter ranges from the universities and their research programs to the economic actors and their investments in technology. These chapters contain the information in a summarized format and refer to specific sections in the Annex (Chapter 6) for a more complete overview.

[1] The term "chemical recycling" is not used in America.

# 3 Waste management in the US

## 3.1 Facts and figures

**Municipal solid waste (MSW). The US in comparison to other countries**

According to the World Bank report "What a waste 2.0" (Kaza et al., 2018) Americans produce more waste than any other nation in the world. With more than 260 million tons per year (2014) they contribute about 14% to the total global waste production. The average American produces 810 kg waste per year, which is more than twice the amount generated by a Japanese person and more than 5 times the amount generated per capita in China. Figure 1 shows a comparison of waste generation data between countries.

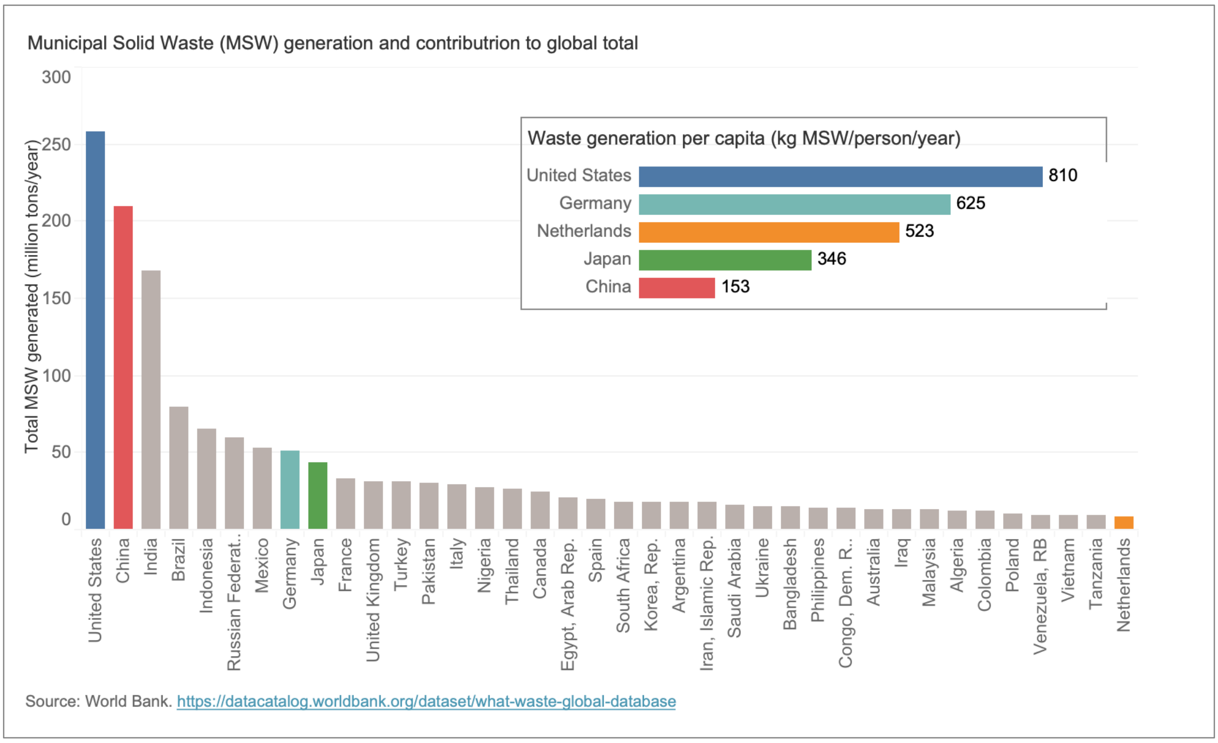


*Figure 1. Municipal solid waste generation. Source: World Bank*

**Waste management trends in the US**

To show the trends in waste management, we use the most recent data from the EPA (Figure 2). The total generation of municipal solid waste (MSW) in 2017 was 267.8 million short tons.[2] Except for the recession years, the US generation of MSW has increased from 88 million tons in 1960 to 268 million tons in 2017.

The dominant waste handling method is landfill: in 2017, 52% of MSW was landfilled. Since 2000, the amount of MSW being landfilled has remained almost stable, as have the amounts of MSW being incinerated with energy recovery. Composting and recycling of MSW have increased.

As shown in Figure 2, plastics contribute circa 35 million tons to the total MSW waste that is generated and show a rapid and continuous increase compared to other product materials such as e.g. paper or glass. Presumably, most of the plastics being recycled are HDPE and PET bottles & jars,

[2] Conversion: 1 US ton or short ton = 0.907 metric tons.

which both have relatively high recycling rates: 31.2% for HDPE and 29.1% for PET bottles & jars (EPA, 2017, 2019).

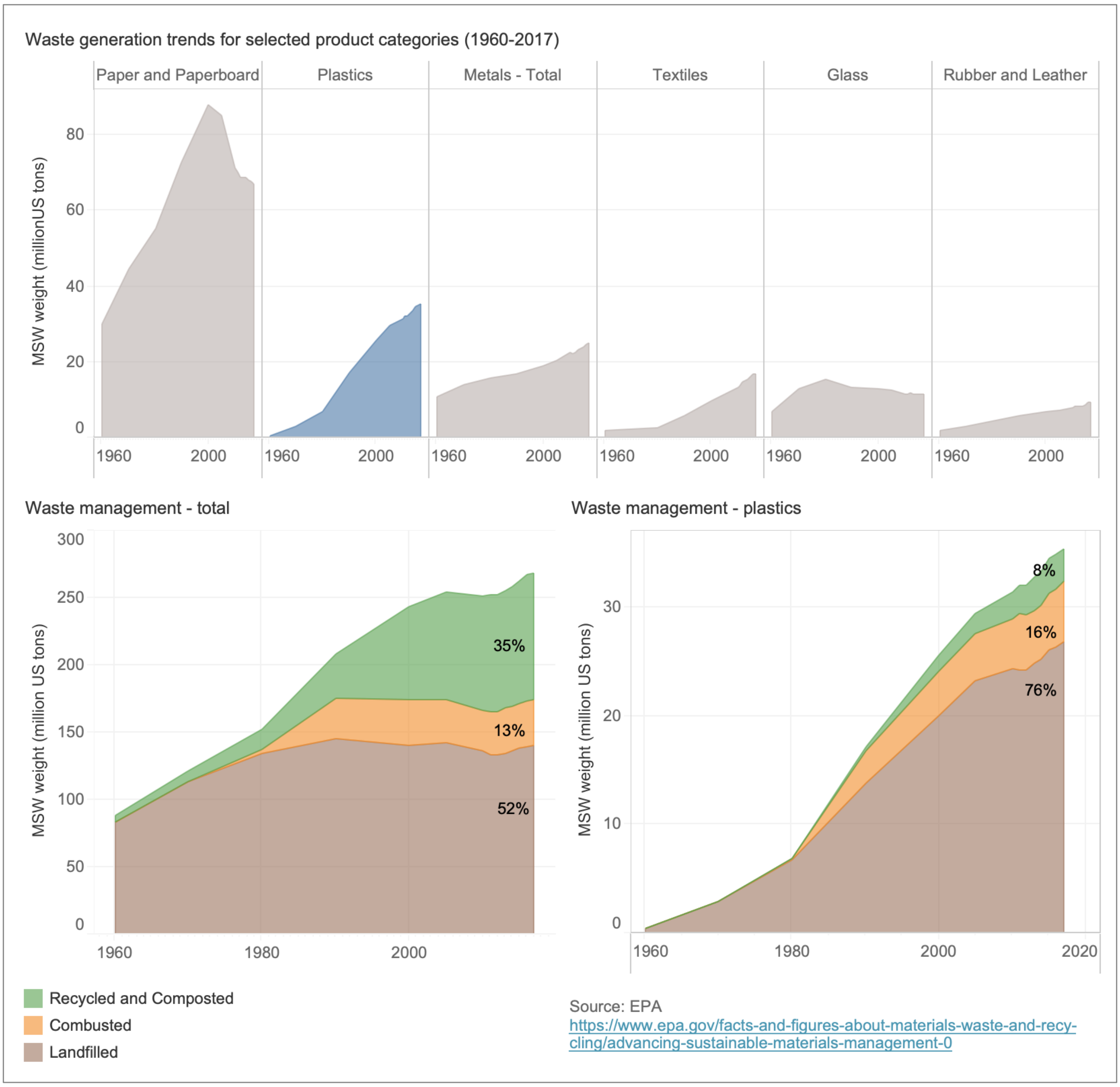


*Figure 2. Municipal solid waste management 1960-2017. Source: EPA*

According to a study compiled by Verisk Maplecroft, a research firm that specializes in global risk, the United States, shows a significant lack of commitment to offsetting its waste footprint. This conclusion is based on their Recycling Index (REI), which captures the willingness and ability of countries to manage solid waste and promote circular material flows by measuring national rates of recycling, collection and adequate disposal, as well as government's commitment to international treaties on waste.[3]

[3] https://www.maplecroft.com/insights/analysis/us-tops-list-of-countries-fuelling-the-mounting-waste-crisis/

*State level data*

The EPA maintains a list of state and local waste and material characterization reports.[4] These reports, however, do not consistently present the data. Table 1 provides the details that were found per state/city in comparison to the federal level.

*Table 1. Selected data on municipal solid waste (MSW) handling. Sources: EPA[5], CalRecycle* (2019)

| | USA 2017 | NYC | Washington DC | California |
|---|---|---|---|---|
| **Total MSW (1.000 tons)** | 267,800 | | 142 | 76,500 |
| **Landfill** | 139,590 (52%) | | 76% | 35,200 (46%) |
| **Incineration (combustion) with energy recovery** | 34,030 (12,7%) | | 11% | 1% |
| **Composting** | 26,990 (10,1%) | | 1% | 12% |
| **Recycling** | 67,180 (25,1%) | | 12% | 32% |
| **Industrial solid waste** | 7,800,000 | unknown | unknown | unknown |

## Economics

According to the 2016 Recycling Economic Information report (EPA, 2016) it is estimated that in 2007, recycling activities contributed 757,000 jobs (0.52% of all jobs in the U.S. economy), $36.6 billion in wages (0.62% of total wages paid), and $6.7 billion in tax revenues (0.90% of total revenues). Construction and demolition provided the largest contribution, plastics recycling is estimated to contribute ca. $3 billion in wages and approximately 75,000 jobs (EPA, 2016).

[4] https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/advancing-sustainable-materials-management-0#U.S.StateandLocal

[5] ibid.

# 4 Policies

Plastic recycling falls within a wider range of waste management policies: material efficiency, the circular economy, the 3R perspective (reduce, reuse, recycle), and sustainable materials management refer, in varying degrees, to how resources should be used by society to reduce the demand for primary materials while enabling prosperity. There are, however, some nuances. The International Resource Panel (IRP) (2020) uses the following definitions:

*Resource Efficiency (RE)* encompasses material efficiency but is a broader term that includes materials, water, energy, and land. The Global Resources Outlook 2019 of the International Resource Panel defines it as achieving higher outputs with lower inputs. The term encompasses strategies of dematerialization (savings, reduction of material and energy use) and re-materialization (reuse, remanufacturing and recycling) in a system-wide approach to a circular economy.

*Sustainable materials management (SMM)* is an approach to serving human needs by using/reusing resources most productively and sustainably throughout their life cycles, generally minimizing the amount of materials involved and all the associated impacts.

*Circular Economy (CE)* refers to an economy where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized.

*The 3R concept (Reduce, Reuse, Recycle)* encompasses similar strategies included in the concepts described above. While originating in waste management policy, the "Rs" affect and are affected by what happens at the production and use stages of the life cycle of products.

In the US, the EPA promotes the concept of SMM, with a website that provides general information, data, tools, and other resources.[6]

## 4.1 Policy drivers and priorities

In the US, waste management is a cooperative effort involving federal, state, regional, and local authorities. Responsibility for managing materials and waste is largely placed at the state and local levels, yet capacity and approaches vary widely. At all levels, the key drivers of recent policies directed at diverting waste from landfills towards composting, recycling and – to a lesser extent – incineration with energy recovery – are:

- *Difficulties in managing pollution from landfills***.** Back in 1976, the Resource and Recovery Act put an end to most leakage of contaminants to the soil and groundwater. Now, the focus is especially on methane emissions, which form a significant part of GHG-emissions.
- *Limitations on space/locations for new landfills***.** It is projected that existing landfills may fill up within the coming decades, whereas public resistance to new landfills has grown.
- *Waste management costs and income from selling recyclable materials.* Especially for cities like New York, that have to export its waste to other states, waste management costs are soaring. Meanwhile, a market has/had arisen for recyclable materials, especially being sold to China. The Chinese ban on waste imports has caused a – temporary – crisis in the recycling business, but it seems that now recycling facilities are starting to grow also within the US.
- *Ocean plastics debate.* Americans are very much aware of the problem of plastics in the marine environment and want to see politicians take action. California, New York, and hundreds of

[6] https://www.epa.gov/smm

municipalities in the U.S. ban or fine the use of single-use plastics in some way. Seventeen other states, however, say it's illegal to ban plastic items.[7]

President Trump has made eliminating federal regulations a priority. His administration has targeted environmental rules it sees as burdensome to the fossil fuel industry and other big businesses. The NY times maintains a list of environmental rules being rolled back.[8] Many of the 95 rollbacks deal with energy and climate-related topics. Topics related to waste, plastics, and recycling are:

- Changed rules to allow states and the E.P.A. to take longer to develop and approve plans aimed at cutting methane emissions from existing landfills.
- Reversed restrictions on the sale of plastic water bottles in national parks designed to cut down on litter, despite a Park Service report that the effort worked.

## 4.2 Federal policies: Environmental Protection Agency

The federal Environmental Protection Agency (EPA) regulates household, industrial, and manufacturing solid and hazardous wastes under the 1976 Resource Conservation and Recovery Act (RCRA). RCRA's goals are to protect citizens from the hazards of waste disposal; conserve energy and natural resources by recycling and recovery; reduce or eliminate waste; and clean up the waste that may have spilled, leaked or been improperly disposed of.

The development of Federal solid waste management policies has gone through four major phases:

1. The *Solid Waste Disposal Act (SWDA)* of 1965 was the first U.S. federal solid waste management law enacted. It focused on research, demonstrations, and training.
2. The *Resource Recovery Act of 1970* emphasized reclaiming energy and materials from solid waste instead of dumping.
3. From the mid-1970s, the Federal government started playing a more active regulatory role, with the *Resource Conservation and Recovery Act (RCRA)* of 1976. RCRA instituted the first federal permitting program for hazardous waste and made open dumping illegal. Subtitle D of the RCRA concerns solid waste and establishes a system for controlling (primarily non-hazardous) solid waste, such as household waste. The program provides the states and local governments with guidance, policy, and regulations for efficient waste management. Implementation of RCRA was relatively slow and has been strengthened through the Hazardous and Solid Waste Amendments (HSWA) of 1984.
4. The 1984 *HSWA Amendments* to the RCRA suggested a policy shift away from land disposal and toward more preventive solutions. RCRA has been amended on two occasions since HSWA: the *Federal Facility Compliance Act* of 1992 which strengthened enforcement of RCRA at federal facilities and the *Land Disposal Program Flexibility Act* of 1996 which provided regulatory flexibility for land disposal of certain wastes. Since the Trump administration is in charge, it seems as if the role of the EPA in waste management has been substantially reduced; statistics which used to be on the website (referred to by older publications by others) have disappeared

[7] National Geographic provides a map that shows where states have banned plastic—and where states have rolled back bans on plastic. https://www.nationalgeographic.com/environment/2019/08/map-shows-the-complicated-landscape-of-plastic-bans/

[8] https://www.nytimes.com/interactive/2019/climate/trump-environment-rollbacks.html

and the available information is quite limited and sometimes outdated. Also, there is very little news on recent policy measures.

The EPA helps to provide national consistency and co-implements RCRA with states by providing states, businesses and other stakeholders with national standards, guidelines, and technical support to more effectively conserve and manage materials and waste. The Resource Conservation & Recovery Act (RCRA) provides the legislative basis for EPA's *Sustainable Materials Management (SMM) Program* (EPA, 2015) – a strategy for 2017-2022, setting a strong preference for resource conservation over disposal. Also, EPA's waste hierarchy continues to provide guidance, highlighting source reduction/waste prevention & reuse over recycling and composting, energy recovery, and treatment & disposal.

Current issues regarding waste management policies especially concern policies to encourage the internal demand for recycled materials, 'bottle bills', use of methane from landfills as a 'renewable energy source' and interstate and international transfer of waste and recyclable materials.[9]

## 4.3 State and local levels

The RCRA of 1976 has provided state, tribal, and some local governments with regulatory responsibility for ensuring proper management of wastes generated from each source in their region, incl. MHWs. As of 2001, the EPA has authorized forty-eight states, except Alaska and Iowa (Hawaii was added in 2001), to implement the RCRA, meaning the states' regulations must meet at least the requirements set at the federal level and may be more stringent.[10]

Municipalities are in charge of local recycling and trash collection. They can choose whether to contract these services out to private companies or not and how to charge for these services. Municipalities also may adopt approaches to converting waste to energy through methods such as generating electricity from landfill gas.[11]

### 4.3.1 New York City

Since the closure of Fresh Kills - the last remaining landfill in New York City (NYC) - in 2001, the city has had no place to burn or deposit its waste within its boundaries. As the need to export all waste for landfilling or incineration drive up costs of waste management, NYC has since then focused strongly, but not very successfully, on reducing total amounts of waste and diverting waste from landfilling towards recycling and composting.

In 2012 NYC generated more than 14 million tons of solid waste per year, including residential, commercial, CDW and fill waste. Most of the city's waste is now being incinerated in New Jersey, while only 17 percent is being recycled (half of what is estimated to be recyclable, see figure 2 below). Plastic film, such as supermarket bags, comprises 7.5 percent of total waste, while clothing and textiles make up 5.7 percent of total waste.[12] More recent numbers are difficult to find.

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[9] https://wasterecycling.org/page/Federal

[10] https://en.wikipedia.org/wiki/Solid_waste_policy_in_the_United_States, retrieved March 6, 2020

[11] Ibid.

[12] https://www.baruch.cuny.edu/nycdata/environmental/recycling-waste.htm

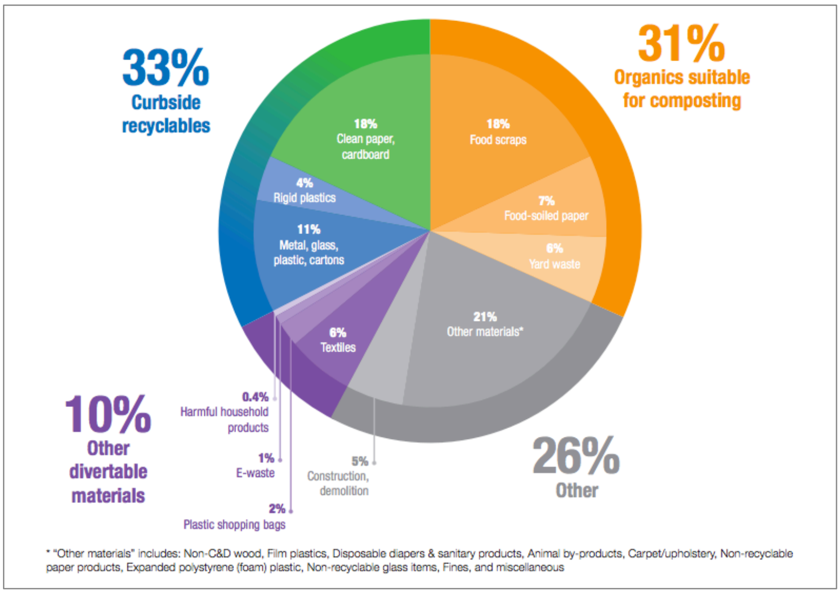


*Figure 3 Waste characterization of NYC MSW. This figure shows that in theory 33% of waste should be recyclable and 31% compostable. Source: NYC Department of Sanitation* (2017)

Paper waste that is properly separated from regular garbage is recycled locally or is processed for further recycling overseas. Glass, metal, and plastics are sent to Brooklyn and New Jersey for recycling or export as recyclable materials. NYC's non-recyclable waste is sent to landfills in states like Pennsylvania, Ohio, and Virginia or incinerated across the Hudson River, in New Jersey.[13]

In 2006 NYC adopted its current *Solid Waste Management Plan (SWMP)*, a 20-year strategy for how New York would deal with the roughly 12,000 tons of waste handled daily by the Department of Sanitation (DSNY). The plan laid out the city's approach for reducing and disposing of its solid waste with three overarching themes: equitably distributing sanitation infrastructure, minimizing environmental effects, and keeping costs manageable.[14]

In 2007, Mayor Bloomberg released the comprehensive *PlaNYC*, a sustainability effort looking ahead to 2030 and aimed at preparing New York City for future population growth, climate change, etc. The plan includes a detailed section on solid waste management with several initiatives that include targeting recycling incentives, creating opportunities to recover organic materials from waste, with goals of increasing diversion from landfills by 75%, reducing GHG emissions by 1 million metric tons, and improve the overall efficiency of New York City's waste management system. (PlaNYC). According to the ten-year evaluation, only limited progress has been made.[15]

In 2015 the PlaNYC was followed up by the even more extensive sustainability strategy "One New York: The Plan for a Strong and Just City" also known as *OneNYC*.[16] Part of OneNYC is the commitment to achieving Zero Waste (to landfill) by 2030.

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[13] https://www.grownyc.org/recycling/facts
[14] https://ibo.nyc.ny.us/iboreports/ten-years-after-assessing-progress-on-the-citys-solid-waste-management-plan-2017.html
[15] https://ibo.nyc.ny.us/iboreports/ten-years-after-assessing-progress-on-the-citys-solid-waste-management-plan-2017.html
[16] https://onenyc.cityofnewyork.us/

The *Zero Waste program* is a key component of OneNYC and emphasizes:

- Highest and best use of commodities and materials in the waste stream, as opposed to incineration with energy recovery.
- Organics collection, sorting and processing throughout the city and within 100 miles of the NYC, ultimately bringing organics collection to all residents by 2030.
- Offering single-stream recycling and eventually an equitable Save-as-You-Throw waste program to engage all residents in waste reduction while expanding markets for recycled materials.
- Bringing recycling service to all New York City Housing Authority (NYCHA) developments and making public housing fully compliant with recycling laws.
- Making all public schools Zero Waste, starting with a pilot program of a few Zero Waste schools in late 2015.
- Expanding opportunities to reuse and recycle textiles and electronics.
- Reducing commercial waste disposal by 90% by 2030 through a variety of new programs and mandates.

One of the key challenges in achieving waste management goals is the somewhat inefficient and expensive system for waste collection. Residential waste is collected and managed by the Department of Sanitation (DSNY) – the world's largest sanitation department – whereas commercial waste is collected by more than 250 private companies. Together the DSNY and private collectors had a spending of $2.3 billion per year.[17] To address these challenges, a plan has recently been introduced to reform the private carting system.

### 4.3.2 Washington DC

In 2017, the residential waste stream in Washington DC (DC) amounted to approximately 142 thousand tons. Of this amount 76% was landfilled, 12% recycled, 11% incinerated with energy recovery and 1% composted (Department of Public Works, 2017).

With the *Sustainable Solid Waste Management Amendment Act* of 2014 requirements were established for the management of solid waste and the separation, collection, and disposal of solid waste by both the DC government and the private waste collectors that operate in the District. The law requires the District to develop a plan to achieve 80% diversion from landfills and waste-to-energy (Zero Waste) and to annually report on progress towards this goal. The *Office of Waste Diversion and the Interagency Waste Reduction Working Group* were created to implement specific requirements of the law and guide the District towards its zero waste goals.

Zero Waste DC brings together government agencies and programs responsible for developing and implementing cost-effective strategies for converting waste to resources, improving human and environmental health, reducing greenhouse gas emissions, creating inclusive economic opportunity, and conserving natural resources.[18]

The city is working towards implementing its waste management sustainability plan – *Sustainable DC 2.0.* The plan was focused on waste recycling with goals to 'increase the citywide recycling rate' and to achieve 80% waste diversion by 2032.

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[17] https://cbcny.org/research/12-things-new-yorkers-should-know-about-their-garbage
[18] https://zerowaste.dc.gov/about-zero-waste-dc

The goals in *Sustainable DC 2.0* are divided into three:[19]

1. To reduce the district's overall waste generation. Target 1 – reduce per capita waste generation by 15% by 2032
2. To accelerate the recovery and reuse of items disposed of in the city. Target 2 – reuse 20% of all waste generated in the district
3. To achieve 80% waste diversion citywide

The city currently has three plastics policies in effect, among them a ban on polystyrene foam foodservice products and a five-cent plastic bag tax. More recently, the city banned plastic straws, mandating that establishments offer compostables or other alternatives.[20]

The difficulties for DC in achieving its targets seem to resemble those of NYC, with a relatively expensive and inefficient collection system as one of the core problems. In contrast with NYC, most of the waste is collected by private companies. The result is that the District government does not have a clear picture of the total waste stream generated (Department of Public Works, 2017).

DC waste management policies seem to be strongly focused on the collection and sorting process; there are no signs that the District is actively investing in 'domestic' recycling facilities, except from (local) composting facilities. Almost all waste seems to be exported to areas outside the District.

### 4.3.3 California

In 2016, California generated 76.5 million tons of solid waste and sent about 35.2 million tons to landfills, which translates to a per capita waste disposal of 6.0 pounds per person per day.

In 2002 it was also the first American state to adopt a zero-waste ambition as part of its Integrated Waste Management Plan.[21]

In California, waste management, recycling, and waste reduction programs are managed by the *California Department of Resources Recycling and Recovery* (also known as CalRecycle). CalRecycle was established in 2010 to replace the California Integrated Waste Management Board and administers and provides oversight for all of California's state-managed non-hazardous waste handling and recycling programs. CalRecycle has a budget of approximately $1.4 billion, including the $1.1 billion Beverage Container Re-cycling Fund. Other funding comes from recycling fees on new electronics, tires, and used oil, and disposal fees charged by landfills.[22]

In 2011, the Legislature and Governor Brown set an ambitious goal of 75 percent recycling, composting, or source reduction of solid waste by 2020, calling for the state and CalRecycle to take a statewide approach to decrease California's reliance on landfills (AB 341, Chesbro, Chapter 476). AB 341 also established mandatory recycling for most of California commercial businesses and multi-family residential buildings with five or more units.

In 2016, the recycling rate was 44 percent, which is well above the U.S. rate of 34.6 percent, but far away from the 75% goal. As the figures below show, the amount of waste being landfilled increased

[19] https://www.starrdumpsters.com/where-does-the-trash-go-in-washington-dc-p-677.html
[20] https://www.wastedive.com/news/dc-zero-waste-bill-organics-epr-landfill-packaging-compost-implications/566872/
[21] https://www.calrecycle.ca.gov/stateagency/iwmplans
[22] https://www.calrecycle.ca.gov/AboutUs/WhatWeDo/

between 2010 and 2016, whereas the recycling rate declined. Unfortunately, there are no more recent figures available.

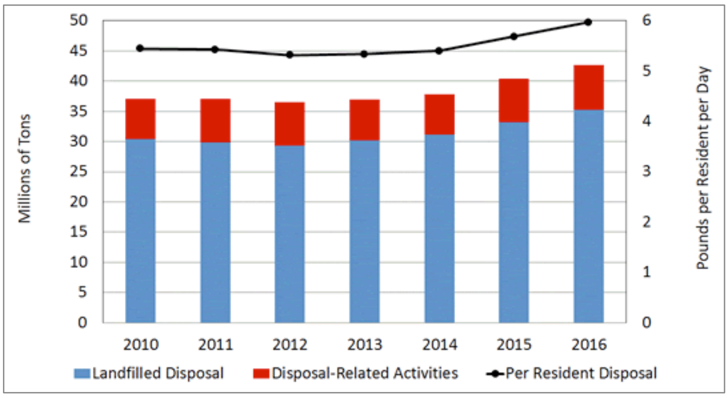


*Figure 4 Overview of Californian waste disposal (excl. recycling and reuse) from 2010 to 2016. Source: CalRecycle.*[23]

California, like other American states with high recycling rates, has been hard hit by the Chinese ban on certain waste imports. In 2016, California exported 15 million tons of recyclable materials of which 62 percent was shipped to China.[24]

As a result of the decreasing scrap value of aluminum and recycled plastics and the tightening of Chinese regulations on waste import, especially California's CRV container recycling program has failed in recent years, leading to the closure of hundreds of redemption centers between 2016 and 2019.[25]

Current policies focus especially on addressing plastic packaging, including a ban on free plastic bags, and food waste. Policy drivers are not only traditional waste-related drivers, but also combating climate change – especially concerning organic waste.

Also, California is working hard to support the development of a domestic/internal recycling industry, through green procurement, (targeted and non-targeted) funding and advice, labeling of products made in California, etc.[26]

[23] https://www.calrecycle.ca.gov/75percent/recyclerate
[24] Ibid.
[25] https://www.waste360.com/legislation-regulation/california-governor-signs-emergency-recycling-bill
[26] https://www.calrecycle.ca.gov/Nav/BusinessAssistance/

# 5 Innovation landscape

## 5.1 Research and development

### A closer look at investment in R&D

The U.S. is still spending more on R&D than any other country, but China is rapidly catching up both in terms of absolute spending, and as a percentage of GDP (see figure 5 for a comparison of the USA with China, Japan, Germany, and the Netherlands).

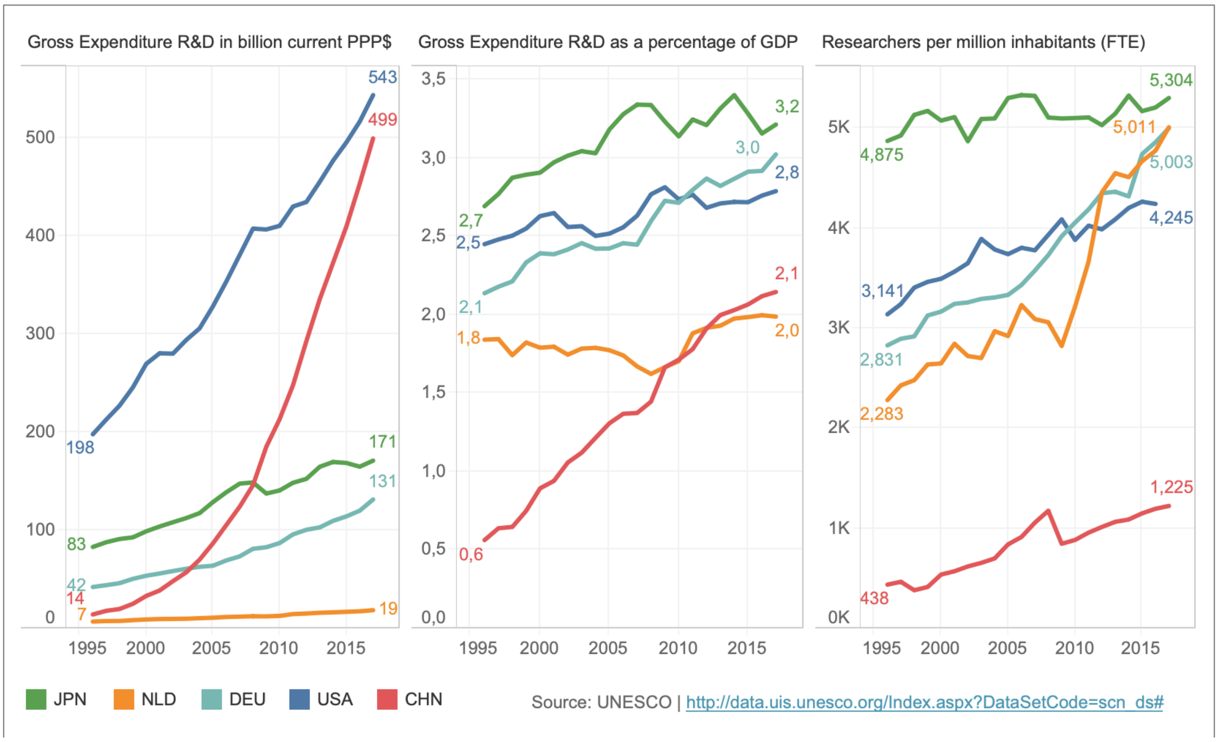


*Figure 5 Trends in R&D efforts for three indicators, comparing the USA to China, Japan, Germany, and The Netherlands. Souce: UNESCO*

In the report "State of U.S. Science and Engineering" (National Science Board, 2020), an overall picture of the innovation landscape can be found. Businesses perform and fund most of the overall R&D in the United States as well as most of the applied research and experimental development. The federal government is the second-largest funder of R&D and funds the largest share of basic research. While federal R&D funding of basic research has increased since 2000 to $150 billion, the proportion of R&D funded by the federal government has declined. Eight federal departments and agencies together account for most of the federal R&D spending. Defense has long been a federal R&D budget priority, accounting for 44% of federal R&D support in 2017. Long-term trends are presented in figure 6.

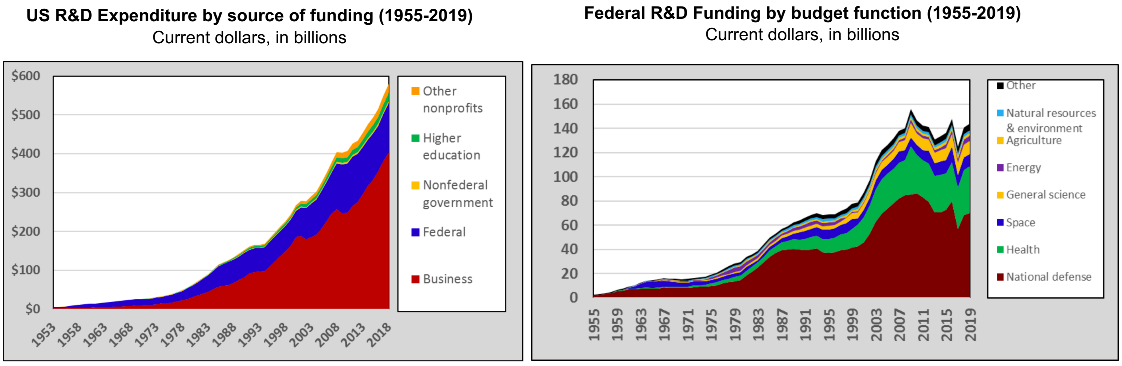


*Figure 6 U.S. R&D expenditure by source of funding (left), and Federal R&D funding by budget function (right). Source: Congressional Research Service* (2020)

According to an ITIF report (Wu, 2018), there are three key challenges under the surface of the robust U.S. business investment in R&D. First, businesses are steering more of their R&D investments toward product development that has the potential to generate returns in the near term and allocating less for basic and applied research that takes longer to bear fruit. Second, the federal government has deprioritized funding for R&D, which reduces the pool of discoveries that private industry can capitalize on by making additional R&D investments of their own. Third, as other countries increase their public and private investments in R&D, they are increasingly competing in high-value-added industries in which the United States historically has had an advantage stemming from its leadership in innovation.

NIST has also warned the American leadership is being challenged and expressed the critical need to modernize the U.S. system of technology transfer and innovation for the 21st Century. In a green paper, they have put forward inputs that could further enhance the U.S. innovation engine at the public-private interface (NIST, 2018).

### Investing in circular economy innovations

When it comes to investments in R&D on topics related to the circular economy, the USA appears to show little interest. At the federal level, it appears not to be a high political priority, while for cities and states there is more interest. According to Joss Blériot, head of public affairs at the Ellen MacArthur Foundation, the very loud silence at the federal level can be explained by the low unemployment rate and good economic growth. According to Blériot, the Americans still have plenty of energy and enough space to landfill the unpleasant by-products of the linear economy if they want.[27]

The previous administration was interested in the circular economy, mostly from the angle of vehicle remanufacturing. As part of the Manufacturing USA initiative, in 2017 the Energy Department launched the Reducing Embodied-energy and Decreasing Emissions (REMADE) Institute, which will be headquartered in Rochester, New York and led by the Sustainable Manufacturing Innovation Alliance, an example of a public-private partnership.  REMADE will leverage up to $70 million in federal funding, subject to appropriations, and will be matched by $70 million in private cost-share commitments from over 100 partners. The institute will focus on driving down the cost of technologies needed to reuse, recycle and remanufacture materials.[28]

[27] https://medium.com/circulatenews/which-country-is-leading-the-circular-economy-shift-3670467db4bb
[28] https://www.manufacturingusa.com/news/energy-department-launches-new-manufacturing-usa-institute-focused-recycling-and-reusing

## 5.2 International aspects

***Sharing best practices in recycling***

The United States, as a member of the G7, participates in Resource Efficiency Alliance (Ministry of the Environment - Japan, 2019). This alliance was created in 2015 and provides an international platform of which the objective is to share best practices for using natural resources less, longer and better. The US has implemented this in their national SMM strategies (see 5.2).

**Collaboration in science and technology**

GROW is a collaboration between the National Science Foundation (NSF) in the United States and 17 partner countries, that includes the Netherlands. The best Ph.D. students from NSF's Graduate Research Fellowship Program (GRFP) can do 3 to 12 months of research abroad thanks to Graduate Research Opportunities Worldwide (GROW).[29]

On a European level, there are numerous examples of collaboration between the EU Joint Research Center and the United States.[30]

## 5.3 Universities and research institutes

**Universities - chemical engineering**

The top-10 Chemical Engineering Schools, according to US News,[31] are provided below, together with general information and R&D expenditure. More information can be found via a link to the chemistry or chemical engineering department website of each institution.

[29] https://www.nwo.nl/en/research-and-results/programmes/graduate+research+opportunities+worldwide+grow

[30] https://ec.europa.eu/jrc/en/publication/brochures-leaflets/united-states-america-and-its-collaboration-jrc

[31] https://www.usnews.com/best-graduate-schools/top-engineering-schools/chemical-engineering-rankings

*Table 2 Characteristics of the top-10 Chemical Engineering Schools.*

| | University | General[32] | | R&D Expenditure (2017)[33] ,Dollars in thousands | | Direct link |
|---|---|---|---|---|---|---|
| | | Control (public; private) | Student pop. (2017) | Chem. | Chem. Eng. | |
| 1 | Massachusetts Institute of Technology (MIT) | Priv. | 11,466 | 26,165 | 37,056 | https://cheme.mit.edu/ |
| 2 | California Institute of Technology (Caltech) | Priv | 2,238 | 51,531 | 9,494 | https://cce.caltech.edu/ |
| 3 | The University of California, Berkeley (UCB) | Pub | 41,891 | 31,246 | 5,641 | https://chemistry.berkeley.edu/cbe |
| 4 | Stanford University (CA) | Priv | 17,534 | 26.834 | 13,060 | https://cheme.stanford.edu/ |
| 5 | University of Minnesota – Twin Cities | Pub | 51,848 | 18,708 | 25,715 | https://www.cems.umn.edu/ |
| 6 | University of Texas in Austin | Pub | 51,525 | 15,040 | 43,517 | https://che.utexas.edu/ |
| 7 | Georgia Institute of Technology | Pub | 29,376 | 24,609 | 23,274 | http://www.chbe.gatech.edu/ |
| 8 | University of Delaware | Pub | 23,774 | 8,919 | 15,651 | https://www.che.udel.edu/ |
| 9 | Princeton University | Priv | 8,273 | 18,943 | 4,331 | https://cbe.princeton.edu/ |
| 10 | University of California – Santa Barbara | Pub | 25,057 | 10,179 | 9,615 | https://www.chemengr.ucsb.edu/ |
| 10 | University of Wisconsin-Madison | Pub | 42,977 | 23,685 | 13,533 | https://www.engr.wisc.edu/department/cbe/ |

Plastic recycling or chemical recycling is not highlighted as a topic by any of the institutions, but there is a lot of R&D in related fields such as material sciences and catalysis. A notable spin-off from academic research is the plastic-to-fuel company, Renewlogy, that was started by MIT alumni.[34]

**National Institute of Standards and Technology**

The National Institute of Standards and Technology (NIST) is a physical sciences laboratory and a non-regulatory agency of the United States Department of Commerce. Its mission is to promote innovation and industrial competitiveness. NIST's activities are organized into laboratory programs that include chemistry, energy, environment, manufacturing, and materials.[35]

[32] The Carnegie Classification of Institutions of Higher Education (n.d.). Retrieved (March 6, 2020) from http://carnegieclassifications.iu.edu/ .

[33] https://ncsesdata.nsf.gov/profiles/site?method=rankingBySource&ds=herd

[34] http://news.mit.edu/2019/renewlogy-plastic-waste-1010

[35] https://www.nist.gov/topics

As an example, in 2018 a NIST grant was given to support plastic recycling research. NIST and Troy University in Troy, Alabama have entered a cooperative agreement that will fund a center for plastics recycling. A three-year, $3.2 million grant from NIST will support research at the university on the properties of polymers during recycling and manufacturing, as well as train students on issues and solutions in plastics recycling—developing the future workforce.[36]

## 5.4 Research programmes

**National Science Foundation**

With an annual budget of $8.3 billion (FY 2020), the NSF is the funding source for approximately 24 percent of all federally supported basic research conducted by America's colleges and universities. The NSF supports all fields of fundamental science and engineering. In addition to funding research in the traditional academic areas the NSF also supports "high-risk, high pay-off" ideas and novel collaborations. NSF operates from the "bottom up," keeping close track of research around the United States and the world.

*EFRI program - Elimination of End-of-Life Plastics (E3P)*
For plastics and recycling the NSF Emerging Frontiers in Research and Innovation program (EFRI)[37] is relevant. It is designed to provide critical, strategic support of fundamental discovery at the frontiers of engineering research and education with transformative opportunities. For the Fiscal year 2020 an anticipated budget will be available for the topics Distributed Chemical Manufacturing (DCheM) and Engineering the Elimination of End-of-Life Plastics (E3P). For E3P the NSF is looking for: robust physical systems and materials for plastic lifecycle management, including sensors for detection and characterization of composition and reaction dynamics, and mass separating agents for capture of plastic materials and plastic-derived molecules; development of novel catalysts and reaction engineering, either chemical or biological, enabling complete depolymerization and/or valorization of plastic waste; and systems-level integration of new plastic remediation and valorization technologies into manufacturing infrastructures, including improving efficiency and economic viability of existing recycling, remediation, and valorization technologies.[38]

*Big Ideas and NSF2026 Ideas Machine*
Since 2017, NSF has been building a foundation for the Big Ideas through pioneering research and pilot activities. In 2019, NSF will invest $30 million in each Big Idea and continue to identify and support emerging opportunities for US leadership in Big Ideas that serve the Nation's future.[39] The NSF 2026 is part of this Big Ideas foundation and has collected community input for investment in bold research questions (analogous to the Nationale Wetenschapsagenda by KNAW). The entries for this, now closed, competition include:[40] A World without Waste ("The challenge is greater than 90% reduction in waste generated from all sources, including vehicle emissions, consumer waste, and industrial waste."); Repurposing, Recycling, Renewable Energy ("Can we do better with our existing waste? How can we create new recyclable materials and create infrastructures for the repurposing of currently environmentally costly resources?"); and Unlocking the Future of

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[36] https://www.nist.gov/news-events/news/2018/09/nist-grant-supports-plastics-recycling-research
[37] https://www.nsf.gov/eng/efma/efri.jsp
[38] https://www.nsf.gov/pubs/2019/nsf19599/nsf19599.htm
[39] https://www.nsf.gov/news/special_reports/big_ideas/
[40] https://www.nsf.gov/news/special_reports/nsf2026ideamachine/index.jsp

Infrastructure ("At the intersection of automated construction and artificial intelligence, can innovative, recyclable and adaptable materials provide symbiotic infrastructure in regards to its local environment?").

**Department of Energy**

As a science agency, the Energy Department plays an important role in the innovation economy. The Department catalyzes the transformative growth of basic and applied scientific research, the discovery and development of new clean energy technologies and prioritizes scientific innovation as a cornerstone of US economic prosperity.

*Plastics Innovation Challenge*
November 2019, U.S. Secretary of Energy Rick Perry announced the launch of the Plastics Innovation Challenge, a comprehensive U.S. Department of Energy (DOE) program to accelerate innovations in energy-efficient plastics recycling technologies. The Innovation Challenge will draw on both fundamental and applied research capabilities within the National Laboratories, universities, and industry. Using a coordinated suite of funding opportunities, critical partnerships, and other programs, the Plastics Innovation Challenge sets the goals for the entire plastic chain, including upcycling and design for recyclability.[41] To reach these goals a funding opportunity of $40 million was opened for Small Business Innovation Research and Small Business Technology Transfer Program Phase 1 Innovation Projects.[42] In February 2020, the U.S. Department of Energy (DOE) and the American Chemistry Council (ACC) signed a Memorandum of Understanding (MOU) to enhance innovation in energy-efficient plastics recycling and reduce waste through enhanced recovery of post-use plastics.[43]

**Environmental Protection Agency (EPA)**

Next to its role as a regulator (see 5.2.1), the EPA researches environmental topics.[44] Waste and materials management research provides ways to reuse materials, derive energy from wastes, produce less waste and better manage unavoidable waste, which will conserve natural resources and reduce disposal costs.

EPA is developing data and tools to optimize the recovery of energy from wastes. This research will be done in collaboration with states to develop reuse options and with the private sector to assess technologies and processes. This information can identify opportunities to further reduce the volume of waste disposal, conserve natural materials, and reduce costs while protecting the natural environment.

A large part of the research is devoted to managing risks associated with materials and waste. EPA collects data on waste and material management (EPA, 2017). Some older reports provide assessment studies for waste management options (Thorneloe, 2012).

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41 https://www.energy.gov/articles/department-energy-launches-plastics-innovation-challenge
42 https://www.energy.gov/plastics-innovation-challenge/plastics-innovation-challenge-funding-opportunity-announcements
43 https://www.energy.gov/articles/us-energy-department-and-american-chemistry-council-sign-memorandum-understanding
44 https://www.epa.gov/land-research

## 5.5 Companies

**General overview**

Closed Loop Partners[45] provides in their report "Accelerating circular supply chains for plastics" (Closed Loop Partners, 2019) a global overview of technology providers for advanced recycling with an assessment of the technology readiness level. For a list of demos and pilots, see 6.6. Also, the report shows the locations of oil and gas refineries, resin production facilities, recyclers, reclaimers, and reprocessors in North America.

223 plastic recycling plants based in the United States are listed in the ENF Recycling directory.[46]

A directory of buyers and sellers of recycled materials is available through the Association of Plastic Recyclers (APR)[47] or through PlasticMarkets.[48]

**Waste to energy - pyrolysis and gasification**

While not specific for plastic, we include here a short section on technologies that convert waste to energy or fuels.

A paper on waste-to-energy technologies (Tan, 2013) assessed the maturity of various techniques (see Figure 7) and found pyrolysis and gasification to be commercially available. In North America, at that time, there were 10 pyrolysis and 22 gasification facilities.

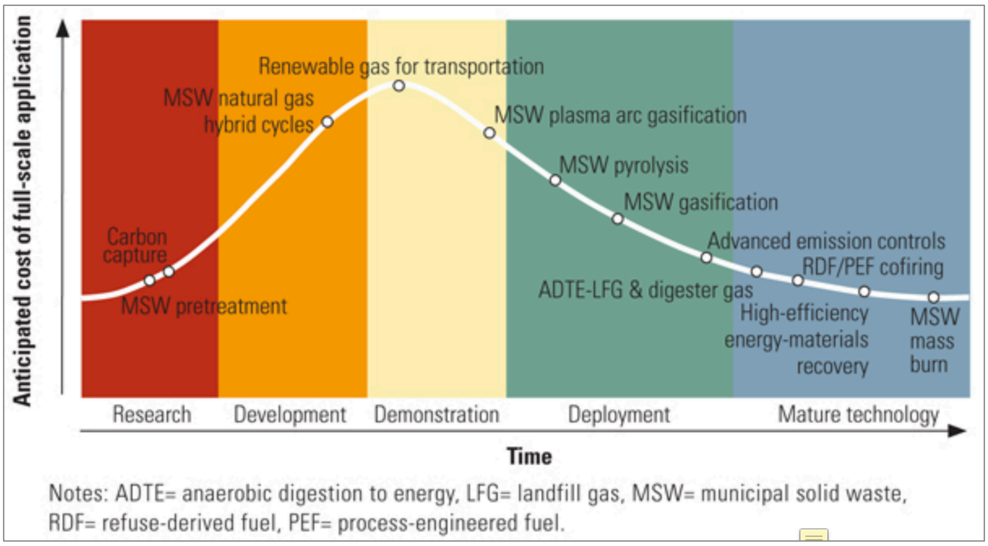


*Figure 7 Waste-to-energy at varying stages of maturity. Source: Tan* (2013)

In another comparison, prepared for the EPA (Thorneloe, 2012), it is pointed out that conversion technologies generally have smaller capacities and are more limited in the types of materials that can be accepted. However, while the main product of incineration is electrical energy (and possibly steam), conversion technologies produce synthetic or bio-based fuels that can be either combusted

[45] https://www.closedlooppartners.com/
[46] https://www.enfrecycling.com/directory/plastic-plant/United-States
[47] https://plasticsrecycling.org/resources/buyers-and-sellers-list
[48] https://www.plasticsmarkets.org/

to produce electrical energy, used as a transportation fuel, or sold as a chemical commodity product based on regional markets. A comparative assessment is provided below:

*Table 3 Evaluation of waste conversion technologies. Source: Thorneloe (2012)*

| | Landfill Diversion | Net Energy Recovery | GHG Emissions Reduction | Commodity Products Potential | Ability to Accept Bulk MSW As Is | Commercial Readiness | Cost |
|---|---|---|---|---|---|---|---|
| Pyrolysis | + [1] | +++ [2] | + | +++ | - | + | + |
| Gasification | ++ [1] | ++ [2] | ++ | + [3, 4] | + | + | ? |
| Anaerobic Digestion | + [1] | + [2] | ++ | + [3] | - | + | ? |
| Landfill | - | + [2] | - | na | +++ | +++ | +++ |
| WTE | +++ | +++ [2] | ++ | + | +++ | +++ | + |

-Worse, + Good, ++ Better, +++ Best, ? Indeterminate/not enough data, na Not applicable

[1] Relatively small facility capacity, may not significantly impact landfill diversion unless there are many facilities. For example, pyrolysis accepts mainly plastic and AD mainly food and green waste.

[2] Energy recovery creates beneficial offset of utility sector electricity production or petroleum fuel production.

[3] May not be available markets or significant enough quantity to lead to marketable products.

[4] Potential glass and metals recovery and associated recycling offsets (would only apply if the facility accepts bulk MSW).

## Changing plastic usage

The plastic landscape is changing. Bans on the production and use of single-use plastics, as well as rising demand for reusable plastics and sustainable alternatives, are affecting all industries that rely on plastics and will alter the role of the chemical industry (Deloitte, 2020).

On 16 January 2019, a group of 30 global companies launched the Alliance to End Plastic Waste to promote solutions to eliminate plastic waste in the environment. This not-for-profit alliance committed to invest USD1.5 billion over five years. They intend to develop and scale solutions to minimize and manage plastic waste, as well as enable circular economy approaches for used plastics.[49] Advanced recycling projects are being assessed as part of a wider plan to address mixed and hard-to-recycle plastic (Alliance to End Plastic Waste, 2019).

To illustrate some of the new ways in which industries use and recycle plastics, some examples are provided here:

*Examples from multinational Chemical industry*

- Sabic and customers launch certified circular polymers from mixed plastic waste[50]
- LyondellBasell and SUEZ Collaborate with Samsonite to Create Recycled Plastic Suitcase Collection[51]

[49] https://endplasticwaste.org/

[50] https://www.eco-business.com/press-releases/sabic-and-customers-launch-certified-circular-polymers-from-mixed-plastic-waste/

[51] https://www.lyondellbasell.com/en/news-events/corporate--financial-news/lyondellbasell-and-suez-collaborate-with-samsonite-to-create-recycled-plastic-suitcase-collection/

*Advanced recycling examples in the USA*[52]

- Agilyx, an alternative energy company, recycles polystyrene (which most people know as Styrofoam™) into high-value petrochemicals. Agilyx's polystyrene recycling process creates like-new materials while generating fewer greenhouse gases than manufacturing does.
- Shaw Industries Group uses chemical recycling for nylon and polyester fiber in carpets. The company has invested more than $20 million to convert products that were once seen as waste into valuable resources. They reclaimed and recycled more than 800 million pounds of carpet from 2006 to 2015.
- Resinate Materials Group collects chemicals from plastic materials and works to promote the practical and economical value of chemically recycled plastics. The company has found several high-value applications for the chemicals harvested from recycled medical plastics. It uses certain types of recycled packaging to create coatings, adhesives, and sealants.
- Patagonia, an outdoor clothing brand, chemically recycles non-wearable polyester and fleece products. Today, the brand features a collection of products made completely from recycled materials. Patagonia's chemical recycling process uses 76% less energy than the process used to make new polyester.

*Examples of plastic reduction or use of recycled plastic packaging by companies*[53, 54]

- BioCellection – Chemical Recycling. The US-based startup BioCellection develops plastic recycling technology using chemical processes to convert post-consumer plastics into the building blocks for synthetic chemistry and synthetic biology: succinic acid, glutaric acid, adipic acid, pimelic acid, suberic acid, and azelaic acid. Extracted chemically from grocery bags, bubble wraps, trash bags, retail packaging, food wraps, and such, their innovation can potentially use plastic waste to replace fossil fuel as a resource for sustainable supply chains.
- NexGenCup – replacing single-use plastic. The US-based startup NexGen Consortium aims to refine and coordinate the entire journey of single-use plastic cups to get them into recycling units. They host the NexGenCup, an open innovation challenge that has already given rise to 12 innovative cup solutions from making them compostable and recyclable at home to new materials for making the cups. Packaging, recovery, and supply chain experts provide insights for using the right type of cups.
- Walmart, the largest retailer in the world, hopes to reach 100% recyclable, reusable or compostable packaging status for its private-label brands by 2025. It is also phasing out single-use plastic bags and is incorporating recycling labels that inform consumers on where to dispose of certain materials.
- Kellogg's is aiming to switch to completely reusable, recyclable or compostable packaging by the end of 2025, while also adopting compostable and paper foodservice products in its plants and offices. It is already working to swap out plastic cereal pouches in its European products for recycle-ready materials by the end of this year.
- Hershey is striving to achieve zero waste-to-landfill at its facilities and a 95% recycling rate by 2025. Consumer packaged goods giant Unilever is also taking a proactive stance on plastic

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[52] https://www.thisisplastics.com/recycling-101-chemical-recycling/

[53] https://www.startus-insights.com/innovators-guide/4-top-plastic-recycling-technology-startups-impacting-packaging/

[54] https://agfundernews.com/25-startups-innovating-with-sustainable-packaging-solutions.html

packaging and investing in circular economy initiatives that ensure plastic packaging components can be reused, recycled, or composted.
- TAG Packaging – The Los Angeles-based startup developed a foaming technology called 100BIO that creates biodegradable styrofoam that can compost in less than nine weeks without exuding carbon dioxide, heavy metals, or methane. It uses 60% less raw materials than conventional paper or plastic products.

## 5.6 Investments in waste management

What is characteristic for the US, is that initiatives for recycling or Circular Economy are mainly set up bottom-up by the private sector. Funding must, therefore, be organized privately (Pers. Communication, Holland Circular Hotspot).

Some investment funds that are active on the topic of plastic waste and (advanced) recycling are:

- The Plastic Solutions Fund, an international funder collaborative, set up by the Rockefeller Foundation.[55] The fund now has ten partners and members and aims to grow further. Partners contribute at least $500,000 per year for at least three years. Launched in 2017, it supports projects to reduce the production of single-use plastic and packaging, focusing on key drivers of systems change in the plastic supply chain.
- Closed Loop Partners[56], a New York-based investment firm.

[55] https://www.rockpa.org/case-study-the-plastic-solutions-fund/
[56] https://www.closedlooppartners.com/

## 5.7 Demos and pilots

The table below provides an overview of technology providers for advanced plastic recycling in or near the states to be visited. A short fact sheet per organization is provided in 7.7 (Closed Loop Partners, 2019)

*Table 4 Technology providers for advanced plastic recycling on the East coast.*

| Company | City | State | Technology type | Stage of Maturity | Supply Chain |
|---|---|---|---|---|---|
| **Nexus Fuels** | Atlanta | GA | Conversion (thermal) | Early Commercial | Plastics to fuels and petrochemicals |
| **University Massachusetts Lowell** | Massachusetts | MA | Decomposition (chemical) | Concept | Plastics to monomers and polymers |
| **Golden Renewable Energy** | Yonkers | NY | Conversion (thermal) | Early Commercial | Plastics to fuels |
| **Plastic2Oil** | Niagara Falls (HQ) | NY | Conversion (thermal) | Early Commercial | Plastics to fuels |
| **PennState** | Pennsylvania | PA | Conversion (thermal) | Lab | Plastics to fuels |
| **Climax Global Energy** | Allendal | SC | Conversion (thermal) | Pilot | Plastics to fuels and petrochemicals |
| **Tyton Biosciences** | Danville | VA | Decomposition (chemical) | Lab | Plastics to monomers |

Other notable initiatives in the USA, include:

- Anellotech (NY)[57] recently announced the development of chemical recycling technology.[58]
- Eastman. An engineering feasibility study for the glycolysis of polyesters (Vollmer et al., 2020).

[57] https://www.anellotech.com/
[58] https://www.waste360.com/fleets-technology/anellotechs-new-technology-recycles-plastic-waste-chemicals

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## 6.2 US policy overview regarding recycling and circular economy

*Table 5. Overview of developments and policy documents regarding recycling and the circular economy*

| Year | Policy document | Policy maker | Key contents |
|---|---|---|---|
| **1976** | Resource Conservation and Recovery Act | EPA (ORCR: Office of Resource Conservation & Recovery) | The Resource Conservation and Recovery Act (RCRA) gives EPA the authority to control hazardous waste from the "cradle-to-grave." This includes the generation, transportation, treatment, storage, and disposal of hazardous waste. RCRA also set forth a framework for the management of non-hazardous solid wastes. The 1986 amendments to RCRA enabled EPA to address environmental problems that could result from underground tanks storing petroleum and other hazardous substances. |
| **1984** | Federal Hazardous and Solid Waste Amendments | EPA (ORCR) | Amendments to RCRA that focused on waste minimization and phasing out land disposal of hazardous waste as well as corrective action for releases. Some of the other mandates of this law include increased enforcement authority for EPA, more stringent hazardous waste management standards, and a comprehensive underground storage tank program. |
| **2001** | | EPA | The EPA has authorized forty-eight states, except Alaska and Iowa (Hawaii was added in 2001), to implement the RCRA, meaning the states' regulations must meet at least the requirements set at the federal level and may be more stringent. |
| **2002** | California Integrated Waste Management Plan | California Integrated Waste Management Board | California was the first American state to adopt a zero-waste ambition as part of its Integrated Waste Management Plan |
| **2006** | NYC Solid Waste Management Plan (SWMP) | NYC Mayor | NYC adopted its current Solid Waste Management Plan (SWMP), a 20-year strategy. The plan laid out the city's approach for reducing and disposing of its solid waste with three overarching themes: equitably distributing sanitation infrastructure, minimizing environmental effects, and keeping costs manageable. |
| **2007** | PlaNYC | NYC Mayor | Mayor Bloomberg released the comprehensive PlaNYC, a sustainability effort looking ahead to 2030 and aimed at preparing New York City for future population growth, climate change, etc. The plan includes a detailed section on solid waste managements with a number of initiatives that include targeting recycling incentives, creating opportunities to recover organic materials from waste, with goals of increasing diversion from landfills by 75%, reducing GHG emissions by 1 million metric tons, and improve the overall efficiency of New York City's waste management system. |
| **2011** | | California Legislature and Governor | The Legislature and Governor Brown set an ambitious goal of 75 percent recycling, composting, or source reduction of solid waste by 2020, calling for the state and CalRecycle to take a statewide approach to decreasing California's reliance on landfills. |
| **2015** | OneNYC | NYC Mayor | PlaNYC was followed up by the even more extensive sustainability strategy OneNYC, incl. a commitment to achieving Zero Waste (to landfill) by 2030. |

## 6.3 Recycling technologies

An overview of recycling technologies for solid plastic waste is provided below

| | | Technique | Advantages | Challenges |
|---|---|---|---|---|
| Mechanical recycling | sorting | Flotation (sink-float) | Well-known technology | Efficiency determined by density differences plastics |
| | | | Cost-effective | Mainly limited to binary mixtures |
| | | | Particle size | |
| | | Melt filtration | Useful to remove non-melting contaminants | Potential pressure fluctuations in production |
| | | | Additional melt pressure | |
| | | FT-NIR | Post-drying not required | Black undetectable |
| | | | Well-known | Plastic should be dry |
| | | Tribo-electric (electrostatic) separation | Efficient for various plastics | Pre-treatment |
| | | | Small particle sizes allowed | |
| | | Froth flotation | Efficiency | Precursor step required |
| | | | | In development for recycled plastics |
| | | Magnetic density separation | Improved density-based technique | Density overlaps remain |
| | | | Multiple polymer fractions in a single step | |
| | | X-ray detection | Accuracy | Cost-effectiveness |
| | | | Useful for PVC | |
| | Reprocessing | | High value recycling | Thermal-mechanical degradation |
| | | | Well-known technology | Challenging for complex mixtures |
| | | | Straightforward | Miscibility of polymer blends |
| Chemical recycling | Chemolysis | | Generates pure value-added products | Requires high volumes to be cost-effective |
| | | | Operational for PET | Mainly limited to condensation polymers |
| | Pyrolysis | | Suitable for highly heterogeneous mixtures of plastics | Complexity of reactions |
| | | | Simple technology | Requires high volumes to be cost-effective |
| | | | | Low tolerance for PVC |
| | | | | Stable waste supply |
| | Fluid Catalytic cracking | | Narrow product outcome | Deactivation of catalyst |
| | | | Less stringent reaction conditions leads to favourable economics | Absence of suitable reactor technology |
| | | | | Presence of inorganics |
| | Hydrogen technologies | Hydrocracking | Quality of produced naphtha | High cost of hydrogen |
| | | | Suitable for mixtures of plastics | High investment and operational costs |
| | | $IH^2$ process | Promising technology for the production of liquid fuels out of biomass | Further research required |
| | | | Different elements already commercialized | |
| | KDV process | | Also suitable for oxygen and halogenated compounds | Chemistry still unknown |
| | | | | Lack of technical information |
| | Gasification | | Syngas is a valuable intermediate | Amount of noxious $NO_x$ |
| | | | Cost of air | Specific drawbacks of air |
| | | | Well-known technology | |

Source: Kim Ragaert, Laurens Delva, Kevin Van Geem, Mechanical and chemical recycling of solid plastic waste, Waste Management, Volume 69, 2017, Pages 24-58, https://doi.org/10.1016/j.wasman.2017.07.044.

There are four main types of chemical recycling: pyrolysis, gasification, solvolysis and depolymerization (see Figure xx). The chemistry of thermal gasification and pyrolysis (or cracking) is reasonably well understood. Challenges lie in the engineering, the lowering of the energy usage and the quality of inputs and outputs. For both techniques, pilots are being developed in the Netherlands. Catalytic cracking is demonstrated for oil industry but is not well suited for plastic streams. Developments in this direction are very much in the academic stage.

Solvolysis and depolymerization have a lower technology readiness. They require more pure input streams but can deliver higher quality products.

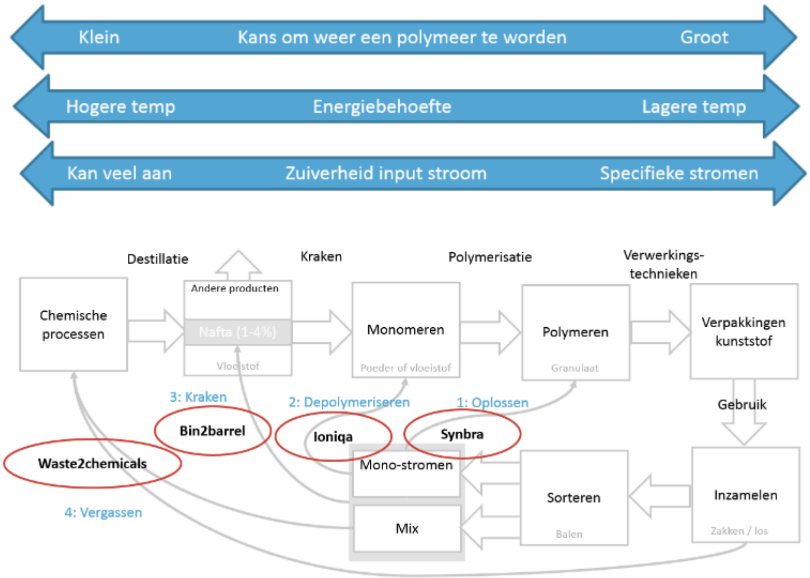


*Figure 8 Overview of different chemical recycling technologies for plastics. Included are 4 pilot that are currently developed in The Netherlands*

## 6.4 Waste and recycling demos and pilots in the US

Fact sheets of selected companies, active in advanced plastic recycling.

nexus FUELS

**LOCATION:**
Atlanta, Georgia, USA

**TECHNOLOGY TYPE:**
Conversion (thermal)

**STAGE OF MATURITY:**
Early commercial

**SUPPLY CHAIN:**
Plastics to fuels & petrochemicals

**CAPITAL NEEDS:**
Closing next round for capacity additions

**LAST UPDATED:**
Mar 14, 2019

| | |
|---|---|
| **DESCRIPTION** | Nexus Fuels was founded in 2008 and uses modern pyrolysis technology to process waste plastics into high-grade fuels and waxes composed of a "clean crude" consisting of gasoline, kerosene, diesel, and wax. |
| **FEEDSTOCK** | Nexus Fuels processes both post-consumer/commercial/industrial plastics waste streams with preference to feedstock from upstream retail, commercial, agricultural, and industrial sources. System is optimized to accept HDPE, LDPE, PP, and PS and tolerates contaminants. The company performs pre-cycling® to eliminate PVC and PET. |
| **FACILITIES** | Nexus Fuels currently operates a commercial 50 ton/day plant scaled from a successful pilot in Atlanta, Georgia, USA. Nexus Fuels welcomes appropriate visitors. |
| **PARTNERS** | Nexus Fuels has contracts with plastic waste providers and off-takers around the USA and are signing strategic partnerships as part of their commercialization strategy. |
| **BUSINESS MODEL** | In the short term, Nexus Fuels is focusing on strategic operating partnerships to scale. The company will not be pursuing licensing; instead, joint partnerships. |

*Based on research and an interview. Validated with Nexus Fuels.

**LOCATION:**
Massachusetts, USA

**TECHNOLOGY TYPE:**
Decomposition (chemical)

**STAGE OF MATURITY:**
Concept

**SUPPLY CHAIN:**
Plastics to monomers & polymers

**CAPITAL NEEDS:**
Data not available

**LAST UPDATED:**
Feb 19, 2019

*Based on research only.

| | |
|---|---|
| DESCRIPTION | University of Massachusetts-Lowell (UML) will be researching recycling and recovery of plastics, specifically, scalable high shear catalyzed depolymerization of multilayer plastic packaging. The process is intended to recover monomers and/or polymers. |
| FEEDSTOCK | UML will target multilayer packaging/film. This includes layers of various polymer materials (e.g., PET, PP, PE, PP, PA) that are sometimes combined with paper and aluminum foil. |
| FACILITIES | Data not available. |
| PARTNERS | This research project is part of The REMADE Institute's Project Call 1.0. Partners include the Michigan State, Unilever, American Chemistry Council, and National Renewable Energy Laboratory. |
| BUSINESS MODEL | Data not available. |

Golden Renewable Energy

**LOCATION:**
Yonkers, New York, USA (HQ)

**TECHNOLOGY TYPE:**
Conversion (thermal)

**STAGE OF MATURITY:**
Early commercial

**SUPPLY CHAIN:**
Plastics to fuels

**CAPITAL NEEDS:**
Currently finishing B Round

**LAST UPDATED:**
Mar 11, 2019

| | |
|---|---|
| DESCRIPTION | Golden Renewable Energy (GRE) uses pyrolysis technology to produce a liquid fuel, with the same characteristics of #2 diesel fuel, from waste plastics. |
| FEEDSTOCK | GRE processes both post-consumer and post-industrial waste streams. The company does not source its feedstock by polymer type and is flexible to take in different mixes of plastics (No. 1-7). |
| FACILITIES | GRE currently owns and operates one facility in Zebulon, North Carolina, USA, which has a feedstock capacity of ~8,000 tons/year, producing ~2.0 MM gallons of recycled diesel/year. |
| PARTNERS | GRE has received plenty of interest and demand for the technology. GRE has contracts/plans in hand to deliver 5 more units in the second half of 2019. |
| BUSINESS MODEL | Currently, the facility in Yonkers is being converted into an assembly plant to build at least 5 more units.<br>In the short term, GRE will continue to be an owner-operator and generate revenue through both ongoing operations as well as sales and licensing.<br>In the long term, GRE will consider either contract manufacturing or the development of a manufacturing facility with the ability to deliver 50 to 100 units/year. |

*Based on research and an interview. Validated with Golden Renewable Energy.

LOCATION:
Niagara Falls, New York, USA (HQ)

TECHNOLOGY TYPE:
Conversion (thermal)

STAGE OF MATURITY:
Early commercial

SUPPLY CHAIN:
Plastics to fuels

CAPITAL NEEDS:
Data not available

LAST UPDATED:
Feb 18, 2019

*Based on research only.

| | |
|---|---|
| DESCRIPTION | JBI, Inc. developed the Plastic2Oil (P2O) technology which transforms unsorted, unwashed waste plastic into ultra-clean, ultra-low sulphur fuel without the need for refinement. Fuel products include naphtha, fuel no. 2 (such as furnace oil or diesel), and fuel no. 6 (such as heavy fuel for industrial boilers and ships). |
| FEEDSTOCK | The P2O technology targets HDPE, LDPE, PP, and other plastics (No. 2, 4, 5, 7) and does not accept PET and PVC (No. 1, 3). |
| FACILITIES | JBI has three operational facilities in the USA. |
| PARTNERS | JBI has a 20-year master agreement with Veridisyn, who has agreed to license the P2O technology and purchase P2O processors. Other partners include GTI, Indigo Energy, RockTenn, XTR Energy, and Coco Paving. |
| BUSINESS MODEL | Currently, JBI licenses its P2O technology and is planning to resume fuel production and sales. |

PennState

**LOCATION:**
Pennsylvania, USA

**TECHNOLOGY TYPE:**
Conversion (thermal)

**STAGE OF MATURITY:**
Lab

**SUPPLY CHAIN:**
Plastics to fuels

**CAPITAL NEEDS:**
Data not available

**LAST UPDATED:**
Feb 15, 2019

| | |
|---|---|
| DESCRIPTION | The Pennsylvania State University developed a process to densify waste plastic into fuel nuggets called Plastofuel™. The technology works by forcing film or rigid plastics through a heated extrusion die. |
| FEEDSTOCK | Plastofuel can process all plastics but targets non-recyclable plastics, with a focus on agricultural and household waste. |
| FACILITIES | The scaled-up prototype at the Pennsylvania State University produces 500 lbs/hr of Plastofuel™. |
| PARTNERS | The technology was developed in the Department of Agricultural and Biological Engineering. |
| BUSINESS MODEL | Data not available. |

*Based on research and validated with The Pennsylvania State University.

## CLIMAX GLOBAL ENERGY

**LOCATION:**
Allendale, South Carolina, USA

**TECHNOLOGY TYPE:**
Conversion (thermal)

**STAGE OF MATURITY:**
Pilot

**SUPPLY CHAIN:**
Plastics to fuels & petrochemicals

**CAPITAL NEEDS:**
Data not available

**LAST UPDATED:**
Feb 14, 2019

| | |
|---|---|
| DESCRIPTION | Climax Global Energy's microwave pyrolysis technology converts waste plastics, used oils, forestry-industry by-products, and biomass into synthetic crude oil, transportation fuels, and industrial petrochemicals. The process does not require a catalyst. Generally, 1 ton of plastic produces approximately 5 barrels of oil. |
| FEEDSTOCK | Climax Global Energy focuses on non-recyclable plastics such as "mixed" 3-7, but can accept all types of plastics (e.g., PET, HDPE, PVC). The feedstock can be mixed, dirty and wet. |
| FACILITIES | Climax Global Energy successfully completed a pilot demonstration in Allendale, South Carolina, USA with a capacity to process 3 tons/day. |
| PARTNERS | Climax Global Energy has relationships with SC Launch and South Carolina Research Authority. |
| BUSINESS MODEL | Currently, Climax Global Energy is the sole owner-operator of the facility. In the short term, Climax Global Energy will establish direct relationships with refineries for the offtake of their output. In the long term, Climax Global Energy will aim to develop facilities that are modular and replicate their technology on a commercial scale worldwide. |

*Based on research only.

**LOCATION:**
Danville, Virginia, USA

**TECHNOLOGY TYPE:**
Decomposition (chemical)

**STAGE OF MATURITY:**
Lab

**SUPPLY CHAIN:**
Plastics to monomers

**CAPITAL NEEDS:**
Data not available

**LAST UPDATED:**
Feb 19, 2019

| | |
|---|---|
| **DESCRIPTION** | Tyton BioSciences (Tyton) uses subcritical water technology to make building blocks for PET and virgin-grade polyester. These building blocks are the PET monomers: terephthalic acid and ethylene glycol. |
| **FEEDSTOCK** | Tyton's technology accepts a broad spectrum of starting materials, including cotton. For the plastics supply chain, Tyton can accept PET plastics and polyester. |
| **FACILITIES** | Data not available. |
| **PARTNERS** | Tyton has joined the Scaling Programme by Fashion for Good in 2018. |
| **BUSINESS MODEL** | Data not available. |

*Based on research only.