USE OF OIL AND GAS PRODUCTS IN THE INDUSTRY

REPORT FOR THE NORWEGIAN OIL AND GAS ASSOCIATION

REPORT

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Revision: 1

Date: 18/10/2019

Report #4E4555	Revision 1
Date of issue: 18/01/2019	
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Definitions

Energy crops	Crops grown specifically for their fuel value. These include food crops such as corn and sugarcane and non-food crops such as poplar trees and switchgrass.
Non-energy use	Energy products used as raw materials in the different sectors; that is not consumed as a fuel or transformed into another fuel. For example most lubricants and bitumen are used for non-energy purposes.
Ozone depletion potential	The relative amount of degradation to the ozone layer a chemical can cause.
Smog	Fog or haze intensified by smoke or other atmospheric pollutants.
Eutrophication	Excessive richness of nutrients in a lake or other body of water, frequently due to run-off from the land, which causes a dense growth of plant life.
Freshwater	Any naturally occurring water except seawater and brackish water. Fresh water includes water in ice sheets, ice caps, glaciers, icebergs, bogs, ponds, lakes, rivers, streams, and even underground water called groundwater.

Abbreviations and units

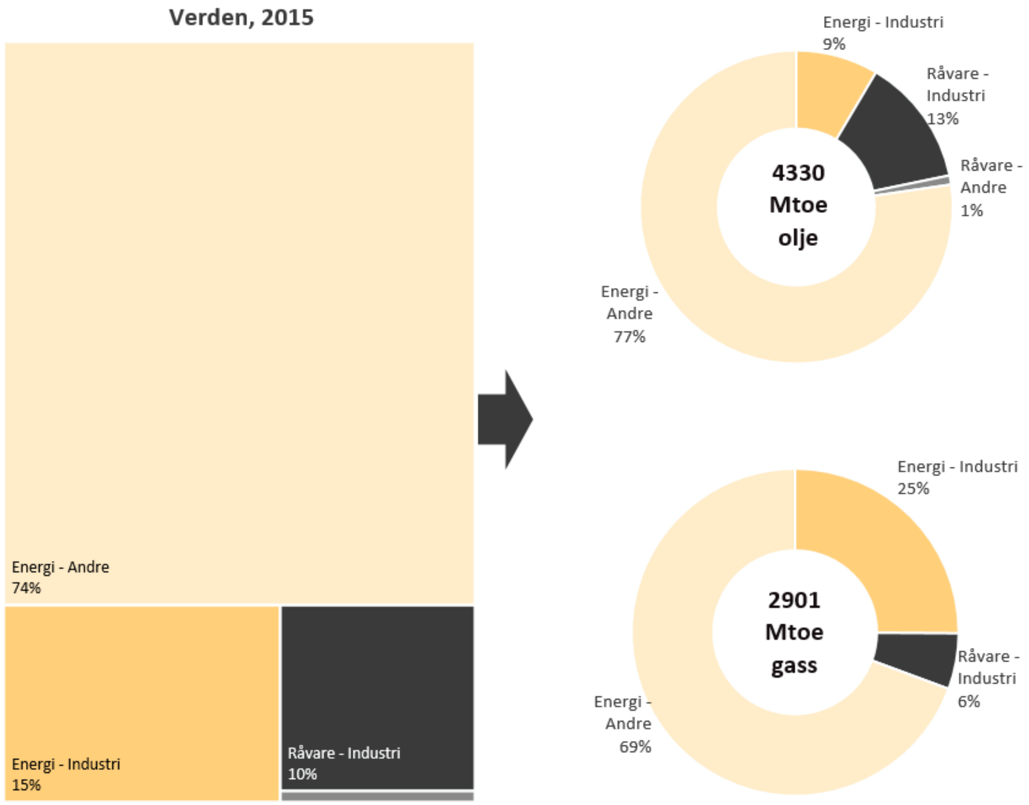
LPG	Liquified Petroleum Gas
Mtoe	Million ton oil equivalent, 1 Mtoe = 11.6 TWh = 41 868 TJ
Mboe	Million barrel oil equivalent
PE	Polyethylene
PP	Polypropylene
PS	Polystyrene
PU	Polyurethane
TJ	Terra Joule
kt	Kilo ton = 1000 ton
Mt	Mega ton = 1 000 000 ton = 1 million ton
Gt	Giga ton = 1 000 000 000 ton = 1 billion ton

1. SAMMENDRAG PÅ NORSK

Forbruk av energirelaterte produkter i verden har mer enn doblet seg de siste 45 årene. Olje er hovedkilden, etterfulgt av kull, naturgass, atomkraft, fornybar og biomasse (IEA, 2016). Disse produktene brukes i de viktigste forbrukssegmentene: industri, transport, husholdninger / tjenester / landbruk, eller i kraftverk. Ikke-energiforbruk spiller også en viktig rolle i etterspørselen etter energirelaterte produkter, hovedsakelig innen industri. «Ikke-energiforbruk» er energirelaterte produkter (f.eks. olje) som brukes som råvarer i de ulike sektorer, og som ikke forbrukes som drivstoff eller omdannes til andre drivstoff.

Denne rapporten presenterer resultatene fra to prosjekt utført av Endrava for Norsk olje og gass. Arbeidet fokuserer på bruk av olje- og gass som energikilde i industrienog til ikke-energiforbruk. Hensikten er å gi en oversikt over denne typen bruk i sammenheng med andre energirelaterte bruksområder, og å vurdere potensielle fremtidige trender. Det geografiske omfanget av denne rapporten er hele verden, med fokus på Europa.

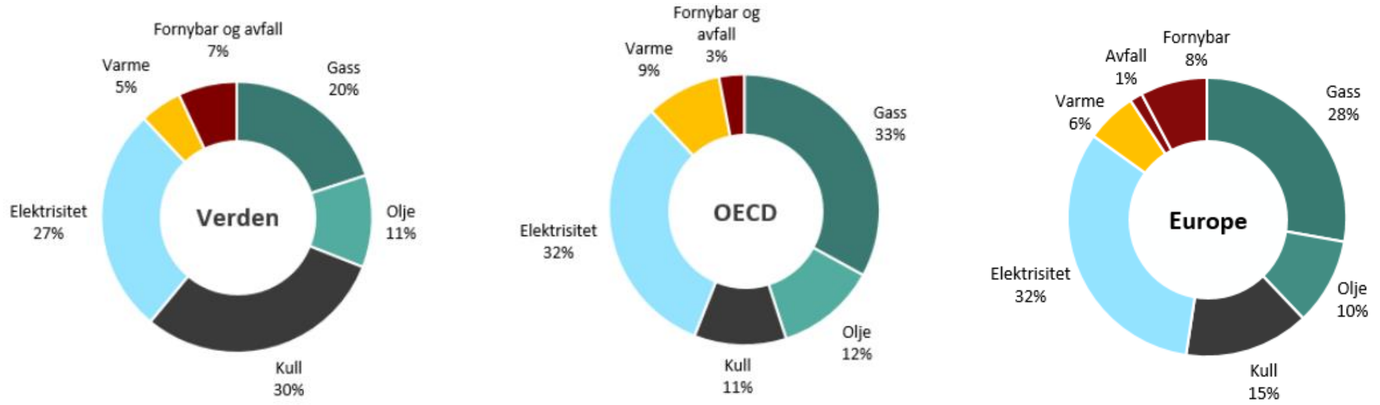
Ifølge data fra IEA (2017) utgjør energiforbruk av olje og gass i industrien 15% av all energi i verden, og ikke-energiforbruk representerer 11%, som illustrert i figuren nedenfor.



Figur 1 Andel olje og gass til ikke-energibruk og industri, verden, 2015 (beregnet, basert på IEA, 2017)

Situasjonen er svært lik i Europa, med 10% til energi i industrien, og 10% som ikke-energiforbruk (Eurostat, 2018a). I tillegg brukes 5% av olje og gass i Europa til "autoproducer" (selvgenererende) kraftverk, som er dedikert til spesifikke industriområder og bruksområder.

For industri på verdensbasis består energimiksen av ca. en tredjedel olje- og gassprodukter (31%, 1.097 Mtoe) og tilsvarende i Europa (38%, 109 Mtoe), som illustrert i figuren nedenfor.



Figur 2 Energikilder til industrien i verden, OECD og Europa (basert på IEA 2017 og Eurostat 2018a), til varmeforbruk, lys, elektriske prosesser og kjøling

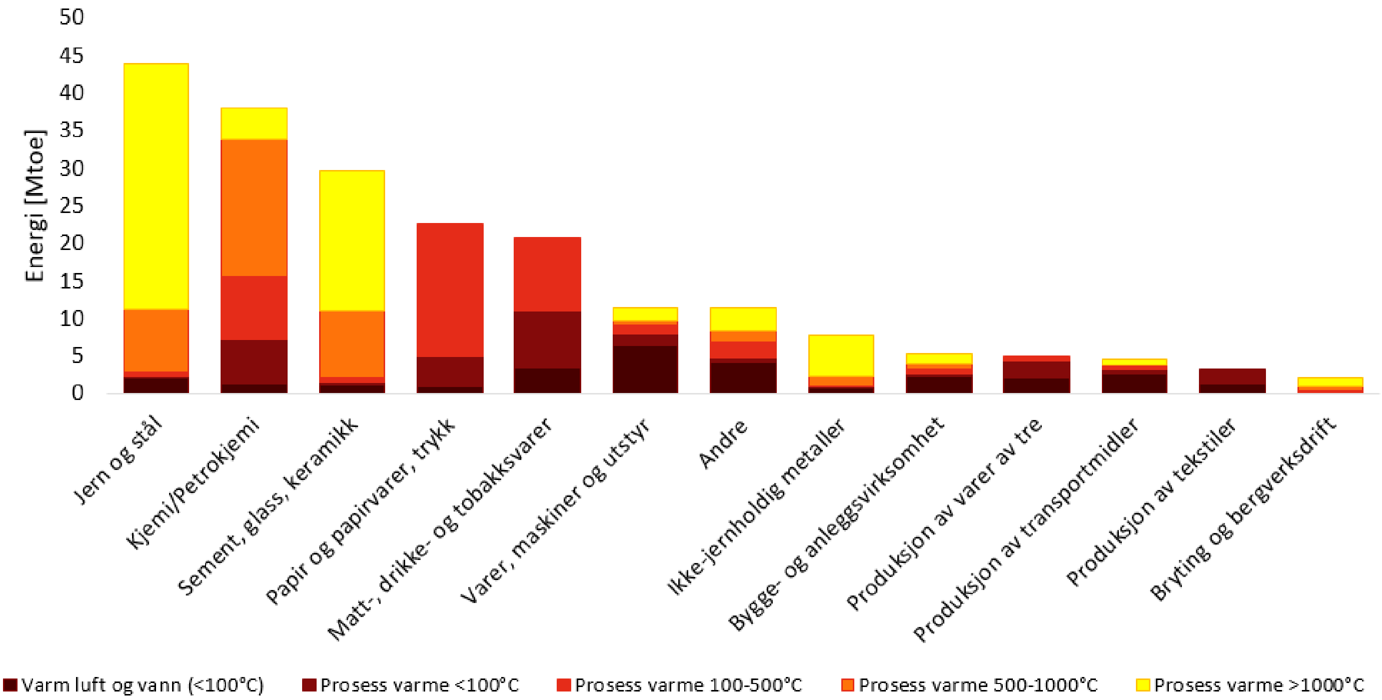
Generelt har industrien i Europa en tendens til å bruke mer strøm og mindre kull enn i resten av verden. El- og varmekategoriene som presenteres i figuren ovenfor forutsetter bruk av olje, gass, kull, avfall og fornybar energi i kraft- og varmeanlegg. Denne indirekte bruken av energiprodukter er ikke vist i figuren.

Fire industrisegmenter bruker mest energi både i verden og i Europa: kjemisk / petrokjemisk industri, ikke-metalliske mineraler (sement, etc.), mat og drikke, og jern og stål. Det totale energiforbruket i Europa har gått ned siden 2007 (-17%), hovedsakelig på grunn av finanskrisen i 2008 og forbedringer i energieffektiviteten.

To tredjedeler av energien som brukes i industrien i Europa, er for varme. Det resterende går til belysning, maskiner og kjøling, som illustrert nedenfor.

Figur 3 Varme og annen energiforbruk i industri i Europa, 2016 (basert på European Commission 2016, Naegler et al. 2015, og Eurostat 2018)

Veldig høy temperatur varme (> 500 ° C) står for ca. 40% av industriens energiforbruk i Europa (109 Mtoe / år). Per 2018 er det nesten umulig å elektrifisere prosesser som benytter høy temperatur varme. Fire industrisegmenter utgjør 90% av all bruk av veldig høy temperatur varme. Disse segmentene er: jern og stål (38%), ikke-metalliske mineraler (sement mm) (25%), kjemisk / petrokjemisk industri (21%) og ikke-jernholdige metaller (aluminium etc.) (6%).

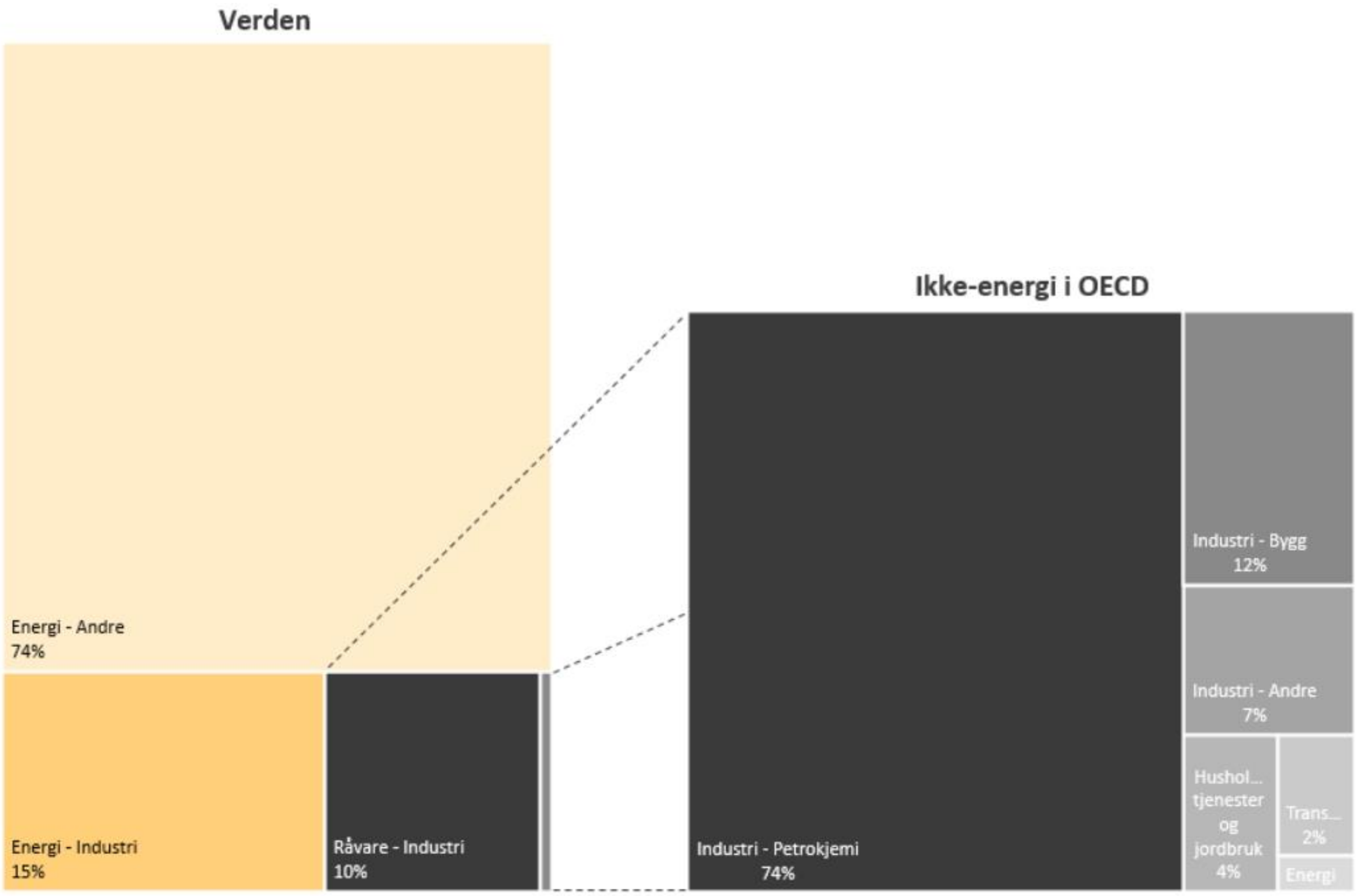


Figur 4 Energibruk for varme i industri, per segment (basert på Naegler et al. 2015. Data er fra 2012)

Endravas analyse av disse fire industrisegmentene, basert på ulike kilder, viser at det totale energiforbruket i industrien i Europa forventes å være stabilt til 2050. Dette skyldes en kombinasjon av industri som forventes å redusere sin energibruk (f.eks. Ikke-jernholdige metaller), og andre næringer som forventes å bruke mer energi i fremtiden (f.eks. kjemisk / petrokjemisk). De fleste endringer i energibruk skyldes forbedring av energieffektiviteten, eller endringer i produksjonsnivå.

Samlet sett forventes bruk av olje- og gassprodukter for energiformål i industrien å forbli stabilt, men det vil avhenge av utviklingen av produksjonsvolum i viktige næringer som kjemiske / petrokjemiske og ikke-metalliske mineraler (sement osv.).

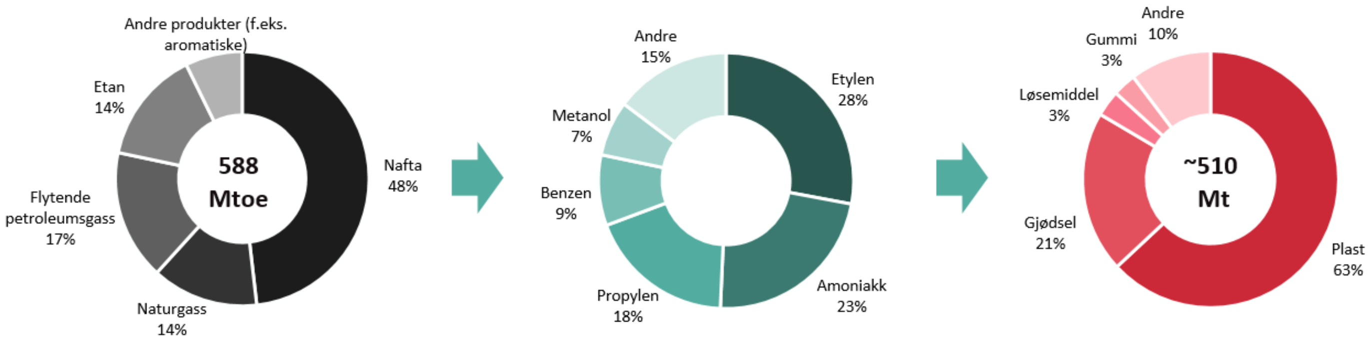
Olje- og gassprodukter er ikke bare brukt til å generere energi. Ikke-energiforbruk fører også til en betydelig etterspørsel etter petroleumsprodukter samt mindre mengder kull. I verden representerte ikke-energiforbruk 11% av olje- og gassproduktene i 2015 (IEA, 2017). Ytterligere informasjon er tilgjengelig for OECD-landene: 74% ble brukt av kjemisk og petrokjemisk industri, ytterligere 12% ble brukt i bygg segmentet (mest bitumen), og mindre mengder ble brukt av andre industrisegmenter, husholdninger og tjenester, og transport (mest smøremidler).



Figur 5 Andel olje og gass til ikke-energiforbruk i verden, og detaljer for OECD-landene (beregnet, basert på IEA 2017, data er fra 2015)

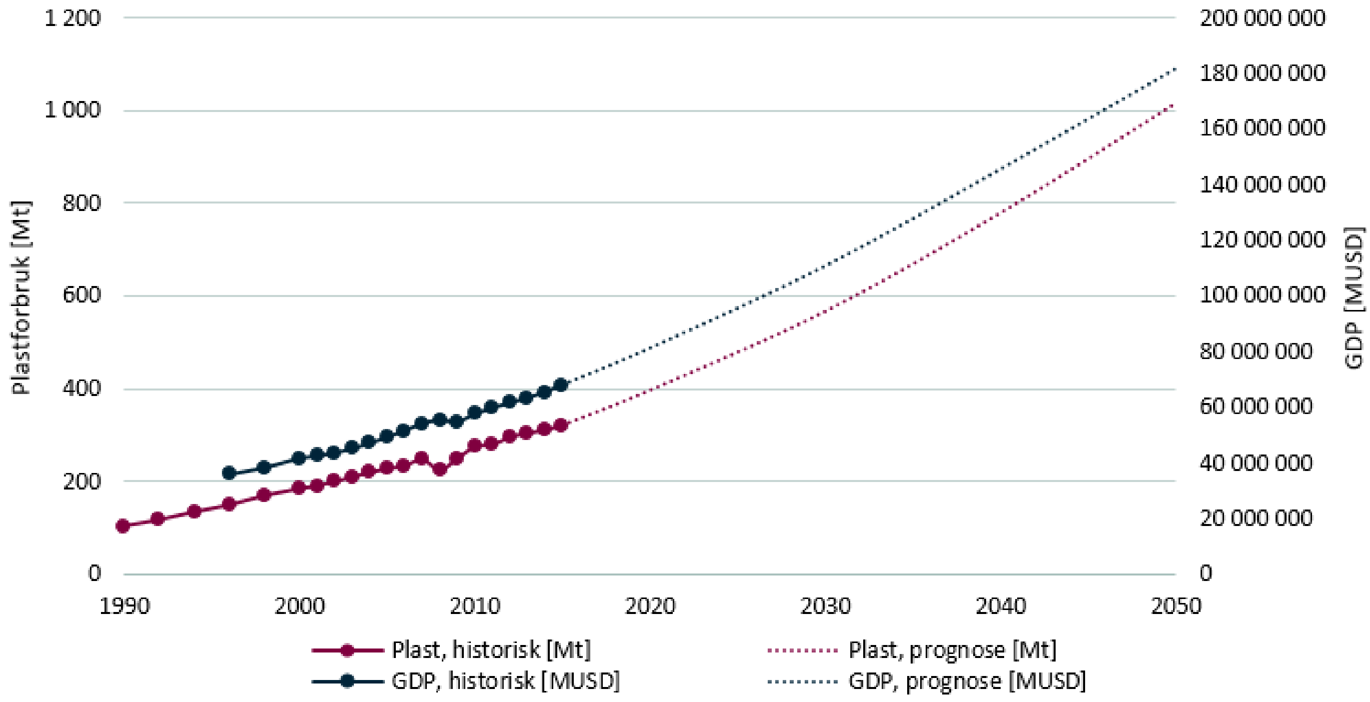
Andelen er omtrent den samme i Europa, hvor kjemisk og petrokjemisk industri representerte 80% av ikke-energiforbruket i 2016 (77 Mtoe), etterfulgt av ca. 15% innen byggebransjen (14 Mtoe).

Ikke-energiprodukter brukes hovedsakelig som råstoff for å produsere petrokjemikalier, som i sin tur transformeres til sluttprodukter. Endravas analyse av petrokjemisk industri viser at de viktigste sluttproduktene er plast (63%), gjødsel (21%), løsemidler og gummi. Etterspørselen etter olje og gass som ikke-energiprodukter er derfor tett korrelert med produksjonen fra kjemisk og petrokjemisk industri.



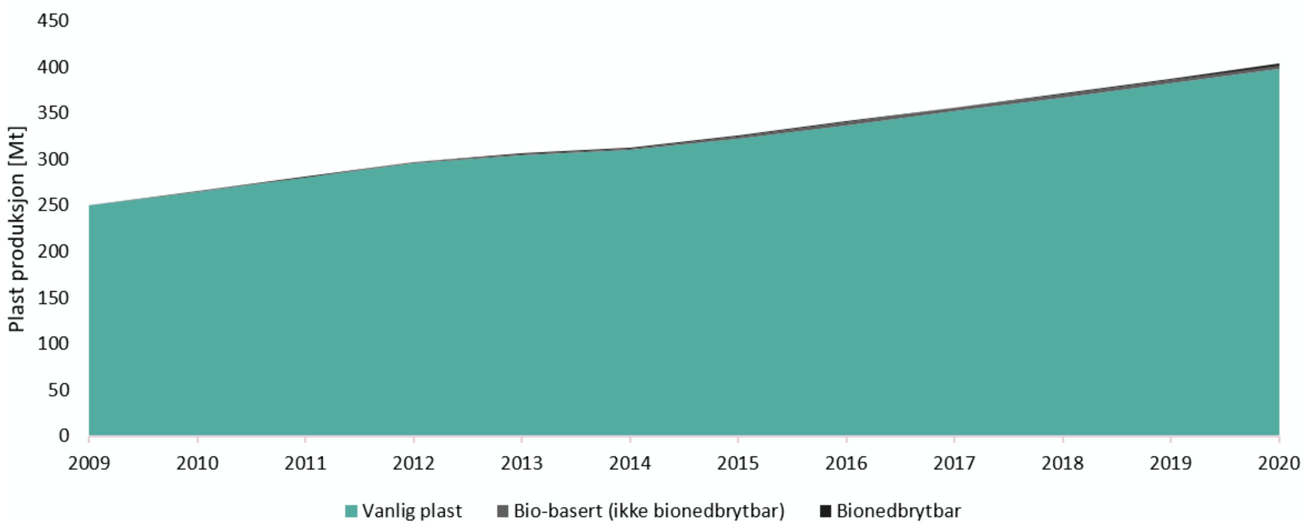
Figur 6 Produksjonsflyt i kjemisk / petrokjemisk industri i verden (beregnet, basert på data fra IEA 2017 og andre kilder)

Etterspørselen etter plastprodukter spiller en viktig rolle, og plastproduksjonen har økt jevnt siden produktene først ble introdusert tidlig på 1950-tallet. Etterspørselen følger BNP, og forventes å nå mer enn 1000 Mt i 2050 (mot ca 350 Mt i 2016).



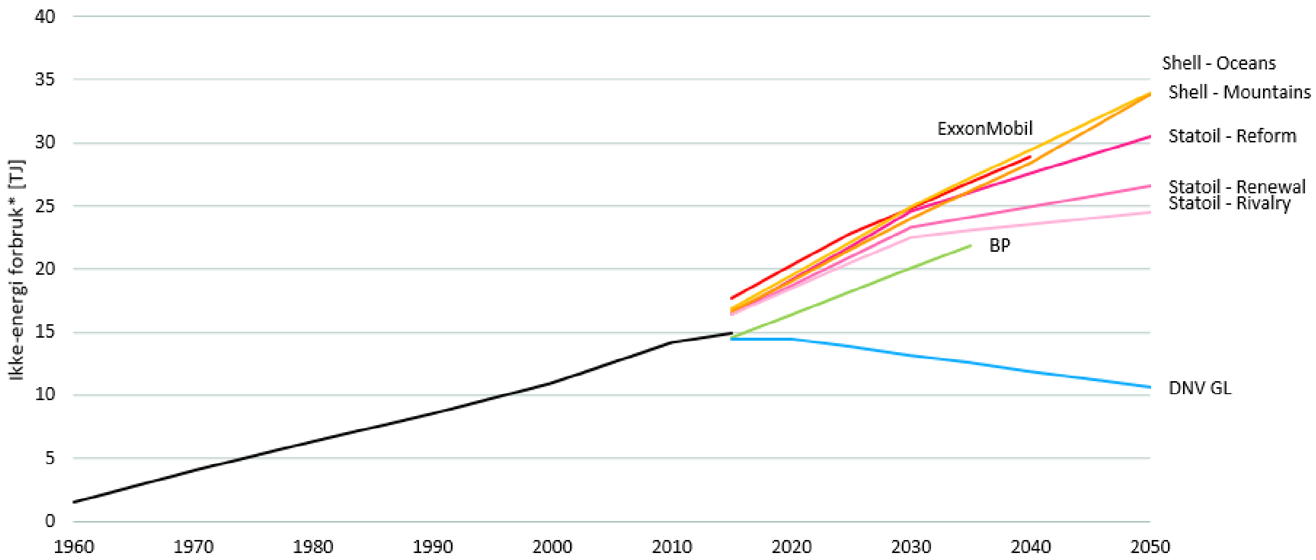
Figur 7 Utvikling i verdens BNP og plastforbruk (uthevede punkter) og prognoser (stiplede liner) (beregning basert på BNP fra OECD, 2017 og historisk plastforbruk fra Plastics Europe, 2016)

En stor andel plastprodukter brukes til emballasje. Reduksjon i bruk av plastprodukter, gjenbruk og resirkulering kan være tre parametere som påvirker plastens etterspørsel i fremtiden, selv om den fremtidige effekten er usikker i øyeblikket. I tillegg øker produksjonen av biobasert plast (fra fornybare kilder), men dette utgjør fortsatt en ubetydelig andel av den totale produksjonen sammenlignet med vanlig plast basert på olje og gass.



Figur 8 Produksjon av biobasert plast og vanlig plast (basert på European Bioplastics 2017, og Plastics Europe 2016)

I tillegg forventes produksjon av ammoniakk (til gjødsel) og metanol (til et bredt spekter av produkter) å fortsette å øke i fremtiden. Derfor forventes det totale ikke-energiforbruket av olje og gassprodukter også å fortsette å øke. De fleste prognoser fra store energiselskaper og organisasjoner er enige om denne utviklingen, som illustrert nedenfor.



** for det meste olje og gass, kan inkludere mindre mengder kull og biomasse, detaljer ikke tilgjengelig*

Figur 9 Historiske data og prognoser for ikke-energiforbruk fram til 2050 (IEA 2017b, BP 2017, DNV GL 2017, ExxonMobil 2017, Shell 2013, Equinor / Statoil 2017)

Hvis etterspørselen etter olje og gass til energibruk (industri, transport og energi) stabiliseres eller reduseres i fremtiden, kan ikke-energi bruk utgjøre en økende samlet andel av petroleumsindustriens produkter.

2. EXECUTIVE SUMMARY

The use of energy products in the world has more than doubled over the past 45 years. Oil is the main source of energy, followed by coal, natural gas, nuclear power, renewables and biomass (IEA, 2016). These products are used across the main consumption segments: industry, transport, housing/services/agriculture, or used in power plants. Non-energy use also plays an important role in the demand of energy products, mostly for the industry. Non-energy use corresponds to energy products (e.g. oil) used as raw materials in the different sectors, and that are not consumed as a fuel or transformed into another fuel.

This report presents the results from two projects carried out by Endrava for the Norwegian oil and gas association. It focuses on the use of oil and gas as energy source in the industry, and for non-energy use. The purpose is to provide an overview of this particular type of use in the context of other energy-related uses, and to investigate potential future trends. The geographical scope of the present report is the whole world, with a focus on Europe.

According to data from IEA (2017), energy use of oil and gas in industry represents 15% of all the energy in the world, and non-energy use represents 11%, as illustrated in the figure below.

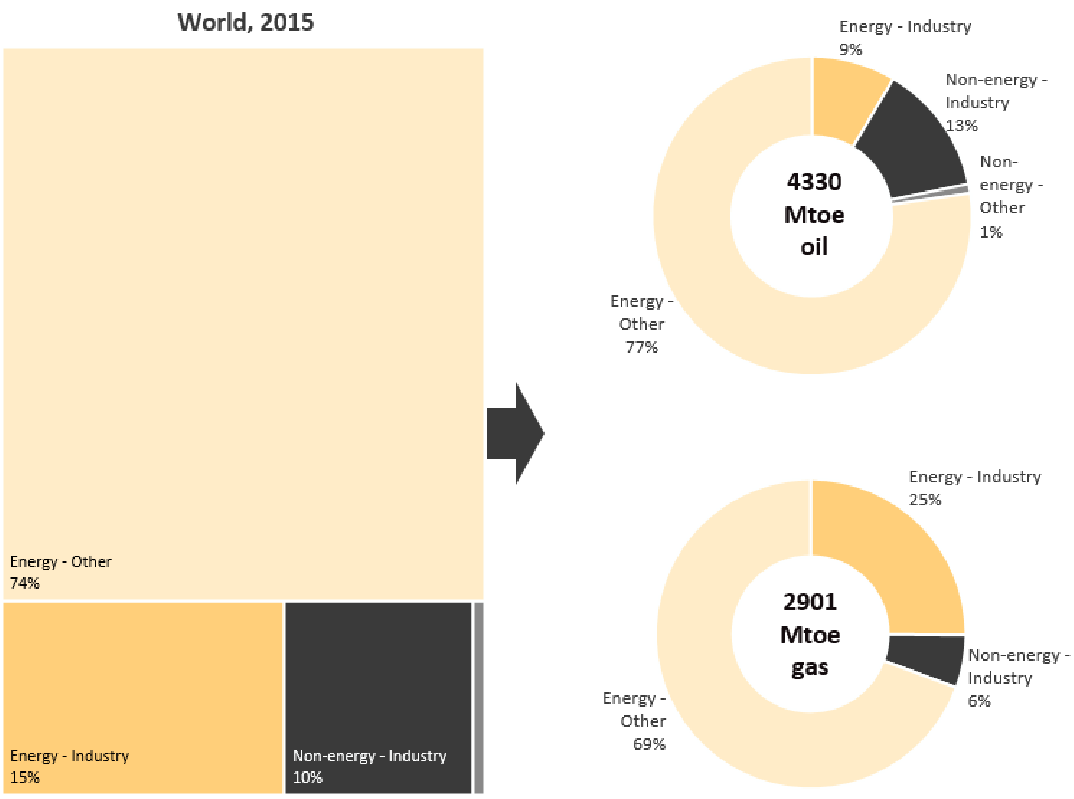


Figure 10 Share of oil and gas to non-energy use and industry, world, 2015 (calculated, based on IEA, 2017)

The situation is very similar in Europe, with 10% to energy in industry, and 10% as non-energy use (Eurostat, 2018a). In addition, 5% of oil and gas in Europe is used in "autoproducer" power plants, which are dedicated to specific industrial sites and uses.

When focusing on energy use in the industry in the world, the energy mix is made of ca. one third by oil and gas products (31%, 1,097 Mtoe) and similarly in Europe (38%, 109 Mtoe), as illustrated in the figure below.

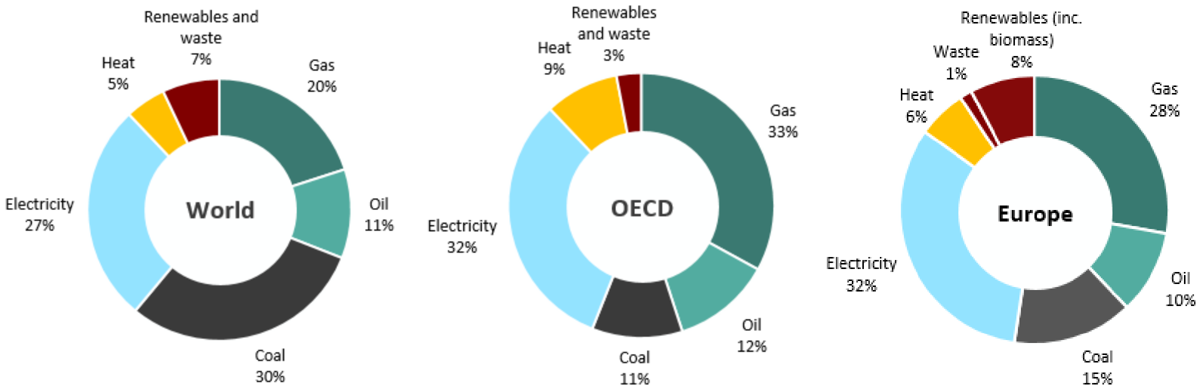


Figure 11 Energy sources to the industry in the world, OECD and Europe (based on IEA 2017 and Eurostat 2018a), for heating, lighting, electrical processes and cooling

In general, the industry in Europe tends to use more electricity and less coal than in the rest of the world. Note that the electricity and heat categories presented in the figure above presuppose the use of oil, gas, coal, waste and renewables in power and heat plants. This indirect use of energy products is not presented in the figure.

Four industry segments are using the most energy both in the world and in Europe: the chemical/petrochemical industry, non-metallic minerals (cement, etc.), food industry and iron and steel. The total energy use in Europe has been decreasing since 2007 (-17%), mostly due to the finance crisis in 2008 and to improvements in energy efficiency.

Two thirds of the energy used in industry in Europe is for heat. The remaining is for lighting, machines, and cooling, as illustrated below.

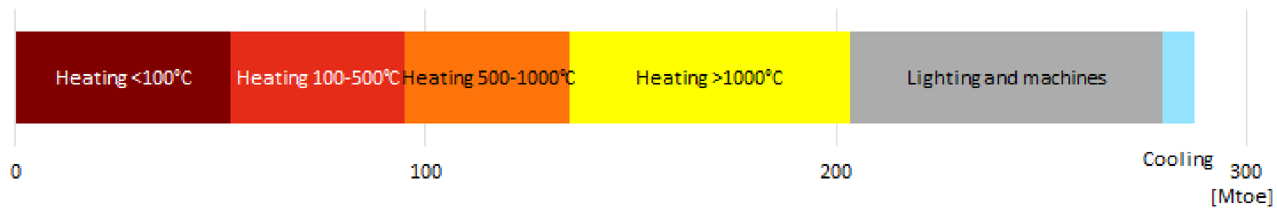


Figure 12 Heat and other energy uses in industry in Europe, 2016 (based on European Commission 2016, Naegler et al. 2015, and Eurostat 2018)

Very high temperature heat (>500°C) accounts for ca. 40% of the industrial energy use in Europe (109 Mtoe/year). As of 2018, it is almost impossible to electrify processes with that high temperatures. Four industry segments make for 90% of all the use of very high temperature heat. These segments are: iron and steel (38%), non-metallic minerals (cement, etc.) (25%), the chemical/petrochemical industry (21%), and non-ferrous metals (aluminium, etc.) (6%).

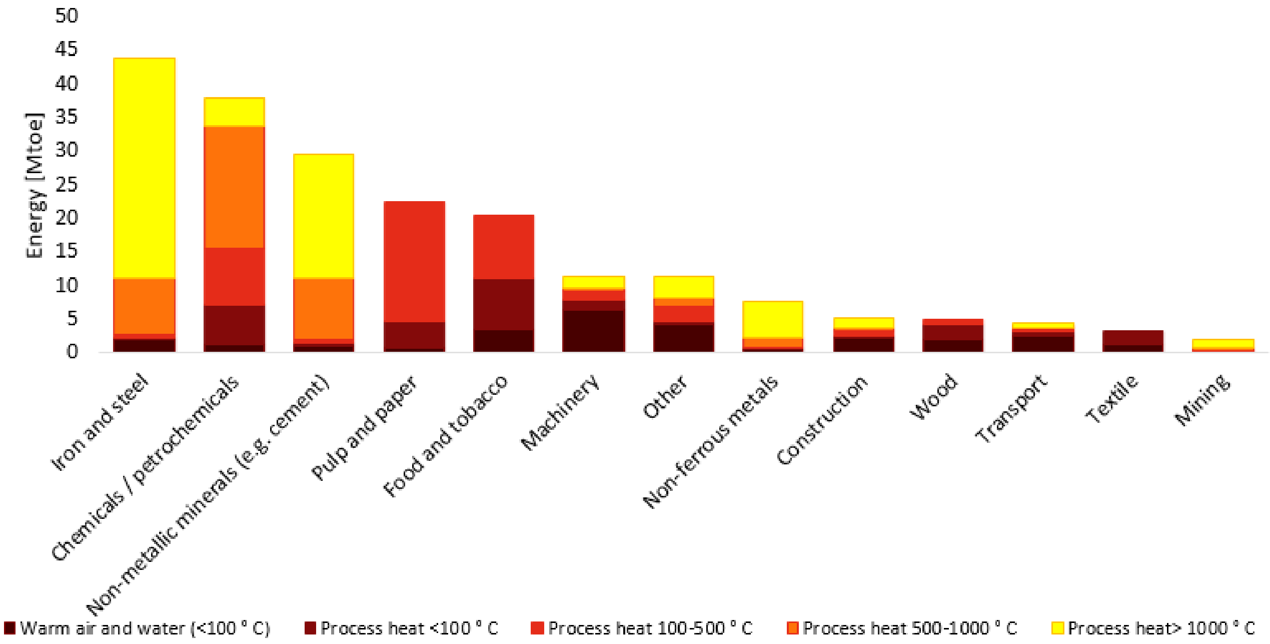


Figure 13 Energy use for heat in industry, per segment (based on Naegler et al. 2015. Data is for 2012)

Endrava's analysis of these four industry segments, based on various sources, shows that the total energy use in industry in Europe is expected to remain stable on the overall until 2050. This is due to a combination of industry expected to decrease their energy use (e.g. non-ferrous metals), and other industries expected to use more energy in the future (e.g. chemical/petrochemical). Most changes in energy use are due to improvement in energy efficiency, or to changes in production levels.

Overall, the use of oil and gas products for energy purposes in the industry is expected to also remain stable, but it will depend on the development of the production volumes in important industries such as chemical/petrochemical and non-metallic minerals (cement, etc.).

Oil and gas products are not only used to generate energy. Non-energy use also leads to a significant demand for petroleum products and to smaller amounts of coal. In the world, non-energy use represented 11% of the oil and gas products in 2015 (IEA, 2017). Details are available for OECD countries: 74% were used by the chemicals and petrochemicals industry, another 12% were used in the construction segment (mostly bitumen), and smaller amounts were used across other industry segments, in housing and services, and transports (mostly lubricants).

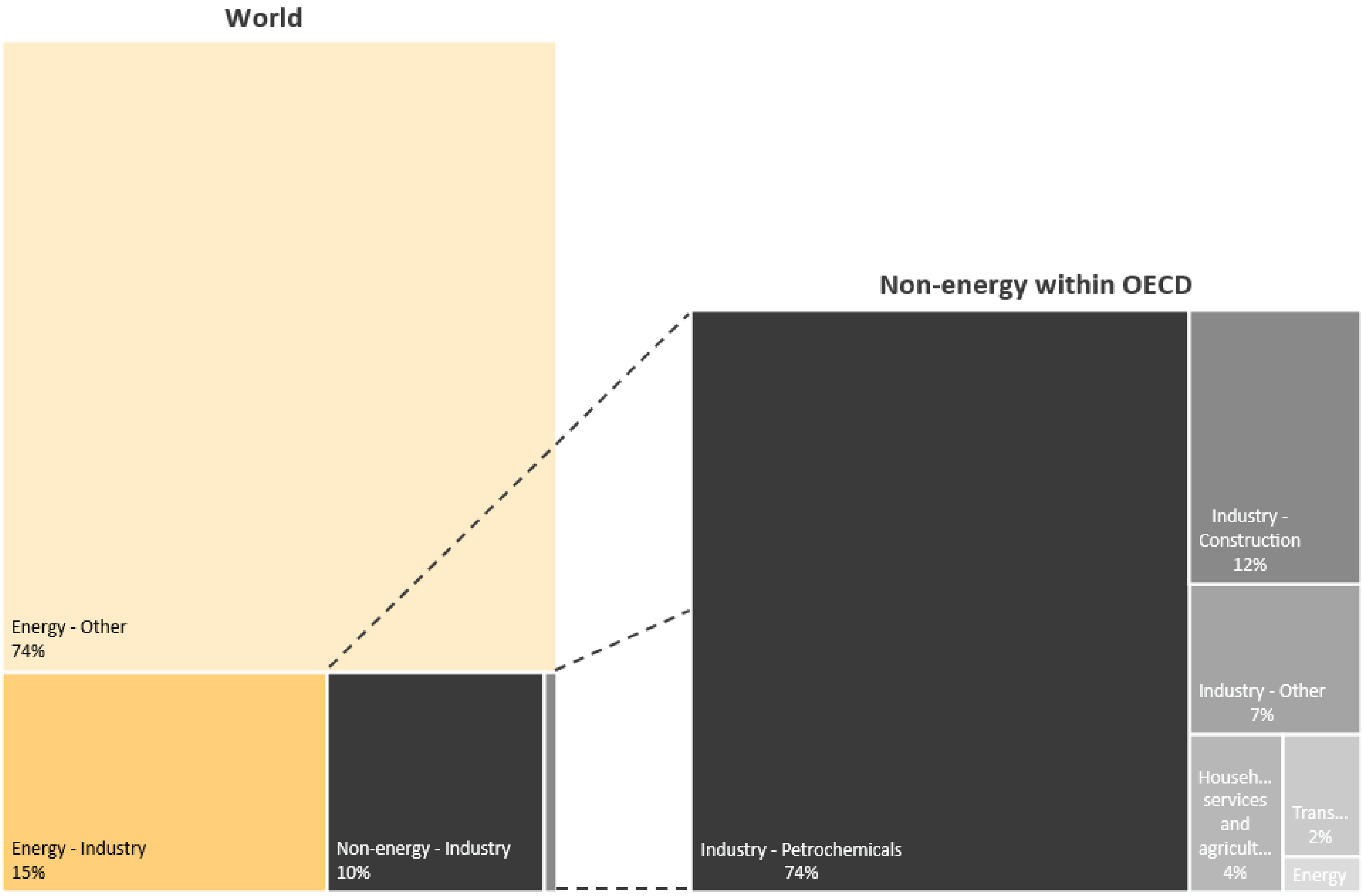


Figure 14 Share of oil and gas to non-energy use in the world, and details for OECD countries (calculated, based on IEA 2017, data for 2015)

The share is about the same in Europe, where the chemical and petrochemical industry represented 80% of the non-energy use in 2016 (77 Mtoe), followed by ca. 15% within the construction industry (14 Mtoe).

Non-energy products are mainly used as feedstock to produce petrochemicals, which are in turn transformed into final products. Endrava's analysis of the petrochemical industry shows that the main final products are plastics (63%), fertilisers (21%), solvents and rubber. The demand for oil and gas as non-energy products therefore follows closely the output of the chemical and petrochemicals industry.

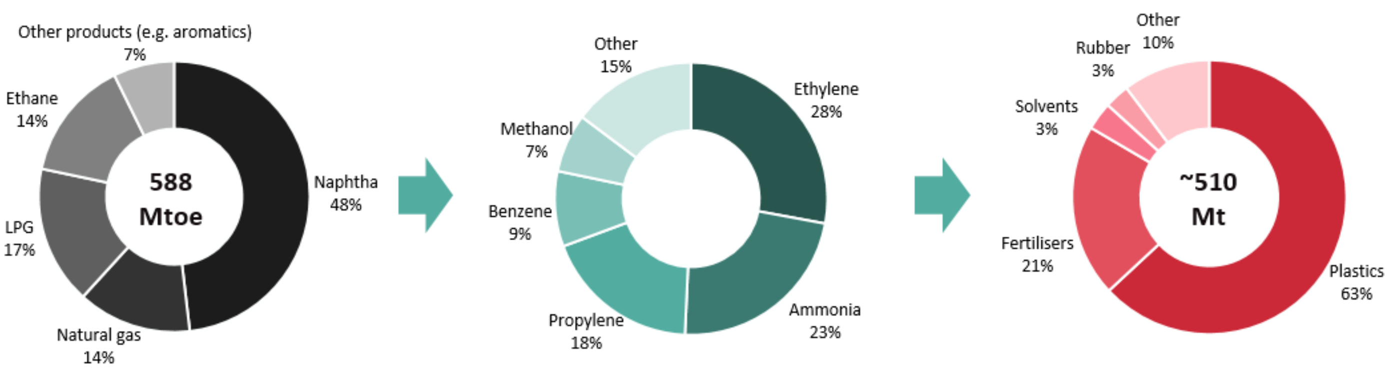


Figure 15 Production flows in the chemical/petrochemicals industry in the world (calculated, based on data from IEA 2017 and other sources)

There, the demand for plastics products plays a major role, and plastics production has been increasing steadily since they were first introduced in the early 1950s. The demand follows the GDP, and is expected to reach more than 1,000 Mt in 2050 (vs. ca. 350 Mt in 2016).

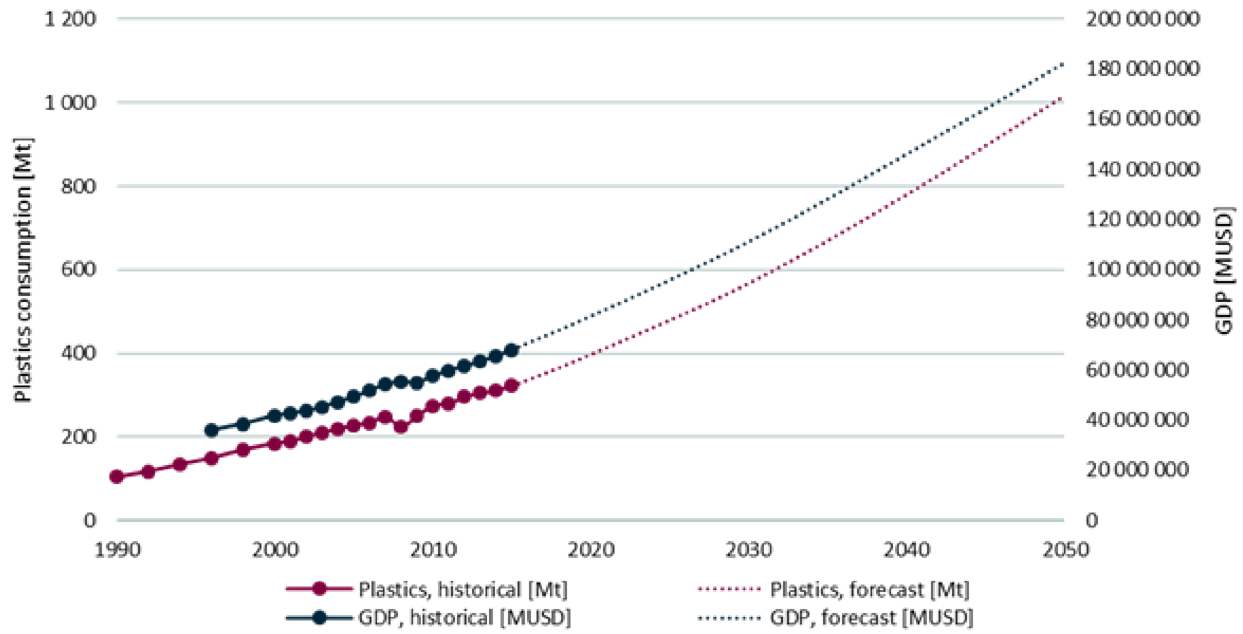


Figure 16 Development in world GDP and plastics consumption (dots), and forecast for both (dashed lines) (calculation based on GDP from OECD, 2017, and historical plastics consumption from Plastics Europe, 2016)

A large share of the plastics products is used for packaging. A reduction in the use of plastics products, their re-use and recycling could be three parameters impacting the plastic demand in the future, although their future effect is uncertain at the moment. In addition, the production of bio-based plastics (from renewable sources) is increasing, but still fails to have a significant impact on the total demand for oil and gas products as feedstock to plastics production.

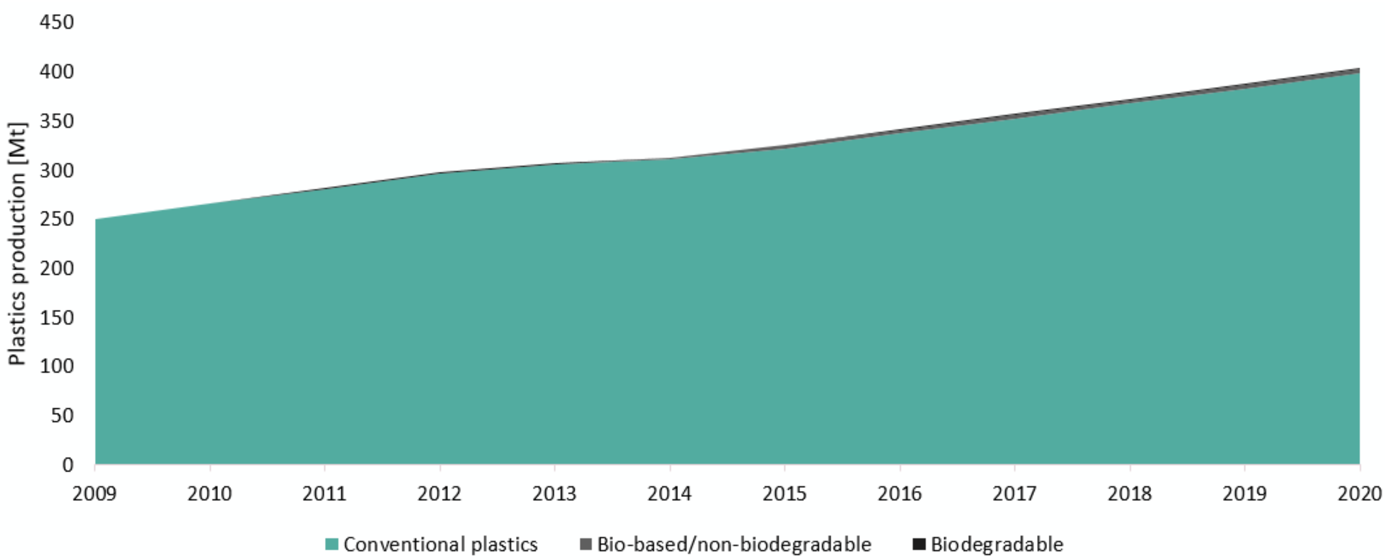
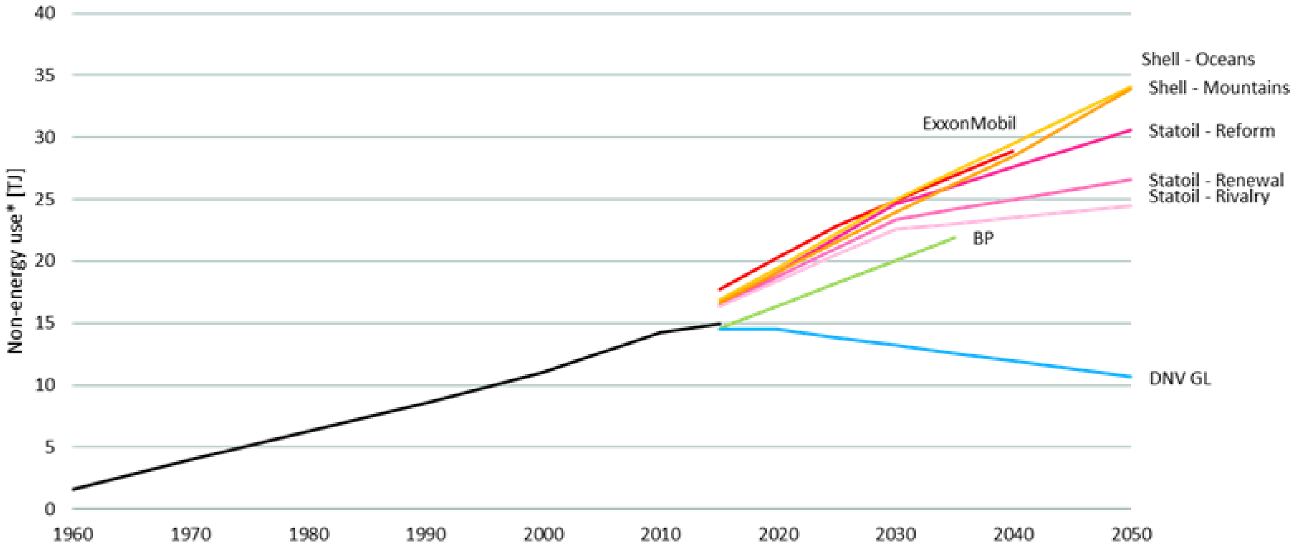


Figure 17 Production capacity for bio-based plastics, and total demand for plastics (based on European Bioplastics 2017, and Plastics Europe 2016)

In addition, the production of ammonia (to fertilisers) and methanol (to a wide range of products) are expected to keep increasing. Therefore, the total non-energy use of oil and gas products is expected to keep on rising. Most energy outlooks from major energy companies and organisations agree on this development, as illustrated below.



** mostly oil and gas, may include smaller quantities of coal and biomass, more details not available.*

Figure 18 Historical data and forecasts for non-energy use until 2050 (IEA 2017b, BP 2017, DNV GL 2017, ExxonMobil 2017, Shell 2013, Equinor/Statoil 2017)

If the demand of oil and gas for energy uses (industry, transport and energy) stabilises or decreases in the future, non-energy use could represent an increasing overall share of the petroleum industry's products.

3. INTRODUCTION - OVERVIEW ON USE

This report presents the results from two projects carried out by Endrava for the Norwegian oil and gas association. It focuses on the use of oil and gas products as energy source in the industry, and in general for non-energy use. The purpose is to provide an overview of this particular type of use in the context of other energy-related uses, and to investigate potential future trends. The geographical scope of the present report is the whole world, with a focus on Europe.

3.1. Energy use in the world

According to IEA (2016), the use of energy in the world has more than doubled over the past 45 years. During the whole period, oil has been the main energy source, with 31.3% of the supply in 2014. Coal and natural gas are the two next largest sources, with 28.6% and 21.2% of the world energy, respectively.

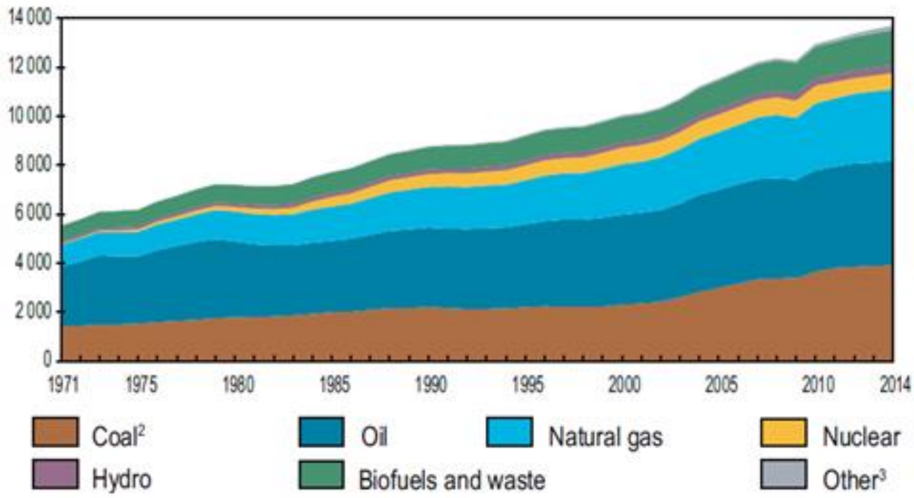


Figure 19 Primary energy supply in the world, 1971-2014 [Mtoe] (IEA, 2016)

For a more detailed overview, energy flows and use can be visualised with the help of a Sankey diagram, as illustrated below.

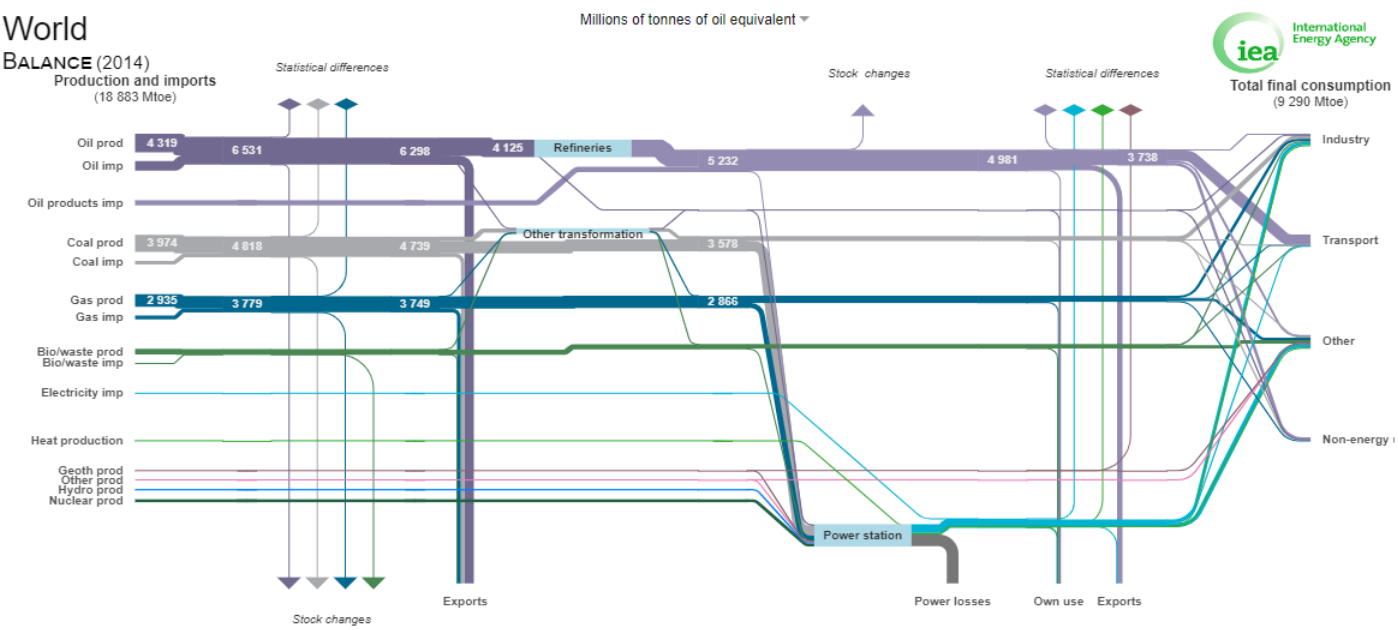


Figure 20 Overview of the use of energy in the world, 2014 (IEA, 2018a)

Energy sources are placed on the left side of the diagram. In 2014, 4,319 Mtoe oil and 2,935 Mtoe gas were produced in the world. Exports and transformation are placed in the middle of the diagram. This is where raw energy is transformed into other products, for example crude oil is transformed into oil products (e.g. LPG, diesel, etc.). Power stations are also placed there, where different energy sources are transformed into electricity and heat.

The final consumption of energy is presented on the right hand side of the chart. This represents the final use of transformed energy into various sectors: industry, transport, non-energy use, and others (agriculture, services, households). Due to losses, transformations, own use, and import/export of products, the total final consumption of energy (right) is about half of what is actually produced (left).

3.1.1. OIL PRODUCTS

The figure below presents the final consumption of oil products in the world.

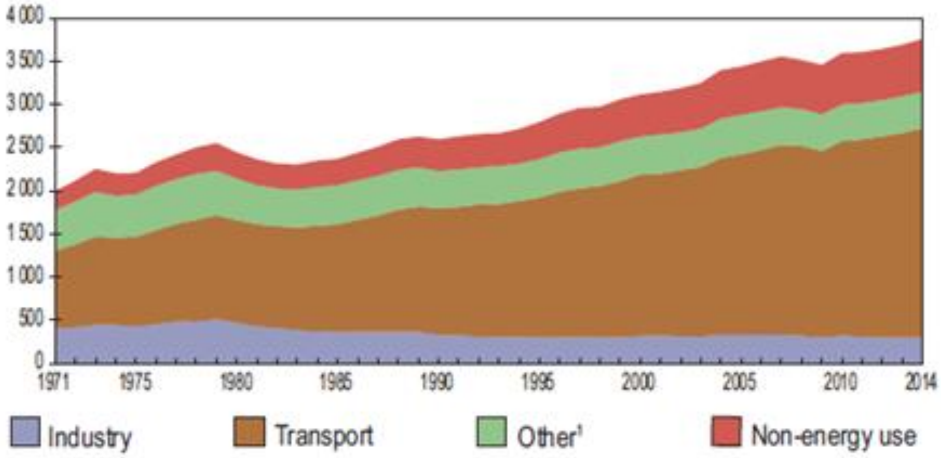


Figure 21 Final consumption of oil products in the world, 1971 to 2014 [Mtoe] (IEA, 2016)

Oil consumption has increased by 67% in the past 45 years, the main uses in 2014 are:

- The transport sector (fuels), with 64.5%.
- Non-energy use, with 16.2%. It has more than doubled during that period of time, from 261 to 609 Mtoe.
- Other (agriculture, services, households), with 11.3%.
- The industry, with 8%.

In 1973, oil was used as one of the main fuels for power stations (not shown on the figure above), with 24.8% of the supply. This use has reduced drastically over the past 45 years, and oil now represents only 4.3% of the energy supply to power stations.

3.1.2. GAS

Similarly, the use of gas in the world has more than doubled over the past 45 years, as illustrated in the figure below.

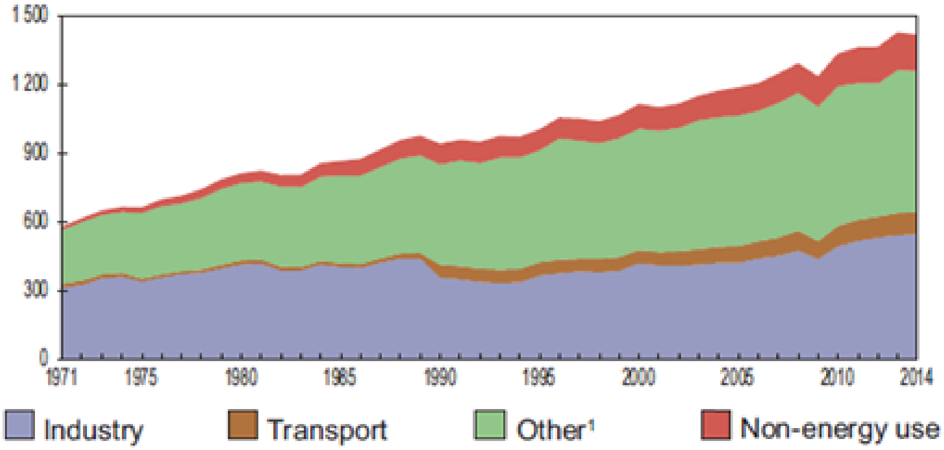


Figure 22 Final consumption of natural gas in the world, 1971 to 2014 [Mtoe] (IEA, 2016)

The final consumption of gas in 2014 is as follows:

- Other (agriculture, services, households), with 43.2% (typically for heating).
- Industry, with 38.6%.
- Non-energy use, with 11%. Use of gas for non-energy purposes has increased about 10 fold since 1971, from 18 to 160 Mtoe.
- Transport, with 6.9%.

In 2014, gas was the second largest energy supply to power stations (21.6%), after coal.

3.2. ENERGY IN INDUSTRY AND NON-ENERGY USE

Endrava calculated the share of oil and gas products used for non-energy purposes and in the industry. This is based on IEA data for the year 2015 (IEA, 2017a), for final consumption of energy. Oil and gas used in refineries, power stations, and for other transformations are not included in this overview.

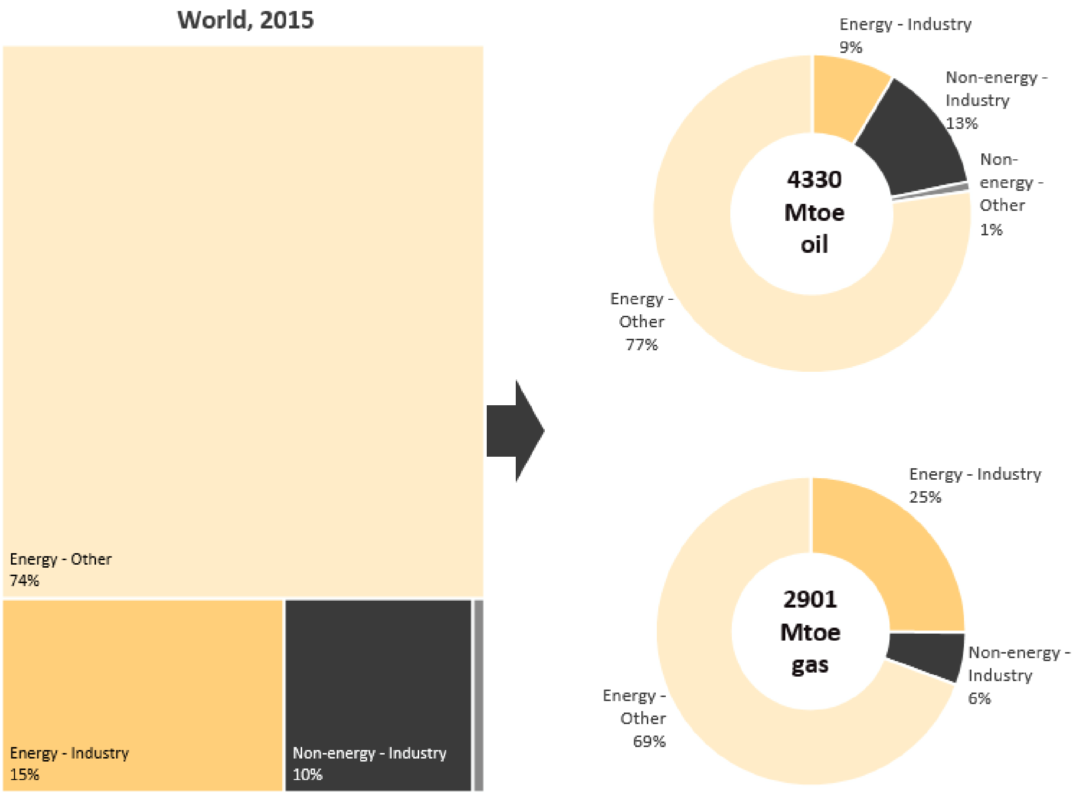


Figure 23 Share of oil and gas to non-energy use and industry, world, 2015 (calculated, based on IEA, 2017)

In 2015, non-energy use and the energy to industry represented 26% of the final consumption of oil and gas in the world.

Oil is used primarily in the industry for non-energy use (feedstock, 13%), and also as energy source (9%). Gas is used mostly as energy source in the industry (25%), and to a lesser extent for non-energy use (6%). Non-energy use in other sectors is minimal, with 1% of the oil used: for example as lubricants in transport, white-spirit in households and agriculture.

Eurostat (2018a) provides detailed data for Europe in 2016, which show a similar situation as the rest of the world.

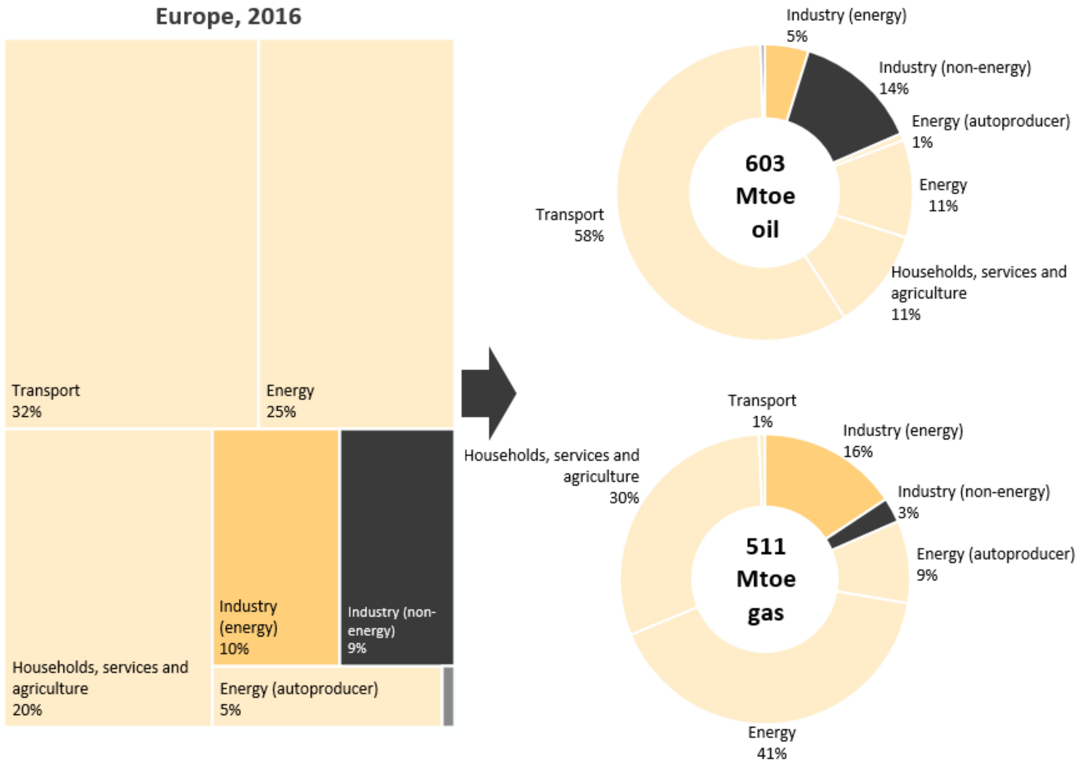


Figure 24 Share of oil and gas to non-energy use and industry, Europe, 2016 (calculated, based on Eurostat, 2018a)

Non-energy use and energy to the industry represent 23% of the final consumption of oil and gas in Europe, when including autoproducer plants. These are facilities generating electricity and/or heat for their own use, as support to their primary industrial activity.

Oil is used primarily in the industry for non-energy use (feedstock, 14%), and also as energy source (5%). This is less use as energy source than in the rest of the world (9%). Gas is used mostly as energy source in the industry (16%), and to a lesser extent for non-energy use (3%). These two figures are lower than in the rest of the world. Non-energy use in other sectors is minimal, with less than 1% of the oil and gas.

The figure below shows the trend in energy use and non-energy use in the industry in Europe since 2007.

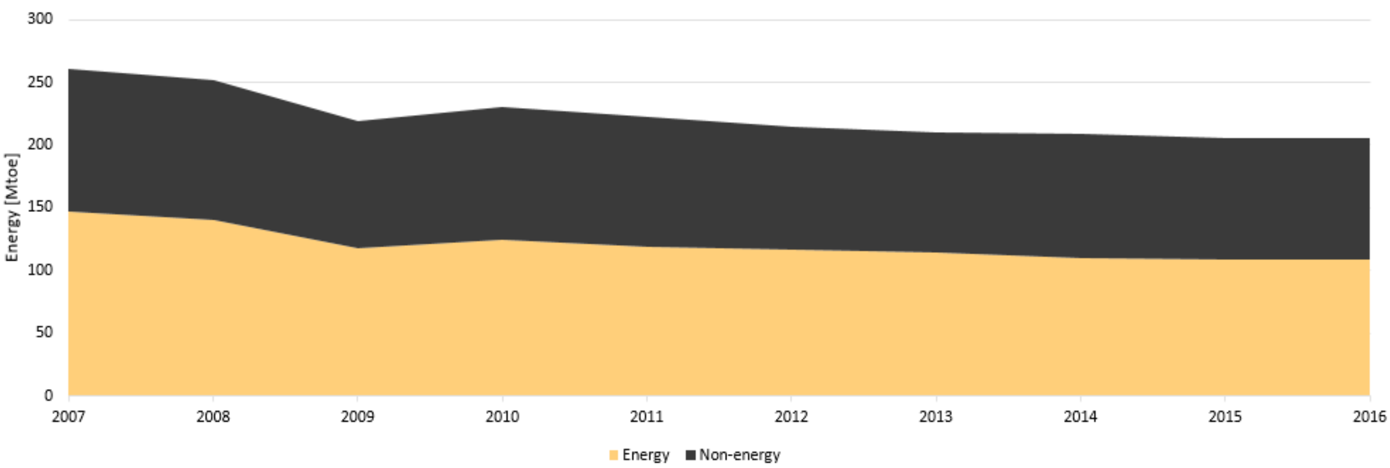


Figure 25 Trend in energy and non-energy use in the industry in Europe since 2007 (Eurostat 2018a)

On the overall, the use of oil and gas in the industry has decreased by 21% since 2007. This is partially due to the finance crisis in 2008, and partially to improvements in energy efficiency. The consumption of oil and gas products for non-energy use has decreased until 2012 and remained stable since then. It represents ca. 45% of all the consumption in the industry (96 Mtoe vs. 206 Mtoe total).

The figure below shows the share of oil and gas for energy or non-energy use in the industry in individual countries in Europe.

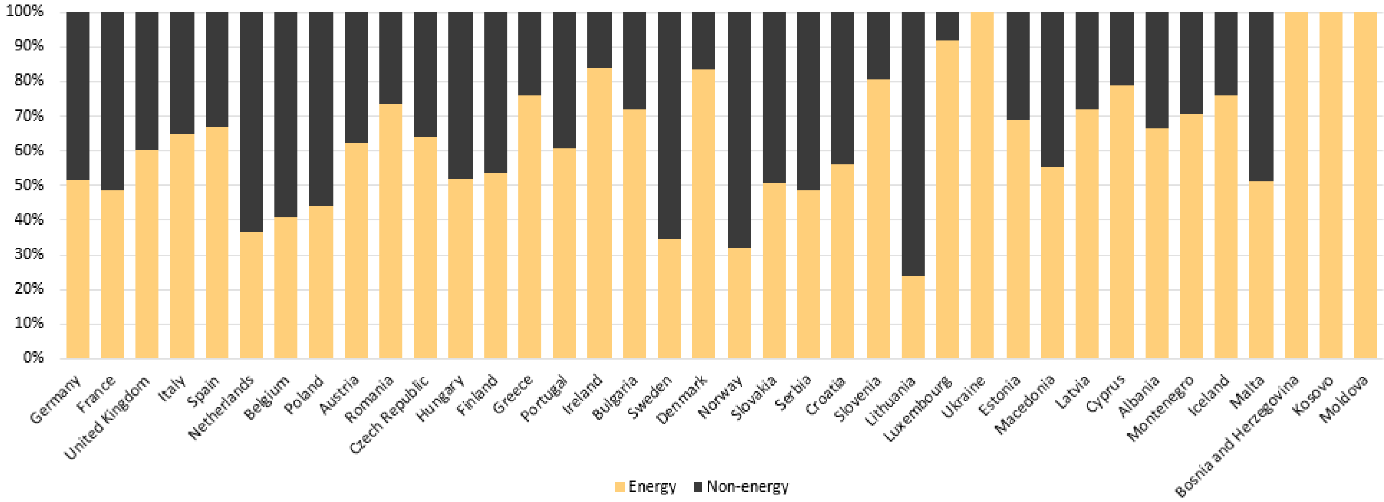


Figure 26 Share between energy and non-energy use in countries in Europe (Eurostat 2018a) (countries are sorted by their total use)

The share of energy and non-energy use in the industry in Europe varies a lot among countries. For example, countries with a large share of chemical/petrochemical industry (e.g. Netherlands, Belgium) consume relatively more oil and gas for non-energy use than others.

4. ENERGY USE IN THE INDUSTRY

About one third of the energy used in the industry in the world is from oil and gas (31%, 1 097 Mtoe), and this share is a bit higher in Europe (38%, 109 Mtoe). The industry in Europe uses more electricity and less coal than the rest of the world.

The chemical/petrochemical industry, non-metallic minerals (cement, etc.), food industry, and iron and steel, are the industry segments using the most energy, both in the world and in Europe. Energy use in Europe has been decreasing since 2007 (-17%), mostly due to the finance crisis in 2008 and to improvements in energy efficiency.

Two thirds of the energy used in industry in Europe is for heat. The remaining is for lighting, machines, and cooling. Very high heat (>500°C) makes ca. 40% of the energy use (109 Mtoe per year in Europe). As of October 2018, it seems very difficult to electrify high temperature heat processes. Four industry segments represent 90% of the use of very high heat. These segments are: iron and steel, non-metallic minerals (cement, etc.), the chemical/petrochemical industry, and non-ferrous metals (aluminium, etc.).

Endrava's analysis of these four industry segments show that the total energy use in industry in Europe is expected to remain stable on the overall. This is due to a combination of industry that will decrease their energy use (e.g. non-ferrous metals), and other industries expected to use more energy in the future (e.g. chemical/petrochemical). Changes in energy use are due to improvement in energy efficiency and to changes in demand for industrial products.

Overall, the use of oil and gas products for energy purposes in the industry is expected to remain quite stable, but it will depend on the development of the production volumes in important industries such as chemical/petrochemical and non-metallic minerals (cement, etc.).

4.1. ENERGY USE IN INDUSTRY IN THE WORLD

According to IEA (2017a), the industry used 1,097 Mtoe of oil and gas as energy source in 2015. This represents 31% of all the energy in the industry sector, with 11% oil products and 20% natural gas.

Other important energy sources are coal (30%) and electricity (27%). The electricity and heat use presupposes additional indirect use of energy products in power and heat plants, not detailed here.

The situation in OECD countries is similar, with the exception of coal. The industry in OECD uses much less coal than the rest of the world. It has to a large extent been replaced by natural gas and electricity.

This trend of replacing coal with electricity and natural gas may continue in the future, in particular in the rest of the world outside OECD. There are however technical limitations to replacing coal with other energy and carbon sources for some specific industries.

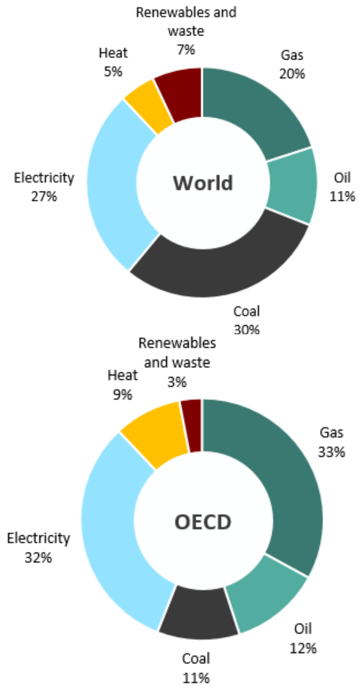


Figure 27 Energy sources to the industry (based on IEA, 2017), for heating, lighting, electrical processes (machines), and cooling.

The IEA data on energy use contains details per industry segment. When details on segments are missing, they were categorised as “other” in the figure below.

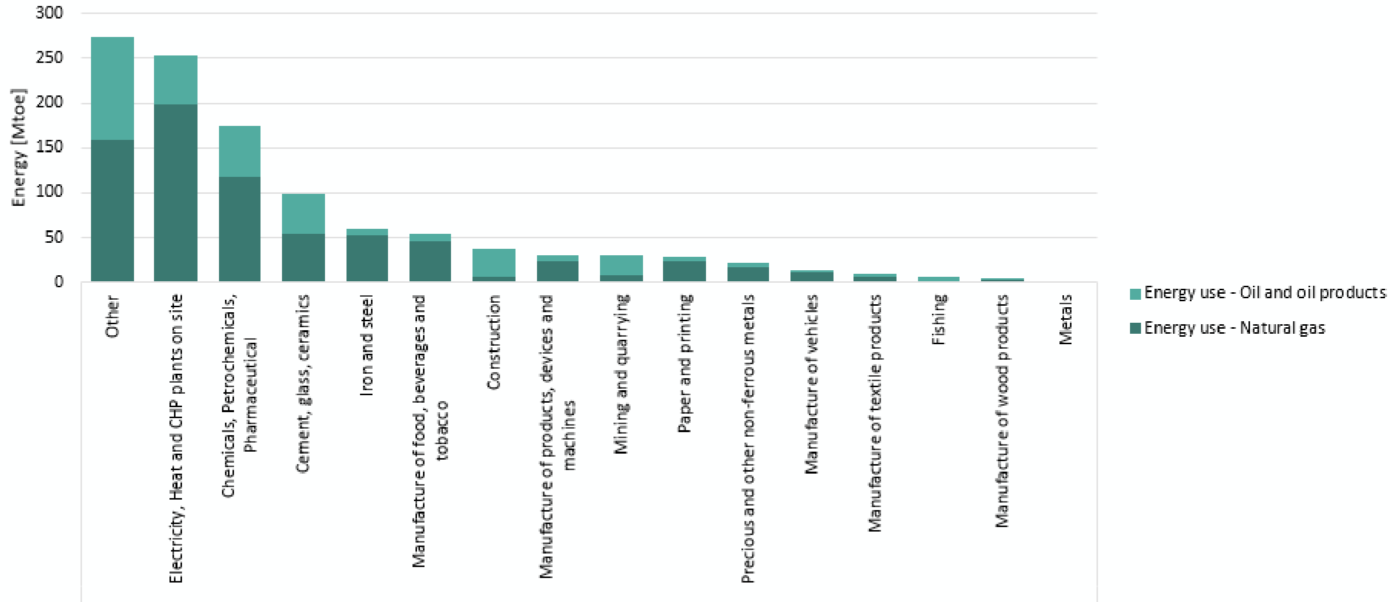


Figure 28 Oil and gas used for energy in each industry segment, world (based on IEA, 2017)

According to the data, the chemical and petrochemical industry are the segments using the most oil and gas in the world, with ca. 174 Mtoe for energy use. Non-metallic minerals (cement, glass, ceramics) comes second, with 98 Mtoe, followed by iron and steel (60 Mtoe). These figures are most likely incomplete, due to the size of the “other” category.

The IEA data also includes energy use for “autoproducer” power plants. These are facilities generating electricity and/or heat for their own use, as support to their primary industrial activity. Autoproducer power plants are not included in the figure above, and used 198 Mtoe gas, and 55 Mtoe oil in 2015. It is not possible to allocate this energy use to each industrial segment, due to missing details. Typical industries with autoproducer power plants would be pulp and paper and refineries for example.

4.2. Energy use and high temperature in industry in Europe

Eurostat provides more detailed data for energy use in the industry in Europe. The figure below shows the trend in energy use in industry in Europe since 2007 (does not include non-energy use).

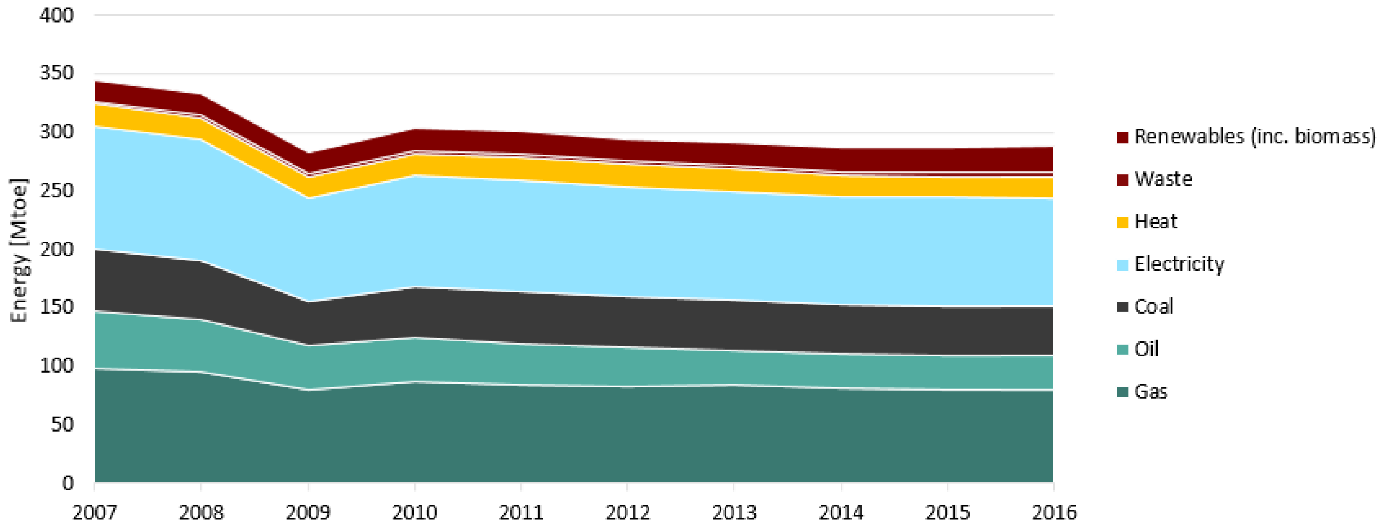


Figure 29 Use of energy in industry in Europe (based on Eurostat, 2018a, non-energy use is not included)

The industry in Europe used 290 Mtoe energy in 2016 with gas and electricity representing the majority of it. The use has decreased for all energy types since 2007, except for renewables (+20%), and waste (+100%).

The Eurostat data is in line with the OECD figures provided by IEA for 2015: Europe uses slightly less gas than the whole of OECD (28% vs. 33%), and slightly more coal (15% vs. 11%).

Note that the electricity and heat categories presented in the figure presuppose the use of oil, gas, coal, waste and renewables in power and heat plants. This indirect use of energy products is not detailed in the figure.

The figure below shows the amount of oil and gas used by the industry for energy purposes, for each industry segment (total: 80 Mtoe gas and 29 Mtoe oil). The data does not include autoproducer power plants (dedicated to specific industries, see also previous chapter) due to the lack of data.

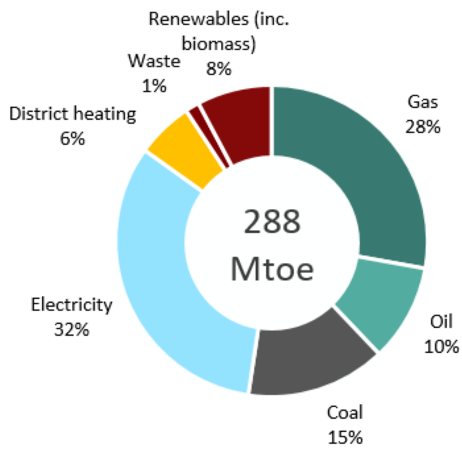


Figure 30 Energy used in industry in Europe, 2016 (based on Eurostat, 2018a), for heating, lighting, electrical processes (machines), and cooling

When details on segments are missing, they were categorised as “Not-specified” in the figure below.

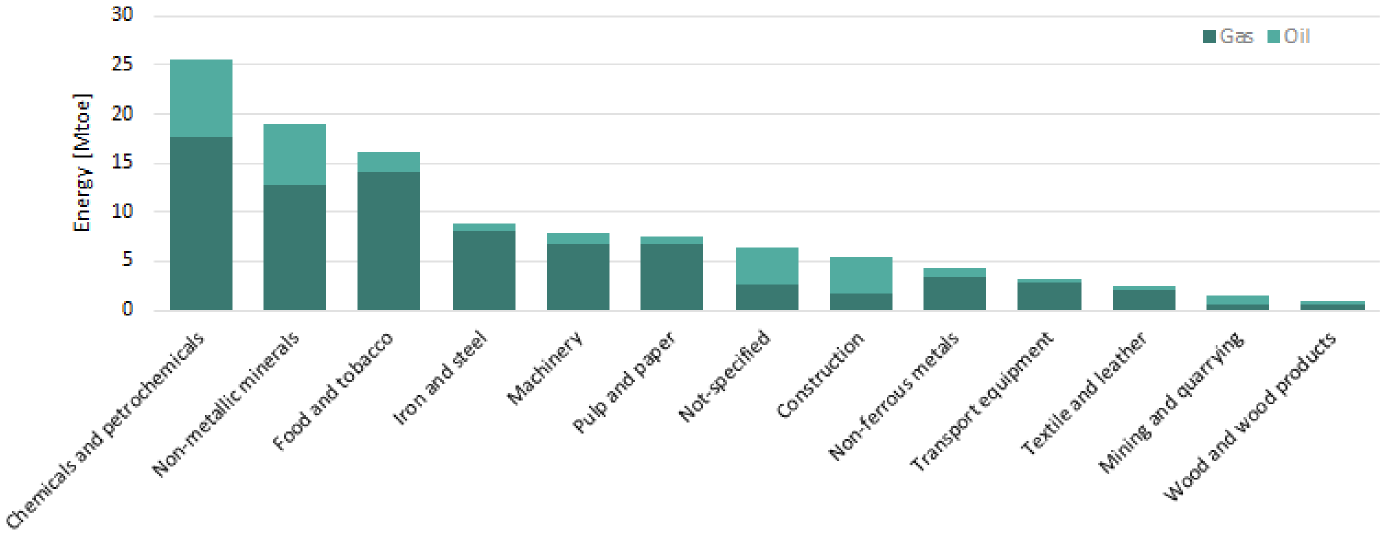


Figure 31 Oil and gas used for energy in each industry segment in Europe, 2016 (based on Eurostat, 2018a)

Similarly to the IEA data, chemicals/petrochemicals and non-metallic minerals (cement, glass, ceramics) segments are the largest users of oil and gas for energy. The order in the next few industry segments shows differences compared to IEA, but the main distribution is similar on the overall. The Eurostat data is more complete than the IEA data, since the “Not-specified” category is much lower than the “other” category in the IEA data in the previous chapter.

In terms of usage of the energy, the European Commission (2016) indicates that heating is the main energy user in industry, with 70.6%. Lighting and electrical processes (e.g. motors for machines) use 26.7%, and 2.7% is used for cooling. Naegler et al. (2015) provide further details the use of heat in industry in Europe. The figure below was produced by combining both sources, together with Eurostat data.

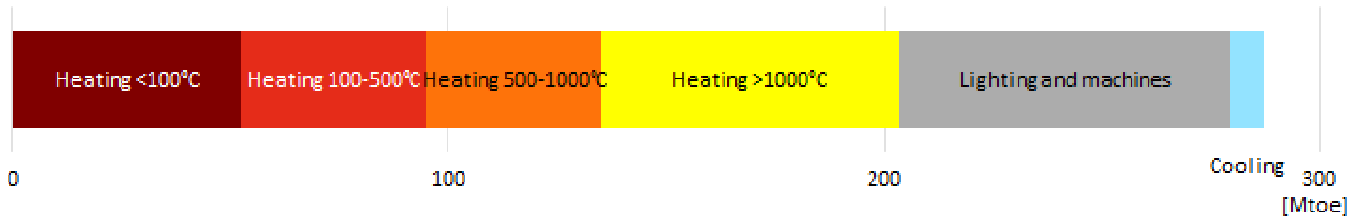


Figure 32 Heat and other energy uses in industry in Europe, 2016 (based on European Commission 2016, Naegler et al. 2015, and Eurostat 2018)

As mentioned earlier, Eurostat (2018a) indicates that the industry uses 32% electricity in Europe. This matches well with the figure above, since 29.4% of all the energy is used for lighting, electrical processes and cooling, which are typically electrically-driven applications.

Very high temperature (> 500°C) represents ca. 40% of the energy use in industry in Europe (109 Mtoe in 2012).

ALTERNATIVES FOR VERY HIGH TEMPERATURE HEAT IN THE INDUSTRIAL SECTOR

Heat at very high temperatures (> 500°C) in the industry is mainly generated from hydrocarbons: gas, oil products and coal. Renewable heat sources, such as not-concentrated solar or geothermal, cannot generate temperatures over 250°C and can therefore not replace hydrocarbons for that purpose (Heinberg and Fridley, 2016).

Biomass and synthetic fuels are in principle good alternatives. The challenge with these sources is related to availability of biomass and competition with other segments (food consumption, transport, feedstock for green chemicals). In addition, the net climate benefit from some of the biomass use for energy purposes (e.g. from forest) is still up for debate (Nature, 2018).

Within the industry sector in Europe, solid biofuels are the main energy source from biomass, with 22 Mtoe (253 TWh) (Eurostat, 2018a). These are typically wood chips, bark, sawdust, shavings, chips, etc. (IEA, 2016). The industry also uses biogas, although in much smaller amounts, with 0.5 Mtoe (6 TWh) in 2016. Pulp and paper and wood are the industry segments using most of the biomass as energy source (81% of the industrial use of biomass). The food industry and non-metallic minerals (cements, etc.) each use ca. 5% of the biomass to industry.

Naegler et al. (2015) details the heat use in industry per country in Europe, as presented in the figure below.

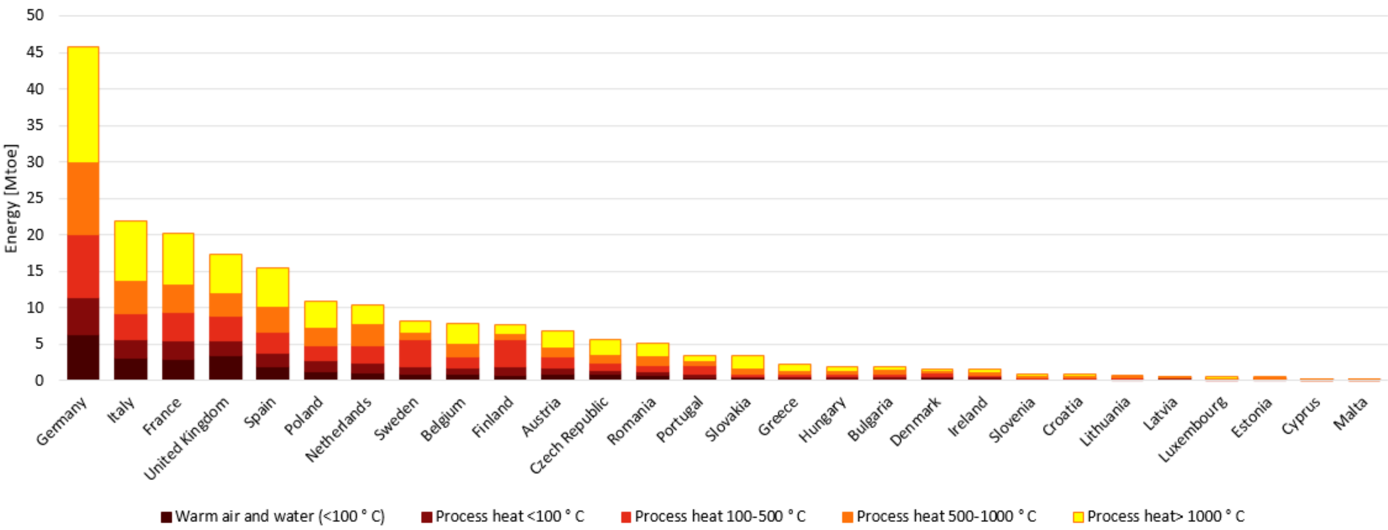


Figure 33 Energy use for heat in industry, per country (based on Naegler et al. 2015. Data is for 2012)

Germany has by far the highest use of energy for heat to industry of all Europe, with more than 45 Mtoe in 2012. Five other countries also use large quantities of very high temperature heat: Italy, France, the UK and Spain. The need for heat varies depending on the type of industry in each country. This is the reason why Sweden and Finland for example have higher need for temperatures between 100 and 500 °C, due to the pulp and paper industry.

The figure below details the heat needs for each industry, sorted by the total heat use.

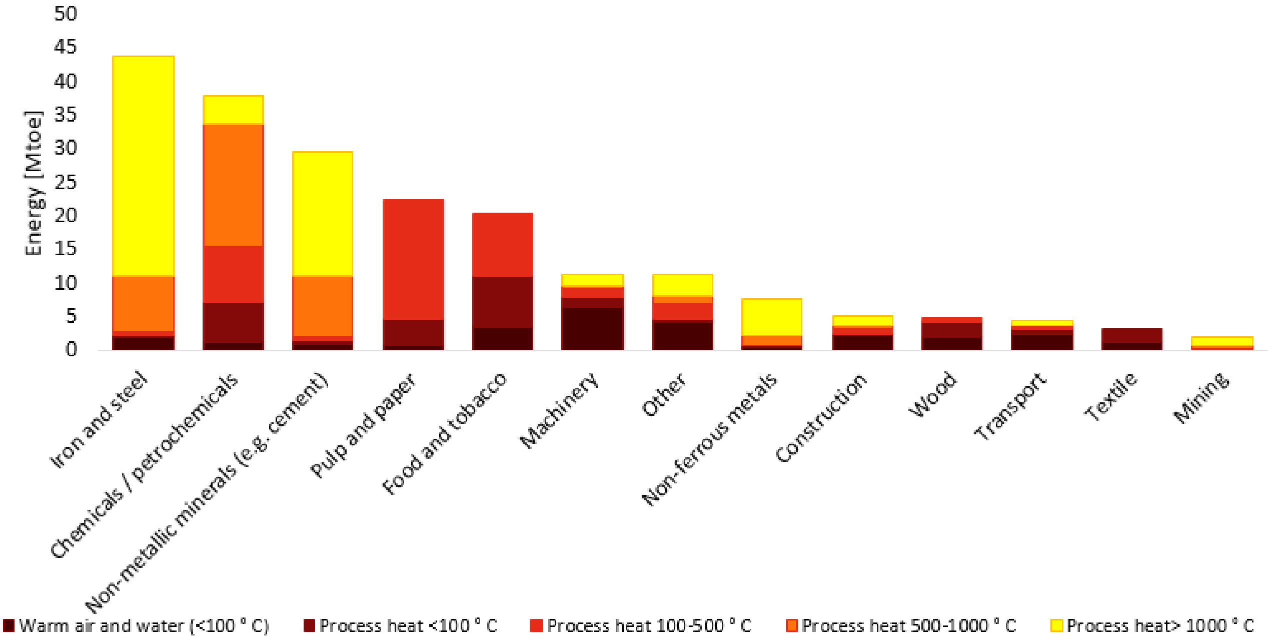


Figure 34 Energy use for heat in industry, per segment (based on Naegler et al. 2015. Data is for 2012)

Four industries are the largest users of very high temperature heat (> 500 °C):

- Iron and steel (38% of all the use),
- Non-metallic minerals (cement, glass, ceramics) (25%),
- Chemicals/Petrochemicals (21%), and
- Non-ferrous metals (6%).

The following sections provide details on energy use and temperatures for each of these four industries.

4.2.1. IRON AND STEEL

Iron and steel represents 17% of the energy use in industry in Europe (51 Mtoe). The energy use in that industry has decreased by 22% since 2007.

Coal is the main energy source (60%), followed by electricity and gas (21% and 16%, respectively).

ICF Consulting (2015) details all the processes within iron and steel, including the main energy-intensive ones:

- A large share of the energy is used to produce primary steel, by reducing iron ore in blast furnaces at temperatures ranging from 900 to 1,300°C. Blast furnaces themselves use 73% of the energy in the blast furnace route for steel-making. Primary steel through this route is 60% of the steel production, in volume.

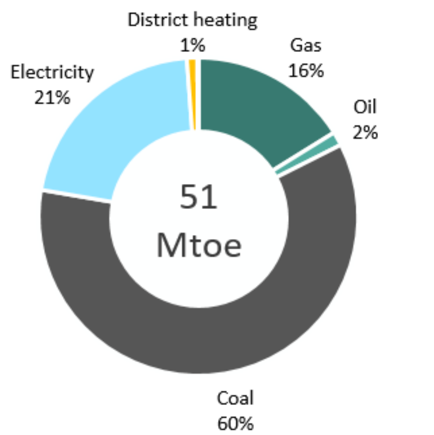


Figure 35 Energy use in the iron and steel industry, 2016 (based on Eurostat, 2018a)

- Direct Reduced Iron is an alternative process for primary steel. It involves the use of natural gas or gas from coal, at temperatures of 800-1,000°C. This process is mostly used outside of Europe at the moment (World Steel Association, 2018)
- Secondary (recycled) steel is made through the electric arc furnace route (EAF). This process is four times less energy-intensive than for primary steel, but also requires very high temperatures, at ca. 1,600°C, through the use of electricity (ca. 60%) and natural gas (ca. 40%). This represents 40% of the steel production in Europe.

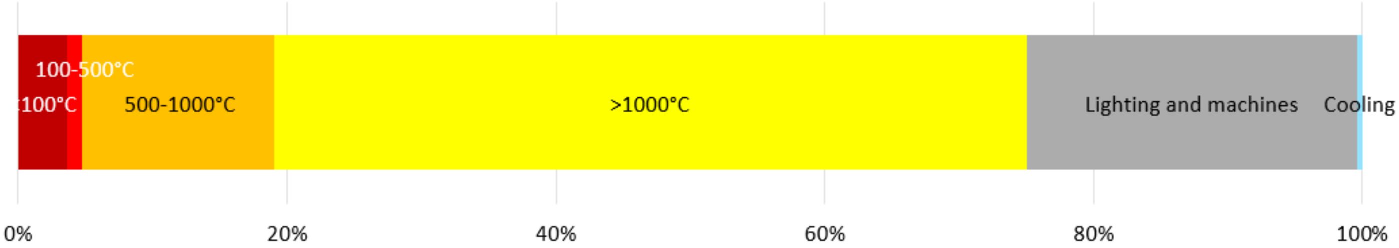


Figure 36 Heat and other energy uses in iron and steel (based on Naegler et al. 2015, and ICF Consulting 2016)

Very high temperature heat (> 500°C) represents 70% of the energy use in iron and steel production (35 Mtoe), with temperatures over 1,000°C itself representing 56% (28 Mtoe).

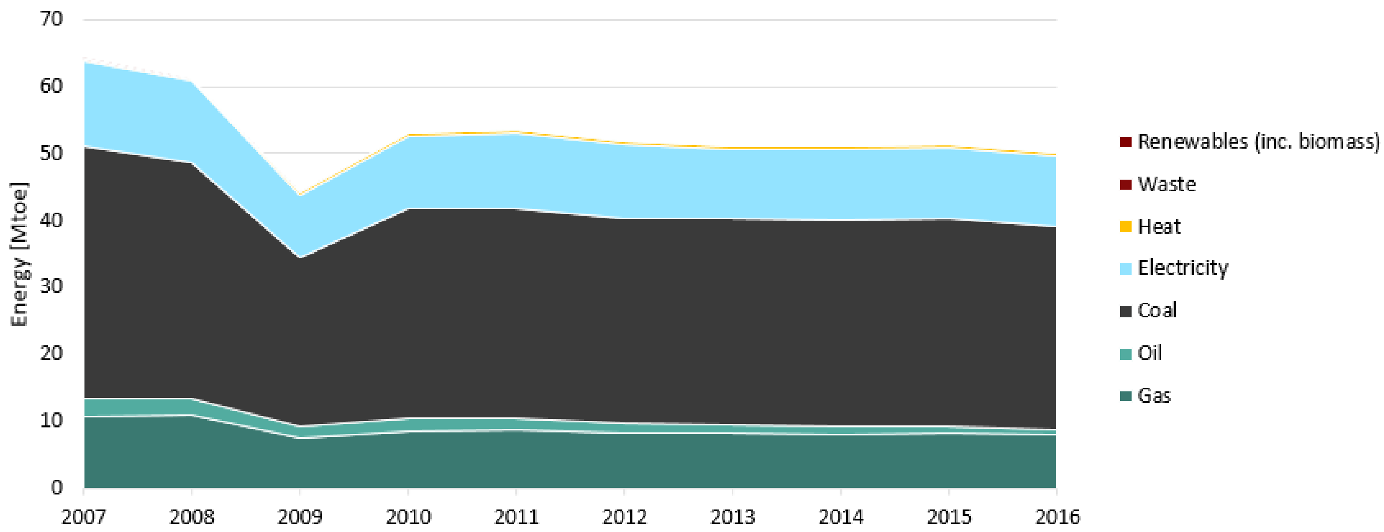


Figure 37 Trend and details on oil and gas use in the iron and steel industry, 2007-2016 (based on Eurostat, 2018a)

Within oil and gas products, the iron and steel industry mostly uses natural gas, and minor quantities of fuel oil (decreasing). The total use of oil and gas in this industry has been decreasing 35% since 2007, more than the decrease in other energy sources.

The Eurostat data for production volumes (Eurostat, 2018b) show a decrease in production since 2007. ICF Consulting (2015) forecasts a moderate increase in production until 2050, and an increase in the total energy use, despite the implementation of energy efficiency measures. The use of natural gas could increase if the industry implements the direct reduced iron process, and/or more recycling.

IEA (2018b), on the other hand, lists a potential decrease in use of oil and gas through the implementation of electric arc furnaces for recycling, and the use of hydrogen from electrolysis in the direct reduced iron process. The further development of these two technologies is uncertain at the moment.

4.2.2. NON-METALLIC MINERALS (CEMENT, GLASS, CERAMICS)

Non-metallic minerals (cement, glass, ceramics) represents 12% of the energy use in industry in Europe (35 Mtoe). The energy use in this industry has decreased by 27% since 2007.

Gas is the main energy source (37%), followed by oil and electricity (18% each), coal (13%) and waste (9%). Cement plants typically use hazardous and/or special waste as a fuel, which both provide energy and is a solution to waste management of these waste.

ICF Consulting (2015) provides details about the main processes in this industry:

- Cement ovens, rotary kilns are used for calcination and production of clinker at temperatures from 700 to 2 000°C. These ovens use a total of ca. 20 Mtoe in Europe.
- Ovens for ceramics, using natural gas as the most common fuel, with temperatures from 1 800 to 2 000°C. Ceramics ovens use ca. 7 Mtoe total in Europe.

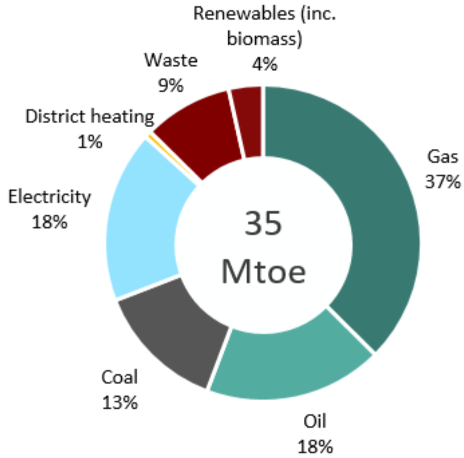


Figure 38 Energy use in the non-metallic minerals industry, 2016 (based on Eurostat, 2018a)

- Processes for glass are more complex, and also include the use of ovens at temperatures between 1,100 and 1,600°C. Natural gas is the main fuel for these ovens, but fuel oil is also used. Glass ovens use ca. 6 Mtoe total in Europe.

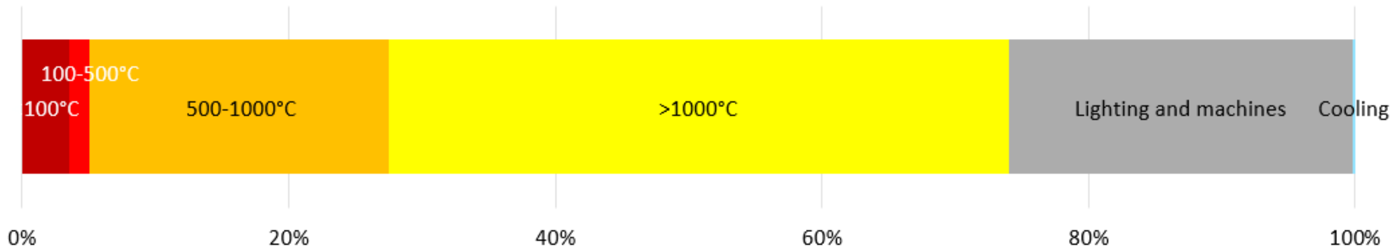


Figure 39 Heat and other energy uses the non-metallic minerals industry (based on Naegler et al. 2015, and ICF Consulting 2016)

Similarly to iron and steel, the non-metallic minerals industry uses large quantities of very high temperature heat (> 500°C), with 69% of the energy use (23 Mtoe). Temperatures over 1,000°C alone represent 47% of the energy used in this industry (16 Mtoe).

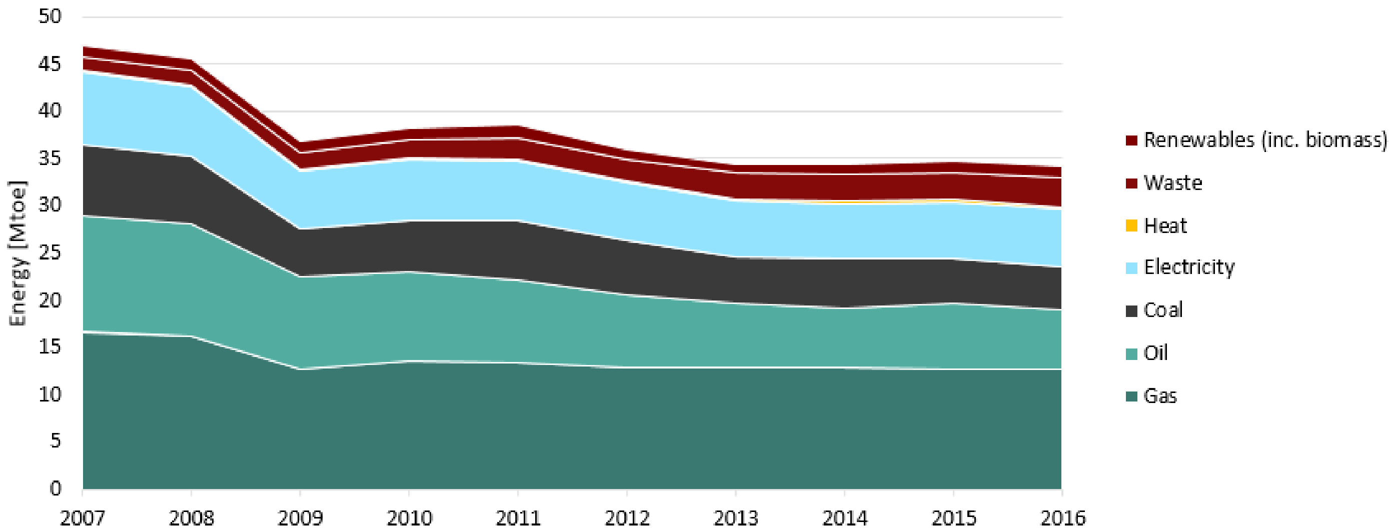


Figure 40 Trend and details on oil and gas use in the non-metallic minerals industry, 2007-2016 (based on Eurostat, 2018a)

Within oil and gas products, the non-metallic minerals industry uses mostly natural gas, and some petroleum coke, although less and less. Petroleum coke is produced in coker units in refineries, when heavy residual oil at the bottom of the distillation column is cracked into lighter compounds and leaves the coke as a by-product.

The total use of oil and gas has decreased by 34% since 2007, representing a larger reduction than for other energy sources in the non-metallic minerals industry.

Production statistics from Eurostat (2018b) show that the production of non-metallic minerals in Europe has increased since 2000. There are however differences between the various minerals. The financial crisis of 2008 resulted in a reduction in production of cement and ceramics, since these materials are used in the construction segment. New investments in infrastructure and buildings in Europe are expected to increase the demand for these products in the future. On the other hand, demand for glass and lime have been decreasing since 2005, and is expected to keep on decreasing.

ICF Consulting (2015) forecasts a stabile production of non-metallic minerals on the overall, until 2050, and a moderate reduction in energy use due to the implementation of energy-efficiency measures. Ovens typically have a lifetime of ca. 40 years, and improvement of the energy efficiency in this industry will therefore take time.

The past reduction in oil and gas as energy to the non-metallic minerals industry is mostly due to the decrease in use of petroleum coke. The use of natural gas has been relatively stable since 2009, and is expected to stay at the same level in the near future.

4.2.3. CHEMICALS/PETROCHEMICALS

The chemical and petrochemical industry represents 19% of the energy use in the industry in Europe (55 Mtoe). Energy use in that industry has decreased by 14% since 2007.

Gas is the main energy source (33%), followed by electricity (31%), oil (14%) and heat (14%).

ICF Consulting (2015) lists some of the energy intensive processes:

- The production of petrochemicals is the main energy user (ca. 27 Mtoe), and three processes are particularly energy intensive:
  - steam cracking converts naphtha, ethane and propane into ethylene, propylene and other base chemicals at temperatures of ca. 800°C.
  - catalytic cracking (hydrocracking) converts gas oil into ethylene and propylene at 550°C.
  - reforming converts naphtha into benzene, toluene and xylenes at 450°C.

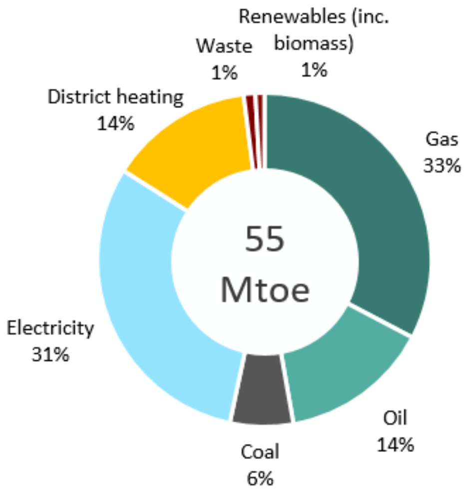


Figure 41 Energy use in the chemical/petrochemical industry, 2016 (based on Eurostat, 2018a)

- Production of basic inorganic chemicals uses ca. 14 Mtoe, for example for the production of ammonia applying the Haber-Bosch process (400-500°C).

In general, the chemical and petrochemical industry uses less heat and lower temperatures than the iron and steel or the non-metallic minerals industries.

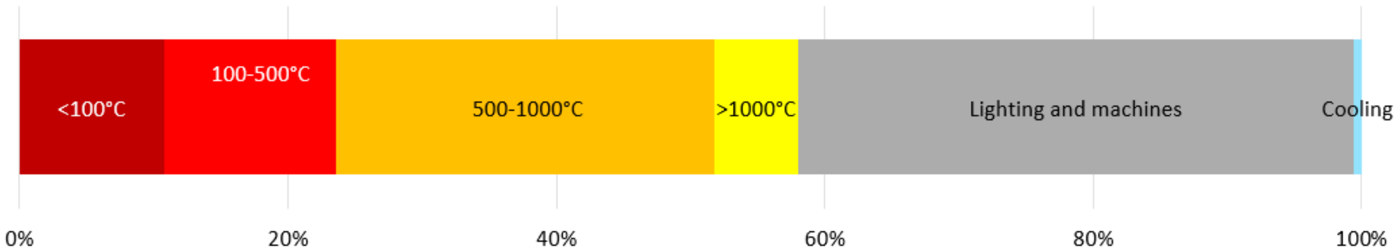


Figure 42 Heat and other energy uses in the chemical and petrochemical industry (based on Naegler et al. 2015, and ICF Consulting 2016)

Very high temperature heat (> 500°C) represents 34% of the energy use in iron and steel production (19 Mtoe), with temperatures over 1,000°C representing only 6% (3 Mtoe).

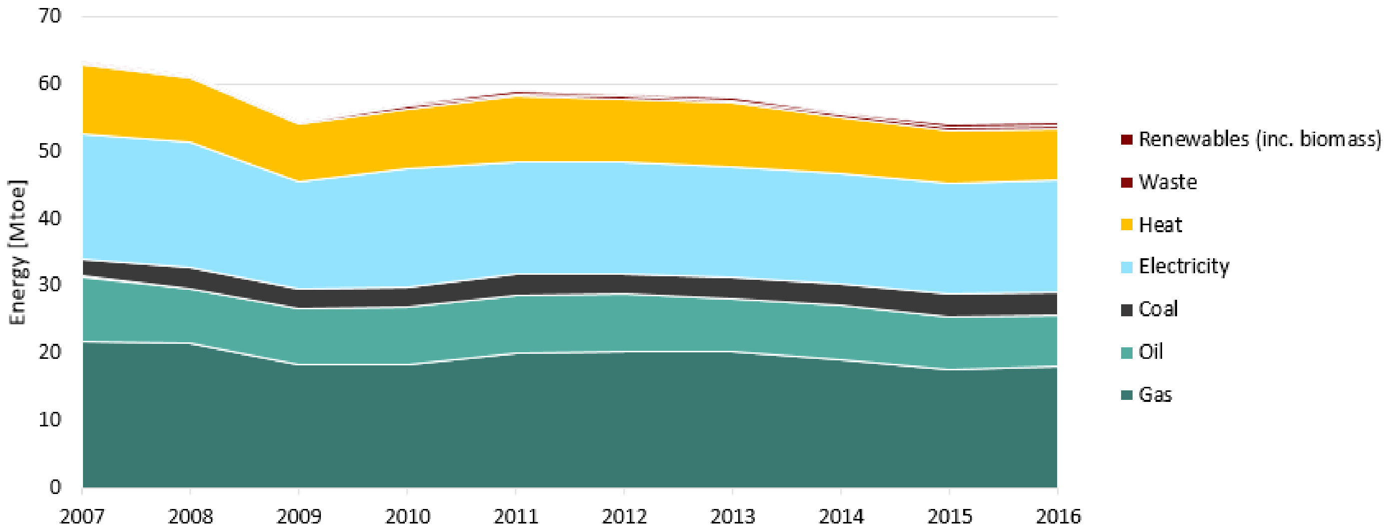


Figure 43 Trend and details on oil and gas use in the chemical/petrochemical industry, 2007-2016 (based on Eurostat, 2018a)

Within oil and gas products, the chemical and petrochemical industry uses a wide range of products, which is logical due to its close ties with the oil and gas industry. The main energy source is natural gas. The total use of oil and gas has been reduced by 18% since 2007, about the same reduction as other energy sources to the chemical and petrochemical industry.

Production figures from Eurostat (2018b) show that the production in the chemical and petrochemical industry has decreased since 2007. ICF Consulting (2015) forecasts an increase in production until 2050, due to a general increase in demand in the world. However, the growth of the segment in Europe is uncertain, due to the competition with the Middle-East and the USA. These two regions have both lower energy/feedstock costs, and lower costs related to regulations compared with the industry in Europe. This is a challenge for the European production, and will likely also be a challenge over the next years.

The segment has implemented energy-efficiency measures and the reduction in energy consumption was more significant in the period 1990-2000 than it was between 2000 and 2010. ICF Consulting interprets this as a sign that the potential for further improvements is more limited in the future. The total energy use in the future is expected to increase, provided that the competition with the Middle-East and the USA will not limit the European industry.

Use of oil and gas in this industry has decreased since 2007, in the same proportion as other energy sources. Since the industry is tightly related to the oil and gas segment, it can be expected that oil and gas products will remain an important energy source.

IEA (2018b) mentions the recycling of plastics as a potential measure in order to reduce the use of oil and gas in the petrochemical industry. This is valid for both feedstock and energy use, since recycling does not require re-processing of products by the petrochemical industry. It is unknown at the moment to what extent plastic recycling would influence the segment in the future.

4.2.4. NON-FERROUS METALS

The non-ferrous metals industry (aluminium, copper, etc.), represents 5% of the energy use in the industry in Europe (14 Mtoe). Energy use in this industry has decreased by 6% since 2007.

This industry uses mostly electricity (64%) and natural gas (26%).

ICF Consulting (2015) lists some of the energy intensive processes:

- For aluminum:
    - primary production with the use of natural gas for converting bauxite into alumina (Bayer Process) (950-1,100°C), and electricity for the rest of the process.
    - secondary production (recycling) through melting of scrap metal with natural gas or electricity (700-760°C).
- Copper: fire refining with the use of natural gas (ca. 1,200°C), and then electricity for the rest of the process.
- Zinc: roasting with use of natural gas (700-1,000°C), and then electricity for the rest of the process.

The non-ferrous metals industry uses less heat than other industries, but the heat it uses is at very high temperatures.

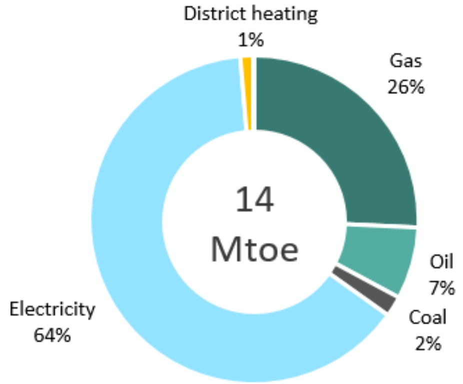


Figure 44 Energy use in the non-ferrous metals industry, 2016 (based on Eurostat, 2018a)

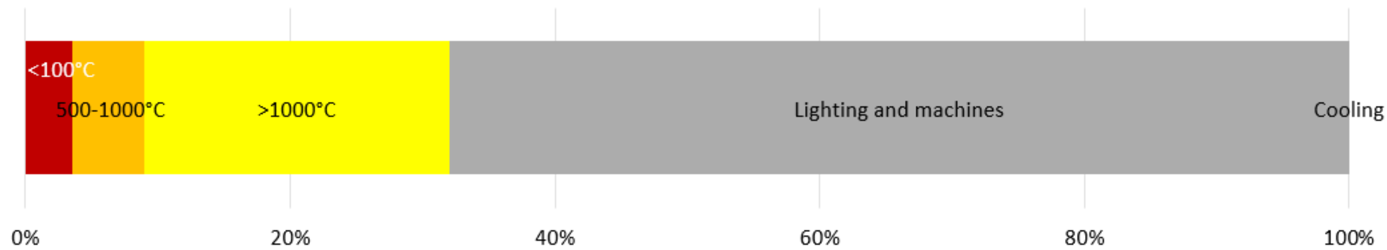


Figure 45 Heat and other energy uses in the non-ferrous metals industry (based on Naegler et al. 2015, and ICF Consulting 2016)

Very high temperature heat (> 500°C) represents 29% of the energy use in iron and steel production (4 Mtoe), with temperatures over 1,000°C representing 23% (3 Mtoe).

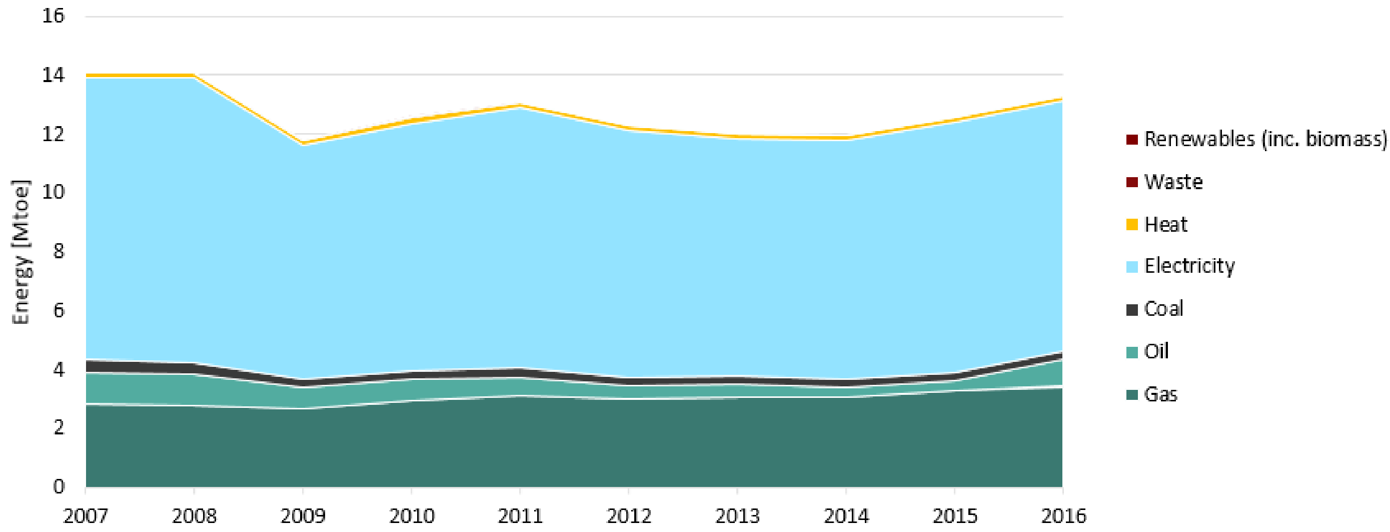


Figure 46 Trend and details on oil and gas use in the non-ferrous metals industry, 2007-2016 (based on Eurostat, 2018a)

Within oil and gas products, the non-ferrous metals industry uses mostly natural gas. The use of fuel oil has decreased since 2007 and is now at the same level as LPG. Petroleum coke is used for making anodes for the aluminium production. The reason for the sudden increase in petroleum coke consumption in 2016 is unknown.

The total use of oil and gas has increased by 12% since 2007, while the use of electricity has decreased in the same period of time.

Production statistics from Eurostat (2018b) show that the production of non-ferrous metals in Europe has been stable since 2000. ICF Consulting (2015) forecasts a stagnation of production until 2050, due to the lack of investment in new production capacity. The European industry suffers from challenging competitive conditions compared to other regions of the world, due to high electricity prices and labour costs in Europe.

The segment has implemented energy-efficiency measures since the beginning of the 1990’s, and the improvements have been stable over time. An explanation is the increase in recycling of aluminium and other metals, which requires much less energy than primary production.

ICF Consulting forecasts a continuous reduction in the energy use until 2050. The use of natural gas has increased since 2007, mainly as a replacement for fuel oil, and consumption may stay stable in the future.

5. NON-ENERGY USE

Energy generation is not the only use of oil and gas products in the industry. Non-energy use also leads to a significant demand for petroleum products. Non-energy use corresponds to energy products used as raw materials in the different sectors; that are not consumed as a fuel or transformed into another fuel. Most of non-energy use is oil and gas products, with smaller amounts of coal.

In the OECD countries, non-energy use was 11% of the oil and gas products in 2015 (IEA, 2017). Of these, 74% are used by the chemicals and petrochemicals industry. Another 12% is used in the construction segment, and smaller amounts are used across other industry segments, in housing and services, and transport (mostly lubricants). The share is about the same in Europe, where the chemical and petrochemical industry used 97 Mtoe of oil and gas products in 2016, consisting of naphtha, natural gas, LPG and ethane. This industry segment uses more ethane in the rest of the world compared to Europe, due to price differences.

Non-energy products are mainly used as feedstock to produce petrochemicals, which are in turn transformed into final products. Endrava's analysis of the petrochemical industry shows that the main final products are plastics (63%), fertilisers (21%), solvents and rubber. The demand for oil and gas as non-energy products therefore follows closely the output of the chemical and petrochemicals industry.

The demand for plastics products plays a major role, and the plastics production has been increasing steadily since first introduced in the early 1950s. The demand follows the GDP, and is expected to reach more than 1,000 Mt in 2050 (vs. ca. 350 Mt at present). A large share of the plastics products is used for packaging. The reduction in the use of plastics products, their re-use and recycling may impact the plastic demand in the future, although the effect is uncertain at the moment. In addition, the production of bio-plastics (from renewable sources) is increasing, but still fails to have a significant impact on the total demand for oil and gas products as feedstock to plastics production.

Ammonia (to fertilisers) and methanol production are also expected to increase, and therefore the total non-energy use of oil and gas products is expected to rise in the future. Most energy outlooks from major energy companies and organisations are in agreement with this forecast. If the demand of oil and gas for energy uses (industry, transport and energy) stabilises or decreases in the future, non-energy use could represent an increasing share of the total demand.

5.1. Overview of non-energy use

In 2015, non-energy use represented ca. 11% of oil and gas products in the world (IEA, 2017), as presented in the figure below.

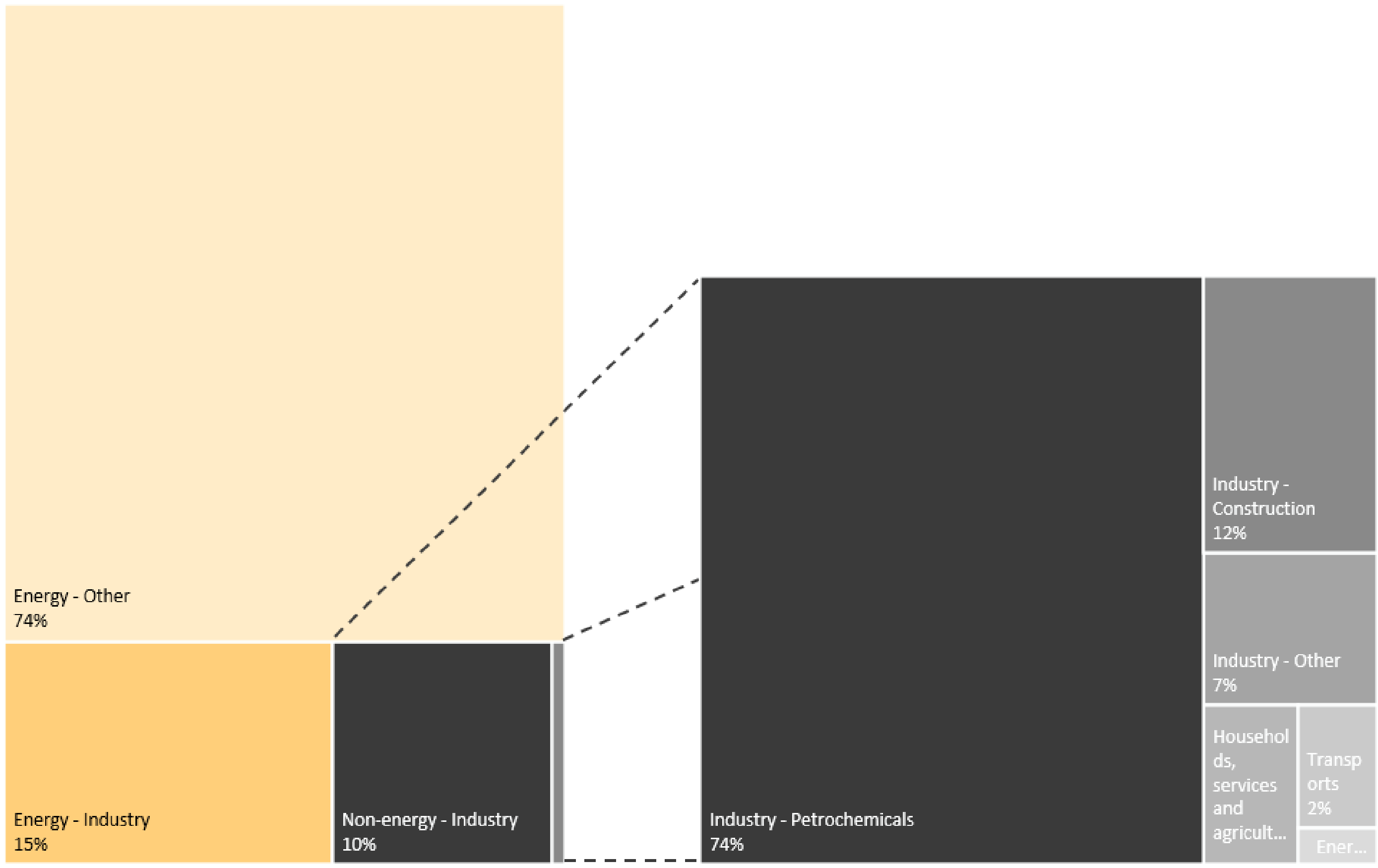


Figure 47 Share of oil and gas to non-energy use in the world, and details for OECD countries (calculated, based on IEA, 2017)

The industry is the main user, and in particular the chemical/petrochemical industry consumed 74% of the non-energy use in the OECD in 2015. The construction industry is the second largest user, with 12%.

The situation is similar in Europe, where non-energy use in industry represents 97 Mtoe. Details are shown in the figure below.

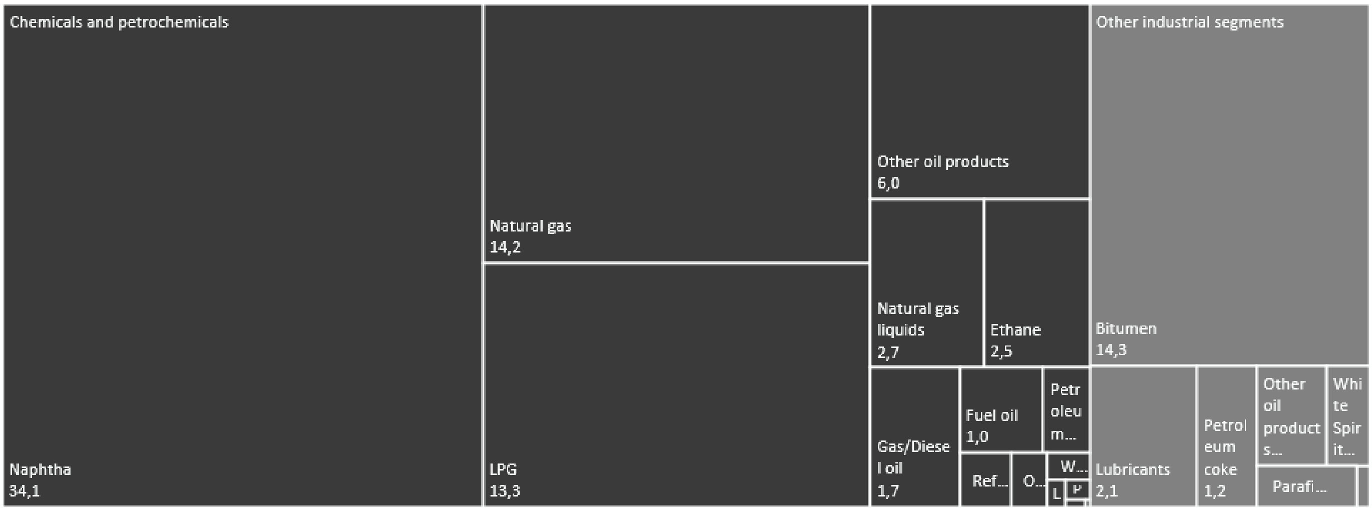


Figure 48 Share of oil and gas products used for non-energy purposes in Europe, and details on the industrial sectors (Eurostat, 2018a)

The chemical/petrochemical industry in Europe consumes 80% of the oil and gas within non-energy use (vs. 74% in the world). This makes a total of 77 Mtoe oil and gas, including 14 Mtoe gas. Naphtha is the product the most used in this industry segment in Europe, with 44% (34.1 Mtoe), followed by natural gas (18%, 14,2 Mtoe), LPG (17%, 13,3 Mtoe), and ethane (3%, 2,5 Mtoe).

The next two sections will provide details for the chemical/petrochemical industry and other segments.

5.2. CHEMICAL/PETROCHEMICAL INDUSTRY

Endrava established an overview of the product flows within the chemical/petrochemical industry in the world, based on data from IEA (2017a), and on production statistics and processing data from a wide range of sources. This overview is provided in the figure below.

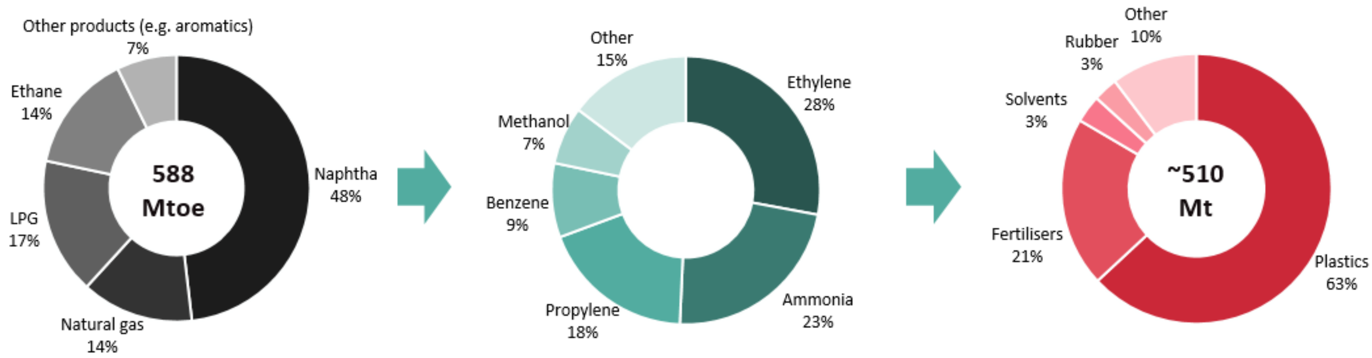


Figure 49 Production flows in the chemical/petrochemicals industry in the world (calculated, based on data from IEA 2017 and other sources)

The chemical/petrochemical industry in the world used ca. 588 Mtoe of oil and gas products as feedstock in 2015. The share of the main types of feedstock is approximately the same in the world as in Europe. The main feedstock is naphtha (48%), followed by LPG (17%), natural gas (14%) and ethane (14%). Comparatively, the industry in Europe uses less ethane than in the rest of the world. This is due to differences in feedstock costs, with cheaper ethane in the USA due to the low cost production of ethane-rich shale gas.

The feedstock are then transformed into petrochemicals, consisting of ethylene (28%), ammonia (23%), propylene (18%), and others. The petrochemicals are in-turn used for the production of materials such as plastics (63%), fertiliser (21%), and solvents (3%). The materials produced by the chemical/petrochemical industry from oil and gas feedstock in the world amount to ca. 510 Mt.

The figure below presents the same overview using a flow diagram, to show the link between products. Note that the flows are not mathematically equal, due to the lack of data and uncertainties in the statistics.

Figure 50 Production flows in the chemical/petrochemicals industry (calculated, based on data from IEA 2017a and other sources)

Some products, such as naphtha or natural gas, are transformed into several different types of petrochemicals, while other products such as ethane are almost entirely transformed into one type of petrochemical (ethane to ethylene). This means that naphtha provides more flexibility in the production process than ethane.

The figure below presents the main feedstock used in the chemical/petrochemical industry in Europe, along with the produced quantity of petrochemicals (Eurostat, 2018a, 2018b).

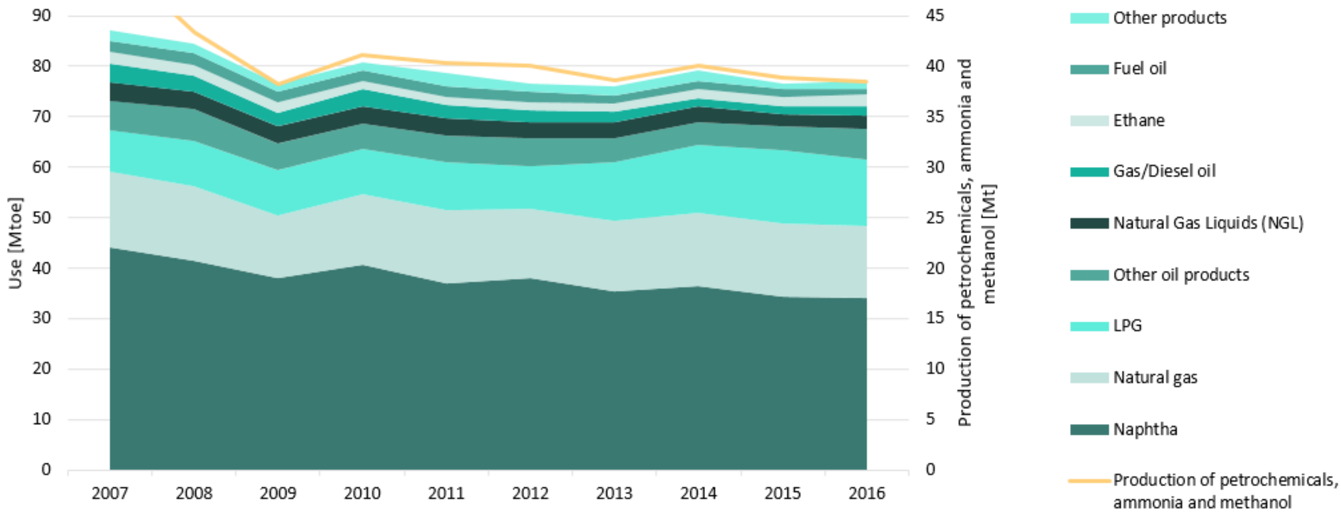


Figure 51 Feedstock used in the chemical/petrochemical industry in Europe, along with the produced quantity of petrochemicals (yellow line) (Eurostat, 2018a, 2018b)

The consumption of feedstock in Europe follow the same trend as the production of the main petrochemical products (ethylene, propylene, benzene, ammonia, methanol, etc.), as shown with the yellow line on the figure above. The overall production of petrochemicals in Europe has decreased since 2007, and the use of feedstock followed the same trend.

Plastics is also one of the main products from the petrochemical industry in Europe, and 60 Mt of plastics were produced in 2016 (Plastics Europe, 2017).

5.2.1. Plastics production, use and fate

Plastics represent the main product category from the chemical/petrochemicals industry, with ca. 63% of the production in the world. Most of the plastic materials are produced from 4 petrochemicals, as presented in the figure below.

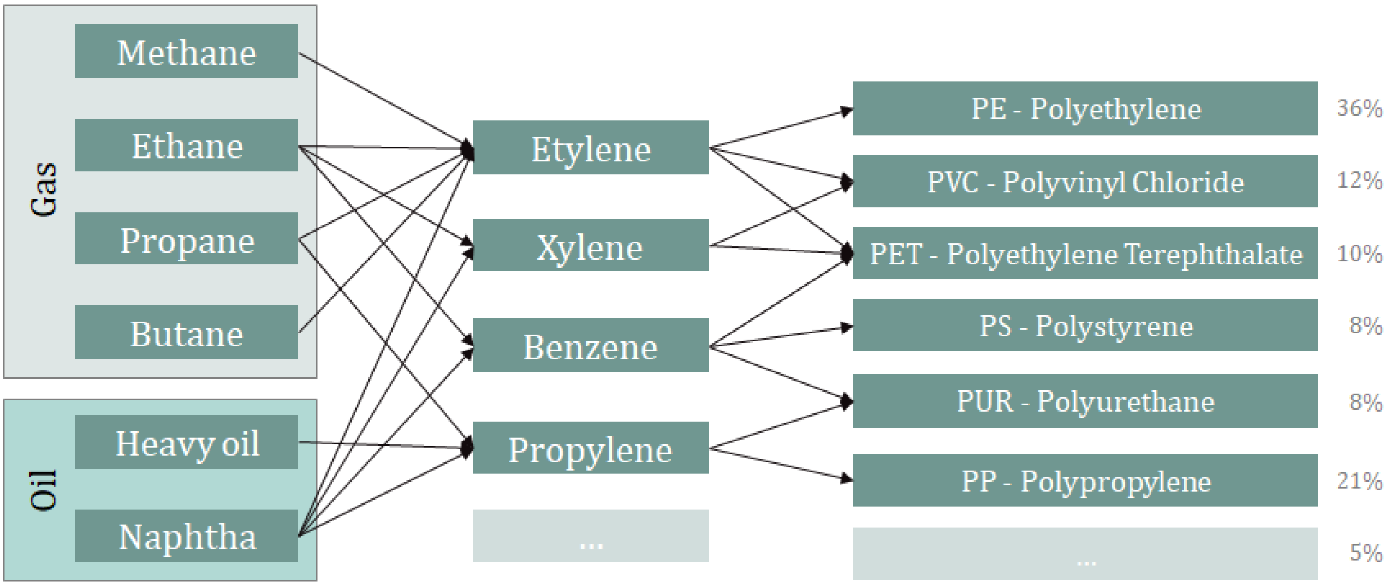


Figure 52 Production flows in the chemical/petrochemicals industry, with the main plastics products on the right (Endrava, based on a wide range of sources). Note: there are too many products for all to be presented in this figure, hence the use of "…" in the light-green boxes at the bottom

Ethylene and propylene are the most used petrochemicals in the production of plastics. All of the four petrochemicals (ethylene, xylene, benzene and propylene) can be produced from various feedstock. The most used feedstock to plastics in the world per today are naphtha, ethane and LPG (butane and propane).

Ca. 322 million ton of plastics were produced in 2015. The plastics production in the world has tripled since 1990, as illustrated in the figure below.

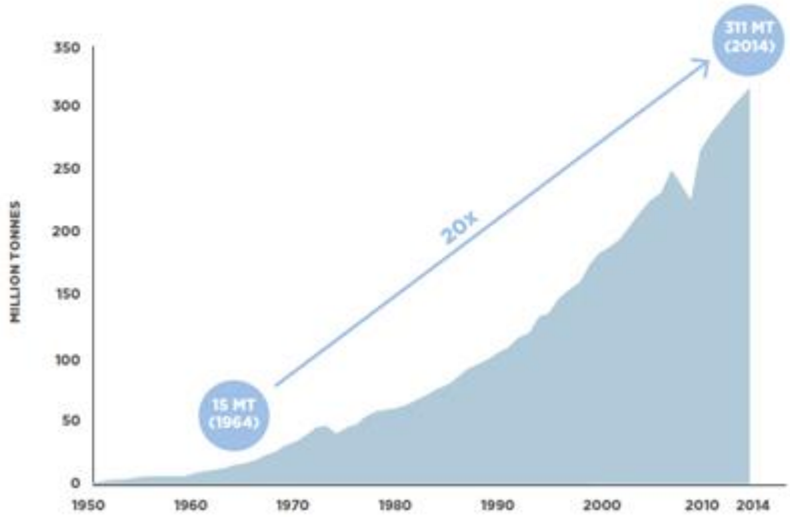


Figure 53 Plastics production in the world since 1950 (Plastics Europe, 2016)

The plastic demand is closely correlated with GDP, and it is therefore possible to forecast future plastic demand based on GDP, see also the section on Plastics demand . The world plastic demand is expected to reach ca. 1,000 million ton per year by 2050 (Endrava, World Economic Forum 2016).

There are many types of plastic materials. Three types cumulate 69% of plastics used: Polyethylene (PE), Polypropylene (PP) and Polyvinyl chloride (PVC). The figure below illustrates the world plastic production and use areas for each of the plastic types.

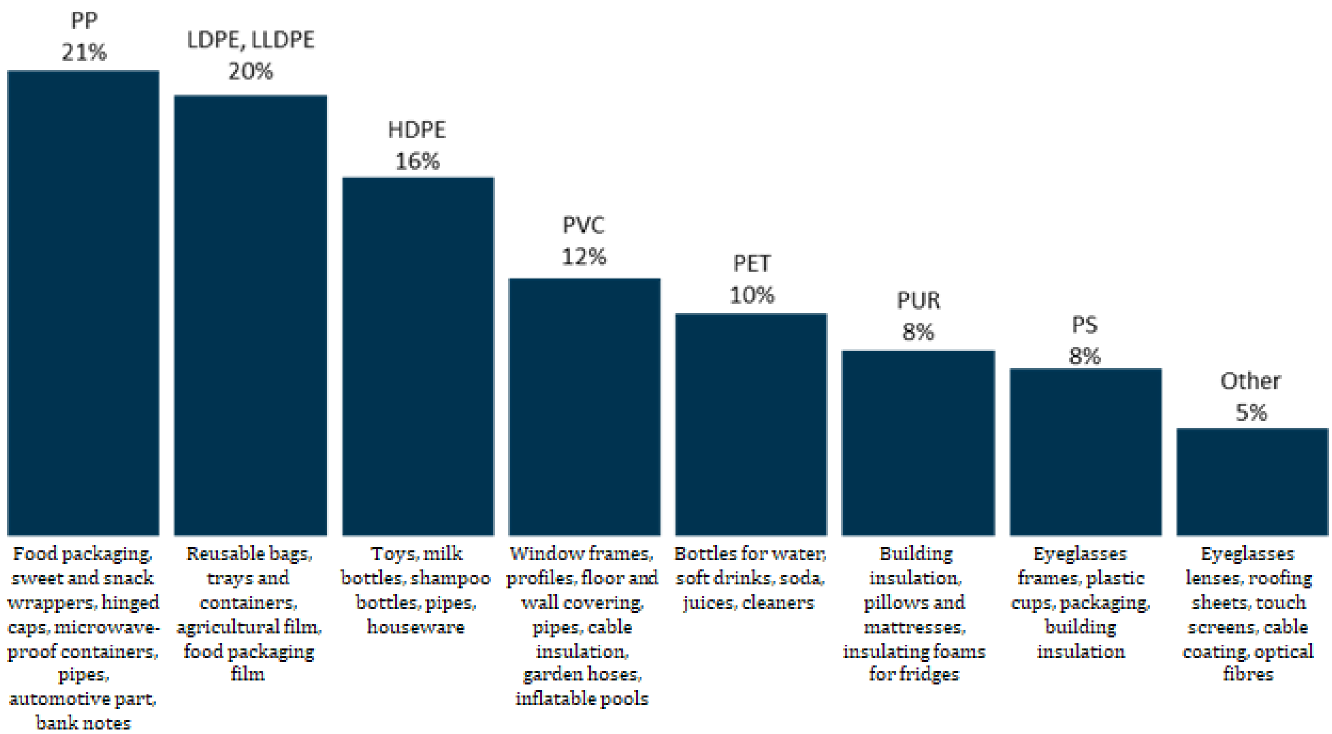


Figure 54 Share of the different plastics types, and typical application (based on Geyer et al. 2017, Plastics Europe 2016)

Polyethylene is most used, with 36%, and is split into low density (LDPE) and high density (HDPE). Its applications vary from grocery bags to bottles, food packaging films, and toys. Polypropylene (PP) is the second most used, with 21% of plastics. It is used among other things for packaging applications, automotive parts, pipes, and bank notes. PVC is the third most used plastics (12%), and is mostly used for construction material (windows, flooring, pipes).

When organised into the type of applications, it is clear that packaging is the main area of use for plastics.

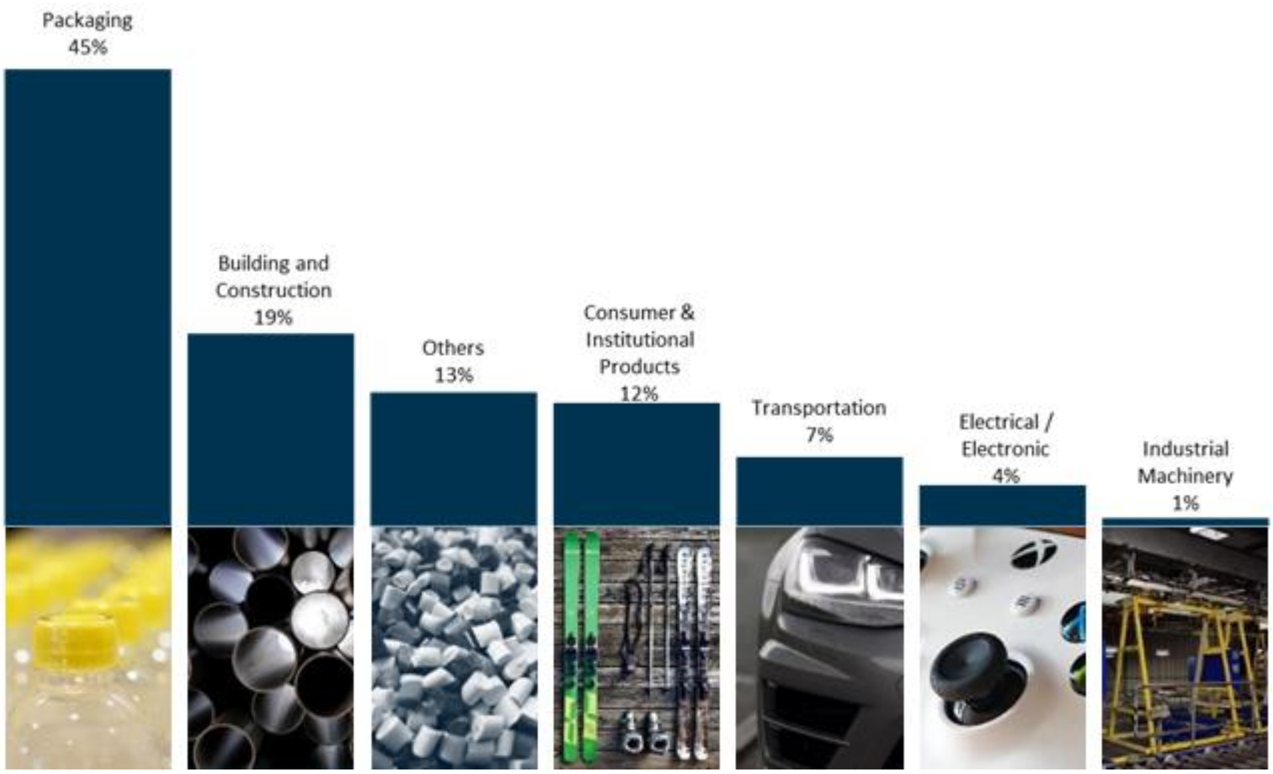


Figure 55 Share of the different type of applications for plastics (based on Geyer et al. 2017)

Packaging makes 45% of all the plastics used in the world, followed by building and construction (19%). All types of plastics are used for packaging, as illustrated below.

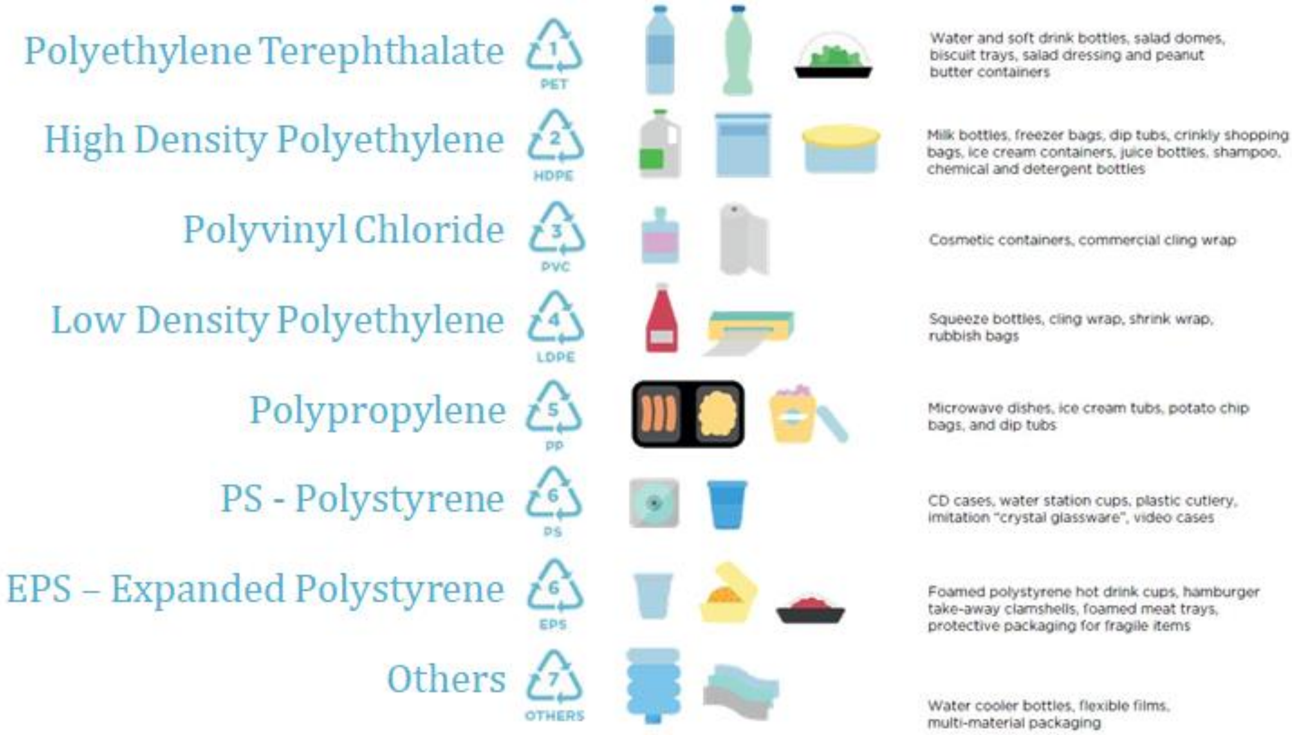


Figure 56 Plastics types used for packaging, and details on the use (World Economic Forum, 2016)

The type of plastic used for each application depends on its properties, e.g. flexibility, UV filtration, etc. The use of several different types of plastics, and in different colours is a challenge for recycling. In addition, plastics contaminated with food or other substances are more challenging to recycle.

The figure below shows the fate of plastic packaging in the world.

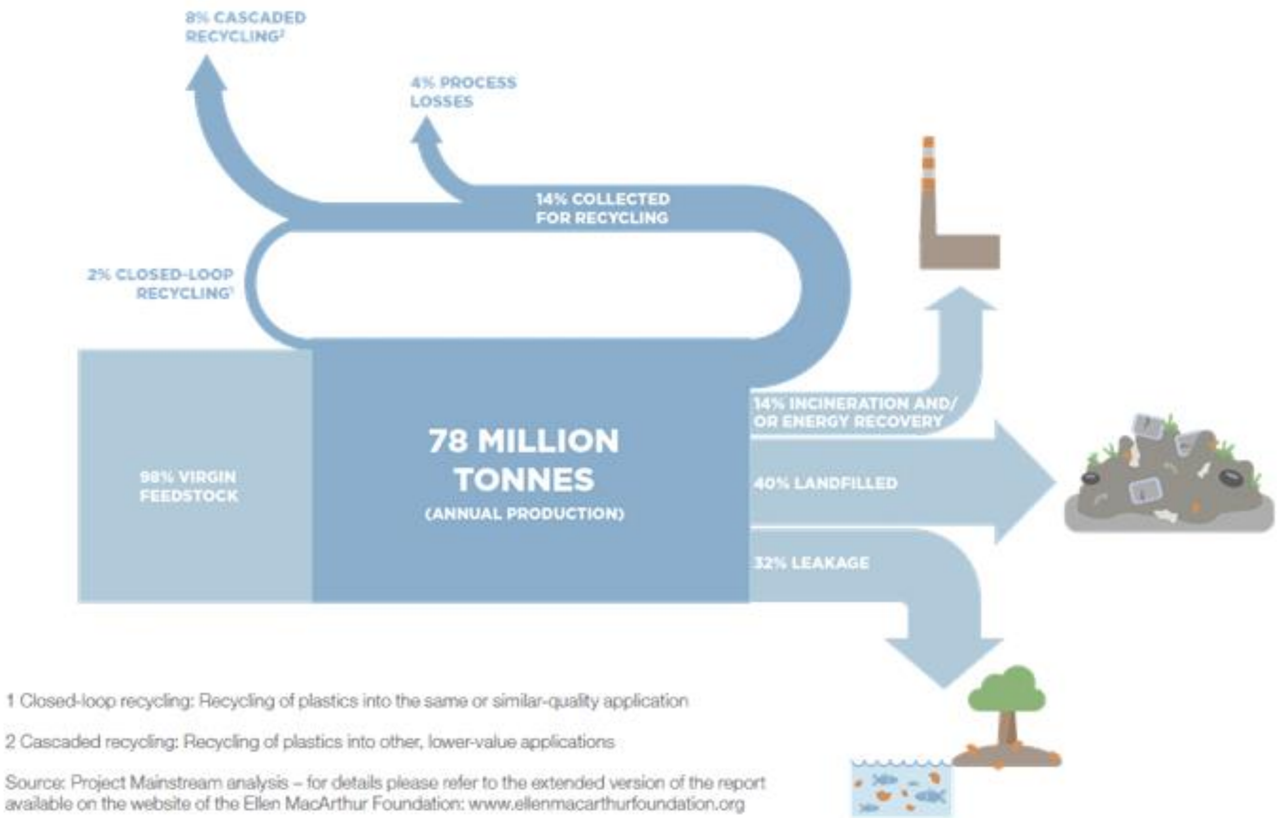


Figure 57 Origin and fate of plastic packaging in the world (World Economic Forum, 2016)

Most plastic packaging in the world is produced from virgin feedstock (98%). Most of the feedstock come from the petrochemical industry. After use, it is estimated that 14% of plastic packaging is recycled, 14% is incinerated (with or without energy recovery), and 40% is sent to landfills. This means that about 32% of the plastic packaging are released to the environment at the end of their lifetime, due to inadequate waste management.

Although 14% of the plastics from packaging are sent to recycling, 4% are lost during the transformation process, and 8% are recycled to other type of products (e.g. PET bottles to clothing), and only 2% are re-used for the same purpose. The effect of recycling on the demand for virgin feedstock is therefore limited.

5.2.2. AMMONIA AND METHANOL PRODUCTION AND USE

Ammonia is produced mostly with methane (ca. 70%), and coal (IEA 2017b). Ammonia production follows the same trend as natural gas production and has almost tripled in the past 40 years (USGS, 2017). The production is highly dependent on the price of natural gas.

Based on ammonia production chemistry, and the world production of ammonia, Endrava estimated that ca. 69 Mtoe of natural gas is used for ammonia production every year in the world. This represents 44% of the natural gas used in the chemical and petrochemicals industry for feedstock.

Other feedstock used for ammonia production are coal (ca. 20%), coke, refinery gas and heavy oil (ca. 10%).

Ammonia is produced through the Haber-Bosch process.

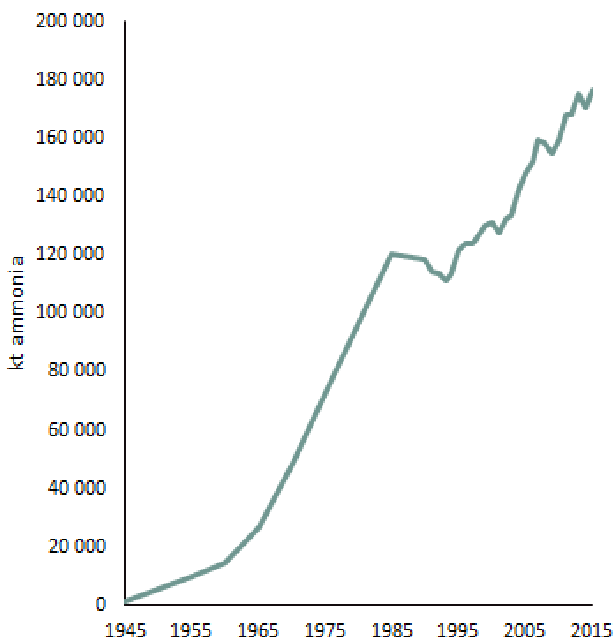


Figure 58 World production of ammonia (USGS, 2017)

This process is often considered as one of the most important discoveries of the 20th century, due to its positive impact on food production and human health in the world (Howarth, 2008). It is estimated that 80% of the nitrogen atoms in the human body originate from the Haber-Bosch process.

Ammonia is mostly used for producing fertilisers (85%), polyamides, nitric acid, and for other uses, as illustrated in the figure below.

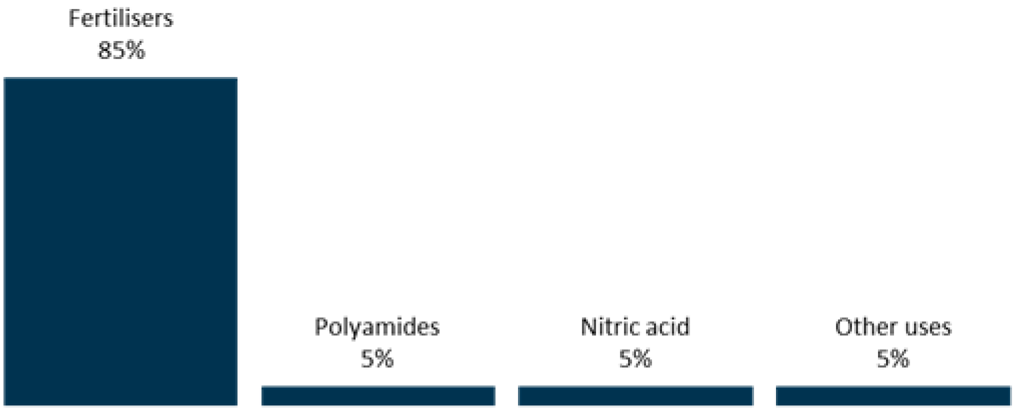


Figure 59 Main uses of ammonia (University of York, 2017)

Ammonia production is expected to keep on increasing in the future, with almost 50% increase until 2050 (estimate based on forecast from the ammonia industry).

Ammonia is composed of a nitrogen atom and three hydrogen atoms. The natural gas used for ammonia production provides the hydrogen, and CO_2 at high concentration is released as part of the process. Natural gas is used since it is a low cost source of hydrogen. Other potential sources for ammonia production include electrolysis from water, and solid-state ammonia synthesis, with direct synthesis of ammonia from nitrogen and water (pilot stage).

Methanol is produced mostly from methane (ca. 50%) and coal (40%). Based on the methanol production chemistry and on the world consumption, Endrava estimated that ca. 26 Mtoe of natural gas is used every year for methanol production (Methanol Institute 2016, IEA 2017b). This is ca. 20% of the natural gas used by the chemical and petrochemical industry for feedstock.

Methanol is used to produce additives for gasoline and diesel, and chemical components for polymers and resins, as illustrated in the figure below.

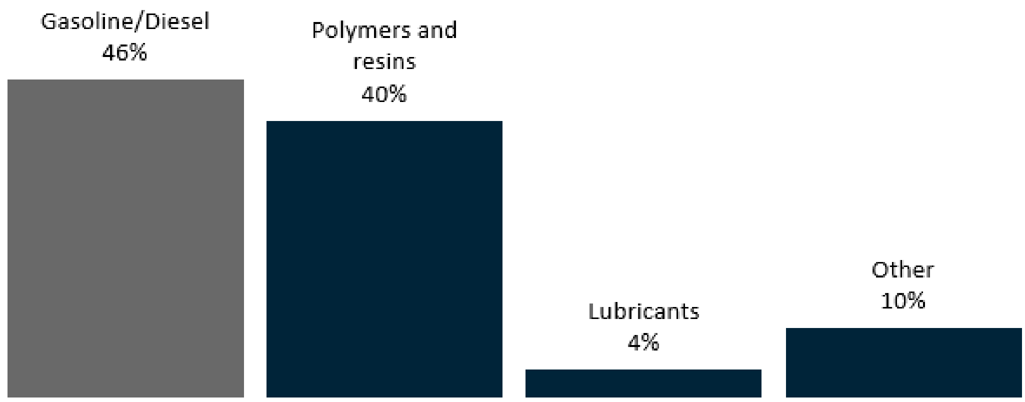


Figure 60 Main uses of methanol (based on IHS, 2016). Grey colour is for energy use

The future methanol demand is uncertain. Some sources consider that methanol could play a key role as a future base-chemical and fuel.

Methanol has a very simple chemical structure, and can therefore easily be produced from other carbon sources than natural gas (NordicGreen, 2015), including:

- biogas (BioMCN), waste and landfill gas (Enerkem)
- biomass (trees, VärmlandsMetanolAB),
- pulp, black liquor (Lundberg, Chemrec),
- CO_2 capture and use (with hydrogen and catalysis) (BASF).

5.3. Construction and other segments

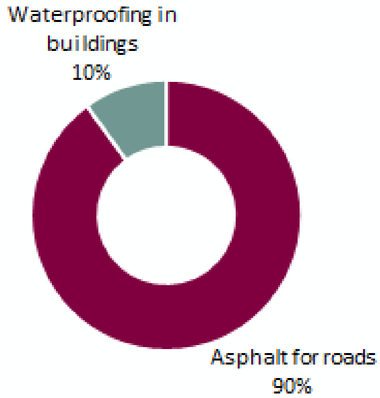
The construction industry is the second largest non-energy user, after the chemical and petrochemical industry, with 12% of the non-energy use of oil and gas in the world.

Bitumen is the main oil and gas product used in the construction industry (41 Mtoe in the world, 14 Mtoe in Europe).

It is considered as a low-value product and the market is very local due to the transport costs (Ecole des Ponts PariTech, 2017). With most current transport solutions, bitumen needs to be warmed-up to 180°C for transport.

Bitumen has two main uses, as described in the figure to the right. Making asphalt for roads is the main usage area for bitumen, with 90%.

The figure below shows the trend for non-energy use in construction and other segments in Europe.



Figur 61 Main uses of bitumen (Ecole des Ponts PariTech, 2017)

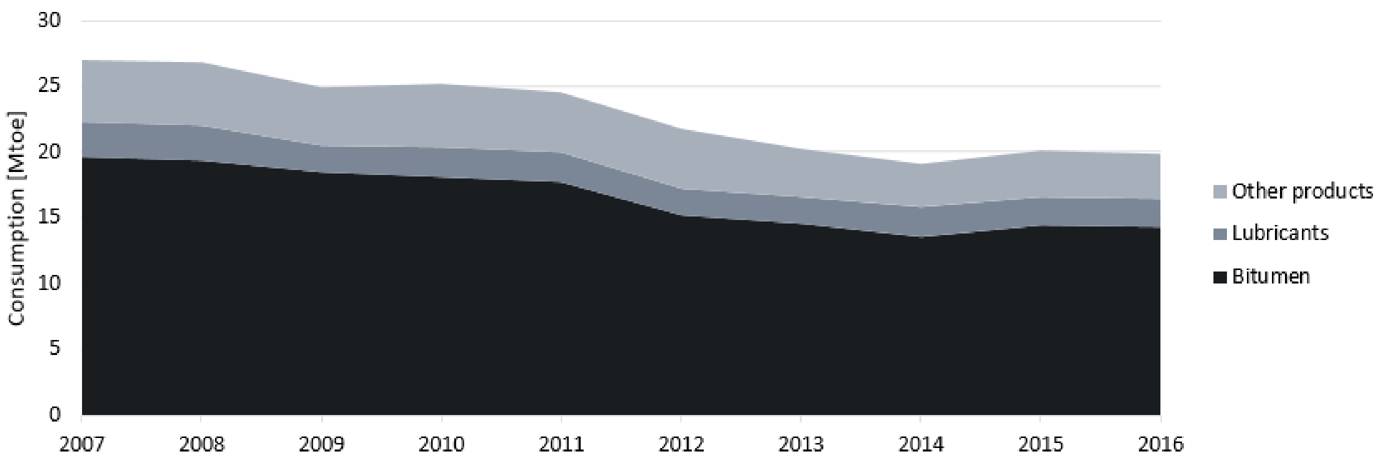


Figure 62 Trend in non-energy use in construction and other industries in Europe (Eurostat, 2018a)

The trend for non-energy use of bitumen in Europe follows the same trend as energy-use within the non-metallic minerals industry (cement, glass, ceramics). This is due to the fact that both are linked to infrastructure projects which were put on hold after the finance crisis in 2008. Many countries in Europe are now re-starting maintenance and new infrastructure projects, which lead to an increase in bitumen demand since 2015. This trend is expected to continue increasing in the future.

The EU has a dedicated project for the “*Use of eco-friendly materials for a new concept of Asphalt Pavements for a Sustainable Environment*” (Kowalski et al., 2016). The project is looking at the potential use of recycled materials from asphalt and construction waste, and the use of lignin-based binder, which is a bi-product of 2nd generation bioethanol. There are also other possibilities for replacing bitumen in the future: use of recycled rubber, asphalt based on waste cooking oil residues, waste-based asphalt (from animal products, agriculture and forestry, microalgaes, coffee waste) (NAPA 2009 and Sun et al. 2017). Cement is also used in some countries as a replacement for asphalt.

In addition to bitumen, the construction industry uses other products such as lubricants, white spirit (solvent for paint). Very little data is available on non-energy use in other industry segments. Lubricants are used across all industries, in machine operations. It can be expected that lubricants demand would follow the overall industrial production in Europe in the future.

5.4. Trends for non-energy use

IEA data (2017b) shows that non-energy use of oil, gas and coal has been constantly increasing over the past 35 years. The annual growth rate in non-energy use has slowed-down to 1.7% in the past 10 years, vs. ca. 3% since the 80’s.

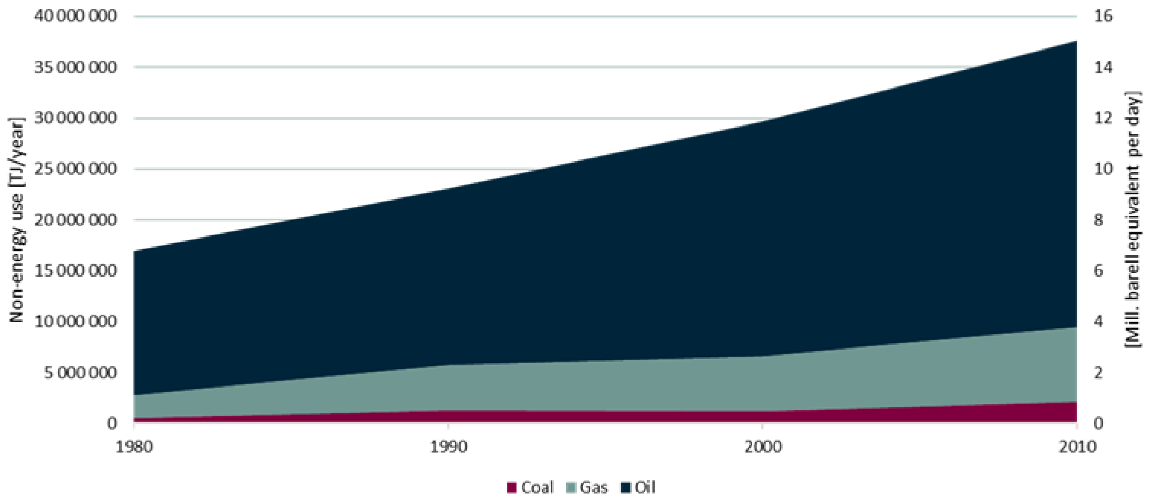
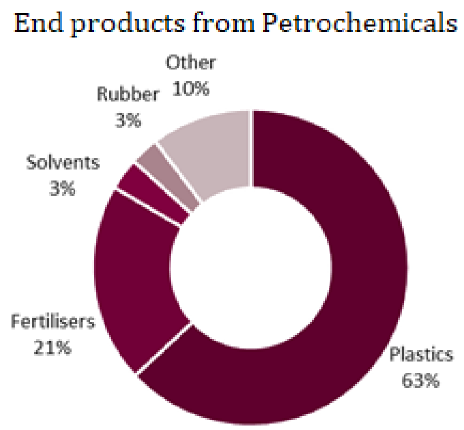


Figure 63 Trend in the non-energy use of oil, gas and coal, 1980-2010 (based on IEA, 2017)

On the overall, most non-energy use is from oil (ca. 72% in 2015), gas (20%) and coal (8%). Biomass for non-energy use is not included in the figure above. The use of biomass for bioplastics is ca. 0.3% of all non-energy use.

5.4.1. Plastics demand

Non-energy use is mainly driven by petrochemicals (> 74%) and more specifically by plastics and fertilisers, which are its main products. The plastic demand is tightly correlated to GDP, due to the increased use of plastics products with the increase in the standards of living.



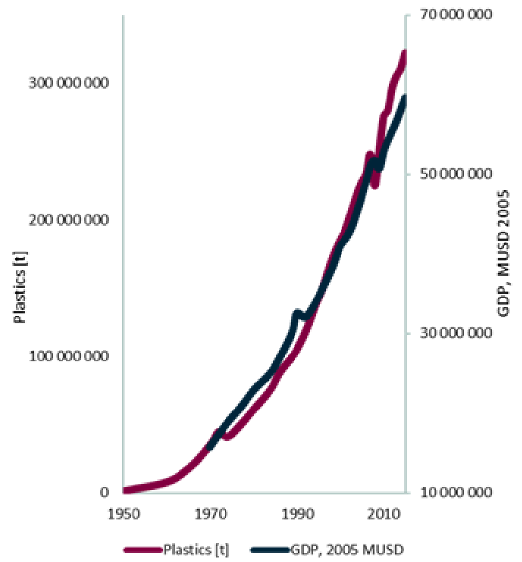


Figure 64 Left: end products from petrochemicals (based on IEA, 2017). Right: correlation between plastics consumption and GDP, 1950-2010 (UNSTATS 2017, Plastics Europe 2016)

By calculating the correlation factor between GDP and plastic demand, and by using world GDP forecasts as a basis, it is possible to forecast the plastic demand until 2050. This forecast contains uncertainties: it assumes that the plastic demand will keep on being linked to GDP (likely), and it assumes that the GDP forecast is correct (uncertain).

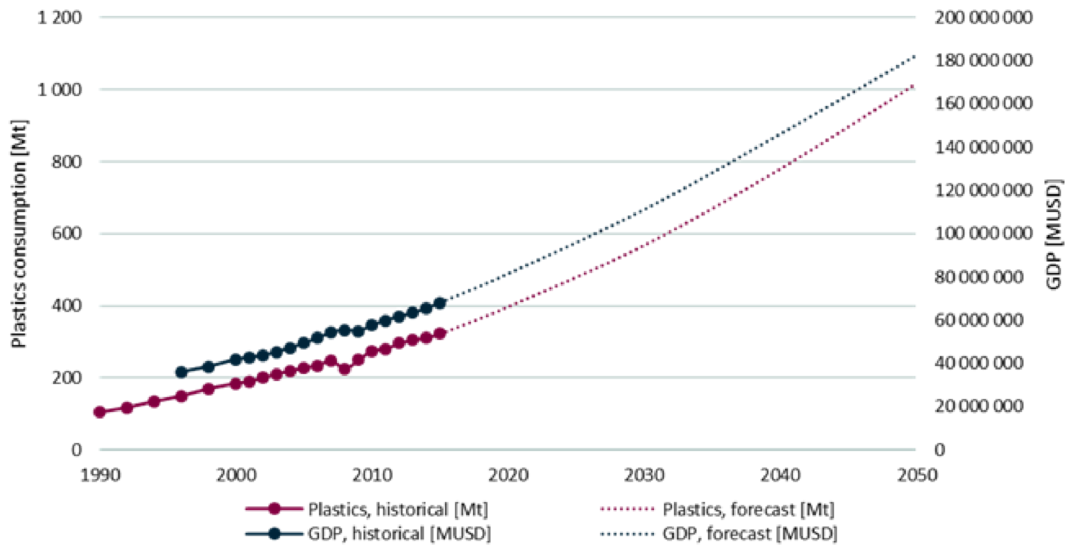


Figure 65 Historic world GDP and plastics consumption (dots), and forecast for both (dashed lines) (calculation based on GDP from OECD, 2017, and historical plastics consumption from Plastics Europe, 2016)

When correlated with the world GDP forecast from the OECD, plastics consumption is expected to reach ca. 1,000 Mt by 2050. This represents a tripling in consumption, and the forecast is in line with other estimates (WEF 2016, Geyer et al. 2017).

Recycling and renewable feedstock are two counteracting trends to the increase need for oil and gas for non-energy use. Energy efficiency has no effect on feedstock use: the yield from one ton of feedstock to plastics products is set by chemistry and material balance (IEA, 2007).

Endrava made a model to forecast the use of oil and gas as feedstock for plastic production towards 2050, based on the recycling rate and the availability of renewable feedstock. This model includes four scenarios, as illustrated below.

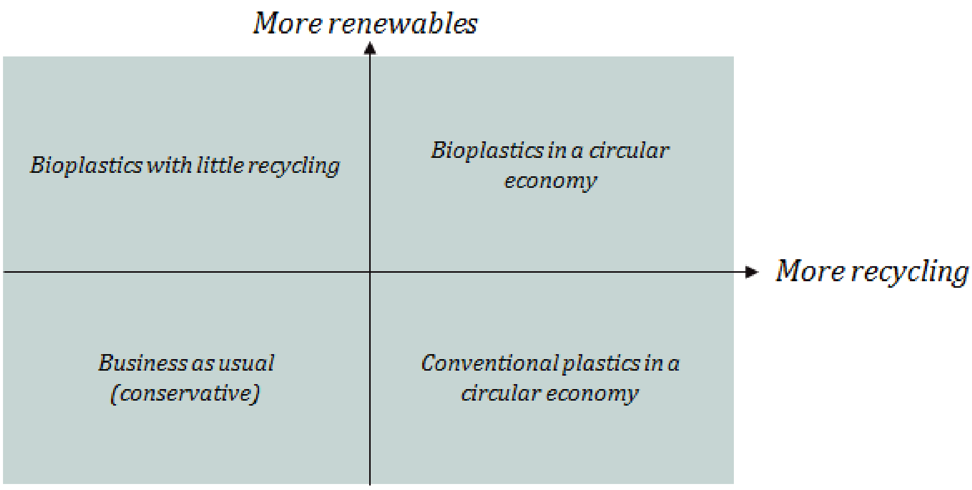


Figure 66 Illustration of the four scenarios for future plastic demand

Each of the next four sections will detail the assumptions and results from the scenarios.

5.4.1.1. Scenario 1 - Business as usual (conservative)

The “Business as usual” scenario assumes that within 2050, bio-plastics provide 2% of all the plastics demand (currently ca. 1.5%, see appendix B), and that the recycling rate remains relatively low (currently ca. 14-18%, see appendix B). This requires an increase in the bioplastics production capacity, as well as an increase in the recycling capacity for plastics, in order to tackle the increase in plastic use and waste.

The figure below shows the total plastics demand as forecasted based on GDP, and the share of the different plastics types and of recycling.

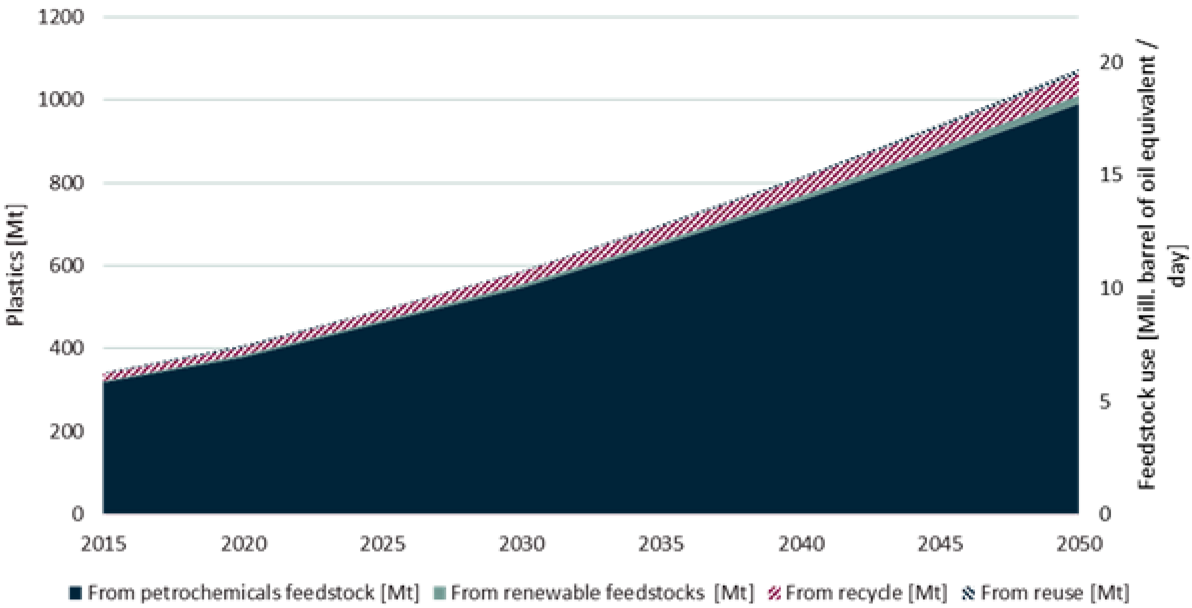


Figure 67 Plastic production for the “business as usual” scenario (#1)

With this scenario, the demand for virgin plastics within 2050 will reach 1,010 Mt, and will be answered by 990 Mt plastics from petrochemicals and 20 Mt bio-plastics. This represents a tripling of the production from petrochemicals, and 7 times higher production of bio-plastics compared with today's production. 20 Mt of bio-plastics would require the use of 0.1% of all agricultural area for that purpose.

In terms of use of oil and gas feedstock, this would represent 1,016 Mtoe/year, or 18.1 Mboe/day. The current use is ca. 328 Mtoe/year, or 5.8 Mboe/day.

5.4.1.2. Scenario 2 - Bioplastics with little recycling

Scenario 2 consists in an increase in bio-plastics, with little recycling. This means that the bio-plastics production capacity would gradually increase, to reach 50% of the demand for virgin plastics by 2050. On the other hand, the recycling rates would remain relatively low (currently ca. 14-18%, see appendix B). This would still require an increase in recycling capacity, to tackle the general increase in use of plastic products. Depending on which bio-plastics are produced, "conventional" bio-PE or new types of plastics chemistries, the recycling industry could also need to adapt and change its recycling processes.

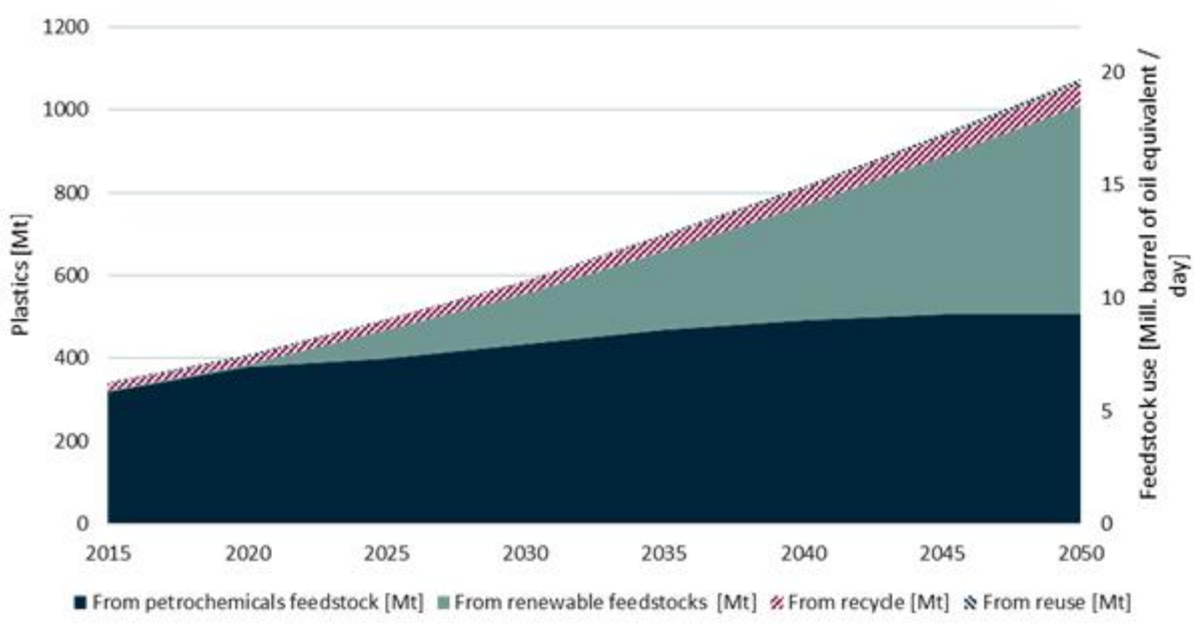


Figure 68 Plastic production for the "bioplastics with little recycling" scenario (#2)

With scenario 2, the demand for virgin plastics would be answered by a 50-50 split between petrochemicals and bio-plastics. This means 500 Mt plastics from petrochemicals (less than double the current amount), and 500 Mt from bio-plastics (170 times higher the current production). feedstock for bio-plastics would take-up 2.9% of all agricultural area, which is significant.

In terms of oil and gas, this would represent 520 Mtoe/year, or 9.2 Mboe/day.

5.4.1.3. Scenario 3 - Circular economy

The "circular economy" scenario assumes a large increase in recycling rate, with 50% of the plastics being recycled in 2050. This presupposes drastic changes to the recycling policies of all countries in the world, including these with the most advanced recycling rates (Europe and China, with 30% and 25% respectively, see appendix B), and also for developing countries and north America. This scenario takes into account that there are losses within the recycling systems, meaning that not all of the plastics sent to recycling are used for new plastics products.

In terms of bio-plastics, this scenario assumes that they will provide 2% of all the plastics demand (currently ca. 1.5%, see appendix B), which means an increase in bio-plastics production capacity.

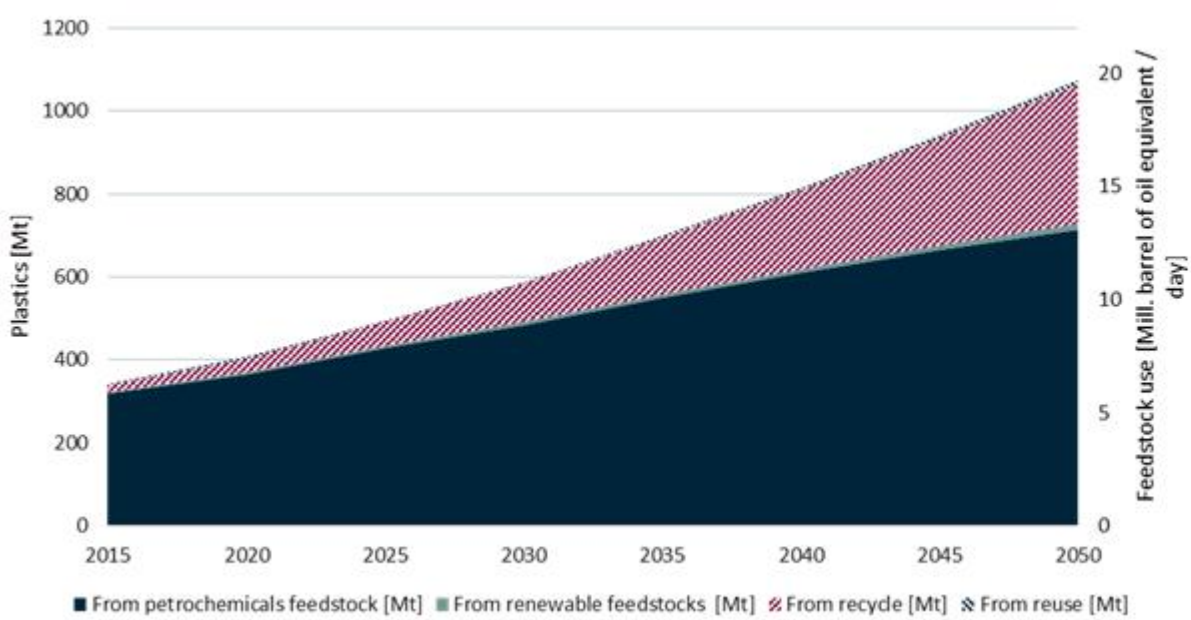


Figure 69 Plastic production for the "Circular economy" scenario (#3)

Scenario 3 means that within 2050, a large part of the plastics demand would be answered by the use of virgin materials from the petrochemicals industry (710 Mt), which is a doubling of the current production. Only 14 Mt would be produced from bio-plastics, which represent 5 times the current production, and use of 0.1% of all agricultural area for renewable feedstock.

In terms of petrochemicals, the oil and gas demand for plastics would reach 730 Mtoe/year, or 13,1 Mboe/day.

5.4.1.4. Scenario 4 - Bioplastics in a circular economy

The last scenario (4) represents a fully circular and renewable economy. This means that the recycling rate increases to 80%, and that all virgin plastics are produced with bio-plastics. Scenario 4 would require a large increase in bio-plastics production capacity (16% annual growth rate, vs. 7.5% expected in the period 2015-2021). In terms of recycling, the changes would be even larger, with almost all recyclable plastics being collected and recycled, including these embedded in products along with other materials. This means drastic changes to recycling policies for all countries in the world, and a dramatic increase in the recycling capacity.

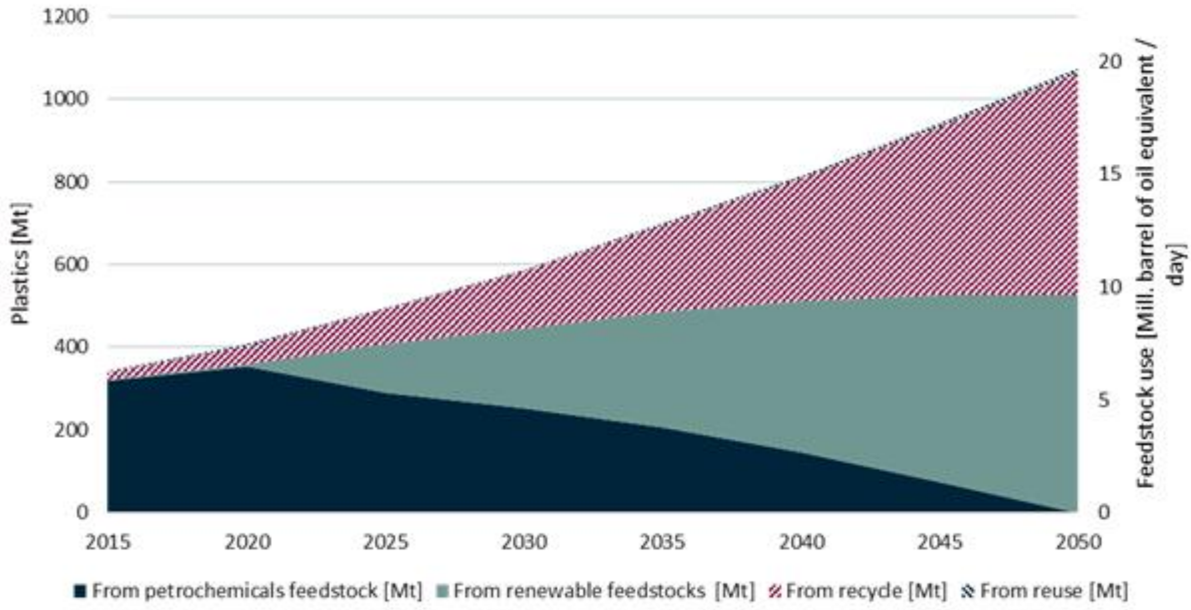


Figure 70 Plastic production for the "bioplastics in a circular economy" scenario (#4)

Scenario 4 means that within 2050, there would still be a need for 525 Mt virgin plastics from bio-plastics (170 times higher than the current production), which would require the use of 3% of the agricultural area.

In scenario 4, there is no need for petrochemical feedstock. This assumes that bio-plastics or other materials have been developed to replace all sorts of plastics types, including advanced plastics.

5.4.2. Fertilisers

Plastics represent ca. 63% of the production from the chemical/petrochemical industry, and fertilisers are also an important driver for non-energy use. Ammonia production has increased 1.7% per year since the early 80's, as illustrated below.

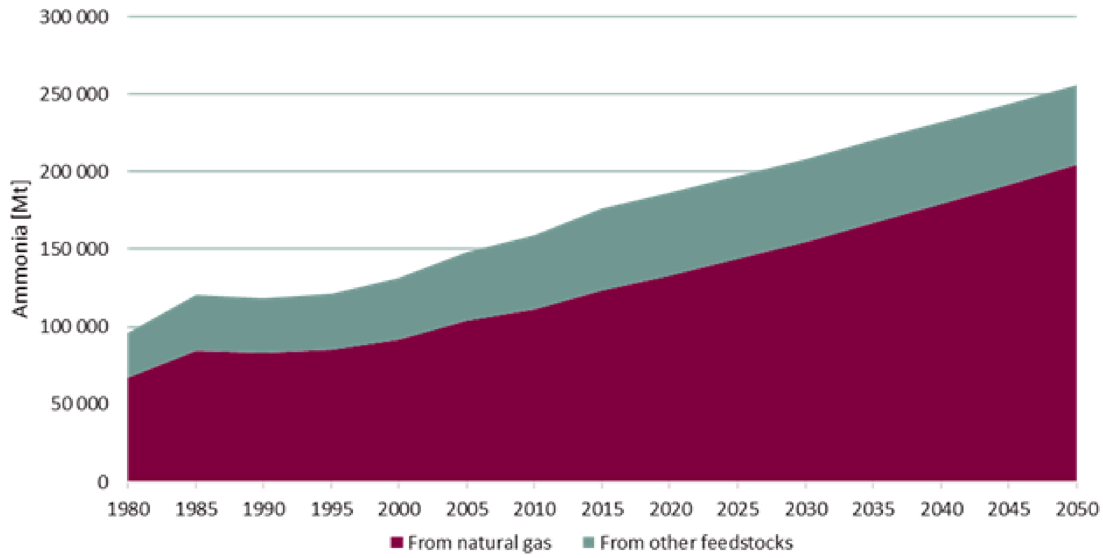


Figure 71 Trend in ammonia production, historical and forecast (IFA, 2015)

The fertilizers industry expects the production to keep increasing at 1.3% annual growth rate until 2030. Gas is expected to remain the main source of hydrogen for ammonia production, and could increase by 70%, to 109 Mtoe in 2050.

5.4.3. METHANOL, BITUMEN AND OTHER PRODUCTS

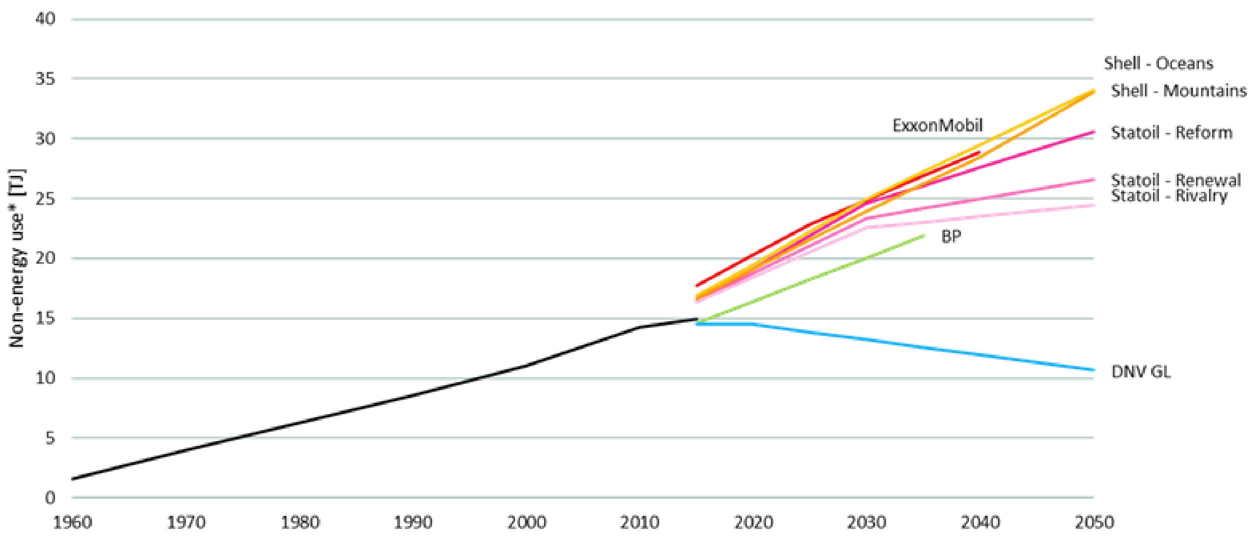
The trend for methanol, bitumen and other products is more uncertain. The demand for bitumen is mainly linked to road infrastructures. It has been decreasing in western Europe over the past 10 years, partly due to the finance crisis in 2008, but also because most infrastructure is already developed and mostly requires maintenance. The demand is increasing in developing countries, in particular the Asia/Pacific region. Short/medium term growth internationally is expected to be 3-4% per year (vs. 1.6% over the past 35 years) (NASDAQ, 2017, Freedonia, 2017)

Methanol consumption is expected to increase 6-7% per year until 2021. Gas is the main feedstock internationally, and use of coal is increasing in China. The long term demand for methanol may be linked to energy use as a fuel (Hydrocarbons Processing, 2017).

Very little data is available for trends and forecasts for other products.

5.4.4. OUTLOOK FOR NON-ENERGY USE: COMPARISON OF SOURCES

Many organisations provide outlooks and forecasts for non-energy use of oil and gas, including: BP, DNV GL, ExxonMobil, Shell, Equinor (Statoil). Endrava compiled these outlooks and established a comparison in the figure below.



** mostly oil and gas, may include smaller quantities of coal and biomass, more details not available.*

Figure 72 Historical data and forecasts for non-energy use until 2050 (IEA 2017b, BP 2017, DNV GL 2017, ExxonMobil 2017, Shell 2013, Equinor/Statoil 2017)

Most outlooks agree on an expected increase in non-energy use over the next 35 years. The annual growth is expected to be between 1.4 and 2.1 %. It has been 1.7% over the past decade. DNV GL is the only organisation within this comparison to forecast a decrease in non-energy use. The basis for DNV GLs scenario is uncertain, and the company indicated that they will revise its model in 2018 (personal communication with B.E. Bakken and C.B. Ellefsen, December 2017).

The data from outlooks and forecasts can also be analysed in terms of share of non-energy use in the total demand for oil and gas, as illustrated below.

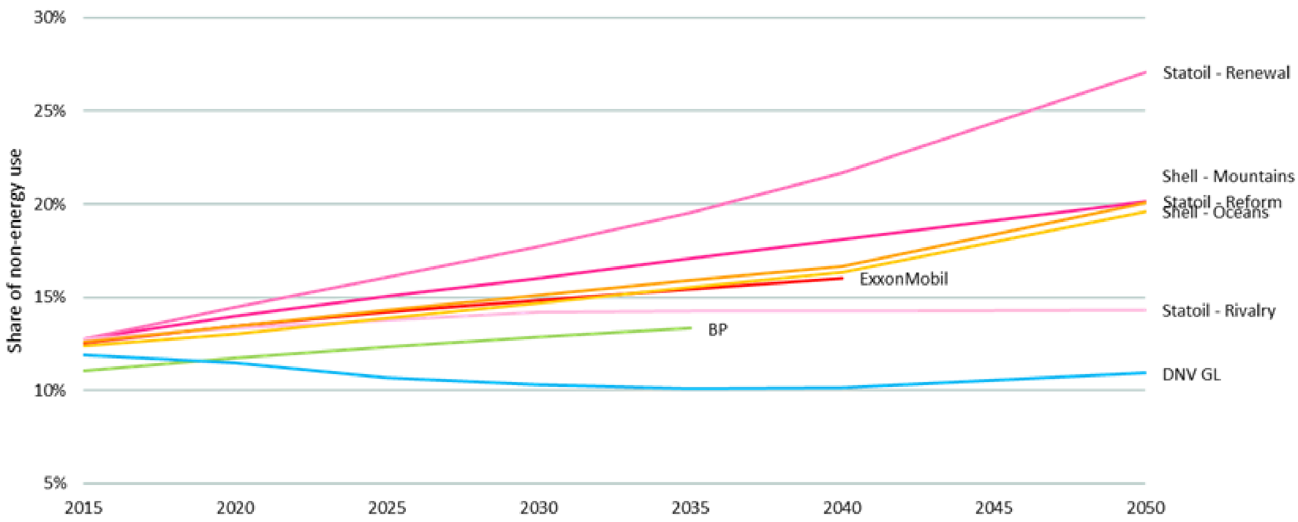


Figure 73 Share of non-energy use in the total demand for oil and gas, forecasts (BP 2017, DNV GL 2017, ExxonMobil 2017, Shell 2013, Equinor/Statoil 2017)

Starting from a 11-13% share of non-energy use (depending on scope), most outlooks agree on an increase until 2050, with up to 27% for one of Equinor's (Statoil) scenarios. The large span in Equinor's outlook is due to the differences between the various scenarios for the total consumption of oil and gas.

As with the previous figure, DNV GLs scenario is the only one forecasting a decrease in non-energy use.

6. SOURCES OF INFORMATION

6.1. DATABASES

6.1.1. IEA DATA

The IEA Energy statistics data (IEA, 2017) provide an overview of the production and use of energy in the world. Data is collected by the IEA via direct contact with the authorities and statistics agencies in each country, and via a dedicated form for the OECD countries. The IEA data is updated on a yearly basis, with a two-years delay. For example, the data for year 2015 was published in 2017.

Access to the detailed data is on a paying basis, and the cost is based on the number of data points requested.

The dataset contains information for each country in the world and for each year: production, import/export, transformation and use of oil, gas, coal, etc. Available data is more detailed for the OECD countries, with a detailed overview of the sectors, industry segments and type of products, including non-energy use. The OECD countries represent ca. 42% of the total use of oil and gas products in the world.

Figure 74 Overview of the countries member of the OECD, and share of oil and gas use in the OECD dataset (based on IEA, 2017)

To test the representativity of the OECD data on non-OECD countries, Endrava made a comparison of the overall use of oil and gas for the industry and for non-energy use in each region (figure to the right).

The comparison shows that the share of oil and gas used in the industry sector in non-OECD countries is higher than in OECD.

On the overall, data for OECD was assumed to be representative for the whole world.

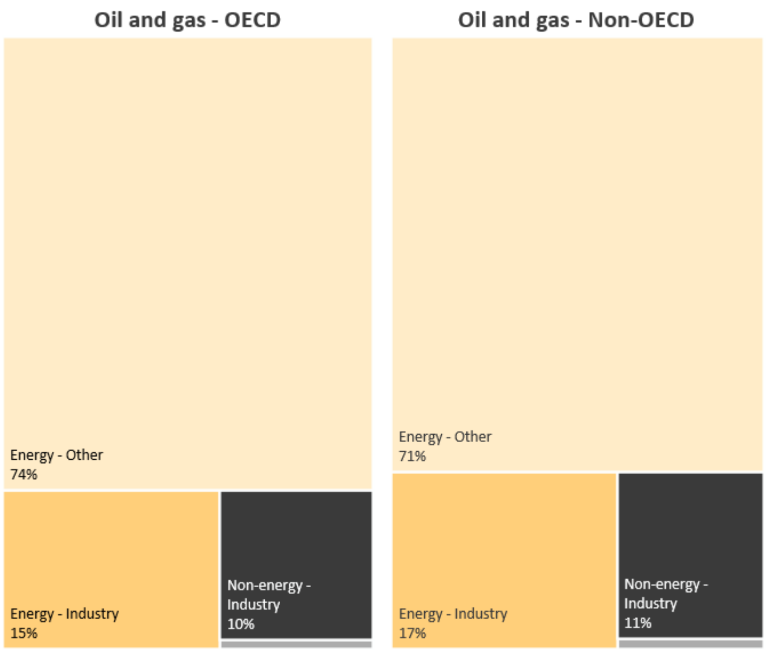


Figure 75 Comparison of the share of industry and non-energy use in the OECD and non-OECD countries (based on IEA, 2017)

For non-energy use, IEA provides detail on the use in the chemical/petrochemical industry, and a sum of the use in other industries in OECD countries. Endrava allocated this sum to each industry based on a qualitative assessment of the typical use of each product in each industry segments. The data contains therefore some uncertainties.

6.1.2. EUROSTAT DATA

Eurostat is the European statistics agency. The agency provides free access to datasets on many topics in EU and non-EU European countries (Norway included).

This report makes use of Eurostat data from two main datasets:

- Energy balances (dataset *nrg_110a*),
- Statistics on the production of manufactured goods (dataset *prom*).

The **energy balances** (Eurostat, 2018a) provide details on the use of energy in Europe between 1990 and 2016. Due to limitations in the size of Excel spreadsheets, only data between 2007 and 2016 was included in this report. The structure for the data is similar to that used by IEA, with a distinction between primary energy, transformation, and final energy use. Eurostat details the energy use per country and per year. Information is provided on the type of energy, the sector and industry segment. Non-energy use is included in the database, but not detailed per industrial segment, except for chemical/petrochemical (as in IEA).

The **statistics on the production of manufactured goods** (Eurostat, 2018b) provide volumes and monetary value for the production on goods from industrial segments in Europe until 2016. The data is detailed per product type, across many different categories. Data is provided on a national level.

6.2. Documents and links

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- IEA, 2017b. Energy statistics for non-energy use of oil, gas and coal
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- Zink et al., 2017. Toward Estimating Displaced Primary Production from Recycling. Journal of Industrial Ecology. DOI: 10.1111/jiec.12557

Appendix B:

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Appendix C:

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APPENDIX A - BACKGROUND ON OIL AND GAS PRODUCTS

Oil and gas products contain mostly carbon and hydrogen atoms, and are therefore called “hydrocarbons”. Products can be categorised according to the number of carbon atoms in their molecules. For example, methane (formula CH_4) contains only one carbon atom, while butane (C_4H_{10}) contains four. Generally, the more carbon atoms, the heavier the product.

In a refinery, crude oil and gas are processed in a distillation column, which makes it possible to separate the different products. Typically, lighter products with less carbon atoms (methane, ethane) will come out at the top of the column, while heavier products with more carbon atoms (fuel oil, bitumen) will be at the bottom of the column.

The figure below presents the main oil and gas products, organised vertically as they would in a distillation column. The typical number of carbon atoms is provided in the right side of the figure. The use of each product is also provided.

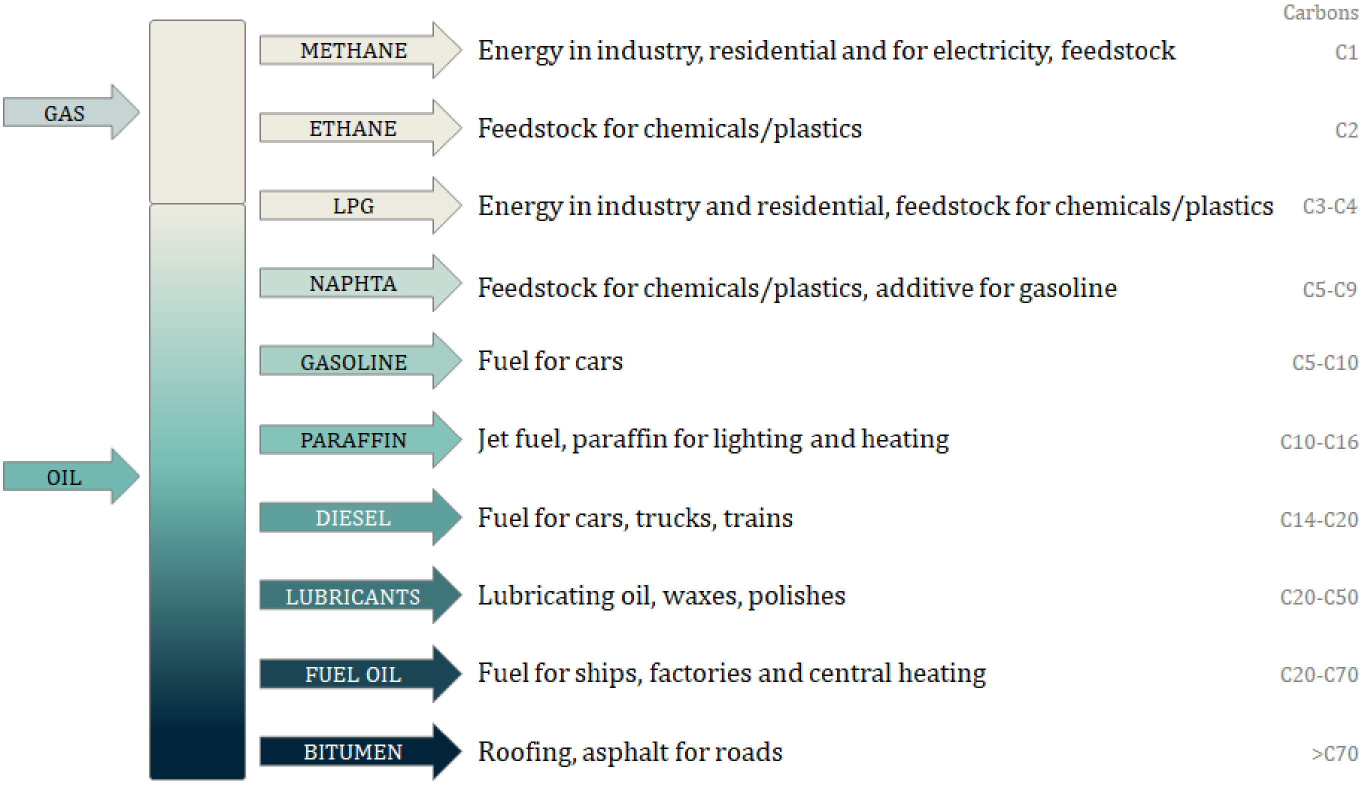

Figure 76 Overview of the different oil and gas products, their use and their number of carbon atoms

The following sections provide more information about the uses of each of the products. Data is from the IEA database for the year 2015, which covers OECD countries (42% of the oil and gas used in the world). There is no data on the use in other countries, but it is assumed to be similar to OECD countries.

A1. Natural gas

Natural gas typically contains 80 to 95% methane (CH_4), along with other gases: ethane, propane, etc. It is mostly used as energy source for electricity and heat production in the power sector, the industry, and in the residential sector.

When including all sectors in the statistics, non-energy use of natural gas represents only a few percent of the total use. The petrochemical industry is the main user, where natural gas is transformed into methanol, ammonia, and other chemical products.

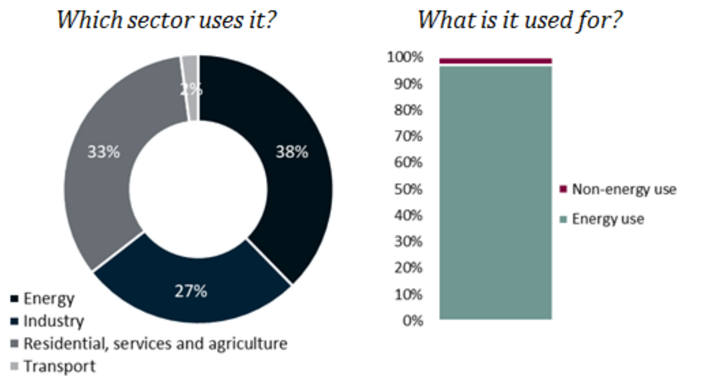

Figure 77 Sectors using natural gas, and share of non-energy use (based on IEA, 2017, for OECD countries)

A2. Ethane

Pure ethane (C_2H_6) is used only in the industry for non-energy use. It is however also used as a component of natural gas, in combination with methane and other gases, across all sectors (see previous section).

The petrochemical industry uses ethane as a feedstock for the production of plastics: Polyethylene (PE), Polyethylene Terephthalate (PET), and Polyvinyl chloride (PVC).

Ethane is also used to produce some chemicals.

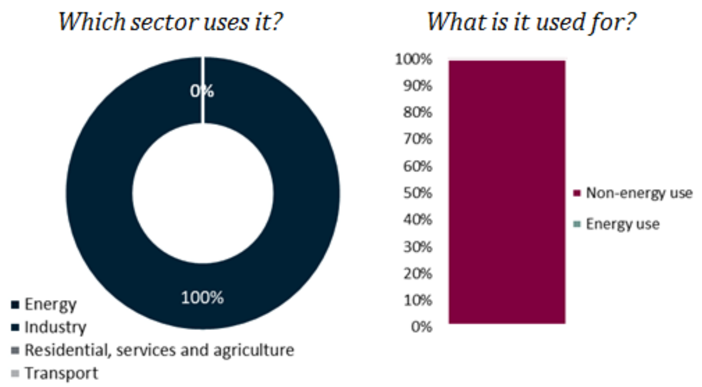

Figure 78 Sectors using ethane, and share of non-energy use (based on IEA, 2017, for OECD countries)

A3. LPG (propane and butane) and Naphtha

LPG contains propane and butane (C_3H_8 and C_4H_{10}). Naphtha contains a range of hydrocarbons with between 5 and 9 carbon atoms.

LPG and naphtha are mostly used in the industry as feedstock for plastics: PE, PET, PVC, ABS, PP, PU, Fiberglass, etc. They are also used for energy in the residential/services sector, in industry, and transports.

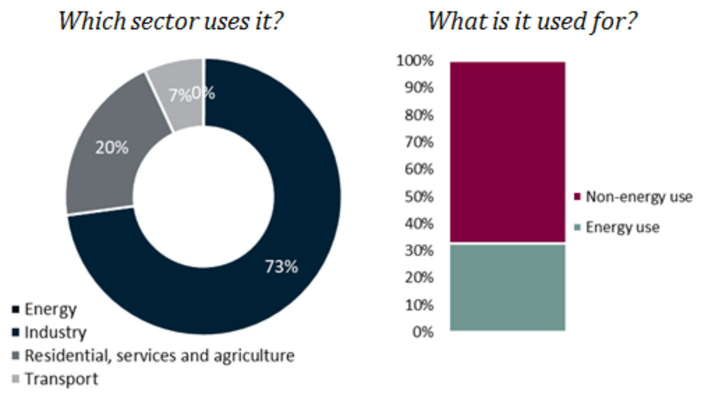

Figure 79 Sectors using LPG and naphtha, and share of non-energy use (based on IEA, 2017, for OECD countries)

Naphtha can be converted to gasoline (transformation, not shown here). In addition, smaller percentages of propane and butane are present in natural gas, in combination with methane and ethane, and used across all sectors, as illustrated in section A1.

A4. Gasoline

Gasoline is a mix of different hydrocarbons with typically between 5 and 10 carbon atoms.

It is only used as fuel, and mostly within the transport sector. The agricultural sector also uses smaller amounts of gasoline.

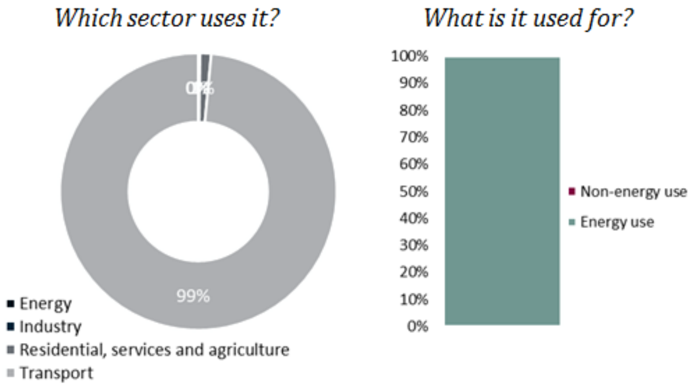

Figure 80 Sectors using gasoline, and share of non-energy use (based on IEA, 2017, for OECD countries)

A5. Paraffin and kerosene

Paraffin and kerosene contain hydrocarbons with between 10 and 16 carbon atoms.

They are mostly used as jet fuel in the transport sector. They are also used as paint thinner and solvent (white spirit), and as lamp fuel. Non-energy use of paraffin and kerosene represent only a few percent of the total use.

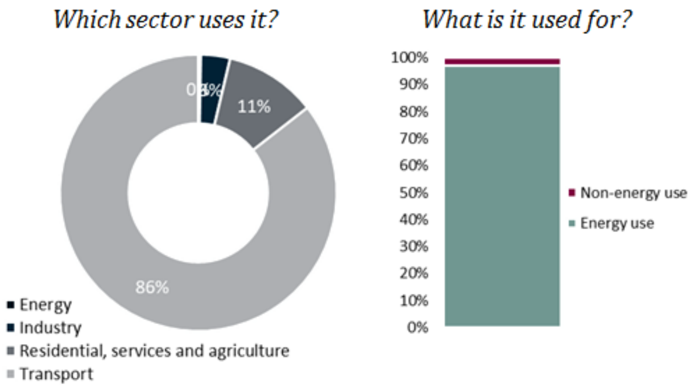

Figure 81 Sectors using paraffin and kerosene, and share of non-energy use (based on IEA, 2017, for OECD countries)

A6. Diesel

Diesel contains hydrocarbons with between 14 and 20 carbon atoms.

Similarly to gasoline, diesel is only used as fuel. The transport sector is the main user, but diesel is also used in the residential/services/agriculture sector, and in the industry.

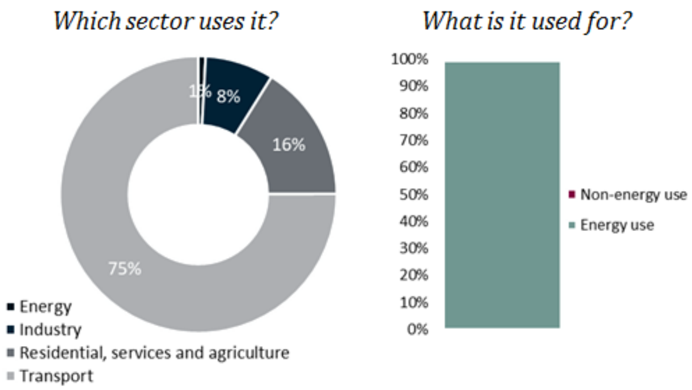

Figure 82 Sectors using diesel, and share of non-energy use (based on IEA, 2017, for OECD countries)

A7. Lubricants

Lubricants contains hydrocarbons with between 20 and 50 carbon atoms.

They are almost entirely used for non-energy use, across all sectors for lubricating motors and machinery. The main sectors using lubricants are the transport sector and the industry.

Since some of the lubricant is combusted in engines, a few percentages of the lubricants appear in “energy use.

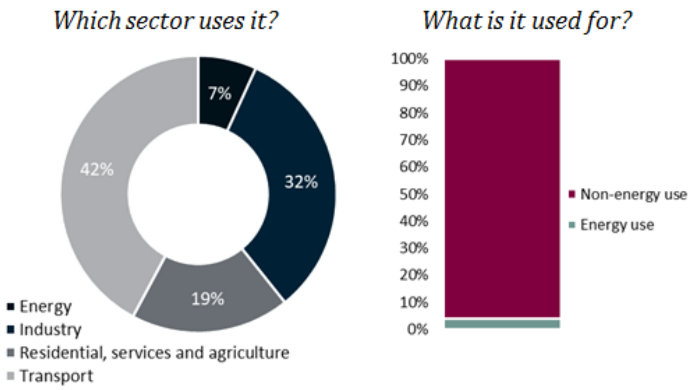

Figure 83 Sectors using lubricants, and share of non-energy use (based on IEA, 2017, for OECD countries)

A8. Fuel oil

Fuel oil contains hydrocarbons with between 20 and 70 carbon atoms, similarly to lubricants, but with a different chemical composition.

Fuel oil is almost entirely used for energy purposes, mainly as a fuel in the maritime sector, but also for electricity and heat production and in the industry.

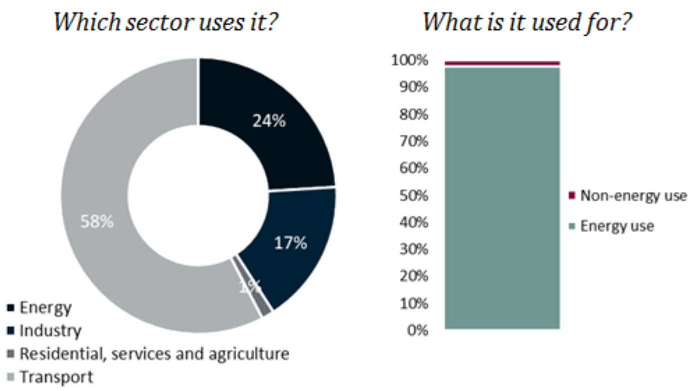

Figure 84 Sectors using fuel oil, and share of non-energy use (based on IEA, 2017, for OECD countries)

A9. Bitumen

Bitumen contains the heaviest hydrocarbons from oil, with more than 70 carbon atoms, at the bottom of the distillation column.

It is almost entirely used for non-energy purposes in the industry: to produce asphalt for road paving, and for waterproofing of roofs in buildings.

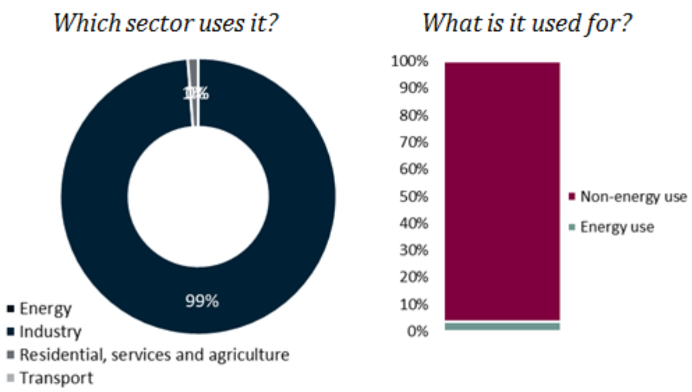

Figure 85 Sectors using bitumen, and share of non-energy use (based on IEA, 2017, for OECD countries)

APPENDIX B - CIRCULAR ECONOMY AND BIOPLASTICS

The World Economic Forum (2016) presents a vision for plastics in a circular economy perspective, as illustrated below.

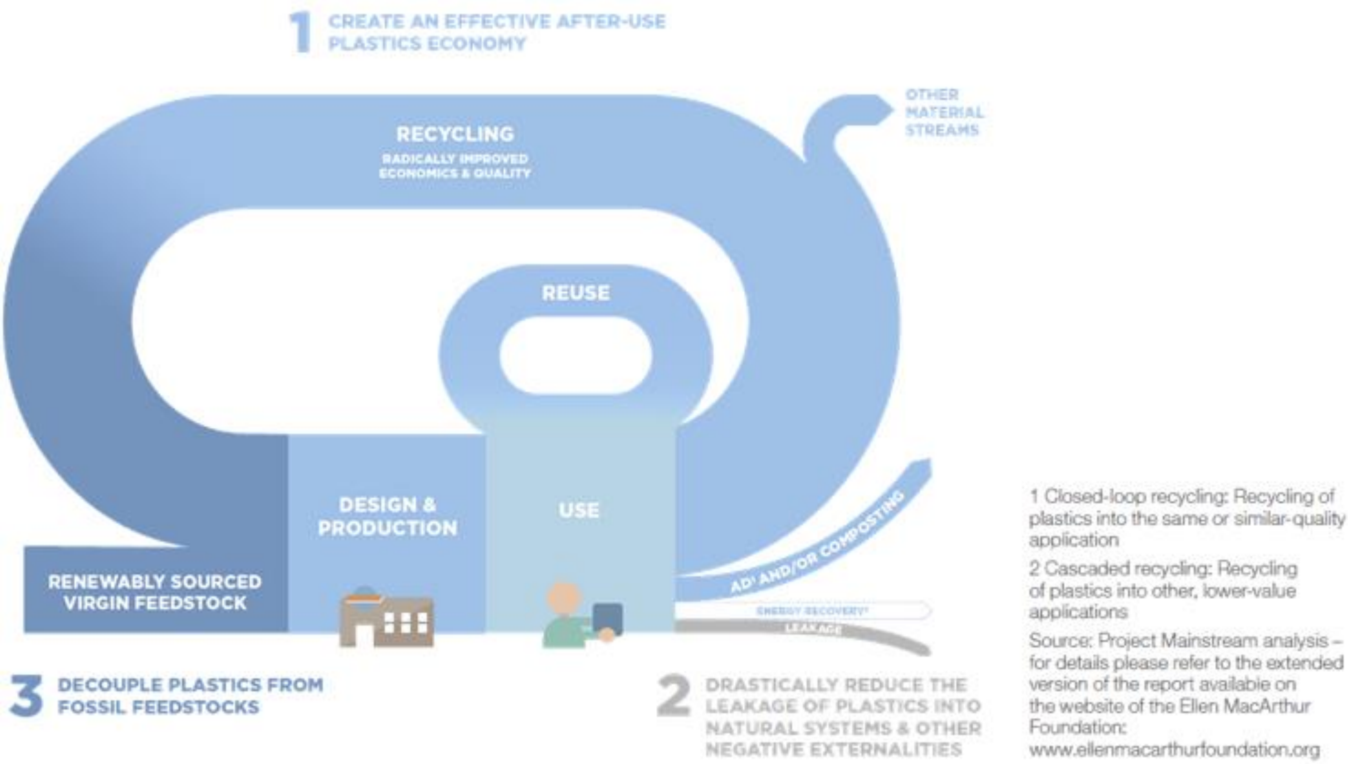

Figure 86 Plastics in a circular economy perspective (World Economic Forum, 2016)

This vision provides an indication of potential future trends for the use of plastics, namely:

- A redesign of plastics products to make them easier to recycle and to use less plastics in general. A counter acting trend is the increased use of composite materials in transports (e.g. BMW i3, Boeing Dreamliner).
- The increase of re-use of plastics products, without going through recycling, for example reuse of soap bottles. The potential is estimated to be limited.
- Increase in recycling rate. It is estimated today that ca. 14-18% of all plastics in the world are recycled, with up to 30% in Europe and 25% in China. Potentially, recycling could increase up to 44% for all types of plastics in the world, towards 2050 (Geyer et al., 2017). A challenge is that virgin materials are sometimes cheaper than recycled ones, which does not stimulate the use of recycled plastics. Conversely, when recycled plastics are cheaper, it makes it more accessible to increase the total use of plastics. This trend is observed for other recycled materials too (Zink et al., 2017).
- Use of renewable feedstock, either through the use of bio-based plastics, or synthetic plastics from the conversion of methane and/or CO_2 into plastics. An example is green polycarbonates from CO_2 (Taherimehr et al., 2014).

There are at least 3 different types of bioplastics, and it is important to differentiate them. The figure below illustrate the differences.

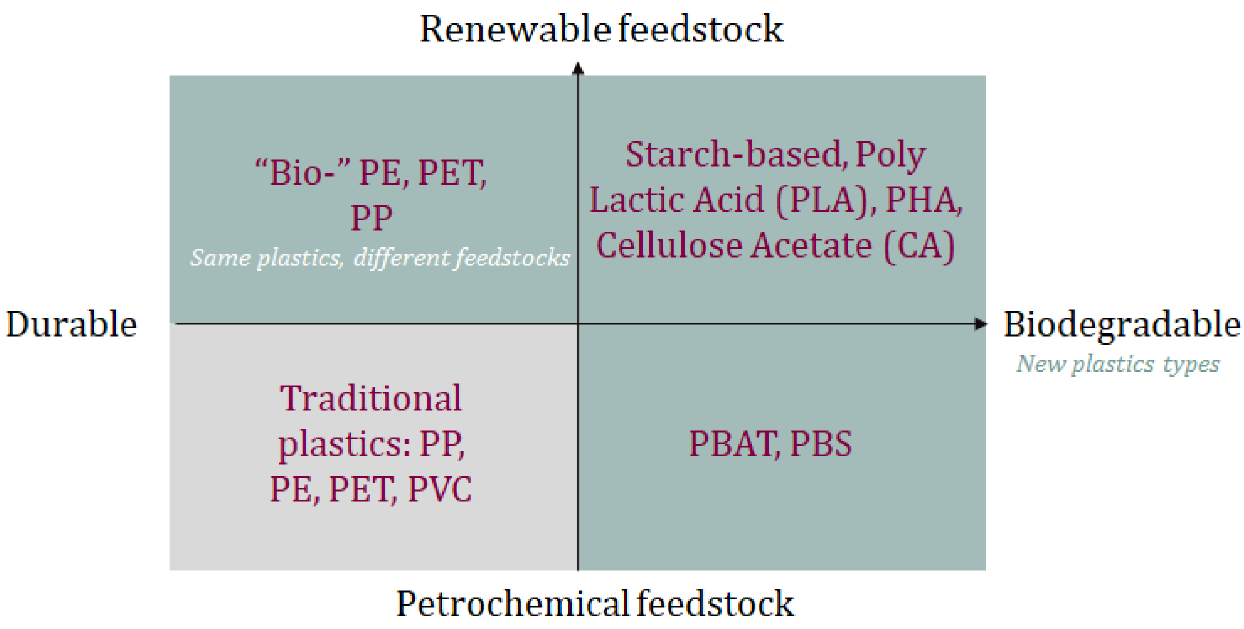

Figure 87 Different types of bioplastics

Two main questions make it possible to differentiate the types of bioplastics:

- is it biodegradable?
- is it made of renewable feedstock?

Biodegradable plastics made of renewable feedstock exist, they are for example based on starch (Poly Lactic Acid - PLA, from corn), or on cellulose. There are also plastics made from renewable feedstock that are not biodegradable, and which will stay intact if left in nature. These are usually conventional plastics (e.g. polyethylene, polypropylene), made from feedstock such as ethanol from sugar cane. These plastics are chemically identical to regular PE or PP, only the feedstock origin differs. Finally, there are biodegradable plastics which are made from petrochemical feedstock, such as PBAT or PBS, and which will degrade if released in nature.

In the rest of this document, plastics made from renewable feedstock (biodegradable or not), will be referred-to as "bio-based" plastics.

There has been an increase in the production capacity of bio-based plastics over the past 10 years, from 0.18 Mt in 2008 to 4.4 Mton in 2017 (European Bioplastics, 2017), as illustrated to the right.

The production of bio-based plastics is expected to reach 6 Mt in 2021, which will represent 1.5 % of all the plastics demand that year. Statistics show that there is much more bio-based, non-degradable, plastics produced than the biodegradable type (3.4 Mt vs. 1 Mt in 2017). This trend is expected to continue in the future.

This means that bio-based plastics are not necessarily an answer to the microplastics issue.

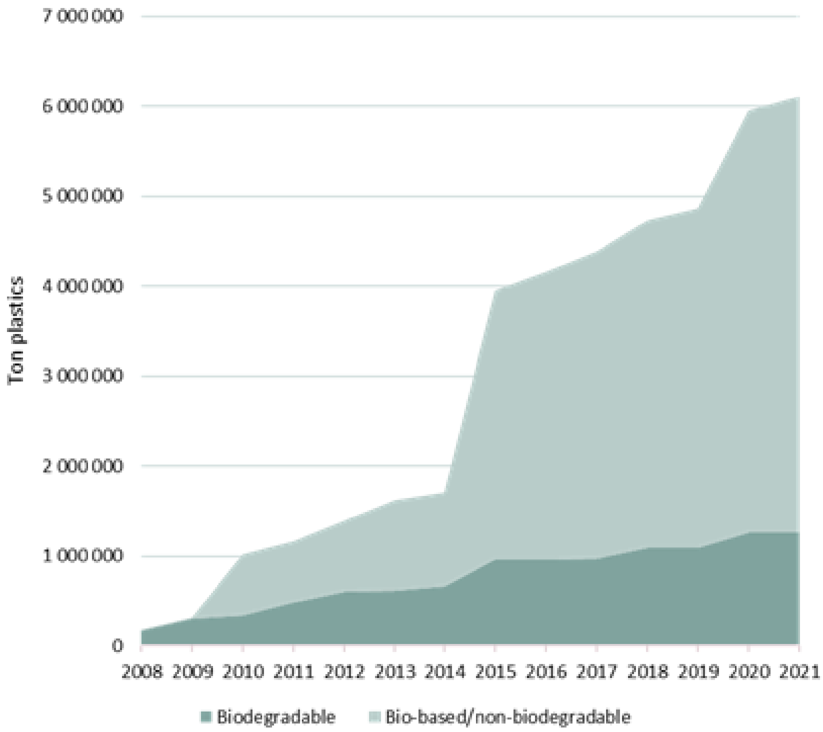

Figure 88 Production capacity for bio-based plastics (European Bioplastics, 2017)

The figure below shows the impact of bio-based plastics on the overall plastics demand until 2020.

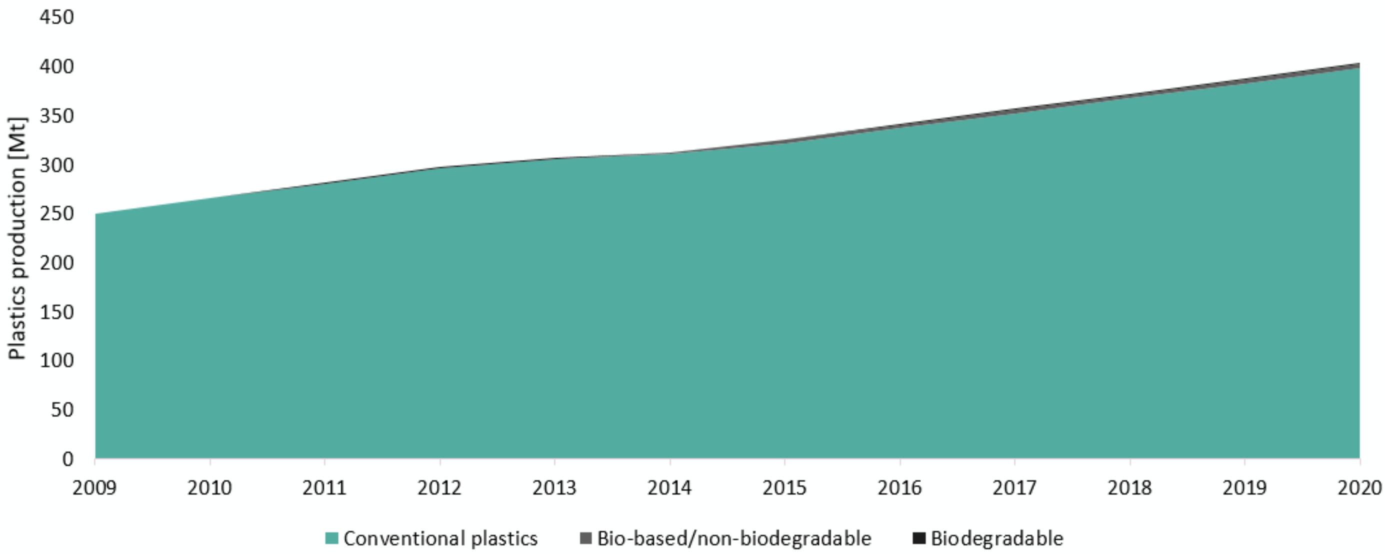

Figure 89 Production capacity for bio-based plastics, and total demand for plastics (based on European Bioplastics 2017, and Plastics Europe 2016)

The figure below illustrates the main difference between bio-based plastics and conventional plastics.

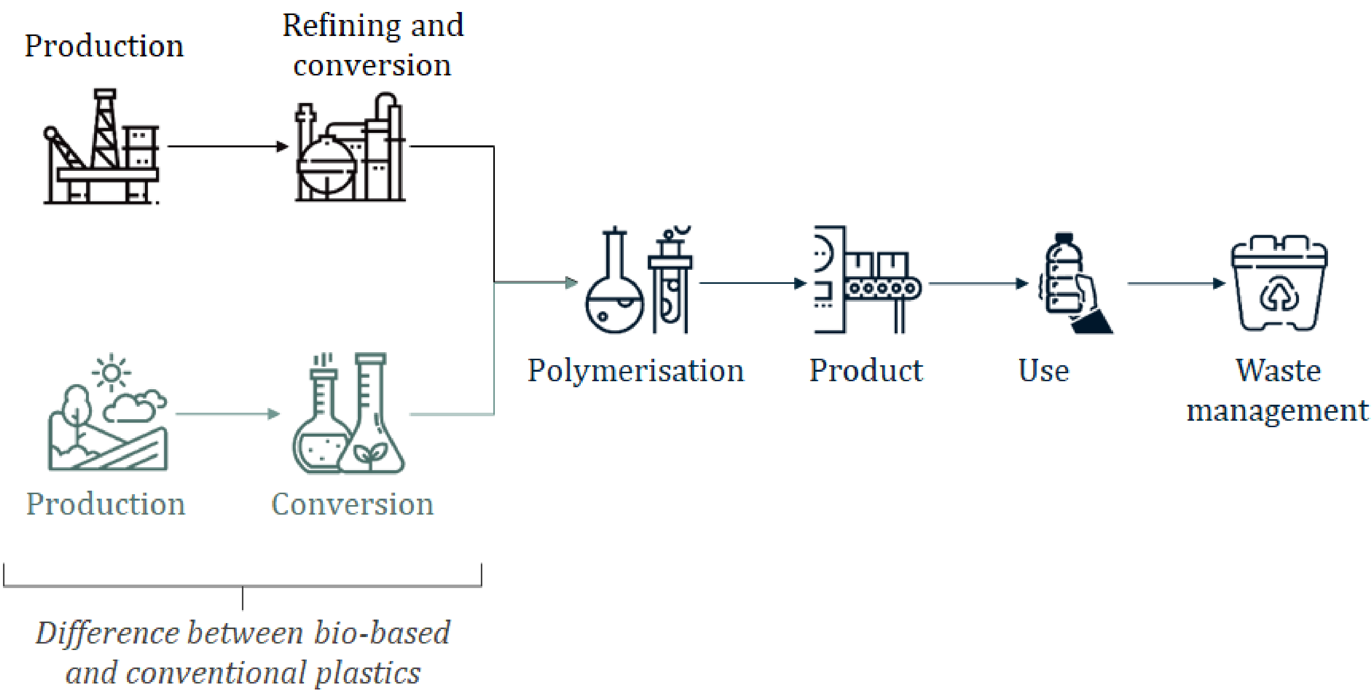

Figure 90 Difference between bio-based and conventional plastics

The main difference is at the origin of the plastics. Conventional plastics are made by refining petroleum products, and converting them to petrochemical feedstock (ethylene, propylene, benzene, etc.). Bio-based plastics are made by growing plants, typically energy crops, harvesting them, and converting them to bio-feedstock. An example is the use of sugar cane to produce ethanol, and then convert it to ethylene to produce polyethylene (PE). Bio-based plastics require areal to grow the necessary feedstock, about 0.2 to 0.4 hectare per ton plastics (Bos et al., 2011).

The remaining of the plastics value-chain is very similar between bio-based and conventional plastics. From a chemical perspective, some of these plastics are identical: bio-based polyethylene has exactly the same chemical and physical properties as petrochemical polyethylene for example. Both plastics types require the same energy and have the same environmental impacts during the production of plastics products. They are equally important to collect and manage the waste in an appropriate way at the end of the product lifetime.

Life-cycle analysis (LCA) provide data on the use of fossil energy and the total climate impact of plastics. The figure below shows the use of fossil energy for the production of PE and PET, both in petrochemical and bio-based version.

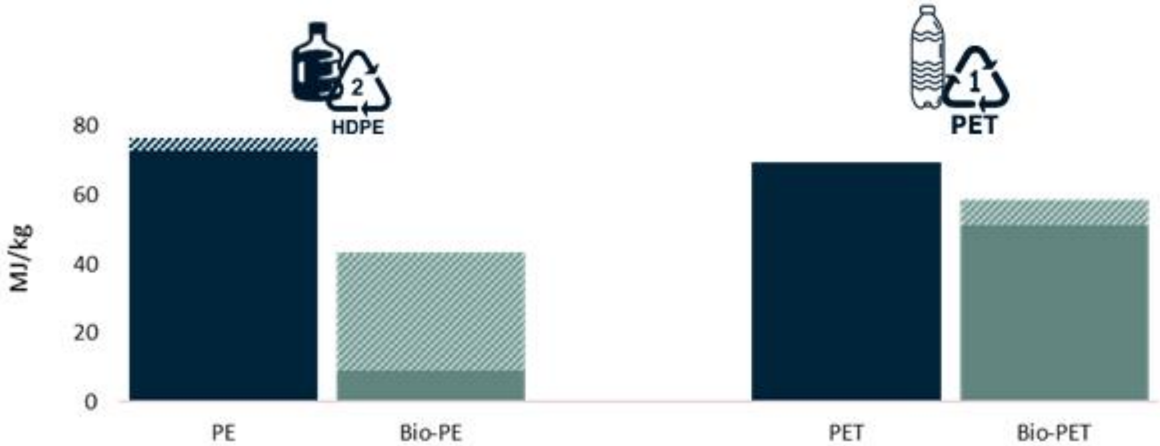

Figure 91 Use of fossil energy for the production of PE and PET (based on Shen et al. 2012, Chen et al. 2012)

Even when they are based on renewable feedstock, bio-plastics require the use of fossil energy during their production: for running the agricultural machines, at the processing plant, for transport vehicles. In general, bio-plastics require however less fossil energy than petrochemical plastics. The difference is not that high for PET, since it contains only ⅓ of bio-based feedstock. The large uncertainty range for bio-PE is related to variations between sugarcane and corn as feedstock. Sugarcane makes it possible to use residues (bagasse) to produce energy at the fermentation plant, which means less fossil energy needed during processing.

The figure below shows the total carbon footprint of plastics production for PE and PET.

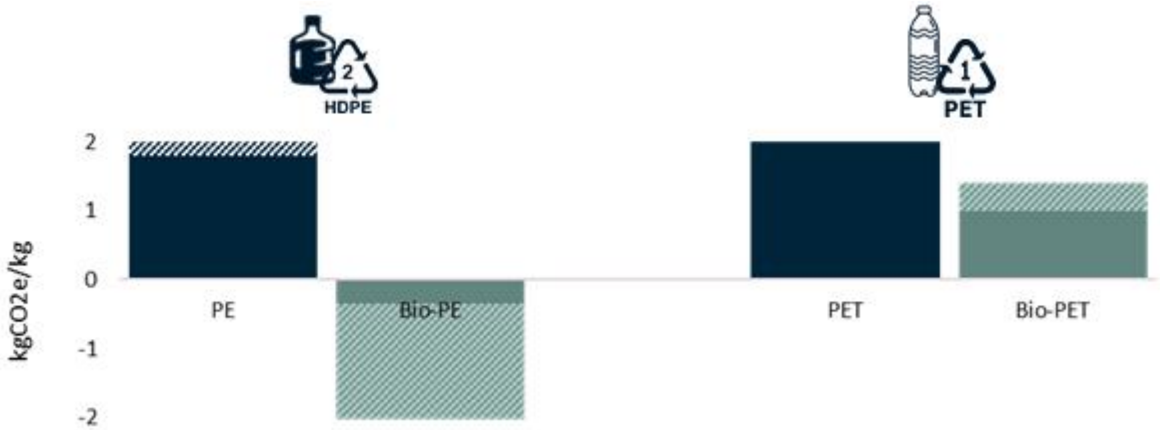

Figure 92 Carbon footprint for the production of PE and PET (based on Shen et al. 2012, Chen et al. 2012)

Generally, bio-based plastics have a lower carbon footprint of production than petrochemical-based plastics. This is due to the fact that feedstock for bio-based plastics capture CO_2 from the atmosphere, as long as the plastics is not incinerated or biodegraded. Emissions related to the production of sugarcane or corn, in this example, and for the conversion of feedstock (e.g. to ethylene) increase the carbon footprint.

The two figures below summarise the use of fossil energy and the carbon footprint for other types of plastics.

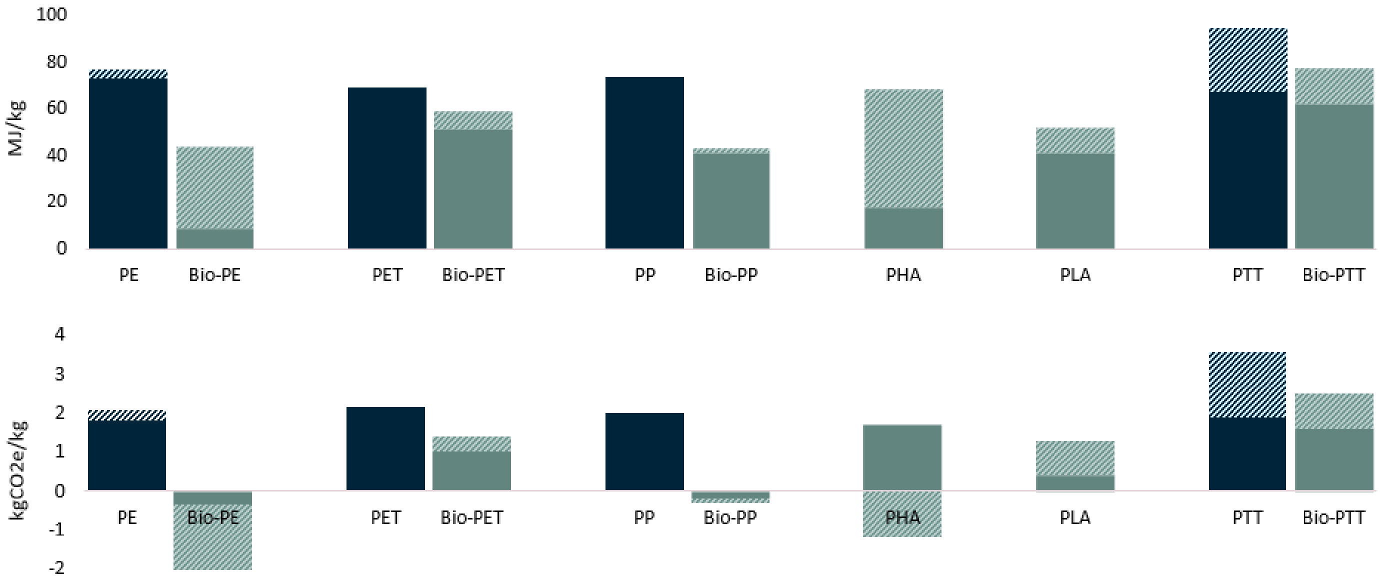

Figure 93 Use of fossil energy (up), and carbon footprint (down) for the production of various types of plastics (based on Shen et al. 2012, Chen et al. 2012)

Hottle et al. (2017) shows that use of fossil energy and the total carbon footprint should not be the only parameters analysed when comparing bio-based plastics to their petrochemicals counterparts. LCAs show that bio-based plastics have higher impacts on the environment for all other parameters than climate and energy: ozone depletion potential, smog, eutrophication, etc. The total carbon footprint of biodegradable plastics is also largely impacted by how much of the plastics is industrially composted (best) or landfilled (worst). For example, landfilling of PLA can lead to a higher carbon footprint than PE of PET over the whole lifecycle. For both bio-based and petrochemicals-based plastics, recycling can reduce the total carbon footprint of the plastics.

B3. Conclusion on bioplastics

The term bioplastics includes many different types of plastics, with different properties. A distinction should be made between bio-based plastics (from renewable feedstock) and biodegradable plastics. Bio-based plastics can have a lower total carbon footprint than petrochemicals-based plastics, but it depends on the feedstock being used for the production. Biodegradable plastics can be either bio-based or petrochemicals-based.

The production capacity for bioplastics is increasing, but it is still minor compared to petrochemical-based plastics, as it will reach 1.5 % of all the plastics demand in 2021. Most of the production increase is for bio-based plastics (non-biodegradable), such as polyethylene from sugarcane, or polyurethane.

APPENDIX C - MICROPLASTICS

Microplastics are plastics particles with a size of less than 5 mm.

There are two types of microplastics (Sundt et al., 2014):

- primary microplastics, which is released to the environment directly as particles, and
- secondary microplastics, which is produced when plastics waste is physically degraded in nature, in particular at sea.

There are still large uncertainties on the effect of microplastics on ecosystems. It is possible that the largest effect is not from the plastics themselves, but from the additives that are added in the plastics to change their properties (colour, flexibility, etc.) (Wagner et al, 2014).

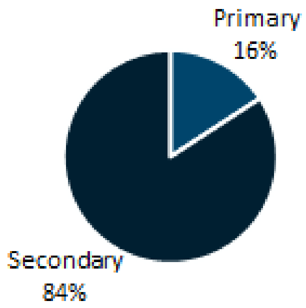

Figure 94 Split between primary and secondary microplastics (based on Jambeck et al. 2015, IUCN 2017)

Since non-degradable, bio-based, plastics have the same chemical and physical properties as petrochemical-based plastics, they can also produce secondary microplastics. Bio-based plastics such as bio-PE, bio-PET are therefore not a solution to the microplastics issue.

Although there has been focus on microplastics at sea, they are also found in freshwater and on land.

It is estimated that between 1.8 and 5 Mton primary microplastics are released to the environment every year, with ca. 50% ending-up in the oceans (IUCN, 2017).

The main sources of primary microplastics are:

- washing of synthetic textiles (35%),
- dust from car tyres (28%),
- dust from cities (24%).

Cosmetics have been often mentioned in the media as a source of microplastics, although they contribute to only 2% of the primary microplastics.

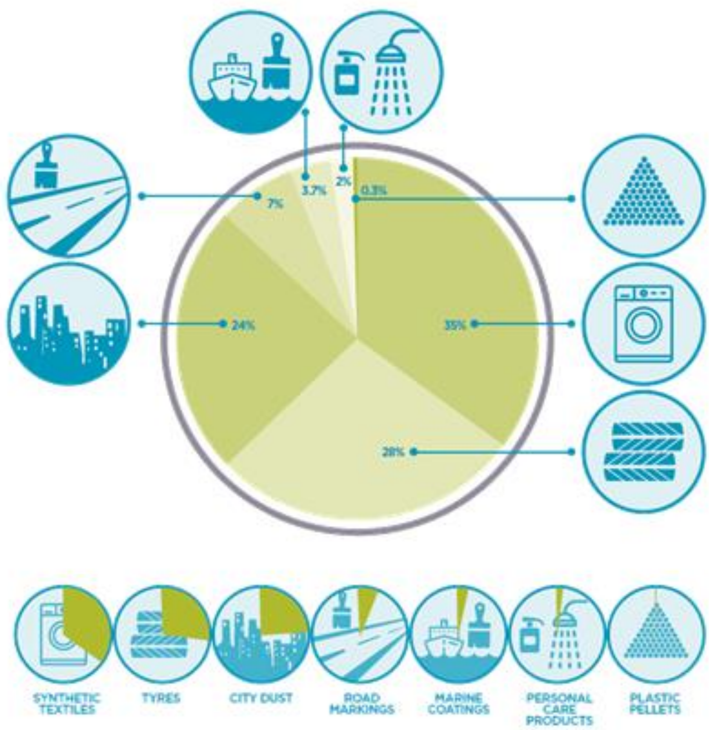

Figure 95 Main sources of primary microplastics (IUCN, 2017)

Geyer et al. (2017) estimates that 18% of the world's plastics are recycled, and 24% are incinerated, with or without energy recovery.

58% of the plastics are landfilled, or released to the environment. Up to 4% of the plastics would end-up in oceans (12.7 Mton). This plastics waste is then physically degraded and becomes secondary microplastics. This is the largest source of microplastics to sea.

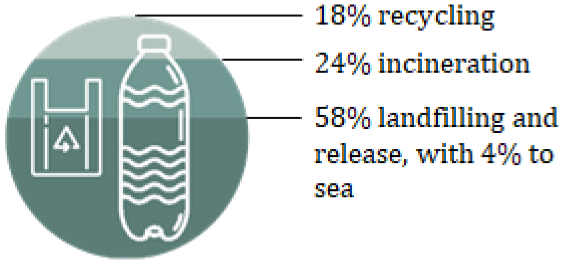

Figure 96 Fate of plastics (based on Geyer et al. 2017)

Due to ocean currents, the plastics waste accumulates in specific areas in oceans, e.g. in the Pacific Ocean on the figure to the right.

Even though the media has described these areas as islands of plastics, they are more similar to a soup of plastics, with ca. 5 kg plastics per square kilometre of ocean.

Figure 97 Location of the plastics concentrations in the Pacific Ocean (National Geographic, 2015)

About Endrava

Endrava is a consulting company based in Oslo, Norway. We support organisations and businesses in embracing sustainability opportunities.

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