accenture

TAKING THE EUROPEAN CHEMICAL INDUSTRY INTO THE CIRCULAR ECONOMY

PREFACE

Dear reader,

The world we live in faces serious societal challenges. While the chemical industry strives to provide solutions we also look towards new business models. We therefore welcome Accenture's study on the Circular Economy and its potential impact on the European chemical industry. It is a first analysis going beyond schemes of better waste recovery and looks at both market opportunities and impact on assets. Accenture highlights the growth opportunities for Europe, and sketches a concept of circularity that has the potential to boost the competitiveness of entire value chains and foster even more co-operation between business partners in the future.

The purpose of the study is to start a meaningful debate. The data provided are not set in stone. The modelling of the future depends on thought-provoking assumptions which are determined by variables like time, technology, trade and economics. Having said this, the report provides the basis for a useful discussion that will help us to shape the future: Which role does the chemical industry play in enabling a circular economy? What are the consequences for society and for industry itself? The report underlines the long-held conviction that the chemical industry has a key role to play in a circular economy, and even more so, a sustainable society.

The study shows a variety of achievements where the chemical industry plays a decisive role, e.g. the major energy-savings achieved in private households with better insulation materials; the impact on fuel consumption and related emissions when using lightweight materials in the automotive industry; and the major progress associated with food packaging to avoid food waste and the associated economic and environmental impacts.

While arguably the continuation on the path of more efficiency is "business as usual" for our industry, the report also touches on some core elements of a circular economy where assumptions may be bolder and investments more uncertain. The study describes a number of approaches for (re)using resources in an efficient and sustainable manner. This ranges from the use of renewable feedstock all the way to waste-to-energy recovery and CO_2 utilization. All these models require access to affordable and low emissions energy and have an impact on existing infrastructures with significant investments.

The economy will gradually become more circular when circular value chains become more competitive. It will be an evolutionary process, involving all players, in which practical solutions will survive if they bring benefits for consumers and are viable and profitable for businesses as well as being more sustainable. To support this process, policies should focus on innovations that reduce the cost of reusing (raw) materials and recovering waste, and which improve the longevity, durability and performance of products, based on a full life-cycle approach.

The study serves as a valuable source for today's discussion in Europe and beyond. It provides encouragement to the chemical industry through the opportunities offered by circular economy and it reminds yet again that such a circular world will only be a gain for society as a whole, if everyone contributes to this story.

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EXECUTIVE SUMMARY

Today, European businesses are increasingly interested in the circular economy, and the chemical industry is likely to play a central role in the evolution towards such an economy.

Recent Accenture research points to two approaches the industry can take in order to transform to a more circular, sustainable model—developing technology and business models to circulate molecules, and enabling the circular economy in downstream industries.

Circulating molecules refers to various practices that rely primarily on the recycling and reuse of chemical industry products and materials. It encompasses five archetypal recirculating loops and Accenture believes that through these loops, up to 60 percent of the molecules provided by the European chemical industry to its customers could be recirculated.[1]

For the chemical industry, making the transition to a more circular economy will have its challenges. From a practical point of view, circulating molecules faces constraints, especially in regard to achieving required performance properties or, alternatively, to finding secondary uses.

Some of the loops will require large amounts of climate-neutral energy so as to not offset the positive impact of the circulating molecules on the carbon balance. Further, the loops will require large investments in infrastructure across Europe—not only in the chemical industry, but in other asset intensive industries as well. Assuming that 20 percent of the European chemical industry's capital spending will be channeled into circular economy projects, it would take 35 to 60 years to build the required assets for molecule circulation. Closing the loops, therefore, cannot be the only path to a more sustainable use of finite resources.

The European chemical industry's products are used by virtually all other industries. It is therefore in a position to help customer industries, such as transportation, residential and commercial construction, and agriculture, to maximize the utility of the products they use. Indeed, with its extended impact across industries, the chemical industry could help reduce overall EU energy consumption by up to 37 percent, which would help meet the EU targets for reducing CO_2 emissions in the medium-term. This reduction potential is substantially greater than what may be saved within the chemical industry itself where—in oil equivalents—5 percent of the total EU energy needs are consumed as manufacturing energy and another 6 percent as feedstock for chemical products. The comparison implies that a more substantial contribution by the European chemical industry can be made through the downstream enablement for circularity and efficiency than through internal efficiency improvements.

Downstream enablement could complement numerous circular economy-related trends, resulting in a substantial demand growth potential. Accenture estimates that this growth potential could be 88 million tons (Mt) of basic chemicals, intermediates and chemicals for customers combined, on top of the generally projected trajectory. Assuming a more or less stable export/import ratio over the next 15 years, this translates into an incremental growth potential for the European chemical industry of similar magnitude.

> Furthermore, a shift in consumer mindsets and behaviors will be required. This does not mean less or no consumption; it means consuming in a different way and consuming different products and services designed for reuse.

By leveraging the circular economy approaches, the industry is likely to reap significant rewards—for itself and for Europe as a whole.

I. UNDERSTANDING THE CIRCULAR ECONOMY

Sustainability has become a vital part of many business strategies across industries, which has prompted growing interest in the circular economy.

It is clear that the drive towards a circular economy is likely to lead to significant change for European chemical companies. This report looks at how the industry might shift to that type of economy, what it will take to get there, and what it will mean for chemical companies. Accenture takes a holistic view that goes beyond individual factors and issues—such as CO_2 emissions, plastics recycling, bio-based chemicals or landfill policy—in order to create an integrated picture of the chemical industry in a circular economy.

Indeed, a holistic view is fundamental to understanding the circular economy, which is not simply focused on using less. Instead, the circular economy aims to keep products, components and materials at their highest utility and value at all times. It is restorative and regenerative, and ultimately does reduce resource consumption. But it is also a classic economy in the sense that all activities are aimed at generating an economic benefit. Thus, the circular economy creates incentives for market participants to contribute to a more sustainable approach to natural resources.

In essence, the circular economy seeks to replace today's linear, "take-make-dispose" approach to resources—where many materials are made into products, the products are used, and then the materials are thrown out. Ideally, in a circular economy, the materials are cycled constantly back through the value chain for reuse, resulting in less energy and resource consumption.

In some industries, elements of the circular economy are already at work. In Europe, for example, 73 percent of all glass bottles are now collected and recycled rather than thrown away.[2] And scrap steel makes up 50 percent of the ingredients used in new steel products.[3]

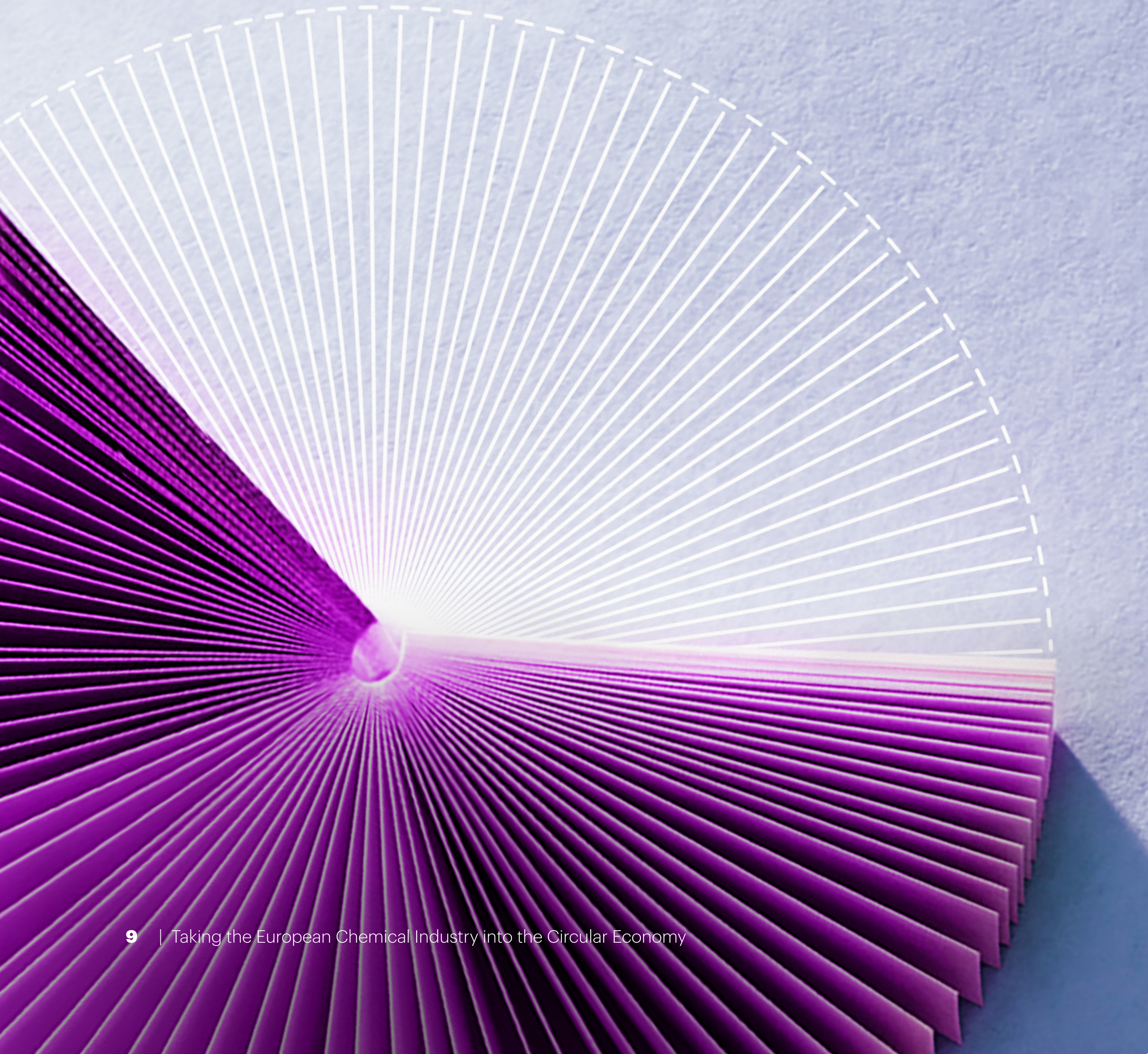
This reuse has helped to increase competitiveness in these industries by decreasing their dependence on virgin raw materials, such as iron ore, and by providing a more competitive raw material source. It is estimated that the steel industry saves up to 25 percent of production cost by using scrap steel—accounting for both raw material cost advantage and energy savings. A key difference, however, between glass and steel products versus chemical products is that chemical products require modification of the molecular bonds. This modification inherently changes the nature of the product itself, and is, therefore, more challenging and energy-intensive to pursue. Moreover, many of today's consumer products rely on mixtures of chemical-industry products, which can make it difficult to separate out specific chemicals when those products reach the end of their lifecycles.

To understand the impact that the circular economy could have on the European chemical industry, this study looks at the issue from two perspectives: **enabling the circular economy in downstream industries** and **circulating molecules to close the loop**. These perspectives will be discussed in detail below.

It is important to note three key assumptions underlying our analysis. First, that the chemical industry (and government) will be prepared to make the significant long-term investments needed in infrastructure and innovation to facilitate the circular economy. Second, that abundant climate-neutral energy—such as energy generated through renewable resources—will be available to drive increased circularity. Today, Europe at 88 EUR/megawatt hour (MWh) is at a disadvantage compared with regions like the US (64 EUR/MWh), the Middle East (40 EUR/MWh for Bahrain to 137 EUR/MWh for Iraq) and China (76 EUR/MWh).[4] And third, that these developments are pursued within a framework that aims to preserve the competitiveness of the European chemical industry. There is no guarantee that these assumptions will hold true in their entirety. Nevertheless, the research illustrates a number of ways forward, and underscores the tremendous potential that the circular economy has for the industry and for society as a whole.

II. THE CHEMICAL INDUSTRY IN EUROPE

The European chemical industry serves customers around the world, and it is known as a highly innovative sector. It has a significant positive economic impact across Europe.



For example, chemical companies employ approximately 1.2 million people in the EU—and the industry generates as much as three times that number in indirect jobs. Chemical companies invest heavily in the workforce, which is highly educated and well-trained—factors that contribute to labor productivity rising at an average annual rate of 2.3 percent between 2002 and 2014.[5] This trend has helped to make the European chemical sector a global leader in terms of productivity.

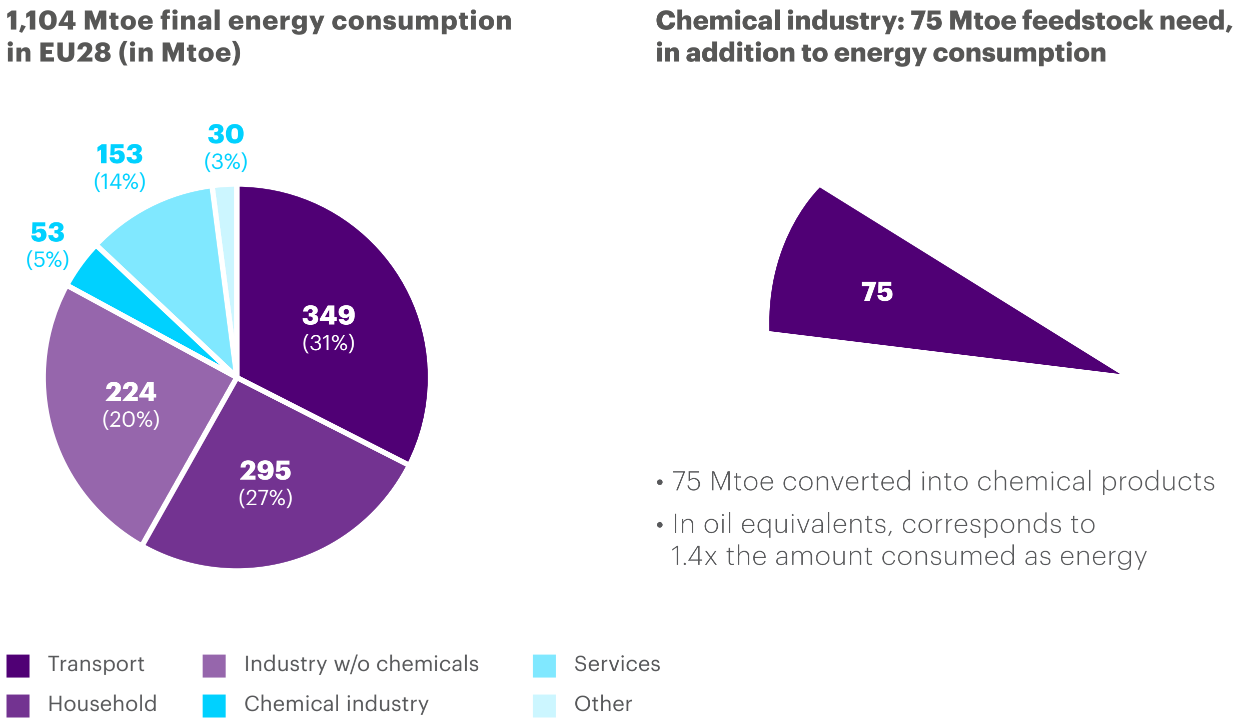
The European chemical industry accounts for EUR 20.7 billion per year in capital expenditures. It also invests heavily in innovation, spending EUR 9.1 billion per year on research and development,[6] as well as supporting innovation in its customer industries through the transfer of technology and know-how.

The industry's impact is also felt in other ways. Chemical companies transform energy and raw materials into products that are used by other industrial sectors, as well as by final consumers. Indeed, the chemical industry is a supplier to virtually every other industry in Europe, producing about 330 Mt of product per year.[7] Nearly two-thirds of this output is used by EU industrial companies. The largest industrial users of chemicals are the rubber and plastics, construction, pulp and paper, and automotive industries. Non-industrial chemical customers include companies in agriculture, services and other industries.

The chemical industry is closely linked to the EU's energy profile, and an emphasis on energy efficiency is key to chemical companies. The industry consumes approximately 5 percent or 53 million tonnes of oil equivalents (Mtoe) of the overall energy used in the EU. An additional 75 Mtoe (held in feedstocks) is converted into chemical products.[8] (See Figure 1) As those figures show, the industry converts more energy-equivalents into products than it consumes to make those products.

The European chemical industry has focused on reducing energy waste for decades. As part of the effort, it has integrated material flows and energy flows (exemplified by the Verbund production structures), and pursued a range of programs designed to increase energy efficiency. This work has borne fruit, with the industry cutting its energy intensity by almost half over 24 years. (See Figure 2)

Figure 1: Chemical industry energy usage



1,104 Mtoe final energy consumption in EU28 (in Mtoe)

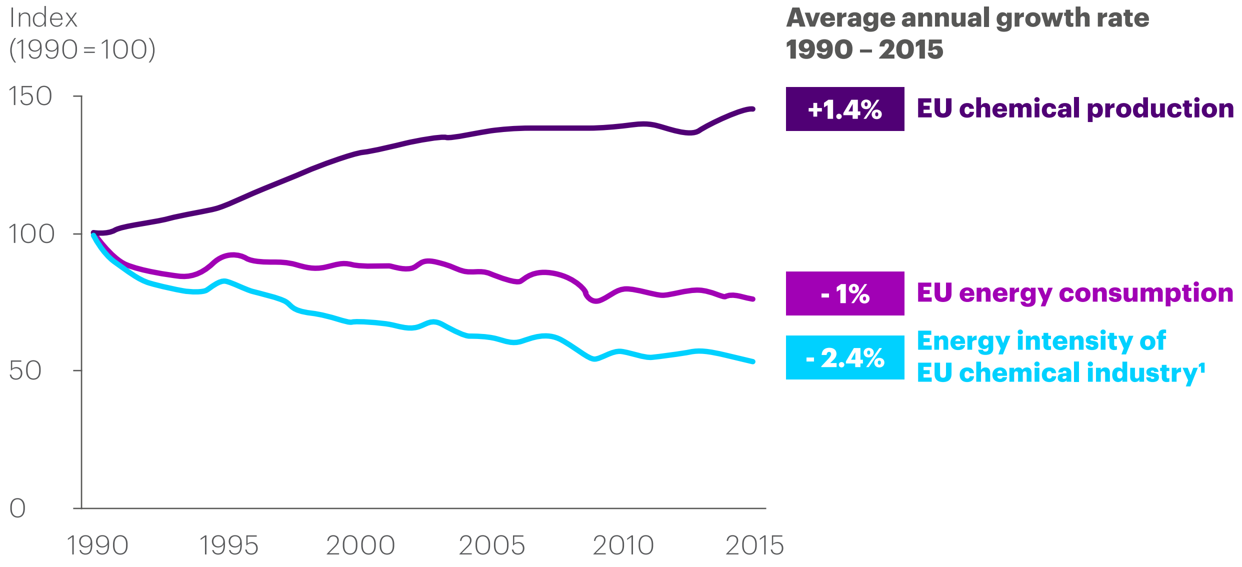
Chemical industry: 75 Mtoe feedstock need, in addition to energy consumption

- 75 Mtoe converted into chemical products
- In oil equivalents, corresponds to 1.4x the amount consumed as energy

Source: Consumption of Energy, Eurostat - Energy Balance, 2013; Accenture analysis

Figure 2: Energy conservation in the EU chemical industry

Energy intensity in the EU chemical industry: Index (1990 = 100)

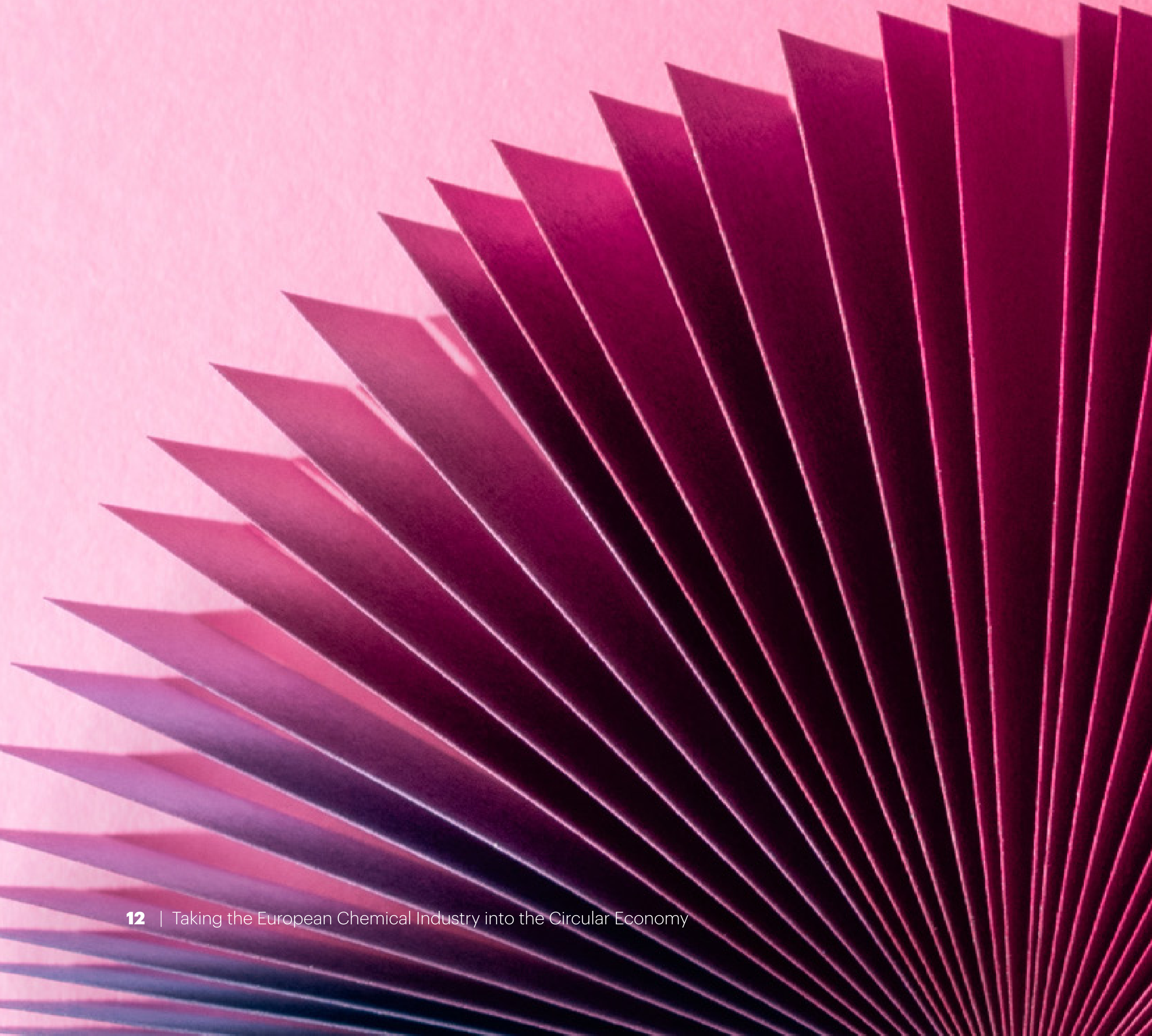


Source: Eurostat, Cefic analysis

[1] Energy intensity is measured by energy input per unit of chemicals production

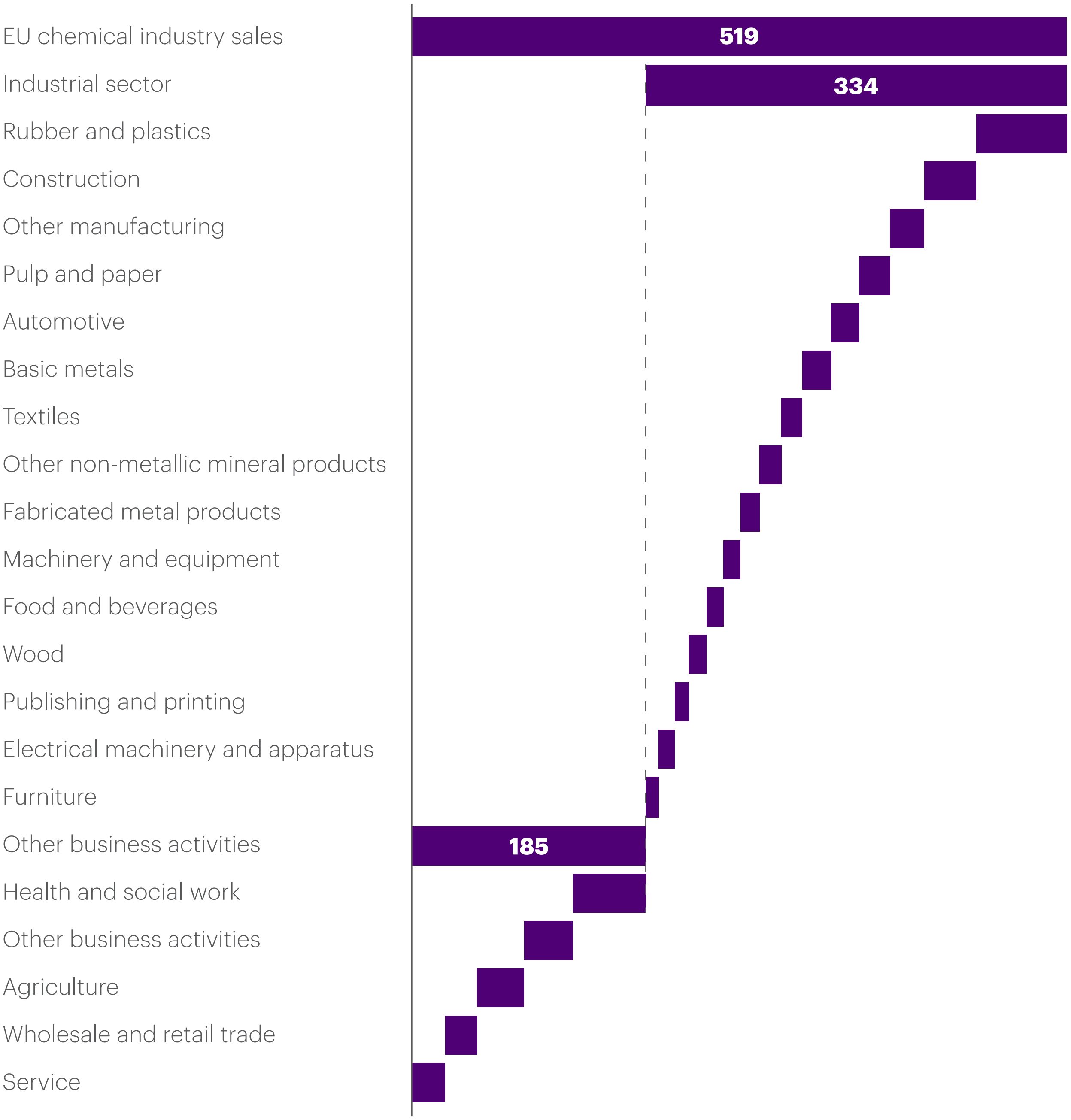
III. ENABLING EUROPE'S LARGER CIRCULAR ECONOMY

The chemical industry produces essential products and solutions that are used by all other industries, often in several steps throughout their value chains, as well as by end users.



As a supplier of products and solutions to a variety of customer industries, the chemical industry today enables greater durability and performance in many industrial and end-use applications. For example, it supplies insulation that reduces thermal energy loss in buildings, lightweight materials that reduce the weight of automobiles and coatings that protect materials—along with a multitude of lesser-known applications. (See Figure 3)

Figure 3: Downstream chemical industry customers, by sales in EUR billion



Source: Cefic Facts and Figures 2016

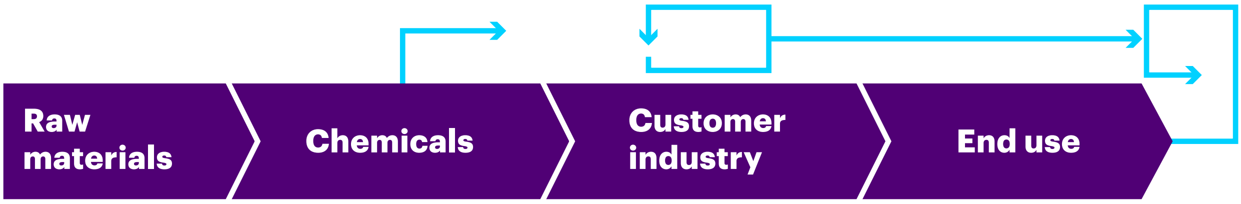
Over the years, EU industries have made a wide range of improvements in their traditional linear value chains, but major waste streams remain. With its contributions to circular models, however, the chemical industry could play a significant role in enabling downstream industries to reduce waste and enhance utility all along their value chains. (See Figure 4)

With its extended impact across industries, the chemical industry has the potential to address the lion's share of total EU energy consumption—which equates to 1,051 Mtoe that is currently used outside the chemical industry.

Within the European chemical industry, after many years of continuous improvement, energy intensity increased slightly in the post-2008 crisis years. Since 2013, however, energy intensity has been improving. While for some markets within the EU the further improvement potential of the chemical industry's energy efficiency is projected to be somewhat lower—e.g. for Germany[9]—a deviation with established thought patterns, such as the common three-year break-even period requirement for energy efficiency measures in chemical corporations, could sustain a higher per annum improvement trajectory over the next decade and beyond. In the context of driving the circular economy, policy makers could support this extended drive for efficiency by setting suitable incentives for prolonging the break-even requirements. Perpetuating a modeled 2 percent per annum energy intensity improvement from 2013/14 through 2030 would yield a reduction of the absolute chemical industry energy consumption from 53 to approximately 37 Mtoe, equalling 29 percent versus the current level.

This calculation is a simplification because it does not reflect a countereffect on energy needs from growing production volumes, which might come from downstream enablement.

Figure 4: Enabling circular models for downstream customers along the entire value chain



Enabling maximum utility in end usage
(e.g., higher durability of goods, making products suitable for sharing and increasing energy efficiency)

Source: Accenture

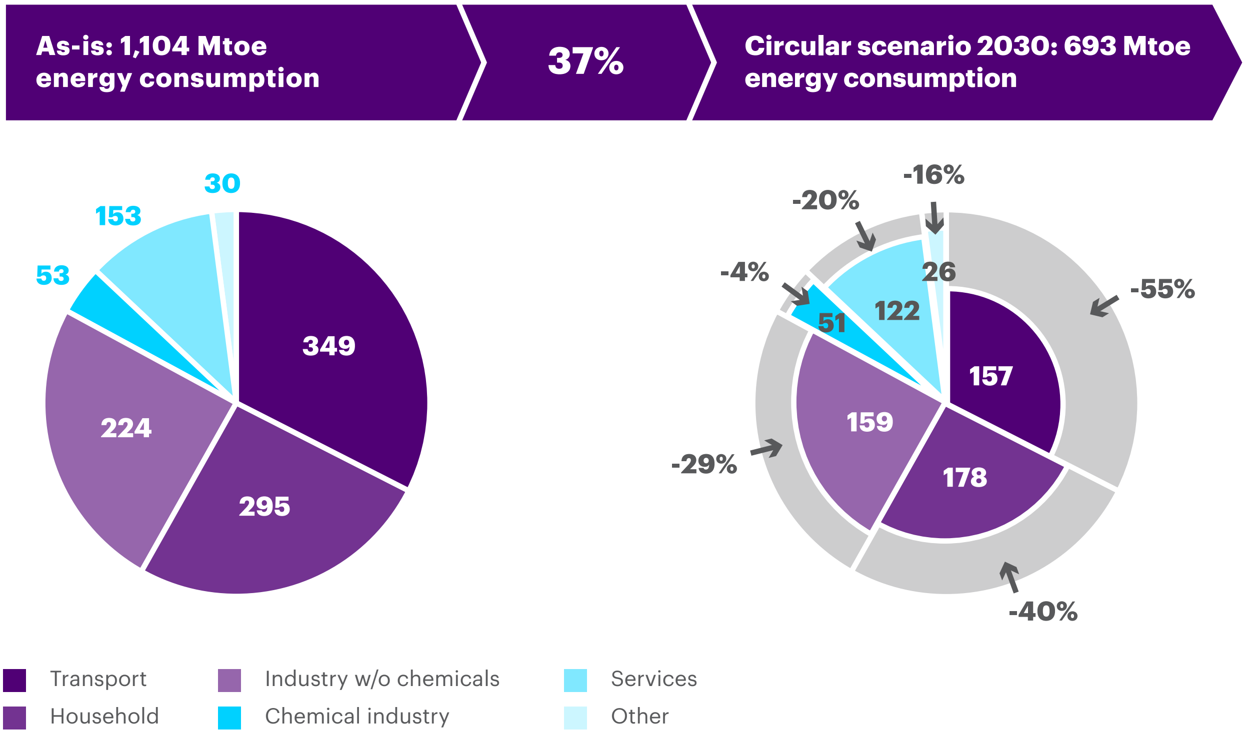
The enablement of circular economy models in end-uses and downstream industries represents a massive growth opportunity for the EU chemical industry. Enabling circularity and maximum utility of resources in downstream sectors increases the demand for chemical products. For example, reducing energy consumption in housing requires more insulation material, but it also requires more performance-enhancing chemicals, such as air sealants and special coatings. On an aggregated level, this implies volume and value growth for virtually all chemical segments—from standard chemicals to performance and specialty chemicals.

Accenture estimates that the total growth potential amounts to 88 Mt, which will be presented in detail further in this report. Assuming the above mentioned 2 percent per annum improvement of energy intensity, the total volume will require an energy input of 51 Mtoe, equalling a reduction of consumption by 4 percent versus the current level despite the volume growth.

The energy consumption that can potentially be reduced in other sectors—through enablement by the chemical industry—is approximately 20 times higher than what can be saved through further efficiency improvements within the chemical industry in a no-growth environment.[10] Overall, through downstream enablement the chemical industry could reduce EU energy consumption by up to 693 Mtoe—37 percent of the current consumption (See Figure 5).

Figure 5: Enabling downstream energy efficiency

Impact of 2030 circularity scenario on energy consumption (in Mtoe)



Source: Consumption of Energy, Eurostat - Energy Balance, 2013; Accenture analysis

The adoption of a more circular economy will lead to a shift in demand patterns. To understand the fundamental mechanisms driving this shift, it is useful to take an in-depth look at a number of sectors. Accenture examined two of the largest final energy-consuming sectors—transportation and private households—which together account for more than 50 percent of total energy demand in Europe. Agriculture and food, which is one of the lower energy-consumption sectors, was also analyzed.

Downstream enablement: mobility and transportation

Transportation accounts for 349 Mtoe, or 31 percent, of the total 1,104 Mtoe of energy consumed in the EU. Most of that goes to road transportation—285 Mtoe, or 82 percent of the transportation energy used. Passenger cars account for 182 Mtoe of that energy consumption, representing as much as 16.5 percent of total EU energy consumption.[11] There are approximately 250 million passenger cars in the EU.[12] In addition to using a significant amount of energy, they also create more than 400 Mt of CO_2 emissions per year.[13] (See Figure 6)

Currently, 20 percent of the mass of a typical passenger car is made up of chemical-industry products, an average of 252 kilograms (kg) per car.[14]

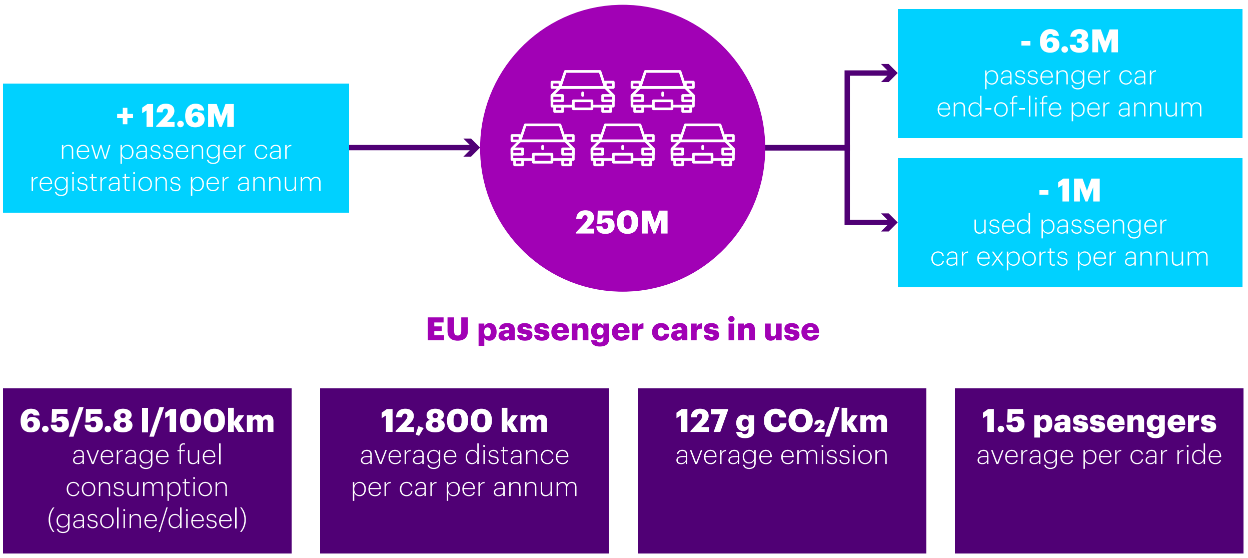
Figure 7 shows the main chemical product groups used in cars.

Circular economy topics are already having an impact on transportation for both environmental and economic reasons. These include requirements to reduce emissions; the increased adoption of car sharing, particularly in congested urban areas; the utilization of renewable materials and fuels; demand for greater efficiency; and the trend towards increased reusability and recyclability.

In the EU today, the average number of passengers per car ride is 1.5. The average car is driven 12,800 kilometers (km) per year, consumes 6.5 liters of gasoline per 100 km driven (5.8 liters for diesel), and emits 127 grams of CO_2 per km. Going forward, a shift in mobility patterns is expected, resulting in growing demand for zero-emission vehicles, longer vehicle life and higher lifetime mileage, and an increasing average number of passengers per car ride.

Evolving consumption patterns will inevitably require a change in product features—new engines and drive trains, lighter vehicles, greater durability, and easier assembly and disassembly. Consequently, this will require different materials: a generally higher chemical content in cars, with materials that offer better performance than today. Many chemical materials have superior material properties compared to conventional materials, for example, lower density resulting in reduced weight, higher intrinsic stiffness, more variety in forming technology that increases design freedom, and better resistance to wear and tear. In some scenarios, total demand may suffer, depending on which of the circularity themes will prevail. Regardless of the scenario, however, it is likely that there will be increasing demand for high-performance polymers and composite materials, as well as for specialty materials, such as those required for batteries and fuel cells.

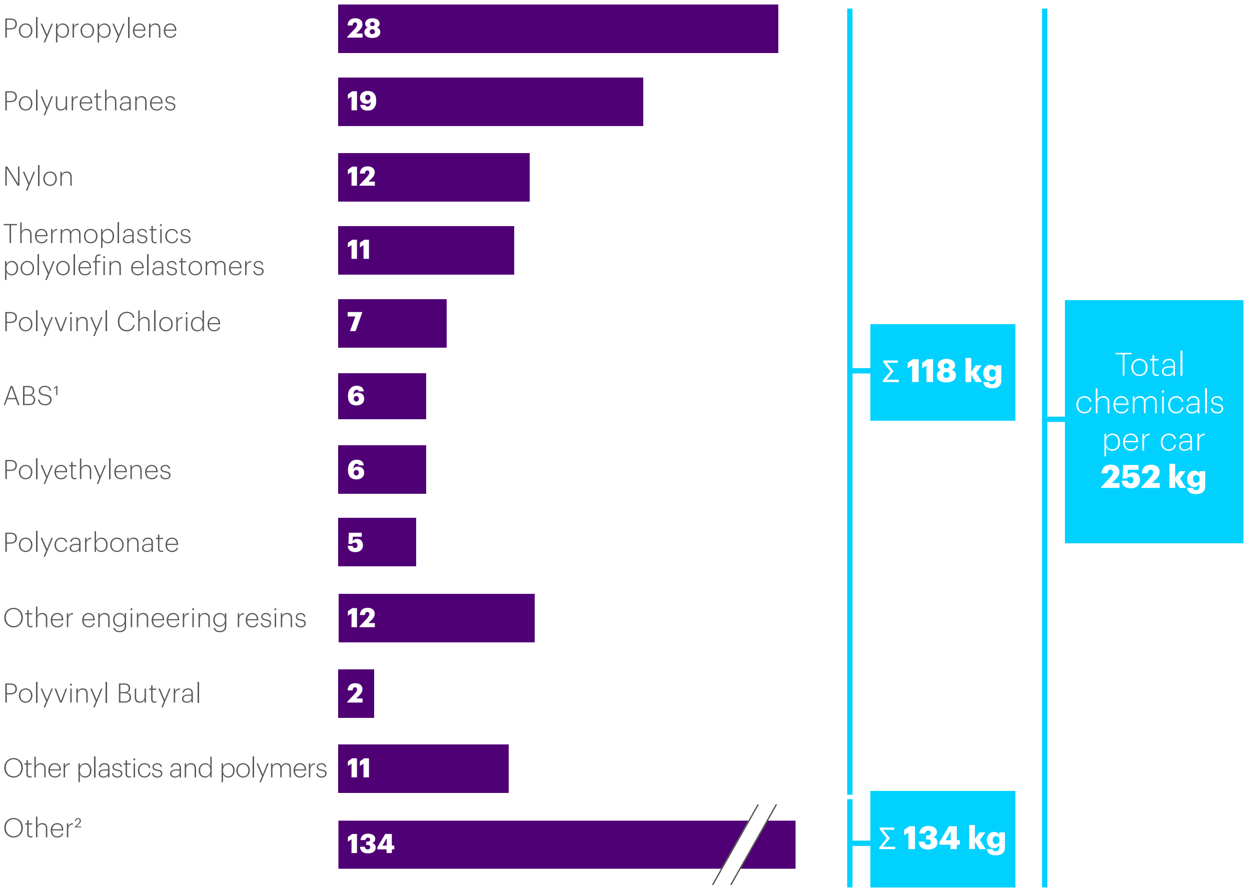
Figure 6: Key parameters of the EU passenger vehicle base



Source: ACEA, Eurostat, ICCT, Accenture analysis (2014 data)

Figure 7: Chemical industry products used in passenger vehicles

Plastics and polymer composites per light vehicle (in kg)



Source: American Chemistry Council; Accenture analysis (data adjusted for average EU car)

[1] ABS = Acrylnitrile-Butadiene-Styrene

[2] Rubber, Coatings, Fluids and Lubricants

Additional developments—such as telematics, increased kinetic energy recovery, autonomous driving, the connected car, and 3D spare parts printing—are expected to become more relevant in the near future—and those could also create demand for chemicals.

The role that the chemical industry could play in the transport industry can be seen by reviewing two circular economy-related trends for mobility:

Lower emissions: The European Commission has set a CO_2 emission target for new cars of 75 g CO_2 by year 2030,[15] which will require a reduction of average fuel consumption from 5.0 liters per 100 km to 3.0 liters per 100 km. Because fuel consumption is sensitive to car weight, the weight reduction will be an important factor in achieving the emission goal, along with an additional contribution from greater engine efficiency. Assuming that the entire targeted CO_2 emission reduction would have to come from weight reduction, the average weight of new cars will have to decrease from 1,390 kg to 1,075 kg, implying a need for lower density polymers and composites with comparable mechanical properties.

Shared mobility: In the emerging car-sharing business, vehicles are typically small and lightweight. Shared cars are used by a higher number of passengers per ride and driven for a longer distance over their lifecycle, compared to conventional owner-driven cars.[16, 17] For example, the top-selling car in the EU and Germany, the VW Golf, has an average model weight of 1,338 kg, while the second top-selling car in Germany, the VW Passat, has an average model weight of 1,571 kg.[18] Meanwhile, cars commonly used by new urban car-sharing providers—vehicles such as the Ford Fiesta at Flinkster, the Smart Fortwo at Car2Go, or the BMW Mini at DriveNow—have an average model weight of 1,077 kg, 880 kg and 1,242 kg, respectively. (See Figure 8)

Figure 8: Typically owned cars versus typically shared cars

Feature	#1 Seller Germany & EU	#2 Seller Germany	Car2Go	DriveNow	Flinkster
Model	VW Golf	VW Passat	Smart Fortwo	BMW Mini	Ford Fiesta
Weight	1,338 kg	1,571 kg	880 kg	1,242 kg	1,077 kg
Length	4,408 mm	4,772 mm	2,695 mm	3,913 mm	3,966 mm
#Cars	271,000	97,500	3,750	2,600	4,000

Source: Car2Go, Deutsche Bahn, DriveNow, Statista, Accenture analysis

Currently, the portion of new cars used for car sharing in the EU is below 1 percent.[19] If that were to increase to 25 percent by 2030, energy consumption would go down by 6 Mtoe, representing 0.5 percent of today's total EU energy consumption. Such a scenario, however, would result in a lower number of cars required to maintain the same supply of mobility in terms of passenger kilometers. Replacing 25 percent of conventional cars with shared cars would lead to a decrease in demand for new cars in the EU by 16 percent, to 12.5 M vehicles.[20,21]

The looming decline in the number of cars will have an impact on chemical demand. As discussed above, a typical car today contains approximately 250 kg of chemical content. Meanwhile, it is a likely scenario that the average chemical content in a car could increase from 20 percent today to 25 percent by 2030 as part of enabling mobility for circularity.

However, this increase in chemical share will not be enough to compensate for the potential reduction in the number of cars. Overall, the combination of higher chemical content and fewer cars in an advanced car-sharing scenario would result in a decline in demand for overall car-related chemicals volume by 18 percent, to 3.1 Mt per year. (See Figure 9)

Nevertheless, the chemical industry can contribute significantly to and benefit from this change by providing the high-performing materials that could be required. In addition, the industry could benefit from a shift from volume to value. For example, a car part made from unidirectional carbon fiber reinforced polymer (UD-CFRP), providing the same functionality as one made from steel, has a relative weight of only 25 percent of the steel part, but costs eight times as much.[22]

Figure 9: Impact of increased car sharing (scenario: 25 percent of passenger kilometers supplied with shared cars)

	New EU cars per annum			**Chemical content per car[2]**	**Total chemical volume (Mt per annum)**	
	Today	**Delta**	**2030**		**Today**	**2030**
Traditional cars	14.97 M	-3.75 M	11.22 M	252 kg	3.77	2.83
Shared cars	0.03 M	+1.29 M	1.29 M	194 kg	0	0.25
Total	15 M	-2.5 M	12.5 M		3.77	3.08
			(-16%)			(-18%)

Maintaining same mobility supply (pax x km)[1]

Source:
ACEA Pocket guide 2015-2016; American Chemistry Council; McKinsey Circular Economy Report; Accenture analysis

[1] For same mobility demand (pax x km), lower number of shared cars required, assuming increase of average pax per car from 1.5 to 2.5 and of average life time mileage from 230K to 400K km

[2] Assuming average car weight reduction from 1,300 to 800 kg, increase in total car life time from 9.7 to 11.8 years, and increase in chemical content per car from 20% to 25%

As the diverging effects of lower emissions and shared mobility show, the impact on chemicals demand is complex and difficult to predict with precision, as there will be a combination of evolving favorable and detrimental factors in play. Sensitivity analysis shows that the increase of chemical content in a passenger car—which currently stands at 20 percent—can significantly drive demand for chemical materials. (See Figure 10) Conversely, weight reduction would result in a significant drop in demand.

In order for the European chemical industry to benefit from the upside potential, it will have to enter into new business models and closely co-innovate with partners across value chain steps through to the car original equipment manufacturers (OEMs).

Downstream enablement: residential housing

An analysis of the European construction industry shows that it accounts for nearly 60 Mt of CO_2 emissions and approximately 820 Mt of waste generation per year.[23]

However, only 18 percent of primary energy consumption occurs during the construction phase, compared to 82 percent during the use phase.[24] Thus, the biggest lever for energy savings in residential and commercial buildings is the prevention of thermal heat loss—a fact that has been widely recognized for some time.

Figure 10: Sensitivity analysis for automotive-related chemical demand

Input factor	Change in input factor by ...	...leads to % impact on automotive-related demand for chemicals
Chemical content per car (lightweight design)	1 p.p. (from 20 to 21%)	5%
	5 p.p. (from 20 to 25%)	26%
Mobility need (pax x km)	1%	1%
Share of all-electric new cars in EU	p.p. (from 1% to 2%)[1]	0.3%
Degree of car sharing adoption	1%	-0.7%
	5%	-3.7%
Lifetime of car	1 year extension of lifetime	-10%
Average car size	Avg. weight reduction from 1,300 to 1,200 kg	-8%
	Avg. weight reduction from 1,300 to 800 kg	-38%

Source: American Chemistry Council, Accenture analysis

[1] Basis: 15 million new cars per annum in EU today, 1,300 kg/car, 252 kg chemicals/car (20% of weight)

This is evident in an analysis of the mass and energy flows of EU residential buildings/private households, which shows that residential buildings account for 281 Mt of CO_2 emissions[25] and 202 Mtoe in energy loss per year.[26]

Circular economy concepts can be seen today in residential construction—both erection and usage—with the adoption of renewable materials, the drive for greater energy efficiency, the usage of recycled or remanufactured materials, and enhanced components.

Housing-sector consumption patterns are undergoing significant change, with a growing focus on energy-optimizing renovation, new construction using the passive house standard, and pressure to build new houses designed to last much longer than traditional houses. Evolving consumption patterns are leading to changing product requirements. For example, appliances are expected to consume less energy and to do so in a "smart," connected manner that helps optimize energy usage.

The sector is also feeling market pressure for more energy efficiency, increased durability of materials, and housing-related products that offer easier assembly and disassembly. This translates into changing material requirements and properties, with growing interest in materials for generating and storing electric or thermal energy, and higher insulation performance and greater durability. Take, for example, insulation materials. Many chemical insulation materials have superior (i.e., lower) thermal conductivity—such as phenolic foam (0.020 W/mK), polyisocyanurate/polyurethane foam (0.023-0.026 W/mK), expanded polystyrene (0.034-0.038 W/mK), extruded polystyrene (0.033-0.035 W/mK), compared to wood fiber, cellulose, wool or hemp (all approximately 0.038-0.040 W/mK)—yet are much more durable.[27]

In general, evolving housing consumption patterns are having a positive impact on demand for chemicals. Today, the chemical industry serves approximately 42 percent of the total EU insulation-materials market, corresponding to 98.5 million m^3 in chemical sales.[28] Further increases in the application of thermal insulation can be expected. In addition, the demand for more high-performing materials is highly likely.

Achieving a 1 percent reduction in overall EU energy consumption could require an increase in the percentage of housing that complies with the passive house energy standard from today's 1 percent of total floor space to 23 percent. If all new building construction and renovation from 2020 to 2030 were to meet that standard, overall energy consumption would decrease by 28 Mtoe. The European chemical industry can substantially contribute to achieving the passive house energy standard by providing:

- Higher-performance and more durable insulation materials for walls, roofs and pipes, such as expanded and extruded polystyrene (EPS and XPS), polyurethane (PUR) and polyethylene (PE).
- High-performance materials for air sealing, such as polyethylene and polypropylene (PE/PP), polyvinyl chloride (PVC), silicones, synthetic rubber and reflective coatings like titanium dioxide.
- High-performance window materials, such as plastic frames, warm edge spacers, gas fill between window panes, triple glazing and surface films.

Besides a lack of consistent and digestible information for home owners, capital is a key constraint when it comes to achieving the potential energy savings in housing, because renovations and new construction based on passive house standards can require large investments. Enabling housing for circularity will require dedicated public schemes to push the adoption of the passive house standard, such as ever-stricter thermal insulation acts, schemes to spur renovation rates, and supporting frame conditions to train and employ a sufficiently large number of craftspeople.

Downstream enablement: agriculture and food

The global population is growing, while additional arable land is essentially unavailable. This implies a looming need for greater efficiency in all areas of food production, including land, equipment, raw materials and labor.

The agricultural and food industry processes large amounts of energy and water, as well as chemical industry products, such as fertilizers and pesticides. This means that changes in the sector will have a multifaceted impact on society in general. (See Figure 11) Here, change is being driven by factors such as the increasing scrutiny and legislation focusing on fertilizers and pesticides, and the emergence of precision-farming technology—both of which are likely to reduce demand for chemicals.

Figure 11: Changing demand for chemicals in the agriculture and food industry

Circular economy theme	Natural fertilizer	Shared services for equipment	Precision farming	Usage of by-products	Digital farming	Service bundles
Shift in consumption pattern	▨ Organic farming	▨ Higher utilization rate	■ Less fertilizer usage	▨ Usage of former waste	▨ Digitization	■ More service contracts
Shift in product features	▨ Bio-based	▨ Smarter equipment		▨ Same quality & performance	▨ Better data quality	▨ One solution provider
Shift in materials	▨ Lower N,P,K content	▨ High performance materials	■ More specialty fertilizers	■ Recycled instead of virgin products	■ Specialty chemicals	■ System solutions
Shift in material properties		▨ Higher durability	■ Higher performance	■ Improved life-cycle assessment	■ Higher performance	
Shift in chemical demand pattern	▨ Less demand		■ Less demand, higher efficiency	▨ Chemicals for waste usage	▨ Less demand	▨ Broader product portfolio

■ High relevance for chemicals ▨ Minor relevance for chemicals

Source: Accenture

On the other hand, higher-performing packaging materials that reduce food waste and the rise of new business models—such as nutrient recovery from waste water—open up new opportunities. Advanced packaging could decrease food waste by more than 1.1 Mt (a 5 percent combined reduction in food loss on the retail and consumer levels)—and presents a EUR 555 million opportunity for the chemicals industry. (See Figure 12)

As a result, the outlook for chemical demand patterns is mixed, and should be further assessed in a differentiated fashion.

For chemical companies, one of the most promising circular-economy growth opportunities in the agriculture and food sector stems from the increasing use of packaging that reduces food waste. Losses can be minimized with advanced packaging solutions that protect food and increase its shelf life through, for example, breakage control, breathable packaging, temperature control, moisture control, oxygen control, ripening control and bacterial barriers. Sustainable packaging could also drive demand for chemicals.

Moving to downstream enablement

As the circular economy takes hold in downstream sectors, it could have a significant impact on the chemical industry in terms of volume and value. This could be driven by trends such as e-mobility and energy-saving housing, along with growing demand for increased durability and efficiency across industries.

Figure 12: The benefits of decreased food waste

Packaging Scenario 2030 [1]	Vegetables	Meat	Fruits
Weight of decreased food waste (Mt)	0.37	0.37	0.37
Consumer price of product (€/kg)	2.00[3]	9.00[3]	4.00[3]
Sales value of product (€)	740 M	3,330 M	1,480 M
Packaging materials	PE, PP, PET[4]	PE, PP, PVC, PET[5]	PE, PP, PET, EPS[4]
Packaging cost (€/kg food product)[2]	0.2	0.9	0.4
Packaging value (€)	74M	333M	148M

Source: Accenture analysis

[1] Exemplary scenario with equal distribution of packaging need among food categories

[2] Economic Research Service, USDA, 10% of total price spent due to packaging

[3] Price example

[4] NNZ - the packaging network (2016)

[5] Food and Agriculture Network of the United Nations (2016)

Higher-performance chemical products are likely to see significant demand increases, while more basic chemical products are likely to see less demand. This will stem from two factors: a shift towards higher-performing grades of same material types, and a substitution of individual basic chemicals with higher performing material classes. Examples include higher usage of lightweight composite materials, and coatings with higher performance (i.e., scratch resistance and more air sealing). It is likely that this will open up new opportunities for research and development, too.

According to Accenture's enablement modeling, the demand growth potential for chemical products could be as high as 26 percent in terms of volume, or 88 Mt (29 Mt of basic chemicals, 31 Mt of intermediate chemicals for further processing and 28 Mt final chemicals for customers).[29] As elaborated above, numerous circular economy-related trends—such as car sharing, adoption of e-mobility, increasing efficiency of industrial equipment, and additional insulation for preservation of thermal energy in buildings and industrial plants—might have a tremendous impact on the consumption patterns of chemical products, both positive and adverse.

What's more, this spike in demand comes with a portfolio shift to higher value chemicals. While the current production volumes of the European chemical industry have an average market value of 1,670 EUR per ton, the average unit value of the incremental demand is expected to be in the range of 1,750-1,800 EUR per ton, according to the Accenture circular economy enablement model.

Figure 13: Expected impact of circular economy-related trends on demand for chemical products until 2030

Product class	Demand driver	Current output	Impact on output until 2030	Demand change
Polymers	Carsharing E-mobility Housing insulation Pipe insulation	45 Mt	-1.5% +2% +30% +10%	-0.7 Mt +0.9 Mt +13.4 Mt +4.5 Mt
Specialties	Carsharing E-mobility Plant efficiency	28 Mt	+5% +23% +10%	+1.4 Mt +6.5 Mt +2.8 Mt
Fertilizer	Digital farming	17 Mt	-5%	-0.8 Mt
Others[1]	-	16 Mt	-	-
Total	**-**	**106 Mt**	**-**	**+28 Mt**

Source: Accenture analysis based on ICIS, Petrochemicals Europe, Knoema, The Essential Chemical Industry, Eurostat

[1] Include inter alia resins, rubbers, solvents

Due to the diversity of chemical products and their respective applications, the shifts in demand will be highly specific to each product-application combination. (See Figure 14) For example, in the auto industry, the trends toward smaller vehicles and car-sharing are likely to reduce demand for standard polymers, dyes and coatings. But the greater focus on durability and design for reuse is likely to increase demand for engineering polymers and specialty chemicals.

Accenture calculates that the increase in existing product volume of 88 Mt could result in an increase in value of EUR 150 billion. In addition, the shift to higher value grades of some material types could increase value by EUR 35 billion, and the shift to higher value material classes could lead to a EUR 26 billion increase. As a result, overall market value is expected to increase by more than EUR 200 billion.

Each chemical company might need to assess the potential impact of demand change on its own business. But in general, as downstream industries provide shifting demand, there will be a move from volume to value, with growth in specialty and high-performance products.

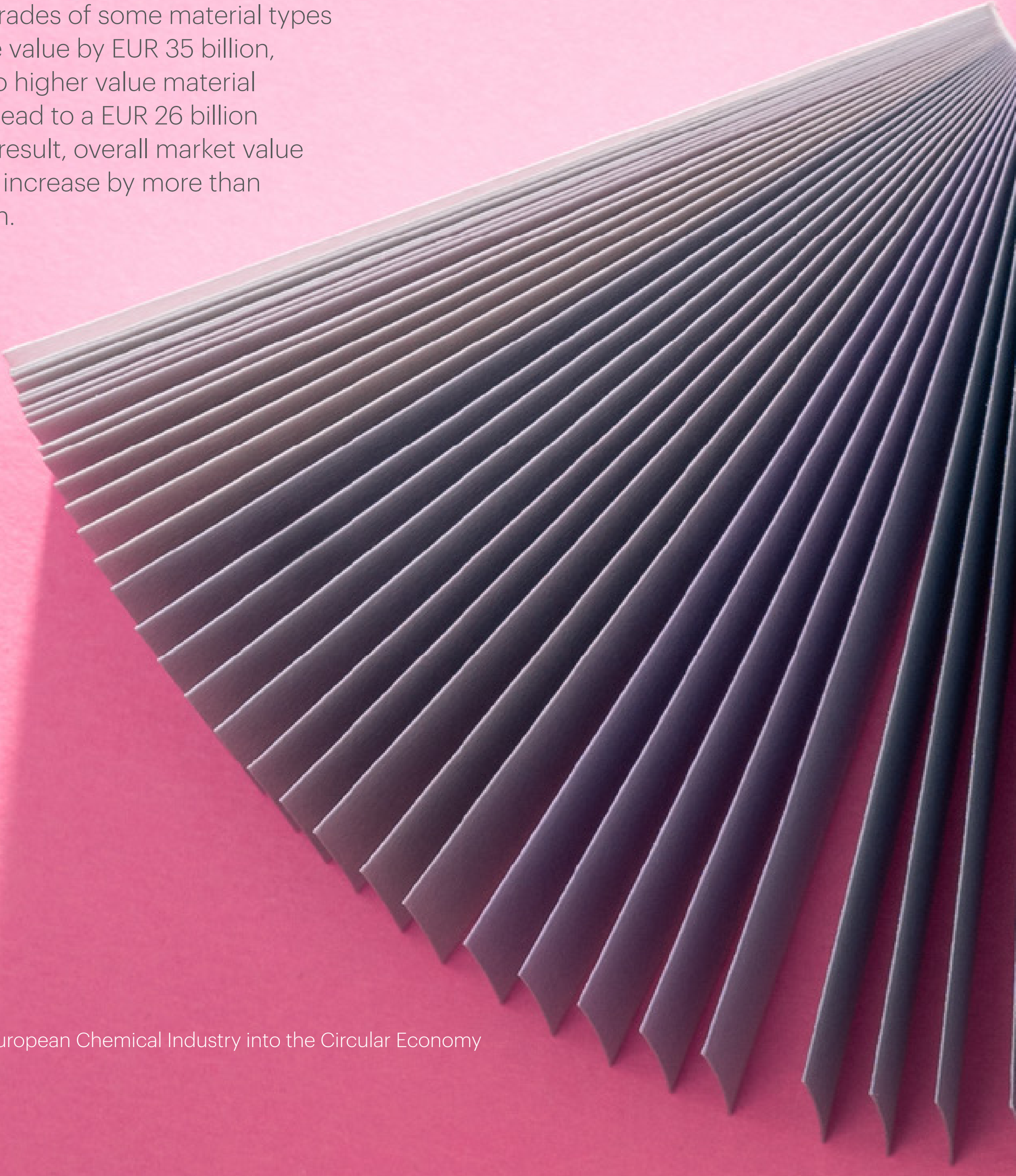
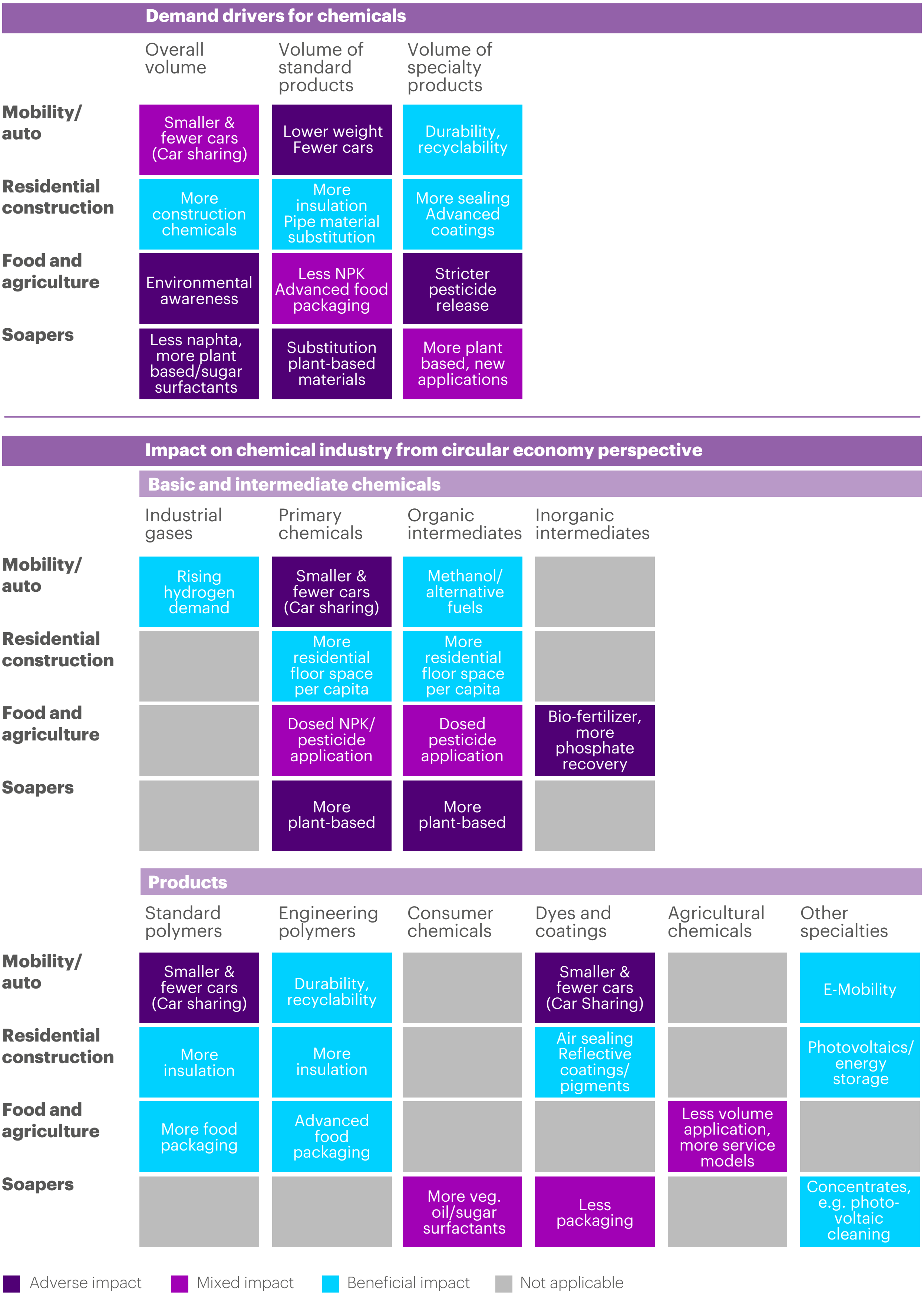


Figure 14: The circular economy's impact on chemical industry segments



Demand drivers for chemicals

	Overall volume	Volume of standard products	Volume of specialty products
Mobility/ auto	🟣 Smaller & fewer cars (Car sharing)	🟪 Lower weight Fewer cars	🟦 Durability, recyclability
Residential construction	🟦 More construction chemicals	🟦 More insulation Pipe material substitution	🟦 More sealing Advanced coatings
Food and agriculture	🟪 Environmental awareness	🟣 Less NPK Advanced food packaging	🟪 Stricter pesticide release
Soapers	🟪 Less naphta, more plant based/sugar surfactants	🟪 Substitution plant-based materials	🟣 More plant based, new applications

Impact on chemical industry from circular economy perspective

Basic and intermediate chemicals

	Industrial gases	Primary chemicals	Organic intermediates	Inorganic intermediates
Mobility/ auto	🟦 Rising hydrogen demand	🟪 Smaller & fewer cars (Car sharing)	🟦 Methanol/ alternative fuels	⬜
Residential construction	⬜	🟦 More residential floor space per capita	🟦 More residential floor space per capita	⬜
Food and agriculture	⬜	🟣 Dosed NPK/ pesticide application	🟣 Dosed pesticide application	🟪 Bio-fertilizer, more phosphate recovery
Soapers	⬜	🟪 More plant-based	🟪 More plant-based	⬜

Products

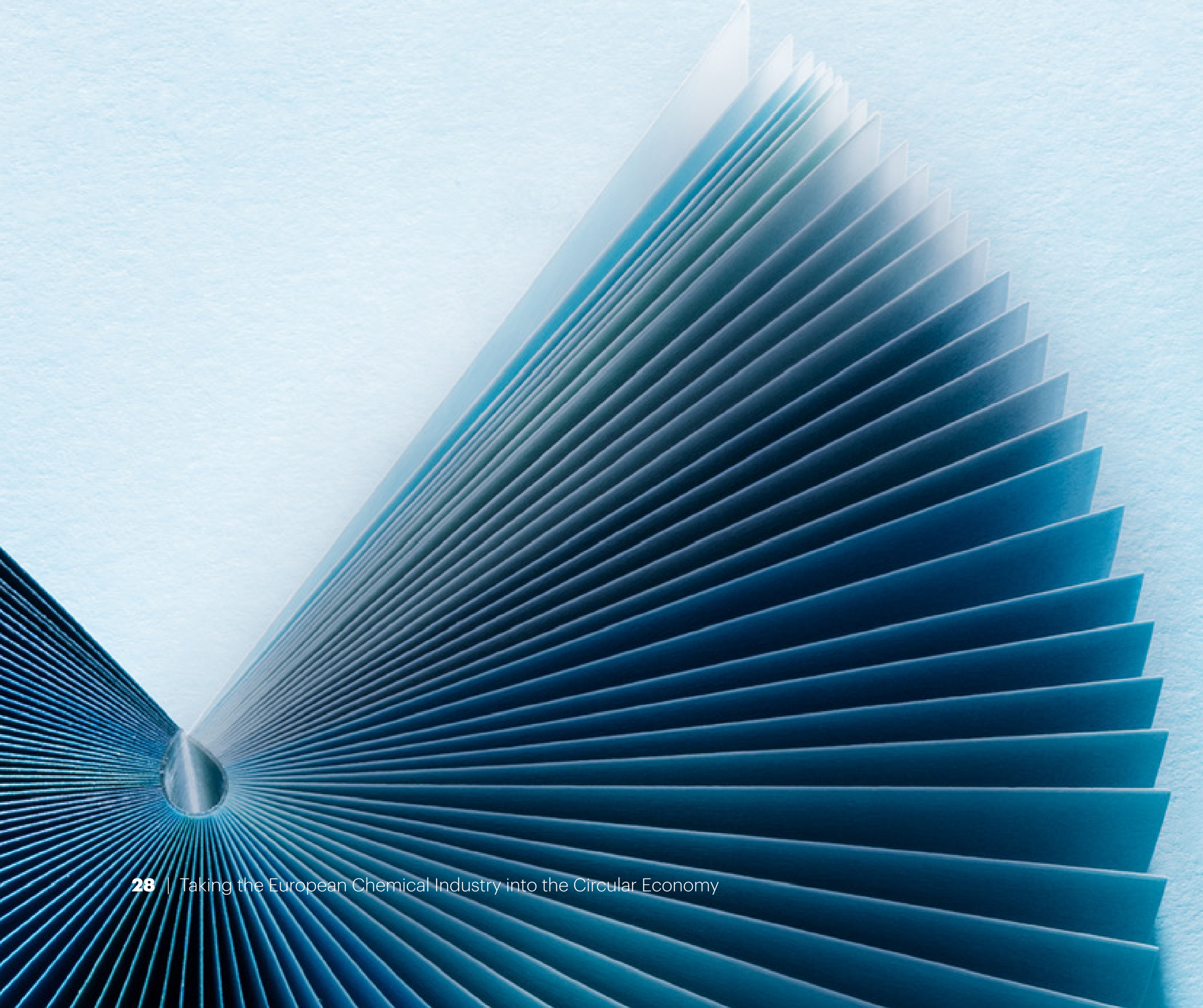
	Standard polymers	Engineering polymers	Consumer chemicals	Dyes and coatings	Agricultural chemicals	Other specialties
Mobility/ auto	🟪 Smaller & fewer cars (Car sharing)	🟦 Durability, recyclability	⬜	🟪 Smaller & fewer cars (Car Sharing)	⬜	🟦 E-Mobility
Residential construction	🟦 More insulation	🟦 More insulation	⬜	🟦 Air sealing Reflective coatings/ pigments	⬜	🟦 Photovoltaics/ energy storage
Food and agriculture	🟦 More food packaging	🟦 Advanced food packaging	⬜	⬜	🟣 Less volume application, more service models	⬜
Soapers	⬜	⬜	🟪 More veg. oil/sugar surfactants	🟣 Less packaging	⬜	🟦 Concentrates, e.g. photo-voltaic cleaning

🟪 Adverse impact 🟣 Mixed impact 🟦 Beneficial impact ⬜ Not applicable

Source: Accenture

IV. CIRCULATING MOLECULES: TAPPING INTO EXISTING MATERIALS

As the term suggests, circulating molecules means reusing existing molecules—in either the form of hydrocarbons contained in biomass or in the form of chemical material contained in end-consumer products.



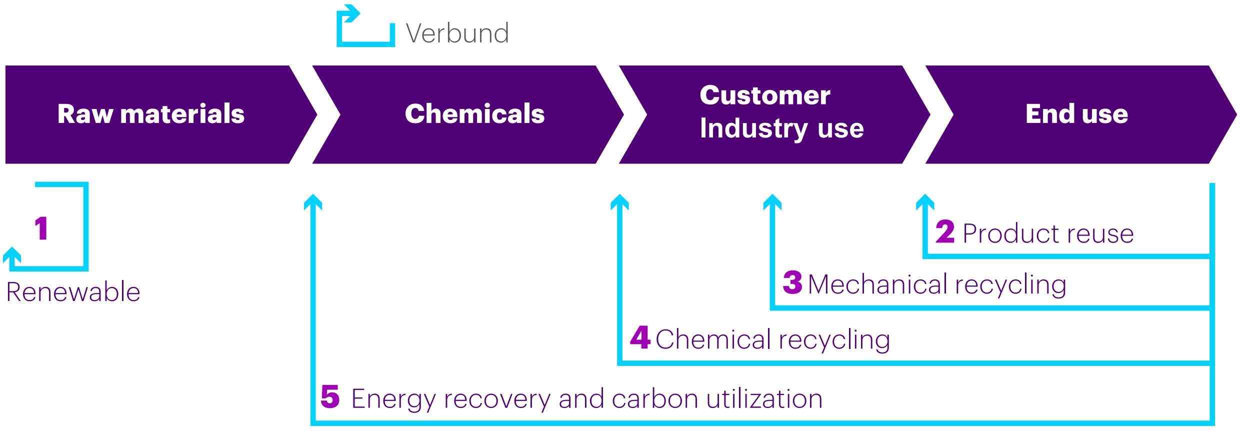
As more existing molecules are circulated, the less need there might be to produce chemical precursors from fossil-based raw materials. In an ambitious scenario, up to 60 percent of the molecules provided by the European chemical industry to its customers can be recirculated, assuming sufficient and cost-competitive energy is accessible, the necessary logistics infrastructure is in place, and abundant capital is available for the needed investments.

This level of recycling could be accomplished through the maximized use of five molecule-circulating loops in the industry: (See Figure 15)

- **Loop 1:** Circularity based on renewable feedstock
- **Loop 2:** Circularity based on increased reuse of products containing chemical-industry outputs
- **Loop 3:** Circularity based on molecule reuse (mechanical recycling)
- **Loop 4:** Circularity based on modification of molecules and reuse as precursors (chemical recycling)
- **Loop 5:** Circularity based on energy recovery and reuse of CO_2.

In order to assess the potential volume of each loop, Accenture built a value chain-oriented production model of the European chemical industry that integrates information from typical chemical synthesis pathways, production capacities and asset utilization rates of key chemical products and their market values.

Figure 15: Circulating molecules through five loops



Maximizing utility of existing molecules (e.g., reusing/recycling molecules such as PET bottles)

Source: Accenture

In this model, Accenture calculates that 92 Mt of feedstock is converted into 107 Mt of basic chemicals, which are converted into 117 Mt of intermediate chemicals, which are finally turned into 106 Mt of output chemicals for sale to customers.[30] Even though the same carbon atoms travel through this chain, volumes at each step differ for stoichiometric reasons. The production output of the European chemical industry is typically reported in aggregate numbers across those three steps, resulting in a total production volume of 330 Mt.[31] Accenture has then calculated the amount of current feedstock that could be replaced with renewable feedstock (Loop 1), and how much of the 106 Mt of chemical output at the end of the described chain could be looped back (Loops 2-5).

Each of these loops has its own requirements and challenges, and each could have a significant impact on the consumption of carbon-based raw materials.

Loop 1: Circularity based on renewable feedstock

The substitution of fossil fuel-based feedstock with renewable feedstock is not a new concept for the industry. Today, the European chemical industry uses 8 Mt of renewable feedstock (approximately 10 percent of the current fossil feedstock of 72.6 Mt). This includes 20 percent sugar and starch, 16 percent vegetable oils, 14 percent chemical pulp and 13 percent glycerol.[32] The conversion of biomass into chemical feedstock has a double benefit. First, because biomass is created through the natural process of photosynthesis, which captures carbon dioxide from the atmosphere and turns it into hydrocarbons, it avoids the addition of new carbon atoms into the system. And second, for some types of renewable feedstock it requires much less energy than the generation of fossil feedstock from naphtha or gas.

Geography and climate-wise, Europe is at a disadvantage with fewer sunshine hours and lower temperatures. The paper industry, for example, has migrated to other world regions for these reasons. To retain the competitiveness of the European chemical industry when re-thinking the raw materials loop, therefore, would require investments in new feedstock infrastructure and conversion assets in a globally competitive way.

There are a number of technologies available today for producing chemicals out of renewable feedstock. For example, fermentation is commonly used to produce alcohols from starch and sugar.

> Today, 90 percent of ethanol is produced through fermentation.[33]

By contrast, butanol is synthesized primarily from fossil feedstock.[34]

There are some examples of this in use, such as the conversion of sugar cane to ethanol, ethylene and polyethylene, currently used in a 200 Kt plant in the Triunfo Petrochemical Complex in Triunfo, Brazil.[35] Others include fermentation processes for vitamins; the conversion of palm oil to oleochemicals; or the production from renewable precursors via the bioseparation of 1,3-propanediol using a genetically modified strain of Escherichia coli.[36]

What's more, converting renewables for use as feedstock is not always a simple process. While generating basic materials for consumer products, such as ethanol, from biomass is technologically and economically viable, most renewable feedstocks do not have the atomic structure needed to easily provide the precursors required for industrial applications. Thus, further transformation of molecules is required, which in turn means that energy and material would be lost in the process.

In addition, it is important to recognize that there are practical limits to the amount of feedstock that can come from biomass sources. Relatively speaking, biomass is less energy intensive than oil or gas, so large amounts of raw material would be required. To replace the EU's entire chemical feedstock demand of 75 Mtoe and generate the industry's energy requirement of 53 Mtoe would require 315 Mt of biomass per year. Producing that amount of biomass would require the complete harvesting of about 266,600 km^2 of land—an area 10 percent larger than that of Romania (238,391 km^2). Looked at another way, it would require as much as 14 percent of the total area used for agriculture in the EU today.[37]

Thus, the raw-materials loop is not, in and of itself, a complete answer. Therefore, the industry will have to explore the other four molecule-circulation loops in conjunction with biomass.

Loop 2: Circularity based on increased reuse of products containing chemical industry outputs

A great many products, parts and components—from polyethylene terephthalate (PET) bottles and polyethylene (PE) cups to plastic shopping bags—are made of chemical industry products. Even though many of these products can be used multiple times, in practice they are often turned into waste after a single use. Of the EU waste streams from all economic sectors and households, 48 percent ends up in landfills, 46 percent of material is recycled in some way, 5 percent goes to energy recovery, and 1 percent is burned without energy recovery.[38] Thus, greater product reuse could have a significant impact in terms of reducing waste.

Based on extensive research and modeling, Accenture estimates that 17 Mt of molecules originating from the chemical industry could be circulated through product reuse. This would represent approximately 16 percent of the total 106 Mt of chemical products that the chemical industry is selling to its customers per year. This figure was determined by making ambitious assumptions about the amount of each of the top 50 produced chemicals that could potentially be reused, in terms of volume (see Research Methodology in the appendix).

The largest volume contributions would come from products based on different grades of polyethylene and polypropylene, as well as PET, polyurethanes, acrylic fibers and polystyrene. The reuse of chemicals also avoids the challenges of separating the molecules found in composite materials, such as polymer compounds, sandwiched materials or coated polymers.

Technologically proven reuse models, such as those involved in the reuse of PET, have been available for a long time. However, the value that is captured is still low,[39] and currently implemented reuse systems are relying on regulations and subsidy schemes. Reuse models beyond PET are conceivable, especially for products such as automotive parts, electronic product components and white goods. While still in their early stages of deployment, new systems for additional reuse of plastic packaging materials have already proven to be technologically viable and are on the market. These include, for example, methods for reusing product containers for cleaning agents, reusable plastic packaging instead of paper packaging in the retail supply chain, and the reuse of printer ink cartridges.

To reduce waste and maximize utility, all partners along the value chain could need to focus on "designing for reuse," enhancing the infrastructure for reverse logistics and investing in additional assets for material handling. Consumer behavior might have to be tackled through an integrated approach by producers of end-consumer products and the chemical industry.

Examples of such value chain cooperations are already in place today (e.g., returnable PET bottles or Tupperware® containers).

Government policies and industry-led agreements could play important roles in unlocking and advancing the potential of this loop.[40,41] Analysis of the EU final energy consumption shows that regulating and supporting the downstream usage (and enabling it with suitable chemical products) represents a greater energy savings lever than regulating recycling and/or the energy consumption of the chemical industry, by order of magnitude, as shown earlier in this report. Scaling up cross-value chain reuse models may benefit from a framework supporting the required upfront investments in R&D, assets and consumer awareness. In return, the design of goods for reuse could lead to a reduction in emission levels and waste generation, and might reduce the need to introduce additional fossil-based carbon atoms into the system.

Further expansion of the reuse loop would have a substantial impact on chemical industry business models. If chemical companies want to counter the potentially adverse impact of the reuse loop on production volumes in the conventional value chain, they will have to collaborate even more closely with companies that work directly with end-consumers. The ability to create products that are suitable for multiple reuse loops will depend on effective innovation partnerships, with the chemical industry contributing materials with advanced properties.

Loop 3: Circularity based on molecule reuse (mechanical recycling)

Mechanical recycling is the process of collecting and processing used end-products and then reinserting their intact molecules back into the value chain farther upstream without modifying their chemical bonds.

The molecule reuse circular model is already in practice, for instance for plastics. Across the EU, between 19 and 51 percent of overall plastic materials are recycled today,[42] depending on the country. The EU Commission is targeting a growth of plastics packaging recycling to 55% by year 2025.[43] However, the amount of chemical materials being mechanically recycled in any given country is largely driven through regulation, and economic viability in the absence of regulation has yet to be proven.

Two major waste streams—end-of-lifecycle automobiles and packaging—account for 68 percent of the total of approximately 26 Mt[44] of plastic waste generated annually in the EU. Given a current EU-average recycling ratio of 30 percent[45] and a technical recycling yield of 72 percent for plastics,[46] close to 6 Mt of plastics waste are currently looped back into the value chain. This amount corresponds to approximately a 5 Mtoe reduction in the virgin feedstock required.[47]

A key challenge to increased mechanical recycling is to have the appropriate collection and waste management systems in place. The European chemical industry has worked successfully to tailor chemical products for specific end-use requirements and to optimize the underlying resource requirement. Over the years, this has led to many innovations meeting the continuously increasing property requirements of products with the least amount of resources. One such product, for example, is a thin multilayer plastics packaging film that is used to protect food. Multilayer packaging material typically contains different polymer types which are more difficult to recycle at the end of product life. Without the use of appropriate compatibilizers or separation techniques, the recyclate from such mixed plastics would have inferior quality and lower value as a raw material compared to virgin plastics. With continued efforts in research and development, the recoverability and recyclability of those types of high performing and resource efficient plastic applications will further improve and enable a higher number of possible use cycles for the contained molecules.

While thermoplastics are often the focus of discussions around molecule reuse in the form of mechanical recycling, the principles are also applicable to other polymers, as well as to other raw materials. For example, rubber from end-of-lifecycle tires can be reduced to granular form and reprocessed into low-grade products. Molecule reuse can also be applied to materials that are becoming increasingly scarce. Phosphorus, for example, can be recovered from wastewater. It is a limited, non-renewable resource, and the EU relies on imports of phosphorus. Thus, there are strong incentives for recovery. Various technologies and approaches for phosphorus recovery have been explored, albeit not yet at industrial scale. There is a significant need and potential for further investigation and technology development on this front.

Combining all the technological potential for mechanical recycling, Accenture estimates that up to 19 Mt, or 18 percent, of the total chemicals output to customers of 106 Mt could be circulated into primary (like-for-like mechanical recycling) and to a larger share into secondary reuse. This would require an enhanced reverse-logistics infrastructure. In addition, the collecting, sorting, cleaning and re-processing of end of life products for the purpose of mechanical recycling would require 12 Mtoe of energy, according to Accenture calculations.[48,49,50] This is a significant amount, considering that overall industry energy consumption today stands at 53 Mtoe. It would erode a sizeable share of the projected virgin-feedstock saving benefit, unless large amounts of the required energy are generated from climate-neutral sources.

The increased circulation of molecules through mechanical recycling would have a number of important implications for business models, including:

- New cascades would be required for molecule reuse over multiple usage cycles—for example, going from high-value uses to medium-value uses, and ultimately to lower-value uses, such as in park-bench construction.
- Products have to be designed to be suitable for mechanical recycling.
- Closed-loop material and product models that aim to maintain type and grade purity of materials would become viable. This could be facilitated by maintaining product ownership at the producer level—for example, through the introduction of leasing models for products and materials.

Loop 4: Circularity based on modification of molecules and reuse of precursors (chemical recycling)

Breaking up long-chain hydrocarbons into precursors—the process of chemical recycling—presents more of a challenge than mechanical recycling. A range of technologies are available for chemical recycling, but the ability to perform the process at industrial scale is still a technological challenge—and currently not economically feasible.

There are two notable technologies for breaking up long-chain hydrocarbons—catalytic cracking and plasma gasification. Catalytic cracking uses a thermal reaction to break polymer chains into smaller molecules through catalyzation with a molecular sieve, such as zeolite.[51] Plasma gasification involves the thermal generation of syngas, which can be utilized as a direct energy source or as an educt to generate smaller molecules, such as methanol or diethyl ether. It can also be used to produce macromolecular petroleum products via Fischer-Tropsch synthesis.

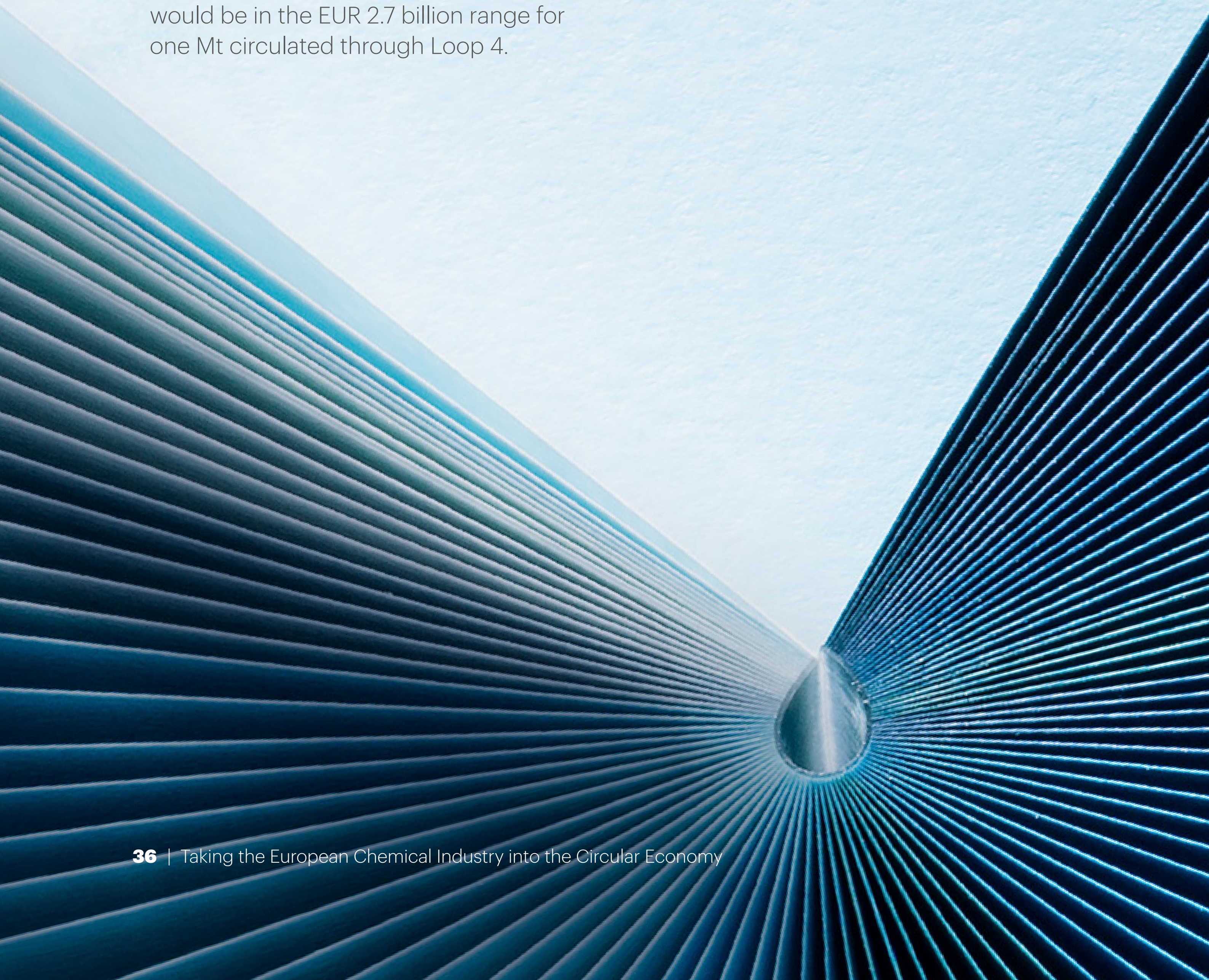
Both of these processes are complicated, as well as capital- and energy-intensive:

- There are no reference data points for commercial-scale gasification plants combined with Fischer-Tropsch synthesis processing for municipal solid waste. However, some cost-estimate numbers are publicly available for plants under development or small- and medium-sized pilot plants. They range from EUR 700 to 1,300 per Mt of waste processed (reference plants: Enerkem, AlterNRG, Plasco, Europlasma).[52]

This assumes that a Fischer-Tropsch synthesis reactor requires an additional capital investment of approximately 34 percent.[53] Given that municipal solid waste contains only 17 percent of waste products targeted for Loop 4 (plastics, rubber, synthetic textiles),[54] the required capital investment would soar to between EUR 4 billion to 8 billion per Mt of chemical output products circulated through this loop.

- The use of catalytic cracking of waste has been explored even less. A feasibility study for a large-scale plant in Malaysia projects that capital costs of EUR 450 million per Mt are required.[55] Assuming a similar share of targeted waste in municipal solid waste as mentioned above, the required capital investment would be in the EUR 2.7 billion range for one Mt circulated through Loop 4.

In the long run, however, this loop has the potential to circulate 8 Mt, or 8 percent of molecules, according to Accenture's calculations. If "thought to the end," chemical recycling might evolve into a new segment of the chemical industry, with a significant asset base. However, current assets producing precursors would become partially redundant as a consequence. In a low/no growth environment, there is limited need for new capacity. Therefore, existing assets would have to be substituted with new ones, which is difficult from an economic-viability and return-on-investment perspective.



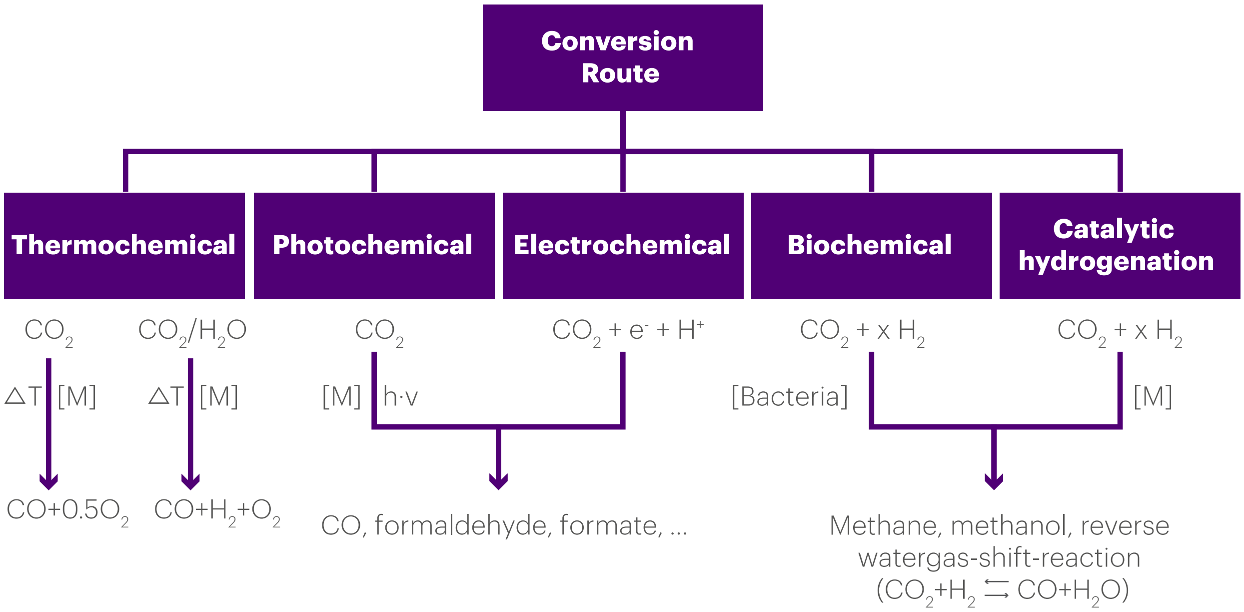
Loop 5: Circularity based on energy recovery and reuse of CO_2

This loop involves recovering the energy released by oxidizing hydrocarbons into carbon dioxide, typically through combustion of the hydrocarbons for energy recovery. After the CO_2 has been captured, it needs to be reduced with hydrogen. Hydrogen can be generated in a climate-neutral way[56] from natural gas by using, for example, plasma separation; or in a climate- and resource-neutral way[57] from water, via electrolysis.

While technologies to capture CO_2 from ambient air are available, it is much more efficient to capture it at a source of concentrated CO_2, such as a power plant or waste-combustion facility. There are a number of conversion routes available for reducing carbon dioxide with hydrogen. (See Figure 16) Once CO_2 is reduced, it can be utilized for building new chemical feedstock via catalytic reaction.

Accenture estimates that this loop could lead to the recirculation of 10 Mt, or 9 percent, of molecules. Even though most hydrocarbon-based chemicals could be fed into this loop, there are significant hurdles. First, carbon capture and utilization is probably the most difficult of all loops to master. It could require new assets for creating dense CO_2 sources (hotspots) and for re-synthesizing carbon into hydrocarbons. Second, this loop requires the establishment of reliable hydrogen supply at large scale. Through combustion, one ton of hydrocarbon creates 3.1 tons of CO_2 on average.[58]

Figure 16: Overview of CO_2 conversion routes



Source: G. Centi, S. Perathoner and G. Iaquaniello: Realizing Resource and Energy Efficiency in Chemical Industry by Using CO_2, Springer-Verlag, London 2013

The regeneration by hydrogenation back to hydrocarbons requires 0.6 tons of hydrogen.[59] Hence, for the assumed 10 Mt of molecule circulation through Loop 5, this would imply a hydrogen requirement of 6 Mt. For comparison, the current annual hydrogen demand in the EU stands at 7 Mt.[60] Third, carbon-neutral sources of energy must be used to generate the energy required for the hydrogen production, as the usage of energy generated with fossil fuel would more than offset the saved CO_2 emissions.

The chemical industry has demonstrated that it can close such loops. The generation of ammonia through the Haber-Bosch process that uses nitrogen and hydrogen from ambient air was developed a century ago, and it is still in use today. However, the technological challenges and immense capital and energy requirements are substantial. It should be noted, though, that energy recovery from waste generated today is an important option in substituting primary raw material consumption for energy generation in chemistry, even without CO_2 utilization.

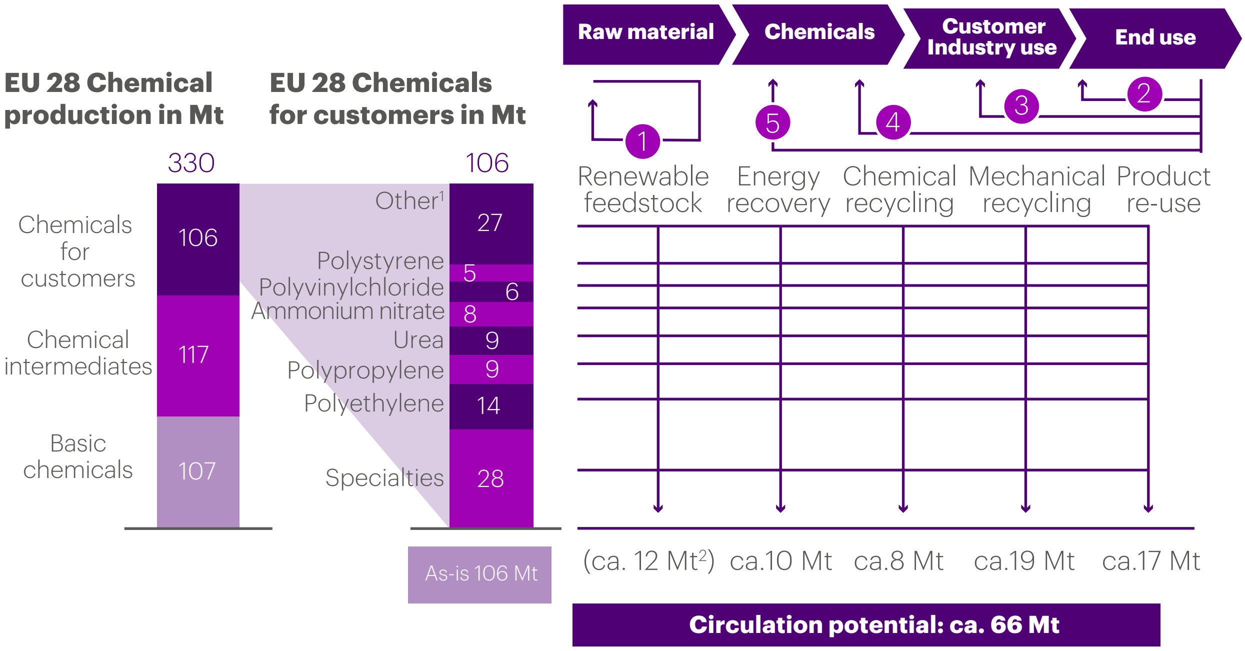
Moving ahead with the five loops

Altogether, these five molecule-circulating loops could have a tremendous impact on the industry, enabling it to recirculate approximately 66 Mt of chemical product molecules a year. (See Figure 17)

However, none of these loops is a "silver-bullet" solution. The chemical industry will probably need to draw on a mix of approaches, and the options may evolve over time.

Figure 17: The five loops' impact on the circulation of molecules

Out of 106 Mt chemicals delivered to customers, up to 60% can be circulated



Source: Accenture analysis

[1] 44 further products assessed, some with limited loop potential, e.g., non-recoverable materials such as nano particles, coatings, solvents.

[2] Loop 1 is fed with biomass rather than from chemicals for customers. Assuming that, after consideration of loops 2-5, ca. 50% of remaining feedstock need can be substituted from biomass. The estimated potential of 12 Mt feedstock substitution is an incremental volume on top of the 8 Mt of renewable feedstock already being utilized today.

While infrastructure for Loop 1 (renewable resources), Loop 2 (end-user reuse) and Loop 3 (mechanical recycling) is now in place to some extent, there is still room for further expansion of these methods through the use of new technologies, and for establishing sustainable economics that do not rely on regulations and subsidies. These loops provide a relatively accessible opportunity that could facilitate the reuse of approximately two-thirds of the total potential molecules that could be circulated. However, even though these loops are asset-light when compared to the more progressive loops, their adoption would imply a massive change to asset setup and business models.

Meanwhile, the technologies and processes for Loop 4 (chemical recycling) and Loop 5 (carbon utilization) are still far from mature, so significant investments and support are needed to develop these loops to technical maturity and economic viability. While development is taking place,[61] at this point these two loops are still fairly theoretical.

Continued effort is likely to be worthwhile, because the increased use of molecule-circulating loops could provide a range of benefits. For example, a greater emphasis on product reuse and mechanical recycling would require new products and solutions, intentionally designed for reuse. This would represent a massive development and growth opportunity for the industry.

These loops would also reduce the European chemical industry's dependence on naphtha and gas-based fossil feedstocks, with their volatile pricing. That would limit the amount of new carbon atoms being extracted from the earth and introduced into the atmosphere, and at the same time create a new source of European competitiveness against raw material-rich regions.

The need for industrial-scale chemical recycling and carbon utilization technology is a clear challenge, as discussed above.

> In order to enable the extensive circulation of molecules, EU chemical companies will have to make significant investments in creating and operating new circular-economy processes, with amounts varying by the loop in question.

For example, as noted above, Accenture believes that approximately 19 Mt of material a year could be processed through the mechanical-recycling loop in Europe, but doing so would require an investment into processing assets of as much as EUR 10 billion to 20 billion. This infrastructure investment includes the assets for granulating, washing and pelletizing chemical products, but excludes investments for the collection, transportation, warehousing and sorting required prior to processing.[62]

For a chemical-recycling loop that could handle 8 Mt a year, an investment as high as EUR 30 billion to 80 billion would be required. (See Figure 18)

In practice, the extensive circulation of molecules would require large amounts of climate-neutral energy. Accenture calculates that fueling the five loops would take 44 Mtoe of additional energy. However, the adoption of those circular practices would lead to reduced conventional chemical production and corresponding energy consumption, leaving a net incremental requirement of 21 Mtoe, or 244 terawatt hours (TWh) of energy per year. That amount of energy corresponds to approximately 19,000 standard offshore wind turbines with an average output of 28 gigawatts (GW), or 22 nuclear power stations with a respective rated capacity of 1,500 MWh each. For comparison, the installed wind power in the EU was 131 GW onshore plus 11 GW offshore, as of 2015.[63] In addition, a comparison of the energy required for circulation with the actual energy content of the products to be circulated suggests that—for Loop 5 in particular—energetic use is likely to make more sense from an economic point of view in the near- to medium-term, considering that the assumption of abundant renewable energy will most likely not materialize over the discussed time horizon until 2030.

Finally, the extensive reuse of molecules would mean smaller markets for fossil-based feedstock and basic chemicals. For example, if it eventually becomes possible to fully circulate thermoplastics, then there would be a substantially reduced need to produce monomers and polymers, rendering the associated assets and business models largely redundant.

Adopting circularity in the chemical industry could also require new business models, as well as changes in the industry's workforce profile. In general, fewer people might be required in production, while more might be required in logistics, marketing and technical applications. Overall, the total number of people employed in the industry will presumably be lower than today.

Figure 18: Circulation volume potential, investment and energy needs by molecule loop

Molecule loop	Volume (in Mt per annum)	Chemical assets investment needed (in EUR Bn)	Energy need (in Mtoe per annum)
1. Renewable raw materials	12	20-40	Insignificant
2. Product reuse	17	n/a	n/a
3. Mechanical recycling	19	10-20	12
4. Chemical recycling	8	30-80	3
5. Carbon utilization	10	100-140	29
Total	**66**	**160-280**	**44**

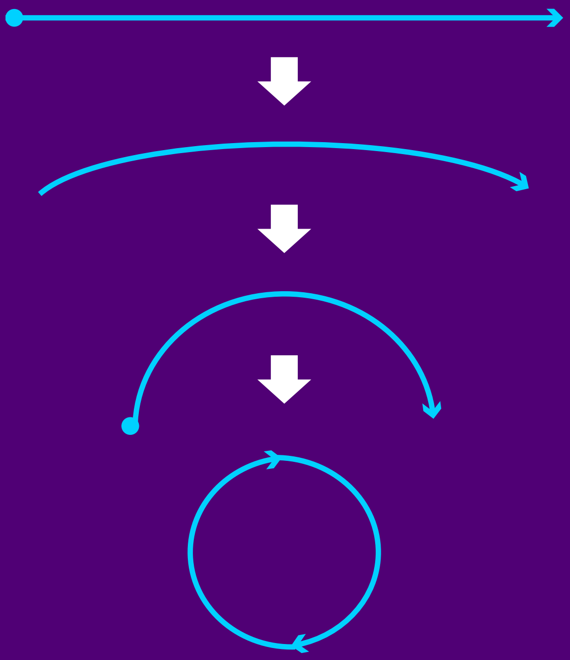
Source: Accenture analysis based on ICIS, Petrochemicals Europe, Knoema, The Essential Chemical Industry, Eurostat, USDA, Nexant, EIA, Plastics Europe, Plasticsinfo

V. TOWARD THE CIRCULAR ECONOMY

Moving into a circular economy will not happen overnight—the transformation will take time. Assuming that 20 percent of the European chemical industry's capital spending will be channeled into circular-economy projects, it would take 35 to 60 years to build the chemical circulating loops described above.

Chemical companies can take a gradual, incremental approach—starting, for example, by implementing one of the molecule-circulating loops. In a sense, they can "bend" the linear take-make-dispose model, working on the two ends—raw materials and increased recyclability of end-products—and continue moving forward until they have created a circular model. (See Figure 19)

Figure 19: Circular economy: A perspective thought through to the very end of ideal resource recovery



Linear Model
- Disposal of molecules at end of lifecycle (landfill, etc.)
- Unmanaged CO_2 emissions

Increasingly "bent" models
- Partially renewable feedstock and energy
- Some level of product reuse and recycling
- Energy recovery

Circular Model (total recovery)
- Full re-use of molecules—with or without modifications of molecular bonds
- Design to re-use for most end products
- Climate neutrality

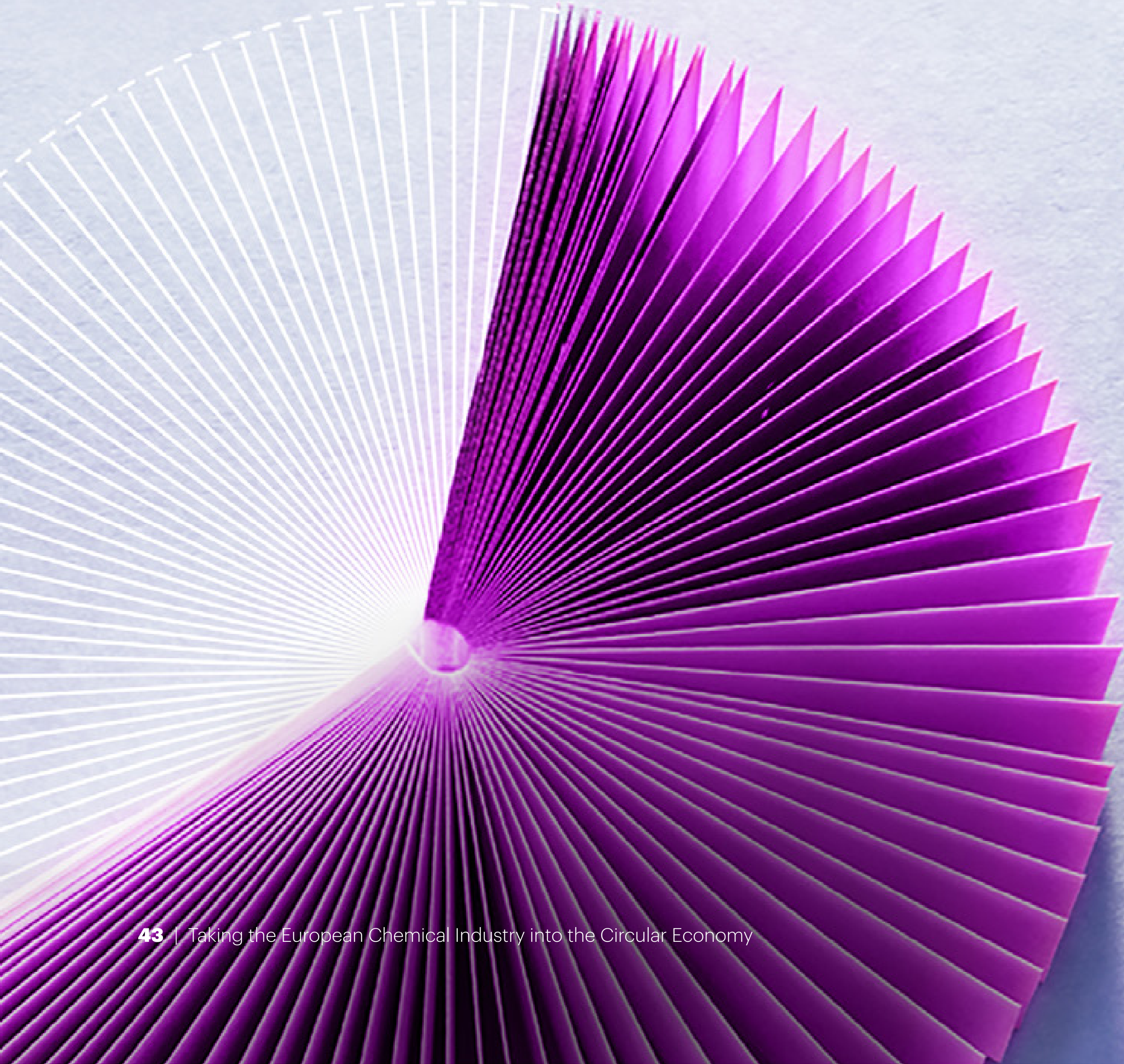
Source: Accenture

As the chemical industry moves to the circular economy, companies should be aware of a number of important implications. For example, the enablement of the circular economy in downstream sectors could drive a shift from volume to value in the long run. The circulation of molecules will require a whole new infrastructure of reverse logistics—far beyond what is available today with, for example, plastics recycling. The circular economy might open up new business-model opportunities, in areas such as chemical leasing and the control and management of molecule-circulating loops. As demand and profits shift to different products, companies will have to explore ways of moving into markets closer to the end customer, and to collaborate much more closely with OEMs in order to generate growth. That kind of shift is comparable to what can be observed, for example, in the steel industry, where some players have been migrating from steel milling to downstream applications, while others are now offering complete solutions, such as escalators and elevators.

Today, markets and policymakers are increasingly interested in making these changes—in moving away from the traditional high-consumption model to one that is more regenerative and that maximizes the utility of resources all along their lifecycles. As that trend continues, European chemical companies should recognize how it might change their world, and where they should focus their efforts to succeed in the circular economy.

VI. IMPLICATIONS FOR INDUSTRY AND SOCIETY

Moving toward a more circular economy will involve decisions about products and processes and, especially, about where to invest. Creating the infrastructure and capacity needed for the broad use of molecule-circling loops will require large capital expenditures.



In addition, a number of circulating-molecule technologies—such as the chemical recycling and carbon utilization loops—are not yet mature or feasible at industrial scale. Thus, society, policymakers and companies will also need to decide where and how much to invest in R&D and innovation.

Fostering the use of renewable resources is an encouraging way forward. However, stakeholders should also recognize that the chemical industry's feedstock requirements cannot be covered by renewables alone—not in Europe or globally, not today or tomorrow. A more realistic perspective, based on facts such as those in this study, will be important in developing effective strategic, economic and policy decisions.

As the provider of molecules for other sectors, the chemical industry will remain dependent on fossil resources in the future. But the industry can help its customers to significantly improve their fossil-fuel balance sheets. This could help enable a more climate-neutral society. Instead of focusing solely on the global reduction of CO_2 emissions—which is critical—it is possible that additional ways forward could be found in climate-neutral structures and schemes in value chains. Both concepts should be followed in parallel.

The circular economy will only take hold if it is economically feasible for stakeholders throughout the value chain. To a great extent, that means efforts should focus on the needs of consumers, the ultimate arbiters of what works and what does not. Regardless of how well designed a product is in terms of resource efficiency and circularity, it will not contribute to the emergence of a circular economy if people do not buy it. There is little evidence to suggest that most consumers place significant value on recyclability alone. Products will also have to continue meeting their needs in terms of cost, quality and utility.

With the need to contend with these issues of competitiveness, consumer/economic requirements and technical challenges, the chemical industry is not going to suddenly switch to circular economy models across the board. Getting there will take time, and the journey may never be fully complete.

The role of government and society

The chemical industry does not operate in a vacuum, of course, and the industry's efforts to move to the circular economy could have implications for government and society.

For example, the cost of circular-economy infrastructure is too large for the private sector to take on alone. Government, with an eye to the broader societal benefit, could explore its own investments in such infrastructure. Similarly, it can invest in research into circular-economy technologies. And it can focus on providing the infrastructure for more renewables-driven energy, which will be key to society realizing the full benefit of the circular economy.

Policymakers should work with a realistic view of the need to ensure the chemical industry's continued economic viability and competitiveness in a circular economy. To do so, they can focus policies on encouraging innovations that reduce the cost of reusing, recycling and recovering raw materials, and that improve the longevity, durability and performance of products. They can also formulate policies that support the use of new business models that will help companies thrive in a circular economy; that help the industry deal with legacy assets as demand for chemical products shifts; and that facilitate the development of new markets, which will help the industry succeed in the circular economy.

Government is also in a position to foster a better understanding across society of the importance of the circular economy, and what it might take to get there. It can provide realistic insights into what actions are most feasible, which ones present challenges, and the timeframes for moving ahead. The shift to a circular economy is likely to take decades—and governments can play a vital role in keeping stakeholders focused on key goals over the long term.

In any case, the chemical industry will be an important enabler for making progress in Europe. It has tremendous opportunity to develop circular processes, and through its extensive impact on downstream industries, to extend those processes to a broad section of society.

There are challenges, to be sure. But the chemical industry has a key asset it can draw on: a proven record of driving innovation to solve problems and open up new opportunities.

Finally, Europe is not an island. EU producers and products compete in global markets, and Europe is one of the largest importers and exporters of goods in the world. Therefore, the circular economy should be considered on a global scale. Optimizing just one region, such as Europe with its 500 million consumers, might not be enough to overcome the issues associated with a global "throw-away" society encompassing some seven billion people. But Europe can provide a vital starting point for the circular economy—at the regional, industry and individual levels.

RESEARCH METHODOLOGY

For the research, Accenture created:

- **Black box models of chemicals and customer industries' mass balance**
- **Three scenarios for pursuing the circular economy**
- **Energy consumption model**
- **Circulation model**
- **Enablement model**

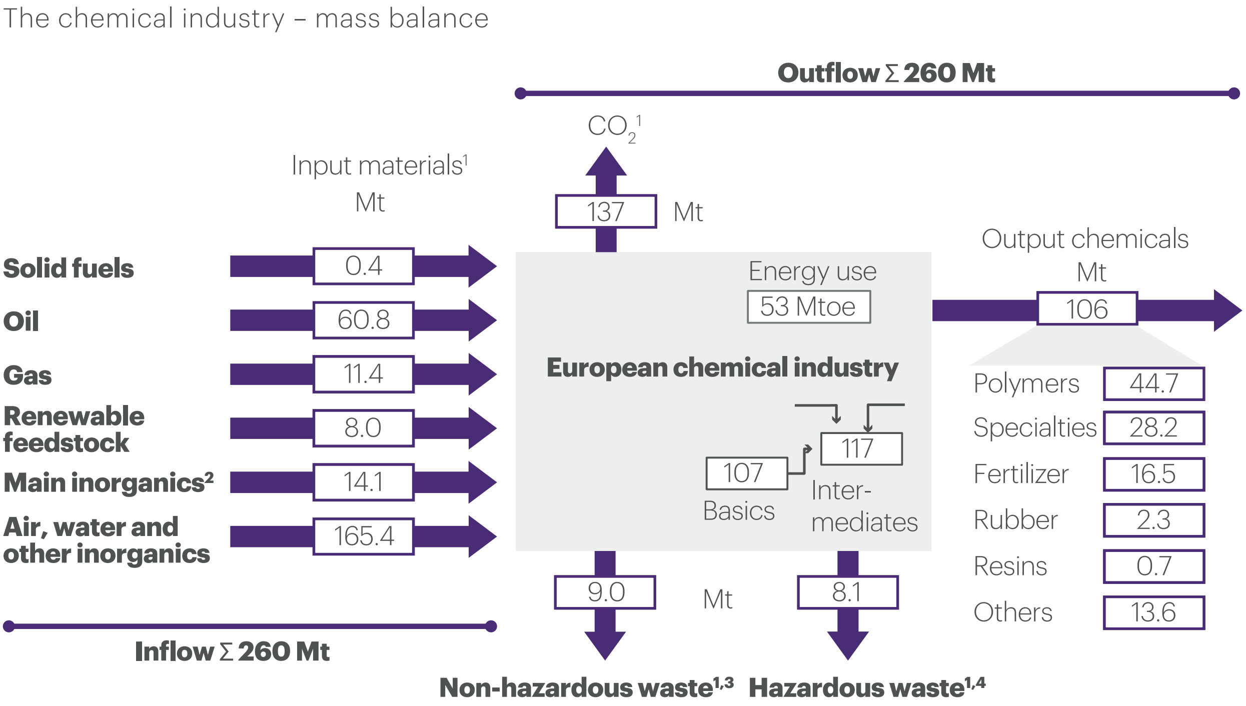
As-is baselines for these models were developed using historical data from a variety of sources, including scientific papers, working papers, government, organization/association reports, newspaper articles and websites.

Black box model for mass balance

As a base for this report, Accenture built a mass balance model for the European chemical industry to identify the most significant material flows. (See Figure 20) The main material inflows are oil, gas, main inorganics and "other." Of this, oil accounts for 60.8 Mt and gas accounts for 11.4 Mt. The main inorganics—which include soda ash, phosphate, potash, hydrogen and sulfur—account for 14.4 Mt. The "other" material stream accounts for 174 Mt and includes air, water, nitrogen, metals and other materials.

The main material outflows are CO_2, non-hazardous and hazardous waste and output chemicals. CO_2 accounts for 150 Mt; non-hazardous waste accounts for 9 Mt; and hazardous waste accounts for 8 Mt. Output chemicals for downstream customer industries account for 106 Mt, with the biggest sub-chemical groups being polymers (45 Mt), specialties (28 Mt) and fertilizer (17 Mt).

Figure 20: European chemical industry black box mass balance model



Source: Eurostat, European Pollutant Release and Transfer Register (E-PRTR), European Environment Agency (EEA)

[1] Data from year 2013

[2] Include soda ash, phosphate, potash, hydrogen and sulfur

[3] Non-hazardous waste split 5.5 Mt recovery and 3.5 Mt disposal

[4] Hazardous waste split 2.5 Mt recovery and 5.6 Mt disposal.

Three scenarios for pursuing the circular economy

The study differentiated between three scenarios: "continue as-is," "capitalize on opportunity" and "thought to the end." (See Figure 21)

In the "continue as-is" scenario, Accenture assumed no change in the chemical value chain. Improvements would be generated through incremental changes—for example, production optimization and energy improvements.

In the "capitalize on opportunity" scenario, Accenture assumed that in addition to the "continue as-is" scenario, there would be some enablement of the customer industries, such as helping the automotive industry produce light-weight cars or providing more effective insulation to the construction industry. Accenture also assumed the use of molecule circulation in the chemical industry, through Loop 2 (product reuse, in which product is used in same shape for same purpose, such as the reuse of PET bottles); and Loop 3 (mechanical recycling is the physical processing without modification of molecules, as in the re-processing of PET bottles).

In the "thought-to-the-end" scenario, Accenture assumed that in addition to actions involved in the previous two scenarios, the industry would further enable customer industries and molecule circulation within the chemical industry. The enablement of the auto industry would include, for example, support for e-cars and greater durability of car parts (involving growth in specialties and polymers). For the construction industry, it could include more durable insulation, such as plastic frames, glazing and surface films, and better insulation around water pipes, all for use in homes and office buildings.

Figure 21: Three circular-economy scenarios

	Key features of the scenario
"Continue as-is"	Continuation in predominantly linear model Further optimization of energy consumption
"Capitalize on opportunity"	Growth by enabling circular economy models in customer industries and end uses Limits to capital and energy: Circulating molecules by product re-use and mechanical recycling
Thought to the end	Growth by enabling circular economy models in customer industries and end uses Abundant capital and energy: Circulating molecules by chemical recycling and CO_2 reutilization

Source: Accenture

In terms of molecule circulation, this scenario assumes that in addition to Loops 2 and 3, the industry would apply Loop 4 (chemical recycling/partial [thermal] degradation of molecules to build monomers used as basic chemicals—for example, the gasification of PET into methanol); and Loop 5 (CO_2 reutilization, which involves complete thermal degradation of material—for example, the combustion of PET into CO_2)—and rehydration.

Energy consumption model

Accenture developed an energy consumption model that projects the evolution of energy requirement under the impact of chemical industry trends, such as a more sustainable method of production, as well as customer-industry trends, such as a movement towards more light-weight vehicles.

Energy consumption was modeled for six sectors: transportation, household, industry without chemical industry, chemical industry, services and "other." The baseline energy consumption for each sector was determined by Eurostat energy consumption data in the EU in 2013. Sectors were modeled with different numbers of variables each, ranging from three to 21, (See Figure 21) and models look at the three scenarios described above. (See Figure 22) The models used expected annual growth rates to project data out to 2030. Data sources included Eurostat, International Council on Clean Transportation (ICCT), Enerdata, Buildings Performance Institute Europe (BPIE) and others.

Transportation: The main assumptions to calculate the potential to reduce energy consumption are that fuel usage of new cars will decrease from 5.0 to 2.3 liters per 100 km, due to further engine efficiency improvements and the further reduction of car weight from an average 1,390 kg to 800 kg per car, supported by a growing trend for urban car sharing, which will come with a transition to smaller cars. Further, Accenture assumes that all cars currently registered, over time, will be replaced by cars meeting the emerging requirements such as lighter weight or the adoption of hybrid and e-car engine technology. In addition, it is assumed that the total car stock will decrease, again due to a consumption pattern change driven by a stronger adoption of car sharing, which also comes with a higher average number of passengers per car ride. For commercial vehicles, the main underlying assumptions are that weight will be reduced from an average 20,000 kg to 17,600 kg per vehicle, which results in a fuel reduction by 5.5 liters per 100 km. Overall, these developments are projected to result in a reduction of energy consumption from 349 to 157 Mtoe, equalling 55 percent.

Housing: The main assumption is that all residential floor space will either be converted into an energy standard of a maximum 100 kWh/ m^2a consumption, or will be replaced by new builds with an energy standard of a maximum 15 kWh/ m^2a consumption. Overall, this leads to a reduction of energy consumption from 295 to 178 Mtoe, equalling 40 percent.

Industry: The main assumption is that further optimization of production processes and equipment efficiency will lead to a reduction of energy consumption in industries without chemicals from 224 to 159 Mtoe and for the chemical industry from 53 to 37 Mtoe, in each case equaling 29 percent.

Figure 22: Variables for the transport sector and projection by scenario

Year	2013	2030 (annual growth rate)		
Transport	**As-is baseline**	**Continue as-is**	**Capitalize on opportunity**	**Thought to the end**
Total energy consumption (in ktoe)	349,000	0.0%	0.0%	0.0%
- Thereof car consumption (in ktoe)	182,000	0.0%	0.0%	0.0%
- Thereof commercial vehicle consumption (in ktoe)	103,000	0.0%	0.0%	0.0%
- Thereof aviation consumption (in ktoe)	49,000	1.0%	1.0%	-2.0%
- Thereof rail, water & pipeline consumption (in ktoe)	15,000	-0.1%	-0.3%	-1.0%
Car stock: Average fuel usage (liter/100km)	6.1	0.0%	0.0%	0.0%
New Cars: Average fuel usage (liter/100km)	5.0	-0.1%	-1.8%	-1.8%
Car: Average CO_2 emission (g/km)	152	0.0%	0.0%	0.0%
Car: km/year/vehicle	12,814	0.0%	0.05%	0.09%
Car stock	251,000,000	0.0%	0.0%	0.0%
New cars build per year	12,500,000	-1.5%	-1.58%	-1.66%
Car withdraw per year	12,500,000	-2.0%	-2.0%	2.0%
New car: vehicle weight (kg)	1,390	-0.3%	-1.5%	-3.2%
Commercial vehicles: Average fuel usage (liter/100km)	15	0.0%	0.0%	0.0%
New commercial vehicles: Average fuel usage (liter/100km)	12	-0.1%	-0.3%	-0.3%
Commercial vehicles: Average CO_2 emission (g/km)	376	0.0%	0.0%	0.0%
Commercial vehicles: km/year/vehicle	19,438	0.0%	0.0%	0.0%
Commercial vehicles stock	36,000,000	0.0%	0.0%	0.0%
New commercial vehicles per year	1,800,000	0.5%	0.0%	0.0%
Commercial vehicle withdraw per year	1,800,000	-0.9%	-0.9%	-0.9%
New commercial vehicle weight (kg)	20,000	0.0%	-0.2%	-0.76%

Source: Eurostat, ICCT, Accenture analysis

Services: This sector includes hotels, restaurants, office, government and institutional buildings, etc. Accenture assumes for these buildings a moderate renovation rate resulting in a reduction of energy consumption from 153 to 122 Mtoe, equalling 20 percent.

Others: This sector includes all remaining sectors, e.g., forestry and agriculture. Accenture assumes a conservative efficiency gain with a high level reduction of 16 percent, resulting in a reduction of energy consumption from 30 to 26 Mtoe.

For all sectors combined in the thought-to-the-end scenario, Accenture projects a potential for reduction of energy consumption from 1,104 to 693 Mtoe, equalling 37 percent.

Molecule circulation model

Accenture built a molecule circulation model to simulate chemical streams through Loops 1 to 5. The model looks at the 130 largest organic and inorganic chemical streams in the EU, measured in terms of capacity and adjusted for average asset utilization in order to compute production volumes. Accenture divided the chemicals into organic and inorganic chemicals, and then mapped the chemicals to their designated place in the value chain. The modeled value chain consists of four stages: feedstock, basic chemicals, intermediate chemicals and output chemicals. For illustration, this is depicted in a value chain tree. (See Figure 23)

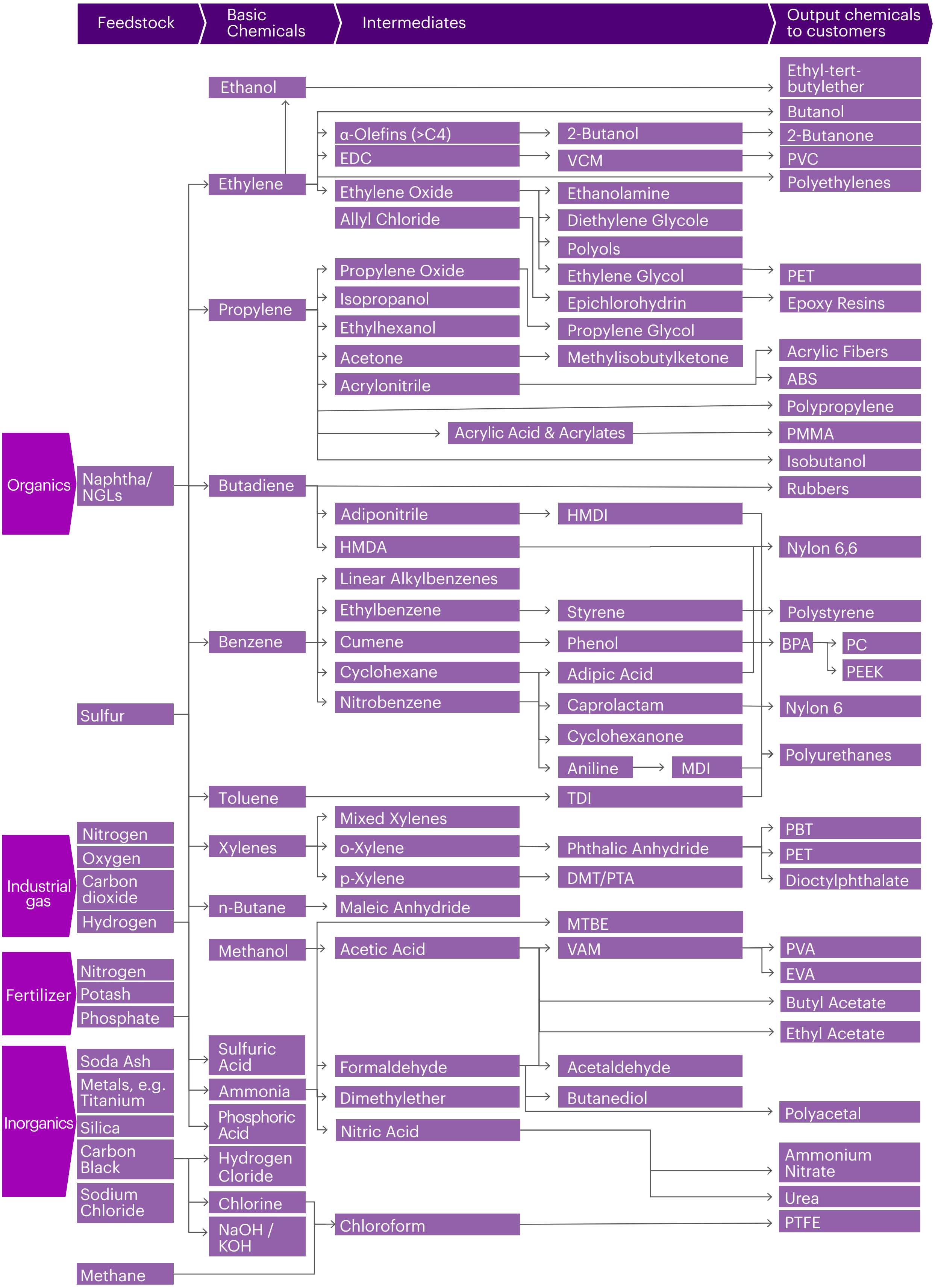
For this model, Accenture used a capacity-utilization rate of 81.5 percent, a rate determined by Cefic for the period 1999 to 2016. Chemical prices were based on the average in mid-August 2016. Using quantity and price, Accenture calculated the market value for each chemical.

The molecule circulation model looks at all chemicals mapped to the value chain as "output chemicals" that are circulated through Loops 2 through 5. Each loop has a distinct impact on the upstream chemical value chain. Loops 2 (product reuse) and 3 (mechanical recycling) reduce the need for intermediate chemicals, basic chemicals and feedstock, because these molecules are not modified in their bond structure and can thus be reused. Loops 4 (chemical recycling) and 5 (CO_2 reutilization) reduce the need for basic chemicals and feedstock, because molecules are modified in their bond structure and primarily get converted into a basic chemical.

In this model, Accenture clustered the output chemicals for downstream customer industries into the following groups: polymers, rubber, resins, fertilizer, specialties and "other." These groups have different circulation potential. For example, approximately 80 percent of polymers and rubbers can be circulated through Loops 2 through 5, where Loops 2 and 3 account for up to 60 percent of that amount. Because these materials are highly suitable for end-use, the technologies for Loops 2 and 3 are already in an industrial stage.

For fertilizers, 40 percent could be circulated through filtration of ground water near large agriculture areas (Loop 3, mechanical recycling). For specialties, that figure is 28 percent through Loop 2 and 5. Specialties are used to produce higher-quality products that tend to be more suitable for reuse, and through Loops 5, their molecules can be modified for reuse as a basic chemical. For resins and other chemicals, approximately 60 percent can be circulated through Loops 2 through 5, depending on the type of chemical and loop.

Figure 23: Molecule value chain tree



Source: Accenture

Loop 1 reduces the need for organic/fossil feedstock through the use of biomass. In the molecule circulation model, Accenture used the biomass ethanol route to calculate the reduced need for feedstock, because the ethanol route already involves highly industrialized biomass technologies.

Currently, 1.7 Mt of bio-ethanol is produced through renewable feedstock in the European chemical industry. This bio-ethanol can then be used to produce other chemicals in the downstream chemical value chain or to produce basic chemicals, such as ethylene. Accenture sees the potential for a shift to more renewable feedstock through 2030, projecting the fossil feedstock substitution by 17 percent.

The loops have different capital investment requirements and energy needs, and the maturity of available technologies varies across the loops. For example, Loop 3 (mechanical recycling) is already in industrial use, while Loop 5 (CO_2 reutilization) is still in pilot scale. For the purpose of this study, in extrapolating capital and energy needs, Accenture assumed that all loops are operating at the technology stage currently available. Further technological advancements towards industrial scale in the future may lead to a reduction of the projected energy and capital needs, particularly for Loops 4 and 5.

In the Accenture model, the looping volume per loop is directly linked to each technology, and capital and energy requirements are calculated accordingly. (See Figure 24)

Data sources for the model include the Independent Chemical Information Service (ICIS), Petrochemicals Europe, Renewable and Sustainable Energy Reviews, Knoema, Agrium, Platts, IHS Chemical Week and others.

Figure 24: Volume potential, energy and CAPEX needs per loops

	Looped chemicals in a full CE in Mt	**Energy needed in Mtoe**	**Energy needed in TWh**	**Capex in EUR p.a.**
Loop 1 Renewable raw materials	12	0.03	0.3	20-40
Loop 2 Reuse business case	17	Not applicable	Not applicable	Not applicable
Loop 3 Mechanical recycling business case	19	12	135	10-20
Loop 4 Chemical recycling business case	8	3	40	30-80
Loop 5 Energy recovery (CO2) though H2	10	29	334	100-140
Total	**66**	**44**	**509**	**160-280**

Source: Accenture analysis

Enablement model

The circular economy can lead to a transformation of chemical customer industries. Key trends in a circular economy that are closely linked to the chemical industry include car sharing, e-mobility, enhanced machinery and improved insulation, with themes ranging from efficiency to durability.

The volume and value of each scenario for the chemical industry was calculated by assessing reductions in demand as driven by molecule-circulating loops, and increases in demand from the enablement for circularity in downstream industries.

In the "capitalize on opportunity" scenario, the model takes into account Loops 2 and 3, and the increase of demand driven by the key industry trends and a shift to higher grades of various materials. The "thought-to-the-end" scenario takes into account Loops 1 through 5 and the increase of demand driven by a shift to higher grades of material, as well as higher value material classes. The model shows that there will be an overall decrease in the production of chemicals. However, the value per production unit increases due to the shift to higher value chemicals. (See Figure 25)

Figure 25: The impact of enabling downstream circularity and of circulating molecules

	As-is	**Enabling circularity**	**Circulating molecules**
Volume	330 Mt	+52 Mt +88 Mt	-99 Mt[1] -117 Mt[1]
Value	553 Bn EUR[2]	+127 Bn EUR +215 Bn EUR	-108 Bn EUR -122 Bn EUR
Value per unit	1,676 EUR/t	+103 EUR/t +164 EUR/t	+239 EUR/t +314 EUR/t
EU energy consumption w/o chemical industry	1,051 Mtoe	-146 Mtoe -409 Mtoe	-
EU energy consumption chemical industry	53 Mtoe	+6 Mtoe -2 Mtoe	-8 Mtoe +21 Mtoe
CAPEX	20.7 Bn EUR/ year	not assessed	30-60 Bn EUR 160-280 Bn EUR

🟪 Results for the capitalize on opportunity scenario ■ Results for the thought to the end scenario

Source: Accenture analysis

[1] Note that Eurostat reporting logic sums up production volumes of basic chemicals, intermediates and chemicals for customers to 330 Mt, which is not a mass balance as the same atoms are counted multiple times across the value chain. The volume numbers shown are the modeled sum across all value chain steps. Out of just the 106 Mt chemicals for customers, 54 Mt can be circulated through Loops 2 to 5 in the thought-to-the-end scenario.

Note: The values from the two circular economy aspects cannot be summed up as the absolute numbers of "circulating molecules" are, inter alia, a function of the volume of chemical products for customers and, therefore, dependent on the incremental volume from enabling downstream circularity. The numbers shown for "circulating molecules" assume zero incremental growth from enabling downstream circularity.

[2] Not the most recent available EU chemical industry revenue figure, in order for it to match with the time horizon for the available total production volume figure. For the most current value figure, please refer to Figure 3 that shows data from Cefic Facts & Figures 2016.

References

[1] The European chemical industry sells 87 Mt of organic products and 19 Mt of inorganic products to its customers (Accenture analysis based on sources Eurostat, ICIS, Petrochemicals Europe, Knoema, Agrium, The Essential Chemical Industry). This study, therefore, concentrates on the impact of carbon-based molecules and the products generated from them, while recognizing that there is also untapped potential in optimizing the inorganic loops of the economy

[2] FEVE – The European Container Glass Federation, 2016

[3] EUROFER – The European Steel Association, 2016

[4] All stated electricity prices are for industrial sector. EU electricity price is the average price from 2005 to 2015. US electricity price is the average price from 2006 to 2015. The Middle East region is defined by the following countries: Saudi Arabia, Kuwait, Iraq, Iran, Bahrain and Dubai and takes into account the electricity price for 2016. China's electricity price is from 2014. Sources: Eurostat, U.S. Energy Information Administration, and Climatescope.

[5] Cefic Facts and Figures 2016

[6] ibid

[7] Eurostat, 2012

[8] Eurostat - Energy Balance, 2013

[9] VCI-Prognos-Studie 2015/16. The projected YoY improvement of 1.5% includes pharmaceuticals. Excluding pharmaceuticals, the study projects an improvement trajectory for energy intensity by 1 percent per annum for Germany

[10] Eurostat - Energy Balance, 2013

[11] Eurostat - Energy Balance, 2013

[12] ICCT, European vehicle statistics, 2015

[13] ACEA, Eurostat, ICCT, Accenture analysis (2014 data)

[14] American Chemistry Council; Accenture analysis (data adjusted for average EU car). Note that chemical content differs from car to car and numerous figures are quoted. Based on Accenture's modeling, a total chemical content of 252 kg per passenger car was assumed for subsequent scenario analysis.

[15] Euractiv, 2030 CO_2 car targets in the EU, 2012

[16] Innovative Mobility Car Sharing Outlook – Berkley, 2015

[17] Car-sharing expands rapidly into new towns and communities, 2015

[18] Volkswagen

[19] Imperial College London, Car-sharing: Evolution, Challenges and Opportunities, 2014

[20] Conventional car is modeled with a weight of 1,390 kg, 230,000 km life time mileage, 1.5 average passengers per ride, and 19 weight-percent chemical content; shared car is modeled with a weight of 800 kg, 400,000 km life time mileage, 2.5 average passengers per ride, and 24 weight-percent chemical content.

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[27] *Green Building Design: Materials & Techniques.* accessed 17 November 2016., accessed November 17, 2016

[28] IAL Consultants (2015), The European Market for Thermal Insulation Products [Press Release]. Retrieved from http://www.ialconsultants.com/uploads/CUBE_press_release/2015-07-15/EUThermal%20Ins%20press%20release%202015.pdf

[29] 88 Mt is the projected demand growth potential from downstream enablement in a "thought to the end" scenario, while in a more moderate "capitalize on opportunity" scenario the projected demand growth potential is 52 Mt, or 16 percent.

[30] Accenture modeling based data from Eurostat, ICIS, Petrochemicals Europe, Knoema, Agrium, The Essential Chemical Industry

[31] Eurostat, 2012

[32] J. Rothermel, Renewable raw materials in the European chemical industry, VCI - DECHEMA, 2015

[33] "Ethanol from Non-renewable or Renewable Resources." *BBC News*. BBC, accessed November 17, 2016

[34] European Biofuels Technology Platform, 2016

[35] Susanne Retka Schillhttp, "Braskem starts up ethanol-to-ethylene plant," *Ethanol Producer Magazine*, September 23, 2010, www.ethanolproducer.com/articles/7022/braskem-starts-up-ethanol-to-ethylene-plant

[36] Kurian, Joseph V. "A New Polymer Platform for the Future – Sorona from Corn Derived 1,3-Propanediol" *Journal of Polymers and the Environment*, Vol. 13, No 2 (April 2005)

[37] The calculations are based on the following assumptions: 1.1 kg oil equivalent is equal to 41.9 megajoules (MJ); the average calorific value of biomass is 17 MJ/kg; and 12 tons of biomass can be harvested per hectare per year.

[38] Waste treatment in Europe, Eurostat 2013

[39] Ellen MacArthur Foundation, New plastics economy, 2014

[40] ibid

[41] Zero waste Europe, Reuse, 2016

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[43] Plastics Europe: Plastics Value Chain Creates a New European Stakeholder Platform to Drive Europe's Polyolefins-based Packaging towards the Circular Economy, 2016

[44] PlasticsEurope, Facts & Figures 2014

[45] Ibid

[46] Deloitte, Increased EU Plastics Recycling Targets: Environmental, Economic and Social Impact Assessment (Final Report), 2015

[47] Stoichiometric conversion of average composition of plastic waste ($C_1H_{2.36}$) to virgin feedstock

[48] Plastics Europe: Plastics - the facts 2014/2015; an analysis of European plastics production, demand, 2015

[49] University of Cambridge: The Impee Project - Recycling of plastics, 2005

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[52] GBB - Solid Waste Management Consultants: Gasification of Non-Recycled Plastics from Municipal Solid Waste in the United States, 2013 ("Plastics Gasification")

[53] National Energy Technology Laboratory: Analysis of Natural Gas-to Liquid Transportation Fuels via Fischer-Tropsch, 2013

[54] Plastics Gasification

[55] Feasibility study for catalytic cracking of waste plastic to produce fuel oil with reference to Malaysia and simulation using ASPEN Plus, 2013

[56] Climate-neutral means not emitting additional carbon into the atmosphere: natural gas is converted into hydrogen, which is to be used for CO_2 reduction, and into carbon, which is to be transferred into permanent storage. The Kvaerner process ($CH_4 \rightarrow 2\ H_2 + C$) represents an available technology.

[57] Not emitting additional carbon into the atmosphere and using only material that is already being circulated.

[58] Assuming an average hydrocarbon composition of $C_1H_{2.36}$, resulting in the combustion reaction: $C_1H_{2.36} + 1.59\ O_2 \rightarrow CO_2 + 1.18\ H_2O$

[59] Assuming the following reduction reaction: $CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$

[60] Certify "Overview of the market segmentation for hydrogen across potential customer groups, based on key application areas"; EU grant no. 633107

[61] Crack it! Energy from a fossil fuel without carbon dioxide; Karlsruhe Institute of Technology, 2015

[62] Plastics Recycling Survey, 2012. Please note that according to Accenture's estimation, the investment needs for a reverse logistics infrastructure are smaller than those for the chemical assets by order of magnitude.

[63] Average offshore wind turbine with 3.6 MW and 0.41 capacity factor. Source: EWEA; windeurope.org; Accenture analysis

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