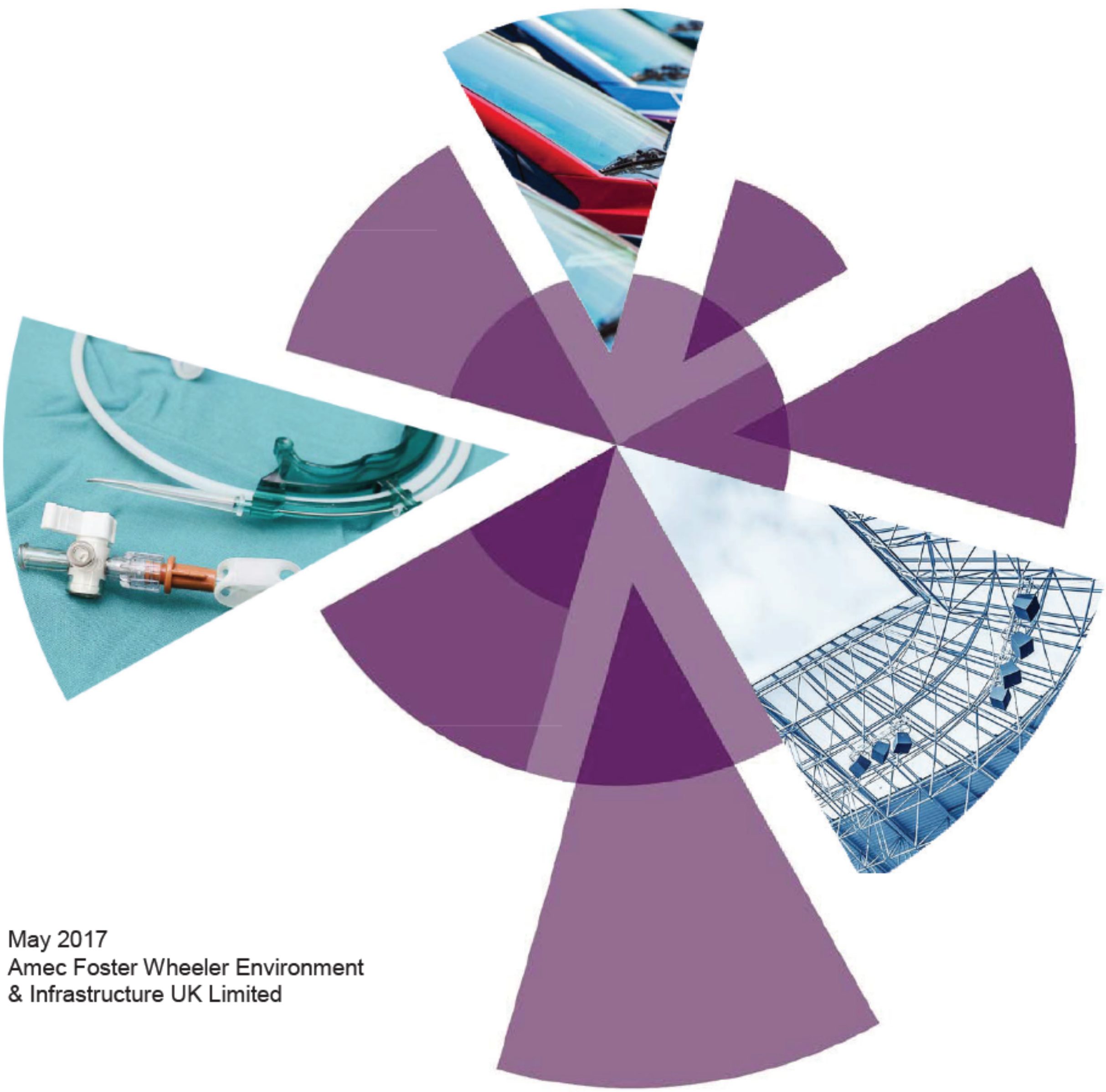
Plastics Europe – Fluoropolymer Group

Socio-economic Analysis of the European Fluoropolymer Industry



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Executive Summary

Purpose of the report

This independent report, commissioned by the Fluoropolymers Group (FPG) of Plastics Europe, identifies the contribution to European society and economy of a group of plastics known collectively as fluoropolymers. These include the well-known PTFE and many other polymers; they are not to be confused with fluorotelomers, which are out of the study scope.

The study – the first such study carried out by the Fluoropolymer industry in Europe – evaluates the contribution made by the manufacture of fluoropolymers in terms of revenue, investment and employment. But much more significant benefits are generated along the value chain via the use of fluoropolymers in various critical applications which we use every day. In these, even though the fluoropolymer content may be tiny, they offer key attributes: non-wetting, high dielectric, non-stick, fire resistant, temperature resistant, weather resistant and with near universal resistance to chemicals. It is their ***specific combinations of properties*** that are not matched by any of the alternatives and which thus make them so valuable.

This socio-economic analysis (SEA) draws on publicly available data, alongside a survey undertaken with members of the Fluoropolymers Group and interviews with a selection of downstream users. Key messages from the analysis are below – also presented graphically.

The fluoropolymer value chain – sectors dependent on fluoropolymers

Fluoropolymers provide vital performance characteristics to products or production processes. Collectively this creates socio-economic value far beyond the direct impact created by the industry itself. Whilst not all of these benefits can be quantified, the report analysed these in eight strategically important sectors:

- **Transport:** By providing durable and effective protection against heat, aggressive fluids and fuels, humidity, vibrations and compression, Fluoropolymers prolong the useful life of various components critical for performance, emission control and safety in both the automotive and aerospace industries.

  Looking specifically at cars, fluoropolymers contribute to safety, engine efficiency, weight reductions and emission control, thereby improving fuel efficiency and reducing leaks and fugitive emissions. Modern road transport emission standards could not have been achieved without these materials. Specifically, fluoropolymer use in fuel hoses alone enables fuel savings worth some €40m per year and lower emissions prevents health damage valued at a further €100m in Europe. Over the vehicle lifetime, this equates to fuel savings in Europe of some €200m.

- **Chemical and power:** Fluoropolymers enable a high level of efficiency and environmental safety in the chemical and power sectors, helping them remain internationally competitive. Uses include piping, vessels, fluid-handling components, filters, vents and cable coatings.

  Fluoropolymer coatings, linings and components prevent corrosion in demanding environments. Each percent reduction in corrosion is estimated to deliver savings of some €150m per year across Europe. Amongst other benefits, they support savings in maintenance through increased component lifetime. Consultation suggested their use effectively doubled the lifetime of equipment, potentially yielding savings in the order of €100m annually. Furthermore, they provide important contributions to applications that prevent or remove pollution; in Combined Heat and Power (CHP)[1] installations alone, fluoropolymer heat exchanger technology contributes to energy savings worth up to €8bn and CO_2 emission reductions worth around €0.5-3bn, across Europe, per year.

- **Cookware:** Fluoropolymer-coated cookware provides easy-clean, non-stick properties, saving time, water and energy. This facilitates cooking with less added fat contributing to a healthy diet.

[1] A highly efficient process that captures and utilises the heat that is a by-product of the electricity generation process.

- **Electronics:** Fluoropolymers are critical to the semiconductor manufacturing process. Here various fluoropolymer components can stand up to the aggressive etching chemicals and provide the necessary purity required in the production of microchips and other electronics, where even trace contaminants can severely affect production yield. Annual benefits of fluoropolymers in semiconductor manufacturing are substantial - estimated in a 2006 study at some €10bn, per year. Semiconductors, in turn, are found in millions of products which are becoming ever more powerful, but compact.

  More generally, fluoropolymers enable improved fire safety, reliability and performance of cables, notably data transmission cables enabling a wide range of ICT[2], industrial, automotive, medical imaging and analysis and a huge range of other applications. A combination of high dielectric properties, high heat resistance and fire resistance is necessary to produce acceptable products.

- **Food and pharmaceuticals:** Fluoropolymers enable durable processing equipment, ensuring high purity of food and pharmaceuticals as well as a high level of efficiency by preventing corrosion and facilitating cleaning. In the European biopharmaceutical manufacturing sector alone, €270m was saved in 2012 compared to 2008 from reductions in contamination and material failure. Such improvements can be attributed to a range of factors, but fluoropolymers play an important role in these efficiency gains.

- **Textiles and architecture:** In clothing and footwear fluoropolymers increase performance and comfort through combining waterproofing and breathability, in low weight but durable materials. They provide durable, fire-safe, easy-to-clean, building materials which can both reduce building cooling costs and energy use, whilst enabling novel “landmark” architectural designs not feasible with other materials. These include the O_2 Dome (London), the Sony Centre (Berlin), Wimbledon Centre Court, the Allianz Arena (Munich), San Mamés stadium (Bilbao) and the Eden Project in Cornwall, UK, all of which use fluoropolymers in the designs, for example woven PTFE fabric, fluoropolymer-coated glass fabric or extruded ETFE film.

- **Medical applications:** Fluoropolymers enable excellent performance and long lifetimes in medical equipment such as surgically-implantable medical devices, catheters, guide wires, filters and pumps. This reduces the risks of failure, replacements, cross-infections and clogging of medical equipment, contributing to the reduction/avoidance of medical complications and the associated pain and public cost.

- **Renewable energy:** Fluoropolymers exhibit a unique combination of properties within various components in renewable energy installations. We estimate that production efficiency increases of certain fluoropolymer-grade modules relative to glass provides a potential yearly saving – depending on uptake – in the order of €40m for European PV[3] module manufacturers, or approximately €90m for PV module customers in the EU. Installed capacity of both PV and wind energy is increasing quickly; a pre-requisite is unit cost reductions driven by efficiency gains. They are also used in energy storage systems such as PEM fuel cells and lithium-ion batteries.

The fluoropolymer industry – direct effects

The starting point of the value chain – sales of fluoropolymers in their basic form – is relatively small in comparison to the wider socio-economic benefits created by downstream fluoropolymer applications, described above.

However, even the production and sale of fluoropolymers themselves creates significant direct socio-economic effects in the EU. In 2015, around 52,000 tonnes of fluoropolymers worth around €780m were sold. By tonnage, the EU is a net importer of fluoropolymers, but the sales values of exports (€380m) are around 18% higher than the sales value of imports (€310m).

EU fluoropolymer manufacturing is a highly innovative sector, with an estimated €43m invested in research and development (R&D) in 2015. This equates to 5.5% of turnover; around triple the EU average.

[2] Information Communication Technology
[3] Photovoltaics

The location of the fluoropolymer industry in Europe plays an important role in allowing EU-based customers to meet lead times for the various end user sectors. This is necessary in maintaining innovation and R&D, as companies are continually customising products for their local customers.

Alternatives?

A high level analysis of alternatives has been carried out for all of the above sectors. Overall, whilst some alternatives might have a similar performance to fluoropolymers for a particular parameter or property, it is the combinations or ranges of properties required for the applications that sets fluoropolymers apart from the alternatives. In summary, whilst the implications of substituting fluoropolymers differ across specific applications, they include:

- **Technical implications** include lower performance, increased weight (with associated effects on fuel consumption and fuel efficiency), and reduced durability. This results in increased challenges (less compatibility and versatility) associated with component design/redesign and operating condition requirements.
- **Economic implications** include regression of advanced technologies and the reduced ability of Europe to compete and attract high and medium technology manufacturing investment (if it is not possible to prototype and produce competitive products), efficiency losses, higher initial (investment) costs and higher maintenance costs. The diversity of specific applications would pose major product qualification issues alongside design implications.
- **Environmental / health implications** include the potential for higher risk of exposure of staff to hazardous substances, higher safety risks (vehicle or aircraft failure) and increases in emissions arising from technical regression (in transport, for example this includes inferior car emission sensors, inferior internal seals, increased fugitive emissions or weight increases). This could put at risk Europe's ability to meets its climate and energy goals.

Socio-economic benefit of fluoropolymer applications

Fluoropolymer sales to key sectors in the EU (2015)	Tonnes	€ m	Example application and benefit of fluoropolymers	Statistics on sectors where fluoropolymers are used
Transport	18,500	300	Fluoropolymer fuel hoses enable fuel savings and reduce damage from emissions, worth ~ €140m per year in EU	> 13 million employed
Chemicals & power	16,500	220	Corrosion prevention saving hundreds of millions of € each year in the EU	Nearly 3 miliion employed
Cookware	3,500	60	Easy clean non-stick properties, allows cooking with less fat	Production value in the order of €2 billion
Electronics	3,500	50	Critical in semiconductor manufacturing, enabling progress in IT that has generated trillions of € globally in the last 20 years	EU semiconductor market worth circa €25 billion
Food & pharma	3,000	40	Safer and cheaper food and pharma by preventing contamination and material failure	Nearly 5 million employed
Textiles & architecture	3,000	40	Enabling novel and unique 'landmark' architectural designs	> 2 million employed
Medical applications	1,500	20	Reduces the risks of failure, cross-infections and clogging of medical equipment	Europe accounts for 41% of global medical device patents
Renewable energy	500	<5	PV module production efficiency increases which save €40m – €90m each year in the EU	Europe leading the global market in installed capacity
Other	2,000	30	–	–
Total	**52,000**	**780**		

The fluoropolymer industry - direct effects

Produced in the EU

Tonnes of fluoropolymers (2015): 51,000

Annual sales /turnover: € 840m

Trade

€ 380m Exports

€ 310m Imports

Employment

2,200 Direct

Research and development (R&D) investment by fluoropolymer manufacturers in the EU

€ 43m = 5.5% of revenue

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Note all sales values are rounded to the nearest €10 million; all tonnage data are rounded to the nearest 500 tonnes

Contents

1. Introduction and Scope

1.1 Introduction and Purpose of this report

In 2016, Amec Foster Wheeler Environment and Infrastructure UK was commissioned, on behalf of the Fluoropolymers Group (FPG) of Plastics Europe, to identify the socio-economic value of the group of plastics known collectively as fluoropolymers, to European society and economy.

The socio-economic assessment (SEA) focuses on the economic benefits of the industry, in terms of revenues, employment and sales to downstream sectors. It also focuses on the downstream sectors in which fluoropolymers are used. This includes a huge variety of applications across Europe; it is not practicable to examine them all. As such, this study considers the use of fluoropolymers in eight strategically important sectors: transportation; applications in the chemical and power generation sectors; cookware; electronics; food and pharmaceuticals; textiles and architecture; medical applications; and renewable energy.

In each, the various benefits that fluoropolymers deliver to both consumers and industry in terms of functionality within specific products are analysed, alongside an assessment of the importance of the sector itself to the European economy. The SEA draws on publicly available data, alongside a survey undertaken with members of the FPG. Further consultation was carried out with a selection of downstream users. The terms 'EU' and 'European' are used interchangeably throughout the report but they mean the same thing: the EU28. When discussing monetary values, 'm', 'bn' and 'tn', refer to million, billion and trillion, respectively.

1.2 What are fluoropolymers?

For the purposes of this study fluoropolymers are defined as follows.

Polymers that have a carbon backbone and contain fluorine atoms directly attached to the carbon. Fluoropolymers are made by polymerisation of olefinic monomers at least one of which contains fluorine bound to one or both of the olefinic carbon atoms. This includes fluoroplastics[4], fluoroelastomers[5] fluororubber[6] products. Examples of fluoropolymers are polytetrafluoroethylene (PTFE) – including expanded PTFE (ePTFE), polyvinylidene fluoride (PVDF), copolymer of tetrafluoroethylene and ethylene (ETFE) elastomers and ethylene-chlorotrifluoroethylene (ECTFE), copolymer of tetrafluoroethylene and hexafluoropropylene (FEP), copolymer of tetrafluorothethylene and perfluoropropylvinylether (PFA). Fluorotelomers [$C_nF_{2n+1}(CH_2)_mH$] and fluorotelomer-based polymers are out of the SEA scope.

Fluoropolymers form crucial parts of very many components, technologies, industrial processes and products with which we come into contact every day. They provide a wide variety of benefits both essential to high technology products and unobtainable in other materials, but are often invisible. They are plastics which are virtually chemically inert, non-wetting, non-stick, highly temperature and fire resistant, and highly weather resistant. It is this specific combination of properties that makes them so valuable.

1.3 Structure of this report

Following section 1; this introduction:

- **Section 2** provides a summary of how fluoropolymers are used in the eight key sectors and what benefits they confer which make them useful in so many applications. The remainder of the report focuses on these uses and sectors.
- **Section 3** contains an analysis of the current socio-economic value of the fluoropolymer industry to Europe. This focuses on direct employment, revenues, research and development

[4] A synonym of fluoropolymers
[5] A special purpose fluorocarbon-based synthetic rubber
[6] A synonym of fluoroelastomer

(R&D) investment, product innovation and the volume and value of sales to the eight downstream sectors.

- **Section 4 considers two things:**
  - Firstly, the benefits to European society or economy that the use of fluoropolymers delivers in the various applications of relevance to the study are illustrated. These benefits may include characteristics in the final products, efficiency improvements in industrial processes, or their use may enable a product or process that would otherwise not be possible.
  - Secondly, given their widespread use across the key sectors, the socio-economic contribution and strategic significance of the eight key sectors themselves is demonstrated, in terms of economic output, employment or international trade.
- **Section 5** evaluates the potential alternatives to fluoropolymers. This covers the key criteria that EU authorities consider when they assess substances, namely: their technical functionality and performance characterisers; their economic feasibility; their health and environmental profile; and whether they are likely to be available in sufficient quantities.

Appendix A contains references, Appendix B provides further information on the treatment of survey data and Appendix C sets out additional details on potential alternatives in several applications.

2. Fluoropolymers – what do they do and how are they used?

Fluoropolymers bring a unique combination of properties and performance characteristics. They provide specific functionality in a wide range of processes, components and end products that is both essential to high technology products and unobtainable in other materials. So widespread is their use that it is a challenge to identify and evaluate the full extent of this and of the socio-economic benefits that they create. As such, this report has focussed on eight “key sectors” where the use of fluoropolymers is considered to be particularly important. Within each key sector, the specific uses (“applications”) of fluoropolymers and the benefits that they deliver are explained. In later sections of the report the most important applications are assessed further. These key sectors are:

- **Transportation.**
- **Chemical and Power.**
- **Cookware.**
- **Electronics.**
- **Food and pharmaceuticals.**
- **Textiles and architecture.**
- **Medical applications.**
- **Renewable energy.**

In the tables below, for each key sector, we set out how fluoropolymers are used and evaluate the characteristics that make them so useful. In the text we refer to specific examples of fluoropolymer such as PTFE, PVDF. Please refer to the definition provided above in section 1.2. The order of the key sectors is consistent throughout the report and ordered based on the sales volume of fluoropolymers in basic form (i.e. the first stage in the value chain) from the largest to the smallest.

Table 2.1 Uses and benefits of fluoropolymers in transportation

Why are fluoropolymers useful?

A unique combination of properties makes fluoropolymers the material of choice for crucial parts (and coatings of electronics and mechanical components) in various automotive and aircraft applications.

Characteristics

Fluoropolymers exhibit the following characteristics, which are particularly important in these applications:

- **Low permeation, but also manufactured to allow for semipermeable structures.**
- **Chemical resistance (protecting components from corrosive fuels and engine oils and fluids).**
- **Low and high temperature resistance (from -200 °C to +260 °C for PTFE and PFA, with other elastomers offer a range of -40 °C to +230 °C).**
- **Non-stick and consequently non-fouling alongside, sufficient bonding in certain multi-layer applications.**
- **Low coefficient of friction.**
- **Long-term compression resistance of fluoroelastomers.**
- **Excellent dynamic properties.**
- **No flame propagation and low smoke generation.**
- **Excellent electrical insulator.**

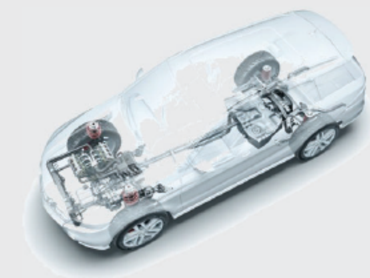
Benefits (Continued overleaf)

Taken together these characteristics enable functionality in cars and aircraft which is now taken for granted and which delivers wider societal benefit, including:

How are fluoropolymers used in this sector?

These benefits are achieved via the use of various fluoropolymers in the following applications:

- **Car manufacturing/automotive components:** Fluoropolymers are used in various sealing and fluid transmission and venting components, including:
  - **Turbocharger hoses: [Benefits A, B, E, F]:** These systems boost cars' performance increasing the air density entering the engine. They are made of multi-layered structures which include fluoroelastomers. Low permeability, low friction, resistance to heat/chemicals are key in these components helping avoid leaks and breakdowns. [Source: 1, 2, 5, 6, 8].



  - **Fuel lines, fuel hoses: [Benefits A, B, D, F, H].** Moving fuel within the vehicle, these are normally made of multi-layered structures containing fluoroelastomers or fluoroplastics. More recently, some fuel hoses are made of fiberglass braid and PTFE liner bonds which can resist up to 800°C for an hour. As above these avoid leaks and breakdowns. [Source: 1, 2, 5, 6, 9].
  - **Hoses in hydraulic systems: [Benefits D, E, F, H, J].** PTFE is used in inner layer hose constructions in hydraulic systems. These are in contact with petroleum, synthetic or water-based hydraulic fluids and need to resist high pressure. Non-stick properties prevent sedimentation, but bonding with other substances, such as silicone may also be poss ble. As above these avoid leaks and breakdowns. [Source: 1, 2, 5, 6, 9].
  - **ABS break lines: [Benefit I].** The inner hose of PTFE with loose steel over-brading allows for better brake efficiency and less aggressive pumping when the ABS is activated thanks to the pressure absorption in the PTFE tube. [Source 7, 16].
  - **O-rings: [Benefits D, E, J].** O-rings are often made of fluoroelastomers, which are used as seals in fuel containment systems and fuel injectors. [Source: 3].

  - **Shaft seals, valve stem seals: [Benefits E, J].** Shaft seals are used to seal engine or transmission components. Fluoropolymers such as fluoroelastomers or PTFE are used as a sealing element (lip). These seals are used to protect the transmission system from dust and aggressive lubricants [Source 4]. Valve stem seals - also made of fluoroelastomers - need to enable adequate lubrication of the valve while being durable and preventing permeability (which prevents evaporative emissions). [Source: 4, 10].
  - **Air intake manifold gaskets: [Benefits A, B, D, E, G, J].** Air intake manifolds channel air into the engine. The gasket seals the system to ensure performance and minimise leaks. Fluoroelastomers are used as sealant beads for the gaskets. Here heat and stress resistance are essential as temperature and pressure are constantly changing in the air injection system; failure would lead to higher emissions and lower fuel efficiency. Alternatives are typically less resistant to solvents, oils and chemicals in combination with heat exposure. [Source: 8, 12].

Why are fluoropolymers useful?	How are fluoropolymers used in this sector?

Why are fluoropolymers useful?

A. **Lower fuel emissions.**
B. **Better fuel economy from weight saving.**
C. **Lower exhaust emissions (both carbon and NOx gasses).**
D. **Increased lifetime of components.**
E. **Better engine performance.**
F. **Improved reliability and lower maintenance costs.**
G. **Increased comfort (and noise reduction).**
H. **Permits use of alternative fuels (like bio-diesel- see table note 21).**
I. **Increased safety (e.g. through reliable performance of parts).**
J. **Cleaner environment by avoiding leakage (e.g. oil or coolant leaks).**

How are fluoropolymers used in this sector?

- **Cylinder head gaskets: [Benefits A, B, D, E, J].** An estimated 80% of new engines in Europe use multilayers of steel gaskets with a sealant coating made of fluoroelastomer between the cylinder heads and the engine block. These gaskets seal the cylinders and prevent gas and liquid leakages (e.g. engine oil, coolants). [Source: 11, 14].
- **Automotive venting products: [Benefits D, E, F].** Used for lighting, electronic control systems, sensors, motors, powertrains, interior electronics, as well as gas powered, hybrid and electric vehicles. Vents block water, automotive fluids and contaminants while effectively reducing condensation, allowing components to vent during rapid temperature/pressure differentials. [Source: 13].
- **Greenhouse emission controls: [Benefits B, C, D, E, F, J].** Fluoropolymers and fluoroelastomers play an important role in cutting carbon emissions via Lambda or oxygen sensors which contain multiple fluoropolymer applications: wires, form hose, grommet and filter which are all operating in hot engine exhaust gases to optimise engine combustion. They also contr bute to nitrous oxide emission reductions with multiple fluoropolymer components in the SCR/AdBlue (Urea) systems to convert toxic mono-nitrogen gases to alternatives that are safer for the environment. [Source: 7, 8, 15, 17, 18].
- **MEAs (Membrane Electrode Assemblies): [Benefits B, D, E, F].** For PEM (Proton Exchange Membrane or polymer electrolyte membrane) type fuel cells powering fuel cell electric vehicles (as well as being used in stationary and portable applications) within the fuel stack to facilitate the electrochemical conversion of hydrogen and oxygen into energy [Source: 13].
- **Lithium ion batteries** (see Table 2.8).
- **Electronic systems:** Fluoropolymers provide a host of important characteristics in electronic components, used extensively in automobiles. This application is covered separately below.

- **Aerospace industry:** The same characteristics as noted above make fluoropolymers suitable for demanding aerospace applications. This includes but is not limited to aircraft and spacecraft manufacturing:
  - **Insulation for cables and wires in aircraft and spacecraft: [Benefits D, F, I].** Wires and cables insulated with fluoropolymers show improved signal integrity for critical data transmission. Because of their broad temperature and UV resistance, flexibility, durability and chemical resistance to solvents and hydraulic fluids, as well as low smoke generation and flame resistance, which is particularly important in aircraft interiors, fluoropolymer insulations offer safe solutions and durability to cables and wires in the aerospace industry. [Source: 6, 7].
  - **Leaky Feeder Antennas: [Benefits B, D, F, I].** Improve in-flight connectivity to wireless networks. Fluoropolymers (e.g. PTFE) are used to ensure low smoke generation, flame resistance and durability and allow more protocols to run through one antenna, reducing the number of antennas required. [Source: 19].

Why are fluoropolymers useful?	How are fluoropolymers used in this sector?
	▶ **Aircraft interior coating: [Benefits D, F, I].** Coated with fluoropolymers due to their flame retardancy, non-fouling and ease of cleaning. [Source: 6]. ▶ **Aerospace materials, tapes and gaskets: [Benefits D, F, I].** Fluoropolymers (e.g. PTFE) provide sealing and surface protection against aviation liquids and UV radiation for access panels, engine cowlings, external fuel tanks, fairings, light assembly seals, passenger floorboards and other components. [Source: 20]. ▶ **Rings and seals for hydraulic systems, hoses and tubing: [Benefits A, B, D, E, F, J].** Fluoropolymers provide similar functions as descr bed above (automotive) for fuel systems, heating cables, circuit boards, engine wire insulation and jacketing. [Source: 7]. ▶ **Electronic systems:** Fluoropolymers provide a host of important characteristics in electronic components, used extensively in transportation (automobiles, aircraft). This application is covered seperatley below. One example is for instance the cables for individual inflight entertainment [Source: 22]. It should be noted that several uses in this sector are common to other sectors and are noted elsewhere in this section of the report. For instance, rings, seals, hoses and tubing (see automotive applications in this table above); circuit boards, semiconductors and wire insulation (see electronics in Table 2.4 below).

Table sources and notes:

[1] http://solutions.3m.com/wps/portal/3M/en_EU/Dyneon_EU/Dyneon_Fluoropolymers/Markets/Automotive/
[2] http://solutions.3m.com/wps/portal/3M/en_EU/Dyneon_EU/Dyneon_Fluoropolymers/Applications/TubeHosePipe/FluidGasHandling/#box2
[3] http://solutions.3m.com/wps/portal/3M/en_EU/Dyneon_EU/Dyneon_Fluoropolymers/Applications/SealantORing/O-Ring/#box2
[4] http://solutions.3m.com/wps/portal/3M/en_EU/Dyneon_EU/Dyneon_Fluoropolymers/Applications/SealantORing/BondedSeal/
[5] http://solutions.3m.com/wps/portal/3M/en_EU/Dyneon_EU/Dyneon_Fluoropolymers/Applications/SealantORing/#box4
[6] Ebnesajjad, S., 2013. Introduction to fluoropolymers: Materials, technology and applications. PDL Handbook series. Elsevier
[7] DuPont Fluoropolymers, An Introduction to Fluoropolymers, May 2009 **Note DuPont Fluoropolymers were spun off into a separate stand-alone company "Chemours" in July 2015.**
[8] https://www.chemours.com/Viton/en_US/applications/automotive_uses.html
[9] http://www.kongsbergautomotive.com/products-services/passenger-cars/fluid-transfer/fuel-lines/fluoro-comp/
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[17] http://densoheavyduty.com/oxygen-af-sensors/oxygen-sensors
[18] http://www.bosch-aa.com.cn/media/parts/engine_systems__auto_parts/gasoline__engine_systems/Lambdasensor_Imagefolder.pdf
[19] https://www.gore.com/products/gore-tm-leaky-feeder-antennas
[20] https://www.gore.com/products/gore-tm-skyflex-tm-aerospace-materials
[21] "Alternative" fuels containing additives such as such as FAME and RME are more corrosive than standard fuel. As a result, vehicle manufacturers need particularly chemical resistant materials for the transition to a higher use of biodiesel in vehicles, as mandated by EU legislation (Fuel Quality Directive, Renewable Energy Directive).
[See source 2, 8, 12 above].
[22] http://us.vocuspr.com/Newsroom/MultiQuery.aspx?
SiteName=DupontEMEA&Entity=PRAsset&SF_PRAsset_PRAssetID_EQ=127481&XSL=NewsRelease&IncludeChildren=True&Lang=English)

Table 2.2 Uses and benefits of fluoropolymers in chemical and power

Why are fluoropolymers useful?	How are fluoropolymers used in this sector?

Characteristics

A combination of performance characteristics mean fluoropolymers are ideal materials for the conditions required in various processes in the chemical and power generation industries. These include:

- **Inertness with an almost universal resistance to chemicals and oil.**
- **Low and high temperature resistance (e.g. from -200 °C to +260 °C for PTFE and PFA).**
- **Excellent insulation properties which enables downsizing and an overall reduction in weight.**
- **Low vapour and chemical permeability.**
- **Non-stick and low friction properties.**
- **High abrasion resistance.**
- **Formulations can be made conductive which helps to prevent static electricity build-up.**

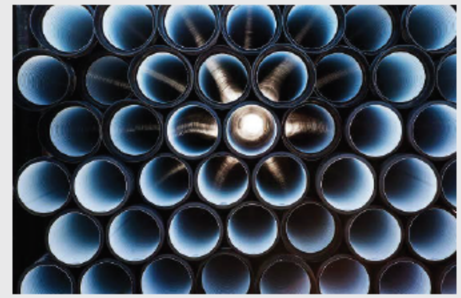
Benefits

Taken together these characteristics enable outstanding functionality, safety and innovation in the chemical and power industries, which delivers wider societal benefit, including:

A. **Increased lifetime of components.**
B. **Lower maintenance costs through corrosion prevention.**
C. **Increased productivity from reduced failures, improved flow of process substances.**
D. **Higher production yields and quality from improved purity of process substances.**
E. **Material cost savings through downsizing and less waste during production and over life cycle of the product.**
F. **Lower levels and risk of pollutant emission and exposure of workforce to pollutants and chemicals.**
G. **Increased energy efficiency.**

These benefits are achieved via the use of various fluoropolymers in the following applications:

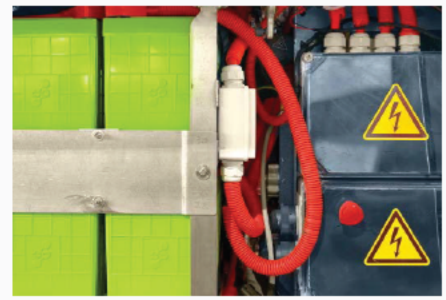
- **Chemical:** They support applications for aggressive chemical fluids as they contribute to corrosion and leaching prevention, lower maintenance and prevention of emissions. Typical applications include:
  - **Lining of piping, flowmeters and fittings, fluid-handling components, process vessels, tanks, storage and transport containers and piping: [Benefits A, B, C, D, E, F].** Frequently made from steel or reinforced plastic lined with fluoropolymers (e.g. PFA, FEP or PTFE) to prevent corrosion and leakage and to extend service life or for their non-stick and friction properties. Fluoropolymer linings can be made conductive to prevent static electricity build-up by adding conductive compounds. [Source: 1, 2, 6, 9].
  - **Filters: [Benefits A, B, D, F].** PTFE is sometimes used as a filter medium and/or casing to ensure high chemical resistance in filtering particulate from fluids [Source: 1, 6.].



  - **Sensors: [Benefits A, B, C, F].** Capacitive sensors could not be made without high-purity fluoropolymers and their connecting cables are often shielded with fluoropolymers. [Source: 1, 6].
  - **Sealants: [Benefits A, B, C, F].** Expanded sealants for flange sealing applications are often made of PTFE with a microfibrillated internal structure (i.e. a structure characterised by very small fibres) for enhanced stability. [Source: 3].
  - **PTFE packaging vents: [Benefits A, B, C, F].** Allow containers for industrial chemicals and cleaners, agricultural products and household chemicals and cleaners to equalise pressure without leaking and rupturing, thereby preventing harm to both users and the environment. [Source: 14].
- **Power:** Due to their heat, oil and chemical resistance, alongside mechanical properties, fluoropolymers are widely used in thermal and other power generators [Source: 5] and a range of further applications in the power sector. The main applications are:

Why are fluoropolymers useful?	How are fluoropolymers used in this sector?

- **Cables: [Benefits A, B, C].** The heat, oil, and chemical resistance as well as the mechanical properties of fluoropolymers mean that they are often used for cables and other equipment – including at power generation plants. [Source: 5].
- **Filters: [Benefits A, B, F].** Because of the chemical resistance of PTFE, filters for dedusting of highly corrosive flue gases (e.g. humid SO_x, HCl, hydrofluoric acid) to abate pollution from fossil fuel power plants and waste incineration plants are often made from woven PTFE. [Source: 10].
- **Flue gas heat exchangers and desulphurisation plants: [Benefits A, B, F, G]. PTFE** or PFA tubes are frequently used in flue gas heat exchangers for heat recovery and heat displacement. These are also often applied in desulphurisation plants which heat the flue gas below the acid dew point to increase the efficiency of power plants and to scrub chemicals like H_2S from the flue gasses. [Source: 8, 11].
- **Energy Storage: [Benefits A, B, C, F].** Fluoropolymers (VDF/TFE copolymer, PVDF) are frequently used as binders in lithium ion batteries for their chemical resistance and endurance. [Source: 4, 7].
- **Fluid handling, filtration and gas sampling in the nuclear industry: [Benefits A, B, C, E, F].** Fluoropolymers such as PFA are widely used for tubes, vessels etc. to handle corrosive liquids and provide a low metals background. Gas handling and filter mediums and casings in the nuclear industry are also often made from fluoropolymers [Source: 12].



Note that fluoropolymers are also used in the renewable energy sector, for instance in wind power generators, solar cells and geothermal plants. This is discussed in more detail below. [Source: 5, 13].

Table sources and notes

[1] https://www.chemours.com/Teflon_Industrial/en_US/uses_apps/semiconductor/bulk.html Note this refers to filters and sensors as referred to in the text above.
[2] http://solutions.3m.com/wps/portal/3M/en_EU/Dyneon_EU/Dyneon_Fluoropolymers/Applications/MetalCoating/IndustrialCoating/#box1
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Table 2.3 Uses and benefits of fluoropolymers in **cookware**

Why are fluoropolymers useful?	How are fluoropolymers used in this sector?
Characteristics **Coating materials for cookware and bakeware benefit from the following characteristics of fluoropolymers:** • **Non-stick.** • **Contribution to corrosion prevention.** • **Durability.** • **Resistance to chemicals.** • **Thermal stability (up to +260 °C).** **Benefits** **Taken together these characteristics enable functionality in cookware and bakeware including:** A. **Increased lifetime of the product (hence consumer savings from less frequent replacement).** B. **Non-stick cooking, avoiding marks/burns.** C. **Easier cleaning, including use in dishwashers.** D. **Reduction of fat/oil use in cooking.**	▶ **Pans, pots and baking trays: [Benefits A, B, C, D].** Fluoropolymers' low surface energy, stability and chemical resistance provides non-stick properties to prevent food sticking/burning, facilitate easy cleaning, provide durability and corrosion prevention, are suitable for use in dishwashers, and reduces the use of fat/oil in cooking. [Source: 1, 2, 4, 5, 6].  ▶ PTFE-coated pans and pots have been in commercial use for some 50 years. While some alternative coatings have been developed, studies have found that PTFE coating systems typically last several times longer than these alternatives. In a survey conducted amongst US consumers in 2012, the majority (66%) stated that they use non-stick cookware. Moreover, 65% of those surveyed stated that PTFE delivers the highest quality. [Source: 2, 3]. ▶ They are designed to be used safely at high temperatures (up to +260 °C) above the smoke point of most cooking oils and fats. [Source: 1, 5].

Table sources
[1] Ebnesajjad, S., 2013. Introduction to fluoropolymers: Materials, technology and applications. PDL Handbook series. Elsevier.
[2] https://www.chemours.com/Teflon/en_US/products/nonstick_cookware.html
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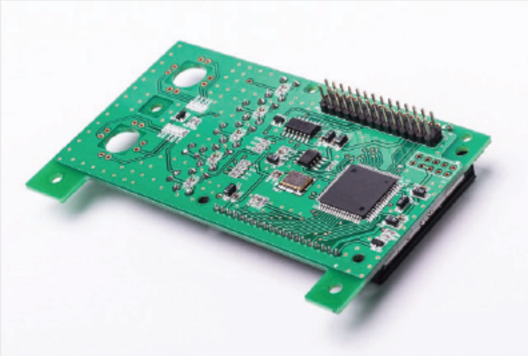
[6] https://www.chemours.com/Teflon/en_US/products/cookware_myths.html#q1

Table 2.4 Uses and benefits of fluoropolymers in electronics

Why are fluoropolymers useful?	How are fluoropolymers used in this sector?
The use of fluoropolymers in electronic applications is essential. They deliver a unique combination of properties making them the material of choice for several major applications in the electronics sector. **Characteristics** **Fluoropolymers exhibit the following characteristics, which are particularly important in these applications:** • **High purity.** • **Chemical resistance.** • **Low and high temperature resistance (e.g. from -200 °C to +260 °C for PTFE and PFA).** • **High abrasion, stress-crack and cut through resistance.** • **Electrical insulation.** • **Low dielectric constant, low variations of conductivity.** • **Non-stick properties.** • **No flame propagation and low smoke generation.** **Benefits (continued overleaf)** **Taken together these characteristics enable outstanding functionality in electronic equipment on which we rely every day, and which delivers wider societal benefit, including:** A. **Ever-improving and affordable microchips and LEDs due to higher production yields in semiconductor manufacturing.** B. **Manufacturing cost savings (component lifetime increase, lower maintenance cost, lower material consumption).** C. **Reduced environmental risk (leak prevention, lower exposure of workforce to chemicals).** D. **Improved performance of high volume data transmission.** E. **Increased reliability and lifetime of electronics.** F. **Facilitation of cleaning of electronics.**	**These benefits are achieved via the use of various fluoropolymers in the following applications:** ▶ **Semiconductor and other electronic manufacturing: [Benefits A, B, C].** Fluoropolymers are of **critical** importance for the manufacturing of semiconductors and other electronics. They play a major role in their production, by allowing the use of various piping, vessels, valves and pumps that can withstand the harsh environment of the aggressive etching chemicals. They can help enable the high purity required to make semiconductors function. The fluoropolymer components include:  ▶ **Fluid handling components (e.g. tubing, piping, fittings, valves, pumps, vessels, instrumentation):** Fluoropolymers such as PTFE, PFA and PVDF are used as the main material, coating or lining for components handling crucial aggressively reactive and/or high-purity processing fluids. This enables greater integration, reduced/avoided contamination (e.g. ionic contaminants) and very low extractable and leachable levels, providing greater reliability and endurance. These properties are compatible with aggressive chemical but can also deliver the required purity. They make fluoropolymers crucial in semiconductor and electronics manufacturing. [Source: 1, 2, 3, 4]. ▶ **Filters:** Fluoropolymers are also used as membranes and casings for filters such as ultra-low penetration air filters. [Source: 3, 4]. ▶ **Semiconductor and printed circuit equipment parts and packaging: [Benefits A, B, E].** Semiconductors, microchips, cables and other electronics components which are manufactured with or contain fluoropolymer components are used in a very wide range of other applications and sectors. These, in turn, enable much of the functionality in a host of other products, such as modern cars, lighting, the internet, medical devices, home appliances and televisions. [Source: 11]. ▶ **Semiconductor equipment parts:** Made from PTFE, PFA and ETFE for their heat resistance, UV-resistance and chemical /contamination resistance. [Source: 5].  ▶ **Printed circuit boards**: Made from fluoropolymers such as PTFE for achieving a low dielectric constant, high heat and flame resistance as well as low variations of conductivity due to low moisture absorbance. [Source: 4, 7]. ▶ **Cushioning or release films in semiconductor moulding and rewiring as well as in printed circuit board laminating:**

Why are fluoropolymers useful?	How are fluoropolymers used in this sector?
G. Improved reliability of electronic systems that control a majority of safety critical operations in industrial use. **H. Improved fire safety.** **I. Facilitate/enables/improves wireless communication.**	Often made from fluoropolymers such as ETFE for their non-adhesiveness, heat resistance and electrical properties [Source: 4, 5, 7]. ▶ **Appliances & other electronic equipment: [Benefits E, F]:** ▶ **Display and touch screen panels and coatings** to prevent finger print marks and provide insulation and chemical resistance (e.g. against cleaning agents and detergents) and transparency. [Source: 4, 5]. ▶ **LED packaging/encapsulants:** Fluoropolymer films are used to provide non-adhesiveness, transparency and durability for LED packaging and encapsulants. They are also used as release films in the parts manufacturing process for LEDs. [Source: 5]. ▶ Examples of fluoropolymer use in other electronic equipment include fluoropolymer (e.g. PTFE) additives in **computer cases** and fluoropolymer tubes (e.g. PFA) in **copier rolls and paper feeders** for non-adhesiveness and heat resistance properties. [Source: 1, 4]. ▶ **Wiring and cabling: [Benefits D, G, H].** Fluoropolymer resins (e.g. FEP, PFA, PTFE, PVDF and ETFE) are used extensively for **insulation, shielding and jacketing of wiring and cabling of all kinds of electronic equipment (as well as in buildings and in transport - discussed above) and communication networks** in order to achieve heat resistance and low flammability, high signal quality with low signal losses, stress-crack and cut through resistance, as well as chemical resistance [Source: 1, 5, 6, 7, 8, 10]. Fluoropolymers are used in many data communication cables, such as: ▶ Micro and mini coaxial cables for Wi-Fi, 3G, 4G and Bluetooth antennas [Source: 8, 9]. ▶ Ethernet shielded twisted pair cables [Source: 8, 9]. ▶ Flat cables [Source: 4]. ▶ Plastic optical fibres and fibre optic raceways [Source: 4, 8].

Table sources

[1] Ebnesajjad, S., 2013. Introduction to fluoropolymers: Materials, technology and applications. PDL Handbook series. Elsevier.
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[3] http://americas.kynar.com/en/markets-applications/industrial-applications/semiconductor/
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[10] https://www.gore.com/products/smt-emi-gaskets-for-mobile-electronics
[11] http://www.microchip.com/technology

Table 2.5 Uses and benefits of fluoropolymers in **food and pharmaceuticals**

Why are fluoropolymers useful?

Fluoropolymers are useful for crucial components in food and pharmaceuticals production and packaging to enable quick and flexible processing, safe storage and meeting the highest purity and hygiene standards.

Characteristics

Fluoropolymers exhibit the following unique set of characteristics, which are particularly important in these applications:

- **High purity.**
- **Almost universal resistance to chemicals and oil (relevant to hygiene standards, no flavour imparting).**
- **Low and high temperature resistance (e.g. from -200 °C to +260 °C for PTFE and PFA).**
- **Non-stick and low friction properties (allows flow of materials and prevents residual or bio-film build-up).**
- **High corrosion and abrasion resistance.**
- **Low vapour permeability.**
- **Low leachables.**

(continued overleaf)

How are fluoropolymers used in this sector?

These benefits are achieved via the use of various fluoropolymers in the following applications:

- **Components of food, diary, beverage and pharmaceutical manufacturing and processing equipment: [Benefits A, B, C, D, E, F].** These include:

  - **Lining of valves, piping, tubing, filters, seals, gaskets and other standard fluid handling components:** Made from or coated with fluoropolymers. Their heat and chemical resistance provide corrosion resistance against aggressive foods, beverages and cleaning products and exhibit a low propensity to impart flavours on other products. Non-stick properties in processing equipment to ensure efficient processing, preserve the purity of the products and facilitate cleaning. [Source: 1, 2, 4, 5, 6, 8, 9, 10, 11].
  - **Vessels, tanks, and belts:** Fluoropolymer coatings are frequently used for vessels to protect the equipment from corrosion and the build-up of bio-films and other residues, preventing product contamination. Fluoropolymer coatings can be applied to virtually any metal substrate and belts can be impregnated for anti-stick performance and easy cleaning. Freeze-drying trays use ePTFE membranes because they provide a high vapour transmission rate in combination with highly-effective barrier protection. [Source: 1, 5, 6, 10].
  - **Fluoropolymers are specifically approved for food and drug processing**. [Source: 8].
  - Among others, **fluoropolymer components or coatings are often used in beer, wine and other alcoholic beverage production, to make fruit juices, dairy products, meat and poultry processing, soft drink & coffee dispensers as well as in processing of sauces and condiments**. [Source: 3].

- **Labware products: [Benefits A, B, D, E, F].** Fluoropolymers are used in sensitive analytical applications in food – and especially – pharmaceutical sectors because of their high purity, temperature and chemical resistance and low surface energy. [Source: 1].
- **Medicine packaging: [Benefits E, G].** Fluoropolymers protect the contents from humidity and preserve their effectiveness. [Source: 7].

Why are fluoropolymers useful?	How are fluoropolymers used in this sector?
Benefits Taken together these characteristics enable outstanding functionality as well as the highest purity and hygiene standards in the food and pharmaceuticals sectors, which delivers wider societal benefit, including: A. Increased lifetime of components. B. Lower cleaning and maintenance costs. C. Increased productivity by enabling production of multiple products with the same equipment, reducing failures and improving flow of process substances. D. Higher production yields and quality from improved purity of process substances. E. Health benefits from high purity and hygiene standards, lower health risks from cross contamination and avoiding over / under dosage of pharmaceuticals. F. Lower levels and risk of exposure of workforce and environment to chemicals, including avoiding leaks. G. Prolonged preservation of the product.	

Table sources:
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[2] http://www.agc-chemicals.com/jp/en/fluorine/products/market/use.html?f_id=8
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[5] https://www.gore.com/products/categories/pharmaceutical-biopharmaceutical
[6] https://www.chemours.com/Teflon_Industrial/en_US/uses_apps/pharmaceutical/index.html
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[11] https://www.gore.com/products/categories/filtration

Table 2.6 Uses and benefits of fluoropolymers in textiles and architecture

Why are fluoropolymers useful?	How are fluoropolymers used in this sector?
The unique combination of properties of fluoropolymers makes them particularly useful for challenging applications in clothing, footwear and architecture. Characteristics **Fluoropolymers exhibit the following characteristics, which are particularly important in these applications:** • **Low permeation but allows for semipermeable structure.** • **Chemical resistance.** • **Helps prevent corrosion.** • **Low surface energy, low friction.** • **Low and high temperature resistance (e.g. from -200 °C to +260 °C for PTFE and PFA).** • **UV resistance and transmittance, articles can be made translucent.** • **Stability at low weight.** • **Flexibility.** • **No flame propagation and low smoke generation.** **(continued overleaf)**	**These benefits are achieved via the use of various fluoropolymers in the following applications:** ▶ **Raincoats, jackets, trousers and more: [Benefits A, B].** Membranes created from fluoropolymers (for instance ePTFE) have a microporous semipermeable structure to provide waterproof, breathability and other protective properties to clothes for personal and professional uses, including in particularly demanding environments. Thin, lightweight, durable breathable moisture barriers protects against exposure to blood, body fluids, chemicals, electrical discharge and water. [Source: 1, 2, 3]. ▶ **Footwear: [Benefits A, B]. Fluoropolymer membranes** can also be applied to footwear, to manufacture waterproof shoes for consumers and professionals that also allow feet to transpire and protect against chemicals or other liquids. [Source: 1]. ▶ **Aerospace suits: [Benefits A, B, F].** Astronauts wear suits which contain fluoropolymers membranes or PTFE coated glass fabric due to their resistance to low temperatures and to fire, alongside durability and electrical insulation properties. [Source: 9, 13, 19].  ▶ **Textiles used in other sectors include:** ▶ **Membranes for composting: [Benefit: H].** Fabric with ePTFE membrane are used as key component for a composting solution for the treatment of organic waste (green waste, food waste, source separated organics, biosolids or Municipal Solid Waste - MSW). [Source: 20]. ▶ **ePTFE sewing thread, fibers and weaving yarn: [Benefits A, B].** Used for outdoor applications l ke awnings, umbrellas, furniture, boat covers and sails, industrial filtration applications in demanding environments and high performance ropes. [Source: 21].

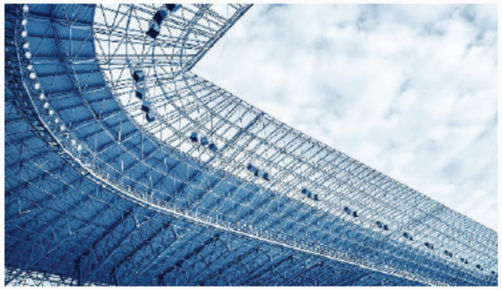
Why are fluoropolymers useful?	How are fluoropolymers used in this sector?

Benefits

Taken together these characteristics enable outstanding functionality and innovation in textiles and architecture, which delivers wider societal benefit, including:

- A. **Combination of waterproofing, breathability and comfort (thin and light).**
- B. **Increased lifetime of the product or building component, even in extreme environments.**
- C. **Reduced maintenance of building structures.**
- D. **Novel architectural designs requiring flexibility and thin materials.**
- E. **Weight reduction of building structures.**
- F. **Improved fire safety.**
- G. **Improving energy efficiency of buildings.**
- H. **Facilitates composting.**
- I. **Non fouling and easy clean.**

- **Coating for architectural applications: [Benefits B, C, F].** Includes fluoropolymer-based paints, fluoropolymer coated glass fabric roofs, and laminated coatings, amongst others. They provide resistance to UV radiation, water, oil, dirt and corrosion and impermeability to gases, which makes them excellent for outdoor applications, especially in roofs in large infrastructure such as airports, stadia, tents in Mecca and skyscrapers [Source: 5, 6, 7, 8]. When used in paints, they maintain paint properties (notably colour and shine). They prevent mould and moss growth and are fire resistant, an essential property for the safety of the thousands of people who gather inside these buildings. [Source: 9, 10, 14, 15]. There is also evidence that specific coating systems can reduce building cooling costs (between around 4% up to 22%, depending on colour, geographical location, climate conditions, and substrate type) [Source: 23].



- **"Signature" buildings: [Benefits B, C, D].** Fluoropolymer-based coating was chosen for prominent projects such as Tokyo Sky Tree (the second tallest structure in the world), Tokyo Gate Bridge, Burj Al Arab hotel in Dubai, Singapore's Marina Bay Sands and Mercedes Superdome in New Orleans [Source: 6, 7, 12]. Fluoropolymer-coated glass fabric roofs have been used in the O_2 Dome in London, the Sony Centre in Berlin, and Reliant Stadium in Houston (the first retractable roof in the NFL) [Source: 9].

- **Novel design solutions: [Benefits D, E, G].** PTFE coated glass fabric roofs are used in domes and stadia and the retractable roof of the Wimbledon Centre Court is made using woven PTFE fabric. They permit natural light but keep the dampness off the ground by controlled air conditioning. Fluoropolymers' excellent insulating properties allow for less material to be used, reducing the weight of the structures. [Source: 9, 11, 22].

- **Bridge and off shore bearing pads: [Benefits B, C, E].** Made from PTFE as it has the lowest friction coefficient of all plastics. [Source: 4].

- **Architectural films: [Benefits A, B, D].** Films from fluoropolymers such as ETFE are used as parts of the roofs in stadia, domes and other structures. They can be made translucent; allowing some natural light through but keeping out heat, improving energy efficiency for buildings and stadia. They are usually shaped as panels or cushions and may be accompanied by a LED-light system enabling external colour and colour changes – famous examples being the Allianz Arena in Munich, San Mamés stadium in Bilbao, Olympic stadium in Baku and the Itaipava Arena in Recife (Brazil). [Source: 11, 15, 16, 17]. A steel structure is usually used to sustain the roof, but ETFE is lighter than materials such as glass [Source: 11, 18].

Table sources
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Table 2.7 Uses and benefits of fluoropolymers in **medical applications**

Why are fluoropolymers useful?	How are fluoropolymers used in this sector?
Characteristics **Because of their unique combination of properties fluoropolymers are the material of choice – exhibiting excellent performance - in a wide range of medical applications:** • **Chemical inertness.** • **Biocompatibility.** • **Durability.** • **Corrosion prevention (resistance to chemical attack and low permeation).** • **Low coefficient of friction and low surface energy.** • **Low and high temperature resistance (e.g. from -200 °C to +260 °C for PTFE and PFA).** • **Flexibility.** **Benefits** **Taken together these characteristics enable outstanding functionality and safety in health care, which delivers wider societal benefit, including:** A. **Reduced risk of cross-infections and thus medical complications.** B. **Increased lifetime of implants reducing risk of failure and risk of replacement.** C. **Allows tissue attachment and cell adhesion without an adverse reaction, reducing risk of complications.** D. **Higher consistency of dosages, increasing effectiveness and safety of drugs.** E. **Less frequent clogging and thus less frequent re-application/replacement for the patient (e.g. catheters, tubes).** F. **Improved functionality of medical equipment (e.g. filtering and venting).** G. **Facilitates non-invasive surgical procedures with guidewires, reducing risk of complications.** H. **Facilitates miniaturisation for keyhole survey.**	**These benefits are achieved via the use of various fluoropolymers in the following applications:**  ▶ **Surgically implantable medical devices such as vascular grafts: [Benefits A, B, C].** Often made with expanded PTFE, grafts are critical in current surgery technology to replace damaged vessels in various body parts. Minimally invasive medical devices such as Stent Grafts or Septal Occluder often used for life-saving operations such as repair of aortic aneurisms or holes in the cardiac septum. Other implantable devices include for instance surgical meshes for hernia repair and sutures for use in vascular, cardiac, and general surgery procedures. [Source: 3, 4, 5, 6]. ▶ **Heart patches: [Benefits A, B, C].** For cardiac reconstructions or repair where it is important that complications associated with the formation of tissue attachment to the material be minimised to facilitate reoperation. [Source: 4, 5]. Heart patches made with fluoropolymers usually have three layers. External layers made of expanded PTFE and a middle layer made of an elastomeric fluoropolymer. [Source: 9, 10]. ▶ **Catheters: [Benefits A, C, D, E].** Catheters are tubes used for a variety of functions. They use the inertness, low coefficient of friction and tissue attachment and cell adhesion without an adverse reaction that fluoropolymers can provide. [Source: 1, 2, 4, 11]. ▶ **Diaphragm pumps: [Benefits A, D, F].** These pumps are critical for medical applications (as well as other applications) and are used e.g. for filtration and pumping in dialysis equipment. They are often made of PTFE or PVDF to be durable, inert and resistant to a variety of other substances. [Source: 2]. ▶ **Membranes for filtering and venting purposes: [Benefits F].** PTFE and PVDF are extensively used as the main material of microporous membranes used to filter particles and bacteria in critical fluids. They are hydrophobic and oleophobic but they can be modified so their surfaces are hydrophilic for removing viral particles. PVDF membranes are also used in “western blot tests” (used to detect proteins in blood or tissue). PTFE membrane venting products are designed for high levels of gas permeability which can allow for fast pressure equalisation and airflow. [Source: 2, 7, 8]. ▶ **Further applications: [Benefits A, C, D, E, F, G].** Include sterile container filters, needle retrieval systems, Tracheosto, catheter guide wire for laparoscopy, valves, fittings, pumps, tubing and medicine inhaler canister coatings. [Source: 12, 13, 14, 15, 16]. They are used in a wide variation of medical data processing, such as cables for imaging techniques.

Table sources
[1] http://cool.conservation-us.org/coolaic/sg/bpg/annual/v11/bp11-33.html
[2] https://www.polymersolutions.com/blog/the-impact-of-fluoropolymers-on-the-medical-device-industry/
[3] Ebnesajjad, S, 2005. Fluoropolymers applications in chemical processing industries. William Andrew Publishing. Elsevier

[4] Ebnesajjad, S., 2013. Introduction to fluoropolymers: Materials, technology and applications. PDL Handbook series. Elsevier
[5] https://www.goremedical.com/na/products?locale=mpd_na
[6] http://www.goremedical.com/products/vg?locale=mpd_na
[7] https://www.membrane-solutions.com/ptfe_venting_medical.htm
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[9] https://www.goremedical.com/products/acusealvg---featured-downloads?locale=mpd_euro
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[16] Modjarrad K. & Ebnesajjad S., 2013. Handbook of Polymer Applications in Medicine and Medical Devices. PDL Handbook series. Elsevier

Table 2.8 Uses and benefits of fluoropolymers in **renewable energy**

Why are fluoropolymers useful?	How are fluoropolymers used in this sector?
Characteristics **Fluoropolymers exhibit a unique combination of properties particularly useful to provide protection and functionality for crucial parts in various components of renewable energy installations:** • **Excellent chemical resistance (helping to prevent corrosion) and abrasion resistance (providing e.g. weatherability).** • **Low and high temperature resistance (e.g. from -200 °C to +260 °C for PTFE and PFA).** • **Allow high optical transparency, whilst removing ultraviolet light (crucial for photovoltaics).** • **Electrical insulation.** • **Permeability and barrier properties.** **Benefits** **Taken together these characteristics enable outstanding functionality in renewable energy installation, supporting their development and delivering wider societal benefit, including:** A. **Increased lifetime of components.** B. **Lower maintenance costs.** C. **Increased efficiency from improved functionality and reduced failures.** D. **Increased efficiency in the manufacturing process.** E. **Indirectly: Enabling sustainable energy and facilitating remote location of installations.** F. **Design flexibility.**	**These benefits are achieved via the use of various fluoropolymers in the following applications:** ▶ **Photovoltaics:** ▶ **Front sheets: [Benefits A, B, C, E].** Frequently protected by fluoropolymers (e.g. ETFE, FEP and PVDF film), providing among others weather resistance (heat, water, abrasion, chemical), ultraviolet removal, optical transparency (stable and high light transmittance), low surface energy (non-adhesiveness), high barrier performance to oxygen, excellent fire resistance, flexibility and cost-effectiveness. [Source: 1, 2, 5, 11].  ▶ **Backsheets: [Benefits 1A B, C, E].** Fluoropolymers (e.g. ETFE and PVDF) are widely used to improve their primary function, such as electrical insulation and protection from humidity and sunlight. The fluoropolymers used are resistant to sunlight degradation, block ultraviolet light and are resistant to most chemicals (including environmental pollutants) and heat, whilst preventing the permeation of gases and liquids. They exhibit high dielectric strength and volume resistivity as well as low flammability. [Source: 1, 2]. ▶ **Vents: [Benefits A, B, C, E].** Fluoropolymer-based vents are used in solar applications like junction boxes, concentrating photovoltaics (CPV) modules, inverters and monitors for rapid pressure equalisation, contamination protection and condensation reduction. [Source: 10]. ▶ **Wind turbines:** ▶ **Paints and coatings on the main towers and blades of wind power generators: [Benefits A, B, C, E].** Fluoropolymers (e.g. PTFE and PVDF) provide high weather resistance. The treatment contributes to increased service life and reliable operation in harsh environments; the extension of maintenance cycles; and a more attractive appearance. [Source: 3, 4]. ▶ **Release film: [Benefit D].** Fluoropolymers-based (e.g. PVF and ETFE) release films support the production of wind turbine blades. [Source: 12].

Why are fluoropolymers useful?	How are fluoropolymers used in this sector?

	▶ **Other renewable energy sources: [Benefits A, B, C, E].** Fluoropolymers are also used in solar thermal installations and geothermal plants. [Source: 8, 9].
	
	▶ **Cables: [Benefits A, B, C, E].** The heat, oil and chemical resistance of fluoropolymers mean that they are used for cables in this application – amongst many others - as discussed above. [Source: 4].
	
	▶ **Energy storage systems:** They are a crucial component of energy systems, which comprise an increasing share of renewable energy:
	  ▶ **Lithium ion batteries: [Benefits A, E].** Fluoropolymers (e.g. VDF/TFE copolymer, PVDF) are used as binders for their chemical resistance and endurance. [Source: 4, 6, 7].
	  ▶ **Polymer electrolyte membrane / proton exchange membrane (PEM) fuel cells: [Benefits A, C, E].** Can provide excellent long term storage of renewable energy when using hydrogen produced with renewable energy as a fuel. Various fluoropolymers are used in several components, including the gas diffusion layer (PTFE, FEP), the separator (ETFE, coatings) and drainage piping (PFA). These benefit from various properties that fluoropolymers can provide, such as protonic and electrical conductivity (compounds that have been made conductive), permeability and barrier properties, as well as resistance to oxidation, chemicals and heat. [Source: 5].

Table sources

[1] http://www.agc-chemicals.com/jp/en/fluorine/products/market/result.html?f_id=5&u_id=49
[2] http://americas.kynar.com/en/markets-applications/energy-and-electrical/Photovoltaic/
[3] http://www.agc-chemicals.com/jp/en/fluorine/products/market/result.html?f_id=5&u_id=48
[4] http://www.agc-chemicals.com/jp/en/fluorine/products/market/use.html?f_id=5
[5] http://www.daikinchem.de/downloads/Daikin_Fluorochemical_Products.pdf
[6] http://www.daikinchem.de/energy_storage.html
[7] http://americas.kynar.com/en/markets-applications/energy-and-electrical/battery/
[8] http://www.agc.com/english/portal/energy_solarheat.html
[9] http://www.agc.com/english/portal/energy_geothermal.html
[10] https://www.gore.com/products/categories/venting
[11] https://www.chemours.com/Teflon_Industrial/en_US/assets/downloads/k23269_Teflon_films.pdf
[12] http://www.dupont.com/products-and-services/membranes-films/pvf-films/brands/tedlar-pvf-films/uses-and-applications/tedlar-wind-energy-applications.html

3. The socio-economic contribution of the fluoropolymers industry

3.1 Introduction

This section evaluates the socio-economic effects arising from the manufacture and sale of fluoropolymers[7] in the EU. This relates to fluoropolymers in basic form; this is just the first stage of the value chain. The data draws from a survey with members of the Fluoropolymers Group (FPG) within PlasticsEurope undertaken between February and June 2016. This survey sought detailed information on the volume and value of fluoropolymers in basic form manufactured and sold in the EU as well as exports and imports.

The members of this group do not represent the entire European fluoropolymer market. Therefore an estimation of the total European market size (tonnage and sales) has been made, based on publicly available data, alongside the original survey data and estimates of the total market provided by the FPG members themselves. Further detail on the process used and the original data are in Appendix B.

All data in this section relates to 2015 unless otherwise stated; key data is provided in metric tonnes and Euro. To protect the commercially confidential information of individual companies, all data is aggregated and rounded. Where fewer than three companies have provided data for any given data point, the results are not shown.

3.2 Volume of use (Fluoropolymers in basic form)

As can be observed in Table 3.1 below, around 52,000 tonnes of fluoropolymers are estimated to be sold in the EU as a whole, note this figure has been derived by extrapolating the original survey data[8]. A similar volume, 51,000 tonnes, are estimated to be produced annually in the EU, from which 40% is exported outside of the EU, with annual imports of around 21,500 tonnes. ECHA (2014) estimate that the European markets represents some 21% of the global market and more recent market research expects strong growth in global demand in the order of 5-6% per year[9]. The data suggests competition from outside the EU in at least parts of the market.

Table 3.1 Quantities of fluoropolymers sold in the EU per year (2015)

Quantities	Total EU market (tonnes, 2015)
Tonnes produced in the EU	51,000
Tonnes imported into the EU	21,500
Tonnes exported from the EU	20,500
Tonnes sold in the whole EU market	**52,000**

Source Amec Foster Wheeler Survey with Members of the FPG, 2016. Tonnages are rounded to the closest 500 hundred tonnes.

[7] The term includes fluoroplastics, fluoroelastomers and fluororubber products. Fluorotelomers [C_nF_{2n+1}-$(CH_2)_mH$] and fluorotelomer-based polymers are out of the SEA scope.
[8] This represents an estimation of the European market developed with the methodology set out in Appendix B. This approach uses original survey results extrapolated to present the market as a whole. This estimation was made because the Fluoropolymers group members that participated in the survey do not cover the whole European market.
[9] marketsandmarktes.com, 2013. Fluoropolymer Market By Type (PTFE, PVDF, FEP, Fluoroelastomers) & Application (Automotive, Electrical & Electronics, Chemical Processing, Industrial) - Global Trends & Forecast to 2018 http://www.marketsandmarkets.com/Market-Reports/fluor-polymer-market-497.html , accessed on 14/05/2014 by ECHA for the purposes of drafting the annex XV report on PFOA and related substances.

3.3 Revenues (Fluoropolymers in basic form)

Based on the volumes above and using the FPG survey data alongside Eurostat market data, the volumes above are estimated to generate revenue of around €780m per year in terms of sales onto the EU market. As previously this is based on an extrapolation of original survey data[10]. Of this, some €840m relates to fluoropolymers actually produced in the EU, with the values of exports (€380m) around 18% higher than the sales value of imports (€310m). Therefore, on average, fluoropolymer products exported from the EU have a higher value per tonne than fluoropolymer products imported into the EU.

It is important to note that this is the sales value of sales of fluoropolymers in basic form; this is just the first stage of the value chain. The value of the final products made using fluoropolymers will be substantially greater, in the order of several billion Euro (see section 4 which discusses the downstream uses and benefits of fluoropolymers).

Table 3.2 Annual sales value of the EU fluoropolymer market (2015)

Quantities	Sales value (€m, 2015)[a]
Sales value of product produced in the EU	840
Sales value of imports into the EU	310
Sales value of exports from the EU	380
Total value sold on the EU market	**780**

Notes:
[a]: Rounded to the closest €10m.
The process used to estimate the total market size refer to publicly available data alongside expert estimates from the FPG members themselves. The numbers are therefore, subject to a certain level of uncertainty.

3.4 Research and development (R&D) and innovation

Innovation takes many forms (e.g. direct R&D, informal processes of learning) enabling the development of new products and more efficient production processes. Innovation increases productivity (higher outputs for same level of capital and labour inputs) enabling firms to reduce costs as well as increasing their competitiveness, both across sectors and internationally. Research has shown that innovation has played a significant role in driving economic growth through increased productivity, earnings and the standard of living (Rosenberg, 2004, IMF 2004).[11] [12] One relatively simple measure of the extent of innovation at company and sector level is by comparing investment in R&D; this also illustrates the extent of competition within markets as well as expectation of future demand growth. Extensive research has shown a correlation between R&D investment and company performance (e.g. sales growth, share price) (Oxford Economics, 2010[13]).

Beyond the companies themselves, R&D creates wider societal benefit through “spill overs” as others learn from, adopt and benefit from a new product or process. Examples may include those to the consumer through better and/or lower cost products and accelerated imitation or learning amongst competitors. Research suggests that R&D spill-overs generate between 50%-100% societal return over and above the direct initial R&D investment (Oxford, Economics, 2008[14]).

Companies that participated in the survey for this project reinvested, on average, 5.5% of their revenue related to fluoropolymers, in R&D activities. Based on extrapolating the survey data – and assuming others’

[10] This represents an estimation of the European market developed with the methodology set out in Appendix B. This approach uses original survey results extrapolated to present the market as a whole. This estimation was made because the Fluoropolymers group members that participated in the survey do not cover the whole European market.
[11] https://www.oecd.org/cfe/tourism/34267902.pdf
[12] https://www.imf.org/external/pubs/ft/wp/2004/wp04185.pdf
[13] Oxford Economics (2010) The socio-economic impact of silicones in North America, Final Report.
[14] Oxford Economics (2008) Study of the impact of the Intermediate Research and Technology Sector on the UK economy

in the market invest at a similar level- then up to almost €43m would be reinvested by the sector as a whole, per year (Table 3.3).

The average investment rate shows the industry is highly innovative; it is ***almost triple the average*** estimated proportion of GDP spent on R&D in the EU Member States[15] (1.9% in 2014). It is likely this investment helps maintain the comparatively high value of fluoropolymer products that are produced in the EU, noted in section 3.3.

Table 3.3 Annual research and development expenditure related to fluoropolymers (2015)

	% of revenue related to fluoropolymers	Upper bound estate – total market €m [a]
Total	5.5%	43

Source: Amec Foster Wheeler market survey – February to June 2016.
[a]: **Based on 5.5% of revenues (€780m)**
Note numbers have been rounded to the nearest million.

Table 3.5 overleaf provides examples where fluoropolymers have aided or enabled the development of innovative products.

3.5 Direct employment (manufacturing of fluoropolymers in basic form)

In terms of employment, in total, 31,700 people are employed in the FPG companies in the EU. Note this is just the companies taking part in the survey.

We have estimated the number of employees directly related to the production of fluoropolymers in their basic form, based on survey data – see Appendix B for details. This indicates that some 2,200 employees are involved across the EU, with a gross annual salary of around €100m. It is important to note that this is simply the first stage in the value chain, a great many more employees are sustained from downstream activities. This is discussed in section 4 of this report.

Table 3.4 Total employment in surveyed companies and direct employment associated with EU fluoropolymer production (2015)

	Number of employees[a]
Total number of employees in the FPG Member Companies	31,700
Employment directly associated with fluoropolymer manufacture (first stage in value chain only)	2,200
Downstream employment in sectors using fluoropolymers in Europe	> 20 million (see section 4)[b]

[a] Rounded to the closest hundred.
Source: Amec Foster Wheeler market survey – February to June 2016. The estimate of 2,200 was based on an extrapolation form the original survey data, see Appendix B.
[b] Note not all of these will be in companies using fluoropolymers, but they play an important enabling role in these sectors – this is discussed further in section 4

[15] http://www.oecd-ilibrary.org/industry-and-services/gross-domestic-spending-on-r-d/indicator/english_d8b068b4-en?isPartOf=/content/indicatorgroup/09614029-en

Table 3.5 Selected examples of fluoropolymer enabled innovations

Key Sector	Product	Description
Transportation / Renewable Energy	Solar Impulse	Solar Impulse is a privately funded project aiming to develop solar-powered aircraft technology. The first two experimental prototypes have been promising, with the second (Solar Impulse 2) successfully completing a circumnavigation of the Earth between 2015 and 2016.
	PTFE membrane technology for fuel cells[16]	A fuel cell is an electrochemical device that converts hydrogen to electricity (and heat energy) by means of interaction with a catalyst and oxygen. Water is the only by-product, making fuel cells not only efficient, but environmentally friendly as well. The Proton Exchange Membrane (PEM) fuel cell has emerged as the best technology for fuel cell vehicles. (= Zero-emission powertrains for cars and buses). It consists of a polymer electrode membrane with electrodes on either side. Hydrogen enters on one side (anode), where it reacts with a catalyst and separates into protons and electrons. The protons pass through the membrane to the other electrode (cathode). Here, they combine with oxygen, and with the help of a catalyst, produce water. The electrons, which cannot pass through the membrane, flow from the fuel cell to be used as electrical energy. MEA or Membrane Electrode Assembly is the heart of a PEM fuel cell. It contains the materials necessary to facilitate electrochemical conversion of a fuel to electrical energy
Chemical and Power	Air Filtration for Gas Turbines[17]	Filters are susceptible to high pressure drop sp kes as they reach the end of their service lifetime. This is caused by swelling of particles in wet or humid conditions. HEPA filters are highly efficient and capture virtually all particles in an airstream over their lifetime. When the filters begin to approach end of life, trend monitoring will begin to show sensitivity to wet and humid conditions. The hydrophobic HEPA filters delays this effect, enabling long lifetime even in challenging conditions.
	Mercury Control System for coal-fired utilities[18]	The Mercury Control System (GMCS) is a fixed sorbent system for capturing elemental and oxidised gas phase mercury from industrial flue gas. The system is based on discrete stackable modules that are installed downstream of a particulate collection system. The modules are designed with an open channel structure which provides extremely low pressure drop, avoiding the need for an additional booster fan. The Sorbent Polymer Catalyst (SPC) composite material is the heart of the GMCS. It is a Fluoropolymer based material, which efficiently captures both elemental and oxidised mercury from the flue gas stream. As such, it is insensitive to fuel or process changes that affect mercury speciation. Mercury is securely bound within the SPC via chemisorption. Unlike many activated carbon sorbents, the presence of SO_3 does not inhibit mercury capture by the SPC, making it a very effective solution for high sulphur coals or for units with SO_3 gas conditioning. The GMCS is an innovative solution that eliminates many of the undesirable complications and high operating costs associated with traditional mercury control systems.
Electronics	'Internet of things'[19]	Modern semiconductors are not conceivable without the use of fluoropolymers. Their chemical resistance in the manufacturing of ever more complex and bigger semiconductors, (Micro-electro-Mechanical Systems (MEMS) and chips, alongside excellent data cable insulation for higher processing speeds and lower data losses.

[16] Source: www.gore.com/products/fuel-cell-components?view=section77941
[17] Source: https://www.gore.com/search?q=turbine+filters
[18] Source: https://www.gore.com/resources/brochure-gore-mercury-control-system-for-coal-fired-utilities?from=%5B%22product%3A6751%22%2C%22content_type%3A321%22%2C%22language%3Aen%22%5D
[19] https://www.chemours.com/businesses-and-products/fluoroproducts/ , https://www.chemours.com/businesses-and-products/fluoroproducts/teflon-for-semiconductor-manufacturing/index.html

Key Sector	Product	Description
		There are 6.4 billion items connected to the internet[20]. This includes smart TV, smartphones, smartwatches, smart kitchen appliances (e.g. fridges, kettles), and more. In the case of home appliances, this is not only to enhance users' experience, but is also envisaged to play a key part in the so-called "energy on demand" concept[21], in which electricity demand is shaped by smart devices at a regional or national level to shape peaks and reduce energy supply costs. In this sector fluoropolymers are used in many of the manufacturing pipes, vessels, valves, pumps and other etching and cleaning components/semiconductor components, in printed circuit boards, release films and coatings, wiring and cabling. They play a key role, as their resistance to chemicals, temperature, avoidance of fluid degradation and metallic contamination enable the manufacturing of these smart devices.
	In-flight connectivity[22]	A relatively recent development enables improved communication and internet access in aircraft with excellent telecommunications and positioning signals without increasing the size/weight of hardware required. This is achieved with cable-based antennas constructed with engineered fluoropolymers and light coaxial cable. Given the reduction in hardware capital costs, it is a cost-effective solution for improving in-flight entertainment. Apart from providing a technological solution, these antennas also comply with the demanding vibration, temperature range, durability shock and fire specifications of aircraft. Alternatively the whole on demand in-flight entertainment system data processing can be run with light weight fluoropolymer insulated data cables.
Textile and Architecture	"Cool roof" technology[23]	A group of multidisciplinary scientists developed a new type of PVDF emulsion resin that did not require the use of solvent and high bake temperatures. This resin has been used as the base of reflective white roof coatings, which is known as "cool roof" technology. This has proven successful in the US, through initiatives triggered by new energy efficiency regulations in US States such as California. This PVDF resin enables roofs to have a total solar reflectance of above 65%, which is required to obtain an Energy Star® rating. Moreover, these roofs are required to maintain at least 50% of this reflectance 3 years after receiving this rate. A typical white paint based on this new resin has an initial total solar reflectance of 81%, and maintains 78% up to five years later (3% reduction). As a result, these roofs provide excellent energy efficiency and have a lower life cycle cost than most traditional coatings.
	Fabric membrane system against heat stress[24]	An intelligent material construction using two ePTFE membranes: A highly breathable layer of thermal protection is positioned directly under the outer material of the garment. The membrane attached to the outer side of this layer prevents liquid penetration from the outside. This thermal insulation layer is combined with a moisture barrier that faces inwards towards the body. This second membrane quickly wicks moisture away and transports it to the outside. It is a lightweight, breathable and waterproof system that delivers high levels of thermal protection in firefighter gear while reducing the risk of burn injuries and heat stress in wet and dry conditions.
	Innovative designs for stadia[25]	Since the construction of Allianz Arena in 2005 and Beijing National Aquatics Centre in 2008, many other new-build stadia have included fluoropolymer cushions and films. As illustrated in section 2, they enable a much lighter and versatile design with possibilities of

[20] Mintel Group Limited (2016) The connected home - UK
[21] http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=6102354&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D6102354
[22] http://www.semiconductorpackagingnews.com/press/37362.html
[23] http://pmse.sites.acs.org/acsteaminnovationaward.htm
[24] Source: https://www.gore-tex.co.uk/professional/fire-and-rescue/technologies/gore-parallon-system-garments-with-gore-tex-moisture-barrier
[25] http://www.birdair.com/press/birdair-provide-unique-etfe-film-new-atlanta-stadium , http://www.agc.com/english/products/jirei_arena.html , http://www.designboom.com/architecture/new-camp-nou-barcelona-football-stadium-n kken-sekkei-04-23-2016/ , http://dunn-lwa.com/portfolio/cuauhtemoc-stadium-etfe/ , http://www.designbuild-network.com/projects/watercube/

Key Sector	Product	Description
		enhancing the public experience with LED-lights and other effects. Modern stadia and sport centres built for major events such as the Olympics or renovated stadia for sports teams such as FC Barcelona, FC Puebla and Atlanta Falcons use architectural films made of fluoropolymers, providing lightweight, durable and safe designs.
Medical applications	Endoprosthesis for the functionality of damaged liver[26]	The proprietary, reduced permeability ePTFE graft lining minimises transmural permeation of bile and mucin (which are common causes of patency loss) and minimises tissue ingrowth into the graft for ease of surgical dissection during liver transplantation. Additionally, it offers improved radial compression strength over the leading, commercially available stents, and ensures secure anchoring with minimal kinking and tissue deformation. The unlined "chain link" segment of the device allows for nutrient portal perfusion
	Membrane for heart defects[27]	Physicians have been performing catheter-based procedures in the heart to make diagnoses and treat heart conditions for many years. Catheter-based closure of a hole in the cardiac septum involves the placement of a permanent implant, such as an ePTFE based medical implant, using a minimally invasive procedure. It is a permanent implant consisting of a wire frame covered with a thin ePTFE membrane. The wire frame is made of a platinum-filled nickel-titanium (Nitinol) alloy. The ePTFE material has been used in open-heart surgery for more than 35 years with a history of proven safety in medical implants.

[26] Source: https://www.goremedical.com/products/cardioform?locale=mpd_na
[27] Source: https://www.goremedical.com/products/cardioform?locale=mpd_na

3.6 Sales of fluoropolymers to downstream sectors

The manufacture of fluoropolymers is just the first stage in the value chain. This section provides further information on various fluoropolymer products that are sold into several downstream sectors which are both important to the wider European economy and where fluoropolymers provide important enabling characteristics.

The FPG survey obtained data on the volume and value of fluoropolymer sales disaggregated into the various sectors. As before these have been extrapolated from survey data (see Appendix B). Overall approximately 52,000 tonnes of fluoropolymers were sold in the EU in 2015, with sales revenue of around €780m.

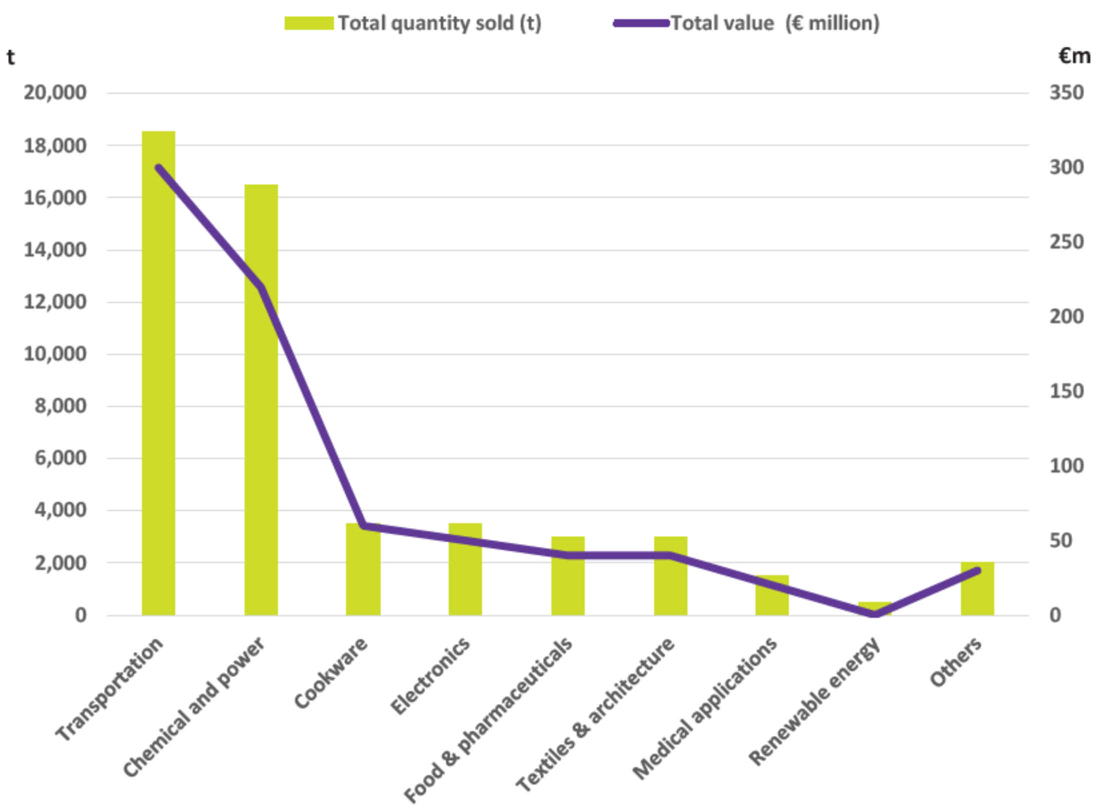
The largest sector in the original survey data was transport, which accounts for 36% of the FPG European sales volume and some €300m for the EU market as a whole. Chemical and power is the second largest sector, with 16,500 tonnes and €220m, respectively. Other relevant sectors in terms of annual volumes include cookware and electronics (with 3,500 tonnes, 7% of EU market in each case), food and pharmaceutical and textiles and architecture (both with 3,000 tonnes, 6%). Other sectors (renewables, medical applications and 'others') comprise a further 7% (some €60m) (Table 3.6). The data is shown graphically in Figure 3.1 below.

Table 3.6 Downstream applications of fluoropolymers (tonnes and value, 2015)

Sector	Typical applications	Total quantity sold (tonnes)	Total value (€m)
Transport	Fuel lines, hoses, hydraulic systems, O-rings, gaskets, electronic systems, coating for a variety of purposes (e.g. cables, wires), fuel cell materials.	18,500	300
Chemical and power	Piping, tubing and fittings, fluid-handling components, vessels, storage tanks, sensors, sealants, binders in energy storage devices (e.g. batteries)	16,500	220
Cookware	Non-stick coating for cook and bakeware (e.g. pots, pans, baking trays)	3,500	60
Electronics	Semiconductors, printed circuit equipment, wiring, cabling	3,500	50
Food & pharmaceuticals	Valves, stainless steel piping, tubing, filters, seals, gaskets and other standard fluid handling components, paper tableware, conveyor belts, labware products, packaging	3,000	40
Textiles & architecture	Waterproof clothes and footwear, space suits, coating for architectural applications, architectural films	3,000	40
Medical applications	Cardiovascular grafts, heart patches, ligament replacements, catheters, filtering membranes	1,500	20
Renewable energy	Front and back sheets for PV, paint and coating for wind turbines, coating for wires and cables, binders in lithium-ion batteries	500	<5
Others	-	2,000	30
Total		**52,000**	**780**

Source: Amec Foster Wheeler market survey – February – June 2016 (% of sales volumes and values). Note all sales values are rounded to the nearest €10m all tonnage data are rounded to the nearest 500 tonnes. (*) Differences between sectors and total and with values quoted in Table 3.1 / Table 3.2 due to rounding.

Figure 3.1 Total quantity sold and total value per key sector (2015)



Source: Amec Foster Wheeler market survey – February – June 2016 (% of sales volumes and values). Note all sales values are rounded to the nearest €10m all tonnage data are rounded to the nearest 500 tonnes.

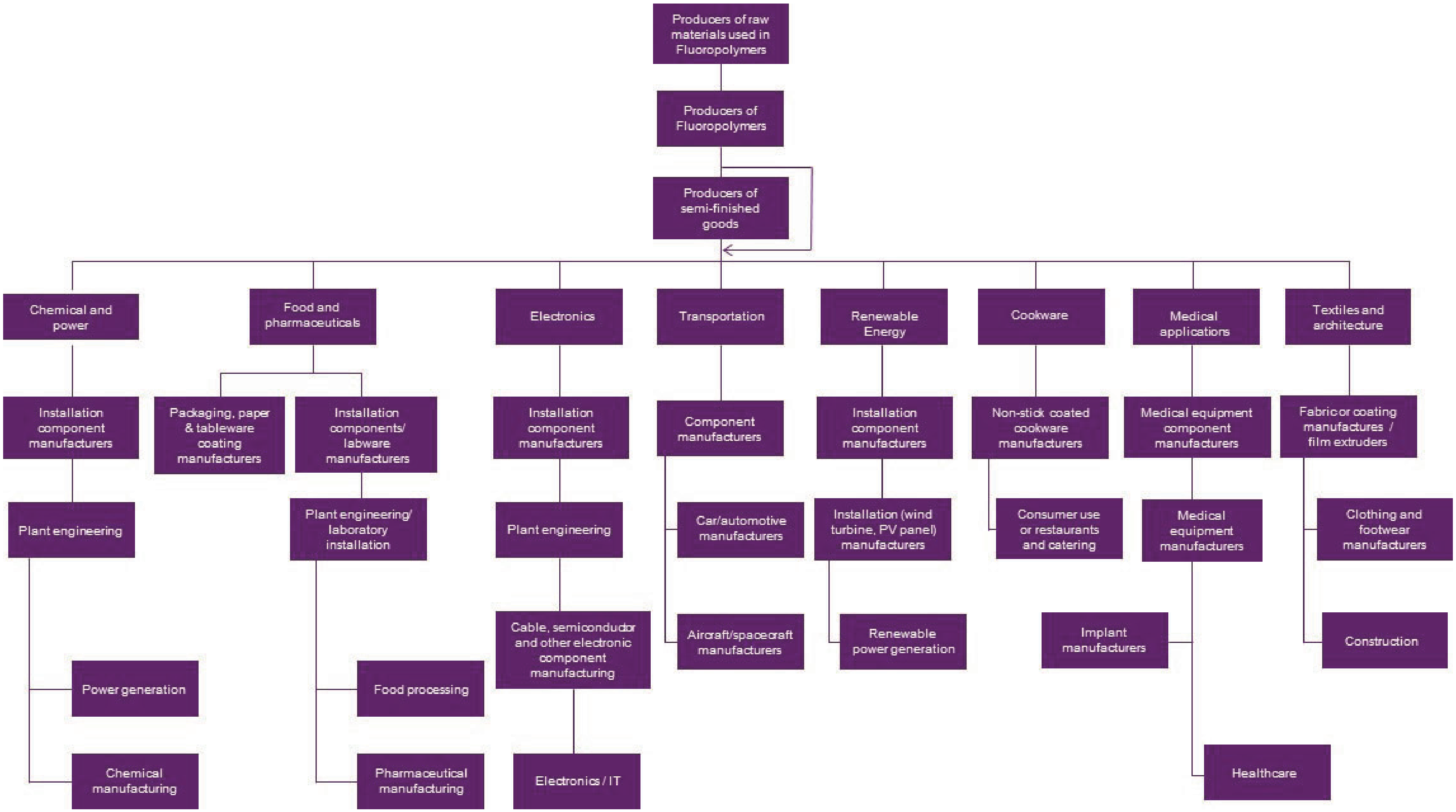
3.7 The fluoropolymer value chain

Figure 3.2 provides an overview of the key stages in the value chain for fluoropolymers within the eight key sectors. The value chain illustrates the various industrial/manufacturing users of fluoropolymers, based on the survey among downstream users and research on uses summarised in Section 2, as well as the diversity of commercial users and end products in which fluoropolymers are used.

The value chain begins with the provision of raw materials and subsequently the production of fluoropolymers. Fluoropolymers are then supplied to the key sectors, via manufacturers of various multi use semi-finished goods[28]. Within each sector, the main value chain elements leading to the manufacturer of the end product or service prior to the point of sale to the final consumer are shown. Note that the diagram is intended to map out the key stages – there will be a large number of individual companies within each stage.

[28] Semi-finished goods include e.g. threads, foils, fibres, sealing material, tubes and membranes and other small parts. These are often generic enough to be used as input to manufacture various products from multiple sectors. However, often they are relatively complex goods. A strict distinction between semi-finished goods and components cannot always be made. Furthermore, in some cases fluoropolymers are applied to specific products in forms other than as semi-finished good, for instance as a coating.

Figure 3.2 Overview of the fluoropolymer value chain stages (key sectors)



Source: Based on downstream applications provided in Amec Foster Wheeler Survey 2016 and in Section 2.

4. Downstream benefits of fluoropolymers

4.1 Introduction

The previous section evaluated the direct economic and social impact of the industry to Europe today. But a much larger socio-economic value is created via the characteristics of the products made by the industry that are used by downstream users, their "enabling characteristics". For each of the eight key sectors, this section evaluates three things:

- Firstly, the specific enabling characteristics that fluoropolymers deliver are illustrated. This benefit is quantified where possible, described qualitatively where not. The evidence in the section is drawn from industry questionnaires and downstream user feedback alongside desktop research. These enabling characteristics includes those with direct economic effects, such as contributions to efficiency, but also sustainability, including emission savings.
- Secondly, by evaluating the socio-economic importance of the wider sectors where fluoropolymers are widely used, we place these benefits in wider context. So not only do fluoropolymers deliver important benefits, the sectors themselves are strategically important to European economy and society. We do not claim this economic activity is reliant on or derived from fluoropolymers, but they serve important strategic functions with the sectors concerned, through the various benefits that they deliver. Later in the report, we discuss a hypothetical situation where fluoropolymers were unavailable; this serves to illustrate the scale of economic activity that might be affected under such a scenario.
- Thirdly, in several instances fluoropolymers make a contribution to wider sustainability, through for example supporting weight reductions, avoiding emissions and/or leaks and carbon emission reductions. These are also drawn out.

4.2 Key Market 1: Transport

Enabling characteristics and socio-economic contribution

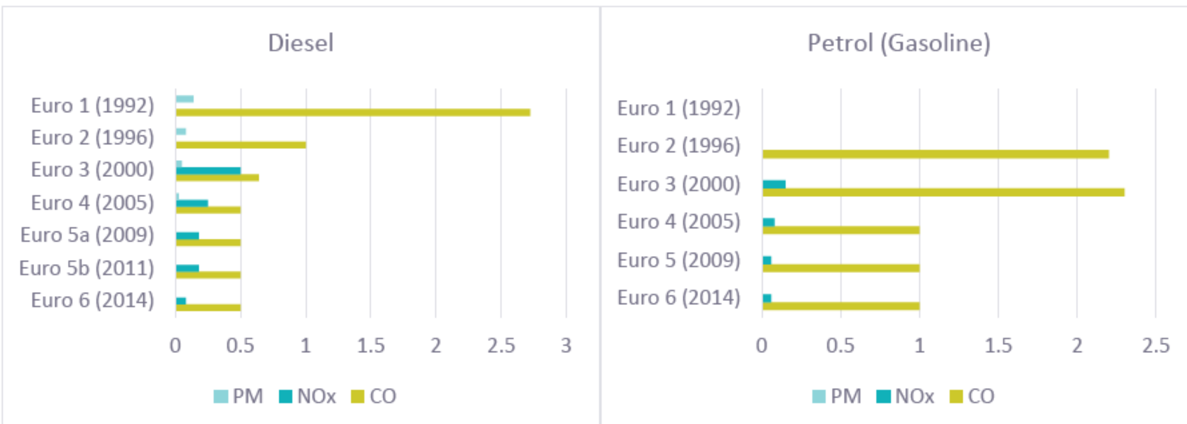
- **Fluoropolymers enhance reliability, safety and communication in aircraft**. They help, alongside other advanced materials, to deliver performance under challenging environmental conditions. This includes safety critical components such as in seals, hoses and tubing as well as various electronic data and communication equipment.
- **In automotive applications fluoropolymers prolong the useful life of various components critical for performance, emission control and safety by providing durable and effective protection against heat, aggressive fuels, humidity, vibrations and compression**. This contributes to increased reliability and durability of car parts, and hence to a reduction in both the cost and extent of maintenance and breakdowns. For instance, a 2006 study[29] estimated **the use of fluoropolymers in high temperature wire insulation and fuel hoses saves €180m (ca. €200m in 2015 prices[30]) over the full lifetime of cars in Europe.**
- The same study[31] estimated that **fluoropolymer use in fuel hoses enables fuel savings worth €35.9m (ca. €40.7m in 2015 prices[32]) annually in Europe.** The study also indicated

[29] NERA Economic Consulting (2006): Societal Benefits of Fluoropolymers and Fluorotelomers. Quoted in: http://www2.dupont.com/PFOA2/en_US/assets/downloads/societal_benefits.pdf.
Note that the source does not specify how exactly Fluoropolymers generate these benefits.
[30] Conversion to 2015 prices based on seasonally and calendar adjusted GDP deflator for the EU-28 from Eurostat: http://ec.europa.eu/eurostat/web/products-datasets/-/teina110.
[31] NERA Economic Consulting (2006): Societal Benefits of Fluoropolymers and Fluorotelomers. Quoted in: http://www2.dupont.com/PFOA2/en_US/assets/downloads/societal_benefits.pdf.
[32] Conversion to 2015 prices based on seasonally and calendar adjusted GDP deflator for the EU-28 from Eurostat: http://ec.europa.eu/eurostat/web/products-datasets/-/teina110.

that **the associated reduction in air emissions add benefits in terms of avoided damage to human health valued at another €86m (ca. €97m in 2015 prices[33]), in the order of €140m in total**.

- **In other components fluoropolymers and fluoroelastomers contribute to engine efficiency, weight reductions and emission control**. Consultation with downstream users of fluoropolymers has indicated that **modern legal requirements such as road transport emission standards, such as "Euro 6" and "Euro 7" could not have been achieved without these materials**. [34] Progressive improvements in these standards over time are shown in Figure 4.1 below. The Euro emission standards aim to reduce the significant health impacts from road transport emissions, which have been estimated to cause economic costs of about $364 billion (bn) in the EU-24 in 2010[35] (equivalent of about €345bn in 2015 prices[36]) from all sources. Fluoropolymers **facilitate advanced energy storage and conversion technologies**, such as PEM fuel cells.

Figure 4.1 Tightening of diesel and petrol vehicle emission limits for selected pollutants according to the Euro emissions standards (g/km)



Source: Amec Foster Wheeler 2016 based on the respective EU Regulations.[37]
Pollutants and health effects.
PM = Particulate Matter - health effects include: respiratory and cardiovascular morbidity, such as aggravation of asthma, respiratory symptoms and an increase in hospital admissions; mortality from cardiovascular and respiratory diseases and from lung cancer[38].
NOx = oxides of nitrogen - mainly impacts on respiratory conditions causing inflammation of the airways at high levels. Long term exposure can decrease lung function, increase the risk of respiratory conditions and increases the response to allergens. NOx also contributes to the formation of fine particles (PM) and ground level ozone, both of which are associated with adverse health effects[39].
CO= carbon monoxide - short term health effects include headache, dizziness and nausea. Long term exposure has been associated with increased risks of heart disease[40].

[33] Conversion to 2015 prices based on seasonally and calendar adjusted GDP deflator for the EU-28 from Eurostat: http://ec.europa.eu/eurostat/web/products-datasets/-/teina110.
[34] Certain Fluoropolymer/Fluoroelastomer components such as seals are crucial in achieving the latest EU emission control standards Euro 6 & 7 See for instance: http://www.seals.saint-gobain.com/news_detail.aspx?id=275938
[35] OECD: The Cost of Air Pollution: Health Impacts of Road Transport. OECD Publishing (2014). http://www.keepeek.com/Digital-Asset-Management/oecd/environment/the-cost-of-air-pollution_9789264210448-en#.V-z_KfkrKM8#page1
[36] Inflation based on U.S. Bureau of Economic Analysis: Table 1.1.9. Implicit Price Deflators for Gross Domestic Product (http://www.bea.gov/iTable/iTable.cfm?reqid=9&step=3&isuri=1&903=13#reqid=9&step=3&isuri=1&903=13). Conversion to Euros based on 2015 yearly average exchange rate from the European Central Bank (https://www.ecb.europa.eu/stats/exchange/eurofxref/html/index.en.html).
[37] For a full list, see http://ec.europa.eu/environment/air/transport/road.htm.
[38] World Health Organisation (WHO, 2013): http://www.euro.who.int/__data/assets/pdf_file/0006/189051/Health-effects-of-particulate-matter-final-Eng.pdf
[39] When nitrogen is released during fuel combustion it combines with oxygen atoms to create nitric oxide (NO). This further combines with oxygen to create nitrogen dioxide (NO2). Nitric oxide is not considered to be hazardous to health at typical ambient concentrations, but nitrogen dioxide can be. Nitrogen dioxide and nitric oxide are referred to together as oxides of nitrogen. Source: http://www.icopal-noxite.co.uk/nox-problem/nox-pollution.aspx
[40] Source: Center for Disease Control and Prevention https://ephtracking.cdc.gov/showCoRisk

Socio-economic value of the sector

Car manufacturing / automotive components

Beyond emission reductions, Fluoropolymers make important contribution to the performance and functionality of automotive vehicles. This includes various fuel line applications, use of on board computers, high temperature CO_2 sensors. This in turn aids global competitiveness and supports the significant economic activity of the sector in Europe in terms of car design, innovation, manufacture and export. Moreover, the role of fluoropolymers is likely to gain in importance in the future. Electric vehicles are enabled by high performance insulators, fluoropolymers in lithium batteries and hydrogen fuel cells. Similarly developments in automatic piloting are reliant on high speed data processing and data communication.

The automotive sector as a whole accounts for 6.5% of the EU GDP (some €955bn[41]). The industry as a whole directly employed some 12.2 million people across Europe (about 6% of the EU workforce). Of these, 2.3 million are high-skilled jobs. Indirectly, the global automotive trade association OICA estimate that for every 1 direct job some 5 further jobs are sustained indirectly along automotive value chains[42]. Similar results come from a 2012 study in the UK which identified some 3.5 additional jobs created from every one full time job at Nissan and Jaguar Land Rover manufacturing facilities[43].

According to ACEA[44], there are currently about 296 automobile assembly and production plants in the EU28, located across 26 countries and manufacturing more than 18 million cars, vans, trucks and buses every year. Some 16 million passenger cars and a total of 18 million motor vehicles were manufactured in Europe in 2015 alone (20% and 22% of global production respectively), contributing to a trade surplus of more than €100bn every year. The automobile sector also contributes to a significant share of R&D activities in the EU28: R&D expenses for automobile sector amount to some €45bn, about 26% of total EU expenses. In 2015 about 6,000 patents were granted to firms in the EU automotive sector. Tax revenues from vehicles in 14 European countries only alone were some €400bn. Global production is expected to exceed 100 million vehicles of all types by 2017[45].

Aircraft and aerospace industry

Fluoropolymers are used in various components in aircraft. They enhance reliability, safety, communication and performance under challenging environmental conditions. This includes safety critical components such as in hydraulic seals, hoses and tubing as well as various electronic communication equipment. Aircraft manufacturing is a genuinely global – and highly competitive - sector with a small, but increasing number of advanced manufacturers. Improvements, even small increments in the functionality of aircraft can result in major operational savings, alongside improved safety. The use of fluoropolymers aids global competitiveness and supports developments in aircraft design, innovation, manufacture and export. They also help to deliver operational savings, once the aircraft is in use.

Europe is a major player in the aviation manufacturing market. 2013 Eurostat data[46], report some 4,100 companies involved[47]. These companies registered a turnover of some €129bn and employed some 438,000 people. Highly skilled; GVA per employee is around €94,000 per year, substantially above the EU average (€54,000 per year). More than 100,000 people are employed in each of the UK and France, with some 95,000 in Germany. Turnover in these three countries represents about 80% of the total EU turnover of this sector (around €104bn out of €129bn).

[41] According to the European trade association ACEA Estimate based on the indicative share provided by ACEA (6.5%) and on 2015 GDP figure for the EU 28 reported by Eurostat of about €14,700bn(rounded figure) ["Eurostat, GDP and main components (output, expenditure and income)", Last update: 14-10-2016. Available from: http://ec.europa.eu/eurostat/data/database]
[42] http://www.oica.net/category/economic-contr butions/auto-jobs/
[43] http://www.economicmodelling.co.uk/2012/05/17/the-impact-of-car-manufacturing-employment/
[44] http://www.acea.be/automobile-industry/facts-about-the-industry
[45] http://www.eulerhermes.com/mediacenter/Lists/mediacenter-documents/Economic-Outlook-The-global-Automotive-market-Sept14.pdf
[46] Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E) [sbs_na_ind_r2]
[47] The definition is "activities relating to the manufacturing and maintenance of aircraft and spacecraft".

The sector is a major source of global exports, some €118bn in 2014[48]. Of this, some €46bn of sales value originated in France, where the headquarters of the largest European civil and military aircraft manufacturing firm EADS (Airbus) are located. Germany follows with €38bn and the UK is third with €14bn of sales[49]. There are several specialised and highly skilled civil and military aerospace activities in specific Member States. These include fuselage design and assembly/testing (France and Germany)[50]; wing design and manufacturing (United Kingdom and Spain[51]); engine manufacturing, landing gear, fuel systems and helicopters (United Kingdom)[52]; carbon fibre reinforced plastic (CFRP) components, internal data and power supply systems (Germany). Some key trends are below:

- Turnover in aerospace and defence (including space) overall amounted to just under €200bn in 2014, of which some €140bn related to aeronautics and around €12bn related to space.
- In terms of the specialist spacecraft manufacturing sector, over 40,000 people were directly employed in the sector as of 2014, which registered over €7bn of final sales. Both sales and employment have been steadily increasing over the preceding decade, from just over €4bn and 30,000 employees.

Figure 4.2 Aerospace and defence sector turnover breakdown between 2009 and 2014 (€bn)

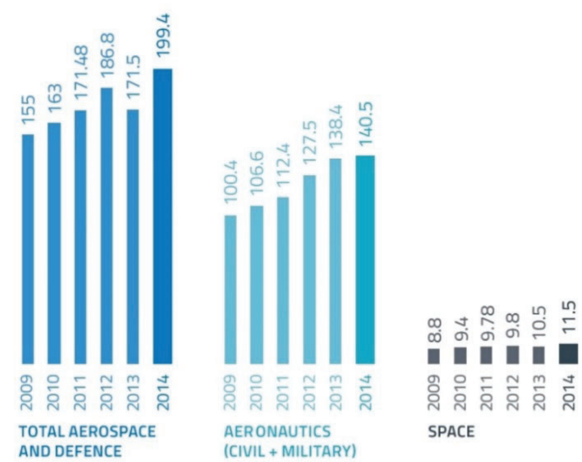
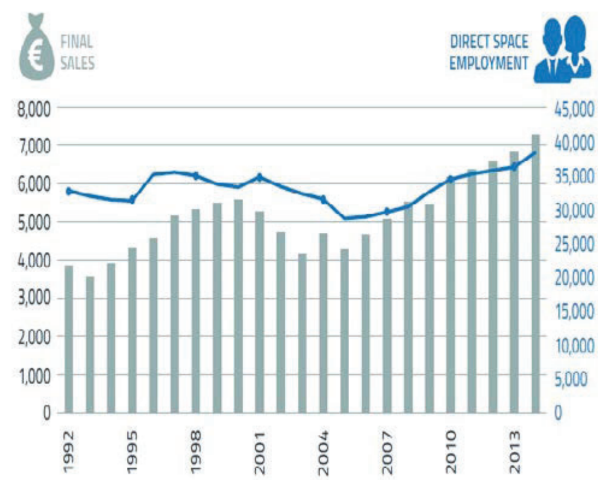


Figure 4.3 Sales and employment in the space manufacturing industry (1992-2014)



Source: reproduced from ASD (2014) Aerospace and Defence Industries, Association of Europe (figures excludes "land and naval revenues"[53].

[48] ECB exchange rate for 2014 $/€ 0.80612, as used in previous sections (Aircraft and Spacecraft)
[49] http://www.worldsrichestcountries.com/top-aircraft-spacecraft-exporters-2013.html sourcing data from Trade Map, International Trade Centre, www.intracen.org/marketanalysis
[50] http://www.airbus.com/company/worldwide-presence/airbus-in-germany/
[51] http://www.airbus.com/company/worldwide-presence/airbus-in-spain/
http://www.airbus.com/company/worldwide-presence/airbus-in-france/
[52] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/31807/12-954-reach-skies-strategic-vision-uk-aerospace.pdf
[53] Available from: http://www.asd-europe.org/communication/publications/facts-figures/

4.3 Key Market 2: Chemical and power

Enabling characteristics and socio-economic contribution

Fluoropolymers and their unique set of properties enable a high level of efficiency and environmental safety in the chemical and power sectors:

- **Fluoropolymer coatings, linings and components prevent corrosion in chemical manufacturing and power installations**. This increases the lifetime of components reduces maintenance costs, waste, consumption of materials to renew corroded components and hence total life cycle costs. Considering each in turn:
  - Corrosion is a significant cost factor in this sector. A 2002 study[54] estimated that the direct cost of metallic corrosion in the United States to the chemical, petrochemical and pharmaceutical industries as $1.7bn annually (0.5% of the gross value added of these sectors in the same year) and the direct cost of metallic corrosion to electricity generating plants as $6.9bn (3.8% of the gross value added (GVA) of the utilities sector in the same year)[55]. Applying this shares of to the GVA of the same sectors in the EU28 in 2013[56], this would imply total costs of corrosion of about €15bn for the chemical and power sectors. Simply making a highly conservative assumption in the absence of specific data - that fluoropolymer uses reduce this by just 1% - suggests **savings of around €150m per year**.
- Fluoropolymers also prolong the lifetime of plant and equipment. Maintenance costs in the chemicals industry are typically around 5% of fixed capital costs[57]. Yearly capital spending in the EU chemical industry has been around €20bn per year over the last 20 years[58]. Hence, current maintenance costs are estimated in the region of €1bn. A chemicals manufacturer consulted as part of the study stated that the use of fluoropolymers in their equipment has increased the lifetime by more than a factor of 2. This suggests that which the installation would have to undergo maintenance significantly less often, up to half as often, saving up to half the maintenance costs. In the absence of specific data, assuming conservatively that about 10% of the European chemical industry use this fluoropolymer application and have managed to achieve savings on this scale suggests total savings to the sector as a whole could be in the order of up to €100m annually[59]**.**
- Facing increasing competition, especially from companies in Asia with comparatively low energy and labour costs, it is especially important for the European chemicals industry to **maintain efficiencies to remain competitive**[60].
- Fluoropolymers also **provide health, safety and environmental benefits.** Durable and reliable fluoropolymer components prevent leaks and facilitate cleaning (via non-stick properties), which

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[54] Gerhardus H. Koch, Michiel P.H. Brongers, Neil G. Thompson, Y. Paul Virmani, J.H. Payer: “Corrosion Costs and Preventive Strategies in the United States (2002). https://www.nace.org/uploadedFiles/Publications/ccsupp.pdf

[55] USA gross value added 2002: Petroleum and coal products: $51,176m; Manufacture of chemicals and chemical products: $207,080m; Plastics and rubber products: $63,490m; Utilities: $180,137m. Source: US Department of Commerce, Bureau of Economic Analysis (http://www.bea.gov/industry/gdpbyind_data.htm).

[56] EU gross value added 2013: Manufacture of coke and refined petroleum products: €24,322m; Manufacture of chemicals and chemical products: €126,236; Manufacture of rubber and plastic products: € 88,611m; Utilities (sum of NACE Codes D and E): €360,456m. Source: Eurostat: National Accounts aggregates by industry (up to NACE A*64) [nama_10_a64].

[57] See for instance:
Harry Silla: Chemical Process Engineering: Design And Economics. Page 38. CRC Press, 8 Aug 2003.
KLM Technology Group: General Process Plant Cost Estimating (Engineering Design Guideline). Page 24. June 2014.
http://kolmetz.com/pdf/EDG/ENGINEERING_DESIGN_GUILDLINE_General_Plant_Cost_Estimating_Rev01web.pdf

[58] CEFIC: http://fr.zone-secure.net/13451/186036/?startPage=3#page=44

[59] Under the assumptions outlined above, maintenance cost of 10% of the European chemical industry are estimated as €100m (10% of €1bn). Without fluoropolymer use, these could be twice as high, so €200m. The savings are equal to the difference between the actual costs (€100m) and the counterfactual cost without fluoropolymer use (€200m). Alternatively, if it is assumed that all of the European chemical industry uses fluoropolymers but achieve savings of just 10% of maintenance costs (assumed in the absence of any specific data), this leads to the same approximate figure. Clearly each plant has differing requirements but this serves to illustrate – in broad terms – the tang ble benefits delivered.

[60] CEFIC: http://www.cefic.org/Documents/About-Us/Short-Introduction-To-the-European-Chemical-Industry-2014.pdf

reduces the risk of accidents and exposure of the workforce to pollutants and dangerous chemicals.

- Exposure can cause a wide range of health effects and people place significant values on avoiding these effects. For instance, the willingness to pay to avoid one acute episode of mild dermatitis lasting approximately two weeks, a relatively minor effect, has been estimated as €227.[61] By helping to prevent exposure to chemicals that can cause these and other effects, fluoropolymers contribute to avoiding such effects.

- They also **enable reliable applications that prevent or remove pollution**, such as filters, membranes, scrubbers and heat exchangers. For instance, fluoropolymers enable heat exchanger technology that improves energy efficiency and therefore reduces greenhouse gas emissions. Based on a case study of a Polish Combined Heat and Power (CHP)[62] plant it is estimated that for CHP installations alone, heat exchanger technology enabled by fluoropolymers could contribute to energy savings worth around €8bn and CO_2 emission reductions worth around €0.5bn at market prices or €3bn considering the societal cost of CO_2 (see box below). While heat exchanger technology is possible without fluoropolymers and thus the benefits are not incurred by fluoropolymers alone, heat exchangers are significantly less expensive and more durable with fluoropolymers when exposed to corrosive flue gases, according to evidence provided during downstream user consultation.

Box 4.1 Case study: Socio-economic contribution of fluoropolymer enabled heat exchanger technology

The installation of heat exchanger technology using fluoropolymer pressure tubes at Siekierki (Poland) combined heat and power generating station with a rated output of 620 MW, has led to energy savings of 46 MW, reducing CO_2 emissions by 17,200 kg/h [Source 1].

- ***46 MW / 620 MW = 0.074***
  (Capacity saved by fluoropolymer-enabled heat exchangers in Siekerki / total capacity Siekerki)

- ***17,200 kg/h / 46 MW = 373,913 kg/h/MW***
  (CO_2 emission reduction Siekerki / Capacity saved by fluoropolymer-enabled heat exchangers in Siekerki).

Total installed CHP capacity (both electricity and heat) in the EU28 was 392 GW in 2013 according to Eurostat [Source 2]. If the same energy savings and CO_2 mitigation per rated output as in Siekierki could be achieved through fluoropolymer heat exchanger technology for all CHP installations in the EU28, this would save about 30 GW of energy and 10 million kg/h of CO_2.

- ***0.074 * 392.4 GW = 29.1 GW***
  (Capacity saved per total capacity in Siekerki * total capacity EU28)

- ***373,913 kg/h/MW * 29.1 GW = 10,885 t/h***
  (CO_2 emission reduction per capacity saved in Siekerki * capacity saved in EU28).

The EU-28 average gas price for industrial consumers in 2015 was 0.032 €/kWh [Source 3].
Assuming that if this energy was not saved, the 30 GW would have to be constantly generated using natural gas at EU28 average industrial consumer prices, this implies yearly savings of about €8.2bn.

- ***29.1 GW * 24h * 365 * 0.032 €/kWh = € 8.237bn***
  (capacity saved in EU28 * 24h for 365d a year * gas price).

In terms of CO_2 emissions – the average Spot Primary Market Auction price for EU CO_2 emission allowances of 2016 until the time of writing (last auction included 06/09/2016) was 5.3 €/t of CO_2 [Source 4]. At this price and assuming constant operation of the installations, the EU-wide CO_2 emission reduction calculated above implies savings of about €500m in EU emission allowances for the operators.

- ***10,885 t/h * 24h * 365 * 5.3 €/t = € 0.507bn***
  (CO_2 emission reduction in EU28 * 24h for 365d a year * CO_2 emission allowances price).

However, the benefit of CO_2 emission reductions to society is greater than the savings in EU emission allowances to operators, as the current CO_2 emission allowance prices do not reflect the full societal cost of carbon. The European Environment Agency has recently applied a value of 33.6 €/t for estimating the cost of pollution from European industrial facilities [Source 5]. At this cost and assuming constant operation of the installations, the EU-wide CO_2 emission reduction

[61] At 2012 prices. ECHA (2016): Valuing selected health impacts of chemicals - Summary of the Results and a Critical Review of the ECHA study. https://echa.europa.eu/documents/10162/13630/echa_review_wtp_en.pdf
[62] A highly efficient process that captures and utilises the heat that is a by-product of the electricity generation process. Source: https://www.gov.uk/guidance/combined-heat-and-power

Box 4.1 Case study: Socio-economic contribution of fluoropolymer enabled heat exchanger technology

calculated above implies societal benefits of about € 3.2bn. Note that savings from EU emission allowances and societal benefits from CO_2 emission reduction are not additive.

- ***10,885 t/h * 24h * 365 * 33.6 €/t = € 3.204bn***
  (CO_2 emission reduction in EU-28 * 24h for 365d a year * social cost of CO_2).

In conclusion, if heat exchanger technology enabled by fluoropolymer pressure tubes was installed in all CHP installations in the EU, that would imply energy savings worth €8.2bn a year and additionally CO_2 emission reductions worth either €0.5bn (if valued at market prices) or €3bn (if considering the societal cost of CO_2). Note that these values reflect savings incurred by heat exchanger technology and not by fluoropolymers alone. Heat exchangers are possible without fluoropolymers, but the downstream consultation has indicated that heat exchangers with alternative materials would be significantly more expensive and less durable when exposed to corrosive flue gases. Thus, heat exchanger technology is economically feasible in fewer cases and the benefits described above would be significantly reduced without fluoropolymers.

Sources:
[1] Dupont/Wallstein: http://www.wallstein.de/fileadmin/Download_s/Presse_Notizen/Press_Release_DuPont_englisch.pdf;
[2] Eurostat: http://ec.europa.eu/eurostat/documents/38154/4956229/CHP+data+2005-2013/62e87958-0b9a-4195-af70-356493e12233;
[3] Eurostat: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_203&lang=en;
[4] European Energy Exchange: https://www.eex.com/en/market-data/emission-allowances/auction-market/european-emission-allowances-auction/european-emission-allowances-auction-download
[5] European Environment Agency: http://www.eea.europa.eu/publications/costs-of-air-pollution-2008-2012.

Socio-economic value of the sector

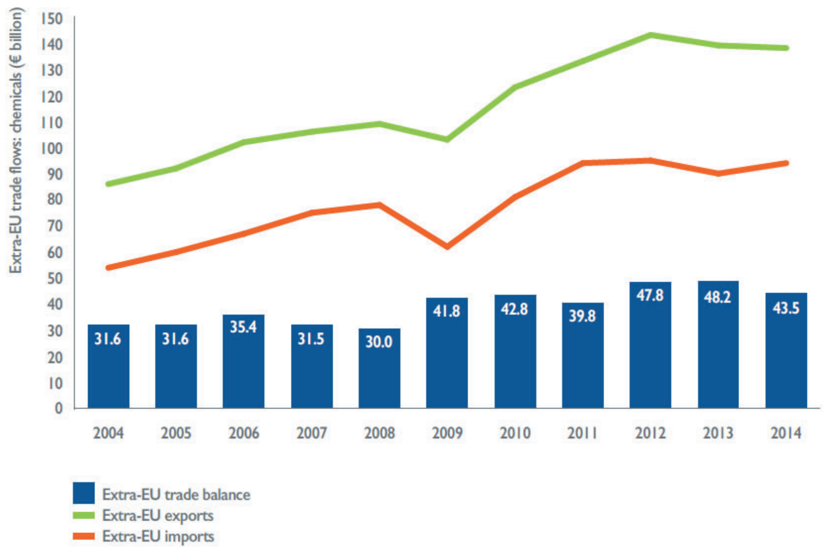
Chemical industry

By enabling efficiency and supporting safety, fluoropolymers play an important role in supporting economic activity in the chemical industry in Europe and aiding its global competiveness. This is particularly important given that the European chemicals sector is a major player worldwide. Of the 30 largest global companies, 12 are European. These registered more than €550bn sales value in 2014, which represented about 17% of global sales (CEFIC 2016). The EU chemical sector accounts for significant trade volumes with a trade surplus[63] of €43.5bn in 2014 (Figure 4.4).

The chemical industry was the fifth largest industrial sector in 2012, contributing to about 7% of total added value from all manufacturing activity in Europe. Germany is the largest producing Member State with €147bn sales in 2014, followed by France, Italy and the Netherlands. Those countries together account for about 60% of total EU chemicals sales. More than 1.2 million people are employed in the sector; typically high skilled (gross added value is around €96,000 higher than the 2012 EU average of €54,000[64]). The chemical sector is strategically important as it underpins various other sectors in the economy.[65]

[63] A trade surplus or positive trade balance means exports exceed imports, in a given period (usually annual).
[64] EU average obtained dividing the estimated €1,620bn value added generated in 2012 by the number of people employed in the same year, estimated at 30 million. Available from Eurostat: http://ec.europa.eu/eurostat/statistics-explained/index.php/Manufacturing_statistics_-_NACE_Rev._2 Employees in the Netherlands and Belgium show the highest gross added value per employee, at €167,000 and €159,000 respectively.
[65] Some 14% of its output is sold into the rubber and plastic sector, 8% is sold to construction, 5% to pulp and paper, with 4% to each of the automotive sector and basic metal sectors. Amongst the non-manufacturing sectors, the healthcare sector is the largest purchaser of chemical products (11%). All data in this section from CEFIC 2016.

Figure 4.4 Contribution to trade balance



Extra-EU trade balance. Source: reproduced from CEFIC, 2016[66]

Power sector

This section covers extraction, production and distribution of energy (renewables are covered separately below). According to the JRC[67], the energy sector currently employs about 1.6 million people in the EU. It generates on average some €250bn value added every year. As of 2013, there were some 101,000 companies in the EU operating in the energy sector with a turnover of about €2.6 trillion (tr)[68]; an economic activity supported by fluoropolymer-enabled efficiency gains.

4.4 Key Market 3: Cookware

Enabling characteristics and socio-economic contribution

- **Fluoropolymer-coated cookware provides non-stick properties**. This is convenient for cooking and cleaning, saving time, water and energy in the process.
- This also facilities **cooking with less fat added for lubrication,** which can contribute to a healthy diet. For instance, it has been estimated that poor diet cost the UK public health system (National Health Service) £5.7bn in 2006-2007[69] (about €9.7bn in 2015 prices[70]).

Socio-economic value of the sector

Some 20 companies in the EU are involved in the manufacturing or distribution of PTFE coatings for use in the manufacturing of cookware, among others[71]. While there are no publicly available EU-wide statistics for

[66] Available from: http://www.cefic.org/Facts-and-Figures/
[67] Joint Research Centre; the European Commission's science and knowledge service https://ec.europa.eu/jrc/en/research-topic/energy-sector-economic-analysis
[68] (EUROSTAT 2015)
[69] Scarborough, P., Bhatnagar, P., Wickramasinghe, K. K., Allender, S., Foster, C., & Rayner, M. (2011). The economic burden of ill health due to diet, physical inactivity, smoking, alcohol and obesity in the UK: an update to 2006–07 NHS costs. *Journal of Public Health*, *33*(4), 527-535. http://jpubhealth.oxfordjournals.org/content/33/4/527.full.pdf+html.
[70] Inflation based the Bank of England inflation calculator (http://www.bankofengland.co.uk/education/Pages/resources/inflationtools/calculator/flash/default.aspx). Conversion to Euros based on 2015 yearly average exchange rate from the European Central Bank (https://www.ecb.europa.eu/stats/exchange/eurofxref/html/index.en.html).
[71] Source http://www.europages.co.uk/companies/ptfe%20coating.html

the sector, these are likely to represent only a small fraction of the total number of companies involved. These companies operate within a larger sector producing tableware and kitchenware from plastics, which had a production value above €2bn as of 2012, and a net export value of some €470m in the same year[72]. As above, fluoropolymers provide important functionality, valued by consumers, that helps ensure European products are globally competitive.

4.5 Key Market 4: Electronics

Enabling characteristics and socio-economic contribution

- **Fluoropolymers are critical to semiconductor manufacturing**. Fluoropolymers play a major role by supplying various piping, vessels, valves, pumps that can withstand the aggressive etching chemicals, alongside the required high purity in the manufacturing process of semiconductors. Semiconductors are *“extremely intolerant of particulate and chemical contamination, which, even in trace amounts, can cause severe decrease in yields.”*[73] Consultation has indicated that semiconductor manufacturing would be seriously affected without the use of fluoropolymers in their production.

- Semiconductors, in turn, form part of millions of larger components from electronic equipment, communication devices to cars and aircraft. A 2006 study[74] funded by DuPont, estimated that **fluoropolymer use in the semiconductor industry results in annual benefits to European semiconductor makers of €10bn (€11bn in 2015 prices[75])**. This does not include benefits of using semiconductors further downstream in the value chain.

- Indirectly, fluoropolymers have played an important role[76] in achieving the doubling of computer power every two years at the same cost - the so called “Moore’s law”. This is driven by increases the number of transistors per square inch in a microchip. It is evident in increased processing speeds and greater computing power in physically smaller components[77]. Consultation with fluoropolymer producers and downstream users, indicate that **Moore’s law and the resulting technological developments would not have been possible without fluoropolymers**. Between 1995 and 2015, the innovation in microchips as described by Moore’s law has generated an estimated $3tr (about €2.7tr) of additional value to global GDP. Including the indirect economic effects of this innovation, the estimate increases to $11tr (about €9.9tr).[78] There are a host of other sectors which indirectly rely on the functionality provided by these electronic components.

- **Fluoropolymers enable improved fire safety, reliability and performance of cables, notably data transmission cables.** These cables are used in crucial applications in a wide range of sectors, especially where reliability in aggressive environments is key. Examples include various automotive cables, controls for a majority of (often safety critical) operations and sensors in industrial installations as well as high volume data transmission in Information Communication Technology (ICT). Fluoropolymer cables maintain constant operation for at least 20,000h at temperature ranges from between -190 °C and +260 °C (depending on which fluoropolymer). Downstream consultation has indicated that known alternatives for most

[72] Data on import and export of plastics kitchenware and tableware available from Prodcom: http://ec.europa.eu/eurostat/web/prodcom/data/database
[73] Ebnesajjad, S. (2014). Fluoroplastics, Volume 1: Non-Melt Process ble Fluoropolymers-The Definitive User's Guide and Data Book. Elsevier.
[74] NERA Economic Consulting (2006): Societal Benefits of Fluoropolymers and Fluorotelomers. Quoted in: http://www2.dupont.com/PFOA2/en_US/assets/downloads/societal_benefits.pdf.
Note that the source does not specify how exactly Fluoropolymers generate these benefits.
[75] Conversion to 2015 prices based on seasonally and calendar adjusted GDP deflator for the EU-28 from Eurostat: http://ec.europa.eu/eurostat/web/products-datasets/-/teina110.
[76] Ebnesajjad, S. (2015). Fluoroplastics, Volume 2: Melt Processible Fluoropolymers-The Definitive User's Guide and Data Book. William Andrew.
[77] A useful overview of Moore’s law, along with supporting data illustrating the exponential increase in transistors per chip is provided in the economist: http://www.economist.com/technology-quarterly/2016-03-12/after-moores-law
[78] Dale Ford, IHS Technology Thought Leadership: Celebrating the 50th Anniversary of Moore’s Law. https://technology.ihs.com/api/binary/532884
Conversion to Euros based on 2015 yearly average exchange rate from the European Central Bank (https://www.ecb.europa.eu/stats/exchange/eurofxref/html/index.en.html).

applications last less than a third of the time under these conditions and do not meet the requirements for all higher frequency applications.

- **The enabling characteristics of fluoropolymers support the ever increasing wireless antenna requirements with high signal quality with low signal losses including for Wi-Fi, 3G, 4G and Bluetooth, this includes in cars and aircraft as well as consumer goods.**

Socio-economic value of the sector

Semiconductors

Semiconductors are used in millions of components in power devices, optical sensor and light emitters in industrial operations, consumer electronics and healthcare applications. These include PCs (personal computers, laptops, servers and tablets) and communications (broadband internet, mobile phones, smartphones, etc.) and other consumer electronics appliances (television sets, music players, gaming consoles, household appliances and fitness gadgets) – as well as various medical devices (discussed separately). Europe accounted for 11% of global demand in 2013 – in terms of manufacturing location of the semiconductor itself, but they are used in millions of other applications throughout Europe[79]. Other data from the same year suggests the EU accounts for €24.7bn, equivalent to 9% of the global sales revenue (€274.3bn).[80] The global semiconductor market has grown quickly, by an average of 7% between 1993 and 2013[81]. It is predicted that it will continue to grow to approximately €344.7bn in 2018[82].

Semiconductors contribute to improved energy efficiency and performance[83] and are present in virtually all modern electronic devices[84]. Ranked as the most R&D intensive sector by the European Commission, the European semiconductor market supports some 200,000 jobs directly and up to 1,000,000 indirect jobs in related activities in Europe[85].

4.6 Key Market 5: Food and pharmaceuticals

Enabling characteristics and socio-economic contribution

- **Fluoropolymers enable durable processing equipment to ensure high purity of food and pharmaceuticals, even when ultra-pure substances, extreme temperatures and/or aggressive substances are required**. In pharmaceuticals, high purity is vital for the effectiveness and safety of (often lifesaving) drugs. In food, it ensures safety and avoids contamination. For both sectors, fluoropolymers play an important role in production efficiency.

- In the **European biopharmaceutical industry alone, €270m was saved between 2008 and 2012 alone due to increased prevention of contamination and material failure in biopharmaceutical manufacturing** (see Box 4.2 below). The biopharmaceutical industry accounted for just 5% of the food and pharmaceutical manufacturing in 2012[86], so savings across the sector could be much larger. Such improvements can be attributed to a range of factors, but **fluoropolymers play an important role in the prevention of contamination and material failure and hence to these efficiency gains**.

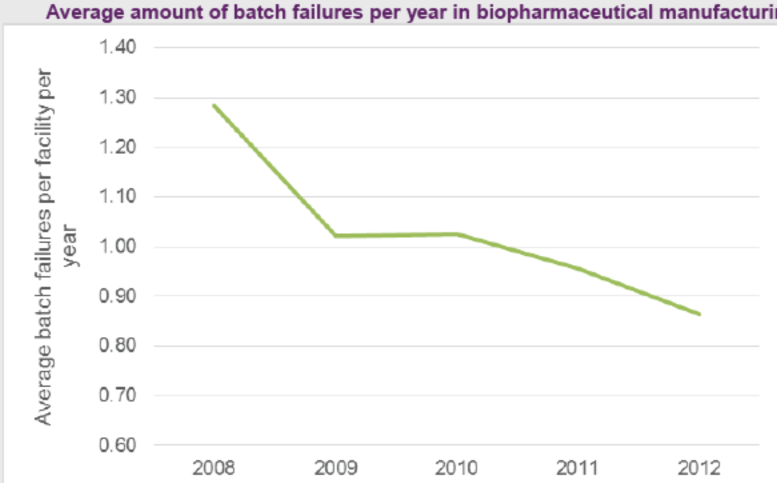
[79] SIA (2014) The US Semiconductor industry, 2014 Factbook
[80] SIA (2014) The US Semiconductor industry, 2014 Factbook. Sales in the EU semiconductor market amounted to €2.4bn *per month* (data for July 2016 - about 10% of the global sales in the same month valued at €23.5bn source: http://www.eusemiconductors.eu/images/static_website/newsroom/PR/ESIA_WSTS_PR_1607.pdf).
[81] SIA (2014) The US Semiconductor industry, 2014 Factbook (http://www.semiconductors.org/clientuploads/Industry%20Statistics/2014%20Factbook%202.0%20-%2002032015.pdf)
[82] http://www.idc.com/getdoc.jsp?containerId=246668
[83] http://www.eusemiconductors.eu/esia/home
[84] http://uk.rs-online.com/web/generalDisplay.html?file=eletronics/how-did-semiconductors-change-our-lives&id=infozone
[85] http://www.eusemiconductors.eu/esia/about-esia
[86] Based on Eurostat: National Accounts aggregates by industry (up to NACE A*64); and Eric Langer, BioPlan Associates, Inc (2013): Biomanufacturing Shows Signs of Maturity. In: Pharmaceutical Manufacturing: Biopharmaceutical Manufacturing Trends 2013. http://www.pharmamanufacturing.com/assets/wp_downloads/pdf/PM_1307_Biopharm_eBook_final.pdf

- **Fluoropolymer coatings and components enable a high level of efficiency by preventing corrosion and facilitating cleaning, thus reducing maintenance, material consumption, etc**. Corrosion prevention has a large potential for cost savings in the food and pharmaceutical industries. For instance, a 2002 study[87] estimated the **direct cost of metallic corrosion to the food processing industry as $2.1bn (about €2.5bn[88]) in the United States**, suggesting costs of a similar order of magnitude in Europe.

Box 4.2 Case study: Socio-economic contribution of reducing batch failures in the biopharmaceutical industry

Around 7% of batches were lost to failures in biopharmaceutical manufacturing in 2008. Approximately half of the failures were caused by either contamination or material failure [Source 1], both of which can be reduced through the use of fluoropolymers. As shown in the figure below, failure rates have decreased by 49% between 2008 and 2012. [Source 2]

Figure 4.5 Average amount of batch failures per year in biopharmaceutical manufacturing in 2008-2012



Source: Amec Foster Wheeler 2016 based on data from Langer 2013 [Source 2]

Assuming batch failures from contamination or material failure have decreased at the same rate, 49% of batch failures from contamination or material failure have been saved in 2012 by this improvement. This corresponds to 1.715% of batches saved:

- ***(7% / 2) * 49% = 1.715%.***

The turnover of the European biotechnology sector (a term used interchangeably with biopharmaceutical in the source) was $20,385m in 2012 [Source 2]. Assuming turnover is created primarily from batch production, every percent of batches saved by the improvements in failure rates between 2008 and 2012 corresponds to approximately one percent of turnover saved. Converting turnover to Euros [Source 3] yields:

- ***$20,385m / 1.2848 $/€ * 1.715% = € 272m.***

Hence, subject to the assumptions outlined above, it is estimated that about €270m was saved in 2012 due to the increased prevention of contamination and material failure in biopharmaceutical manufacturing, compared to 2008. Fluoropolymer coatings are used for the prevention of contamination and material failure and whilst no information is available on what exact share of the above savings are attributable to fluoropolymers, they are part of an evolving process of improvement and efficiency.

Sources:
[1] Eric Langer (2008): Biotech Facilities Average a Batch Failure Every 40.6 Weeks;
http://www.bioplanassociates.com/publications/articles/BioProcessIntlBatchFailuresOct08.pdf
[2] Eric Langer, BioPlan Associates, Inc (2013): Biomanufacturing Shows Signs of Maturity. In: Pharmaceutical Manufacturing: Biopharmaceutical Manufacturing Trends 2013;
http://www.pharmamanufacturing.com/assets/wp_downloads/pdf/PM_1307_Biopharm_eBook_final.pdf
[3] Ernst & Young (2013): Beyond borders: matters of evidence - Biotechnology Report 2013;
http://www.ey.com/Publication/vwLUAssets/Beyond_borders/$FILE/Beyond_borders.pdf
[4] Conversion to Euros based on 2014 yearly average exchange rate from the European Central Bank. (https://www.ecb.europa.eu/stats/exchange/eurofxref/html/index.en.html).

[87] https://www.nace.org/uploadedFiles/Publications/ccsupp.pdf
[88] In 2015 prices Inflation based on U.S. Bureau of Economic Analysis: Table 1.1.9. Implicit Price Deflators for Gross Domestic Product (http://www.bea.gov/iTable/iTable.cfm?reqid=9&step=3&isuri=1&903=13#reqid=9&step=3&isuri=1&903=13). Conversion to Euros based on 2015 yearly average exchange rate from the European Central Bank (https://www.ecb.europa.eu/stats/exchange/eurofxref/html/index.en.html).

Socio-economic value of the sector

Food and beverage

Fluoropolymers play an important role in food safety and cost-efficiency of food and beverage manufacturing. This sector, in turn, plays an important role in the European economy. As with other sectors, efficiency is important in global competitiveness, keeping costs to consumers low. Avoiding contamination in production is essential. FoodDrinkEurope estimated that the sector accounted for 15% of turnover and some 13% added value of the manufacturing industry in 2012. Around 289,000 companies were involved, employing some 4.2 million people and generating turnover of €1.2tr as of 2013[89]. By Member State, the largest turnover in the food production sectors were registered in Germany (€173bn), France (€155bn) and Italy (€111bn) respectively[90].

A large number of companies in the sector are small and medium enterprises (SMEs) – some 286,000 accounting for 99% of all companies, half of turnover and two thirds of employment. Annual R&D expenditure is around €2.8bn[91]. The EU is a major exporter of food: 21% of global food exports are from within the EU, with a sales value of almost €92bn in 2014. (Food Drink Europe, 2016).

Pharmaceutical industry

The EU pharmaceutical market is a key player globally accounting for almost 27% of the global market in 2011. The EU market for production of pharmaceuticals was valued at €213bn for 2012, generating a trade balance of some €87.6bn[92].

In 2012, R&D expenditure in the sector amounted to €30bn. More than 690,000 people were employed in the European pharmaceutical sector, of which some 115,000 were employed in R&D activities. Public expenditure on pharmaceuticals (for ambulatory care) amounted to some €193bn. (EFPIA 2014[93]). According to EFPIA (2014 figures based on Eurostat data), the pharmaceutical industry has amongst the highest added-value per employee, with GVA per employee in 2012 at €140,000[94] significantly higher the EU average (around €54,000) (WIFOR, 2015). In 2012 Germany was the largest employment location in Europe with some 110,000 people employed in the sector, followed by France (96,000) and the UK (73,000), whilst the highest sales values were in France (€27bn) and Germany (€26bn) followed by Italy (€20bn).

The market tends to be dominated by a few multinational enterprises, with the 20 largest pharmaceutical firms accounting for 66% of the global market by sales revenue in 2012 (Blanc, 2014). These large companies play a leading role - 50% of the new molecules introduced since 1950 were developed by the top 15 pharmaceutical firms (Munos, 2009, quoted by Blanc, 2014). Of the 20 largest pharmaceutical companies worldwide five are headquartered in Europe. These companies include Sanofi (France), GlaxoSmithKline (UK), Novo Nordisk (Denmark) and Bayer and Boehringer Ingelheim (Germany) (Source: Evaluate Pharma, 2013, quoted in Blanc, 2014). Fluoropolymers enable the European pharmaceutical manufacturers to produce high-purity products at competitive prices, supporting this economic activity in Europe.

4.7 Key Market 6: Textiles and architecture

Enabling characteristics and socio-economic contribution

- **Fluoropolymers provide a combination of waterproofing, breathability as well as low weight and thinness to clothing and footwear. This increases comfort and performance for professionals and consumers.**
- **Fluoropolymers provide durable, fire-safe, easy-to-clean building materials whose mechanical attributes enable progressive architectural designs that would not be**

[89] Of which €940bn for food only. Source Food Drink Europe (2015), based on Eurostat structural business statistics.
[90] (Eurostat, 2013).
[91] http://www.fooddrinkeurope.eu/publication/fooddrinkeurope-congress-2015-a-taste-of-tomorrow/
[92] Key figures by EFPIA (EU trade association of pharmaceutical producers).
[93] Data relating to total import and exports include EU 28 intra-trade which in some cases includes double-counting.
[94] Original figure of $179,900 converted using the average ECB exchange rate for 2012 available from: https://www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-usd.en.html

feasible with other materials. Specialised construction activities such as airports, stadia, domes and skyscrapers are widely enabled by fluoropolymer-based materials. EU examples include the O_2 Dome in London, the Sony Centre in Berlin, the Allianz Area and Munich Airport. Innovative architectural designs and "flagship buildings" facilitate leisure activities such as sports, music and tourism, yielding significant economic impacts along the value chain, alongside raising the profile of an attraction or region. There is also evidence that **specific coating systems can reduce building cooling costs and the associated energy use** (by between 4% up to 22%, depending on colour, geographical location, climate conditions, and substrate type)[95].

- To illustrate this, two examples – the **Eden Project and Wimbledon Stadium**, both in the UK - are described below.

Box 4.3 Case study: Fluoropolymers and signature architecture - *The Eden Project*[96, 97, 98]

The realisation of the Eden project in Cornwall, UK, attracted £16m (€24m) worth of EU investment funds from the Objective One Programme, and has generated a substantial economic impact to the region.

While total project costs were around £130m (€195m), over five years the project has created a net additional impact to the economy of some £0.7bn (some €1bn).

It is estimated that between 2007 and 2017 an additional £1bn value will be generated (€1.5bn).

Eden employs locally over 420 people injecting, via the wage bill £8m (€12m) to the local area (which is in receipt of ERDF Objective One funding) every year.

The project is also estimated to generate over 2,000 additional jobs at the UK at regional level and almost £100m in net additional GVA (€150m).

The Eden project consists of two biomes, using an innovative architecture based on hexagon and pentagon windows made from translucent, UV-transmitting, self-cleaning and durable fluoropolymer films (ETFE) – a unique design inspired by nature and mathematical patterns.[99]

Eden also incorporates recycled and plant-based material and includes environmental initiatives such as "Waste Neutral" and plans to address energy, water supply and climate change issues as part on ongoing improvements. It has also implemented training and education programmes, and has developed a sustainable transport plan to mitigate the environmental impact of additional journeys generated. (Source: Objective One, 2007[100]).

[95] Based on a study conducted by the U.S. Department of Energy's Oak Ridge National Laboratory, referenced in an article by the American Coatings Association: http://www.paint.org/article/fluoropolymer-coatings-for-architectural-applications/
[96] http://www.amion.co.uk/case-studies/eden-project-evaluation/
[97] http://www.objectiveone.com/O1htm/O1-legacy/06_EDEN.pdf
[98] Original figures in GBP £ have been converted using an average exchange rate with € between 2001 and 2007 of 0.66739.
[99] http://www.edenproject.com/eden-story/behind-the-scenes/architecture-at-eden
[100] Original figures in GBP £ have been converted using an average exchange rate with € between 2001 and 2007 of 0.66739.

Box 4.4 Case study: Fluoropolymers and signature architecture - *Wimbledon centre court*[101]

Wimbledon Open is one of four tennis "Grand Slam" tournaments and has the largest turnover amongst them, with prize money amounting to some £27m (€37m[102]) in 2015[103].

Fluoropolymers have been used for the centre court roof, allowing games to continue in adverse weather conditions. The roof was completed in 2009 and cost an estimated £80-£100m[104][105]. It is a moving roof hydraulically operated but is translucent, weighing 1,000 tonnes and covering 5,200 square metres[106]. The roof can be deployed in wind conditions of up to 69kph and plays an important role in avoiding disruption of the game[107].

Socio-economic value of the sector

Textiles and clothing

Fluoropolymers are a unique material in the textiles market, enabling specific functionality in textiles products. Textiles and clothing are an important sector in Europe, some 174,000 companies were active in the textile and clothing sector in the EU in 2013 with a turnover of almost €170bn and sustaining 1,700,000 employees[108]. Added value per employee is above the EU average (€84,000 compared to €54,000 EU average) the European market focuses on specialist product lines. Italy was the largest producer with a turnover of over €63bn and 347,000 employees, followed by Germany with around €23bn and France with some €15bn. Romania is the second largest employer where these sectors generate some 240,000 jobs.

Small and medium enterprises (SMEs) are the backbone of the European sector, over 90% of textile companies have fewer than 50 employees and producing almost 60% of the sector's value added[109]. The EU is also the second largest exporter of textiles globally with a share of 24% of global textile exports (only marginally less than China, with 26% share).

Architectural applications

The use of fluoropolymer enabled designs contribute to economic activity in both the construction sector as well as architectural design. Both play an important role in the European economy.

Some 18 million people are directly employed in the European construction sector (c.5% of the EU workforce and about 9% of EU GDP)[110].

Architectural design plays an important role as part of the European "creative industry". Activities in this sector had a turnover of €36.2bn, with some 493,000 jobs (registered architects) in the EU as of 2012. Demand is driven largely by new buildings, which for instance in France provided for some 73% of revenues

101 Picture taken from: http://www.dezeen.com/2012/07/08/is-the-centre-court-roof-the-real-star-of-wimbledon-2012-telegraph/
102 Conversion used 2015 average exchange rate £/€ of 0.72584
103 http://theconversation.com/two-weeks-of-top-spin-and-net-returns-wimbledon-by-numbers-43932
104 http://www.dezeen.com/2012/07/08/is-the-centre-court-roof-the-real-star-of-wimbledon-2012-telegraph/
105 http://www.telegraph.co.uk/sport/tennis/wimbledon/9381145/Is-the-Centre-Court-roof-the-real-star-of-Wimbledon-2012.html
106 http://www.wimbledon.com/en_GB/atoz/centre_court_roof.html
107 http://www.dezeen.com/2012/07/08/is-the-centre-court-roof-the-real-star-of-wimbledon-2012-telegraph/
108 Figures provided by EU industry association EURATEX (2015) and based on Eurostat data. We note that many companies will not be using fluoropolymers, this data is intended to demonstrate the importance of the wider sector, we draw out the specific role of fluoropolymers in the section above.
109 https://ec.europa.eu/growth/sectors/fashion/textiles-clothing/eu_en . This is consistent with similar figures from industry associations.
110 According to data provided by the industry trade association (European Builders Confederation, EBC).

for architectural firms as of 2011[111]. The EU architectural sector is a highly innovative and EU firms are increasing their market share abroad and gaining stronger international reputation (e.g. the architectural "Pritzker Prize[112]" was won 8 times by EU firms since 2000) (EY, 2014[113]).

Specialised construction activities and signature architecture, which are of particular interest in the context of fluoropolymers, often create significant economic value in terms of output and jobs along the value chain. Additionally, they raise the profile of the particular site or region and can accelerate generate economic activity from tourism and other recreational activities and attract other ancillary investment.

4.8 Key Market 7: Medical applications

Enabling characteristics and socio-economic contribution

- Fluoropolymers enable excellent performance and long lifetimes in a wide range of medical equipment. This reduces the risks of failures, replacements, cross-infections and clogging of medical equipment. They contribute to the **reduction/ avoidance of medical complications and additional or repeated medical care, hence contributing to avoided pain and the public cost of medical care**. Besides the inherent social benefits, this can be expressed in economic benefits as illustrated by the following examples:
  - Guide wires lined with PTFE facilitate surgical procedures, helping to shorten their duration alongside reducing patient risk and facilitating complicated procedures. On average, every minute a surgery is reduced implies savings of about €15.[114] Based on a sample of 36 types of surgical procedures, at least 20 million procedures take place per year in the EU-28[115], so reductions in all surgeries by just one minute across the EU would save at least €300m, per year.
  - The durability and bio-compatibility of implants made with fluoropolymers reduces the risk or frequency of the implant having to be replaced. Based on the same cost of surgery as above, each 5h surgery avoided altogether would save €4,500 in each case. [116].
- In 2000 it was estimated that adverse drug events, infections caught in the hospital and surgical complications, all of which can be reduced through the use of fluoropolymers (alongside other procedures and substances) affected approximately 2 million patients per year in the USA, resulting an estimated $4.5–5.7bn (about €5.4bn-6.9bn in 2015 prices[117]) per year in additional costs for patient care, as well as 90,000 deaths.[118] European numbers of patients affected may be broadly comparable. Again, even marginal improvements generate substantial savings.
- **Fluoropolymers play an essential role in enabling medical imaging and analysis (via electronic chips and semiconductors in X-ray, MRI, CT scan and echography) as well as medical analysis (blood, tissue, urine analysis)**. This is covered under "key market 4 – electronics" more generally but the importance of this specific application is highlighted here.

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[111] http://www.thecreativeindustries.co.uk/industries/architecture/architecture-facts-and-figures
[112] http://www.pritzkerprize.com/
[113] Ernst & Young Global Limited. Creating growth. Measuring cultural and creative markets in the EU. December 2014. Available from: http://www.ey.com/Publication/vwLUAssets/Measuring_cultural_and_creative_markets_in_the_EU/%24FILE/Creating-Growth.pdf
[114] Estimate based on literature. Macario 2010 suggests a cost of surgery of USD15 or USD20 per minute as ballpark figure. Waeschle et al. 2016 calculated an average cost of surgery of €16.63/minute for a German hospital. Note that charges for surgery, which reflect other factors than the bare cost of the procedure itself can be much higher (compare Macario 2010).
Macario, A. (2010). What does one minute of operating room time cost?. *Journal of clinical anesthesia*, *22*(4), 233-236.
Waeschle, R. M., Hinz, J., Bleeker, F., Sliwa, B., Popov, A., Schmidt, C. E., & Bauer, M. (2016). Mythos OP-Minute. *Der Anaesthesist*, *65*(2), 137-147.
[115] Eurostat: Surgical operations and procedures performed in hospitals by ICD-9-CM.
[116] Calculated as: 5h * €15/min = €4,500.
[117] Inflation based on U.S. Bureau of Economic Analysis: Table 1.1.9. Implicit Price Deflators for Gross Domestic Product (http://www.bea.gov/iTable/iTable.cfm?reqid=9&step=3&isuri=1&903=13#reqid=9&step=3&isuri=1&903=13). Conversion to Euros based on 2015 yearly average exchange rate from the European Central Bank (https://www.ecb.europa.eu/stats/exchange/eurofxref/html/index.en.html).
[118] Kohn LT, Corrigan JM, Donaldson MS, editors (2000). To err is human: building a safer health system A report of the Committee on Quality of Health Care in America, Institute of Medicine. Washington, DC: National Academy Press.

Socio-economic value of the sector

The global market for medical applications is worth around €215bn. While the US dominates the market, European countries account for significant shares. The top ten medical devices markets globally in 2012 included Germany (7% share), France (4%), the UK (3%) and Italy (2.6%)[119]. The European medical device sector is characterised by a high degree of innovation, accounting for 41% of patents in the medical sector globally, with over 11,000 patents filed in 2014, in this sector, alone[120]. As of 2015 some 575,000 people were employed in the sector in Europe, with total sales around €100bn and a positive trade balance of €15bn.

Medical technologies continue to improve, supported by a host of technical advances. But efficiency of routine tasks is also essential, given that most European healthcare systems are funded via general taxation. The sector plays a key role in the provision of efficient, quick, cost effective yet safe healthcare of EU citizens[121].

4.9 Key Market 8: Renewable energy

Enabling characteristics and socio-economic contribution

- Fluoropolymers provide optical transparency and electrical insulation to photovoltaic (PV) panels and protect them from wind, humidity, UV, extreme temperatures and chemicals. This **increases the efficiency and lifetime of PV installations and minimises failures and maintenance stoppages and associated costs**. **Failure rates** (electrical current leaking to the frame which is a safety hazard and a potential ground fault, putting the panels at risk) **are as low as 0.1% in recent designs which use fluoropolymer film-based backsheets, compared to 45% in early backsheet designs**[122].
- **Fluoropolymers in PV frontsheets and backsheets are lightweight and allow for more efficient panel production**. Therefore they reduce the cost of production of the panels, enable lower packaging and shipping costs and enable faster and easier installation[123]:
  - **Production efficiency increase of ETFE modules relative to glass modules implies savings in the order of €40m for European PV module manufacturers, or approximately €90m for PV module customers in the EU** (see Box 4.5).
- Release films making use of fluoropolymers' non-stick and low friction properties enable **efficiency gains in wind turbine production**. For instance, **PTFE mould linings for wind turbine blades increases the amount of blade print cycles before replacement up to 10-fold**[124].
- Fluoropolymers facilitate advanced energy storage and conversion technologies, such as lithium-ion batteries

[119] Source: https://www.ic.gc.ca/eic/site/lsg-pdsv.nsf/eng/h_hn01736.html
[120] Medtech (2015). The figure include EU28, Switzerland and Norway.
[121] Source: https://ec.europa.eu/growth/sectors/medical-devices_enhttps://ec.europa.eu/growth/sectors/medical-devices_en See also (MedTech 2015).
[122] http://www.dupont.com/content/dam/dupont/products-and-services/solar-photovoltaic-materials/solar-photovoltaic-materials-landing/documents/DPVS-Brochure.pdf
[123] http://www.pv-magazine.com/opinion-analysis/blogdetails/beitrag/innovative-etfe-film-technology-discussed_100001678/#ixzz4K272QzZQ
[124] http://www.norton-films.com/detailimg.aspx?id=246406 No cost data has been identified.

Box 4.5 Case study: Potential savings for EU manufacturers and consumers from improved production efficiency by using ETFE instead of glass.

Production efficiency increase of around 2% can be achieved by ETFE modules relative to glass modules. [Source 1]

The average PV module price was around $0.6 (around €0.54) per Watt of capacity in 2015. [Source 2]
European production of PV modules was estimated as about 4GW in the same year. [Source 3]

A comparison of the hypothetical situations in which all of these modules are made with ETFE and in which they are made with glass yields the potential savings for EU PV manufacturers:

- ***2% * 0.54 €/W * 4 GW = €43.2m***
  (Efficiency increase * PV module cost * PV module production in EU 2015).

8.1 GW of new PV modules were installed in the EU in 2015. [Source 4]

Assuming that the savings from increased production efficiency are passed on to customers, comparing the situation in which all of these modules are made with ETFE and where they are made with glass yields potential savings for EU PV customers:

- ***2% * 0.54 €/W * 8.1 GW = €87.5m***
  (Efficiency increase * PV module cost * PV module additional installed capacity in EU 2015).

Note that these savings are not additive due to overlap between the two, as it is likely that a significant share of the installed capacity in the EU has also been produced in the EU.

Sources:
[1] Saint-Gobain: http://www.pv.saint-gobain.com/lightswitch-frontsheet.aspx;
[2] IRENA: http://resourceirena.irena.org/gateway/dashboard/?topic=3&subTopic=32. Conversion to Euros based on 2015 yearly average exchange rate from the European Central Bank;
(https://www.ecb.europa.eu/stats/exchange/eurofxref/html/index.en.html).
[3] Europe accounted for 6% of the 63-69GW global production according to REN21: http://www.ren21.net/wp-content/uploads/2016/06/GSR_2016_Full_Report_REN21.pdf (p.65);
[4] European Commission Strategic Energy Technologies Information System:
https://setis.ec.europa.eu/newsroom/news/europe-sees-growth-solar-pv-2015.

Socio-economic value of the sector

Solar energy

Europe is a leading global market for PV energy and installed capacity is increasing very quickly. In 2015 approximately 180 Gigawatt of solar PV capacity had been installed (IRENA, 2015a) compared to just 1.2 GW in 2000. In 2014 alone total installed capacity increased by 30% (EPIA, 2014; IRENA, 2015a). Of the ten countries with the greatest installed capacity, six are in Europe. These are led by Germany, and include Italy, the UK, Spain, France and Belgium. Demand is not only driven by rising energy prices and the need for alternative energy sources, but also by efficiency gains, particularly improved conversion efficiencies (Deutsche Bank, 2015). The increase in capacity has been facilitated by significant production cost reductions over the same period. Between 2000 and 2013 unit costs decreased by 89% (IRENA, 2014a).

Activities related to solar PV technology account for around 2.5 million jobs globally. In Europe, the sector employed some 140,000 people in 2015 (IRENA, 2016a). Germany and France were the largest employers with 38,000 and 21,000 employees respectively.

Wind energy

Again Europe is leading the market globally, with around 38% of the global installed capacity of 318 GW. The EU accounts for the largest share of installed capacity (some 122 GW in 2013) and 6 among the top ten countries for installed wind capacity are European (Germany, Italy, France, UK, Spain and Denmark). A small number of wind turbine manufacturing companies account for a large volume of the installed capacity. Ten companies produce some 70% of existing supply, with two of the top three being European: Vestas (Denmark) and Enercon (Germany) (REN21, 2015).

Geothermal energy

Currently used in ground source heat pumps, direct use and geothermal power plants. These account respectively for about 14.9 GW, 3 GW and 0.95 GW of geothermal capacity installed in the EU (JRC, 2015). The enabling characteristics of fluoropolymers for for geothermal applications include high temparature resistance, good electrical insulating, steam and chemical resistance. They provide durability and functionality for various components of these installations such as tubes, linings and wire coatings. According to IRENA (2016), 160,000 people are currently employed in the geothermal energy sector. Of these more than 100,000 are employed in the EU, with almost 50,000 in France and Germany alone[125].

The wider importance of renewable energy: decarbonisation of the economy
The EU is a leading player in international efforts to fight climate change met, in part, through a gradual shift away from fossil fuels toward a larger share of clean energies in the energy mix. Data from the EEA, 2015 examines the contribution of renewable energy use to gross avoided Greenhouse Gas (GHG) emissions as a percentage of total emissions across the EU (based on 2013 data) (EEA, 2015). It has contributed to a reduction in GHG emissions of 388 million metric tonnes compared to 2005. This represented a 19% increase in avoided emissions due to renewable energy sources compared to 2012. Renewables also contribute to reducing Europe's energy dependence on imported fossil fuels. The same EEA study shows additional use of renewables has allowed fossil fuel demand to be cut by 98 million tonnes of oil equivalent in 2012 and 116 million tonnes of oil equivalent in 2013, compared to 2005.

[125] IRENA. Renewable Energy and Jobs. Annual Review 2016.

5. Potential alternatives and implications of use

This section considers a hypothetical scenario whereby fluoropolymers were not available. For each of the key sectors and applications in the previous chapters, we consider the possible alternatives to fluoropolymers, whether these were used historically, before the transition to fluoropolymers, or are used in other similar applications today. This is a high level assessment based on limited consultation with industry conducted in 2016, alongside desktop research. The consultation was conducted among five manufacturers of fluoropolymers and 17 downstream users which operate in all the sectors covered by this study (see Appendix C).

It is recognised that R&D activities within the companies consulted and amongst the large number of downstream users are confidential and that they are ongoing. Alternatives are potentially viable in specific applications and contexts, not all of which can be detailed in this report. Conclusions are drawn at sector and/or application level. Further information is contained in Appendix C.

In considering the implications of alternatives, the criteria considered[126] are as follows:

- Technical feasibility: Could the alternative provide an equivalent technical function to fluoropolymers in the application concerned? Would the alternative provide the final products with the same/similar technical functionality?
- Economic feasibility: Would adoption of the alterative incur additional costs to manufacturers, downstream users or consumers? This may arise from higher unit costs, process or production changes requiring new or altered machinery or loss of functionality to the end user, which might impose additional costs.
- Availability: Is the alternative likely to be available? Are they likely to be available in the required quantities and without undue delay?
- Hazards and risks of the alternative: Would the overall risks to human health and the environment from the use of the alterative increase or decrease?

The information on alternatives contained in Appendix C is based on general feedback on alternatives and on specific examples. As a result, it does not necessarily cover all applications and/or all products. The alternatives mentioned as part of the consultation include steel and other metals; high nickel alloys, polypropylene, PVC, glass, ceramics, mica, polyether sulfone, polyimide, ethylene propylene diene monomer (M-class) rubber (known as EPDM rubber), nitrile rubber (NBR), hydrogenated nitrile rubber (HNBR), acrylic rubber (ACM), Ethylene-acrylic rubber (AEM rubber), fluorosilicone (FVMQ)[127], graphite, aramid, slip agents. Each would only be a possible alternative for some of the applications of fluoropolymers.

Fluoropolymers are widely used in various specific components, each serves a slightly different purpose and hence each requires different characteristics. Overall, whilst some alternatives might have a similar performance to fluoropolymers for a particular parameter or property, it is the combination or range of properties required for the applications where fluoropolymers are used that is the key characteristic. In sectors such as chemical & power, pharmaceuticals or transport, fluoropolymers provide resistance to a wide range of low and high temperatures and universal chemical resistance. This “universal” resistance to chemicals is a crucial characteristic of fluoropolymers that is not present in any of the alternatives, according to consultation feedback. There are alternatives that are more or less resistant to specific chemicals but there is not one that is universally suitable.

In summary, whilst the implications differ across specific applications, they include:

- **Technical implications:** Various implications which include lower performance, increased weight (with associated effects on fuel consumption and fuel efficiency), and reduced durability

[126] Our approach follows the criteria set out by the European Chemicals Agency (ECHA) in consideration of alternatives (ECHA (2014) ‘Format for socio-economic analysis and analysis of alternatives’. European Chemicals Agency. Available from: http://echa.europa.eu/applying-for-authorisation/preparing-applications-for-authorisation [accessed 25/09/2016]
[127] This substance is covered in the analysis, given its hypothetical nature, but in practice it is l kely that if fluoropolymers were not available, then neither would fluorosilicones.

less compatibility and versatility, hence increased challenges associated with component redesign and operating condition requirements.

- **Economic implications:** Various which would include efficiency losses, higher initial (investment) costs and higher maintenance costs. The diversity of specific applications would post major product qualification issues alongside design implications.
- **Environmental / health implications:** Potential for higher risk of exposure of staff to hazardous substances, higher safety risks (vehicle or aircraft failure), higher emissions arising from weight increases, e.g. in transport.

Appendix A
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Appendix B
Original survey data

B.1 Introduction

The data in this report draws from a survey with members of the Fluoropolymers Group (FPG). The members of this group do not represent the entire European fluoropolymer market. Therefore an estimation of the total European market size (tonnage and sales) has been made, based on publicly available data, alongside the original survey data and estimates of the total market provided by the FPG members themselves. Further detail on the process used are contained below. For transparency both the original and extrapolated data are shown.

B.2 Volume of use

Table B.1 Quantities of fluoropolymers sold in the EU per year (2015)

Quantities	Unit	Total EU market [a]	Original survey results [a]	Methodology to extrapolate from survey results to total market
Tonnes produced in the EU	*Tonnes (2015)*	51,000	36,500	Value derived from the three numbers below
Tonnes imported into the EU	*Tonnes (2015)*	21,500 [b]	7,500	Final extrapolated figure based on EUROSTAT and estimations from the FPG group members
Tonnes exported from the EU	*Tonnes (2015)*	20,500 [b]	14,500	Final extrapolated figure based on EUROSTAT and estimations from the FPG group members
Tonnes sold in the whole EU market	***Tonnes (2015)***	**52,000**	**29,000**	**Estimation based on various sources and FPG group members** **[see table notes for details]**

Notes:
a: Source Amec Foster Wheeler Survey with Members of the FPG, 2016. Tonnages are rounded to the closest 500 hundred tonnes.
b. Note the original survey data relates to 2015, import and export data was extrapolated to the total EU market using EUOROSTAT figures from the last five years. This longer term data was used because the Eurostat data fluctuated year on year. The purpose of the extrapolation was to judge the total market size, so this average was judged as more likely to be accurate.
Note on the methodology for estimating the total size of the fluoropolymers market in the EU (volumes): Estimates of the total EU market have been derived from three sources. First in the ECHA (2014) Annex XV report, the global demand for fluoropolymers was between 235,000 and 267,000 tonnes in 2011. The same source states that the EU accounted for 21% of the global demand in 2010 (that is, around 52,700 tonnes based on 21% of midpoint of the range above). This source provides an estimate of the total sold on the EU market not of imports and exports. Second, estimates provided by the Fluoropolymers Group – on the total size of the EU market (production), imports and exports. Four estimates were provided (an average of 52,000 tonnes). Third, EUROSTAT provides data on the EU trade of fluoropolymers (import to and export from the EU). The average imported and exported tonnage in the last 5 years was used for the reasons set out above.
All sources were in reasonable agreement. Note the numbers have been rounded.

Total EU production data was determined using the tonnes sold, imports and exports estimations (as total EU production = Total volume sold + exports – imports).

Sources: Amec Foster Wheeler market survey – February to June 2016.
Amec Foster Wheeler consultation on EU market size with FPG Group– July to August 2016.
EUROSTAT, 2016. *EU trade since 1988 by SITC [DS-018995], imports and exports of 'product 57394- Fluoropolymers'* [kg]
ECHA, 2014. *ANNEX XV PROPOSAL FOR A RESTRICTION – Perfluorooctanoic acid (PFOA), PFOA salts and PFOA-related substances*, European Chemicals Agency; based on FluoroCouncil, 2013. FluoroCouncil, 2013. *Personal communication with ECHA*, Jin, 2012. Jin, J., 2012. Chemistry of Aryl Trifluorovinyl Ethers. *Chemistry in New Zealand* 76, 24-26.; Ebnesajjad, S., 2013. *Introduction to Fluoropolymers - Material, Technology, and Applications*. pp32, Elsevier.

B.3 Revenues (Fluoropolymers in basic form)

Table B.2 Annual sales value of the EU fluoropolymer market (2015)

Quantities	Unit	Sales value (€m)[a]	Original survey results (€m)[a]	Methodology to extrapolate from survey results to total market
Sales value of product produced in the EU	*€m (2015)*	840	600	Scaling factor of 36% based on the difference between production volume (tonnes) figures (survey results vs total EU market estimation) [see note on methodology]
Sales value of imports into the EU	*€m (2015)*	310	120	No scaling factor used, figure obtained from EUROSTAT
Sales value of exports from the EU	*€m (2015)*	380	230	No scaling factor used, figure obtained from EUROSTAT
Total value sold on the EU market	***€m (2015)***	**780**	**500**	**Total value obtained using the three numbers above**

Notes:
[a]: Rounded to the closest €10m.

Note on the methodology for estimating the total size of the fluoropolymers market in the EU (sales): Note the approach used is based on scaling up the results from the survey to estimate the size of the EU market as a whole. The approach assumes that the remainder of the market (in terms of quantities) are of similar value to that derived from the survey. This provides an estimate of the total value of the market. Sales value of imports and of experts are taken from Eurostat.

Imports and exports data has been obtained from EUROSTAT (average of the last 5 years).

The total size of the EU market has been obtained from the estimated sales of product produced, imports and exports calculated with the method outlined above (given that EU market size [total sales] = Value of product produced + imports – exports).

Sources: Amec Foster Wheeler market survey – February to June 2016.
EUROSTAT, 2016. *EU trade since 1988 by SITC [DS-018995], imports and exports of 'product 57394- Fluoropolymers'* [€]

B.4 Research and development (R&D) and innovation

Table B.3 Research and development expenditure related to fluoropolymers (2015)

	% of revenue related to fluoropolymers	Upper bound estate – total market €m [a]	Original survey results (€m) [a]	Methodology to gross up the original data
Total	5.5%	43	27 (5.5% of the total revenue stated by companies)	5.5% of the estimated total sales value of the market (i.e. €780m)

Source: Amec Foster Wheeler market survey – February to June 2016. Note numbers have been rounded.
[a] Based on an 83% response rate. It has been assumed that those producers that have not responded to the survey invest a similar proportion of their revenue in research and development.

B.5 Direct employment

In terms of employment, in total, 31,700 people are employed in the FPG companies in the EU. Of these, the survey respondents estimate that some 1,600 are employed in activities relating directly to fluoropolymers (Table 3.4). This represents 5% of the total employment of these companies in Europe. The figure includes all relevant staff (manufacturing, commercial/sales, research and development). Collectively, the gross annual salaries of those employees directly related to fluoropolymers are estimated to account for around

€85m[128], which supports indirect economic activity in the domestic economies from the expenditure of employees on housing, recreation, and goods and services, for example.

It should be noted that since not all fluoropolymer manufacturers responded to the survey, the total EU employment figures related to fluoropolymers below are certainly underestimated. Providing an estimation of the remaining number of employees is more uncertain, as it is not exactly correlated with the volume produced, but reflecting a wide range of issues such as where there is spare production capacity. However, by using an average figure of 22.7 tonnes[129] of fluoropolymer produced per EU employee, this would equate to 2,200 employees at EU level, with a gross annual salary of €116m.

Table B.4 Total employment in surveyed companies and direct employment associated with EU fluoropolymer production (2015)

	Number of employees[a]
Total number of employees in the FPG Member Companies	31,700
Directly employed in activities related to fluoropolymers	1,600
Extrapolated to represent total market	2,200

[a] Rounded to the closest hundred.
Source: Amec Foster Wheeler market survey – February to June 2016.

B.6 Sales of fluoropolymers to downstream sectors

Table B.5 Downstream applications of fluoropolymers (tonnes and value, 2015)

Sector	Typical applications	Total quantity sold (t)	Total value (€m)	Original survey results (t)	Original survey results (€m)
Transport	Fuel lines, hoses, hydraulic systems, o-rings, gaskets, electronic systems, coating for a variety of purposes (e.g. cables, wires)	18,500	300	10,500	190
Chemical and power	Piping, tubing and fittings, fluid-handling components, vessels, storage tanks, sensors, sealants, binders in energy storage devices (e.g. batteries)	16,500	220	9,000	140
Cookware	Non-stick coating for cook and bakeware (e.g. pots, pans, baking trays)	3,500	60	2,000	40
Electronics	Semiconductors, printed circuit equipment, wiring, cabling	3,500	50	2,000	30
Food & pharmaceuticals	Valves, stainless steel piping, tubing, filters, seals, gaskets and other standard fluid handling components, paper tableware, conveyor belts, lab ware products, packaging	3,000	40	1,500	30
Textiles & architecture	Waterproof clothes and footwear, space suits, coating for architectural applications, architectural films	3,000	40	2,000	20
Medical applications	Cardiovascular grafts, heart patches, ligament replacements, catheters, filtering membranes	1,500	20	1,000	10

[128] Hourly wages were obtained from EUROSTAT (Labour cost, wages and salaries (including apprentices) - NACE Rev. 2. Manufacture of chemicals and chemical products; average for the EU28). For obtaining annual salaries, it was assumed that each employee worked 40 hours per week, 50 weeks per year.
[129] This has been obtained dividing the aggregated value of tonnage produced obtained from the survey (36,400 tonnes) by the number of employees directly related to fluoropolymers.

Sector	Typical applications	Total quantity sold (t)	Total value (€m)	Original survey results (t)	Original survey results (€m)
Renewable Energy	Front and back sheets for PV, paint and coating for wind turbines, coating for wires and cables, binders in lithium-ion batteries	500	<5	<500	<5
Others		2,000	30	1,000	20
Total		**52,000**	**780**	**29,000***	**500**

Source: Amec Foster Wheeler market survey – February – June 2016 (% of sales volumes and values). Note all sales values are rounded to the nearest €10m all tonnage data are rounded to the nearest 500 tonnes.
The EU market size (volumes and sales) has been obtained from the calculations descr bed in sections 3.3 and 3.4. The proportion of tonnages and sales in each sector are taken from the survey results, therefore it is assumed that the proportion of sales/tonnage in each sector among market participants not part of the survey mirrors those who were part of the survey.
(*) Differences with values quoted in Table 3.1 due to rounding.

Appendix C
Potential alternatives

Table C.1 Number of interviews with downstream users and sectors covered

Chemical and power	Food & pharma	Electronics	Transport	Renewables	Cookware	Medical	Textiles & architecture	Others	Total
12	7	3	5	4	1	5	3	5	17*

Note (*): The sum of downstream users across sector is larger than the overall number as most users are active in more than one sector.

Table C.2 Summary of alternatives and their technical, economic, health and environmental implications, where available

Key market	Sector	Alternative/s	Example potential application	Overview of likely technical economic and environmental implications
Chemical & Power	Chemical industry	Stainless steel [Source 1], copper [Source 2]	Pipes, liners, tubing [Source 3]	Possible for certain very specific components. However, metals likely to result in: - Inferior insulation properties. - Increased weight and size/design of components. - Inferior resistance to corrosion and/or abrasion. - Inferior non-stick and non-friction properties. - Lack of flex bility. All of the above imply pipe damage would be more l kely, higher risk of leaks and failures. Lack of flex bility. Higher weight, fuel consumption and emission with associated costs. Costly redesigns, higher maintenance costs, higher design costs. Higher safety risks.
		High-performance nickel alloys [Source 4]	Pipes, desulphurisation heat exchangers [Source 5] and filters [Source 6]	Various grades [Source 7], are available for specific applications [Source 8]. They are often quoted as highly resistant to corrosion [Source 8]. Consultation with manufacturers suggests that fluoropolymers are generally more resistant to chemicals and at higher temperatures [Source 9]. Likely to be more costly, especially nickel-chromium-molybdenum alloys [Source 10]. This "universal" resistance to chemicals is a crucial characteristic of fluoropolymers that is not present in any of the alternatives, according to consultation feedback. There are alternatives that are more or less resistant to specific chemicals but there is not one that is universally suitable. If there were no fluoropolymers, not only would the alternatives have inferior performance, a specific alternative would have to be developed and introduced for each manufacturing process, with potential differences across the industry. Only titanium and tantalum could have similar resistance, but their cost is very high and they do not have other of the required properties. Therefore, they are not considered as viable poss ble alternatives, by those consulted for the study.
		Polypropylene and PVC	Commonly used in pipes and liners	Low resistance to chemical attack hence lower corrosion prevention [Source 4]. Unsuitable for demanding applications, unless coated or reinforced (for instance with fluoropolymers).
		Glass and ceramics	Historically used in several applications [Source 11,12,13,14]	Brittle, considerably heavier and more difficult to transport.

Key market	Sector	Alternative/s	Example potential application	Overview of likely technical economic and environmental implications
		Polyether sulfone [Source 15] and polyimide [Source 16]	Seals [Source 11, 12]	Their thermal resistance is similar to that of some fluoropolymers. It is understood chemical resistance may be inferior. They are also rigid, posing design difficulties.
		Rubbers and silicones such as NBR [Source 17], HNBR [Source 18], ACM [Source 19], AEM rubber [Source 20, 21] or FVMQ [Source 22]	Seals [Source 17-22], O-rings[Source 25] and other applications	Suitable for other applications and resistant to specific chemicals. They have generally lower resistance to temperature changes, abrasion and chemicals than fluoropolymers [Source 23, 24, 25].
		Graphite and aramid [Source 26]	Gaskets	Aramid is sensitive to acids (i.e. they cannot prevent corrosion) and ultraviolet light [Source 27]. Graphite, whilst chemically resistant [Source 28] is brittle.
	Power [Source 29]	Mica[Source 30]	Insulation material for sensors, probe and cables	Rigid and brittle, lower chemical resistance than fluoropolymers. Performance could be improved with additional insulation (additional weight, similar brittleness).
		EPDM rubber reinforced with lead	Underground cables and submersible pumps[Source 31]	Higher weight, lower chemical and temperature resistance compared to fluoropolymers [Source 19]. Due to their inaccessibility, durability is essential, implying increased downtime and higher maintenance costs.
		Slip agents [Source 32]	Cable applications	These are additives designed to reduce friction and provide appropriate lubrication during polymers processing (e.g. adhering a film to a metallic surface) [Source 28]. Whilst these perform well for the elimination of melt fractures, die build-up and higher energy consumption may be problematic in some applications [Source 33].
Food and pharmaceuticals	Food industry	Ceramics [Source 34]	Coating applications	Commercially available [Source 30], but the durability of fluoropolymers is understood to be superior (see “cookware”).
		Animal or vegetable fats	Coating applications	The use of animal fat based products would necessitate the use of harsh cleaning methods with powerful solvents, to which staff would be exposed. Higher risk of exposure to carcinogenic degradation products of overheated fats.
		Steel	Processing equipment such as pipes	Steel is already in use. It tends to be coated (often with fluoropolymers) to prevent iron contamination / corrosion.
	Pharmaceutical industry [Source 35]	Polymethyl pentene (PMP or TPX) [Source 36]	Lab ware	It can withstand temperatures of up to 150°C and can be autoclaved. However, extremely brittle and can break easily at room temperature or if it falls from the table/lab benchtop [Source 36]. Also, fluoropolymers have a wider temperature range.

Key market	Sector	Alternative/s	Example potential application	Overview of likely technical economic and environmental implications
Electronics	Electronics	Polyolefin with flame retardant	Cable insulation [Source 37]	It is understood these do not offer the same resistance to temperature *range* as fluoropolymers (maximum limits differ [Source 37], but minimum working temperature of polyolefins is higher than that of fluoropolymers, reducing their performance in cases where coolants are used to decrease the temperature of data processing systems, for example). Polyolefins also have inferior fire resistance often requiring a flame retardant [Source 37]. There is some evidence that these in turn affect electrical properties of polyolefins [Source 37]. The consultation with industry also highlighted the use of polyolefins would l kely result in weaker data processing and slower signal return, reflecting inferior purity, friction properties and stability compared to fluoropolymers. If an alternative is found at some point, the industry states it may require at least 10 years to replace equipment and adapt manufacturing methods and processes [Source 28].
	Electronics	Non-conductive plastics	Historically used in semiconductor manufacture	Unviable. The modern semiconductor industry has stringent requirements [Source 39] and fluoropolymers are the only material that can currently protect the processing equipment in which semiconductor are etched and cleaned from the chemicals used in the manufacturing process [Source 40, 41] while at the same time offering the highest purity. Microprocessors and chips need to be increasingly small, yet powerful, preventing metallic contamination and corrosion in order to maximise chip yields [Source 41].
Transportation	Automotive	Stainless steel [Source 42], aluminium or copper [Source 43]	Fuel lines Protection for plastic fuel lines [Source 44, 45]	Fuel lines made entirely of copper or stainless steel are available in the market [Source 42, 46, 47]. However at least some products are only suitable for relatively old cars (1980s and earlier) [Source 46]. Plastic fuel lines covered with braided metal thread are also commercially available; indeed some fuel hoses made of fluoropolymers are covered with braided metal [Source 48]. However, in applications where the use of metals may be technically feasible, they are heavier and have lower chemical resistance, with the associated maintenance and replacement costs this implies, in what are "hard to reach" parts, they would also lead to increased fuel use and reduced fuel efficiency.
Transportation		XLPE [Source 49] (cross-linked polyethylene), thermoplastic elastomers (TPE) [Source 50]	Hoses, cables and wire solutions [Source 49, 50]	Successful for applications in other sectors (and in some automotive applications e.g. in cold air intake systems [Source 51] or control elements in car interiors [Source 52]. Although thermal resistance of XLPE and TPE is in the range of that for certain fluoropolymers such as standard ETFE, their chemical resistance does not reach the standards provided by fluoropolymers. [Source 52, 53].
Transportation		Silicone rubbers (for references see chemical industry above)	Gaskets, cables or hoses	Silicone materials offer a range of properties that are suitable for other applications used in various applications in modern vehicles such as paint additives, air bag coatings, and radiator seals. Whilst they offer a range of properties suitable for these applications, however they do not have the specific combination of properties required in fluoropolymer applications.

Key market	Sector	Alternative/s	Example potential application	Overview of likely technical economic and environmental implications
Transportation		Mica-insulation (as above)	Mica-insulated sensor cables for oxygen and nitrogen sensors	This is a very specific application with specific requirements. It is l kely that sensors would have to be placed in less demanding locations, since these cables are not able to resist the conditions at the optimum measurement point. This would result in less accurate measurements, which would in turn lead to higher emission levels and less efficient fuel consumption, as an accurate control of the air-fuel ratio is essential for fuel efficiency. Also, mica-insulated cables are heavier and more rigid and brittle.
Transportation		Polyetheretherketone [Source 54] (PEEK), polyether sulfone [Source 55]	Fuel hoses, lines, gaskets, seals, cables, wire insulation	They have similar temperature resistance. For example, PEEK is able to resist up to 260 °C [Source 56]. They are rigid which may impact on design possibilities and chemical resistance is lower. Furthermore electrical and data transmission properties are inferior.
Transportation	Aerospace	Those proposed for the automotive industry	As in the automotive industry	Many of the applications in the automotive industry are the same in the aerospace industry, with at least as demanding operating conditions, durability requirements, safety performance tests and approval systems. The sector has particularly strict quality testing and approval procedures, which would delay the appearance of alternatives in the market for the applications where fluoropolymers are used [Source 57].
Renewable energy		Glass (Top sheets) UV-resistant PET or polyimide (Backsheets) [Source 58]	Top sheets / Backsheets in solar panels	Glass has been historically used and UV-resistant PET and polyimide are currently available in the market. Glass is brittle and fragile. As for UV-resistant PET and polyimide, evidence suggests that Fluoropolymer-based backsheets perform better in certain parameters such as adhesion between layers (especially those based on ECTFE) [Source 55]. Moreover, fluoropolymers are still the market leader [Source 59].
Cookware	-	Ceramics	Coating for non-stick cookware	Ceramics is already in the market. Initial non-stick properties are acceptable but not as good as those of PTFE-coated cookware [Source 60], Ceramic-coated cookware is eventually more expensive since it reportedly loses its non-stick properties considerably faster [Source 61] and has to be replaced more often.
Medical applications	-	PEEK [Source 62]	Tubes, catheters and other hospital material	This alternative is commercially available. It is resistant to high temperatures and the products made of this alternative can be sterilised with autoclave [Source 62]. They are suitable solutions for disposable hospital goods. It is biocompat ble but it is generally not suitable for uses where longer term (30+ day) contact with tissue or blood is required [Source 63]. As a result, they are inferior to fluoropolymers for solutions such as heart patches. Some publicly available evidence suggests that PEEK may eventually be suitable for long-term solutions, but is currently comparatively expensive [Source 64]. The sector has particularly strict quality testing and approval procedures, which would delay the appearance of alternatives in the market for the applications where fluoropolymers are used.

Key market	Sector	Alternative/s	Example potential application	Overview of likely technical economic and environmental implications
		Polyurethane [Source 64]	Tubes and catheters	It is not suitable for steam sterilisation [Source 65]. Higher costs than current solutions [Source 64] Consultation has highlighted concerns with clogging.
Textiles and architecture	Architecture	Steel	Insulation materials, pipes and tubes	It is heavier and more inflexible than fluoropolymers. It is not resistant to corrosion. It is not able to meet the design possibilities of fluoropolymers. Higher maintenance costs due to corrosion.
		Polycarbonate sheets	Membranes for architectural applications such as roofing	They are resistant to temperature and UV light and can withstand force. PVC/PES membranes for architectural applications are common [Source 66] However, these are often coated with a protective layer (often made of PVDF, a fluoropolymer) providing UV-resistance and weatherability. Without this coating, they offer lower performance due to not being resistant to denting [Source 67] nor certain chemicals.
Renewable Energy		Pb (Lead acid) battery	Batteries [69]	Pb batteries are around one third heavier than Lithium-ion batteries.
		High temperature fuel cells	Fuel Cells (stationary applications) [70]	The key disadvantage, compared to PEM fuel cells is that they can only be used in stationary applications.

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