INTESA SANPAOLO
INNOVATION CENTER

INDUSTRY TRENDS REPORT
DECARBONISATION

TECHNOLOGIES AND MATERIALS TO REDUCE THE GLOBAL CARBON FOOTPRINT

FROST & SULLIVAN

INTESA SANPAOLO INNOVATION CENTER

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EXECUTIVE SUMMARY

At the 2021 COP26 conference in Glasgow, the EU and the US announced commitments to become carbon neutral by 2050 with China and India aiming for 2060 and 2070.

There are different ways to define the process of **decarbonisation** with the Greenhouse Gas Protocol using three "scopes" as a framework to measure and manage progress. Frost & Sullivan considers it to be the process of reducing carbon dioxide (CO2) emissions or "carbon intensity" at any time across a product or service's lifecycle.

This notably includes **removing the carbon dioxide that is already present in the environment** through the deployment of *Capture, Utilization and Storage (CCUS) Solutions.* It also relies on **avoiding the creation of new CO2** by either *increasing the efficiency of production processes and using less or green energy or by changing production processes to make new things or the same things differently*

Globally, the market for **CCUS** is expected to generate revenues of $36.4 billion (b) by 2030 with cumulative capacity reaching 1,616.2 metric tons per annum.

In the short term, it will find applications in hard-to-abate sectors like power generation and heavy industry via the retrofit of existing plants but, to have a greater impact, Bio and Direct Air Capture solutions will need to be used. In the long term, CCUS hubs will play a significant role by bringing industrial clusters into the ecosystem, creating economies of scale and reducing risks.

Europe currently boasts 63 commercial projects with the market relatively concentrated at the top amongst large international conglomerates. They and emerging players are looking to Carbon Capture as a Service as a way in which to address customers' full CO2 value chain from source to storage

From a technology point of view, CCUS can be broken out into those that are for capture, compression & purification and injection & storage. The most commercially proven post-combustion capture process is solvent absorption with membrane separation rapidly emerging as an alternative solution. Compression and purification ensure that captured CO2 is ready for transportation while saline formations are used extensively for storage although carbon is also increasingly injected into oil and gas reservoirs as well as un-mineable coal seams. Moving forwards, utilization is expected to be favored over storage as it promises to combine emission reductions with additional revenues with research currently focusing on the use of CO2 in chemicals, fuel and plastics.

In order to create a decarbonised future, significant investment is required in electrification, renewables and hydrogen. These are the key ways to avoid creating new CO2 by increasing the efficiency of production processes and using less or green energy.

Electrification delivers Greenhouse Gas (GHG) emission reductions by shifting energy use away from fossil fuels towards Renewable Energy Sources (RES) or other low carbon power generation systems and by acting as an enabler and allowing efficiency improvements through the increased adoption of emerging digital technologies.

The impacts of electrification are notably being felt across industry and in the buildings, maritime, aviation, agriculture and transport sectors.

Industrial emissions account for 29% of the global total with market participants turning to innovative heating technologies to reduce footprints. Heating is similarly the largest source of the CO_2 from ***buildings*** but electrification is facilitating a shift to outcome-based energy management while the ***maritime*** sector is currently almost completely reliant on fossil fuels so will need to embrace new approaches to vessel and port operations.

Electrification is equally necessary but challenging for ***aviation*** where all-electric aircraft are expected to become a reality between 2040 and 2050 and, in ***agriculture***, energy makes up more than 20% of emissions so many stakeholders are investigating emerging powertrain and pumping solutions. Overall, electrification is the most advanced in the ***transport*** sector were electric vehicles, batteries and charging infrastructure proliferate.

More recently, attention has shifted to ***data centers*** with demand driving global energy consumption from ~250 Terawatt-hours (TWh) in 2020 to 975 TWh in 2030. Operators have adopted a dual approach to decarbonisation by procuring RES and reducing emissions from stand-by power supplies. In parallel, they are improving efficiency by investing in sensors, digital twins and automation and also by rethinking the design of data centers.

In the short and medium term, **renewables** will underpin the move to electrification and more broadly decarbonisation.

Solar is notably expected to contribute about 28% of Europe's cumulative installed power generation capacity by 2030 with investment driven by continued declines in CapEx costs and innovations in areas like solar trackers.

In the longer term, **hydrogen** is increasingly recognized as the best low or zero carbon alternative to fossil fuels.

Overall, global production is expected to create an industry worth over $400b in revenue terms by 2030 with growth driven by the emergence of commercially viable fuel cells which will spur automotive and aerospace applications. ***Green hydrogen,*** generated from carbon-free sources, represents the "holy grail" and will drive the next wave of investment in renewable energy sources.

Across industries, **lightweighting** is one of the most widespread ways in which market participants are looking to avoid creating new CO_2 by changing production processes to "make the same things differently".

In the aerospace sector, ***additive manufacturing*** technologies such as fused deposition modelling have the potential to make Urban Air Mobility become reality while, on the automotive side, ***high strength steel, aluminum, magnesium*** and composites are expected to take share from steel in internal and external applications.

More broadly, end-users are looking to move away from petrol-based products with ***bio-based plastics*** a prime example of reducing CO2 by “making new things”.

Sustainable solutions represent less than 1% of total global polymer production today but demand and supply factors bode well for scale-up moving forward while the trends are similar in ***coatings, adhesives*** and ***sealants***. Here, vendors are partnering and investing in R&D in order to surmount some of the key challenges around performance, cost and the availability of natural materials.

Elsewhere, the food, agriculture and nutrition industries account for about a third of global GHG emissions making the sector a focus for decarbonisation. Farmers are notably driving emerging waste-to-energy initiatives and taking creative approaches to developing ***biofuels*** while agricultural biomass increasingly serves as a basis from which to draw ***natural cellulosic materials*** that can replace their synthetic alternatives and the up-take of plant, microbial or cell-cultured ***meat analogs*** minimises the impact of livestock farming.

In the building space, the deployment of ***smart lighting*** solutions stems largely from the potential for cost and energy savings and the EU’s Renovation Wave Strategy is expected to generate interest in ***Lighting as a Service*** platforms which facilitate green retrofitting.

Overall, **recycling** can be considered to be the ultimate expression of both “making new things” and “making the same things differently”.

Frost & Sullivan estimates that the European market was valued at $214b in 2021 with double digit growth in municipal, industrial and plastic segments. ***Direct*** decarbonisation efforts are focused on hard-to-recycle but CO2 intensive items like petroleum-based and synthetic oils while ***indirect*** efforts include leveraging digital technologies to reduce the carbon footprint of the recycling industry itself. Recycling is also shaping the highly-polluting carbon ***black*** industry with the use of recovered material in the production process enabling circularity and market participants also looking to make manufacturing cleaner and more efficient by using zero emission pyrolysis solutions.

The deployment of ***new materials*** as an input to and output from production processes will be key to the success/failure of many decarbonisation initiatives.

As noted, ***lightweight materials*** offer a significant solution and are finding applications notably across the automotive and aerospace industries but also more broadly in areas such as power generation, construction and consumer goods. Uptake is being driven by a combination of push and pull factors with local, national and international regulations mandating change while both manufacturers and consumers increasingly appreciate the benefits that emerging light solutions bring to bear. Nonetheless, there are challenges to further adoption including concerns about costs and performance.

Market participants are achieving lightweighting in multiple ways with clear advances in manufacturing capabilities facilitating the launch of new materials.

The use of heavy and polluting conventional steel is declining with high-strength, ultra-high-strength and advanced high-strength a common replacement while metal alloys, in particular aluminum but also magnesium, titanium and beryllium, offer another alternative and promise very consequential weight savings. More broadly, plastics continue to provide effective lightweight solutions across many applications despite the fact that the majority remain petrol-based and composites, including carbon-, glass- and natural fiber-reinforced polymers, are gaining ground thanks to their strength-to-weight ratio.

In the longer term, additive manufacturing promises to move beyond rapid prototyping to provide lighter products with short lead times and reduced cost and metal gels and aero foams are examples of other emerging innovations which meet the demand for lightweight thermally insulating materials across industries.

Recycled materials are another area of focus with specific attention currently being paid to polymers and Waste Electrical and Electronic Equipment (WEEE).

Plastics are more problematic than most materials in that they are both carbon-intensive to produce and extremely challenging to dispose of after their use. Today, about 80% of polymers are recycled using mechanical processes but biological and combination solutions promise new low-emission approaches while industry participants are increasingly looking to incorporate recovered plastics into their products.

On the WEEE side, 78% of e-waste was uncollected in globally 2020, prompting concerns about its impact and the growing shortage of valuable raw materials. “Urban mining” is becoming a key enabler for market participants looking to conserve resources, reduce costs and lower their carbon emissions with Apple one of many electronics giants launching circular economy initiatives with the company saving 4.3 million tons per annum of carbon via its recycling programmes.

CO2 capturing materials are similarly coming to the fore and segment into three main groups with the technology used pre- or post-combustion or as an oxyfuel.

Pre-combustion uses gasification and steam reforming to capture 95% of CO2 while the most commercially proven post-combustion process is solvent absorption although solid absorption is an alternative which requires less energy. Membrane separation selectively segregates emissions from exhaust streams while direct air capture is an emerging solution which takes carbon dioxide from the atmosphere.

CO2 utilizing materials are also expected to grow rapidly with Frost & Sullivan forecasting that the market will reach 183 million tons per annum by 2030, up from just 3 today. Captured CO2 can be exploited across a broad range of areas and notably in the chemicals, fuels, plastics and buildings industries. Carbon8 (UK), for example, is using CO2 to create low-carbon materials which include sustainable aggregates for the construction trade while it also has direct and indirect applications in the foods and beverages.

Source: Frost & Sullivan

INTRODUCTION

At the 2021 COP26 conference, the EU and the US announced commitments to become carbon neutral by 2050 with China and India aiming for 2060 and 2070

Europe is the most mature region for carbon neutrality initiatives. Countries here, especially in the Nordics, prioritize the climate and are sensitive to sustainability. The 27 members of the European Union voted to reduce Greenhouse Gas (GHG) emissions by at least 55% from 1990 levels by 2030. Carbon and exchange-traded fund taxes are in place to encourage European companies to cut their carbon footprints.

North America follows Europe. President Biden wants the US to reduce GHG emissions by at least 50% by 2030. This is a priority for heavy industries such as iron, steel and aluminum. The United States is the second largest chemical producer globally and the third-largest cement supplier, making them focus areas.

Asia is less advanced. A lack of government support, financing and technological advances is challenging for developing markets such as Thailand and the Philippines. Wealthier countries like South Korea and Japan are driving the adoption of carbon neutrality measures with the former planning to cut emissions by 40% from 2017 levels by 2030 and the latter targeting a 46% reduction in emissions from 2013 levels by 2030.

There are different ways to define decarbonisation with the Greenhouse Gas Protocol using three "scopes" as a framework to measure and manage progress

Scope 1 emissions are those that are under the direct control of an organization and which are tied to its activities or operations.

Scope 2 emissions are those that are under the indirect control of an organization and which are caused by the energy that it purchases and uses.

Scope 3 emissions are those that are not associated with 1 or 2 but stem from up (e.g. suppliers) or down (e.g. customers) an organization's value chain.

The global GHG Protocol builds on a 20-year partnership between the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) to provide a comprehensive global framework or "environmental accounting standard" for GHG and is used by companies and other organizations as well as cities and countries.

Frost & Sullivan considers it to be the process of reducing CO2 emissions or "carbon intensity" at any time across the full lifecycle of a product or service. This notably includes removing the carbon dioxide that is present in the environment through the deployment of Capture, Utilization and Storage Solutions

It also relies on avoiding the creation of new CO2 by either:

- **Increasing the efficiency of production processes and using less or green energy**
- **Or changing production processes make new things or the same things differently**

Source: Frost & Sullivan

CAPTURING AND STORING EXISTING CO2

Globally, the market for CCUS is expected to generate revenues of $36.4 billion by 2030 with cumulative capacity reaching 1,616.2 metric tons per annum

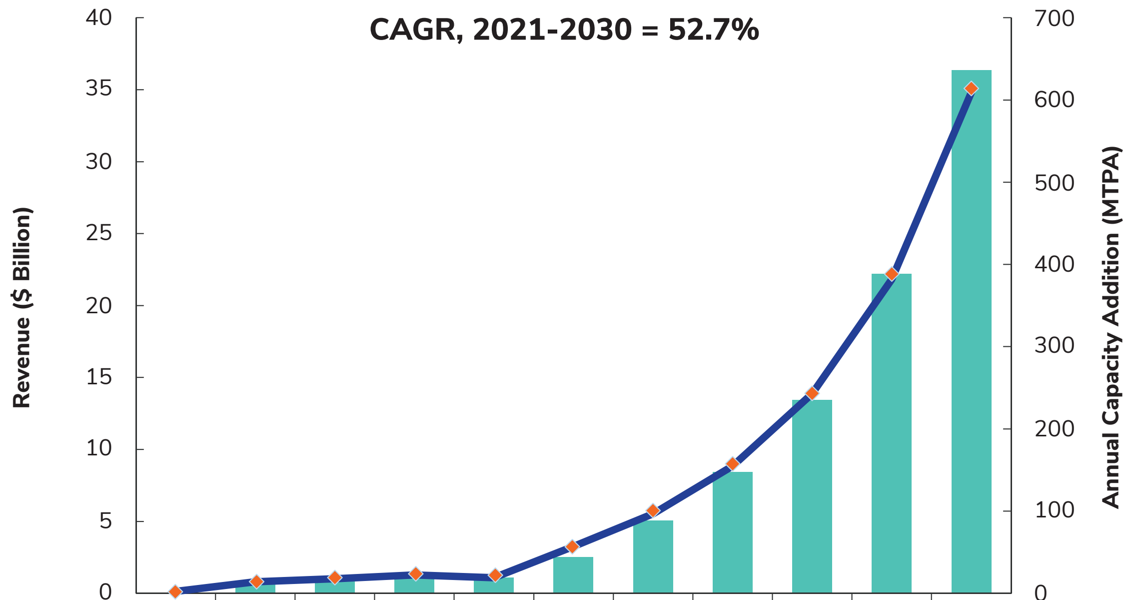
Carbon Capture, Utilization and Storage (CCUS) refers to a series of technologies that can be efficiently used to **capture** CO2 from large point sources, including power plants and industrial units, which use fossil fuel or biomass as inputs.

The captured CO2 can then be compressed and transported via rail, sea and road or through pipelines to be converted for **use** in a product or service.

Alternatively, it can be **stored** in deep geological formations, such as depleted oil and gas reservoirs or saline formations, both onshore and offshore.

CCUS has the potential to play a pivotal role in meeting the terms of the Paris Agreement as it can be applied in many ways across a range of different sectors. The deployment of CCUS in one area of the economy could have a "ripple effect" on others.

CCUS MARKET ANNUAL REVENUE AND CAPACITY ADDITIONS, GLOBAL, 2020-30



	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Revenue	0.1	0.8	1.0	1.2	1.1	2.5	5.1	8.5	13.5	22.2	36.3
Annual Capacity Addition	2.3	14.2	17.7	22.3	19.0	57.2	96.9	154.9	242.7	381.9	609.5

Source: Frost & Sullivan

In the short term, it will find applications in hard-to-abate sectors like power generation and heavy industry via the retrofit of existing plants

In order to meet net-zero goals, it is essential to target emissions from energy-intensive sectors including the cement, iron and steel and fertilizer and chemicals segments.

Heavy industries account for 20% of global emissions and Frost & Sullivan believes that, in the foreseeable future, CCUS will complement the use of alternatives to fossil fuels and become a key decarbonisation technology for these sectors.

Cement production, for example, generates significant process emissions and, with practically no alternative ways to manufacture effectively, the industry has a strong incentive to implement CCUS.

Similarly, natural gas contains up to 90% CO2 which has to be removed before sale or compression into Liquefied Natural Gas. These emissions are currently mostly vented into the atmosphere but could be captured and stored. They could also be used for Enhanced Oil Recovery (EOR) which refers to the process of extracting the crude from an oilfield which cannot be captured through conventional primary or secondary methods but can be released by leveraging carbon dioxide, water and either a thermal, gas or chemical injection.

Overall, demand from the hard-to-abate industries will be a powerful commercial driver for the development and deployment of CCUS technologies with the sector growing at a Compound Average Growth Rate (CAGR) of 61.8% from 2021 to 2030 to contribute $5.5 billion to the total market.

Source: Frost & Sullivan

To have a greater impact, negative emission solutions such as Bioenergy Carbon Capture and Storage and Direct Air Capture will need to be used

Although low-emission technologies will help with the reduction of GHG emissions, the continuous demand for energy from industrial, power and agricultural systems means that there is also a need for negative emission technologies to meet climate targets.

Negative emission technologies are net removers of CO2 from the atmosphere.

Bioenergy Carbon Capture and Storage (BECCS) consists of the sequestration of CO2 by biomass and the consequent use of the biomass to produce energy (by, for example, the generation of electricity through the combustion or production of biofuels). Since the biomass combustion cycle is assumed to be almost carbon neutral, sequestrating the carbon dioxide emitted results in a net removal of CO2 from the atmosphere.

The global carbon capture market for BECCS is expected to increase to be valued at $8.6 billion by 2030 and grow at a CAGR of 95.0%.

Unlike BECCS, **Direct Air Capture with Storage** (DACCS) plants extract CO2 directly from the atmosphere. Capturing CO2 from the atmosphere is challenging and expensive since it diluted and requires high energy to concentrate.

Globally, there are a few DACSS projects that are currently in the pilot phase. One such example is being developed by Carbon Engineering (Canada) and the cost of capture is expected to be $150 per tonne of CO2.

Carbon Engineering

Country: Canada

Brief Description: Direct Air Capture with Storage

Multimedia: https://carbonengineering.com/direct-air-capture-and-storage/

DACCS is a very flexible technology and offers the advantages that plants can be co-located with storage locations and deployed along with renewable electricity. It has the potential to capture 29 to 30 Gigatonnes (Gt) of CO2 globally in the longer term and innovations around DACCS continue apace but the market will remain limited in the short to medium term, growing slowly to reach just $0.7 billion by 2030.

In the long term, CCUS hubs will play a significant role by bringing industrial clusters into the ecosystem, creating economies of scale and reducing risk

The benefits of CCUS can be enhanced by reducing the cost of capture, transportation and storage. This can be achieved by linking industrial centers with common CO2 infrastructure, thereby lowering the Capital Expenditure (CapEx) that is required for constructing multiple compression plants and reducing Operational Expenditure (OpEx) by sharing power consumption and also the Operation and Maintenance (O&M) cost of pipelines.

Clusters and hubs will play a critical role in accelerating the adoption and deployment of CCUS projects. They offer the opportunity to aggregate, compress, dehydrate and transport CO2 from various sites or clusters, acting like a pivot between carbon capture facilities and storage locations and increasing source and sink efficiency.

Collaborations to create CCUS hubs are already occurring.

One of the most advanced hubs that is currently under development is the Northern Lights Project. The facility is being jointly established by Equinor (Norway), Shell (UK) and Total (France) and is expected to be operational in 2024. It will compress and liquefy CO2 at the emission source plant before transporting it on ships to the storage site with the facility connecting clusters from Germany, Sweden, Poland, the Netherlands and Belgium.

Northern Lights Project

Country: Canada

Brief Description: Carbon capture and storage hub

Multimedia: https://www.equinor.com/energy/northern-lights

The global revenue for carbon capture from CCUS clusters is expected to increase from $0.3 billion in 2022 to $1.3 billion by 2030, a CAGR of 22.1%.

Source: Frost & Sullivan

Europe currently boasts 63 commercial or pilot projects with the market relatively concentrated at the top amongst large international conglomerates

The ten facilities which are currently operating have a combined total capture capacity of 2.9 MTPA. Most of these projects are based on BECCS technology but also include Natural Gas (NG) processing and waste-to-energy solutions.

The European Green Deal and climate law have paved the way for the roll out of additional EU policies which support the development and deployment of CCUS projects thereby by converting political commitment into a net-zero climate neutrality reality.

In particular, the upcoming framework for the certification of carbon removal will provide an incentive for BECCS and large DACCS projects whilst increased transboundary movement of CO2 will support the development of CCUS hub projects in the region.

Frost & Sullivan expects that emerging innovative funding programs will continue to support the scale up of low-carbon technologies and will fast track CCUS projects across the planning, construction and operational phases.

In Europe, notable market participants include Mitsubishi Heavy Industries (Japan) and Baker Hughes (US) as well the carbon capture specialist Svante (Sweden).

This is a reflection of the global competitive landscape which is dominated by conglomerates where CCUS projects make up a sub-segment of their overall operations. They are joined by medium sized companies, such as Aker Carbon Capture (Norway), which are focused on CCUS technologies and services, as well as emerging players, like Carbon Clean (UK), which are typically developing solutions that are still pre-commercialization.

They and emerging players are looking to Carbon Capture as a Service as a way in which to address customers' full CO2 value chain from source to storage

High capital costs and perceived investment risks have already necessitated business model innovations in the nascent CCUS market. CCUS-as-a-service (CCUSaaS) is an integrated offering and will cover everything a customer needs to reduce its CO2 emissions.

Under this model, clients only pay per tonne of CO2 captured and the service provider handles the CO2 across the full value chain. Typically, CUSaaS technology providers will help customers to set up a carbon capture plant while the transport and storage will be handled by their strategic partners.

Customers who are new to the concept of Carbon Capture, Utilization and Storage will benefit from the CCUSaaS model since they will not need to be concerned about financing, contract management and the risks associated with long-term storage liabilities.

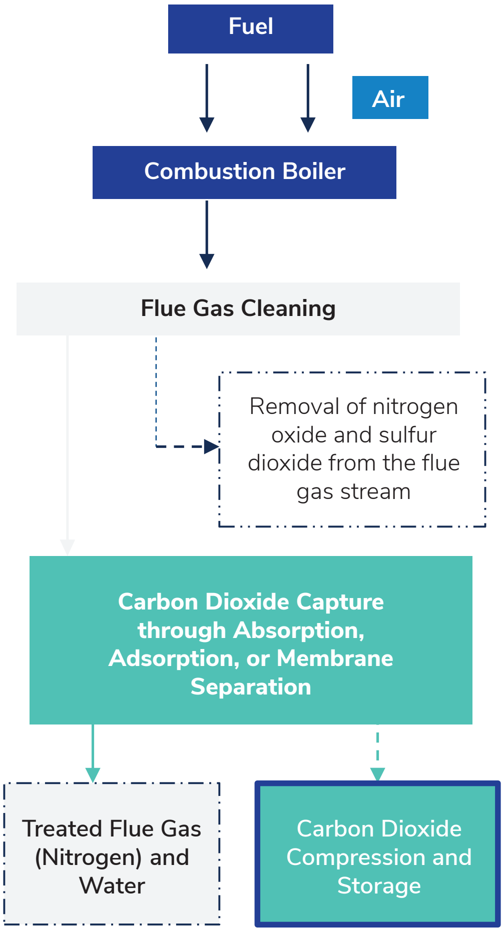
From a technology point of view, CCUS can be broken out into those that are for:

- **Capture,**
- **Compression and purification**
- **Injection and storage**

Source: Frost & Sullivan

The most commercially proven post-combustion *capture* process is solvent absorption with solid absorption and membrane separation rapidly emerging as alternative solutions

CARBON DIOXIDE CAPTURE PROCESSES



Post-combustion absorption capture, which is explored in further detail in the third chapter, involves extracting carbon dioxide from the flue gas stream after the burning of fuels such as coal and natural gas.

The ***advantage*** of solvent or solid absorption and membrane separation is that they can all be easily retrofitted into existing industrial equipment as minimal modifications are required. The ***disadvantage*** is that separating low-concentration CO2 is challenging and energy intensive. In addition, when the volume of flue gas that requires treatment is high, substantial equipment is required which increases the physical footprint of the process.

Source: Frost & Sullivan

Compression and *purification* ensure that captured CO2 is ready for transportation

Purification involves separating captured CO2 from impurities in the flue gas stream, immediately followed by dehydration and compression. It is an important and recommended step prior to transport as it enhances the value of the captured carbon dioxide to downstream processes within the CCS value chain.

Removing flue gas impurities, including hydrogen sulfide and oxides of sulfur and nitrogen, prevents corrosion in pipelines or shipping containers and regulates captured carbon dioxide's density and viscosity to make it conducive for transport.

Dehydration and compression are, however, energy-intensive processes that increase OpEx while technical limitations reduce the purity level of captured carbon dioxide.

Saline formations are used extensively for *storage* although carbon is also increasingly *injected* into oil and gas reservoirs as well as un-mineable coal seams

Geological and deep offshore sites are suitable storage formations for captured CO2 with each having its own pros and cons.

For the former, carbon dioxide from industries and other non-point sources is injected into deep, onshore underground formations. The injected CO2 spreads out consistently within the formations because of their porous structure and permeability while a safe barrier at the top of the structure prevents leakages into the atmosphere.

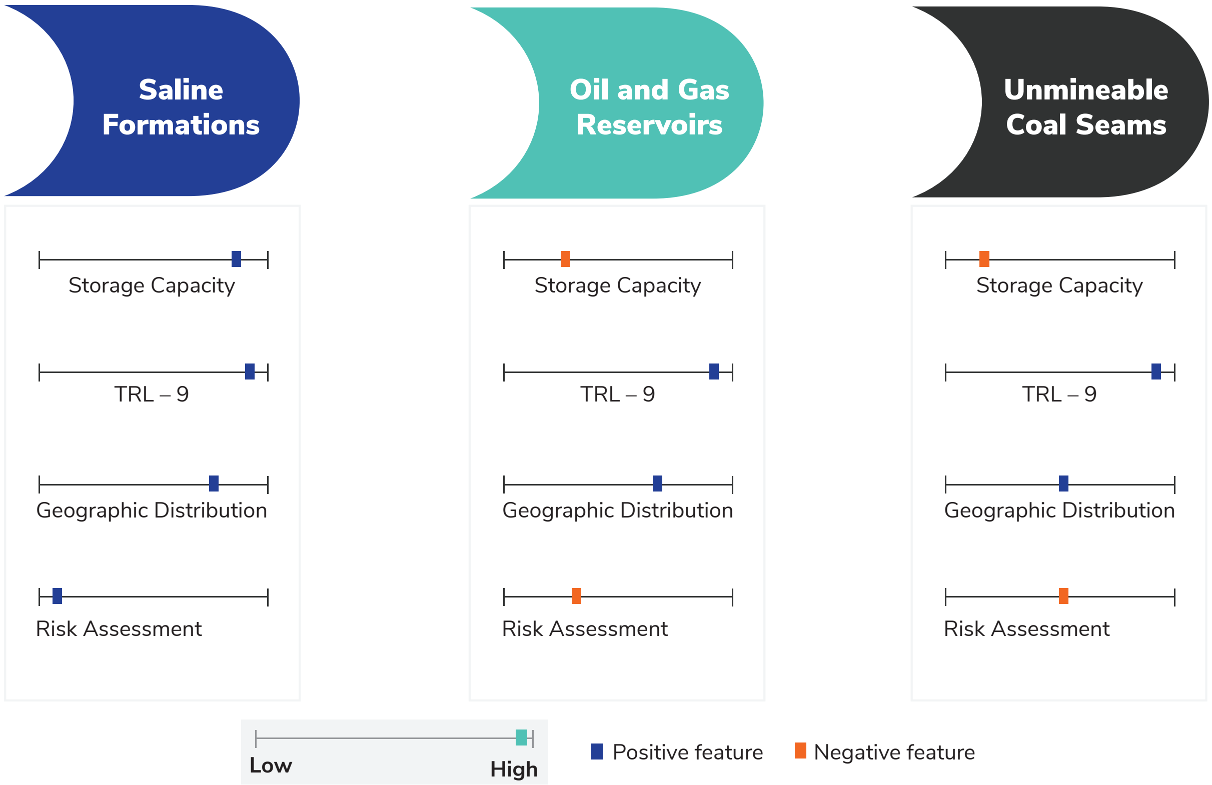
Geological storage sites are typically sedimentary basins with innate huge depressions in the earth's crust filled with sediments.

Well-drilling injection technologies integrated with digital reservoir simulation software and continuous real-time monitoring enable their smooth operation. As the oil and gas industry already uses these technologies, they are readily available for CCS projects.

The key types of geological storage are:

- **Saline formations** which are filled with brine and span large volumes within the storage site. Structural, residual, solubility and mineral trapping mechanisms are used to contain captured carbon dioxide within the brine. Saline formations with Total Dissolved Solids (TDS) of more than 10,000 Parts Per Million (ppm) are ideal for geological storage
- **Oil and gas reservoirs** which are predominantly found in North America offer huge volumes of permeable voids that have held hydrocarbons for years and can be filled with captured carbon dioxide. The voids help enhance oil recovery as they push oil fluid out when CO2 is injected
- **Un-mineable coal seams** which are coal reserves that are not exploitable due to technological and geological factors but that have enough permeability to trap captured carbon dioxide chemically and retain it for permanent storage

CARBON DIOXIDE CAPTURE PROCESSES



Source: Frost & Sullivan

Other options include **basalt formations** where volcanic activity results in the buildup of deposits and chemical reactions between captured CO2 and basalts' magnesium and calcium content form permanent carbonate minerals in storage sites and **shale formations** where, in a similar way to un-mineable coal reserves, adsorption can be used to trap captured carbon dioxide.

Moving forwards, *utilization*, which is explored in further detail in the third chapter, is expected to be favored over storage as it promises to combine emission reductions with additional revenues

Research is currently focused on the use of CO2 in chemicals, fuel and plastics

CO2 can be recycled into **chemicals** using water and electricity only or converted into ethanol and oxygen using catalyst. There are also opportunities for gas fermentation and electrochemical carbon monoxide reduction reactions whilst captured carbon dioxide can be made into formic acid, fertilizers and oxalic acid.

Recently, market participants have begun to investigate leveraging carbon dioxide to obtain methanol (MeOH) through hydrogenation while CO2 pressurization cost can be reduced by using caesium carbonate (Cs2CO3) as a catalyst.

For **fuels**, biomass process energy can be deployed to convert CO2 to liquids while emissions can power photo-bioreactors to cultivate algae. Selective conversion and sorbent technologies can also be applied. Finally, syngas is a popular "target" output from deploying chemical looping, direct recycling and a novel electrolyzer with a bipolar membrane.

CO2 can be converted into novel material, including **plastics**, using microorganism cultures and other approaches. Carbon nanotubes can, for example, be created via electrolysis and electrochemical separation while catalyst technologies can transform CO2 into polyols. Carbon dioxide is also an input to algal polyacrylonitrile fiber production technology.

Source: Frost & Sullivan

AVOIDING CREATING NEW CO2

Increasing the efficiency of production processes and using less or green energy

In order to achieve a decarbonised future, significant economic investments are required in *electrification, renewables* and hydrogen

Electrification, which refers to the process of replacing fossil fuel-based systems with technologies that use electricity as a source of energy, delivers GHG emission reductions in two main ways

Firstly, it shifts energy use away from fossil fuels towards Renewable Energy Sources (RESs) or other low carbon power generation systems

Beyond direct electrification, the drive to decarbonise will compel businesses and other organizations to deploy on-site electrical infrastructure and source renewables through Power Purchase Agreements (PPAs).

In addition, the roll-out of Distributed Energy Resources (DERs) and Battery Energy Storage System (BESSs) are expected to play an increasingly significant role in accelerating electrification whilst at the same time providing balancing services, improving grid system reliability and ensuring the optimal consumption of available RESs.

DERs and BESSs currently account for only a fraction of installed generation capacity globally but their penetration will intensify as stringent environmental regulations at national and supranational levels come into play.

Secondly, it acts as an enabler, allowing efficiency improvements through the increased adoption of emerging digital technologies

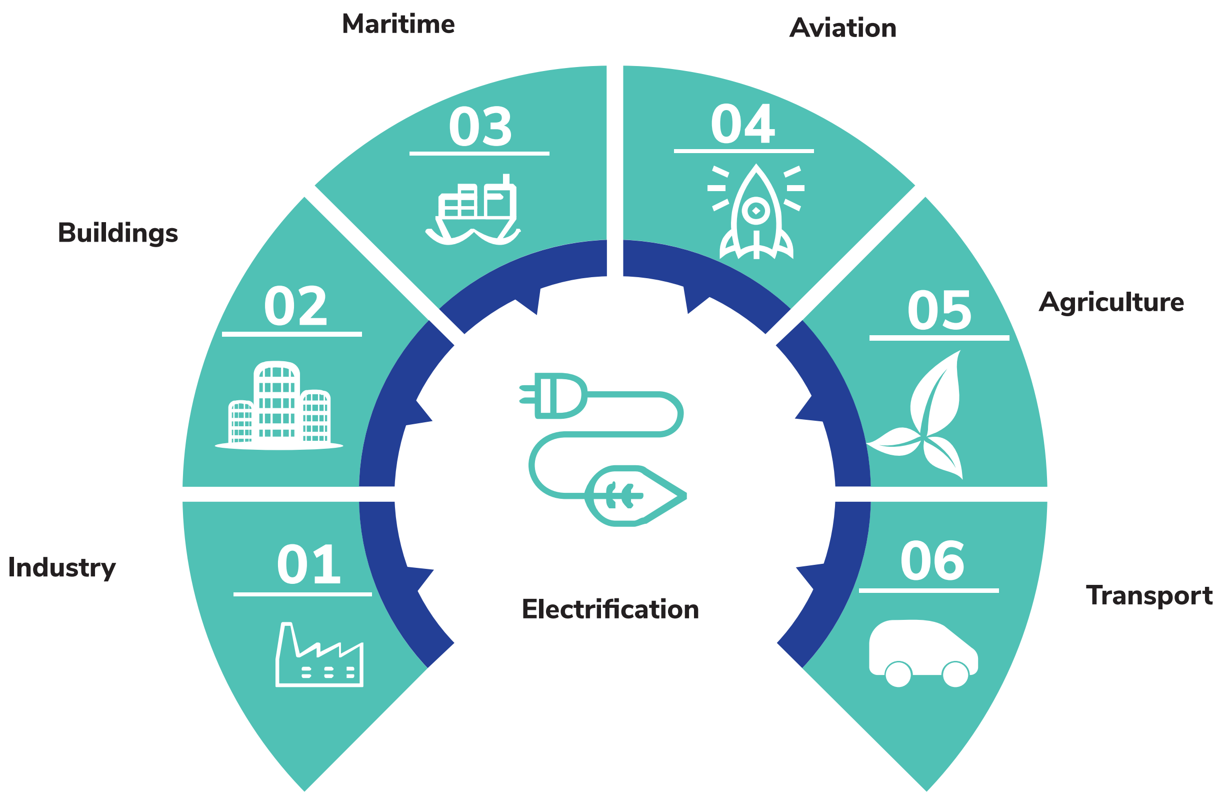
Electrification promotes the integration of emerging digital technologies including Artificial Intelligence, Big Data Analytics (BDA) and Augmented or Virtual Reality (AR/VR) across industries to create intelligent networks. The smart sensors embedded in electrification technologies facilitate more efficient operations and effective decision-making.

In addition, digitalization allows the real-time monitoring and analysis of assets which improves their utilization, reduces OpEx costs and decreases unplanned downtime. The establishment of "smart environments" also has the potential to reduce waste while in parallel ensuring the safety of people and protecting the condition of equipment.

Source: Frost & Sullivan

The impacts of electrification are notably being felt across industry and in the buildings, maritime, aviation, agriculture and transport sectors

PRINCIPAL SECTORS IMPACTED BY ELECTRIFICATION



Industrial emissions account for 29% of the global total with market participants turning to innovative heating technologies to reduce footprints

Industrial electrification offers a range of benefits. However, the challenge here is to achieve scale and price competitiveness in comparison to conventional fossil fuel solutions. This is particularly true for assets that often have a significant operational lifetime.

There are different degrees to which the industrial sector will be electrified in future.

The substitution of fossil fuels with natural or synthetic fuels is one option and will work well for some existing equipment while the replacement of specific units of operation or partial electrification will help organizations that have assets of differing age ranges

Overall, the success or failure of industrial electrification will be determined by the extent to which it can be applied to heating applications, in particular in areas such as iron, steel and cement production where very high temperatures are required for operations.

Direct reduction through the use of Electric Arc Furnaces (EAFs) and the substitution of feedstocks with environmentally friendly alternatives will play a role. Electromagnetic (e.g. induction or infrared) and electrical resistance heating solutions will also become key.

Source: Frost & Sullivan

Heating is similarly the largest source of the CO2 from *buildings* but electrification is facilitating a shift to outcome-based energy management

Buildings have a very significant carbon footprint and tackling the issue of water and, in particular, space heating – which can account for 65% of emissions – will be pivotal to achieving long term emission reduction goals.

The use of new technologies such as ductless mini-split or central Air Source Heat Pumps (ASHPs) will drive building electrification by replacing fossil fuel furnaces.

More broadly, comprehensive Building Energy Management (BEM) systems have become a cornerstone of owners' and operators' sustainability strategies.

BEMs includes but also extends beyond Heating Ventilation and Air Conditioning (HVAC) solutions to provide holistic computerized systems which monitor, manage and optimize the energy performance of both commercial and industrial buildings.

From a technology point of view, the deployment of digital twins and cloud networking is allowing BEM vendors to check energy consumption in real-time and provide predictive and preventative services which in turn is facilitating a shift to as-a-service business models where their financial reward is tied to efficiency gains and energy savings.

The *maritime* sector is currently almost completely reliant on fossil fuels so will need to embrace new approaches to vessel and port operations

Today, shipping accounts for about 3% of global GHG emissions but with increasing global trade this is expected to increase by 50% by 2050 to account for 17% of the total.

The International Maritime Organization (IMO) is responsible for regulating ships' emissions and has set a target to reduce C02 by 50% compared to 2008 levels by 2050. It has also put in place similar goals for sulfur (SOx) and nitrogen oxide (NOx).

Its efforts in respect of electrification are, however, being frustrated onshore by a lack of dedicated infrastructure and offshore by batteries which, with limited energy density and extended charging times, are heavy and take a long time to refuel.

Maritime stakeholders, including port operators and shipping companies, are nonetheless working together to drive a more sustainable future. Emerging motor technology and improved BESSs are paving the way for diesel-electric hybrid and, eventually, fully electric propulsion systems whilst renewable-powered on-shore charging systems are becoming increasingly commonplace with support from utilities and operators

Source: Frost & Sullivan

Electrification is equally necessary but challenging for *aviation* where all-electric aircraft are expected to become a reality between 2040 and 2050

Here, as in the maritime sector, market participants are focusing on electrifying both in-air and on-ground operations but are finding very similar short-term hurdles.

Airport operators such as those at Copenhagen (Denmark) and O'Hare (US) have started to plan and implement infrastructure changes and additions to support electrification. In parallel to those that directly impact aviation, they are also taking a more holistic approach and looking, for example, to deploy greener heating technologies.

Airline operators are partnering with aircraft OEMs as well as engine, battery and component producers, investors and authorities to similarly develop electric solutions. EasyJet (UK) is, for example, working with Wright Electric (US) and BAE systems (UK) to design a 186 seater electric commercial plane with flight testing expected to begin in 2023.

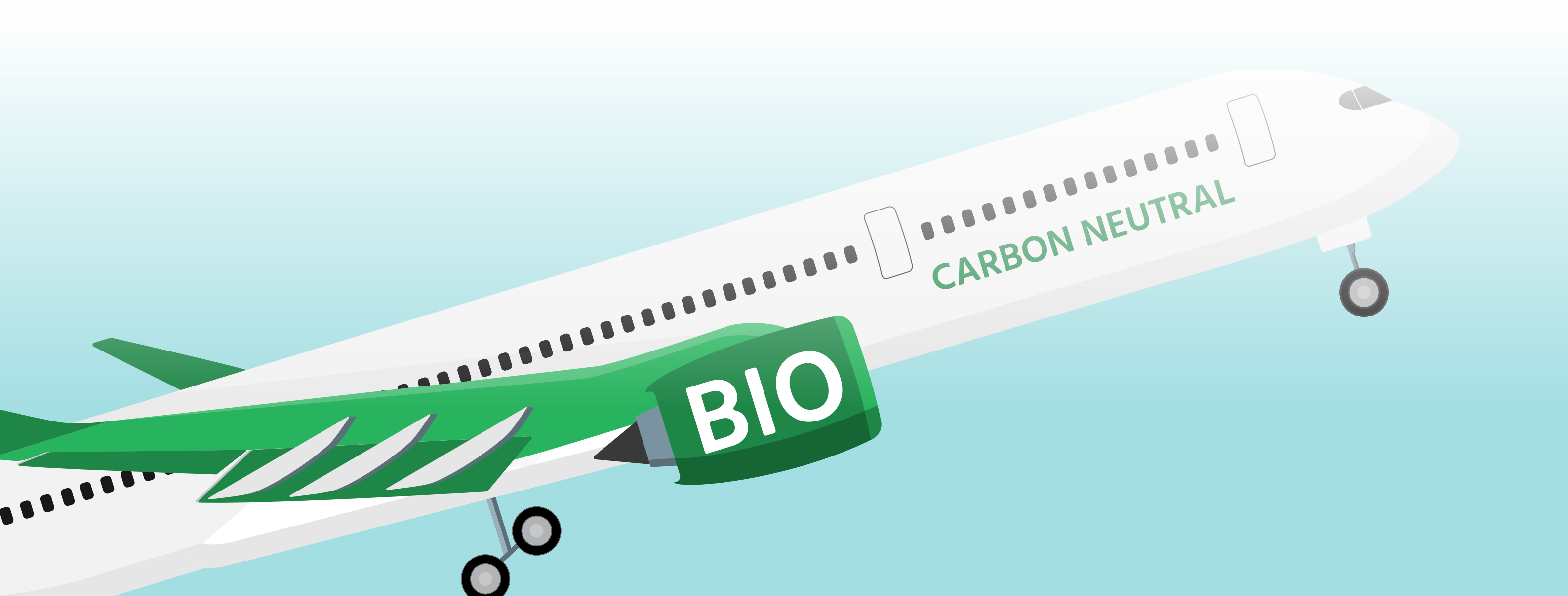
Fully electric platforms like Heart Aerospace ES19 (Sweden) and the eCaravan (Magnix, US) will, in addition to lowering CO2, also bring ancillary benefits including reduced noise and maintenance. They are also expected to open up new destinations especially on shorter routes where conventional aircraft are not currently cost-efficient

Copenhagen Airport

Country: Denmark

Brief Description: Infrastructure for carbon neutral aircraft

Multimedia: https://www.cph.dk/en/about-cph/press/news/2020/10/EU-project-helping-CPH-and-European-airports-for-carbon-neutral-aviation



Source: Frost & Sullivan

In *agriculture*, energy makes up more than 20% of emissions so many stakeholders are investigating emerging powertrain and pumping solutions

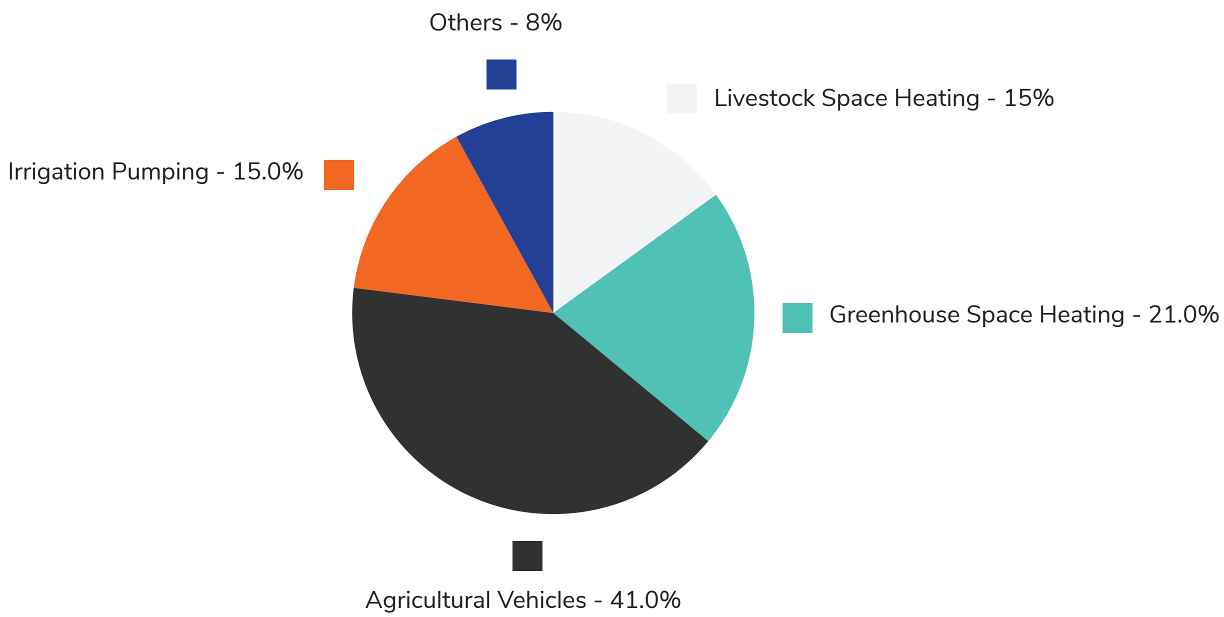
Electrification forms part of a broader transition to sustainable agriculture practices which is expected to stem from more effective crop, land and soil management as well as the more efficient deployment of key inputs such as water, fertilizer and feed.

41% of global demand for energy within agriculture stems from vehicles and 15% from irrigation pumps so industry stakeholders are seeking to replace Internal Combustion Engines (ICEs) in tractors, harvesters and other items of heavy equipment

In parallel, increased electrification is expected to serve as a platform for greater digitalization with the deployment of new powertrains combined with the use of AI and other solutions paving the way for the emergence of precision agriculture.

Urban and regenerative farming are examples of new digitally-enabled approaches which will scale up in parallel to electrification, improving farm utilization and productivity and creating a virtuous circle where enhanced yields lead to reduced emissions.

SHARE OF ENERGY DEMAND FROM AGRICULTURAL SYSTEMS, GLOBAL, 2021



Source: Frost & Sullivan

Electrification is perhaps the most advanced in the *transportation* sector were electric vehicles, batteries and charging infrastructure proliferate

Together, commercial and passenger vehicles, motorbikes and three wheelers, Off-highway Vehicles (OHVs) and buses and trucks are responsible for about a quarter of global GHG emissions and have the potential to account for 40% without an accelerated programme of electrification and the collective efforts of all stakeholders.

Fortunately, technological innovation across vehicles, powertrains and batteries is generating improved performance whilst a narrowing of the price differential between ICE and electric vehicles (EVs) is boosting sales. The increased cost of petrol in the second half of 2021 and into 2022 has provided further market momentum.

Frost & Sullivan estimates that significant uptake of EVs could add 15% to 20% to total electricity demand. Utilities and other operators will therefore need to invest not just in charging but also in power transmission, distribution and – increasingly – storage infrastructure to provide for a fully electric transport system.

By 2040, it is possible to imagine a world in which fossil-fueled commercial and passenger vehicles are completely banned and synthetic fuels will dominate the hard-to-abate transport segments where electrification is insufficient and cannot reduce emissions alone.

More recently, attention has shifted to data centers with demand driving global energy consumption from ~250 TWh in 2020 to 975 TWh in 2030

Operators have adopted a two-pronged approach to decarbonisation by procuring RESs and reducing emissions from stand-by power supplies

Since 2015, the ICT sector has accounted for 45% of corporate renewable PPAs whilst, according to the International Energy Agency, Amazon was the largest buyer of RESs in 2020 with 8GW or power, closely followed by Google with 6.5GW.

Data center operators have also started replacing backup gas and diesel generators with batteries. As lithium-ion solutions become cheaper and more powerful, they offer a low emission alternative and also promise – via their energy storage capabilities – to make data centers into more active grid participants which will in turn also allow them greater access to electricity from renewable sources.

Source: Frost & Sullivan

In parallel, they are improving efficiency by investing in sensors, digital twins and automation and also rethinking data centers' design

The digitalization of data centers, through component sensoring and virtual modeling, allows operators to gain deeper insights over their current and future performance. This, combined with the use of AI, digital twins and automation, enables scenario simulation and real-time infrastructure management which leads to a better allocation of resources including those for energy-intensive power and cooling.

For greenfield sites, data center owners are leveraging solutions from the likes of Future Facilities (UK) to design facilities with low emissions in mind. In particular, they focus on their location and IT room layout to maximize power and cooling efficiency.

Future Facilities

Country: UK

Brief Description: Data center digital twin

Multimedia: https://www.futurefacilities.com/

In the short and medium term, renewables will underpin the move to electrification and more broadly decarbonisation

Source: Frost & Sullivan

Solar is notably expected to contribute about 28% of Europe's cumulative installed power generation capacity by 2030 with investment driven by continued declines in CapEx costs and innovations in areas like solar trackers

SOLAR PV MARKET KEY METRICS, EUROPE, 2021-30

Life Cycle Stage	Revenue	Installed Capacity	Estimated Installed Capacity	Estimated Revenue
Growth	$19.67 B	170.64 GW	465.57 GW	$29.03B
	(2021)	(2021)	(2030)	(2030)

Growth Rate	Compound Annual Growth Rate	Regional Contribution to Cumulative Installed Capacity	Total Market Potential
68.3%	4.4%	15.5%	$272.74 B
(2021)	(2021–2030)	(2030)	(2022–2030)

Emerging inverter technologies, including those with silicon carbide (SiC) or gallium nitride (GaN) switching devices as well as 210 mm module compatible solutions, will gain traction between now and 2030 and continue to reduce solar PV prices.

In particular, they will eliminate the need for foundations for installations and require fewer trackers and cables whilst, at the same time, supporting grid protection and management using sophisticated control systems and interactive communications systems.

Solar trackers, on the other hand, will increase energy efficiency by up to nearly 30% when compared with conventional solar mount panels. Nevertheless, progress needs to be made to reduce their technical complexity and lengthen their lifespans.

In the longer term, hydrogen is increasingly recognized as the best low or zero carbon alternative to using fossil fuels

Source: Frost & Sullivan

Overall, global production is expected to create an industry worth over $400b in revenue terms by 2030 with growth driven by the emergence of commercially viable fuel cells which will spur automotive and aerospace applications

Hydrogen can help curb carbon emissions and, in turn, address climate change, by:

- Decarbonising carbon-intensive areas of the economy such as the transportation and manufacturing sectors
- Integrating more Renewable Energy Sources into the energy mix
- Providing greater resiliency and reliability to the electricity grid as a green Energy Storage System (ESS)

As noted, the accelerating growth in battery powered EVs will add to the pressure on power grids. Hydrogen Fuel Cells (FCs) offer a promising alternative to existing solutions as they do not require long charging cycles. The demand for hydrogen FCEVs is increasing with the current focus particularly on forklifts trucks and other OHVs.

Hydrogen FCs have an energy-to-weight ratio that is ten times greater than Lithium-ion batteries. However, their adoption has been restrained due largely to high production costs. Manufacturers are making progress to reduce the price of key components and to make FCs competitive from a performance and a commercial standpoint.

Green hydrogen, generated from carbon-free sources, represents the "holy grail" and will drive the next wave of investment in renewable energy

Although it is, in itself, a clean energy, almost all of the hydrogen used today is produced from fossil fuels with CO2 released into the atmosphere.

Based on the method of production, ~99% of hydrogen is either:

- **Brown hydrogen** which is produced from coal through a gasification process. This releases high amounts of up to 60% carbon dioxide and carbon monoxide whilst also requiring significant levels of energy consumption
- **Grey hydrogen** which is produced from natural gas and biomass. This consumes less energy than brown hydrogen however it still has a relatively high carbon monoxide and carbon dioxide production up to 55%

Grey hydrogen can be used in the short-term to meet the growing demand. However, in the long term, this method will be unsustainable and require alternative measures.

In the medium term, "blue" hydrogen – produced from fossil fuels but leveraging Carbon Capture Utilisation & Storage – will play a key role in the transition:

- Blue hydrogen is produced from fossil fuels and biomass. The process is similar to that which is used for grey hydrogen but the carbon which is emitted can be captured, stored and used for other industrial uses through the deployment of a Carbon Capture Utilisation and Storage system

Green hydrogen is produced from water through electrolysis and water splitting using renewable energy. This process produces low- or even zero-emissions with carbon monoxide and carbon dioxide production up to only 20%.

Source: Frost & Sullivan

Changing production processes to make new things or the same things differently

Across industries, lightweighting, which is explored in further detail in the third chapter, is one of the most widespread ways in which market participants are looking to decarbonise by "making things differently"

In the aerospace sector, additive manufacturing technologies such as Fused Deposition Modelling have the potential to make Urban Air Mobility become reality

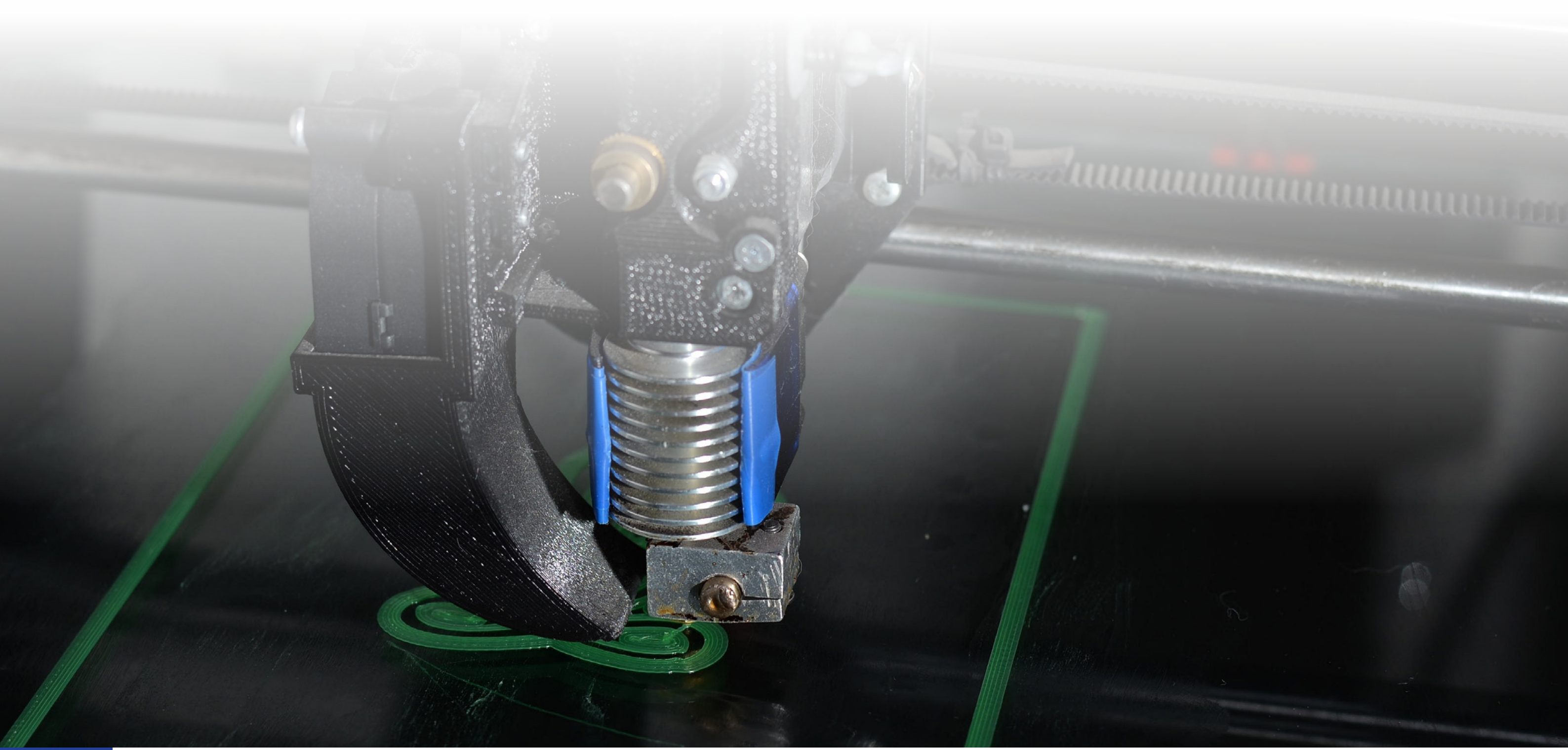
3D printing is being adopted for designing, prototyping and manufacturing components with multi-material printing expected to be the next step.

Fused Deposition Modelling (FDM) was one of the first technologies to address the market and continues to be the most widely used and commercially available solution.

Also known as Fused Filament Fabrication (FFF), the process leverages a continuous filament of thermoplastic material as a base material with objects then manufactured by selectively positioning the pre-determined path of a molten material across this.

In addition to its lightweight properties, FDM/FFF has an advantage over other additive manufacturing techniques in that the printer and material costs are relatively low and the equipment is easier to maintain. This makes the technology a prime candidate for providing parts to the nascent Urban Air Mobility (UAM) market.

Frost & Sullivan estimates that at least sixty companies globally are actively engaged in developing and testing UAMs with approximately fifty cities considering Electrical Vertical Take-off and Landing (eVTOL) solutions as a means by which to reduce transport-related CO2 emissions. 3D printing has the potential to accelerate their commercial roll-out and address line/retrofit and aftermarket opportunities in the wider aerospace market.



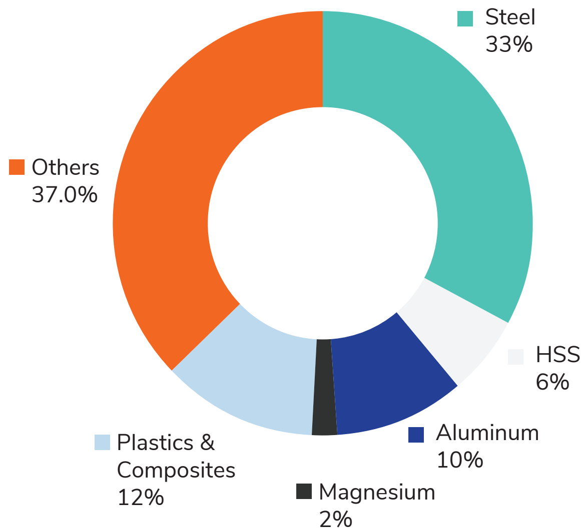
Source: Frost & Sullivan

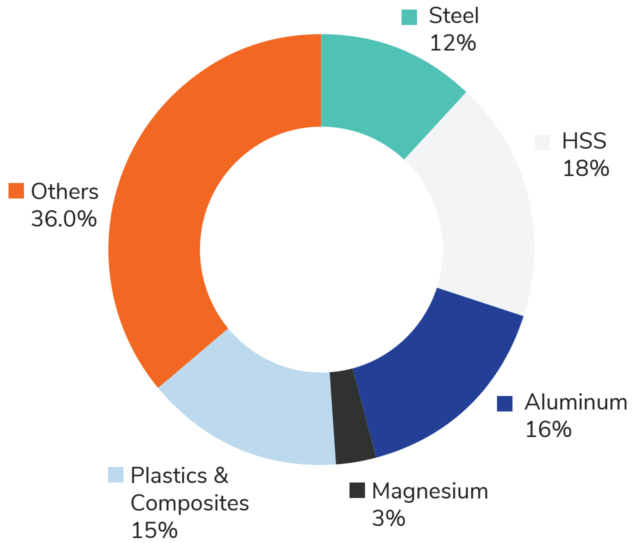
On the automotive side, high strength steel, aluminum, magnesium and composites are expected to take share from steel in internal and external applications

By 2025, the average proportion of steel per vehicle globally is expected to fall to 12% from 33% in 2018. In relative terms, this will primarily be to the benefit of high strength steel which is expected to see nearly threefold growth and account for 18% (up from just 6%) due to its extensive use in key structural parts.

The ease of manufacturing complex parts will pave the way for increased usage of plastic and composite components in future vehicles which will contribute 15% and replace metal parts in interiors. Applications for magnesium are also set to increase over time but this will still only account for about 3% in 2025.

AVERAGE WEIGHT DISTRIBUTION PER VEHICLE BY MATERIAL, GLOBAL, 2018 AND 2025





Source: Frost & Sullivan

More broadly, end-users are looking to move away from petrol-based products with bio-based plastics a prime example of reducing CO2 by "making new things"

Sustainable solutions represent less than 1% of total global polymer production today but demand and supply factors bode well for scale-up moving forward

While recycling continues to gather steam, bioplastics are in parallel enjoying growing acceptance. Policy developments and limitations on the use of non-biodegradable solutions are expected to drive the industry to invest in new capacity – global output is slated to expand 3x between 2021 and 2026 – and also ramp up material innovation.

The APAC region in particular is expected to contribute significantly to global bioplastics supply. NatureWorks (US) for example, a leading manufacturer, is setting up a 75,000 tonnes per annum facility in Thailand for its Polylactic Acid (PLA) products.

Indeed, bio-based PLA as well as Polyamide (PA), Polybutylene Succinate (PBS) and Polybutylene Adipate Terephthalate (PBAT) are the focus of significant R&D dollars and are expected to grow to represent the most widely used sustainable bio-solutions.

They and other bioplastics are increasingly used in diverse set of applications notably in the food and beverage sector. In October 2021, Coca Cola (US) for example launched a plant-based plastic bottle prototype while the company has partnered with Virent (US) to convert bio Paraxylene (bPX) into plant-based Terephthalic Acid (bPTA). Similarly, in December 2021, Suntory (Japan) announced the launch of its equivalent solution which is developed in partnership with Annelotech (US) and converts wood-based bPX into bPTA

The Coca Cola Company

Country: US

Brief Description: Plant-based plastic bottle

Multimedia: https://www.coca-colacompany.com/news/100-percent-plant-based-plastic-bottle

The trends are similar in coatings, adhesives and sealants

Here, vendors are partnering and investing in R&D in order to surmount key challenges around the performance, cost and availability of natural materials

For bio-based Coatings, Adhesives and Sealants (CASs) to replace existing petrochemical-based solutions, they will need to offer the same ease of processing and functionalities as their predecessors at a similar or lower cost. Equivalent performance and price parity must also be matched with access to sufficient and secure sources of raw materials which do not upset the balance of delicate human and/or animal food chains.

Market participants are striving to reduce these gaps by pursuing a range of strategies which are based primarily on collaboration and innovation.

In February 2021, for example, Dow (US) and Henkel (Germany) announced a tie-up to develop sustainable hot-melt adhesives for packaging applications. The companies' product is available under the former's AFFINITY RE range and as part of the latter's SUPRA ECO portfolio. In April 2021, Teknos and Brightplus (both Finland) similarly launched a new and sustainable barrier coating for food and beverage applications. Wacker (Germany), Beardow Adams (UK) and Cardolite (US) are among others investing in product development.

Teknos and Brightplus

Country: Finland

Brief Description: Bio-based barrier coating

Multimedia: https://www.teknos.com/lt-LT/newsroom/2021/teknos-and-brightplus-cooperation/

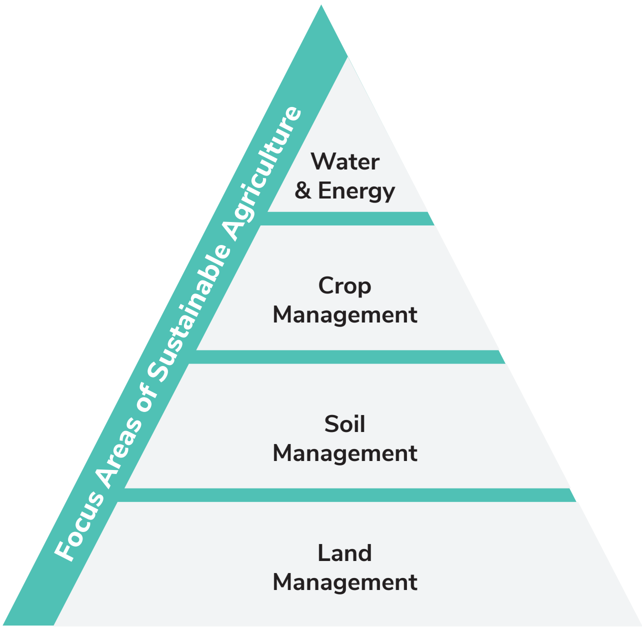
Source: Frost & Sullivan

Elsewhere, the food, agriculture and nutrition industries account for about a third of global GHG emissions making the sector a focus for decarbonisation

According to the Food & Agriculture Organization, the global population will reach 9 billion by 2050 which will exacerbate emissions from a sector which already produces 18 billion tons of CO2 equivalents annually. In parallel, demand for food, agricultural production and related inputs such as water and energy will increase meaning that the sector is not only impacted by the UN's broader Sustainable Development Goals (SDGs) such as Climate Action (#13) but also sector-specific programmes such as Zero Hunger (#2), Responsible Consumption and Production (#12) and Life on Land (#15).

These factors, combined with growing awareness of the need for a change in approach (among farmers on the supply side and consumers on the demand side) is giving rise to technology-enabled sustainable farming practices which look to better manage the use of inputs, land, soil, crops and outputs with a view to reducing carbon emissions.

SUSTAINABLE FARMING PRACTICES



Farmers are notably driving emerging waste-to-energy initiatives and taking creative approaches to developing biofuels …

The US Environmental Protection Agency (EPA) has defined waste as any garbage or refuse resulting from residential, commercial, industrial and agricultural operations. Some of the most common types of waste generated from these activities are Municipal Solid Waste (MSW), water lipids, plastics and, in the case of the farming industry, biomass.

Biomass is the renewable organic material obtained from plants and animals. Heating applications use energy stemming from this for cooking and comfort. A variety of techniques are used to convert biomass to a liquid or gas fuel with **thermochemical waste reforming** technologies the fastest growing and most well-established.

Within this, **Hydrothermal Liquefaction** (HTL) which has a Technology Readiness Level (TRL) of 7 leverages wet biomass and **ionic gasification** (TRL 8) produces cleaner syngas than conventional techniques while **fast pyrolysis** (TRL 8) meets the demand to efficiently convert dry biomass into bio-crude.

Beyond biofuels, market participants such as Ostara (US) are exploring how nutrient recovery could improve agricultural sustainability by replacing traditional fertilizers.

Source: Frost & Sullivan

… while Agricultural biomass increasingly serves as a basis from which to draw natural cellulosic materials which can replace their synthetic alternatives …

Plant biomass contains a high volume of cellulose (long linear chain polysaccharides), hemicellulose (short cross-linked chained polysaccharides) and lignin (non-carbohydrate organic) compounds.

Natural cellulose can be produced via a range of chemo-mechanical techniques such as bleaching, hydrolysis and alkalization with researchers and market participants working to develop cost-efficient and environmentally-friendly ways of extracting it from biomass.

This and the synthetic, composite and nanocellulose varieties have the advantage of being biodegradable and compostable, durable and fire resistant whilst also offering high stability as well as moisture absorption and insulation properties.

As such, cellulosic materials offer a green alternative to established products across a wide range of end-industries with commercial solutions (TRL 9) currently available in area such as textiles (cellulose acetate), food and cosmetics (cellulose nanocrystal) and buildings and construction (cotton).

Companies such as Fiber365 (Germany) and Renewcell (Sweden) are promoting the conversion of agricultural waste into cellulose with the industry targeting its use as a coating in high-tech application areas such as water treatment processes and medical devices.

… and the up-take of plant, microbial or cell-cultured meat alternatives minimizes the impact of CO2-intensive livestock farming

Overall, the global meat analogs protein ingredients market is expected to grow from $1.5 billion in 2020 to $2.6 billion by 2026 which represents a CAGR of 8.9%. The sector is in a nascent phase of development but its positive prospects are underpinned by demand from an increasingly flexitarian population and growing awareness of the health benefits of largely plant-based regimes.

In addition, consumers and producers are increasingly concerned about the carbon footprint of conventional meat production with production and postproduction CO2 emissions stemming from lamb and cattle approximately 8x and 5x that of, for example, nuts. In parallel, technological advances mean that alternatives are progressively more able to match the taste and texture of animal-derived products.

The majority of the meat analogs is currently accounted for by plant proteins, notably wheat and pea, but microbial (primarily fungal) and cell-cultured products represent emerging alternative solutions. In the former, Quorn Foods (US) is to date the only supplier of mycoprotein products while Eat Just (Singapore) and Super Meat (Israel) have launched lab-grown approved solutions.

Quorn Foods

Country: US

Brief Description: Quorn microprotein

Multimedia: https://www.quorn.us/mycoprotein

In the building space, the deployment of smart lighting solutions stems largely from the potential for cost and energy savings

Building owners and occupiers are shifting from conventional lighting systems to advanced lighting solutions that allow them to meet energy efficiency targets whilst simultaneously improving occupants' experience and comfort.

Smart lighting encompasses LED lamps, luminaires and strips, lighting controls and sensors as well as a range of platforms all of which are connected to the internet which allows them to act autonomously or be accessed remotely.

Market leaders such as Signify (Netherlands), Acuity Brands (US) and Helvar (Finland) are increasing leveraging AI and ML to integrate lighting with other equipment and drive the creation of fully connected residential and commercial premises. This will be a prerequisite for achieving zero energy buildings of the future.

In parallel, the EU's Renovation Wave Strategy is expected to generate fresh interest in Lighting as a Service platforms which facilitate green retrofitting

Lighting as a Service (LaaS) is a subscription-based business model where the end-user or landlord "purchases" the light rather than the hardware that delivers it. With this approach, the vendor and occupier or owner typically enters into a multi-year agreement with LaaS sold either separately or as a component of a broader energy performance contract or energy efficiency service project.

LaaS stands to benefit from increased focus on renovating existing buildings.

The European Commission estimates that 11% of the Union's stock undergoes some level of refurbishment each year but energy-focused projects account for just 1%. The EU's Renovation Wave Strategy aims – through a combination of direct and private investment, research and innovation and technical assistance to lower market barriers – to at least double renovation rates in the next ten years. This is with a view to improving resource efficiency and provides LaaS vendors with an opportunity to promote their services as one of the key planks of the solution.

Full details of the Renovation Wave Strategy can be found at the following link:

https://ec.europa.eu/commission/presscorner/detail/en/IP_20_1835

Schiphol in the Netherlands is a case in point. The operator has a target of becoming the most sustainable airport in the world and is working to reduce energy consumption as well its overall environmental footprint. Partnering with Signify, the company is testing a circular lighting model where LEDs lamps are installed in its lounges and they can be returned to the vendor for reuse or recycling.

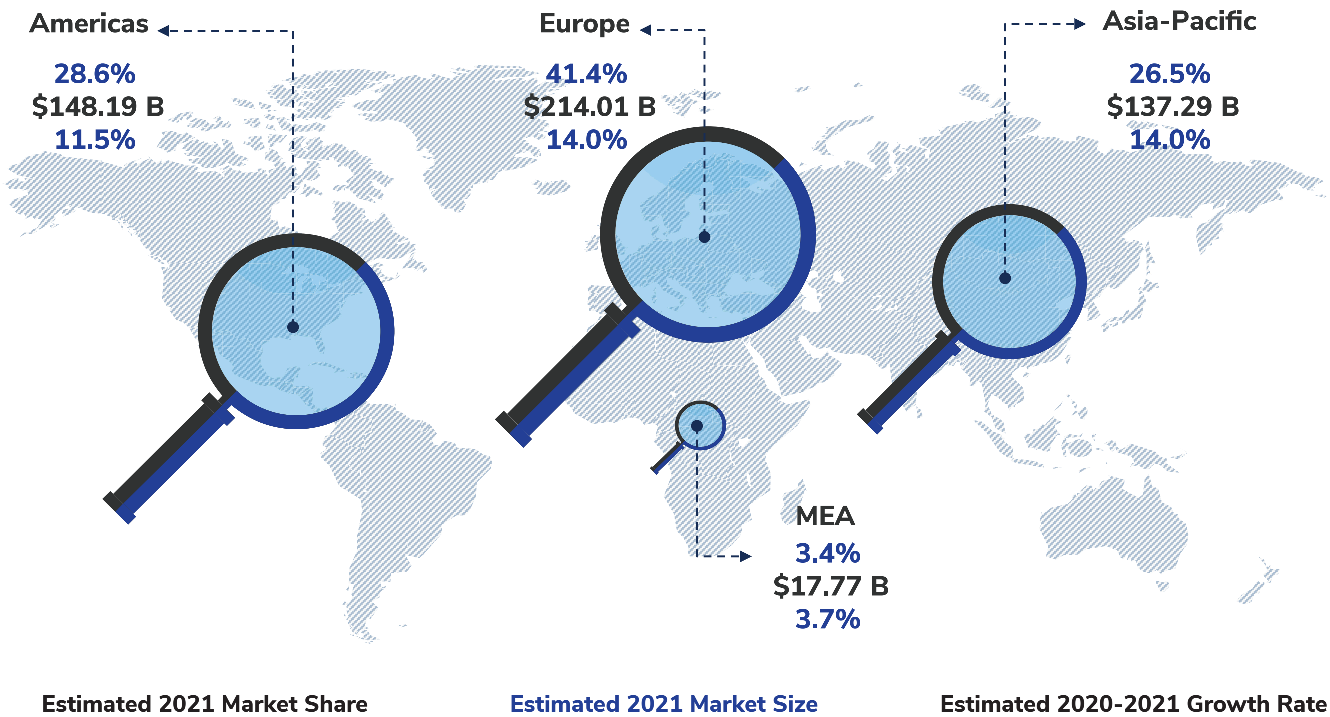
Currently, the airport is witnessing a 50% reduction in electricity consumption thanks to 3,700 newly installed luminaires which can be replaced on an as-needed basis.

Overall, recycling can be considered to be the ultimate expression of both "making new things" and "making things differently"

Frost & Sullivan estimates that the European market was valued at $214b in 2021 with double digit growth in municipal, industrial and plastic segments

In addition, the hazardous waste segment expanded by 50% from a low base to be valued at $37b while the Waste Electrical and Electronic Equipment and the Construction & Demolition (C&D) segments grew at only low single digit rates.

WASTE RECYCLING MARKET KEY METRICS, GLOBAL, 2020-21



Source: Frost & Sullivan

Direct decarbonisation efforts are currently focused on polluting and CO2 intensive items such as petroleum-based and synthetic oils …

The recycling of waste oil is preferred to disposal as it limits environmental damage, increases material recovery, protects crude resources and enables cost control. Motor oil lends itself to reuse as it does not wear out but becomes contaminated and, after re-refining, can meet the requirements and the quality levels of the original oil.

Key opportunities for market participants in the sector are linked with processing motor oils for applications in the petroleum and refining industries. Recycled scrap metal from oil filters can be also used as feedstock for the steel industry.

Chem-Ecol (Canada) offers exclusive reclamation solutions dedicated to industrial oils and PurePath Green Technology (China) provides turnkey solutions to recover high-quality oil and diesel from used lubricants while Brent Technologies (Uganda) has developed the innovative and low-cost S-TECH technology dedicated to the recycling of used oil into valuable new motor oil and diesel.

Chem-Ecol

Country: Netherlands

Brief Description: Single source lubrication products

Multimedia: https://www.chem-ecol.com/

Source: Frost & Sullivan

… while *indirect* efforts including leveraging emerging digital technologies to reduce the carbon footprint of the recycling industry itself

The development of smart sorting and recycling solutions is driven by the growing need for more effective processing and the higher purity of sorted waste. Robots, advanced computer vision systems and AI are being installed at recycling facilities to enable the energy-efficient separation of plastic waste, fiber, metals and other materials.

In the future, these and similar solutions will increasingly be supported by technologies dedicated to smart packaging. Digital labels, for example, use readable markers (such as watermarks, barcodes and QR codes) to provide information about material composition and enhance sorting and recycling rapidity and reliability.

AMP Robotics (US) and ZenRobotics (Finland) provide solutions in this first category with their computer vision and deep learning trainable recycling robots enabling the precise separation of different waste types.

Security Matters (Australia) plays into the second market, offering its customers integrated solutions for material tracking across the entire product lifecycle through the use of sub-molecular markers. Digimarc (US) similarly supplies its Platform product digitization system which enables the efficient identification of materials and goods.

Recycling is also shaping the highly-polluting carbon black industry with the inclusion of recovered material in the production process enabling circularity

Over two billion tons of End-of-Life Tires (ELT) are collected each year globally. Most ELTs are recycled whilst a third are treated in waste-to-energy facilities. This leads to a growing dependence on sourcing carbon black for new tire production and increases CO2 emissions from the production of rubber-based components.

The current situation is unsustainable, increasing concerns about climate change and raw material consumption and resulting in a poor economic model where valuable ELT feedstock is lost along the supply chain.

Carbon black can however be obtained from the ELT recycling process and is known as recovered carbon black (rCB). The chemical industry is increasingly seeking to use rCB in notably as a pigment and a filler. RCB has the same grade and quality as the initial ELT meaning it can be deployed as a 1:1 replacement.

Source: Frost & Sullivan

Market participants are also looking to make manufacturing cleaner and more efficient by using zero emission pyrolysis technologies

Carbon black production consumes liquid hydrocarbons (as a feedstock), natural gas (as a fuel) and air (as an oxidant) and results in a mix of tail gas and suspended carbon black. GHG emissions occur during tail gas combustion with approximately 44 GJ/ton of carbon black and 3.3 tons of CO2/ton of carbon black.

Manufacturers therefore need to invest in new technologies and incorporate emerging solutions to move the industry towards zero or at least lower emissions.

To this end, Mitsubishi Heavy Industries (MHI, Japan) has for example backed US-based Monolith Materials. Monolith develops systems that produce hydrogen and carbon black from natural gas using plasma-based methane pyrolysis technology and which deploy renewable energy as their primary heat source.

Monolith Materials

Country: US

Brief Description: Methane pyrolysis for hydrogen and carbon

Multimedia: https://monolith-corp.com/methane-pyrolysis

Source: Frost & Sullivan

USING AND PRODUCING NEW MATERIALS

The deployment of new materials as an input to and output from production processes will be key to the success/failure of many decarbonisation initiatives

Lightweight materials offer a significant solution and are finding applications notably across the automotive and aerospace industries but also more broadly in areas such as power generation, construction and consumer goods

Uptake is being driven by a combination of push and pull factors with regulations mandating change while manufacturers and consumers increasingly appreciate the benefits that emerging "light" solutions can bring to bear

This is particularly true in the automotive sector where, despite a lack of harmonized global emission standards, the overall tightening of regulations which require improved fuel efficiency across the globe is creating a steady tailwind.

In the US, a national fuel economy programme was proposed in 2009 to regulate GHG emissions from vehicles. Under the scheme, vehicles model from 2017 to 2025 were set to be limited to an average of 37.8 miles per gallon (mpg) in 2017 and 54.5 mpg by the end of 2025. However, in March 2020 the requirement across segments was slashed by 30% and the new bar for vehicles from 2021 to 2026 was pegged at 40.4 mpg.

In Europe, the standards are stricter still. The Parliament's Regulation EC 443 from 2009 mandated CO_2 emission targets for new vehicles with 95% of passenger cars needing to achieve 95g CO_2 per km by 2020 and 100% compliance required 2021. This entailed an average reduction of 35 g CO_2 per km with annual saving of 7g CO_2 per km per year while more stringent targets have been adopted for 2025-3030.

Given that a 10% reduction in vehicle weight can result in a 6% to 8% improvement in overall fuel economy, these dramatic changes can only be achieved if OEMs shift their focus towards the use of alternative and lightweight materials in production.

Nonetheless, there are challenges to further adoption including concerns about costs and performance and the need to consider total lifecycle emissions

Whilst in the future hybrid materials may offer a solution and improved recycling rates will also play a role, in the short term the industry is faced with a significant hurdle which is to match the weight and functionalities of lighter alternatives with the economics of the parts that they are set to replace. Magnesium is for example more than twice as expensive as steel while composites can cost up to 30x more.

These differentials mean that emerging solutions need to not only equal but ideally exceed the performance of conventional solutions when measured by weight and a range of other characteristics. Aluminum for example has the potential to reduce vehicle mass by up to 40% but is relatively susceptible to galvanic corrosion compared to steel.

End-users across industries judge lightweight materials according to their tensile and torsional strength and resistance from a ductility or creep, wear, shock or vibration and temperature point of view. Increasingly, they are also taking into account the CO_2 that is created not only across the manufacturing process and the use of the product but also at its end-of-life based on for example its recyclability.

Source: Frost & Sullivan

Market participants are achieving lightweighting in multiple ways with clear advances in manufacturing capabilities facilitating the launch of new materials

In addition to replacing elements of high specific weight with lower density alternatives, direct lightweighting is being complemented by indirect lightweighting which typically relies on the downsizing parts and components. This approach is being enabled by changes to production process such as the development of new joining techniques as well as the advent of 3D printing. Improvements in design and construction are also playing a role.

The use of heavy and polluting conventional steel is declining with high-strength, ultra-high-strength and advanced high-strength a common replacement

Conventional steel is heavy and carbon-intensive to produce making it a prime candidate for substitution with lighter and greener alternatives across multiple applications.

Over time, vendors have looked to develop like-for-like replacements with the first-generation offering strength at the cost of low elongation while the second was characterized by ductility but faced joining challenges.

The latest versions of **high-strength**, **ultra-high-strength** and **advanced high-strength steel** (HSS, UHSS and AHSS) have largely overcome these issues and importantly provide strength and therefore the safety properties that are needed for structural parts.

AHSS manufacturers are currently looking to reinforce its credentials by highlighting its relative energy efficiency across the production process.

Metal alloys, in particular aluminum but also magnesium, titanium and beryllium, offer another alternative and promise very consequential weight savings

Aluminum is not a new material and, in many cases, its content has been steadily declining due to the development of alternatives. Nonetheless, it remains an important component, notably for aerospace OEMs, and is again gaining ground thanks to new grades such as aluminum-lithium which is a high-strength, low-density and high-stiffness alloy that demonstrates superior damage tolerance and corrosion resistance.

Overall, the four main lightweighting alloys offer a range of pros and cons:

- **Aluminum** can provide weight savings of 40% compared with steel and is highly formable, flexible and recyclable but sensitive to surface defects
- **Magnesium** (60%) offers one of the lightest specific weights for metal alloys and is resistant to thermal fatigue but has a low formability and elasticity
- **Titanium** (50%) is widely available, very strong and unaffected by corrosion but relatively heavy and complex and costly to manufacture
- **Beryllium** has high structural stability and allows good heat dissipation but is brittle and produces dust which is very toxic and can be harmful to health

Source: Frost & Sullivan

More broadly, plastics continue to provide effective lightweight solutions across many applications despite the fact that the majority remain petrol-based while composites, including glass-, carbon- and increasingly natural fiber-reinforced polymers, are gaining ground thanks to their good strength-to-weight ratio

Big data analytics provides the ability to manage and integrate information generated at all stages of the value chain, from discovery to real-world use after regulatory approval. In particular, its use is key in maximizing internal and external collaboration. The growing wealth of new analytical techniques will enhance future innovation and feed the material development pipeline by reinforcing chemicals companies' analytical capabilities.

Composites can be up to 70% lighter than a cubic foot of cast steel and provide superior design flexibility, durability, corrosion resistance, toughness and performance characteristics in comparison with metals. In addition, they require fewer parts and thereby also optimise the production timelines and costs during assembly.

Within composites, **Glass Fibre-reinforced Plastic** (GFPR) is a fairly low-cost material, which makes it suitable for large structures. It demonstrates good resistance to solvents and acids. Properties such as low moisture absorption, heat resistance and low dielectric constant make it attractive for use in most applications.

Carbon Fibre-reinforced Plastic (CFRP) is extremely light weight. It is in a relatively early stage of development and deployment compared with GFPR but its resistance to extremely high temperature (of up to 1000°C) makes it suitable for use in high-performance settings. The cost of this material is also decreasing gradually.

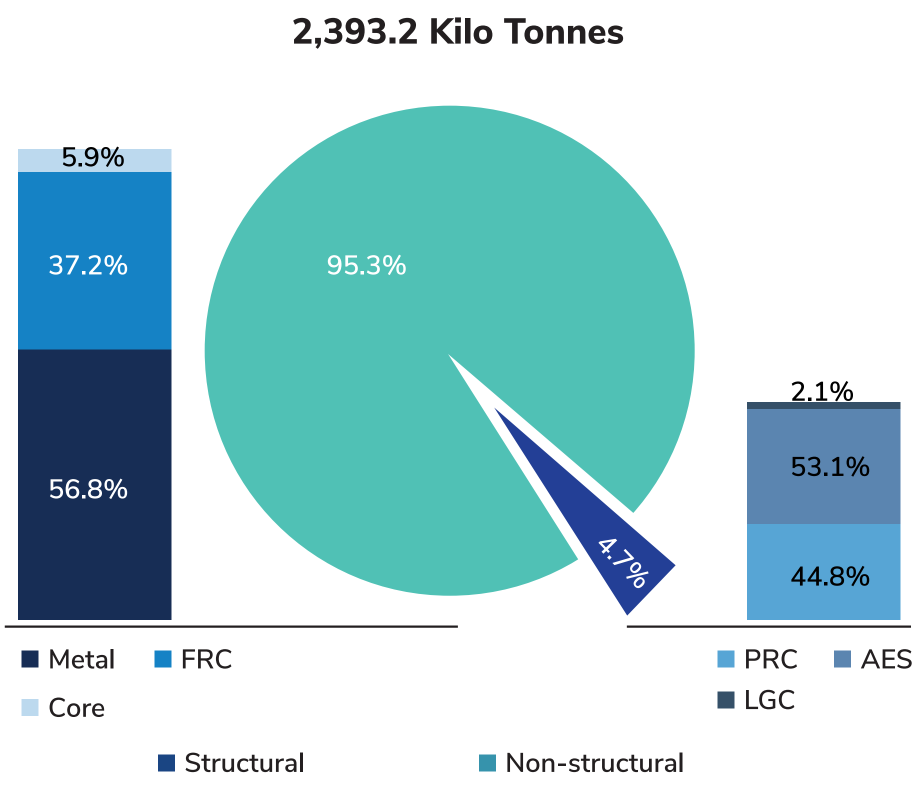
Natural Fibre-reinforced Polymers (NFRP) is less than expensive than other composites. The material is easy to process and is also biodegradable and 100% recyclable.

Overall, composites are becoming the norm for body modules in EVs whilst they and plastics are increasingly playing a role in reducing the density of battery packs. In the aerospace sector, composites represent 50% of the lightweight content of Boeing's B787 and 53% of Airbus' A320/A350 airframe, engine and interior materials.

In addition, they have become a key input to the wind energy industry with Fiberglass Reinforced Composites (FRC) combined with epoxy resin accounting for 37% of rotor materials globally in volume terms and 41% when measured by revenues. FRC forms the backbone of wind turbine blades, giving lightweight strength to the structure and providing an aerodynamic profile. With increasing blade lengths, higher volume of composites will be required per blade to ensure stability as well as strength and damage resistance

Source: Frost & Sullivan

SHARE OF WIND TURBINE MATERIALS IN UNIT TERMS, GLOBAL, 2026



Source: Frost & Sullivan

This is to the advantage of leading GFRP and CFRP suppliers such as tier one players Hexcel (US), Solvay (Belgium, through its acquisition of Cytec) and Toray (Japan).

Hybrid materials can also improve material performance

There are several ways of assembling and forming multi-materials by joining metals like steel and aluminum with other metals, with polymers, with nanostructures or with fibers. By adapting their structural design, hybrid solutions have the potential to offer improved strength and formability whilst also enabling light weighting.

The US Department of Energy (DOE) has, for example, conducted studies which show that, in automotive applications, aluminum and carbon fiber cam carries can provide comparable performance to conventional materials with a 20% weight reduction whilst aluminum and steel clutch hubs can save up to 60%.

On the downside, the EU's End of Life Vehicle Directive has put pressure on OEMs to increase recyclability. The use of multi-materials makes this a challenge as each metal, polymer of fiber typically requires a different approach. Developing effective sorting and recycling techniques will therefore accelerate adoption.

In the longer term, additive manufacturing promises to move beyond rapid prototyping to provide lighter products with short lead times and reduced cost while metal foams and aero gels are examples of other emerging innovations which meet the demand lightweight thermally insulating materials across industries

Metal foams are manufactured by injecting a gas into a solid metal to form gas-filled pores either through a closed or open cell method. The resulting material's unique porous structure helps in lightweighting whilst it also absorbs energy and offers acoustic and thermal insulation properties. Aluminum-based metal foams are expected to have the highest commercial impact in the short term with market participants such as BAE Systems (UK), Cymat (Canada) and Alucoil (Spain) promoting their application in car parts and ship hulls as well as in the building and construction industry.

Aero gels are produced in a similar fashion with gas replacing the liquid component in metals but also silica, chalcogens, polymers, carbon and graphene. They are typically prepared using a sol-gel process in which they are "super critically dried". Silica aero gels are leading the market development with companies in APAC such as LG (South Korea) and Hitachi (Japan) looking to scale up capacity so that they can be deployed as lightweight acoustic barriers for building envelops and for thermal insulations in windows. In the longer term, they could be used as a catalyst for hydrogen production and in drug delivery.

Recycled materials are another area of focus with specific attention currently being paid to polymers and Waste Electrical and Electronic Equipment (WEEE)

Plastics are more problematic than most materials in that they are both carbon-intensive to produce and extremely challenging to dispose of after their use

Polymers are one of the most widely used materials for consumer, industrial and commercial applications due to their lightweight and transparent nature and relatively low cost compared to other solutions such as metal, wood and glass.

However, as a result of their deployment in single-use products, huge volumes of plastic waste are generated across the globe. This is proving difficult to manage as polymers can take 500 to 1,000 years to breakdown when deposited in landfills.

Land and marine ecosystems are adversely affected by polymer waste. There is therefore an urgent need to develop ways to manage plastic in order to protect the competitiveness of manufacturing companies, the environment and human health as well as to reduce the strain on the earth's finite resources. Changing how plastics are designed, used and reused and creating a circular economy will require stakeholders to take three actions:

- Eliminate all problematic and unnecessary plastic items
- Innovate to ensure that 100% of plastics are needed are reusable, recyclable or compostable
- Circulate all plastic items that are used to keep them in the economy and out of the environment, focusing only on plastics that are free from hazardous chemicals (especially plastic packaging)

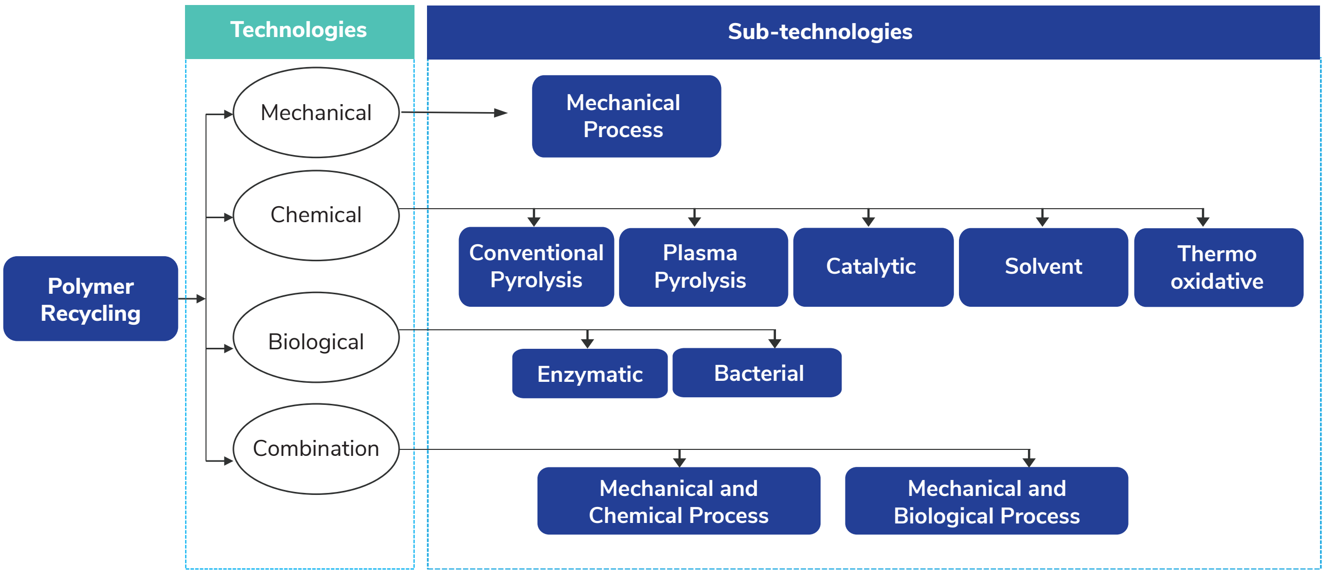
The promotion of the concept of circularity in the plastic industry is also being driven on the supply side by the implementation of environmental regulations, market participants' focus on sustainability and the deployment of new and digital technology.

On the demand side, consumers are increasingly rejecting sing-use plastic solutions.

Source: Frost & Sullivan

Today, 80% of polymers are recycled using mechanical processes but chemical, biological and combination solutions promise new low-emission approaches

POLYMER RECYCLING PROCESSES



Mechanical recycling is the conventional pathway to polymer reuse and refers to the physical process of collecting, sorting, grinding, washing, drying, pelletizing, compounding and converting used plastic products into secondary solutions without changing their chemical structure. It consumes less energy than other approaches but there are losses at each stage of the value chain and the presence of contaminants can impact quality.

Other, emerging alternatives include:

- **Chemical** recycling which is attractive due to its ability to use waste from multiple sources. Conventional pyrolysis is the most widely adopted chemical-based solution with innovative companies such as Agilyx (US) developing a proprietary process for recycling Polystyrene (PS)
- **Biological** recycling which has the advantage of being completely free from CO2. Enzymatic solutions have the highest potential in the biological category in the short term as they are more technologically advanced. Here, Carbios (France) is recycling Polyethylene Terephthalate (PET) using hydrolase
- **Combination** recycling uses mechanical and chemical or mechanical and biological processes and looks to combines the pros of each. Waste polymers are collected, sorted, cleaned and shredded mechanically before the material is depolymerized using a chemical process

Mobius (Germany) is among the market participants working in this last area with the company promising to return Polyurethane (PU) monomers to their original state.

Mobius

Country: Germany

Brief Description: Combination plastic recycling

Multimedia: http://mobiustechnologies.com/

Source: Frost & Sullivan

Industry participants are increasingly looking to incorporate recovered plastics into their products as environmentally friendly, cost-effective building blocks

Proctor & Gamble (P&G) is for example leading the European BIOCLEAN Horizon2020 Marie Curie funded project in partnership with ten research universities. Participants in the €3.9m programme have successfully identified bacteria which, following chemical and physical pretreatment, can be used for the recycling of many synthetic polymers.

On the WEEE side, 78% of e-waste was uncollected in globally 2020, prompting concerns about its impact and the growing shortage of valuable raw materials

An alarming rise in e-waste volumes following explosive growth in consumption of Electrical and Electronic Equipment (EEE) is forcing manufacturers, distributors and retailers to explore new business models. This has brought the notion of "circular electronics" into the spotlight with direct market participants looking to facilitate and promote the use of recycled and refurbished EEE products.

Leading EEE suppliers and vendors are increasingly offering "buybacks", charging advanced recycling fees (which are paid upfront by the consumer at the point of purchase) and selling refurbished products as part of a push to boost their environmental credentials, comply with local and international legislation, improve product lifecycles and in order to differentiate themselves from competitors.

Governments are also playing an instrumental role in effectively and efficiently managing e-waste by framing and implementing policies such as those centered on imposing Extended Producer Responsibility (EPR). ERP as a concept is expected to be a gamechanger and, with further adoption in countries like India and China, will shape players' approaches to EEE recycling moving forward.

"Urban mining" is becoming a key enabler for market participants looking to conserve resources, reduce costs and lower their carbon emissions

Globally, Frost & Sullivan estimates that the market for WEE recycling was valued at $3.9b in 2020 and will expand to reach $4.7b in 2025.

Growth will stem, at least to some extent, from the collective recognition that the recycling of e-waste is becoming an indispensable due to the presence of precious and scarce rare earth metals such as silver, gold, platinum, neodymium, indium, ruthenium, rhodium, iridium, osmium, cobalt and palladium in EEE products.

"Urban mining" will become an important strategy, allowing electric and electronic equipment producers to secure the supply of raw materials – a recent report from the World Energy Council found that as much as 7% of the global demand for gold could be met through the recycling of e-waste – whilst also reducing their CO2 footprints.

Source: Frost & Sullivan

Apple (US) is one of many electronics giants to launch a circular economy initiative with the company saving 4.3 MTPA of carbon via its recycling programmes

Its strategy is centered around four main pillars:

- Focusing on deploying fourteen recyclable and **renewable materials** (e.g. aluminum) and eliminating most single-use plastic
- Improving the **product lifecycle** via longer battery life, ongoing software upgrades and authorized repair services
- Facilitating greater **material recovery** with the use of intelligent disassembly robots for both components and rare materials
- Enabling **device recycling** through the Apple Trade-In programme and with local dealers providing collection points

CO2 capturing materials are similarly coming to the fore and segment into three main groups with the technology deployed pre- or post-combustion or as an oxy-fuel

	Pre-combustion	Post-combustion	Oxy-fuel
Principal Technologies	Gasification	Chemical solvents, porous solids and membrane separation	Oxygen treatment
Example applications	Integrated Gasification Combined Cycle (ICCG) and gasification plants	Pulverized coal, cement, iron and steel plants and refineries	New and refurbished power plants
Compatibility with plants	Requires remodification	Compatible with traditional coal technologies	Requires some modification

Source: Frost & Sullivan

Pre-combustion uses gasification and steam reforming to capture 95% of CO2

This is higher than post-combustion technologies with the process involving capturing CO2 from fuels before their combustion is complete. The hydrogen and Carbon Monoxide (CO) which is produced can be readily used in water gas shift reactions and the CO converted into highly pure carbon dioxide for storage.

Gasification is suitable for all type of primary fuels and consumes less energy than post-combustion capture which results in lower OpEx requirements. However, it involves multiple steps and additional processes to reduce hydrogen sulfide formation which increases CapEx requirements and its physical footprint.

As mentioned in the chapter on capturing storing existing CO2, the most commercially proven post-combustion process is solvent absorption

Solvent absorption leverages liquids like amine, ammonia and alkaline. Amine-based solvent absorption is the most established solvent-based carbon capture solution.

The process involves transforming the carbon dioxide in an exhaust gas or atmospheric air into a liquid through selective absorption in a solvent. Here, heating between 40°C (absorption) and 120°C (desorption) regenerates solvent-rich CO2, resulting in pure carbon dioxide release.

Solvent absorption is the most mature separation method conventionally used in oil and chemical industries. It is less expensive than and almost as efficient as gasification with capture rates of 80%-90% but vent regeneration is energy-intensive as it requires high temperatures.

Solvent-based absorption scrubbers have been installed in several power plants and carbon- intensive industries. Currently, they collectively successfully capture about 60,000 tons of CO2 annually and operate for more than 8,000 hours a year.

Solid absorption, an alternative, requires lower energy for solvent regeneration

Solid absorption uses carbon- and zeolite-based porous solids.

Capturing CO2 from gas streams via adsorption and the subsequent selective separation through desorption offers a promising option. The process relies on surface adsorption and the diffusion rate of various components in the flue gas stream. Absorbents can consist of either high- or low-temperature materials with the main solutions being pressure swing and temperature swing adsorption.

In contrast to solvent absorption, solid approaches require less energy while zeolites and carbon-based absorbents are inexpensive and abundant. Nonetheless, these processes cannot be easily retrofitted so require new process design.

Solid adsorbent systems, when commercialized on a large scale, can capture 3,000 to 5,000 tons of carbon dioxide a day. The plants are fully automated and can be integrated with compression and liquefaction facilities to avoid carbon leakage.

Membrane separation selectively segregates emissions from exhaust streams

Membrane separation deploys semi-permeable membranes to accelerate the selective transport and separation of CO2 from the flue gas stream and depends on gas solubility and molecular size.

This is a multi-stage operation that relies on the selective and specific permeation of various gases with the difference in partial pressure between the membrane's two sides (retentate and permeate) acting as the driving force for separation.

Membrane separation is characterized by a high tolerance to sulphur and nitrogen oxides which eliminates the danger caused by the emission of toxic gases but a large surface area is required in order to separate low concentration CO2.

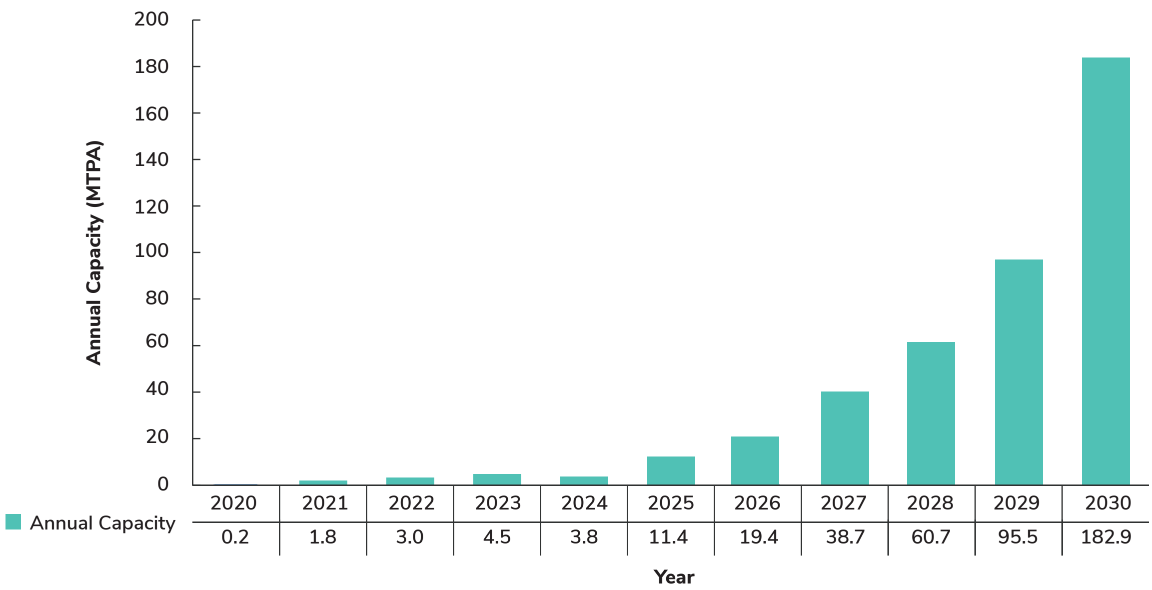
Membrane systems aid in eliminating chemicals, thereby reducing emissions associated with chemical handling. They can capture up to 1 ton of carbon dioxide a day and be integrated with liquefaction units to enhance carbon dioxide transport and storage.

Source: Frost & Sullivan

CO2 utilizing materials are also expected to grow rapidly with Frost & Sullivan forecasting that the market will reach 183 MTPA by 2030, up from just 3 today

CARBON DIOXIDE UTILIZATION MARKET ANNUAL CAPACITY ADDITIONS, GLOBAL, 2020-30

CAGR, 2021–2030 = 66.7%



Captured CO2 can be exploited across a broad range of areas and notably, as mentioned earlier in this report, in the chemicals, fuels and plastics industries

In the construction industry, rapid developments in the optimization of reaction rates and efficiency have resulted in the development of emerging **mineral carbonation** processes. In this context, alkaline rocks and/or wastes can be made to react with captured CO2 to yield carbonates as final products. These include blocks, precast concrete, ready-mix concrete, screed and other construction materials.

The advantages of mineral carbonation over other carbon utilization approaches are that it relies on a spontaneous reaction which makes the entire process less energy intensive. In addition, the process is relatively stable and opens up access to a huge market for Calcium Carbonate products. This means that the use of CO2 in the building industry is potentially more attractive than in chemicals, fuels and plastics.

Source: Frost & Sullivan

Carbon8 (UK), for example, is using CO_2 to create low-carbon materials which include sustainable aggregates for the construction trade

Carbon8

Country : UK

Brief Description : Carbon negative virgin aggregate

Multimedia : https://www.carbon8.co.uk/products

The company has developed a proprietary CCU technology called Accelerated Carbonation Technology (ACT) that economically treats industrial emissions and waste and creates marketable, low-carbon products using the captured CO_2.

Carbon8 has partnered with companies such as CEMEX to co-develop and field test the ACT solution to produce building materials. More broadly, it is active in hard-to-abate industries such as cement, waste management, biomass, paper and steel.

Its technology is made available in a containerized solution that is deployed on-site at industrial plants and has a capacity of up to 12,000 tons per year. It offers benchmarked savings of 30% by eliminating the need to landfill waste.

Carbon8 is in the early stages of commercialization. It has two operational plants in the UK and has achieved positive results by collaborating with other industry participants. It is currently in the process of making its low-carbon products available in France.

It also has applications, directly and indirectly, in the Food & Beverages space

Captured CO_2 can be used as carbonating agent to produce various products such as soft drinks and alcohols. Additionally, it can be deployed in the food and beverage industry as a preservative, packaging gas and a solvent in flavouring agents. The use of CO_2 without pressurization for on-site supplementation represents an interesting opportunity in itself but can also serve to significantly reduce CO_2 transportation costs thereby enhancing the overall attractiveness of CCU technologies across the board.

Source: Frost & Sullivan

PRINCIPAL ABBREVIATIONS

AHSS	*Advanced High Strength Steel*
AI	*Artificial Intelligence*
APAC	*Asia Pacific*
AR	*Augmented Reality*
ASHP	*Air Source Heat Pump*
B	*Billion*
BDA	*Big Data Analytics*
BECCS	*Bioenergy Carbon Capture and Storage*
BEM	*Building Energy Management*
BESS	*Battery Energy Storage System*
C&D	*Construction and Demolition*
CAGR	*Compound Average Growth Rate*
CapEx	*Capital Expenditure*
CAS	*Coatings, Adhesives and Sealant*
CCUS	*Carbon Capture, Utilization and Storage*
CCUSaaS	*Carbon Capture, Utilization and Storage as a Service*
CFPR	*Carbon Fibre-reinforced Plastic*
CO	*Carbon Monoxide*
CO2	*Carbon Dioxide*
Cs2CO3	*Caesium Carbonate*
DACCS	*Direct Air Capture with Storage*

DER	*Distributed Energy Resource*
EAF	*Electric Arc Furnace*
EEE	*Electrical and Electronic Equipment*
ELT	*End of Life Tire*
ERP	*Extended Producer Responsibility*
ESG	*Environmental, Social and Governance*
ESS	*Energy Storage System*
EU	*European Union*
EV	*Electric Vehicle*
EVTOL	*Electrical Vertical Take-off and Landing*
FC	*Fuel Cell*
FCEV	*Fuel Cell Electric Vehicle*
FDM	*Fused Deposition Modelling*
FFF	*Fused Filament Fabrication*
FRC	*Fiberglass Reinforced Composite*
GaN	*Gallium Nitride*
GFPR	*Glass Fibre-reinforced Plastic*
GHG	*Greenhouse Gas*
Gt	*Gigatonne*
GW	*Gigawatt*
HSS	*High Strength Steel*

Source: Frost & Sullivan

HTL	*Hydrothermal Liquefaction*	**PPA**	*Power Purchase Agreement*
HVAC	*Heating Ventilation and Air Conditioning*	**PPM**	*Parts Per Million*
ICCG	*Integrated Gasification Combined Cycle*	**PS**	*Polystyrene*
ICE	*Internal Combustion Engine*	**PU**	*Polyurethane*
LaaS	*Lighting as a Service*	**RCB**	*Recovered Carbon Black*
M	*Million*	**RES**	*Renewable Energy Source*
MeOH	*Methanol*	**SDG**	*Sustainable Development Goal*
ML	*Machine Learning*	**SiC**	*Silicon Carbide*
MTPA	*Metric Tons Per Annum*	**SOx**	*Sulfur*
NFPR	*Natural Fibre-reinforced Polymer*	**SRI**	*Socially Responsible Investing*
NG	*Natural Gas*	**TDS**	*Total Dissolved Solid*
NOx	*Nitrogen Oxide*	**TRL**	*Technology Readiness Level*
O&M	*Operation and Maintenance*	**TWh**	*Terawatt-hour*
OEM	*Original Equipment Manufacturer*	**UAM**	*Urban Air Mobility*
OHV	*Off-Highway Vehicle*	**UHSS**	*Ultra High Strength Steel*
OpEx	*Operational Expenditure*	**UK**	*United Kingdom*
PA	*Polyamide*	**US**	*United States*
PBAT	*Polybutylene Adipate Terephthalate*	**VR**	*Virtual Reality*
PBS	*Polybutylene Succinate*	**WEE**	*Waste Electrical and Electronic Equipment*
PET	*Polyethylene Terephthalate*	**VR**	*Virtual Reality*
PLA	*Polylactic Acid*	**WEE**	*Waste Electrical and Electronic Equipment*

Source: Frost & Sullivan

ABOUT INTESA SANPAOLO INNOVATION CENTER:

Intesa Sanpaolo Innovation Center is the company of Intesa Sanpaolo Group dedicated to innovation: it explores and learns new business and research models and acts as a stimulus and engine for the new economy in Italy. The company invests in applied research projects and high potential start-ups, to foster the competitiveness of the Group and its customers and accelerate the development of the circular economy in Italy.

Based in the Turin skyscraper designed by Renzo Piano, with its national and international network of hubs and laboratories, the Innovation Center is an enabler of relations with other stakeholders of the innovation ecosystem - such as tech companies, start-ups, incubators, research centres and universities - and a promoter of new forms of entrepreneurship in accessing venture capital. Intesa Sanpaolo Innovation Center focuses mainly on circular economy, development of the most promising start-ups, venture capital investments of the management company Neva SGR and applied research

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