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GREENHOUSE GAS CAPTURE: Patent Landscape for Biotechnology-Based Systems

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1 EXECUTIVE SUMMARY

1.1 OVERVIEW

IP Pragmatics is a technology and IP commercialisation consultancy, with broad expertise across the Life Sciences, Human Health, Animal Health, Agritech, and Food & Nutrition. The intention of this white paper is to provide an overview of the patent landscape across greenhouse gas capture technology. The information in this report does not constitute legal advice and should not be interpreted as such.

1.2 KEY FINDINGS

1.2.1 PATENTING TRENDS

The high number of patents filed over the last 20 years indicates significant research and development in biological means for greenhouse gas capture.

The main areas of commercial interest that were identified through the landscape analysis include:

1. The use of microorganisms for carbon oxide capture, with particular focus on algae/microalgae
2. Bioreactors
3. Enzymes

Other areas of particular interest include the application of adsorbants, absorbants, biochar, as well as anaerobic fermentation for waste treatment.

Most of the innovation appears to be focused on the removal of carbon oxides from waste gases with increased patent filings for liquid phase processes, means for collecting fermentation gases, and stationary adsorbents.

1.2.2 KEY MARKETS

The global distribution of patent filings was analysed to identify key markets. While the high number of granted and lapsed patent families worldwide suggests a globally well-established field with significant commercial interest, the high number of pending patents shows that greenhouse gas capture is still a growing area.

The top priority country appears to be China, which is a good indication of where most of the research appears to be happening. It is followed by US, Japan, Korea, and Europe. Great Britain is ranked 8th on the list.

Most of the granted active patents appear to be in China, which is a good indicator of the leading market. As with the top countries for research, it is followed by the US, Europe, Korea, and Japan. Great Britain is ranked 10th on this list.

China appears to have recently emerged as the leading market, as suggested by the low number of expired patent families and high number of pending patents.

The lower proportion of pending patents compared to the high number of granted patents in the US appears to be indicative of a more well-established market, which is also supported by the high proportion of expired patents.

It may be difficult to enter the market in Japan, as indicated by the higher number of revoked patent families.

1.2.3 KEY PLAYERS

The top ten assignees from the patent landscape highlight organisations with the highest patent activity. These key players mostly consist of commercial companies rather than research institutions, which suggests significant business value in the area.

The organisations include Lanzatech, Chinese Academy Of Science, Exxonmobil Corp, China Petroleum & Chemical Corp Inc., Air Liquide S.A, Zhejiang University, BASF SE, INEOS Group Limited, CO2 Solutions Inc, and Harbin Institute Of Technology.

Exxonmobile, BASF and CO2 Solutions are the most well-established players in the field of greenhouse gas capture, while Lanzatech and the Chinese Academy Of Science are the most influential newcomers.

Lanzatech appears to dominate the area of the patent landscape concerned with carbon capture using microbial fermentation, while the Chinese Academy Of Science appears to have a more diversified patent portfolio.

The patent portfolio of Exxonmobil Corp appears to be focused on fuel cells and acid salts for gas separation, wherein the portfolio includes a number of patents relating to adsorbant fibres in an area of low patent coverage.

CONTENTS

2 INTRODUCTION

Climate change is defined as the long-term variation in global temperatures. It is understood to occur naturally, however it has become clear that human activities have exacerbated this change[1]. The advent of the industrial revolution has resulted in an increase in anthropogenic emissions, wherein carbon dioxide is the principal contributor to climate change. This has had significant repercussions on the environment, which has resulted in growing concerns regarding the future of our planet. The effects of climate change highlight the importance of developing sustainable mitigation strategies.

Government legislation is one of the key measures driving us towards a net-zero emissions economy, as exemplified by the Paris Agreement, which is a legally binding international treaty on climate change that aims to help countries adapt to climate change. Numerous tax incentives have been created to promote the use of renewable energy sources and carbon capture and sequestration efforts. The main strategies are focused on adopting renewable energy sources, improving energy efficiency, as well as more sustainable transport, and use of land. However, it has been reported that a reduction in emissions will not be enough to prevent climate change, wherein capture and sequestration of greenhouse gases will be imperative.

Environmental biotechnology has emerged as one of the key tools for addressing greenhouse gas capture. Although economic limitations have hampered developments[1], the ability of microorganisms to process emissions for the production of bioenergy and conversion of waste into useful materials may overcome the inherent challenges. The purpose of this article is to investigate the patent landscape for the biological capture and sequestration of greenhouse gases, and explore how such technology is supporting global efforts to mitigate climate change.

[1] https://www.sciencedirect.com/science/article/pii/S2772656821000075

3 LANDSCAPE

This section of the report gives an overview of the landscape in relation to patenting activity in the field of greenhouse gas capture using biotechnological methods.

3.1 SEARCH STRATEGY

The following search strategy was drafted utilising key search terms and classification codes to identify the overall patent landscape for greenhouse gas capture using biotechnological methods. The search strings were drafted using IP Pragmatics' subscription landscape tool, Derwent Innovation, with additional analysis conducted in Orbit by Questel.

A range of key search terms and classifications were utilized to construct an effective search strategy that covers the most relevant greenhouse gas capture technologies. The search terms and classifications were searched in a variety of combinations, in order for the patent landscape analysis to cover the various biotechnological and greenhouse gas capture components, as well as limit the number of irrelevant results within the dataset.

The following document collections were searched:

Africa – ARIPO Granted; OAPI Granted; Morocco Granted, Morocco Applications; South Africa Applications; Tunisia Applications

Americas - Argentinean Utility Models; Argentinean Applications; Brazilian Utility Models; Brazilian Granted; Brazilian Applications; Canadian Granted; Canadian Applications; Columbian Applications, Costa Rican Applications; Costa Rican Utility Models; Cuban Applications; Cuban Granted; Mexican Granted; Mexican Applications; Uruguayan Applications; US Granted and US Applications.

Asia – Chinese Utility Models; Chinese Granted; Chinese Applications; Eurasian (EAPO) Granted; Gulf Cooperation Council Granted; Indian Granted; Indian Applications; Indonesian Simple; Indonesian Applications; Israeli Granted; Japanese Utility Models; Japanese Granted; Japanese Applications; Korean Utility Models; Korean Granted/Examined; Korean Applications; Malaysian Granted; Singaporean Granted; Singaporean Applications; Thai Granted/Examined; Vietnamese Granted and Vietnamese Applications.

Europe - Austrian applications; Austrian Granted; Austrian Utility Models; Belgian Applications; Belgian Granted; Bulgarian Applications: Bulgarian Granted; Bulgarian Utility Models; Croatian Applications; Croatian Granted; Croatian Utility Models; Czechoslovakia Granted; Czech Applications; Czech Granted; Czech Utility Models; Estonian Applications; Estonian Granted; Estonian Utility Models; European Granted; European Applications; Finnish Granted; Finnish Applications; French Granted; French Applications; German Utility Models; German Granted; German Applications; Greek Granted; Greek Applications; Hungarian Granted; Icelandic granted; Irish Applications; Irish Granted; Irish Utility Models; Italian Granted; Latvian Granted; Lithuanian Granted; Luxembourgian Granted; Luxembourgian Applications; Moldavian Granted; Moldavian Utility Models; Monacan Granted; Dutch Applications; Dutch Granted; Norwegian Granted; Norwegian Applications; Polish Granted; Polish Utility Models; Portuguese Applications; Portuguese Granted; Portuguese Utility Models; Romanian Applications; Romanian Granted; Romanian Utility Models; Russian Utility Models; Russian

Applications; Serbian applications: Serbian Granted; Serbian Utility Models; Slovakian applications: Slovakian Granted; Slovakian Utility Models; Slovenian Granted; Slovenian Utility Models; Spanish applications; Spanish Granted; Spanish Utility Models; Swedish applications; Swiss Granted; Swedish applications; Swiss Granted; British Granted and British Applications

Oceania - Australian Granted; Australian Utility Models; Australian Applications, New Zealand Granted.

World - WIPO (PCT) Applications

Please see the following summary of the search strategy used to search the above collections to investigate the patent landscape:

AIC=(Y02*) AND CTB=((*methan* OR CH4 OR carbon* OR CO2 OR ((nitrous OR dinitrogen) ADJ2 (oxid* OR monoxid*)) OR N2O OR (greenhouse* ADJ2 (gas*2 or gases OR gaseous* OR gass* OR pollut* OR emission* OR emit*)) OR GHG*1 OR hydrofluorocarbon* OR perfluorocarbon* OR ((sulfur OR sulphur) ADJ2 hexafluorid*) OR (nitrogen ADJ2 trifluorid*) OR hexafluoroethan* OR chlorofluorocarbon*) NEAR3 (captur* or sequest* or remov*)) AND (AIC=(C07K* OR C12*) OR CTB=(bio OR biolog* OR microb* OR (micro ADJ2 organism*) OR microorganism* OR bacter* OR yeast* OR fungi* OR enzym*))

AIC=(Y02C20/*) AND (AIC=(C07K* OR C12*) OR CTB=(bio OR biolog* OR microb* OR (micro ADJ2 organism*) OR microorganism* OR bacter* OR yeast* OR fungi* OR enzym*))

AIC=(Y02*) AND AIC=(C01B002120 OR C01B002122 OR C01B003240 OR C01B003250 OR B01D005354* OR B01D005360 OR B01D005362 OR B01D225740* OR B01D225750* OR B01D22577025) AND (AIC=(C07K* OR C12*) OR CTB=(bio OR biolog* OR microb* OR (micro ADJ2 organism*) OR microorganism* OR bacter* OR yeast* OR fungi* OR enzym*))

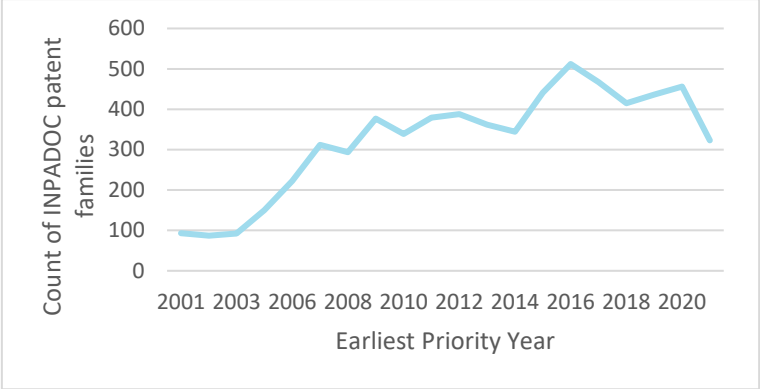
The search generated a result set of **7,664 INPADOC families** (19,494 individual cases).

The definition of classifications and search codes utilized in the search strategy can be found in the Appendix of this report.

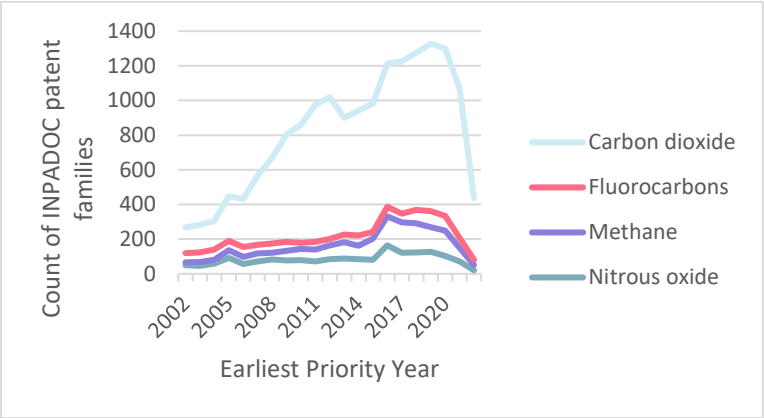
3.2 PATENTING TRENDS

3.2.1 FILING RATE

The patent landscape relating to biological means for greenhouse gas capture appears to be expanding with a high number of patents filed over the last 20 years, indicating significant research and development taking place. The field has witnessed a more rapid increase in the annual filing rate between 2003 and 2007, as well as 2014 and 2016. The sharp increase in the number of patents filed between 2014 and 2016 appears to coincide with the Paris Agreement, which illustrates the significant effect that government legislation has on innovation within the area. Despite the subsequent slower patent filing rate, the last 5 years represent approximately 32% of the total landscape, thereby indicating room for growth within the field of greenhouse gas capture. The annual filing rate has significantly decreased in 2021, however this is likely due to the 18-month gap between priority application and publication, hence 2021 and 2022 data given in the graph will not be complete.



In order to provide a more quantitative measure of the key areas of interest, a more in-depth comparison was performed to investigate the focus of patent filings. as shown in the following graphic. It can be observed that innovation is most concentrated on the capture of carbon dioxide, which is unsurprising considering its reported role as the main greenhouse gas contributor to global warming[2].



[2] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5837998/

Although the annual filling rate for biotechnology-based greenhouse gas capture technology appears to be following the positive trend exhibited by the environmental sector, the following graph dissects research interest further. It is evident that research interest in greenhouse gas capture is significantly lower than other areas relating to environmental technologies. Interestingly, a number of research publications have indicated that mitigation strategies are not sufficient to alleviate climate change[3], which highlights the importance of greenhouse gas capture. The relatively low number of patents relating to greenhouse gas capture may therefore be indicative of space for growth, although the lack of innovation may also be explained by significant barriers for entry.

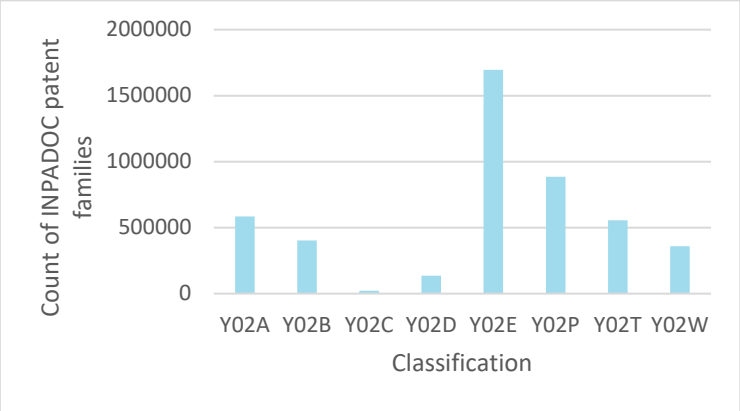


Table 1. Classification definitions.

IPC	Definition
Y02A	TECHNOLOGIES FOR ADAPTATION TO CLIMATE CHANGE
Y02B	CLIMATE CHANGE MITIGATION TECHNOLOGIES RELATED TO BUILDINGS, e.g. HOUSING, HOUSE APPLIANCES OR RELATED END-USER APPLICATIONS
Y02C	CAPTURE, STORAGE, SEQUESTRATION OR DISPOSAL OF GREENHOUSE GASES [GHG]
Y02D	CLIMATE CHANGE MITIGATION TECHNOLOGIES IN INFORMATION AND COMMUNICATION TECHNOLOGIES [ICT], I.E. INFORMATION AND COMMUNICATION TECHNOLOGIES AIMING AT THE REDUCTION OF THEIR OWN ENERGY USE
Y02E	REDUCTION OF GREENHOUSE GAS [GHG] EMISSIONS, RELATED TO ENERGY GENERATION, TRANSMISSION OR DISTRIBUTION
Y02P	CLIMATE CHANGE MITIGATION TECHNOLOGIES IN THE PRODUCTION OR PROCESSING OF GOODS
Y02T	CLIMATE CHANGE MITIGATION TECHNOLOGIES RELATED TO TRANSPORTATION
Y02W	CLIMATE CHANGE MITIGATION TECHNOLOGIES RELATED TO WASTEWATER TREATMENT OR WASTE MANAGEMENT

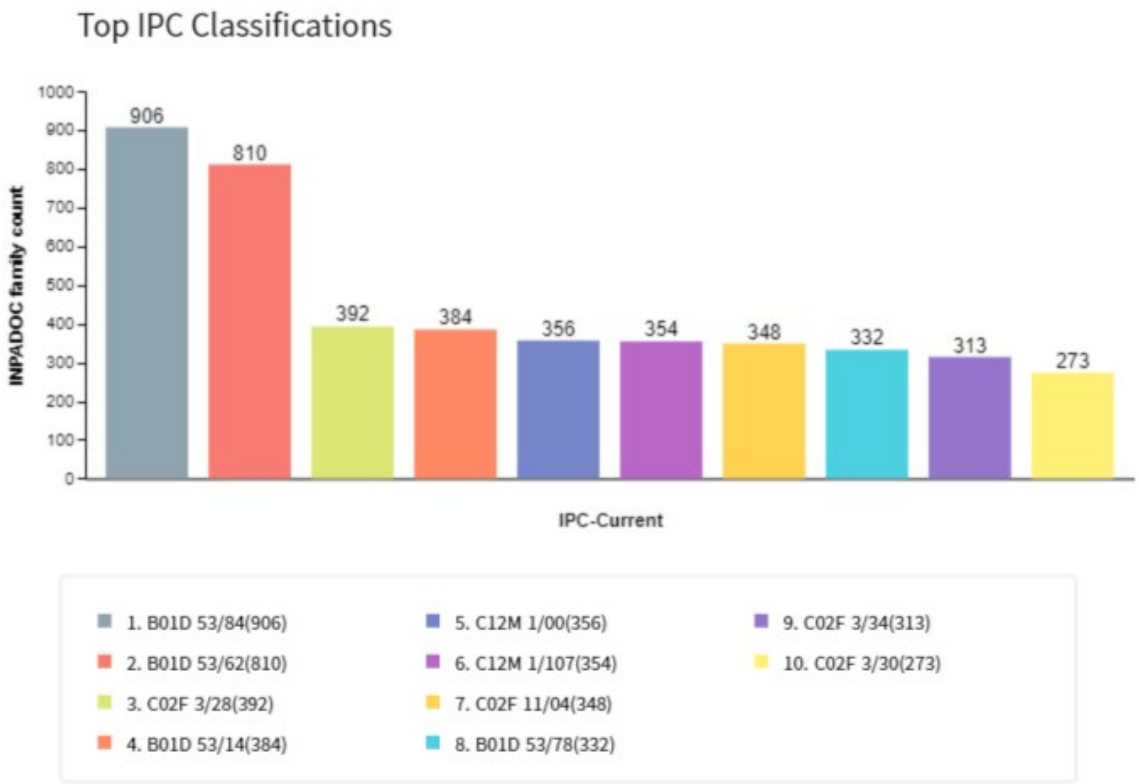
[3] https://cen.acs.org/environment/greenhouse-gases/Capturing-carbon-save-us/97/i8

3.2.1 CLASSIFICATIONS

The International Patent Classification (IPC) provides a hierarchical system of language independent symbols for the classification of patents and utility models according to the different areas of technology to which they pertain. The IPC divides technology into eight sections with approximately 70,000 subdivisions. The appropriate IPC symbols are indicated on each patent document, of which more than 1,000,000 were issued each year in the last 10 years.

In order to verify the relevance of the patents listed, and to look in more detail at the areas of technical focus shown in the landscape map, an analysis of the top 10 current IPC codes from the broad list was performed (see table below). As mentioned above, IPC codes are a mechanism of categorising the patents by detailed subject matter and have been used in part to frame the BROAD list via the initial searches, so there will be some bias towards the top-level codes used in the search in these results.

Each patent is typically classified according to one or a few IPCs as they may cover one or a number of technology fields. The top 10 IPC listing highlights and explains those IPC codes that have most frequently occurred within the patent families listed:

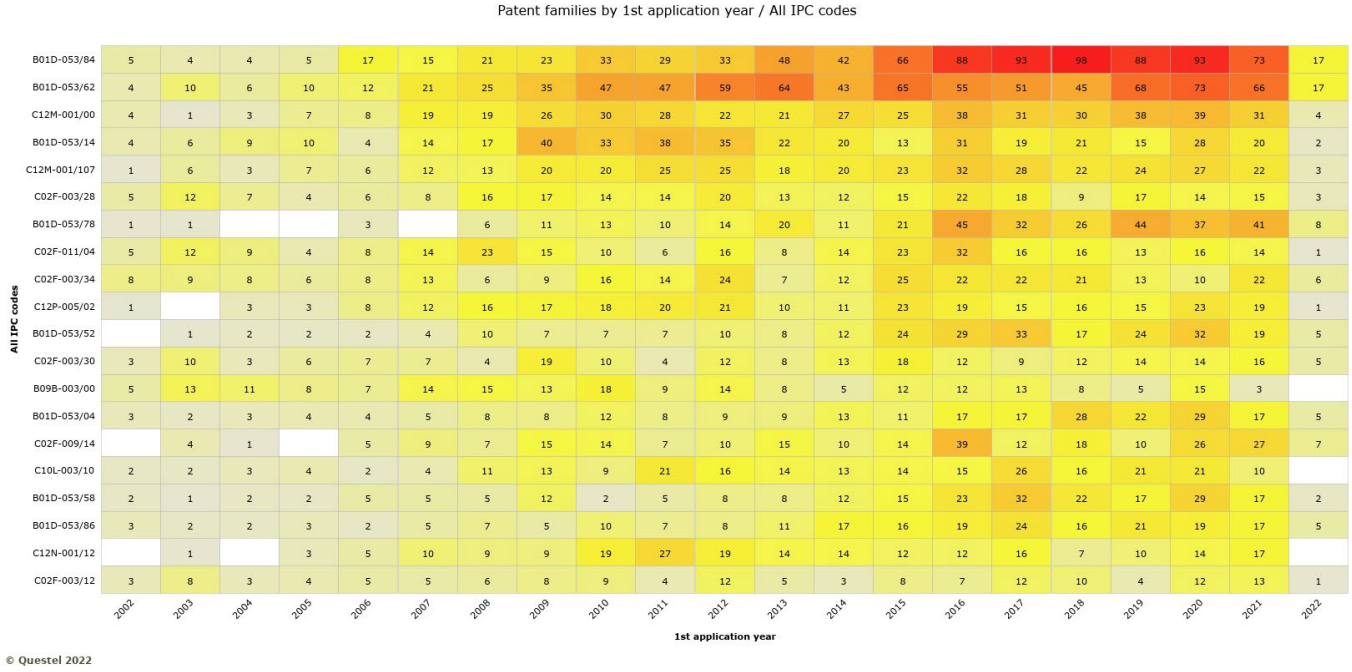


Rank	IPC	Number of Families	Definition	
1	B01D53/84	906	B01D53/00	Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases, aerosols
			B01D53/34	Chemical or biological purification of waste gases
			B01D53/74	General processes for purification of waste gases; Apparatus or devices specially adapted therefor
			B01D53/84	Biological processes
2	B01D53/62	810	B01D53/00	Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases, aerosols
			B01D53/34	Chemical or biological purification of waste gases
			B01D53/46	Removing components of defined structure
			B01D53/62	Carbon oxides
3	C02F3/28	392	C02F3/00	Biological treatment of water, waste water, or sewage
			C02F3/28	Anaerobic digestion processes
4	B01D53/14	384	B01D53/00	Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases, aerosols
			B01D53/14	by absorption
5	C12M1/00	356	C12M1/00	Apparatus for enzymology or microbiology
6	C12M1/107	354	C12M1/00	Apparatus for enzymology or microbiology
			C12M1/107	with means for collecting fermentation gases, e.g. methane
7	C02F11/04	348	C02F11/00	Treatment of sludge; Devices therefor
			C02F11/02	Biological treatment
			C02F11/04	Anaerobic treatment; Production of methane by such processes
8	B01D53/78	332	B01D53/00	Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases, aerosols
			B01D53/34	Chemical or biological purification of waste gases
			B01D53/74	General processes for purification of waste gases; Apparatus or devices specially adapted therefor
			B01D53/77	Liquid phase processes
			B01D53/78	with gas-liquid contact
9	C02F3/34	313	C02F3/00	Biological treatment of water, waste water, or sewage
			C02F3/34	characterised by the microorganisms used
10	C02F3/30	273	C02F3/00	Biological treatment of water, waste water, or sewage
			C02F3/30	Aerobic and anaerobic processes

The majority of the top 10 IPCs are within the B01D53/00 classification group which broadly covers the field of separation of gases. A number of top IPCs are also within the C12M classification, which encompasses microbiology-based technology, thereby verifying that the landscape analysis is centered on biotechnological solutions for greenhouse gas capture. Most of the innovation appears to be focused on removal of carbon oxides during the purification of waste gases. Classification analysis also reveals significant focus on biological treatment of waste water using anaerobic digestion processes, purification of waste gases by absorption and liquid phase processes, as well as means for collecting fermentation gases, e.g. methane.

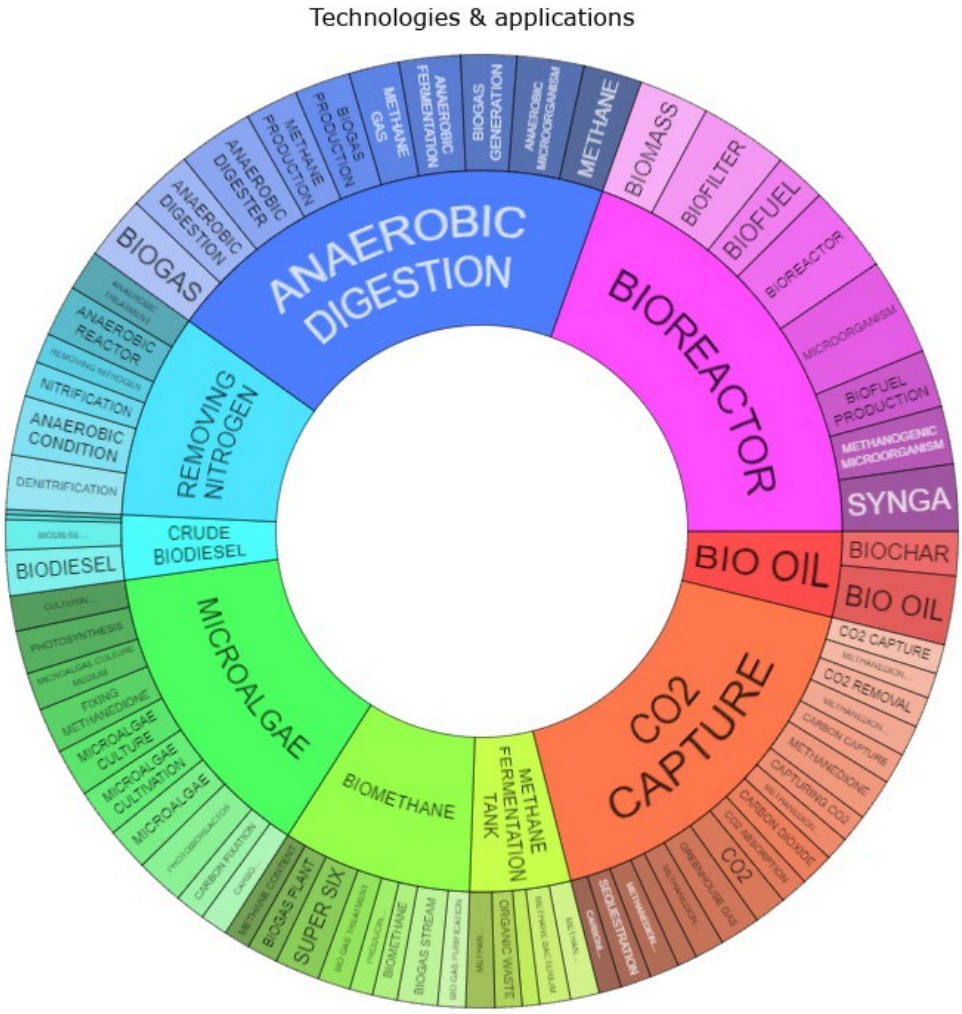
3.2.1 TECHNOLOGY TRENDS

In order to investigate the landscape further, the following heatmap examines how the key technology areas have changed over time, wherein classification definitions are listed in the Appendix section. The graph shows that research in biological purification of waste gases (B01D53/84) is becoming the most concentrated area, with significant interest in carbon oxides (B01D53/62) and microorganisms (C12M1/00). The process for purification of waste gases using liquid phase processes with gas-liquid contact (B01D53/78) follows a similar patent filing trend, as does research in enzymatic/microbiological means for collecting fermentation gases (C12M1/107). Interestingly, while research in gas separation by absorption (B01D53/14) appears to have peaked in 2009, recently there appears to be increased interest in stationary adsorbents (B01D53/04), which may suggest a more beneficial process. Concept analysis also revealed significant research interest in microalgae, wherein the heatmap shows that innovation in microalgae (C12N1/12) was most concentrated in 2011, with recently renewed interest. A similar trend is exhibited in biological treatment of water, waste water, and sewage (C02F9/14), as well as the removal ammonia (B01D53/58).



3.2.2 LANDSCAPE CONCEPTS

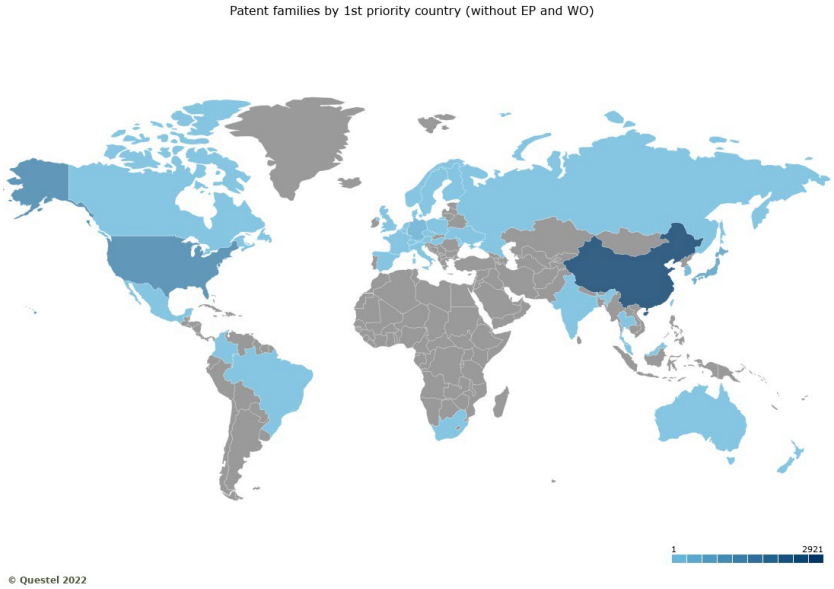
The following figure illustrates the distribution of the main concepts across the patent landscape relating to biological methods of greenhouse gas capture, which provides additional depth to key research areas identified from classification analysis. It can be seen from this graphic that the landscape analysis is primarily concentrated on carbon dioxide capture, with research interest also in methane and nitrogen removal. Concept analysis reveals that the primary areas of application for greenhouse gas capture technology are in bioreactors, anaerobic digestion, and methane fermentation tanks. The analysis also shows significant interest in biochar for providing a carbon sink on agricultural lands, as well as the application of microalgae.

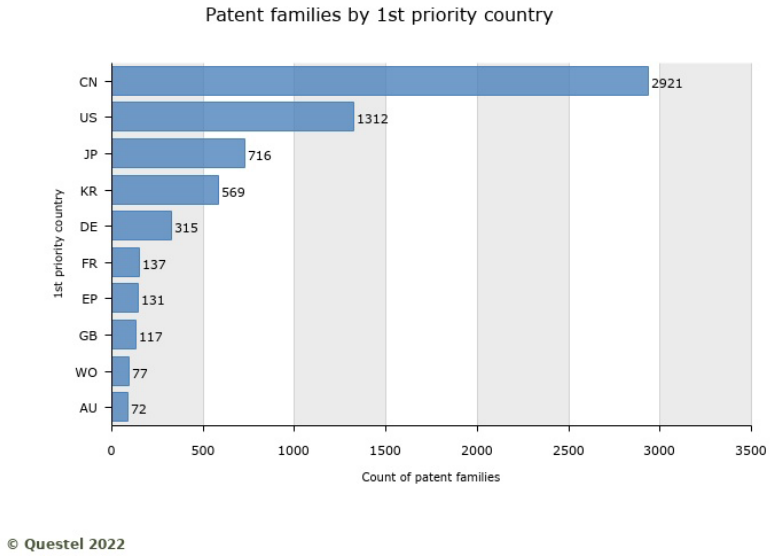


3.2.3 PRIORITY COUNTRIES

The top priority countries can be analysed to see where the patent applications are initially filed and claiming their priority from. This can be a good indication of the countries where the majority of research and innovation in a particular technology field is taking place, since organisations generally file patent applications first in the local territories where their research bases are located. Likewise, for universities the priority country will usually tend to be the country in which they are based. In this

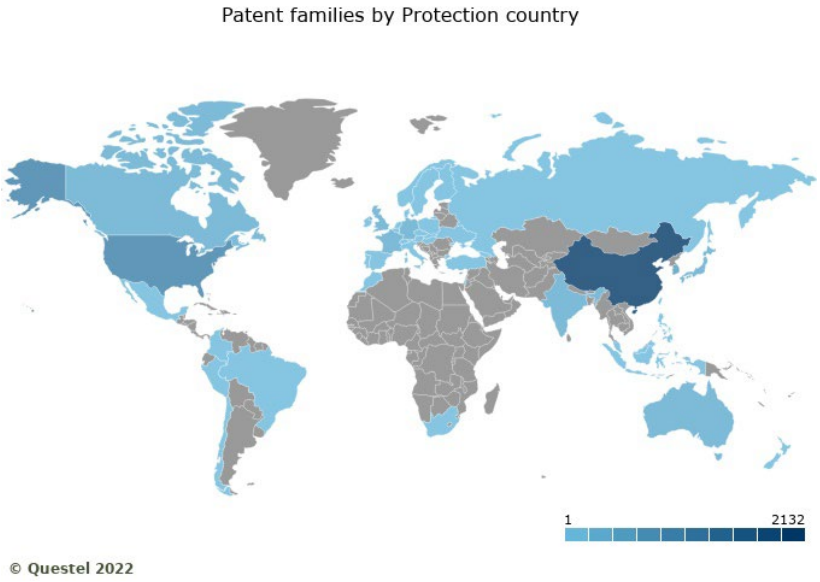
instance, the landscape is dominated by China, which accounts for approximately 43% of the patent landscape. It is followed by US which represents approximately 19% of all priority applications, which is closely followed by Japan (10.5%) and Korea (8.3%). This is significantly higher than the amount of priority applications in Great Britain, which accounts for approximately 1.7% of the patent landscape.

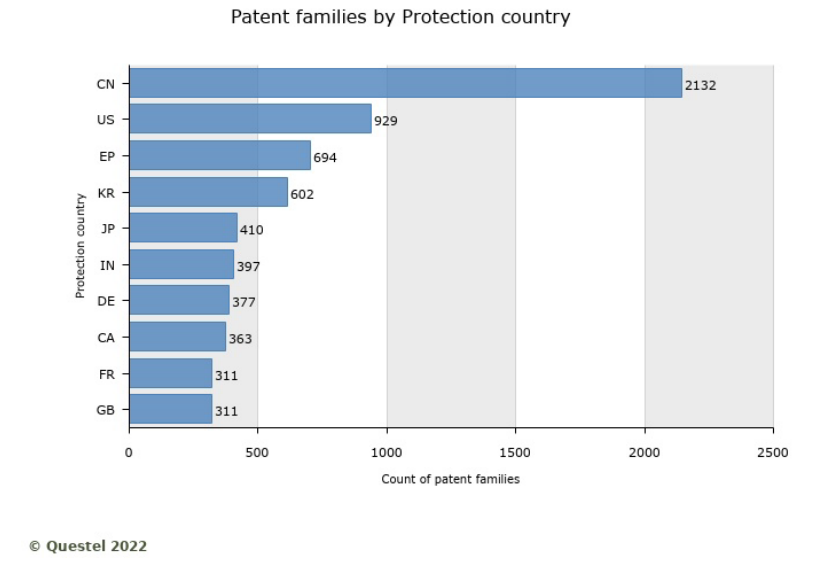




3.2.4 PROTECTION COUNTRY

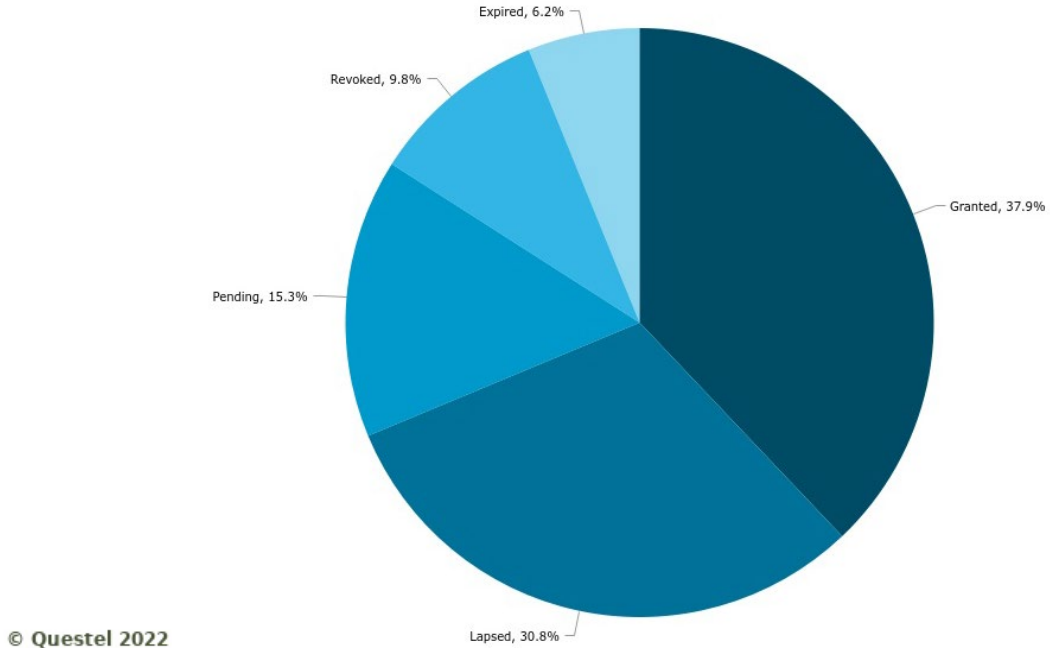
Similarly, the following map shows the protection countries, meaning the jurisdictions of granted active patents including which countries European patents are active. This is a good indication of the leading markets in a given field. In this instance China is also the leading jurisdiction, accounting for approximately 21.5% of all granted patents. It is followed by US which represents 9.4% of the patent landscape, and Europe which has approximately 7% of all granted patents. Great Britain represents approximately 3.1% of the patent landscape.





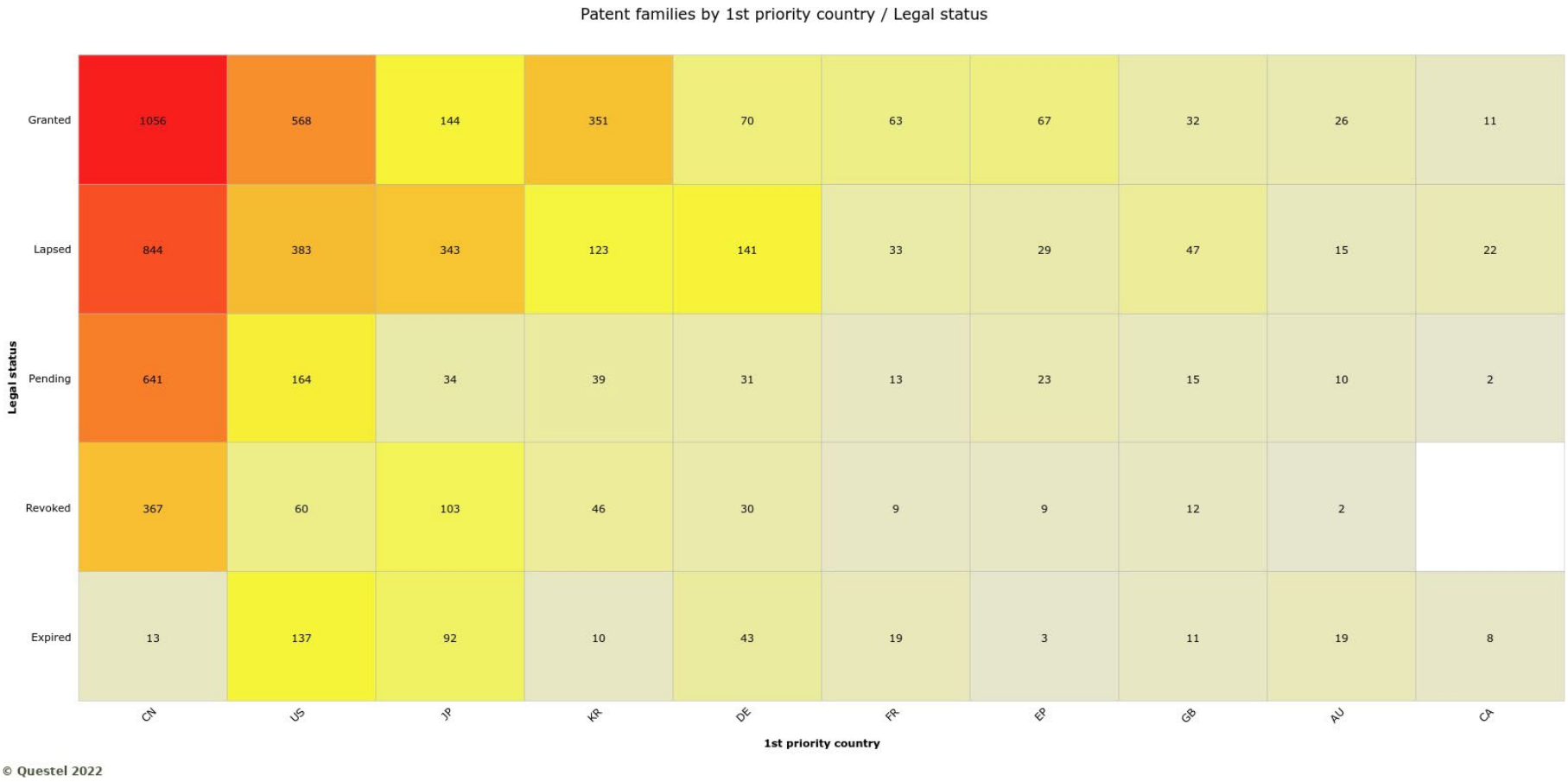
3.2.5 GLOBAL GRANT SUCCESS

An assessment of the proportion of granted patents compared to patent applications can give additional insight into the commercial value of the technology, and the stage of development of the market, as well as provide information on market entry and competition. The following graph investigates the legal status of patent families relating to biotechnological solutions for greenhouse gas capture. It is evident from the higher proportion of granted patent families, compared to pending and lapsed patents, that this is a globally well-established field with significant commercial interest. The relatively high number of pending patents shows that greenhouse gas capture is still a growing field, however the proportion of revoked patents appears to be indicative of barriers to market entry and competition in the area.



In order to dissect the patent landscape further, the following graph compares the legal status of patent families in key jurisdictions. The most well-established markets are represented by China, US, Japan, Korea, and Europe, as can be observed from the proportions of granted, pending and lapsed patent families. Further analysis of expired patent families in each territory appears to suggest that the US and Japanese markets may be the most well-established, while China appears to have emerged as the leading market more recently, which may be driven by the fact that China is the world's largest source of greenhouse gas emissions[4]. The analysis of revoked patent families can also give insights on the challenges to market entry, wherein it may be most difficult to enter the field in Japan, as indicated by the higher number of revoked patent families, which also appears to be supported by the lower number of pending patent applications.

[4] https://www.cfr.org/backgrounder/china-climate-change-policies-environmental-degradation


Patent families by 1st priority country / Legal status
Legal status
Granted
Lapsed
Pending
Revoked
Expired
1056 568 144 351 70 63 67 32 26 11
844 383 343 123 141 33 29 47 15 22
641 164 34 39 31 13 23 15 10 2
367 60 103 46 30 9 9 12 2
13 137 92 10 43 19 3 11 19 8
CN US JP KR DE FR EP GB AU CA
1st priority country
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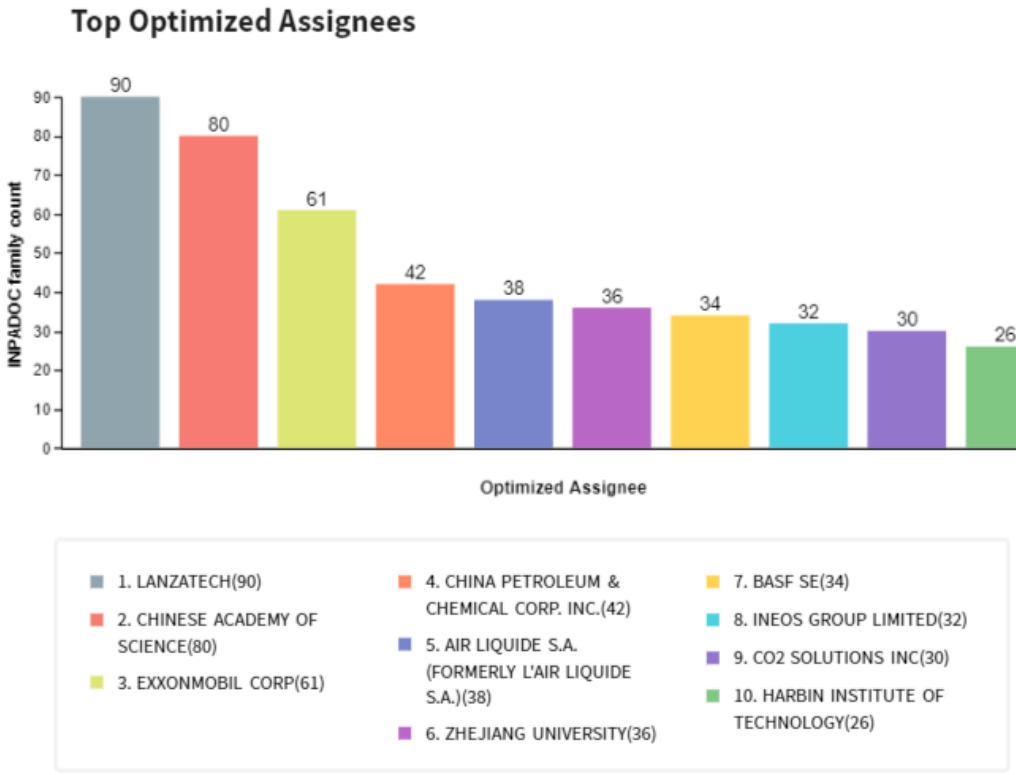
3.2.6 TOP ASSIGNEES

Considering the global distribution of patent filings, it can be expected to see the patent landscape dominated by US and Chinese organisations. The following chart highlights the top 10 assignees for the number of patents in relation to biological greenhouse capture technologies, which represent both the top industry and academic groups in the field in terms of patenting activity. It can be observed that most top players within the field appear to be commercial, which is a good indication of significant commercial and economic interest in the field. A summary of each patent portfolio is provided within this section.



Rank	Assignee/Applicant	Document Count	Organisation Type	Country
1	LANZATECH	90	Commercial	US
2	CHINESE ACADEMY OF SCIENCE	80	Academic	China
3	EXXONMOBIL CORP	61	Commercial	US
4	CHINA PETROLEUM & CHEMICAL CORP INC.	42	Commercial	China
5	AIR LIQUIDE S.A (FORMERLY L'AIR LIQUIDE S.A.)	38	Commercial	France
6	ZHEJIANG UNIVERSITY	36	Academic	China
7	BASF SE	34	Commercial	German
8	INEOS GROUP LIMITED	32	Commercial	UK
9	CO2 SOLUTIONS INC	30	Commercial	Canada
10	HARBIN INSTITUTE OF TECHNOLOGY	26	Academic	China

Lanzatech (https://lanzatech.com/) is focused on developing carbon recycling technology that utilizes greenhouse gas emissions. The company patent portfolio is primarily focused on recombinant species of Clostridium and Alkalibaculum, wherein said microorganisms are applied in fermentation bioreactors to capture gases, such as carbon oxides. The patent filing rate has increased over the last 20 years, with a significant focus on the US, Canadian, Chinese, Indian, and European markets, wherein approximately 76.6% of the company portfolio is granted and 23.2% is pending. The increasing trend in technology investment coupled with a large proportion of granted patents shows that the company is an active key player in the patent landscape.

Chinese Academy Of Science (https://english.cas.cn/) is a national academy for natural sciences, which has research interest in a number of greenhouse gas capture technologies, such as modified biochar materials, fermentation reactors, microalgae, adsorption towers, and microbial electrolytic cells. The patent portfolio has increased significantly in the last 20 years, with most patents being filed in China, wherein approximately 37.6% of the portfolio is granted, while approximately 20.8% is pending.

Exxonmobil Corp (https://corporate.exxonmobil.com/) is a multinational oil and gas corporation, which has invested significantly in greenhouse gas mitigation and capture technology, as indicated by the increasing number of patent filings. The patent portfolio is focused on bioreactors for the treatment of gas, as well as fuel cell and waste water purification, wherein 72.7% of the portfolio appears to be granted, while 9.1% is pending. The company appears to be targeting the North American markets, with interest also in Europe, China, India, Korea, Japan, and Australia.

China Petroleum & Chemical Corp Inc. (http://www.sinopecgroup.com/group/en/) is an energy and chemical conglomerate that is engaged in oil and gas exploration and production. The patent portfolio held by the company is focused on methods for treating carbon dioxide, nitrogen oxides and sulfur dioxide in exhaust gases or flue gases and waste liquid, wherein the main technological focus is the introduction of said gases into a photobioreactor for microalgae culture. The patent portfolio has increased significantly in the last 10 years, with China being the main focus, wherein approximately 68.57% of the portfolio is granted, while approximately 20% is pending.

Air Liquide S.A (Formerly L'air Liquide S.A.) (https://www.airliquide.com/) is a multinational company that supplies industrial gases and services to various industries. The patent portfolio is focused on biogas scrubbing, wherein patents are directed towards methods for producing biomethane with limited carbon dioxide emissions. The patent filing rate is increasing, with approximately 77.4% of patent families being granted and 12.9% being pending, wherein the portfolio is focused on the European, US, Chinese and Canadian markets.

Zhejiang University (https://www.zju.edu.cn/english/) is a national public research university, which owns a diversified patent portfolio of microbial technologies for greenhouse gas capture, such as microalgae, biochar, direct air capture, microbial fuel cells, and carbon oxide removal from biogas and waste water. The patent filing rate has increased over the last 20 years, with approximately 40.54% patents being granted and 10.81% being pending, while 45.95% is lapsed.

BASF SE (https://www.basf.com/gb/en.html) is a multinational chemical manufacturing company, which holds a diverse patent portfolio that includes processes for removing greenhouse gases, such as nitrous oxide and carbon dioxide, from various gas streams. The patent filing rate has remained

relatively stable over the last 10 years, wherein approximately 54.2% of the patent portfolio is granted, and 16.7% is pending. Patent filings primarily target US, Canadian, European and Chinese markets.

INEOS Group Limited (https://www.ineos.com/) is a multinational chemical company that holds a patent portfolio covering technology for reducing greenhouse gas emissions, for instance through engineered microorganisms within fermentation bioreactors. The patent filings by the company peak in 2013, which was followed by a reduction in innovation. This is reflected by the lack of new pending applications, wherein 80% of the portfolio is granted, and 13.3% has expired. The majority of the patent filings are in in India, China, and Brazil, with interest also in Europe and the US.

CO2 Solutions Inc (http://www.co2-solutions.com) develops technologies for capturing and producing of carbon dioxide, wherein the company has filed patents in relation to enzyme-based systems for efficient carbon dioxide capture from various industrial flue gasses, wherein gas is transformed into carbon containing bio-products. Most patents filed by the company are directed towards engineered carbonic anhydrases that act as a biocatalyst within a reactor. The patent portfolio is focused on the US and Canadian markets, with a smaller number of patents filed in Europe, China and India. Although the company has filed a significant number of patent families, the filing rate has decreased; most of the portfolio held by the company is lapsed (69.9%), with approximately 13% of patents being granted, and 8.7% being pending.

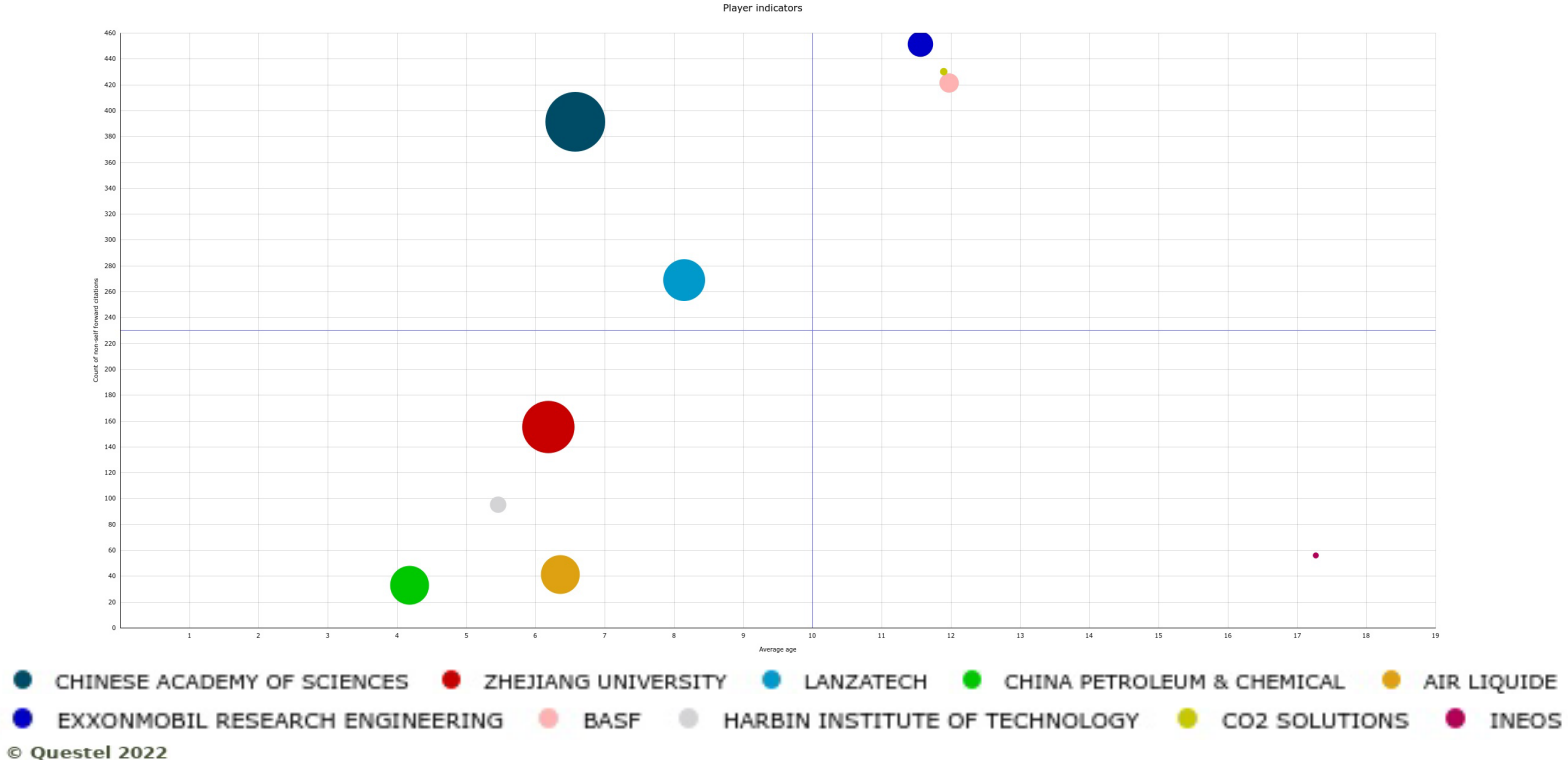
Harbin Institute Of Technology (http://en.hit.edu.cn/) is a public research university with a focus on science and engineering. The patent portfolio is primarily focused on waste water treatment, which includes bacteria and microalgae. The number of patents filed by the Institute has increased significantly in the last 20 years, wherein 25.81% of the portfolio is pending, while 35.48% is granted. The greenhouse gas capture portfolio is concentrated on the Chinese market, with a smaller number of patent filings in the US.

Since larger US, Chinese, and European corporations dominate the patent landscape, the dataset was filtered further to identify key UK players having relevant greenhouse gas capture portfolios:

- **CroBio** (https://www.crobio.co.uk/)
- **C Capture Ltd** (https://c-capture.co.uk/)
- **Autichem** (https://autichem.co.uk/)
- **Algoil** (http://www.britishalgoil.com/)
- **CCM Technologies** (https://www.ccmtechnologies.co.uk/)
- **Bioplex Technologies** (https://www.bioplex.co.uk/)
- **Ecotricity Group Ltd** (https://www.ecotricity.co.uk/)
- **Bp P.L.C.** (https://www.bp.com/)
- **Cardiff University** (https://www.cardiff.ac.uk/)

3.2.7 TOP ASSIGNEE PATENT STRENGTH

The strength of an assignee's patent portfolio can be benchmarked by comparing the number of forward citations (vertical axis) (forward citations are where a patent is referred to by a later filed patent) relative to the average age of the portfolio (horizontal axis). Portfolios positioned further to the right side of this graph correspond to pioneers in the area studied. A position at the top right is indicative of a pioneer with a strong impact on the field studied (potential blocking player). The portfolios further to the left side of this chart are the portfolios of the newcomers. A position at the top left corresponds to a later entrant into the space who quickly became important in the field (strong impact). The size of the bubbles corresponds to the number of families that have at least one family member issued. The larger the bubble, the greater the crowd/competition potential within the sector. Using the analysis for the top 10 assignees identified, it can be observed that Exxonmobile, BASF and CO2 Solutions are the most well-established players in the field of greenhouse gas capture, while Lanzatech and the Chinese Academy Of Science are the most influential newcomers.



3.3 LANDSCAPE MAP

Derwent Innovation can be used to generate sophisticated patent landscapes to visualise the relationship between patents in a common technology area based on key words within the claims and/or abstracts/text of individual patents within the searched field. This can be used to locate competing or similar patents to the patents of interest. As with a geographic landscape the contour lines and intensity of peaks on the patent landscape represent areas of high patent activity with closely related concepts.

The set of INPADOC patent families identified in the landscape search discussed above was mapped using Derwent Innovation's proprietary ThemeScape™ mapping tool. ThemeScape uses term frequency and other algorithms to cluster documents based on shared language – in this case the English Title from the patents together with the Titles and Abstracts were mapped. It uses several algorithms to perform terminology-based clustering. The text from each record is compared with the text from all other patent records within the search collection. The map uses vectors to give each patent record a proximity score to all of its peers. The outcome of this analysis is a visualisation of the patent space with each patent (dot) represented once in the map, with patents in close proximity sharing more phraseology than those located apart. Each peak is labelled with the key terminology concepts contained in the patents within the cluster. We used the Themescape tool on the Landscape Search patent set, mapping one representative patent from each of the INPADOC families. The resulting map is shown below, with some broad subject areas highlighted. This allows us to identify some broad areas of interest in the field, represented by the highest "peaks" on the map.

Although the landscaping is not a precise tool, it is possible to identify clusters of technology areas on the map and this can be a useful tool for analysing both trends and also who is operating in a particular patent field. This can be a way to visualise and start to identify both potential freedom to operate issues and/or identify potential collaborators and licensees who have similar patented technologies and interests.

In this instance, the landscape map was used to identify areas of high patent coverage and areas of low patent coverage, as well as gain insight into the position of the patent portfolios of top three key players. Interestingly, the patent portfolio held by Lanzatech appears to dominate the area of the map concerned with carbon capture using microbial fermentation, as shown by the red circles in Figure 1. On the other hand, the patent portfolio of Exxonmobil Corp appears to be focused on fuel cells and acid salts for gas separation, wherein said portfolio includes a number of patents relating to adsorbent fibres in an area of low patent coverage. While the patent portfolios of Lanzatech and Exxonmobil Corp appear to be very concentrated, the patent portfolio held by the Chinese Academy of Science appears to be evenly distributed around the landscape map.

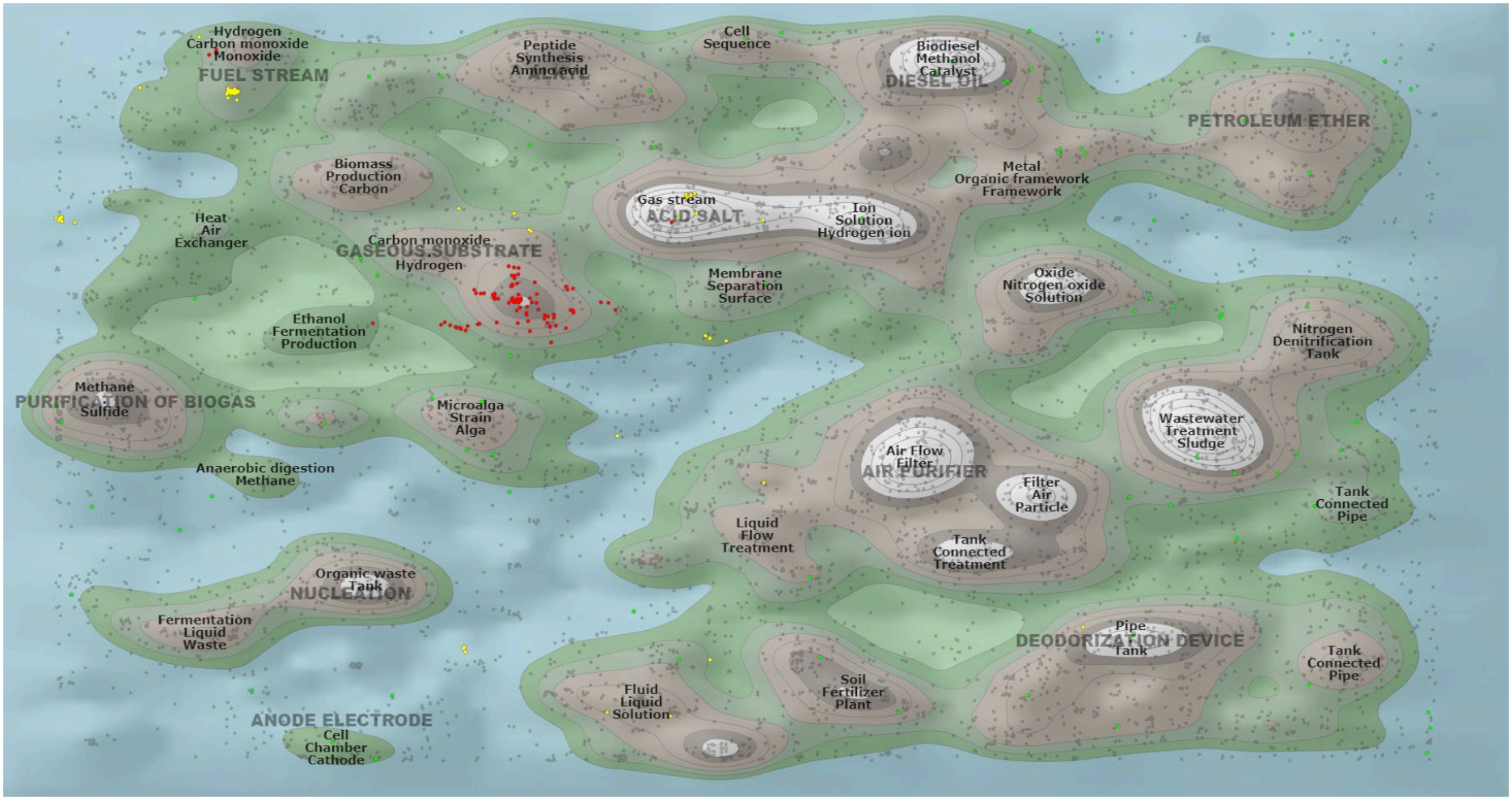


Fig 1. Themescape map for greenhouse gas capture technologies. Each dot indicates the location of an INPADOC patent family on the map. The map has been overlaid with the key areas in which the patents fall on the map. The red circles indicate the location of the published Lanzatech patent portfolio on the landscape map, while yellow circles represent patent families owned by Exxonmobil Corp, and green circles represent patent families owned by the Chinese Academy Of Science.

4 APPENDIX

4.1 SEARCH STRINGS

Search Strategy	Patent Families
Landscape (Derwent Innovation)	
AIC=(Y02*) AND CTB=((*methan* OR CH4 OR carbon* OR CO2 OR ((nitrous OR dinitrogen) ADJ2 (oxid* OR monoxid*)) OR N2O OR (greenhouse* ADJ2 (gas*2 or gases OR gaseous* OR pollut* OR emission* OR emit*)) OR GHG*1 OR hydrofluorocarbon* OR perfluorocarbon* OR ((sulfur OR sulphur) ADJ2 hexafluorid*) OR (nitrogen ADJ2 trifluorid*) OR hexafluoroethan* OR chlorofluorocarbon*) NEAR3 (captur* or sequest* or remov*)) AND (AIC=(C07K* OR C12*) OR CTB=(bio OR biolog* OR microb* OR (micro ADJ2 organism*) OR microorganism* OR bacter* OR yeast* OR fungi* OR enzym*))	5242
AIC=(Y02C20/*) AND (AIC=(C07K* OR C12*) OR CTB=(bio OR biolog* OR microb* OR (micro ADJ2 organism*) OR microorganism* OR bacter* OR yeast* OR fungi* OR enzym*))	1932
AIC=(Y02*) AND AIC=(C01B002120 OR C01B002122 OR C01B003240 OR C01B003250 OR B01D005354* OR B01D005360 OR B01D005362 OR B01D225740* OR B01D225750* OR B01D22577025) AND (AIC=(C07K* OR C12*) OR CTB=(bio OR biolog* OR microb* OR (micro ADJ2 organism*) OR microorganism* OR bacter* OR yeast* OR fungi* OR enzym*))	2744
Sub-Search –Climate Change Technology Comparison (Questel Orbit)	
(Y02A)/IPC/CPC	584155
(Y02B)/IPC/CPC	403674
(Y02C)/IPC/CPC	21077
(Y02D)/IPC/CPC	135546
(Y02E)/IPC/CPC	1696614
(Y02P)/IPC/CPC	886161
(Y02T)/IPC/CPC	556630
(Y02W)/IPC/CPC	359709
Search – Captured Greenhouse Gas Comparison (Questel Orbit)	
(Y02C-020/10)/IPC/CPC	2403
(Y02C-020/20)/IPC/CPC	2099
(Y02C-020/30)/IPC/CPC	1601
(Y02C-020/40)/IPC/CPC	15677

4.2 SEARCH CLASSIFICATION CODES

4.2.1 LANDSCAPE CLASSIFICATION CODES

IPC/CPC Code	Definition	
B01D53/54*	B01D53/00	Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases, aerosols
	B01D53/34	Chemical or biological purification of waste gases
	B01D53/46	Removing components of defined structure
	B01D53/54	Nitrogen compounds
B01D53/60	B01D53/00	Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases, aerosols
	B01D53/34	Chemical or biological purification of waste gases
	B01D53/46	Removing components of defined structure
	B01D53/60	Simultaneously removing sulfur oxides and nitrogen oxides
B01D53/62	B01D53/00	Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases, aerosols
	B01D53/34	Chemical or biological purification of waste gases
	B01D53/46	Removing components of defined structure
	B01D53/62	Carbon oxides
B01D2257/40*	B01D2257/00	Components to be removed
	B01D2257/40	Nitrogen compounds
B01D2257/50*	B01D2257/00	Components to be removed
	B01D2257/50	Carbon oxides
B01D2257/7025	B01D2257/00	Components to be removed
	B01D2257/70	Organic compounds not provided for in groups B01D2257/00 - B01D2257/602
	B01D2257/702	Hydrocarbons
	B01D2257/7022	Aliphatic hydrocarbons
	B01D2257/7025	Methane
C01B21/20	C01B21/00	Nitrogen; Compounds thereof
	C01B21/20	Nitrogen oxides; Oxyacids of nitrogen; Salts thereof
C01B21/22	C01B21/00	Nitrogen; Compounds thereof
	C01B21/20	Nitrogen oxides; Oxyacids of nitrogen; Salts thereof
	C01B21/22	Nitrous oxide (N2O)
C01B32/40	C01B32/00	Carbon; Compounds thereof
	C01B32/40	Carbon monoxide
C01B32/50	C01B32/00	Carbon; Compounds thereof
	C01B32/50	Carbon dioxide
Y02*	Y02	TECHNOLOGIES OR APPLICATIONS FOR MITIGATION OR ADAPTATION AGAINST CLIMATE CHANGE
Y02C20/00	Y02C20/00	Capture or disposal of greenhouse gases

4.2.2 TECHNOLOGY TRENDS CLASSIFICATION CODES

IPC	Definition	
B01D53/84	B01D53/00	Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases, aerosols
	B01D53/34	Chemical or biological purification of waste gases
	B01D53/74	General processes for purification of waste gases; Apparatus or devices specially adapted therefor
	B01D53/84	Biological processes
B01D53/62	B01D53/00	Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases, aerosols
	B01D53/34	Chemical or biological purification of waste gases
	B01D53/46	Removing components of defined structure
	B01D53/62	Carbon oxides
C12M1/00	C12M1/00	Apparatus for enzymology or microbiology
B01D53/14	B01D53/00	Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases, aerosols
	B01D53/14	by absorption
C12M1/107	C12M1/00	Apparatus for enzymology or microbiology
	C12M1/107	with means for collecting fermentation gases, e.g. methane
C02F3/28	C02F3/00	Biological treatment of water, waste water, or sewage
	C02F3/28	Anaerobic digestion processes
B01D53/78	B01D53/00	Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases, aerosols
	B01D53/34	Chemical or biological purification of waste gases
	B01D53/74	General processes for purification of waste gases; Apparatus or devices specially adapted therefor
	B01D53/77	Liquid phase processes
	B01D53/78	with gas-liquid contact
C02F11/04	C02F11/00	Treatment of sludge; Devices therefor
	C02F11/02	Biological treatment
	C02F11/04	Anaerobic treatment; Production of methane by such processes
C02F3/34	C02F3/00	Biological treatment of water, waste water, or sewage
	C02F3/34	characterised by the microorganisms used
C12P5/02	C12P5/00	Preparation of hydrocarbons or halogenated hydrocarbons
	C12P5/02	acyclic
B01D53/52	B01D53/00	Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases, aerosols
	B01D53/34	Chemical or biological purification of waste gases
	B01D53/46	Removing components of defined structure
	B01D53/48	Sulfur compounds
	B01D53/52	Hydrogen sulfide
C02F3/30	C02F3/00	Biological treatment of water, waste water, or sewage
	C02F3/30	Aerobic and anaerobic processes
B09B3/00	B09B3/00	Destroying solid waste or transforming solid waste into something useful or harmless

IPC	Definition	
B01D53/04	B01D53/00	Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases, aerosols
	B01D53/02	by adsorption, e.g. preparative gas chromatography
	B01D53/04	with stationary adsorbents
C02F9/14	C02F9/00	Multistage treatment of water, waste water, or sewage
	C02F9/14	at least one step being a biological treatment [2006.01]
C10L3/10	C10L3/00	Gaseous fuels; Natural gas; Synthetic natural gas obtained by processes not covered by subclass C10G, C10K; Liquefied petroleum gas
	C10L3/06	Natural gas; Synthetic natural gas obtained by processes not covered by C10G, C10K3/02 or C10K3/04
	C10L3/10	Working-up natural gas or synthetic natural gas
B01D53/58	B01D53/00	Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases, aerosols
	B01D53/34	Chemical or biological purification of waste gases
	B01D53/46	Removing components of defined structure
	B01D53/54	Nitrogen compounds
	B01D53/58	Ammonia
B01D53/86	B01D53/00	Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases, aerosols
	B01D53/34	Chemical or biological purification of waste gases
	B01D53/74	General processes for purification of waste gases; Apparatus or devices specially adapted therefor
	B01D53/86	Catalytic processes
C12N1/12	C12N1/00	Microorganisms, e.g. protozoa; Compositions thereof; Processes of propagating, maintaining or preserving microorganisms or compositions thereof; Processes of preparing or isolating a composition containing a microorganism; Culture media therefor
	C12N1/12	Unicellular algae; Culture media therefor
C02F3/12	C02F3/00	Biological treatment of water, waste water, or sewage
	C02F3/02	Aerobic processes
	C02F3/12	Activated sludge processes

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