LexInnova

Oxy-fuel Combustion Systems (OCS)

Technology Landscape

Jun - 13

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Introduction

Historically, air/fuel combustion has been the conventional technology used in nearly all industrial heating processes. In this technology when a fuel is burned, oxygen in the combustion air chemically combines with the hydrogen and carbon in the fuel to form water and carbon dioxide, releasing heat in the process. Air is made up of 21% oxygen, 78% nitrogen, and 1% other gases by volume. During this combustion, the chemically inert nitrogen in the air dilutes the reactive oxygen and carries away some of the energy in the hot combustion exhaust gas.

Recent developments in oxy-fuel combustion systems have made it more amendable for a variety of applications. In the past, the benefits of using oxygen could not always offset the added costs. New oxygen generation technologies, such as pressure and vacuum swing adsorption, have substantially reduced the cost of separating O_2 from air. This has increased the number of applications in which using oxygen to enhance performance is cost-justified. Another important development is the increased emphasis on the environment. In many cases, OCS can substantially reduce pollutant emissions. This has also increased the number of cost-effective applications.

The area of oxy-fuel combustion has witnessed a tremendous innovation in the last decade. The growing demand of energy-efficient systems used in various industries has catalyzed the research going on in this sector.The Gas Research Institute in Chicago and the U.S. Department of Energy, have sponsored independent studies that predict that OCS will be a critical combustion technology in the very near future.

OCS (Oxy-fuel combustion Systems) is the next step of air-fuel combustion systems. Using this technology an industry can:

- Increase efficiency by reducing flue gas heat losses.
- Lower emissions by using specific burner designs.
- Improve temperature stability by allowing more stable combustion.
- Productivity can also be increased for the same fuel input because of higher flame temperature, increased heat transfer to the load, and reduced flue gas

This article aims at understanding the basic concepts of an Oxy-fuel system and their applications. Also, it looks into the major companies doing research in this area through patent analysis.

1. Market Research

Analysis shows that AIR Liquide, HITACHI Ltd., Air Products and Chemicals, General Electric, Praxair and Linde are major assignees. All the dominant assignees except HITACHI, who are using this technology and applying it in various domains, have a decent growth rate. In Figure 1 the blue line shows the average growth rate of the companies based on financial data of 2010-2012. Linde has the highest growth rate of around 11% amongst its competitors.

Analysis has been done to distinguish the presence of dominant assignees in developed and developing nations according to the list released by HDI (Human Development Index). Amongst all the dominant assignees,Linde has the highestfocus on developing nations i.e. 69%of its total operations are based out of developing countries.The second in this order is Air Liquide. Analogous trend is observed between the revenue growth rate of the companies and their percentage focus on developing economies.

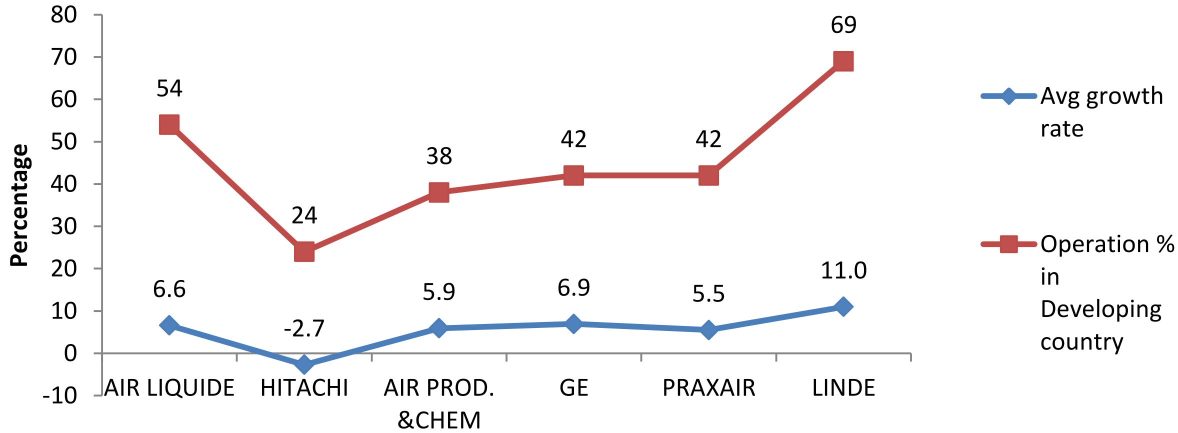


Figure 1: Trend of growth-rate and operational developing countries of dominant assignees

In conclusion, the annual performance of companies were attributed to increase in sales in developing economies where growth was sustained due to continued start-ups, ramp-ups, solid growth in demand and some small acquisitions. Also less growth in sales is observed in advanced economies, signaling a stabilization of oxy-fuel technology.

2. Technical Analysis

In this patent analysis, the patent set was categorized amongst two distinct domains. Technical interpretation of each domain is further explained in detail in the following subsections.

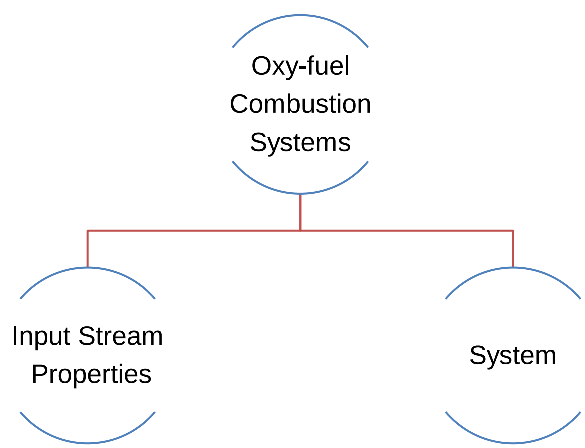


Figure 2: Division of OCS in different Domains

3.1 Input stream Properties

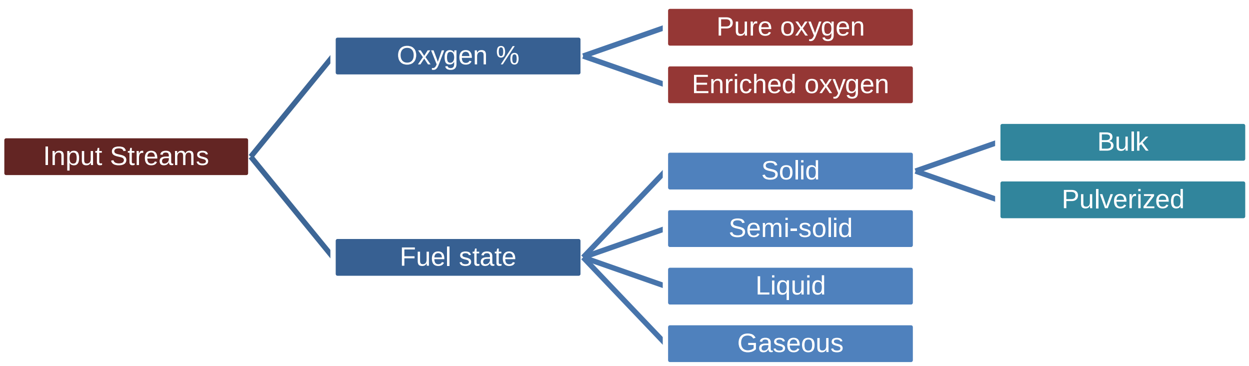


Figure 3: Input streams and their categorization

In combustion system, input streams refer to fuel and oxidant used for melting and heating applications. Many industrial heating processes may be enhanced by replacing some or all of the air with high-purity oxygen. Amount of oxygen in the oxidant mixture can be varied by various control mechanisms on the basis of the oxygen demand of the furnace for optimum efficiency. The oxygen concentration can be pure i.e. more than 90% by volume in the oxidant or can be enriched i.e. more than that of air but less than 90% by volume.

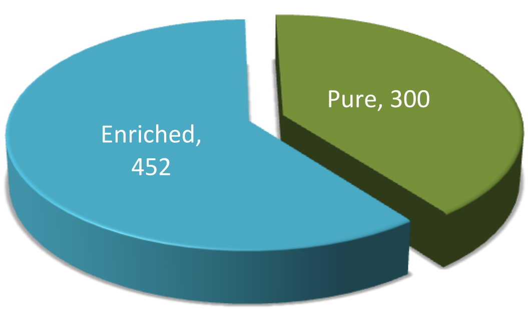


Figure 4: Distribution of patents based on concentration

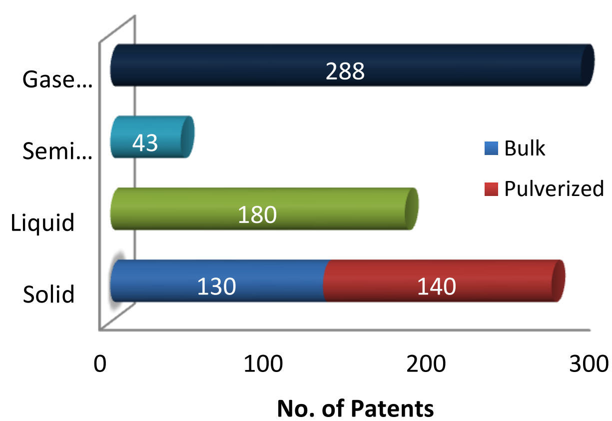


Figure 5: Distribution of patents based on fuel state

Figures 4 and 5 show the distribution of patents according to different states of input streams. Enriched oxygen is more preferred than pure oxygen because of cost efficiency and relatively low oxygen demand in particular industrial sectors. On the other hand semi-solid fuel state is least popular due to its non-homogeneous phase.

3.2 System

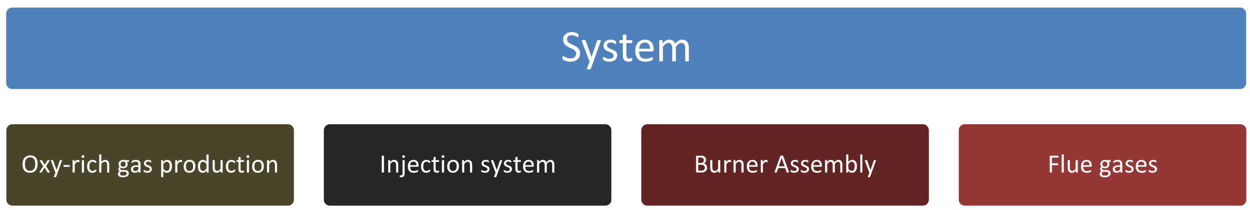


Figure 6: Components of Oxy-fuel Combustion System

"System" word is used in a very broad sense which includes all components of an OCS. It defines the whole assembly of the combustion unit employed in an industry. This further includes ASU's (Air Separation Units) and treatment units for exhaust gases.

3.2.1 Oxy-rich gas Production

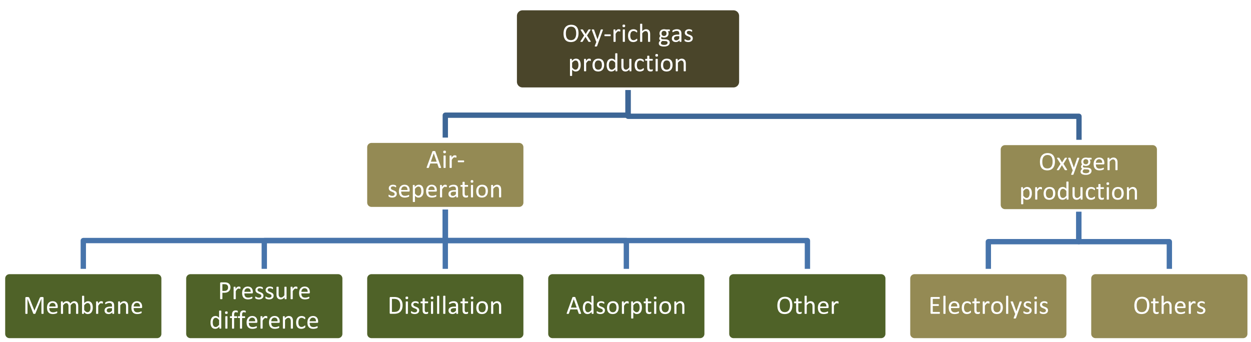


Figure 7: Categorization of oxy-rich gas production

Most industrial furnaces that use oxygen or oxygen-enriched air, use either liquid oxygen to increase the oxygen concentration in the combustion air or vacuum pressure swing adsorption units to remove some of the nitrogen and increase the oxygen content. These may also use membrane separation for improving the oxygen content in air. The aforementioned methods have substantially reduced the cost of separating oxygen from air and therefore have a wide application area.

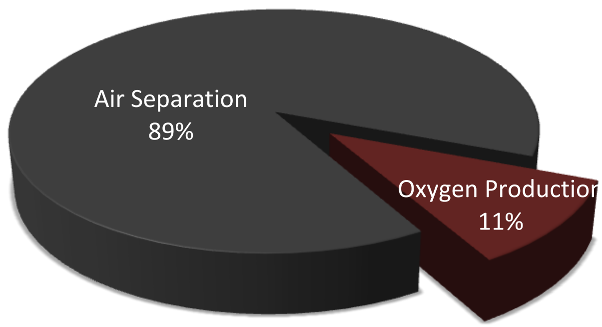


Figure 8: Percentage distribution of Patents based on type of oxygen-rich gas production

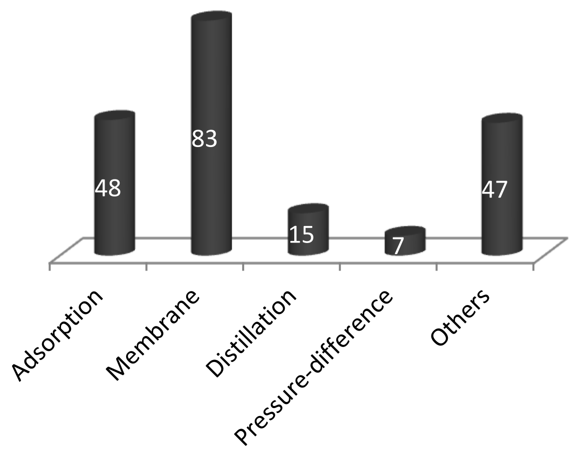


Figure 9: Distribution of patents based on different types of Air separation techniques

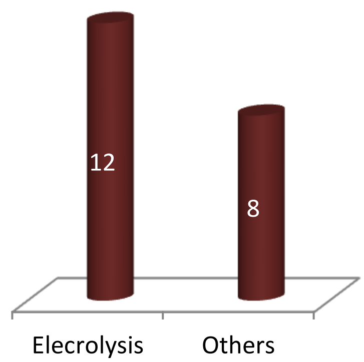


Figure 10: Distribution of patents based on different types of oxygen production techniques

Figures 8, 9 and 10 shows that the patents filed related to oxygen production are very less as compared to other separation techniques like membrane separation, adsorption and distillation owing to their cost in-effectiveness. Methods like electrolysis, despite of being cost inefficient, are used in applications where the high purity of oxygen is critically required.

3.2.2 Injection System

Injection system head represents the control systems and techniques employed to inject the input streams into the required system.

A. Control

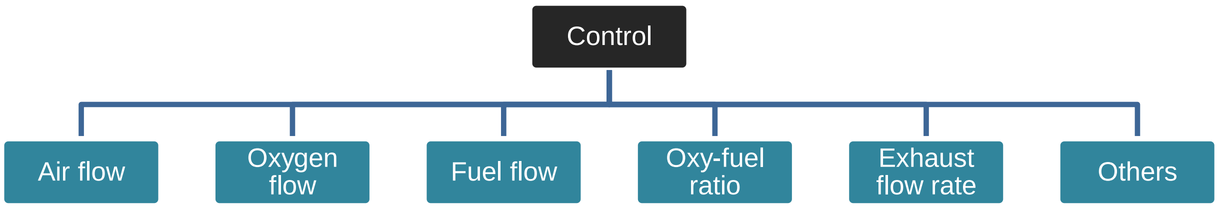


Figure 11: Different mediums being controlled by controllers

The control system being the most important part of an OCS is responsible for the efficiency of the entire process.The control system controls the flow rate of input or exit streams.This enables the flow of oxidant and fuel to be synchronized with feed. The flame shape and heat release pattern may be adjusted by controlling the amount of oxygen used in the process. Exhaust flow control is also necessary to keep emissions under check and maintaining a desired velocity in the furnace.Air control also plays important role in heat management, mixing and reducing chamber temperature.Figure 11 shows different input streams which are controlled in the system, by the use of flowcontrollers.

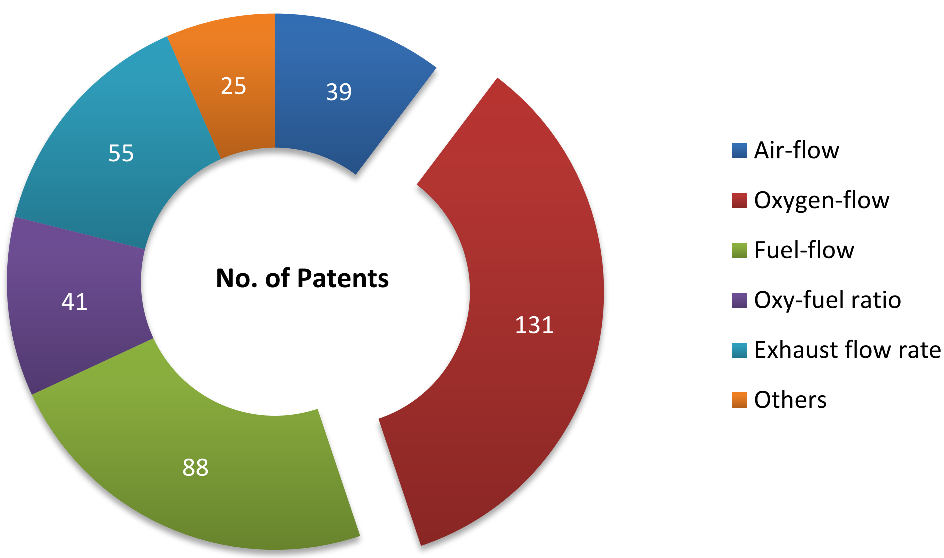


Figure 12: Distribution of patents based on different control streams

Figure 12 shows oxygen and fuel being the most important control streams due to their contribution in the improvement in efficiency of fuel, overall combustion and effectively reducing emissions.

B. Techniques

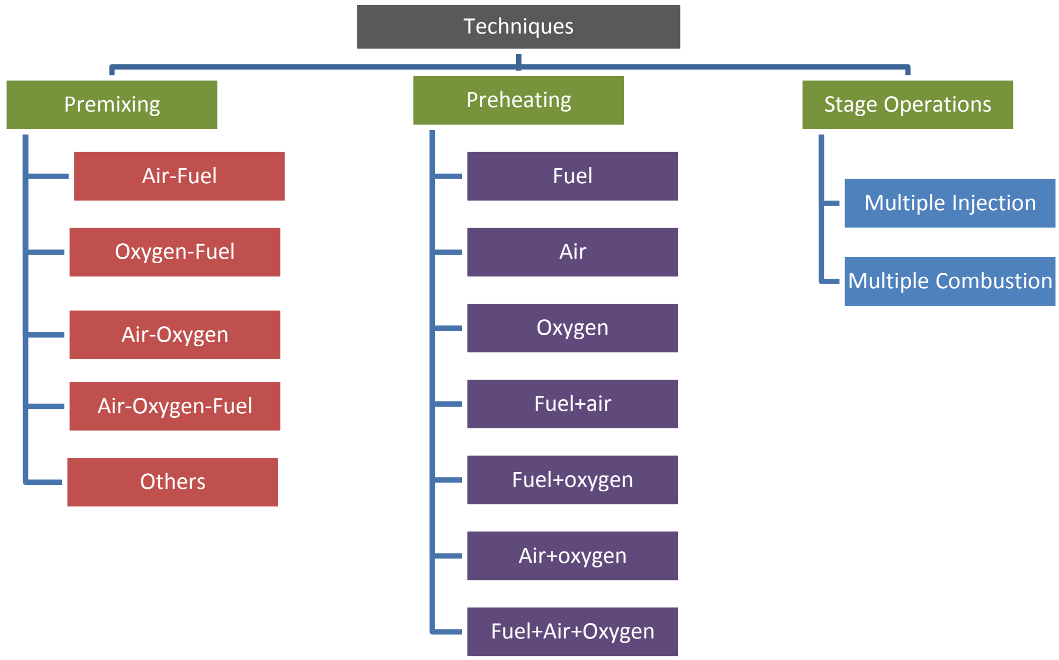


Figure 13: Different types of combustion techniques used

Techniques head represents mixing and heating operations on input streams before injecting them into the system. It also includes the technique of staging of operation whether it is multiple injection (i.e. multiple fuel stages) or multiple combustion (i.e. multiple oxygen stages). The latter is irrespective of fuel stages.

Premixinghelps reducing nitrous oxide emissions but on the other hand could be dangerous and can lead to explosions.Air-fuel premixing is done in cases where fuel requires a medium to travel, like in case of pulverized fuel. Premixing ensures the smooth flow of fuel and maintains uniform temperature in the chamber.Air-Oxygen premixing is done to bring the oxygen percentage to the required levels and making it more cost effective. Also, premix enrichment of oxygen into a combustion airstream has been used to shorten the flame length. Oxygen-Fuel mixing is really helpful in bring down the nitrous oxides emissions but there is potential of explosion due to high reactivity of oxygen with fuel.

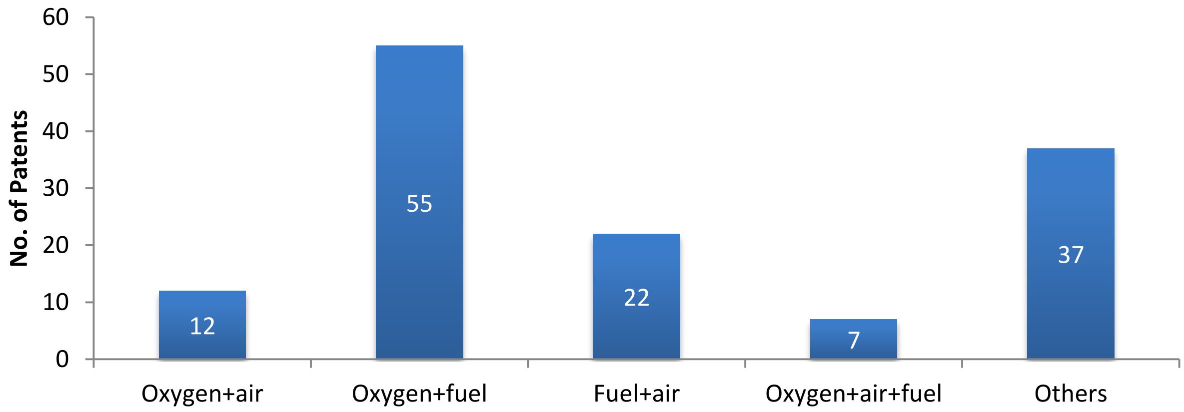


Figure 14: Patent distribution based on mixing input streams

Figure 14 shows the distribution of patents on the basis of mixing components. Patents related to oxy-fuel mixing are more in number because it is most effective in avoiding hot spots and making the flame temperature uniform to increase the heat release from the flame which lowers the flame temperature, and to control the chemistry in the flame zone to minimize nitrous oxides formation.

Preheatingthe input streams is important in reducing the fuel consumptions and making process cost effective.Heat recovery in the form of preheating is commonly used for higher-temperature heating processes to increase the thermal efficiencies. Preheating air or oxygen has a disadvantage of increased nitrous oxides emissions which has to be dealt in later stage of combustion.

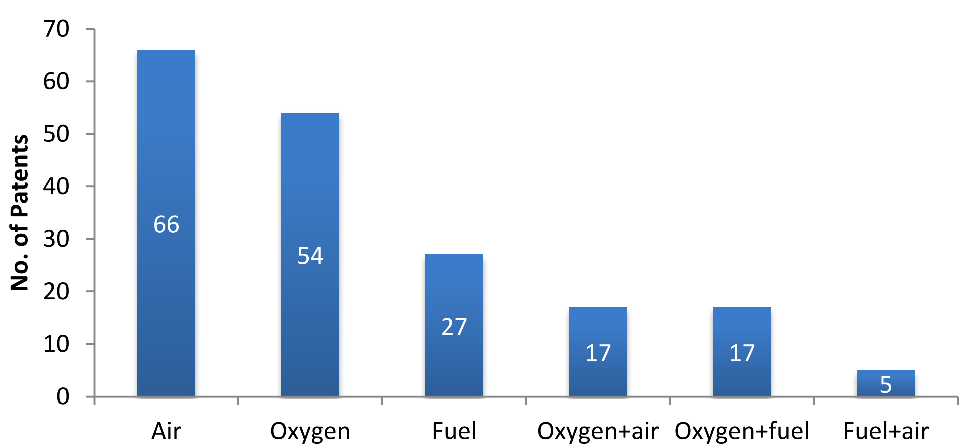


Figure 15: Patent distribution based on preheated streams

Preheating air has a dramatic impact because the increase in sensible heatis very significant due to the large mass of air in the combustion reaction. The thermal efficiency of the combustion increases at a higher rate in case of heating air than oxygen. This is because the initial efficiency without preheatingwithoxygenis already 70%. Thereare also safety concerns when flowing hot oxygen through piping, heat recuperationequipment and a burner.

Staged combustionis an effective technique for lowering nitrous oxides. Staging means that some of the fuel or oxidizer is added downstream of the main combustion zone. The fuel, oxidizer, or both may be staged in the flame. For example, there may be primary and secondary fuel inlets where a portion of the fuel is injected into the main flame zone and the balance of the fuel is injected downstream of that main flame zone. Fuel staging of multiple injection is effective because the peak flame temperatures are reduced, which reduces nitrous oxides. Similar benefits are achieved with oxidizer staging or multiple combustion. In addition it also helps in complete combustion of fuel.

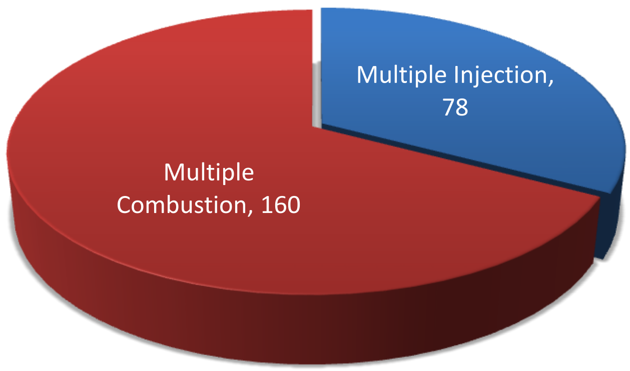


Figure 16: Patent distribution based on type of staging

Figure 16 discloses that multiple combustion or oxidizer staging is getting more attention because of its capability to greatly improve the efficiency of fuel, reducing Nitrous oxide emissions and making process cost effective.

3.2.3 Burner Assembly

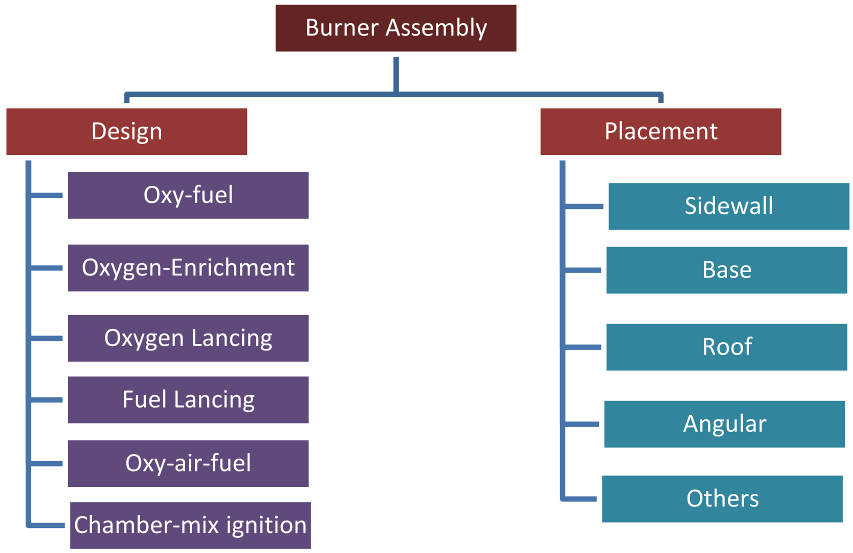


Figure 17: Burner based categorization of a patent

Burner is a device used to generate a flame to heat up products using a gaseous, liquid or solid fuel such as natural gas, kerosene or pulverized coal respectively. In case of liquid fuel, the fuel is atomized into a fine spray usually by forcing it under pressure through a nozzle. This spray is usually ignited by an electric spark. Design and placement of the burner is essential in reducing pollutants, increasing efficiency and product throughput rate. Figure 17 shows the categorization of the burner assembly based on design and placement.

Design: Input streams are commonly injected into the chamber through a burner in six primary ways:

S.no.	Design	Structure
1	Oxy-fuel	Nozzle-mix-burners; replacing combustion air with high purity Oxygen
2	Oxygen-enrichment	Nozzle mix burners; add oxygen into the incoming combustion airstream,
3	Oxygen lancing	Injecting oxygen into an air/fuel flame
4	Fuel lancing	Injecting fuel through a lance into the furnace
5	Oxy-air-fuel	Separately providing combustion air and oxygen to the burner
6	Chamber mix ignition	Directly injecting the fuel, oxidant into the chamber and igniting

Table 1: Different types of burner designs

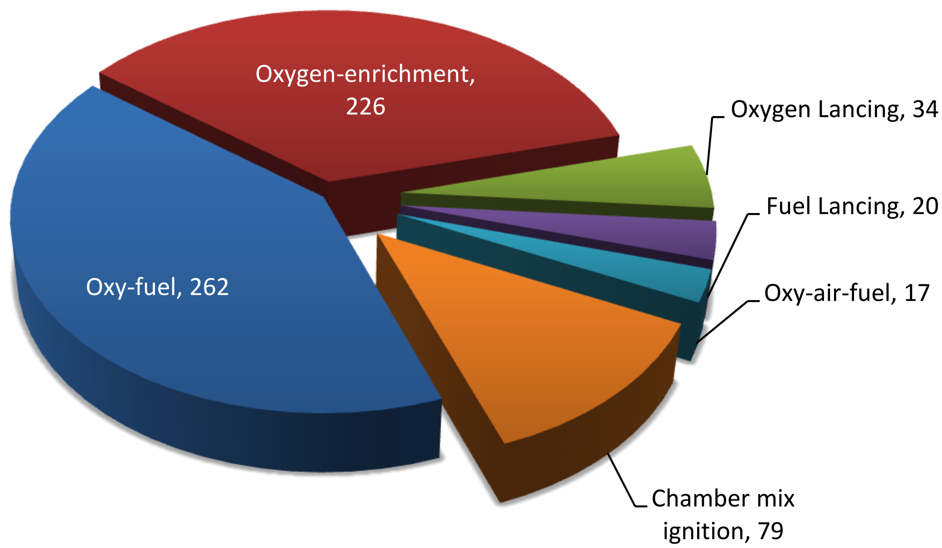


Figure 18: Distribution of patents based on burner design

Figure 18 discloses that most patents have been filed on nozzle-mix burners i.e. oxy-fuel and oxygen enrichment burners. These designs help in maintaining high furnace temperature and better fuel efficiency. Although higher nitrous oxide levels are observed that can be offset by using various techniques like staged combustion, post-treatment etc.

Placement: If the flame from an OCS burner is allowed to impinge directly on the wall of a furnace, most typical refractory materials would be damaged. This can be prevented by the proper choice of burner positioning. The flame length should not be so long that it impinges on the opposite wall. Figure 18 shows the frequency graph of patents with placement of burners at different positions.

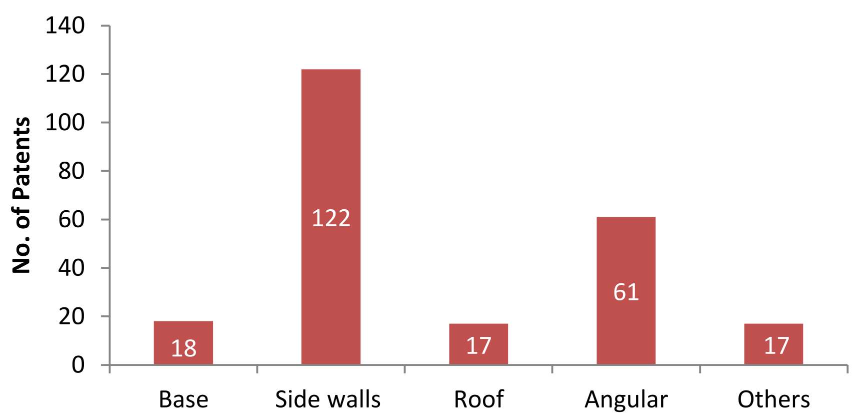


Figure 19: Distribution of patents based on burner placement

Burners at the side walls are preferred because then their flame cannot directly impinge the refractory wall of the furnace so reducing damages even burners with placement at side walls enables uniform distribution of temperatures. Angular placement of burners has their own importance in concentrating heat at a specific place in order to achieve high temperatures.

3.2.4 Flue Gases

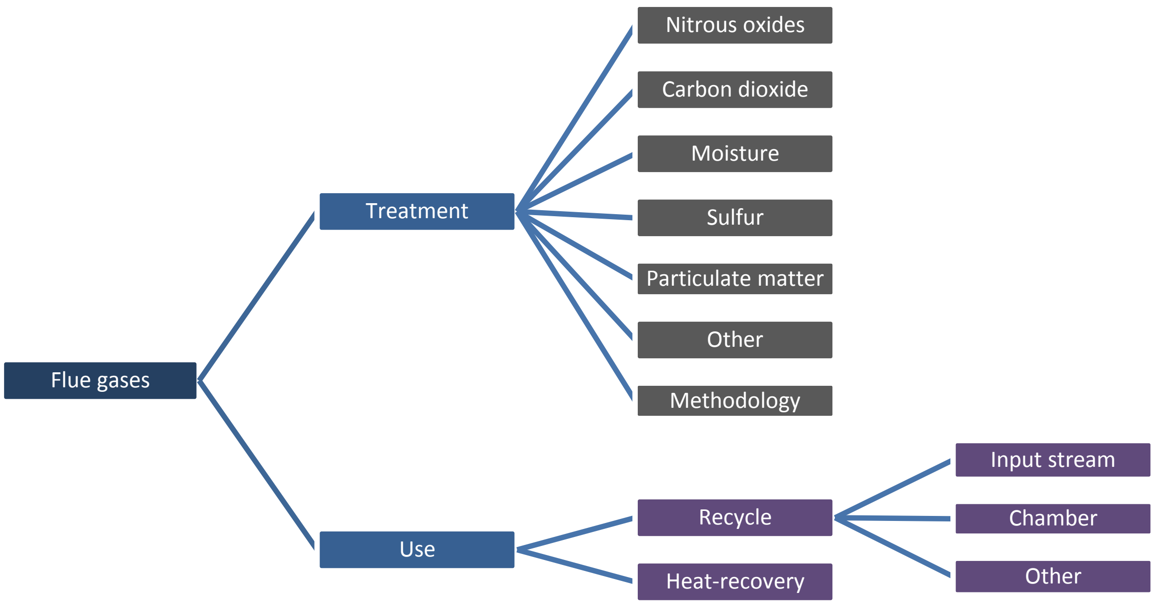


Figure 20: Categorization of flue gases based on their composition, treatment and use

Flue gases are the gases produced after the whole combustion reaction. OCS basically involves removing nitrogen from the oxidizer. One obvious change compared with air/fuel combustion is the reduction in the flue gas volume. The reduction in flue gas volume is even larger when considering the increased fuel efficiency using OCS. Less fuel is required to process a given amount of material; therefore, fewer exhaust products are generated. Any pollutants, such as nitrous oxides or sulphur dioxides, are easier to remove in an oxy/fuel exhaust because they are in much higher concentrations compared with the air/fuel combustion.

Figure 20 shows the categorization of flue gases done in terms of treatment and use. Treatment head discloses types of pollutants and method to treat them. On the other hand use of flue gas is been analyzed in terms of recirculation and heat-recovery source.

A. Treatment

Although using OCS reduces the emissions to a reasonable extent but still many processes have been adapted to curb the pollutants in the flue gases after combustion. In pretreatment, the incoming feed materials are treated in such a way as to reduce nitrous oxides. Some of these include fuel switching, using additives, fuel treatment and oxidizer switching. Preheating and premixing is also an important aspect of pretreatment. Post treatment as the name suggests is performed after the combustion of fuel. This includes using absorbers, scrubbers and membrane air separators. Combustion modification is done by means of modifying the combustion process. This includes modifying burner, staged combustion etc. Following are the pollutants and the way they are been treated.

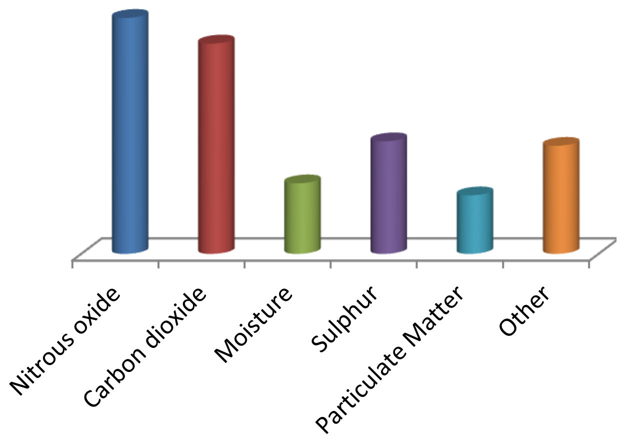


Figure 21: Distribution of patents based on pollutant in flue gases

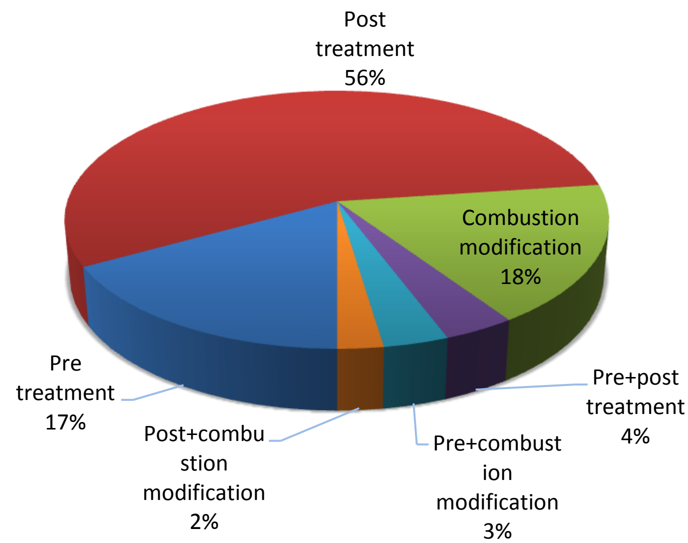


Figure 22: Distribution of patents based on treatment methodology

Figure 21 shows that more patents have been filed disclosing reduction of nitrous oxides with different methods. Reasons could be the dangerous nature of this compound, stringent emission limits and that increasing oxygen content itself magnifies the nitrous oxides emissions. Hence appropriate methods must be adapted to reduce the emissions.

Figure 22 shows maximum patents have been filed in post-treating flue gases because oxy-fuel combustion system itself reduces emissions like carbon dioxide, particulate matter, sulfur and its oxides. And a post-treatment chamber can be easily retrofit in the existing design.

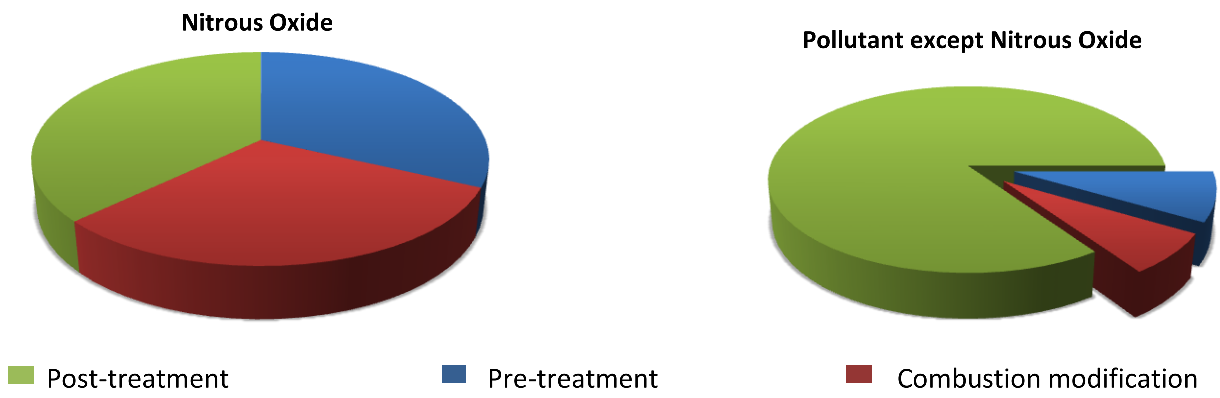
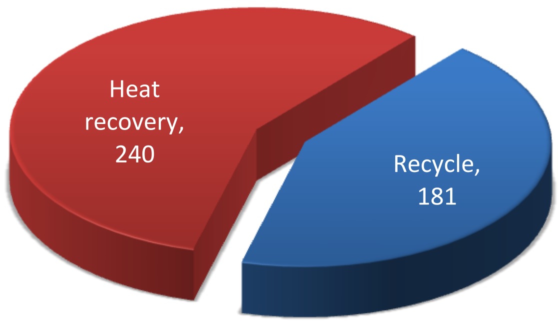


Figure 23: Distribution of patents based on pollutant-wise treatment methodology

Figure 23 shows dependence of the treatment techniques on the type of pollutant present in the exhaust stream. According to this if the pollutant is nitrous oxide then all three methods are equally important as the system itself is responsible for emission of excess nitrous oxide. So enough research has been done on pre-treatment and combustion modification treatment methods in order to reduce the production of nitrous oxides at its source. Oxy-fuel combustion system inherently helps in reducing the volume and concentrating the pollutants except Nitrous Oxides. Hence appropriate post-treatment techniques are required to curb the emitted pollutants. System itself is responsible for emission of excess nitrous oxide. So enough research has to be done to pre-treatment and combustion modification in order to reduce the production of nitrous oxides at its source.

B. Use

In this analysis use of the flue gas as a recycling stream and as a heat recovery source have been stressed upon. Heat recovery is an important aspect in which the input streams or even feed has been heated by absorbing the heat from flue gas using heat-exchangers. Underthe recirculation headtheexhaust gases in the flue are recycled back through the burner into the flame viaductwork external to the furnace. Although the furnace or flue gases are hot, theyare considerably cooler than the flame itself and, therefore, act as a diluent whichreduces the overall flame temperature which in turn reduces nitrous oxides.



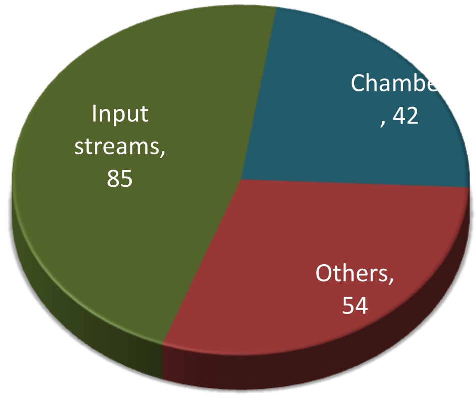


Figure 24: Distribution of patents based on use of flue gas

Figure 25: Distribution of patents based on the place of injection of recycled stream

Figure 25 showsthat there are more patent filings on the recirculation of flue gases in input streams because the recycled gases can pneumatically transfer the pulverized fuel to the combustion chamber i.e. act as a carrier gas, and also performs preheating

3. Applications

Following are the major applications of the oxy-fuel combustion system.

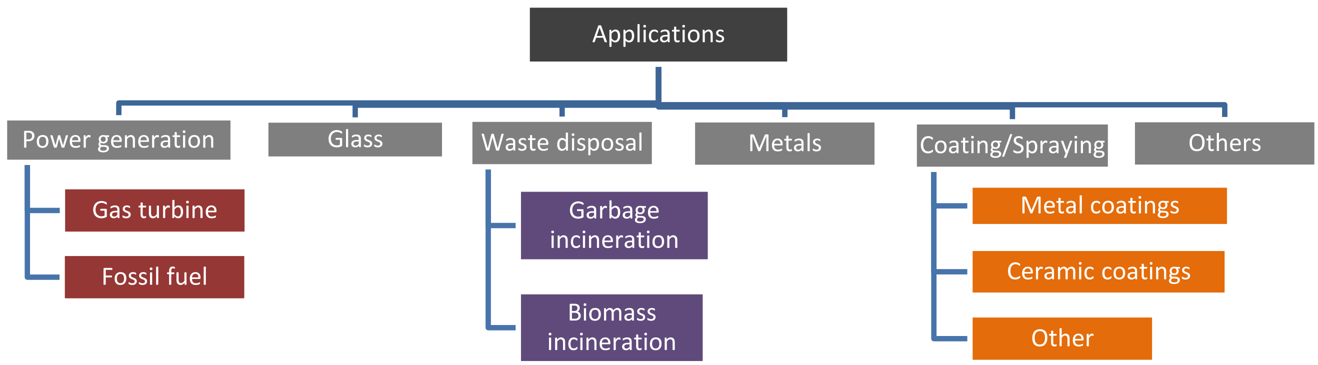


Figure 26: Different Applications of OCS

Oxygen enhanced combustion is used in a wide range of industrial heating applications. In general, oxygen enhanced combustion hasbeen used in high-temperature heating and melting processes that are either veryinefficient or otherwise not possible with air/fuel combustion. Industrial oxygen has been used to enhance combustion in the glass and power industry. Most of these installations utilized supplemental oxygen/fuel(oxy/fuel) burners, premixed oxygen enrichment of the combustion air or undershotlancing of oxygen to the port or burner. Oxygen rich combustion increases the thermodynamic efficiency of coal, used for electric power generation and glass melting.In power generation either OCS can be employed in boilers to generate steam which in turn runs the turbine or directly gasifying coal to drive a gas turbine. Coating/spraying of metals and ceramic compounds demands very high temperatures, so high purity oxygen is used in this process. HVOF (high velocity oxy fuel) systems are an example of oxy-fuel combustion employed in spraying/coating application.

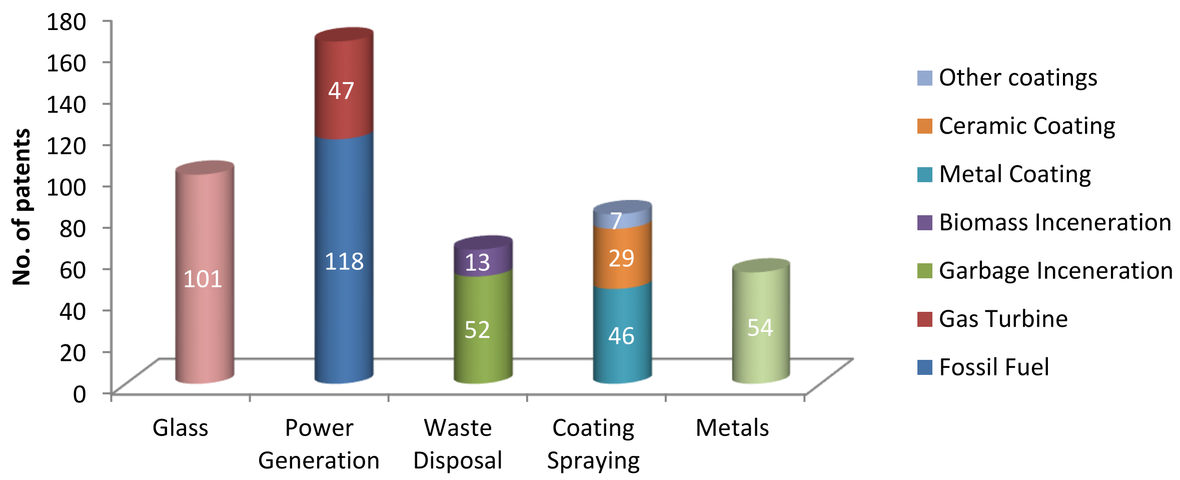


Figure 27: Patent distribution based on different applications

Figure 27 shows the distribution of patents according to their application areas. Power generation and glass melting industries demand high thermal efficiency of fuel thereby accepting oxy-fuel as a cost effective technology. HVOF (high velocity oxy-fuel) devices have helped to achieve high temperature required for coating/spraying application.

Publication number	Title	Technology Focus
US20100199897A1	Process and plant for incinerating waste with preheating of the latter.	Incineration
US20120222593A1	Oxy-fuel combustion with integrated pollution control	Membrane separation ASU
US8034175B2	Apparatus and method for manufacturing semiconductor device, and electronic apparatus	Oxygen production by electrolysis
US20120216539A1	Module-based oxy-fuel boiler	Oxy-fuel ratio control
US20090297993	Method of and system for generating power by oxy-fuel combustion	Exhaust gas flow control
US20100021853A1	Burner apparatus and methods	Premixing (Oxygen & Fuel)
US20110232545A1	High pressure direct contact oxy-fired steam generator	Preheating
US20090274985A1	Powdered fuel conversion systems and methods	Staged Combustion

US20080113163A1	Thermal barrier coating for combustor panels	Chamber mixed ignition
US8,057,221B2	Method and burner for burning with oxygen	Burner placement
US20090007827	System and method for minimizing nitrogen oxide (NOx) emissions in cyclone combustors	Nitrous oxide Treatment
US20100081103A1	Furnace with multiple heat recovery systems	Sulfur oxides treatment
US20090148797A1	Method for carrying out combined burning in a recovering furnace	Heat recovery
US20100300153A1	Downward firing oxygen-fuel burners for glass melting furnaces	Glass furnace
US20120183790A1	Thermal spray composite coatings for semiconductor applications	Coating & spraying

Table 2: List of Important Patents related to Technology Domains of Oxy-fuel Combustion Systems

4. Patenting Trend Analysis

Analysis of patents related to oxy-fuel revealed that the overall filing trend of patents related to oxy-fuel combustion has been increasing since 2005. A steep increase in research activities has been observed around 2007-08 owing to the increased budgets announced by US, Australian and Germany governments in clean energy and oxy-fuel systems.

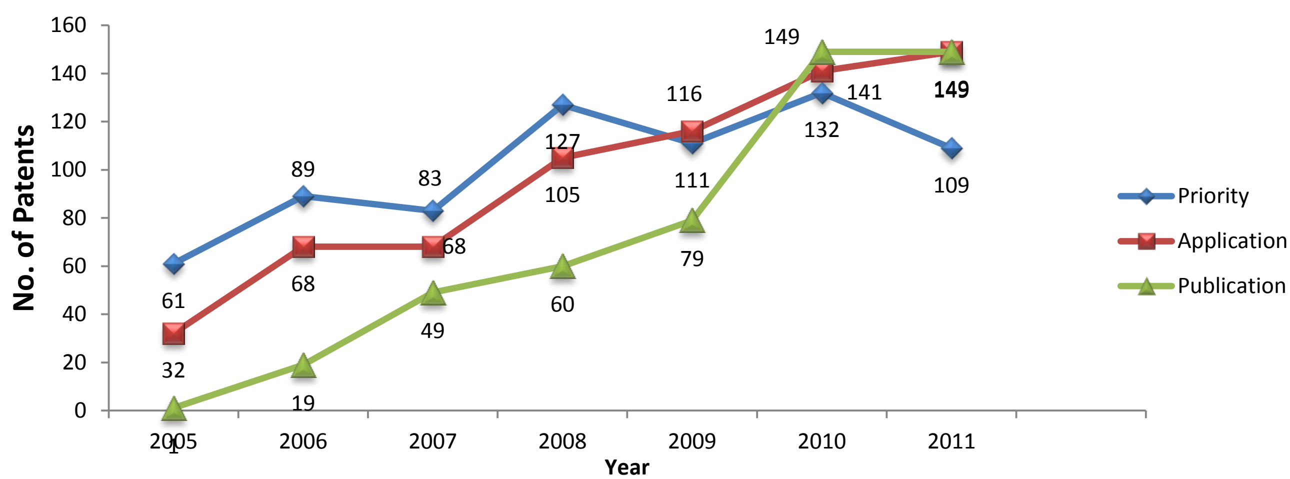


Figure 28: Patent priority, filing and publication trend

5. Dominant Assignees

6.1 Patent filings

Figure 28 shows the major players in the field of Oxy-fuel combustion systems. It alsoshows the number of patents filed by the major players in different technologies related to OCS.

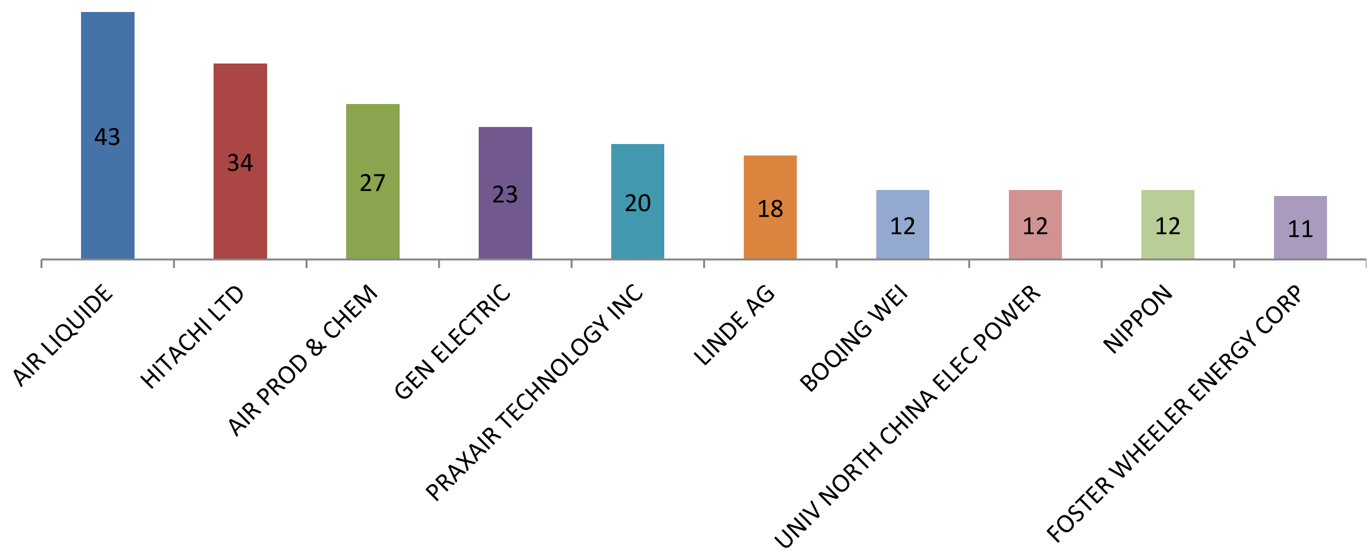


Figure 29: Major Assignees

Air Liquideseems to be the most dominant assignee. It has 43 patents and patent applications combined in its portfolio. Hitachi has next highest number i.e. 34 patents and applications in portfolio. Hitachi is followed by Air Products, General Electric, Praxair and Linde.

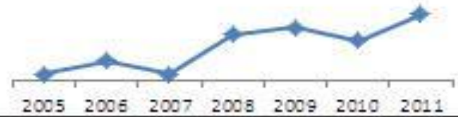
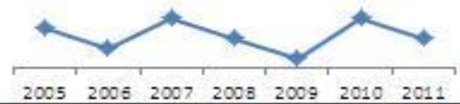
Number of Patents OR Applications	Assignee Name	Percentage of Portfolio by Application year (2005 Onwards)	Patent of Portfolio recently Filed (2008 Onwards)
43	AIR LIQUIDE		86%
34	HITACHI Inspire the Next		85%
27	AIR PRODUCTS		91%
23	GE		52%
20	PRAXAIR Making our planet more productive		75%
18	THE LINDE GROUP		70%

Table 3: Dominant Assignees and their patent filing trend in Oxy-fuel combustion technology

Most of the patent filings were done by Air Liquide in the year 2011 whereas the other competitors havebeen gradually increasing their patent portfolio. Patent filing of Praxair Inc. also has a steep increase from 2010 to 2011. General Electric is found to have filed the highest number of patents in 2005 and its research has been more or less at a constant pace. If the filings done after 2008 are considered, then percentage portfolio files by Air Products and Chemicals is maximum followed by Air Liquide and Hitachi Ltd.

5.1 Technology Focus (Major Assignees)

During the study, patent search was conducted for the following fields

1. Input stream Properties
2. Air-separation
3. Control and Techniques
4. Burner Assembly
5. Flue gases

On the basis of the full text, relevant patents with priority after 2005 were selected for each field. Figure 30 illustrates the distribution of the technologies amongst the leading assignees.

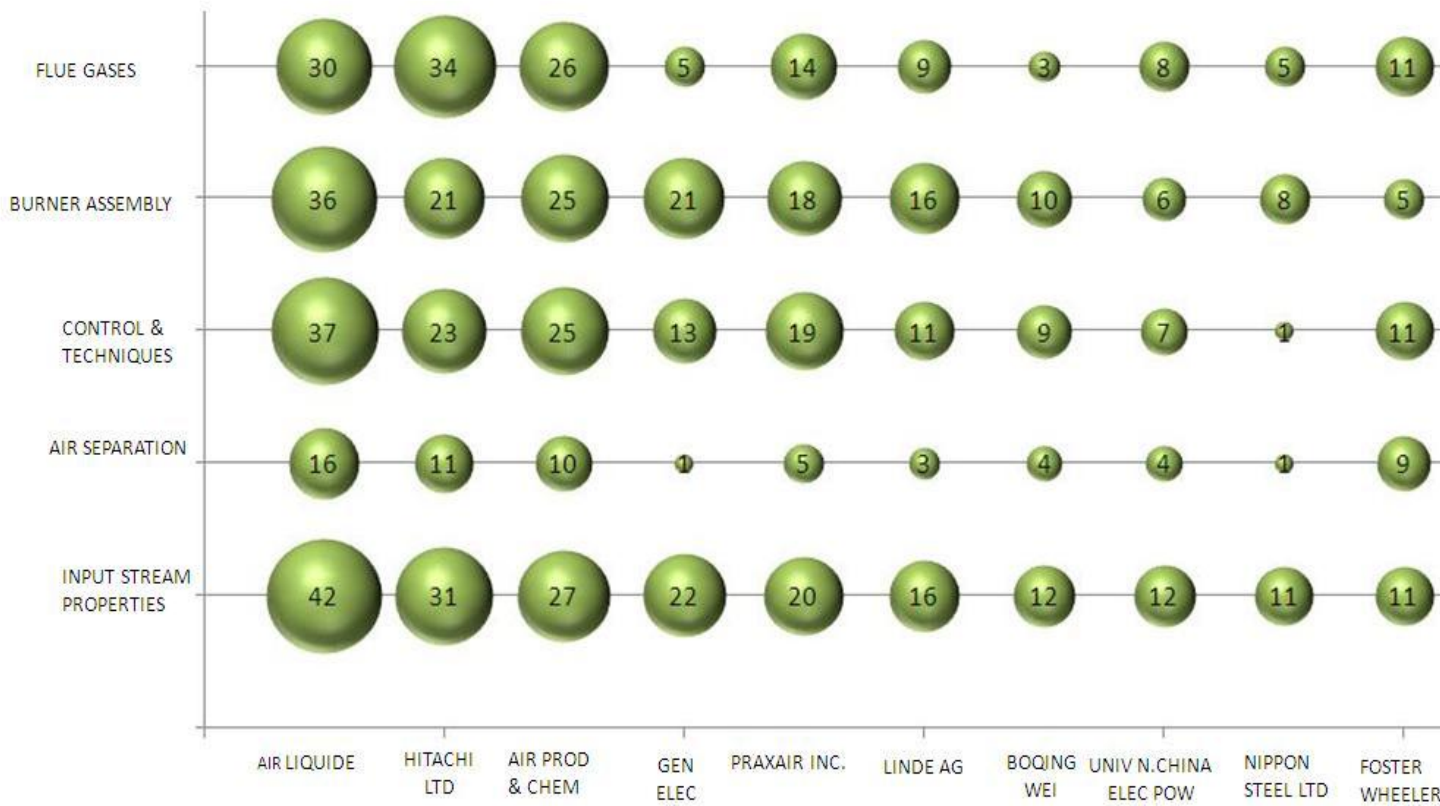


Figure 30: Distribution of patents of dominant assignees based on their focus on broad technical areas

Following inferences can be made from Figure 30

- Air Liquide, Air Products & Chemicals, Hitachi, Praxair are working on all the aspects of OCS.
- General electric and Chinese inventor/assignee Boqing Wei have focus on control techniques and burner assembly.
- Linde AG has a less focus on air separation systems.
- Foster Wheeler is filing more patents in air separation systems, control systems and treatment systems for flue gases.

5.2 Application Industries

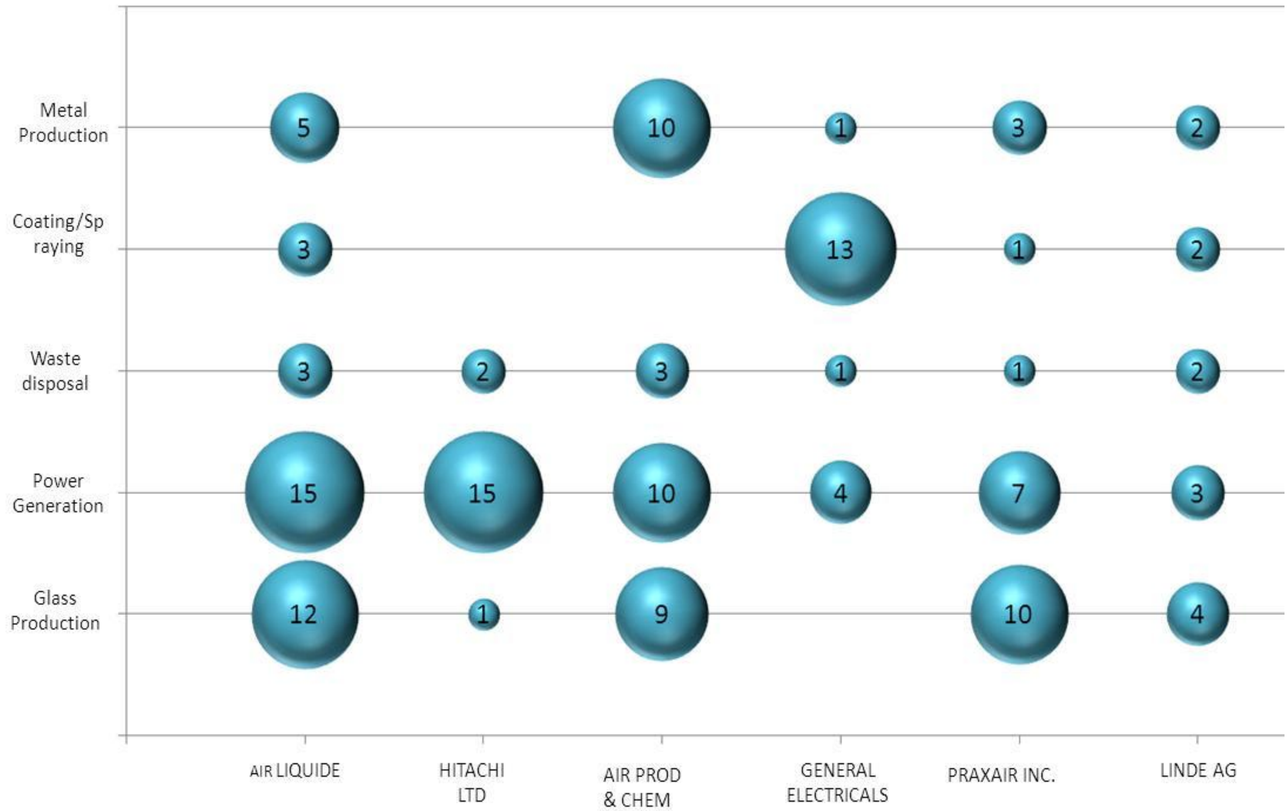


Figure 31: Distribution of patents of dominant assignees based on their focus application industries

Figure 31 shows that Air Liquide, Air Products & Chemicals and Praxair are filing more patents in glass manufacturing and power generation applications whereas General Electric has its prime focus on coating and spraying applications. Hitachi is more concentrated to power generation sector. Linde has its patent filings in all the application areas. Table 4 shows the list of important patents of dominant assignees. These patents contain information on different components of Oxy-fuel Combustion Systems (OCS).

Publication Number	Title	Assignee	Year
WO2007048429A1	Oxygen/fuel burner with variable flame length	AIR LIQUIDE	2007
US8065879B2	Thermal integration of oxygen plants		2008
EP2224165A3	Oxyfuel combustion boiler plant and operating method for the same	HITACHI Inspire the Next	2010
US20090084294A1	Combustion System and Process		2007
US8316784B2	Oxy/fuel combustion system with minimized flue gas recirculation	AIR PRODUCTS	2008
US20070254251A1	Ultra-low Nox burner assembly		2007
US20090078175A1	Method and apparatus for operating a fuel flexible furnace to reduce pollutants in emissions	GE	2007
US20110302901A1	Zonal mapping for combustion optimization		2010
US20100081103A1	Furnace with multiple heat recovery systems	PRAXAIR Making our planet more productive.	2010
US20110290163A1	Hybrid oxy-fuel boiler system		2010
US20100242545A1	Cyclical stoichiometric variation of oxy-fuel burners in glass furnaces	THE LINDE GROUP	2009
US20120214116A1	Apparatus and method for heating a blast furnace stove		2011

Table 4: List of important patents by dominant assignee

6. Conclusion

The area of oxy-fuel combustion has witnessed a tremendous innovation in the last decade. The growing demand of energy-efficient systems used in various industries has catalyzed the research going on in this sector. There are numerous examples of using OEC in a wide variety of industrial heating applications. In some cases, low-level oxygen enrichment of an existing air/fuel combustion system can have dramatic results. In other cases, oxy/fuel burners may be used to provide needed solutions.

Considering the present patent scenario in this domain some techniques like oxygen production for pure oxygen are still cost in-effective in a few application domains. Also the technology areas of air separation systems and oxygen production systems have are relatively less dense, when compared with other technology domains, in terms of the filings done by the major assignees. This gives an indication of possible white spaces in the domain of OCS and also of the areas which would be the centers of future research.

Many techniques related to burner nozzles design, treatment of major pollutants such as nitrous oxides and the recirculation of flue gases are have a lot of patents related to them mainly because these help in increasing the efficiency of OCS and also help in making it a cost effective solution even for other application areas. These areas are rife with activity by the major assignees giving an indication of the areas which are the prime focus of the research being done in this domain.

Power generation and glass melting industries demand high thermal efficiency of fuel thereby accepting oxy-fuel as a cost effective technology. HVOF (high velocity oxy-fuel) devices have helped to achieve high temperature required for coating/spraying application as a result of which this application area is gaining a lot of focus from various companies. Air Liquide, Air Products & Chemicals and Praxair are filing more patents in glass manufacturing and power generation applications whereas General Electric has its prime focus on coating and spraying applications. Hitachi is more concentrated to power generation sector.

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