GHG Emissions in industrial activities: the role of technologies for their management and reduction

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Keywords: Green House Gases, industrial emissions, energy production, carbon capture, renewables, co_2 reutilization

ABSTRACT – To deal with the problem of the Climate System Change and the Global Warming, countries as well industries require to decrease the amount of CO_2 emissions released globally by developing greener technologies and improving the use of renewable energies. The role of the research, in particular process engineering, is to develop and demonstrate technologies in order to protect the world from the current deterioration situation, which could potentially develop more frequent natural disasters, raising in the sea level and cause harm to the human health and ecosystems. The Chemical Engineering group at Department of Civil and Industrial Engineering of Pisa University has been involved in several projects concerning carbon reduction and emission from energy production in different Sectors, in collaboration with public and private organizations and international networks. The research topics have been briefly reviewed and objectives for further studies have been identified.

INTRODUCTION. – The Climate system change and the global warming, associating the upsurge of global average temperature to the observed increase of the anthropogenic greenhouse gases (GHG) concentrations in the atmosphere. Carbon dioxide (CO_2) is considered the most important GHG, due to the dependence of industrial sectors on fossil fuels, where combustion processes are the most important sources. To deal with the problem of the Climate System Change and the Global Warming, countries as well industries require to decrease the amount of CO_2 emissions released globally by developing greener technologies and improving the use of renewable energies.

Energy is essential for societal development. All energy sources will be needed to meet growing demand, including renewables and oil

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DOI XXXXXXXX

and gas. Access to affordable, reliable energy is essential to the growth of strong economies, sustained improvements in the quality of life and the eradication of poverty. To ensure these benefits for today's and future generations alike, GHG reduction and climate change adaptation objectives must balance the need for development, economic growth, environmental protection and energy security. Oil and gas have a continuing role to play in a future of increasingly diverse energy sources, steadily improving energy efficiency and new technologies to minimize emissions.

The International Energy Agency has recently published the Global Energy and CO_2 Status – Report 2018, from which the main conclusions can be drawn:

- **Global energy consumption** in 2018 increased at nearly twice the average rate of growth since 2010, driven by a robust global economy and higher heating and cooling needs in some parts of the world. Demand for all fuels increased, led by natural gas, even as solar and wind posted double-digit growth. Higher electricity demand was responsible for over half of the growth in energy needs. Energy efficiency saw lackluster improvement.
- **Energy-related CO_2 emissions** rose 1.7% to a historic high of 33.1 Gt CO_2. While emissions from all fossil fuels increased, the power sector accounted for nearly two-thirds of emissions growth. Coal use in power alone surpassed 10 Gt CO_2, mostly in Asia. China, India, and the United States accounted for 85% of the net increase in emissions, while emissions declined for Germany, Japan, Mexico, France and the United Kingdom.

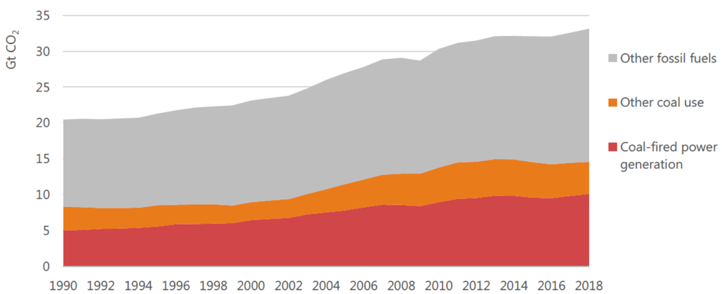

FIG. 1. Global energy related carbon dioxide emissions by source, 1990-2018 (Source: Global CCS Status Report: 2018. International Energy Agency, 2019).

Figure 2 shows the changes in global carbon dioxide emissions and avoided emissions from 2017 to 2018. It is evident that the measures for avoiding the emissions – energy efficiency, renewables, natural gas and other – are still not sufficient to balance the increase of generation due to increasing energy demand. This issues are also related to the capability of new technologies to become reliable and sustainable in terms of costs and acceptability from different stakeholders, including local communities.

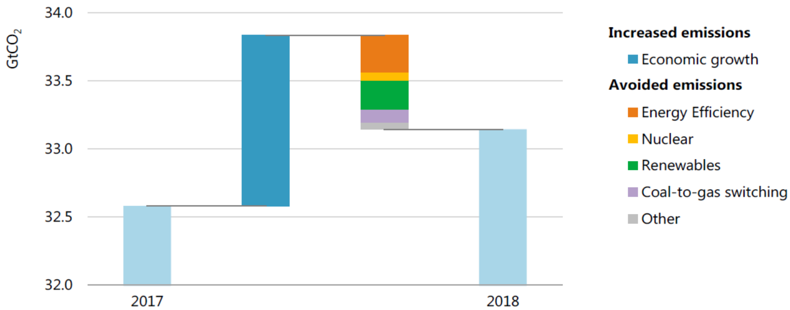

Fig. 2. Changes in global carbon dioxide emissions and avoided emissions 2017-2018 (Source: Global CCS Status Report: 2018. International Energy Agency, 2019).

The long term climate actions and policies. – September 2015, United Nations general assembly issued 17 Sustainability Development Goals (SDG) and 169 targets underpinning the new universal Agenda. The SDG's will stimulate action for the next 15 years in critical areas of importance for humanity and the planet. Among these SDG's, the 13th SDG lays the climate action goal which shows that climate change is one of the issues that requires the international cooperation, commitment from governments and corporations.

The United Nations Framework Convention on Climate Change (UNFCCC, *https://unfccc.int/*) is the main international agreement on climate actions and is ratified by 195 countries. Since then there has been two issues related to the UNFCCC:

Ratification of the Doha amendment to the **Kyoto Protocol**, which concerns commitments under the second period, running from 2013-2020.

Paris Agreement – or **COP21** is a new global climate change agreement covering all UNFCCC countries, its ratification, implementation and enter into force in 2020. The Paris agreement sets out a global action plan to put the world on track to avoid dangerous climate change by limiting global warming to well below 2°C and pursuing efforts to limit it to 1.5 °C. According to *Intergovernmental Panel on Climate Change* (*https://www.ipcc.ch/*) cumulative emissions of CO2 and future non-CO2 radiative forcing determine the probability of limiting warming to 1.5 °C.

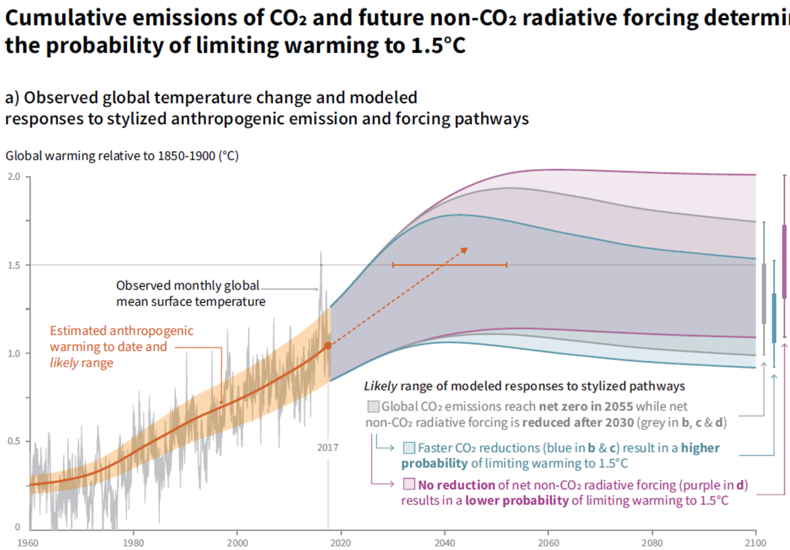

FIG. 3. Observed global temperature changes and modeled responses to stylized anthropogenic emission and forcing pathways *(Source: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty; Intergovernmental Panel on Climate Change 2018).*

One of the most effective measure to limit carbon emission has been set up by EU. The EU emissions trading system (EU ETS) is a cornerstone of the EU's policy to combat climate change and its key tool for reducing greenhouse gas emissions cost-effectively. It is the world's first major carbon market and remains the biggest one.

The EU ETS works on the "cap and trade" principle. A cap is set on the total amount of certain greenhouse gases that can be emitted by installations covered by the system. The cap is reduced over time so that total emissions fall. Within the cap, companies receive or buy emission allowances which they can trade with one another as needed. They can also buy limited amounts of international credits from emission-saving projects around the world. The limit on the total number of allowances available ensures that they have a value. If a company reduces its emissions, it can keep the spare allowances to cover its future needs or else sell them to another company that is short of allowances. A robust carbon price also promotes investment in clean, low-carbon technologies.

THE TECHNOLOGIES AND THE ROLE OF RESEARCH. – The Department of Civil and Industrial Engineering of Pisa University is involved in several projects concerning carbon reduction, the Climate Change and access to energy, in collaboration with public and private organizations, and international networks. The research topics at DICI can be summarized as: 1. Managing emissions from industrial production; 2. Reducing emissions from power generation: natural gas and renewables; 3. Carbon capture.

MANAGING EMISSIONS: ENERGY CONSERVATION AND BEYOND. – The relevant GHGs for industrial activities are CO_2, CH_4, N_2O. The main sources in a typical industrial facility are: Combustion: fuel consumption (gas, diesel, kerosene, …) for power generation, transportation; Flaring: routine flaring, emergency flaring (including start up and commissioning phases, blow downs) and flaring during drilling and well workovers; Venting: process and emergency venting, venting from gas processing units, storage tanks; Fugitives: unintentional leakages from valves, flanges, etc. within the plant.

DICI has a long term collaboration with ENI through a University Master – *Management of Health, Safety, Environment and Quality Systems.* The Master trains experts in the development and Management of HSE&Q Systems. Ongoing projects, including flaring reduction, control of methane emissions and other efforts are reviewed and analyzed as project works within Master activities. In parallel, DICI has collaborations with industrial sectors (iron & steel, pulp & paper, refineries, glass, cement) to improve energy efficiency in production: conserving energy goes beyond traditional energy efficiency measures, including recovery and recycle of secondary raw materials in a circular economy frame (Tognotti, 2019).

Reducing emissions from power generation: natural gas. – The power sector accounts for about half of global energy-related GHG emissions. Multiple approaches and technologies can be used to reduce the GHG intensity of this sector. In the near term, one of the most cost-effective and impactful steps that society can take is to switch from coal to natural gas. This step could cut emissions in half for every unit of electricity generated. Reducing the GHG intensity of the power sector could enable the electrification of parts of the transport, residential, commercial and industrial sectors to decrease their GHG intensity. Natural gas is the cleanest-burning fossil fuel and is increasingly accessible, affordable, abundant and flexible. With ongoing management of emissions, natural gas will continue to play a pivotal role as a dependable lower carbon fuel in the transition to a low-carbon energy future. DICI has developed original modeling approaches in the study of clean and efficient natural gas combustion, including hydrogen enrichment (Aminian *et al.* 2011, 2016), energy recovery from flue gases and recuperative burners (Galletti *et al.* 2007, Parente *et al.* 2008), gas turbine diagnostics and optimization (Bellagoni *et al.* 2019).

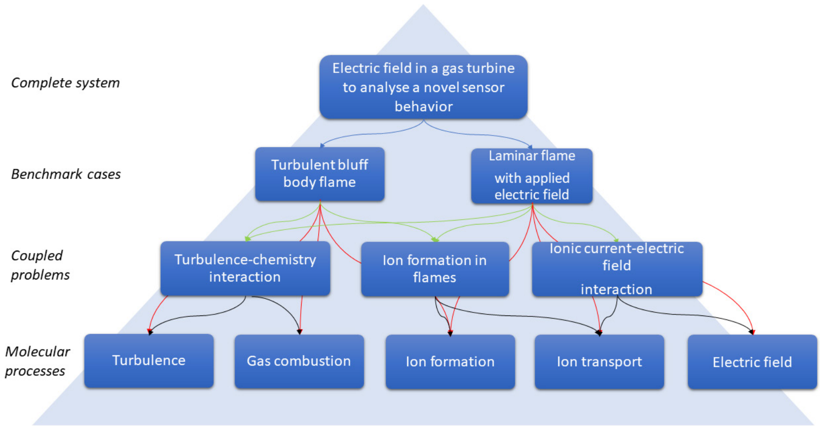

Fig. 4. Hierarchical scheme for CFD study validation: application to gas turbine diagnostics.

Reducing emissions from power generation: renewables. – Near-zero emissions options for energy generation at local and medium scale are represented by renewables. While these technologies continue to be developed, additional technical breakthroughs will be needed to achieve cost-effective deployment at the scale needed to transform the energy system.

Biomass combustion, in collaboration with DESTEC -Department of Energy, Systems, Territory and Construction – (Barontini *et al.* 2018, Capusciutti *et al.*, 2018), and biomass gasification (Biagini *et al.* 1014, 1015, 2016; Simone *et al.* 2012, 2013a, 2013b) have been the main topics of research of DICI in the last decade, including biofuel production such as biomethane, biodiesel and torrefied biomass (Bacci di Capaci *et al.* 2019, Tasca *et al.* 2019; Li *et al.* 2013).

The main objective, among others, was to demonstrate the feasibility and availability of technologies for local, small scale, distributed generation (Galletti *et al.* 2016, Patronelli *et al.* 2018). Biomass combustion at the Cornia 2 hybrid geothermal/biomass power plant of Enel Green Power – an innovative technology integrating renewable and geothermal energy – has also been investigated (Galletti *et al.* 2017).

Carbon Capture and Storage (CCS). – Carbon Capture and Storage is a technology which is used to capture large emissions of CO_2 released into the atmosphere from stationary point sources such as power plants and energy intensive industrial processes (pulp and paper, steel and oil refineries, etc.). The technology can be integrated into the combustion of fossil fuels during energy generation, where CO_2 is captured and transported to the “storage bank” in order to isolate it from the atmosphere.

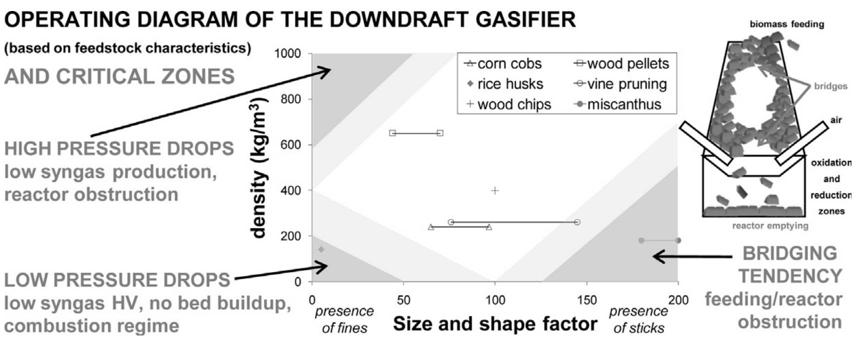

Fig. 5. Operating diagram of the downdraft gasifier (Biagini *et al.* 2015).

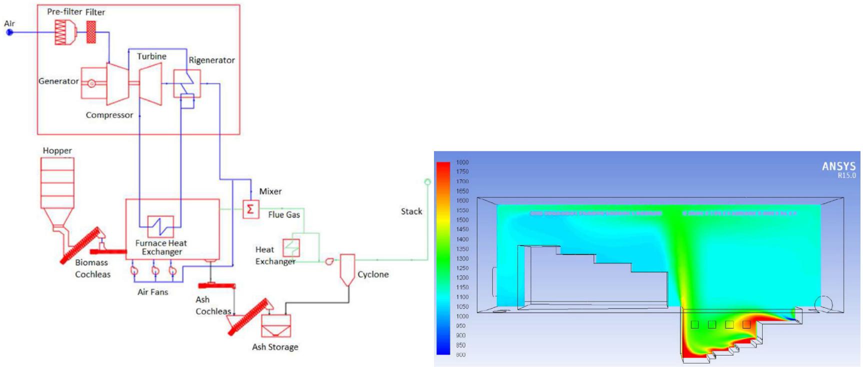

Fig. 6. Biomass furnace for externally fired gas turbine: development and validation of the numerical model (Galletti *et al.* 2016).

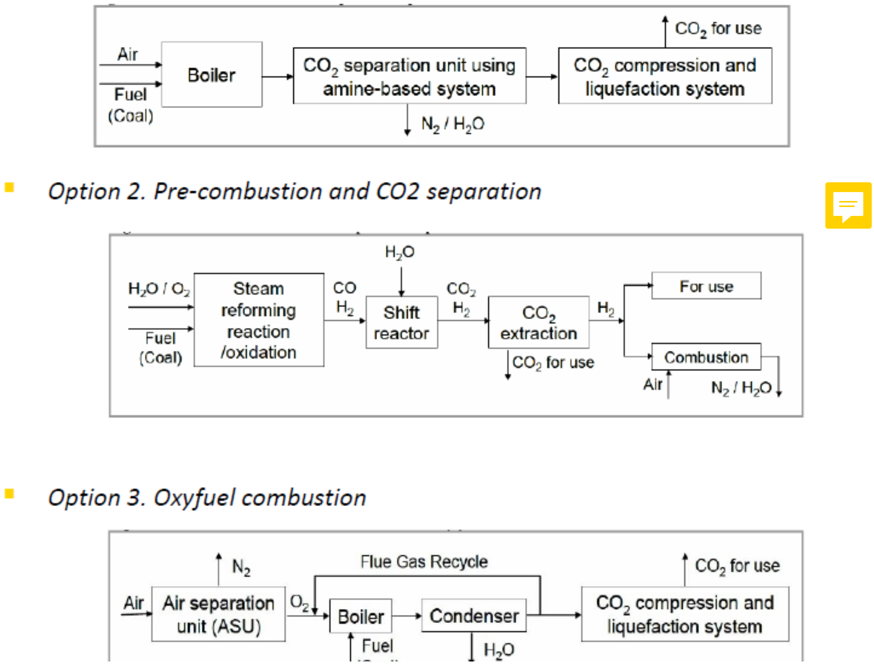

Fig. 7. Carbon Capture options.

CCS involves three major steps; capturing CO_2 at the source, compressing it for transportation and then injecting it deep into a rock formation at a carefully selected and safe site, where it is permanently stored. DICI research on CCS has been devoted on the Capture phase, i.e. the separation of CO_2 from other gases produced at large industrial process facilities such as coal and natural-gas-fired power plants, steel mills, cement plants and refineries. The Capture options are represented in Figure 7.

Research at DICI has been conducted on all the options, with particular focus on oxyfuel combustion, in which the combustion of fuel takes place with a mixture of oxygen and recycled flue gas (RFG) (Coraggio *et al.* 2011, Galletti *et al.* 2013a, 2013b). The applications for gas combustion in a O2–RFG mixture are both the retrofit of existing fired utility boilers and the building of new ones expressly designed for this technology.

Deployment of CCS on a scale that makes a material contribution to reducing CO_2 emissions requires addressing current barriers, which include: cost, complexity along the value chain, regulatory/policy uncertainty, public acceptance, large-scale storage sites and long-term liability issues.

More recently efforts have been focused on CO_2 recycle market. Two categories, direct utilization of CO_2 and conversion of CO_2 to chemicals and energy products, can be used to classify different forms of CO_2 utilization. Regarding the direct utilization of CO_2, in addition to its use in soft drinks, welding, foaming, and propellants, as well as the use of supercritical CO_2 as a solvent, are being considered with different levels of technology readiness. The conversion of CO_2 to chemicals and energy products can be achieved mainly through: i) photosynthesis to directly fix carbon into microalgae, which can then be digested to produce biogas/biomethane (Barontini *et al.* 2016); ii) co-electrolysis with water using renewable/surplus energy to produce syngas and then methanol; iii) direct catalytic hydrogenation of CO_2 to methanol.

Conclusions. – Meeting the aims of the Paris Agreement implies a transformation of the energy and industrial system over the course of this century. Throughout this transition, fossil fuels will continue to be an important part of the broad energy mix needed to deliver affordable, reliable and modern energy products and services. There are many possible pathways to reach a low-emissions future, most of which share three common elements: improving **efficiency** and saving energy; reducing **emissions** from power generation; and deploying alternative **low-emission options** in end-use sectors. Carbon capture and storage (CCS) is a key technology to support this transition. As an example, Figure 10 reports the predictions of CO_2 eq emissions from the implementation different policy scenarios at global level: the measures needed to surpass current Nationally Determined Contributions (NDCs)to reach the 2 °C trajectory through 2040 are indicated.

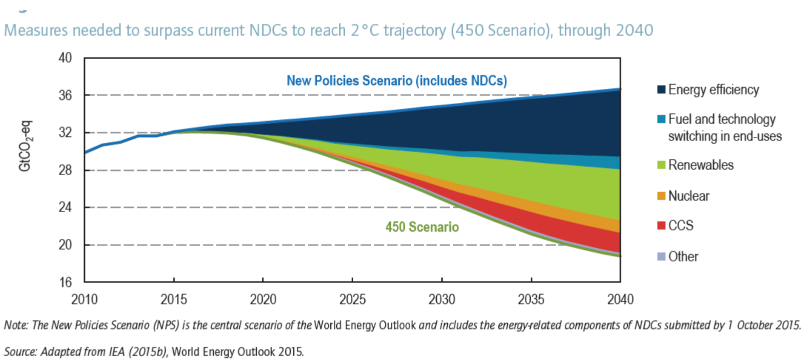

Fig. 8. CO_2 emissions for different policy scenarios (Source: Energy, Climate Change & Environment: 2016 Insights).

The role of the research, in particular industrial process engineering, is to develop and demonstrate technologies in order to protect the world from the current deterioration situation, which could potentially develop more frequent natural disasters, raising in the sea level and cause harm to the human health and ecosystems. Research at different steps of development, from fundamental to demonstration phases, is still needed: to reducing CO_2 emissions requires addressing current barriers, which include cost, complexity along the value chain, regulatory/policy uncertainty, public acceptance.

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