Clean combustion, a path to net zero

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Introduction

Use of fossil fuels as the major source of energy is one of the main sources of GHG emissions that contribute to global warming. However, for at least a foreseeable future, the world will still continue to rely on fossil fuels to sustain the economy and the quality of life. IEA is evaluating the pathways for the energy sector attain global net-zero emissions by 2050. The pathways cover the deployment of existing technology, need for innovation and policy in addition to the required investment in this space.

The number of the countries that announced pledges to achieve net-zero greenhouse gas emissions is growing but the main question is what the transitional pathways are to keep the global warming below 1.5 °C.

UN defines net zero as "cutting greenhouse gas emissions to as close to zero as possible, with any remaining emissions re-absorbed from the atmosphere by oceans and forests for instance" (Ref. UN climate change, net zero coalition). Combustion of fossil fuels for transportation, industry and during power generation is one of the major sources of GHG emissions. An additional source of GHG emissions, which has been significantly underestimated, are those that occur during operations and maintenance of wells and facilities.

The greenhouse gases of current major concern are carbon dioxide, methane, nitrous oxide (N2O) and fluorinated gases. Effect of each gas depends on its quantity in the atmosphere, how long it stays and how strong it impacts the atmosphere (EPA). Carbon dioxide, being the product of complete combustion is dominant focus of the UN climate initiatives, is considered to be the most important GHG and has become the main point of attention for the majority of the stakeholders in the industry, policy makers, academia and the communities and governments, attracting a significant amount of investment to develop and deploy technologies to capture and remove it from the atmosphere [1].

Methane and Nitrous oxides as the products of incomplete or non-optimized combustion have recently attracted the attention of the industry and scientific community due to their global warming potential that is greater that CO_2. Over a 20-year period, Methane has a GWP of 86 over CO_2 leading the UN and the European Union to flag it a low hanging fruit opportunity. The formation of particulate matter "PM" and soot during inefficient combustion processes has historically been measured as black smoke and ignored despite of their climate and health effects [1,2]. Black carbon has the global warming potential of 460-1500 times higher than carbon dioxide with a short lifetime of 4-12 days[3].

This paper is a brief discussion on the impact of current or under development technologies to reduce greenhouse gas emission, and the role of clean combustion to support net zero objectives.

The current Net Zero pathways

Globally, there are tremendous efforts towards deployment and scaling of alternative and renewable energy sources such as hydrogen, wind, solar, tidal, biogas and biodiesel so as to research and deployment of using carbon capture utilization and storage "CCUS" for long term storage of CO_2. The intention is to minimize the lifecycle CO_{2e} emissions involved in generation and utilization of such energy resources, though they don't account more than 10% of the current global energy consumption and whether or not these resources can provide a reliable and secure source of energy to respond to the global growing energy demand is still debatable.

The Energy Return on Energy Invested ratio is important when comparing the alternatives. A fuel needs an EROEI of at least 3 to be economically viable for the society. The conventional oil, gas and coal production have an approximate ratio of 20 and 46, renewables such as wind, solar, biodiesel and geothermal have an approximate value of 18-20, 19, 2-5 and 9 respectively. For hydrogen production, depending on the production method, the reported values in literature vary between 1 to 8 [4,5]. In comparison, the EROEI for an example CCS project of converting CO_2 to methanol is 0.45 in which reveals that the input energy of ~45 Gj/t-methanol would rather to be used in a more efficient process than conversion of CO_2 to low energy density (19.7 Gj/t) methanol [6].

For CCUS technologies, the process yield, EROEI and net emissions are three important factors. CCS should only be considered if CO_2 is available as a cheap feedstock or when the economic analysis of the product demonstrates that the product has the same quality with the same price when synthesized using the conventional methods and CCS deployment doesn't increase net CO_2 emissions when providing the same service. Simply speaking, substitution of the feedstock has to minimize the production cost and the fossil derived carbon content. The key driver for cost reduction is the deployment at scale [6].

CO_2-EOR projects have been the primary CCU projects that have been used in the industry for decades in the economy of scale in some regions of the world, though the economics are sound but variable depending on the price of oil vs the price of CO_2. At the oil price of approximately USD$100/ bbl., CO_2-EOR is economically viable if the price of CO_2 is less than 45 $/ton. (17). Overall, with the current scale of global CO_2 production vs utilization for sequestration in a long-term period, the impact of CCS will be approximately more than just 1%, and role of scaled-up EOR is estimated to be 4-8%. Therefore, CCU projects have minimal impact on the climate change unless being a supplement to long term CCS [6].

Recent advancements in methane studies

Methane as the second most important greenhouse gas that has the global warming potential of 84 - 86 times higher than CO_2 over 20 years, has not been the main focus of policy makers and industry for many years.

Natural gas with the primary component of methane has been considered as a clean fuel, however there are still emissions during production, processing, transmission and delivery activities that account for 25% of US total emissions. That is mainly due to venting activities, fugitive emissions and incomplete or inefficient combustion. The following graph shows the contribution of methane in the total lifecycle emissions. Opportunities to reduce GHG emissions exist around implementation of advanced combustion technologies, and reduction of fugitives methane emissions from wells, that elimination of which can have a significant impact on the total methane emissions [7].

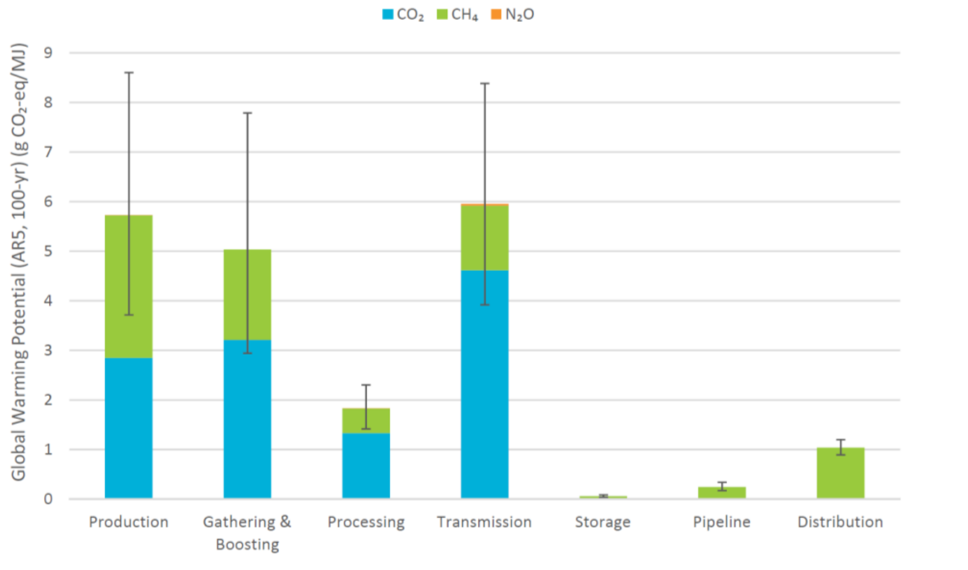

Figure 1 Methane contribution in the total life cycle emissions [7]

Recent developments in the top-down approaches and advancement of emerging aerial technologies to measure emissions, particularly methane from flares, have been eye opening in terms on finding flares that are emitting methane to the atmosphere, which would have not been feasible a few years ago (Figure 3). Aerial measurements also presented a variance between the reported numbers and actual emissions, as recent studies demonstrated upstream oil and gas methane inventory is significantly underestimated [8–11]. Exception of the large number of flares from field performance testing (250,000 to a 500,000 in US alone), assuming the 98% efficiency results in the uncertainty and lack of data on actual methane emission from the flares.

NETL study has also accounted for a 98% flare efficiency in its inventory but due to the variability that is observed in multiple basins, did not present a deterministic table for flaring emission profiles [7]. The following table demonstrates the impact of combustion efficiency on emissions in terms of tCO_{2e} [12].

Combustion Efficiency (%)	CO_{2e} (tons/day)	Increase in CO_{2e} From Less Efficient Combustion (%)
0	9.11	811
30	6.68	568
65	3.84	284
85	2.22	122
95	1.41	41
98	1.16	16
99.99	1.00	0
Table is based on methane having 25 times the GWP of CO_2.		

Figure 2 Impact of combustion efficiency of 16,000 ft^3/D of pure methane on GHG emissions [12]

The role of clean combustion

Combustion emissions contribute significantly to air pollution. Clean combustion happens when emissions are minimized, and fuel consumption is optimized. Poorly combusted gas not only generates hazardous air pollutants but also emits greenhouse gases that contribute significantly to the climate change. Advanced combustion systems leverage high efficiency burners where a minimum amount of fuel generates the maximum thermal energy, with minimum emissions. As a result, the efficiency of the system is high. Efficiency is a measure of capability of the device to completely oxidize the hydrocarbons to carbon dioxide and water. Therefore, a combination of fuel selection, burner design and even after treatment methodologies can be used to testify the efficiency and environmental performance of the system.

Besides, economic performance and affordability of the system is also critical, though post combustion treatment methods are the least desirable when there is an option to improve the efficiency of the combustion system through appropriate design and selection of fuel such as natural gas that is still considered as a clean fuel [12,13].

Open flaring has been a routine practice in the oil and gas industry. Compared to an enclosed combustion system, which has a consistent efficiency in a professionally designed system, the variable efficiency of the open flaring poses an environmental and health risk. A properly designed flare is expected to emit a negligible amount of methane (i.e.2%), but due to the impact of ambient environmental conditions such as temperature and crosswind, variable operational conditions, the system malfunction and the presence of many old flare systems in the industry, the combustion efficiency is not what is expected or reported according to the emission factors mandated by the regulators [14–16].

Although combustion research is extremely broad for multitude of applications, technology already exists to cleanly combust waste gas where conservation is not either feasible or economically viable. Enclosed combustion of waste gas not only provides 100% efficiency, but also provides an opportunity for post combustion gas capture for CCUS or heat recovery for applications such as water vaporization or power generation [12].

According to the International Energy Agency (IEA), flare combustion efficiency has been an overlooked area by the regulators [14]. From an economic perspective, the cost of cleanly combusting waste gas is less than USD$ 1/tCO_{2e}. As an example, if methane emissions of 6.2 Bcf from hydraulic fracturing in the US in 2011 were cleanly combusted, there was 89% less emissions at the cost of about USD$ 0.4/ tCO_{2e}. Another economic case is cleanly combusting VOCs and BTEX emissions from natural gas dehydration process in an enclosed clean combustion system. Compared to a traditional flare, fuel consumption is between 60-80% lower therefore, operating costs are lower as are GHG emissions. Our expertise demonstrated a payout in less than 6 moths on the invested capital due to the reduction of the operational costs.

Our analysis demonstrated that the cost of emission reduction from 38,000 dehydrators in the US is USD$ 1.65/ tCO_{2e} in a 10-year period. This contributes to reduce the social cost of environmental pollution due to the adverse effects of HAPs/ BTEX on human health that are emitted to the air as a result of incomplete combustion of traditional systems or direct venting to the atmosphere [12].

Takeaway

Clean combustion demonstrates a terrific, cost-effective opportunity to contribute to the global emission reduction initiatives to battle climate change. As discussed, there are multiple pathways towards achieving net zero goals such as deployment of renewable energy, hydrogen as a fuel and CCUS. However, their contribution to the immediate need to reduce greenhouse gas emissions is minimal and there is a long road to deploy them at the economy of scale globally. The research on clean combustion and methodologies to reduce emissions through advanced combustion system design is mature and can readily be deployed commercially in the short term.

References

1. Bessagnet, B.; Allemand, N. *Review on Black Carbon (BC) and Polycyclic Aromatic Hydrocarbons (PAHs) emission reductions induced by PM emission abatement techniques*; 2020;
2. Timonen, H.; Karjalainen, P.; Aalto, P.; Saarikoski, S.; Mylläri, F.; Karvosenoja, N.; Jalava, P.; Asmi, E.; Aakko-Saksa, P.; Saukkonen, N.; et al. Adaptation of Black Carbon Footprint Concept Would Accelerate Mitigation of Global Warming. *Environ. Sci. Technol.* **2019**, *53*, 12153–12155.
3. Black carbon | Climate & Clean Air Coalition Available online: https://www.ccacoalition.org/en/slcps/black-carbon (accessed on Jul 4, 2022).
4. Bellini, M.; Pagliaro, M. V.; Marchionni, A.; Filippi, J.; Miller, H.A.; Bevilacqua, M.; Lavacchi, A.; Oberhauser, W.; Mahmoudian, J.; Innocenti, M.; et al. Hydrogen and chemicals from alcohols through electrochemical reforming by Pd-CeO2/C electrocatalyst. *Inorganica Chim. Acta* **2021**, *518*, 120245.
5. Sathre, R.; Scown, C.D.; Morrow, W.R.; Stevens, J.C.; Sharp, I.D.; Ager, J.W.; Walczak, K.; Houle, F.A.; Greenblatt, J.B. Life-cycle net energy assessment of large-scale hydrogen production via photoelectrochemical water splitting. *Energy Environ. Sci.* **2014**, *7*, 3264–3278.
6. Mac Dowell, N.; Fennell, P.S.; Shah, N.; Maitland, G.C. The role of CO2 capture and utilization in mitigating climate change. *Nat. Clim. Chang.* **2017**, *7*, 243–249.
7. Skone, T.; Littlefield, J.; Marriott, J.; Cooney, G.; Demetrion, L.; Jamieson, M.; Jones, C.; Mutchek, M.; Yan Shih, C.; Schivley, G.; et al. Life Cycle Analysis of Natural Gas Extraction and Power Generation. *U.S. Dep. Energy* **2014**, 1–200.
8. Mider, Z.R. The methane hunters Available online: https://www.bloomberg.com/features/2021-methane-hunters-climate-change/.
9. Cusworth, D.H.; Duren, R.M.; Thorpe, A.K.; Olson-Duvall, W.; Heckler, J.; Chapman, J.W.; Eastwood, M.L.; Helmlinger, M.C.; Green, R.O.; Asner, G.P.; et al. Intermittency of Large Methane Emitters in the Permian Basin. *Environ. Sci. Technol. Lett.* **2021**, *8*, 567–573.
10. Environmental Defense Fund The Permian Methane Analysis project Available online: https://data.permianmap.org/pages/operators.
11. Cusworth, D.H.; Duren, R.M.; Thorpe, A.K.; Olson-Duvall, W.; Heckler, J.; Chapman, J.W.; Eastwood, M.L.; Helmlinger, M.C.; Green, R.O.; Asner, G.P.; et al. Intermittency of Large Methane Emitters in the Permian Basin. *Environ. Sci. Technol. Lett.* **2021**, *8*, 567–573.
12. Mascarenhas, A.M.; Sutherland, J.J. *What Is All This Talk About Emissions ? Page 1 of 4 What Is All This Talk About Emissions ? What Is All This Talk About Emissions ? Page 2 of 4*; 2015;
13. Kohse-Höinghaus, K. Clean combustion: Chemistry and diagnostics for a systems approach in transportation and energy conversion. *Prog. Energy Combust. Sci.* **2018**, *65*, 1–5.
14. International Energy Agency *Curtailing Methane Emissions from Fossil Fuel Operations*; 2021;
15. Kostiuk, L.W.; Johnson, M.; Glen, T. University of Alberta Flare Research Project. *Eff. a fuel diluent*

Effic. jet Diffus. flames crossflow **2001**, *1*, 1–6.

16. Willis, J.; Checkel, D.; Ahah, A.; Joiner, M. *Flare Efficiency Estimator and Case Studies*; 2013;