Criteria Pollutant Control in Decarbonization

A report by the Institute of Clean Air Companies

June 2024

Introduction

Criteria pollutant emissions and greenhouse gases (GHGs) are generated from various sources, ranging from commercial and industrial facilities, electric utilities to forest fires and motor vehicles. Technology developments and government regulations have helped to reduce emissions from these sources, but as countries around the world continue to industrialize, the demand for air pollution control solutions, measurement and monitoring will grow.

Many solutions that can mitigate emissions of criteria pollutants are well-developed and ready to deploy at scale. Additionally, there are both existing and emerging solutions to address GHG emissions which require an array of emission control and measurement technologies. To reach U.S. health and climate goals, it is essential to deploy a diverse portfolio of environmental and energy solutions that includes technologies that manage multiple criteria pollutants, and GHGs.

For over 60 years, the members of the Institute of Clean Air Companies (ICAC) have met the challenge of mitigating harmful emissions from process and waste gas streams. Armed with this expertise and the capabilities to enable large-scale technologies and system design, ICAC members are focused on addressing both greenhouse gas emissions and criteria pollutants through emerging technologies and systems through proven, commercially available technologies.

Criteria Pollutants

The Clean Air Act requires EPA to set National Ambient Air Quality Standards for six common air pollutants, also known as criteria air pollutants. Acceptable levels of exposure are to be established for each of these, which include **carbon monoxide**, **lead, ozone, particulate matter, nitrogen dioxide** and **sulfur.**

Greenhouse Gases

Emissions of GHGs, which include **carbon dioxide, methane, nitrous oxide,** and **fluorinated gases**, are considered to be the primary drivers of the global rise in temperature.[1] In response, there are increasing numbers of federal and state programs to fund efforts to reduce emissions of GHGs.

Criteria Pollutant Control in the Energy Transition

A just and equitable energy transition requires both a diversification of global energy sources and traditional pollutant control in order to effectively mitigate climate and health-related risks. There are occasional tradeoffs when a decarbonizing solution is implemented as there may be other pollutants produced in that process. For example, some carbon capture technologies, a key emerging GHG management solution, will also require criteria pollutant controls in order to achieve the targeted CO_2 removal from the flue gas. These and other effective control and precise emission monitoring technologies are critical to ensuring that both climate and environmental justice goals are met.

[1] Climate Change 2021: The Physical Science Basis. Contribution of Working Group 1 to the sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge United Kingdom and New York, NY US. DOI10.1017/978009157896. https://www.ipcc.ch/report/ar6/wg1/

CASE STUDY: Hydrogen Combustion- Pairing Decarbonizing Solutions with Proven Aftertreatment Controls

PRIMARY EMISSIONS

Gas turbines, fuel cells and internal combustion engines (ICE) are being actively developed to decarbonize the transportation industry. Here we focus primarily on the ICE applications utilizing hydrogen.

Hydrogen as a fuel has great potential for decarbonization in our path toward net zero. According to the Department of Energy, hydrogen is currently in widespread commercial use with annual consumption of around 10 million metric tons domestically each year.[2] Other countries have already adopted policies to include hydrogen-powered ICE in their mobility mix and it is almost certain that the opportunities to use hydrogen-ICE (H2-ICE) will expand to other industries and applications.

While H2-ICE have near-zero GHG emissions, they will still produce small levels of pollutants that can easily and effectively be treated with exhaust aftertreatment systems.

Based upon data gathered for engines coming into production in the next few years, the main exhaust emissions observed are NOx and H_2 slip. The principal source of NOx comes from ambient air used during combustion when nitrogen and oxygen, the most plentiful constituents of air, react under high temperatures. For engines only powered with H_2, there will be a small quantity of hydrocarbons produced by the incidental combustion of lubricating oils. The lube oils combustion will also generate a small quantity of particulate emissions.

Primary emissions are:

- Hydrocarbons
- Carbon monoxide
- Nitrogen oxides
- Nitrous oxides
- Ammonia
- Particulates

While utilizing hydrogen will not add any **hydrocarbons** to the exhaust emissions, any generated from the lubricants are anticipated to be at a very low level. They can be managed with an oxidation catalyst at the appropriate operating temperature.

Carbon monoxide (CO) would be introduced through the partial combustion of any natural gas if there is hydrogen fuel blending. Complete hydrogen fuel combustion will not add any CO unless under certain combustion conditions (such as rich burn stochiometric operation). If there is any lubricant leakage into the exhaust, this could partially combust to form CO (expected to be minor), which an oxidation catalyst can effectively destroy.

Nitrogen oxides (NO and NO_2) result from the oxidation of nitrogen in the intake air of the combustion process. The high combustion temperatures in the presence of oxygen facilitate NOx formation. This thermal NOx will be present regardless of the degree of hydrogen blending in the fuel. For hydrogen-fired lean burn engines, the level of NOx poses the most significant difference for aftertreatment compared to natural gas fired engines. New ICE engines capable of burning hydrogen are being developed with con-

[2] Hydrogen Production, Department of Energy | https://www.energy.gov/eere/fuelcells/hydrogen-production

sideration for reducing thermal NOx formation through innovative combustor design. These designs will not completely eliminate NOx, but the efforts are focused on keeping thermal NOx at or below equivalent levels experienced with current natural gas combustion.

Hydrogen is not expected to contribute any additional **particulates**. Any unburned hydrocarbons from lubricants would add to particulate levels, but again this is minimal and control is not required.

Hydrogen resulting from carryover of unburnt fuel, needs to be oxidized to reduce the hydrogen slip.

AFTERTREATMENT CONTROLS

Hydrogen fueled combustion process **aftertreatment controls** for the primary emissions include selective catalytic control (SCR) and oxidation catalyst.

Ammonia SCR

SCR technology is a proven and effective method to reduce NOx emissions. During the combustion process, the nitrogen and oxygen present in the combustion air combine to form NOx. Prior to being released to the atmosphere, the exhaust gas is passed through a large catalyst where the NOx reacts with the catalyst and ammonia and is converted to nitrogen and water. Selective catalytic reduction typically removes over 90% of the NOx that is in the exhaust combustion system.

This aftertreatment control technology can achieve high levels of NOx destruction (97%) and catalysts are available for a broad operating temperature range (250°C to 600°C).

Key considerations for ammonia SCR:

1. Cold start emissions can be a challenge. During cold start scenarios, increases in fuel and air are essential to ensure initiation of combustion. Therefore, during cold start periods, proportionately larger amount of NOx emissions can be reasonably expected based on the oxygen-rich conditions during start-up. Additionally, NOx conversion employing SCR is dependent upon the temperature ramp of the catalyst. Conversion efficiency at lower temperatures is expected to be impaired.
2. The ratio of NO_2/NOx is important to maintain high destruction efficiency. For most hydrogen fired combustion processes, the ratio is typically well below 0.5 which is necessary for high SCR efficiency. If an oxidation catalyst is required prior to the SCR, then the level of NO_2 can increase the ratio above 0.5.
3. Ammonia slip emissions can be effectively controlled with optimum SCR system design, and if further reduction is required, ammonia slip control catalyst technology can be applied.

Hydrogen SCR

Work on developing hydrogen as the reductant for the SCR reaction is being explored. Typically, hydrogen as a reagent operates at relatively low temperatures (usually around 200°C). Selectivity is above 90% to N_2, but higher nitrous oxide emissions can be a problem. The operating window is narrow preventing broad application across many combustion processes.

Nitrous Oxides (N_2O)

We do not expect any significant level of N_2O from the engine. However, nitrous oxides need to be taken into consideration as they will be formed by the aftertreatment system either by the oxidation catalyst or in the SCR. It is of particular interest for OEMs to minimize N_2O formation as a “zero emissions vehicle” needs to have GHG level near to 0. This is valid for N_2O but also for H_2.

Oxidation Catalyst

If hydrocarbons or CO need to be controlled, oxidation catalysts are well established control technologies. The nature of the hydrocarbons will determine the operating conditions necessary for proper destruction.

Generally, CO can be controlled at 200°C and higher. Hydrocarbons need higher temperatures, and depending on the compounds, the proper temperature is typically above 350°C.

A catalyst is usually installed upstream of an ammonia SCR system to prevent oxidation of the ammonia to NOx. If located downstream of the ammonia SCR, it must be designed to prevent excessive conversion of ammonia to NOx post SCR catalyst.

CONCLUSION

In order to effectively address the unique emission characteristics of hydrogen blended fuels, system optimization is required and there are proven technologies available to address NOx, hydrocarbons, and CO.

SCR technology, demonstrated through decades of successful operation across a wide range of combustion processes is the most viable approach for controlling NOx emissions.

Oxidation catalyst technology is well proven to control any hydrocarbons or CO in the exhaust.

ICAC members are ready to provide technical information and the solutions needed for a portfolio approach to decarbonization to help reach all climate and environmental goals.

Criteria Pollutant Control in Decarbonization 6

2024 Institute of Clean Air Companies Members

Arq	Bison Engineering, Inc.	Burns McDonnell
DURAG	JM Johnson Matthey Inspiring science, enhancing life	Lhoist
MLC AN HBM COMPANY	Mitsubishi Power	Origen
ThermoFisher Scientific	umicore	GORE

Contact

Institute of Clean Air Companies
2101 Wilson Blvd Ste 530, Arlington, VA 22201
icac.com

Clare Schulzki
Executive Director
cschulzki@icac.com

Jordan Flanagan
Senior Associate
jflanagan@icac.com