HYDROCARBON
PROCESSING®

Originally appeared in
Hydrocarbon Processing, November 2024.
Posted with permission.

PROCESS CONTROLS, INSTRUMENTATION AND AUTOMATION

Improving ammonia production sustainability

M. MACHUCA, Emerson, Austin, Texas

Ammonia manufacturing is a wonder of the chemical industry in that it has solved many food shortage issues over the last century. While approximately 70% of ammonia production is used to make fertilizers, it is also identified as the largest carbon dioxide (CO_2)-emitting chemical industry process. This happens on an enormous scale when all global ammonia production is considered. For example, ammonia production consumes 3%–5% of global natural gas production and around 1.8% of global energy output each year. Global ammonia production produces 500 MMt of CO_2, which is about 1.8% of global CO_2 emissions.

Since the global agriculture industry cannot do without ammonia and still feed 8 B people, it is critical to find ways to produce it in more sustainable and less carbon-intensive ways. Technologies are available, but how can they be implemented economically? Safety is also critical since the production process involves highly combustible and toxic chemicals in combination with high-pressure and high-temperature process conditions. Finding effective solutions to these challenges will have a significant impact on the transition to a low-carbon future.

The Haber-Bosch ammonia synthesis process (**FIG. 1**) has been in use for more than a century. There have been many improvements, but the basic steps remain similar. However, for a present-day ammonia plant, the actual synthesis reaction is only part of the larger process. When examining the unit from end-to-end, most of it is dedicated to creating hydrogen (H_2) feedstock from the methane found in natural gas via steam methane reforming (SMR).

Looking at the production steps, it is easy to see that much energy is expended making H_2, which is the source of most of the CO_2 emissions since each methane molecule stripped of its hydrogen atoms also results in a CO_2 molecule. The CO_2 must be removed to make ammonia (NH_3). The removal portion of the process produces a stream of essentially pure CO_2, which is released to the atmosphere.

In some facilities, the CO_2 can be used in other processes. For example, it is common for ammonia and urea plants to be co-located since urea production needs a significant source of CO_2, and up to 40% of the CO_2 produced by an SMR unit can be used for urea production. Unfortunately, this is not the case for the fuel gas used in the combustion process in the reformer, where 40% of the total emissions from ammonia production are concentrated, as recovery of CO_2 from the flue gas for reuse is a much more difficult process.

This leaves three main strategies for reducing carbon emissions:

1. The greatest improvement comes from eliminating natural gas as a feedstock entirely and switching to green H_2. This also eliminates the need for an SMR unit. The only emissions come from boilers supporting the actual Haber-Bosch synthesis reactor, and these could be switched to a renewable power source.
2. Where green H_2 is unavailable, it may be practical to use carbon capture and storage (CCS), capturing it from the CO_2 removal vessel. This eliminates emissions from 55%–65% of natural gas consumed by the SMR unit. As previously mentioned, CO_2 can also be consumed where an ammonia production facility is combined with urea production.
3. Tune up operations of the SMR unit by improving instrumentation and process automation. While this may not deliver the dramatic improvements of the first two, it is more modest in scope and can be approached incrementally without straining budgets. Nonetheless, when applied strategically, a few such improvements can boost energy efficiency and add up to significant emissions reductions.

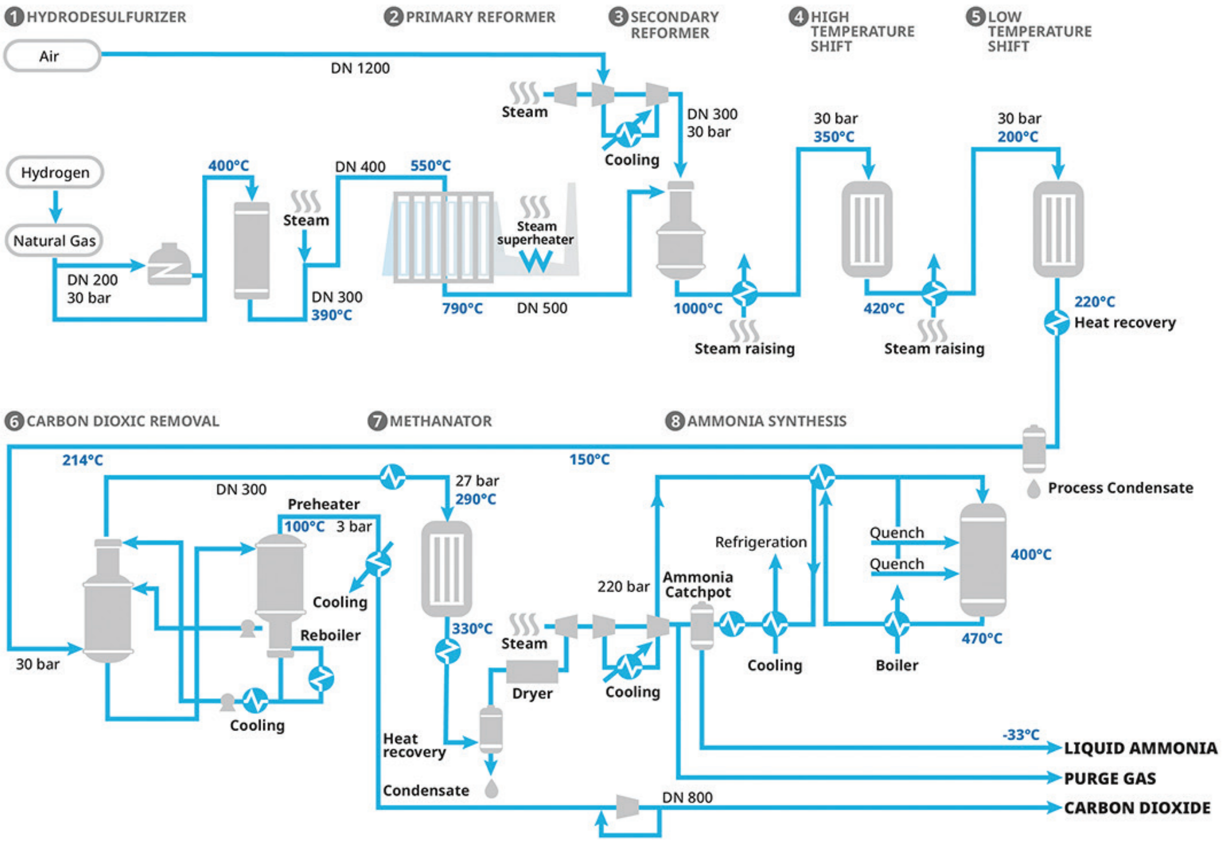

FIG. 1. A diagram of a typical ammonia production unit, using SMR to create H_2. The actual Haber-Bosch synthesis reaction is only the lower, right-hand quadrant.

FIG. 2. Coriolis flowmeters, like the one shown here[a], can also provide accurate density information about natural gas, making it easier to control fuel flow precisely.

Starting with the SMR unit. Since this is the point where most energy is used, this is normally the section to start, but where exactly? The diagram in **FIG. 1** shows that this is a complex process in two main sections: the primary reformer and the CO_2 removal unit. Each of these two sections is supported by a series of boilers and fired heaters, so combustion control is top of the list.

Primary reformer. The primary reformer must heat natural gas feedstock to 790°C and mix it with steam injected at 30 bar. Controlling combustion in this part of the process has an enormous effect on overall energy consumption. This calls for two critical instrumentation applications: fuel flow control and the measurement of oxygen content in flue gas.

Fuel flow control. Since natural gas is the primary fuel, most installations depend on traditional volumetric flowmeters. However, these are not always capable of responding adequately to variable fuel compositions. In many plants, including those producing ammonia, excess combustible gases, such as H_2, can be recycled back into the fuel gas feed. A far more complete picture of combustion performance is available by measuring natural gas flow using a Coriolis mass flowmeter (**FIG. 2**) because

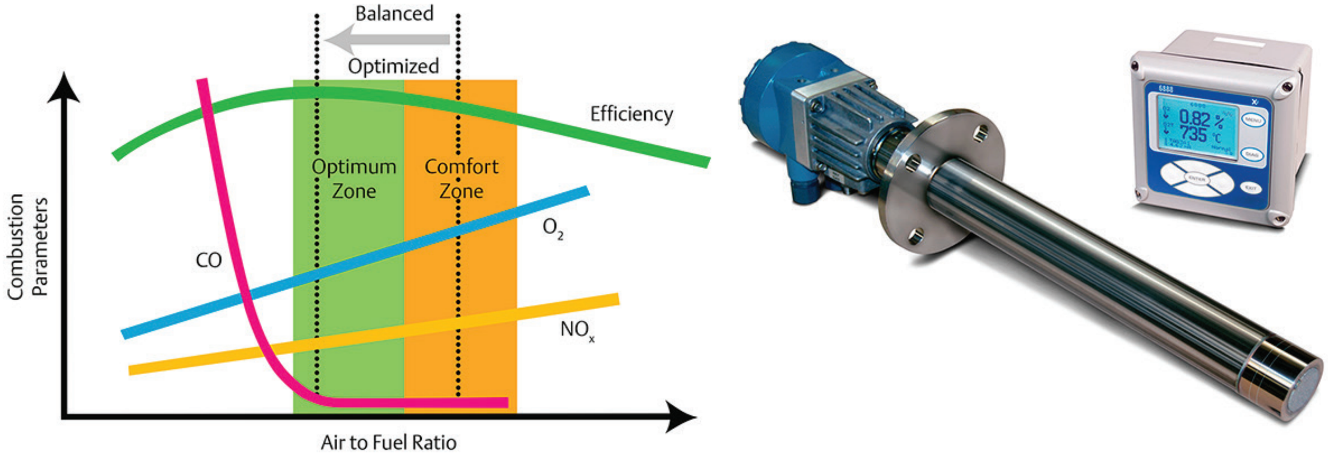

FIG. 3. Effective combustion control requires operating as close to the stoichiometric balance as possible. A zirconia sensor used with an oxygen analyzer provides continuous measurement of excess oxygen from any combustion process, including SMR furnaces and boilers.

mass flow and heating value are closely related. Controlling based on mass flow provides improved air-to-fuel ratio control, increasing efficiency and reducing emissions.

Combustion analysis. Most combustion processes use an oxygen analyzer monitoring flue gas to evaluate the mixture of air and fuel and optimize combustion efficiency (**FIG. 3**). The target is operating just above the stoichiometric amount of oxygen to cover for imperfect fuel and air mixing. However, too much air decreases efficiency and increases emissions. For example, a 2% increase of oxygen in the stack can increase emissions by 25%–30%.

A more effective combustion control system uses feedforward control based on the fuel measurement and feedback control based on the oxygen measurement to optimize fuel flow and air, delivering the maximum recoverable heat with minimum emissions.

Steam-to-carbon ratio. Since the amount of steam consumed determines how hard boilers must work, controlling its use is critical. Breaking methane molecules in the primary reformer requires heating the feedstock but also injecting steam; however, in many units, steam is wasted because there is inadequate flow instrumentation. Usually, steam flow is too high because low steam flow causes furnace overheating and cracking of reformer tubes.

One solution is to install a steam flow measuring system using a vortex flowmeter (**FIG. 4**). Vortex technology is well-suited to steam flow measurement, plus units are available with safety certifications for use in a safety instrumented system. The configuration is designed to provide the highest level of safety, while avoiding false trips by applying a 2-out-of-3 (2oo3) voting scheme, hence three safety-certified transmitters, plus a fourth for process control. Using this approach, it is possible to match steam flow accurately to feedstock flow for maximum process efficiency, while protecting against safety hazards of imbalances.

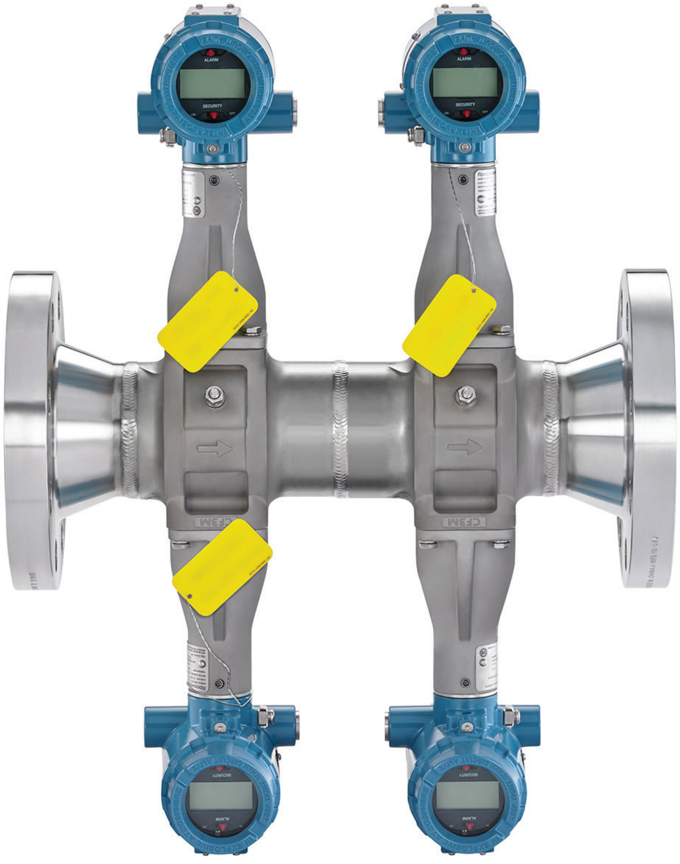

FIG. 4. The vortex flowmeter shown here[b] includes three safety-certified transmitters, plus one for normal process control.

CO_2 removal. Gas coming out of the shift converter is a mix of H_2, nitrogen and CO_2. This step forces the mixed gas through an absorption vessel filled with a liquid solvent so the fluids flow counter-currently. The liquid captures CO_2, and the saturated solvent is then pumped to the desorption vessel where it is subjected to an abrupt temperature increase and pressure drop, causing CO_2 to bubble out like soda water. The solvent is cooled and recirculated, and the process continues.

Many operators rely on manually sampling of the solvent to control the circulation and regeneration rates, but a better approach is using a Coriolis mass flowmeter (**FIG. 2**). This type of meter measures solvent flow and density continuously and simultaneously, providing operators with the information they need to optimize the make-up rate, which improves CO_2 capture efficiency and minimizes energy consumption.

FIG. 5. Gas analyzers, like the proprietary technology[c] shown here, use non-dispersive infrared photometric detectors to detect and quantify components common to SMR, helping guide operators as they monitor the effectiveness of each subsequent step.

Optimizing stage by stage. As **FIG. 1** shows, SMR happens in stages over multiple reactions. Each of these must be considered its own process and optimized appropriately before any major sustainability advances will be practical. The challenge is determining if each stage is creating its respective intermediate efficiently so the next stage can do its job just as well. Naturally, operators will have all the relevant process variables in the control room, but an actual verification of what is happening in each reactor calls for a process gas analyzer at the output stages.

For example, there are several points where measurements can be used to improve efficiency. Measuring unreacted methane at the exit of the reformer is an indication of poor reformer efficiency. Carbon monoxide (CO) and CO_2 must be removed prior to ammonia synthesis to prevent poisoning of the catalyst, so these gases should also be measured. Gas analyzer monitoring points after the shift converters, methanator and amine scrubber are important to ensure process efficiency.

Today's analyzer technologies (**FIG. 5**) provide multiple measurement capabilities optimized for the specific ana-

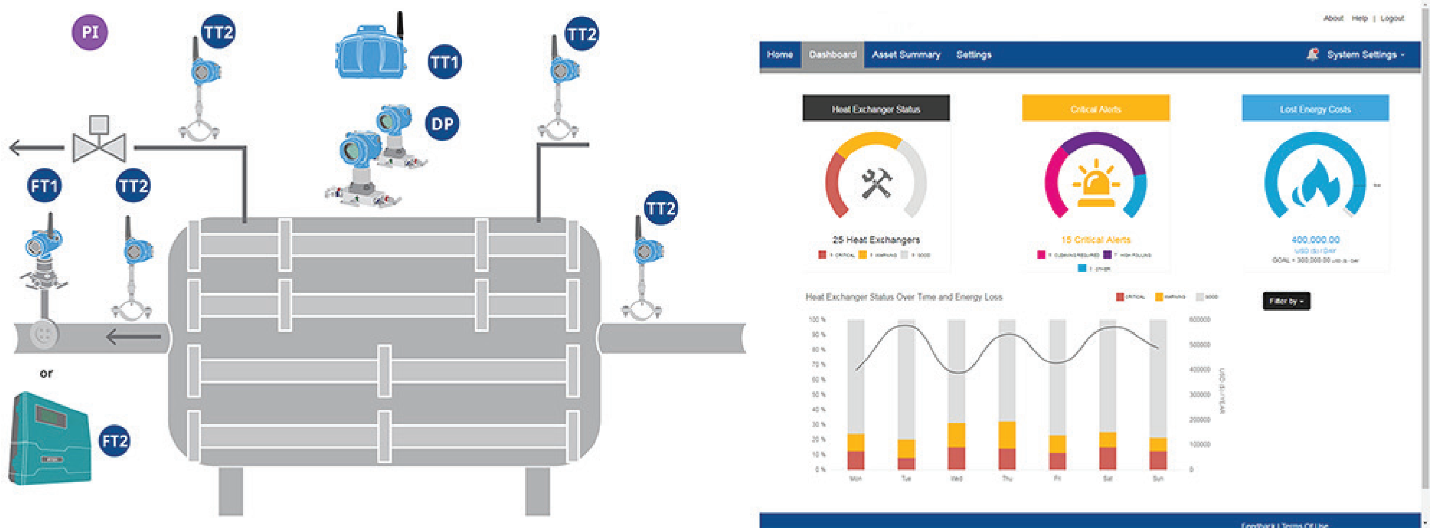

FIG. 6. When the instruments monitoring heat exchanger parameters send their data to an analytics platform[d], efficiency is monitored continuously, and maintenance personnel are alerted when fouling may be forming.

lytes, using non-dispersive infrared, non-dispersive ultraviolet, paramagnetic, photometric and other technologies. With this approach, each step of the process can be tuned for maximum efficiency.

Heat exchanger efficiency. There are also dozens of heat exchangers throughout the larger ammonia process, so they deserve special consideration, given the amount of energy consumption involved. Shell-and-tube heat exchangers can perform very reliably, or they can be energy wasters and operational headaches, depending on how they are maintained. Equipment performance studies in oil refineries show that when fouling restricts throughput by just 2%, up to 10% of total energy input is wasted. Still, many ammonia producers depend on manual inspections or schedule-based cleanings to maintain heat exchangers. This is usually because many heat exchangers have only the most rudimentary instrumentation.

Determining how efficiently a shell-and-tube heat exchanger is operating requires basic measurements (**FIG. 6**):

- Process fluid temperature differential (inlet compared with outlet)
- Process fluid pressure differential
- Process fluid flow
- Transfer fluid temperature differential
- Transfer fluid flow.

Flow and temperature measurements can be added to a heat exchanger without process penetrations using instruments that measure through the pipe wall (**FIG. 7**). Information from the analysis platform empowers plant personnel to perform maintenance at optimal intervals.

Sustaining safety. Safety incidents can cause enormous releases of CO_2, and leaks of natural gas—even if they do not result in fires—release methane, a greenhouse gas far worse than CO_2. Additionally, ammonia leaks, whether gas or liquid, must also be detected since it is toxic and corrosive. Keeping a plant safe and sustainable means detecting and fixing leaks as quickly as possible.

Leaks of pressurized gases can be detected using three technologies (**FIG. 8**):

- Acoustic detectors, which listen for the characteristic noise of a compressed gas leak
- Point detectors, using either catalytic bead or infrared sensors
- Open-path detectors, which detect a target gas cloud moving through a beam of light.

FIG. 7. Non-intrusive, clamp-on ultrasonic flowmeter[e] (left) can measure flow through a heat exchanger without a process penetration. Similarly, X-well temperature transmitters (right) can measure temperature through the pipe wall, so these instruments can be added without process shutdowns.

FIG. 8. Gas detectors use different approaches, including (left to right): acoustic, point and open path.

If a leak is detected, first responders can locate the source quickly if multiple sensors can help pinpoint the location. If the escaping gas is combustible and finds an ignition source, detecting the fire quickly minimizes personnel injury and plant damage. Today's technologies (**FIG. 9**) identify characteristic wavelengths of ultra-violet or infrared radiation produced by flames. Since the range of possible fuels in an ammonia facility is limited, detectors can zero-in on relevant wavelengths, thereby minimizing the potential for false alarms.

While ammonia is clearly understood as both toxic and corrosive, it is not the only hazardous product in the larger process. Depending on the solvent used in the CO_2 removal stage, there are also points in this unit that are subject to highly corrosive conditions. These situations are especially dangerous because corrosion attacks piping and vessels from the inside, making metal loss invisible until it is too late.

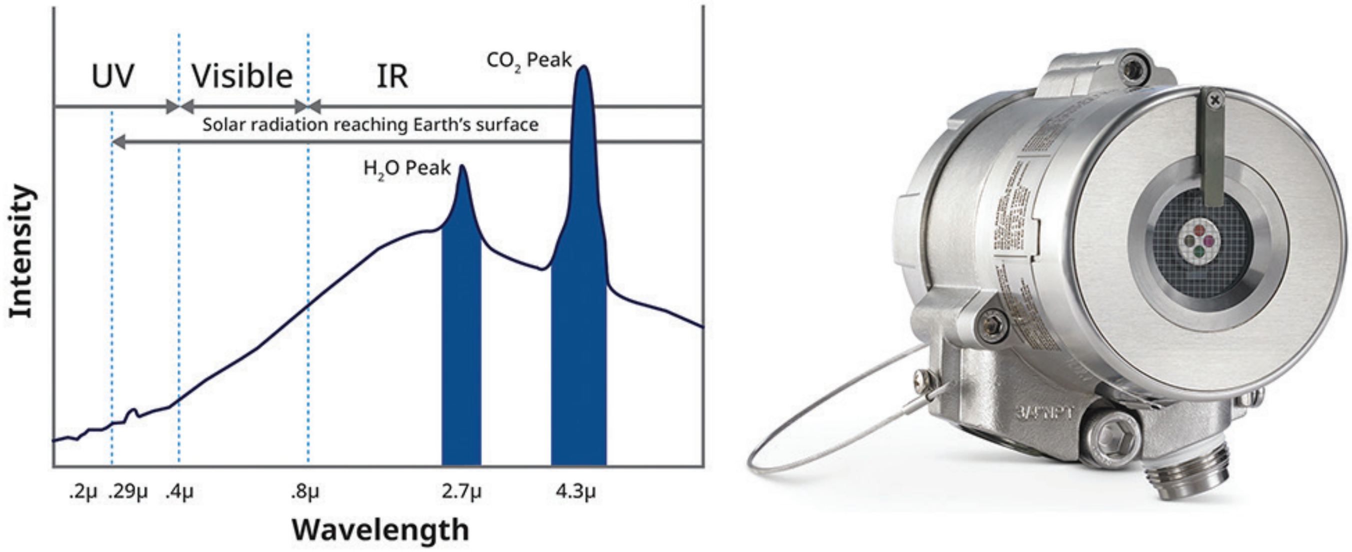

FIG. 9. Flame detectors[f] respond to specific wavelengths produced by burning H_2- or carbon-based fuels.

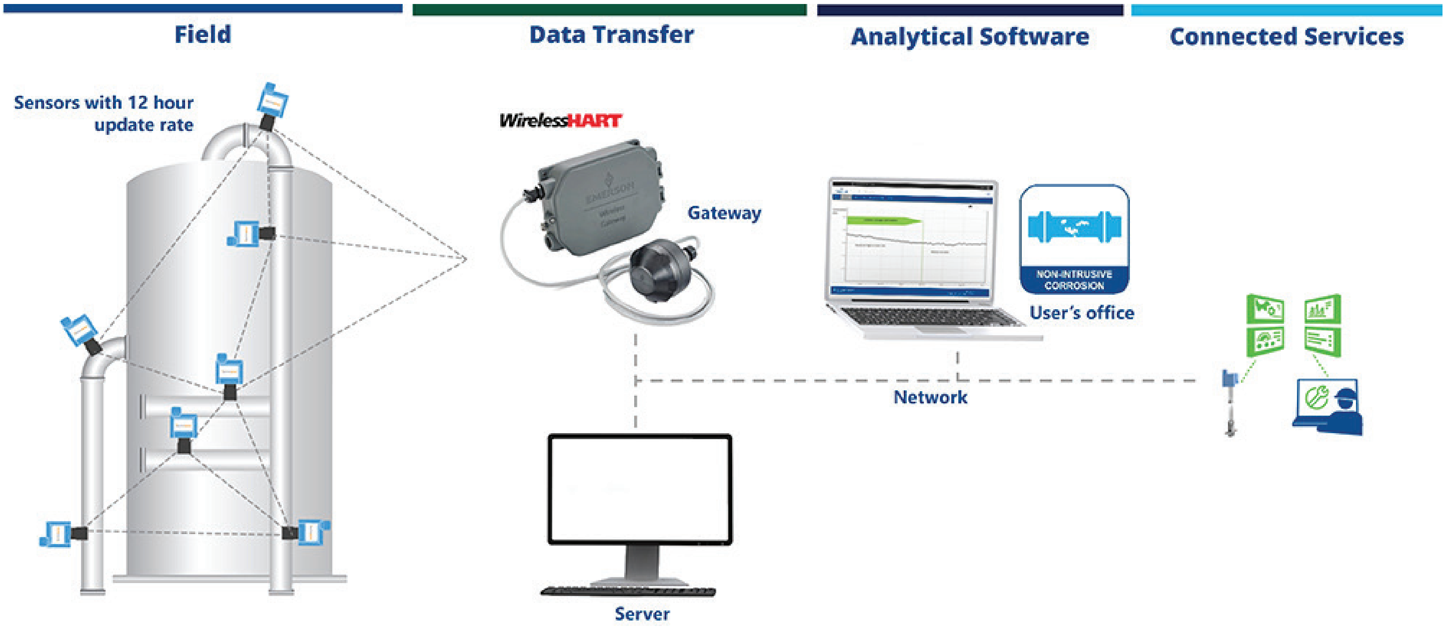

FIG. 10. Sensors can be mounted in strategic positions. They share their data using existing WirelessHART networks, and data can be analyzed using a web-based platform[g].

Fortunately, ultrasonic metal thickness sensors (**FIG. 10**) can be mounted on strategic points in the CO_2 removal and final ammonia handling stages of the process to monitor metal thickness continuously. These sensors are designed to be mounted permanently, and they send their data via a WirelessHART network to a central data collection and analysis platform. They can measure changes as small as 10 microns, so it is possible to watch the action of corrosion in real time, with the ability to set alarms if any points reach a critical level, and to optimize the addition of inhibitors.

Building sustainability. Naturally, ammonia producers are concerned about the potential cost effects or production restrictions resulting from sustainability efforts:

- Switching to green H_2 has the greatest benefit, but there are few locations where this is possible due to its lack of availability.
- The availability of CCS sites and the necessary supporting infrastructure is growing, but there will necessarily be an associated cost of transport and sequestration for a facility wanting to convert to blue H_2.
- The improvements suggested in this article can be applied universally, and they have the combined benefits of reducing energy use and emissions, while improving safety and reducing costs, and even boosting output.

These solutions can be approached incrementally, and many of them are self-supporting since more effective fuel use reduces energy costs. Improving burner control of the primary SMR unit alone can yield substantial energy savings and maintenance cost reduction. Whichever approach a company chooses, partnering with a reliable automation expert who can provide the equipment and know-how is critical to solving the challenges of both gray and blue ammonia production. HP

NOTES

[a] Emerson's Micro Motion™ Coriolis flowmeters
[b] Emerson's Rosemount™ 8800 Quad Vortex flowmeter
[c] Emerson's Rosemount™ X-STREAM Enhanced Continuous Gas Analyzers
[d] Emerson's Plantweb Insight™ application
[e] Emerson's Flexim™ flowmeter
[f] Emerson's Rosemount™ 975 Flame Detector
[g] Plantweb Insight™

MICHAEL MACHUCA is the chemical industry Marketing Director for the measurement instrumentation portfolio at Emerson. He has been with Emerson for more than 18 yr in various product management and marketing roles, supporting industrial process measurement applications in the oil and gas and chemical industries. Machuca earned a BS degree in mechanical engineering from the University of Houston.