

Valve, Regulator, and Actuator Selection for Blue Hydrogen Applications

Successful blue hydrogen production depends on properly specified valves and related control equipment for reliable operations.

Table of Contents

1. What is blue hydrogen?	2
1.1. Green hydrogen	2
1.2. Black and brown hydrogen	2
1.3. Grey hydrogen	2
1.4. Blue hydrogen	3
2. Methane reforming hydrogen processes	3
2.1. Blue hydrogen production using SMR	3
2.2. Blue hydrogen production using ATR	4
3. Valves, regulators, and relief valves in blue hydrogen production	4
3.1. Hydrogen/synthesis gas isolation valves, regulators, and relief valves	6
3.2. Carbon capture control valve selection	7
3.2.1 Amine feed valve (#1)	8
3.2.2 Absorber level control valve (#2)	8
3.2.3 Lean amin pump recirculation valve (#3)	9
3.2.4 Dehydrator control valves (#4 and #5)	9
3.2.5 Antisurge Valve (#6)	10
3.2.6 Carbon dioxide flow/pressure control valve (#7)	11
3.3. PSA isolation valves	11
3.4. Remote pipeline valve actuators	13
3.5. Carbon dioxide storage injection valves	13
4. Key takeaways	14



1.0 What is blue hydrogen?

Hydrogen has fueled all manner of cutting-edge endeavors, from the early balloonists to the Gemini and Apollo space programs. Decades later, a confluence of environmental challenges is enabling hydrogen to play a significant role in the world’s energy strategy by decarbonizing energy sources to address the pressing challenges of global warming. The demand for hydrogen has been rising exponentially, but elemental hydrogen barely exists in the earth’s atmosphere, making up about 0.00005% of the atmospheric air volume. This leaves industrial processes as the primary source for global hydrogen supplies. There are many ways to produce hydrogen, but the environmental impact of those options varies widely. Hydrogen industrial processes are often designated by color, providing an indication of their environmental ramifications (Figure 1).

1.1 Green hydrogen

Green hydrogen utilizes non-carbon sources of electricity, such as wind and solar, to power electrolysis cells, which separate water into hydrogen and oxygen. Green hydrogen processes generate no additional greenhouse gases and are the most preferable source of hydrogen, but green hydrogen is also the most expensive type to produce.

Source	Feed Stock/ Electricity Source	Technology	CO ₂ Emission	Color of Hydrogen
Fossil Fuels	Black Coal	Gasification	High	Black
Fossil Fuels	Brown Coal	Gasification	High	Brown
Fossil Fuels	Natural Gas	Reformer	High	Grey
Fossil Fuels	Natural Gas/ Coal	Reformer/ Gasification + CCS	Low	Blue
Water	Wind, Solar, Hydro, Geothermal	Electrolysis	Minimal	Green

Figure 1: Hydrogen can be produced using various methods. The color assigned to each process indicates the greenhouse gas impact of each alternative, listed from worst to best.

1.2 Black and brown hydrogen

On the opposite end of the environmental spectrum are black and brown hydrogen, which use coal gasification to generate hydrogen. These are the least desirable hydrogen production methods since they generate large amounts of carbon dioxide and other greenhouse gases.

1.3 Grey hydrogen

Currently, the most common and least expensive method of hydrogen production is grey hydrogen, which combines methane (CH₄) with steam (H₂O) at high temperatures to create hydrogen, carbon dioxide (CO₂), and carbon monoxide (CO). This method usually involves a steam methane reforming process (SMR), and it is used in refineries and ammonia plants across the world to create abundant quantities of hydrogen. The technology is well understood and mature, and the processes are proven to be reliable in use. Unfortunately, the undesired greenhouse gases (CO₂ and CO) are typically vented to the atmosphere, along with additional CO₂ and CO created by the combustion of fuel gas, to power this highly endothermic reaction.

SMR and grey hydrogen production are an environmental improvement over black and brown hydrogen, but these processes generate far too much CO₂ and CO to meet global greenhouse gas targets.

1.4 Blue hydrogen

A more recently introduced method of production is blue hydrogen. This method utilizes the same or similar processes as grey hydrogen production, but it captures and stores most, if not all, of the resulting greenhouse gas emissions. While the method may not be as environmentally beneficial as green hydrogen, it can use existing SMR equipment and technologies to produce very high volumes of hydrogen with significantly reduced greenhouse gas emissions.

Existing SMR plants converted to produce blue instead of grey hydrogen must include the added cost of adding carbon capture. This added cost results in a price increase when upgrading from grey to blue hydrogen production, but it might shrink if government regulations begin taxing CO₂ and CO emissions directly, raising the cost of unmitigated grey hydrogen production. The difference might also shrink due to a new steam reforming technique called autothermal reforming (ATR). Both SMR and ATR are discussed in detail in the next section.

2.0 Methane reforming hydrogen processes

All methane reforming processes decompose methane (CH₄) into hydrogen using one of two main techniques: steam methane reforming (SMR) or autothermal reforming (ATR). There are differences and similarities between the two processes, and each has its pros and cons. Both are described here.

2.1 Blue hydrogen production using SMR

SMR is an older, more well understood, and much more pervasive technology than ATR, and it is used worldwide in refineries and ammonia plants. A process diagram of SMR is shown in Figure 2.

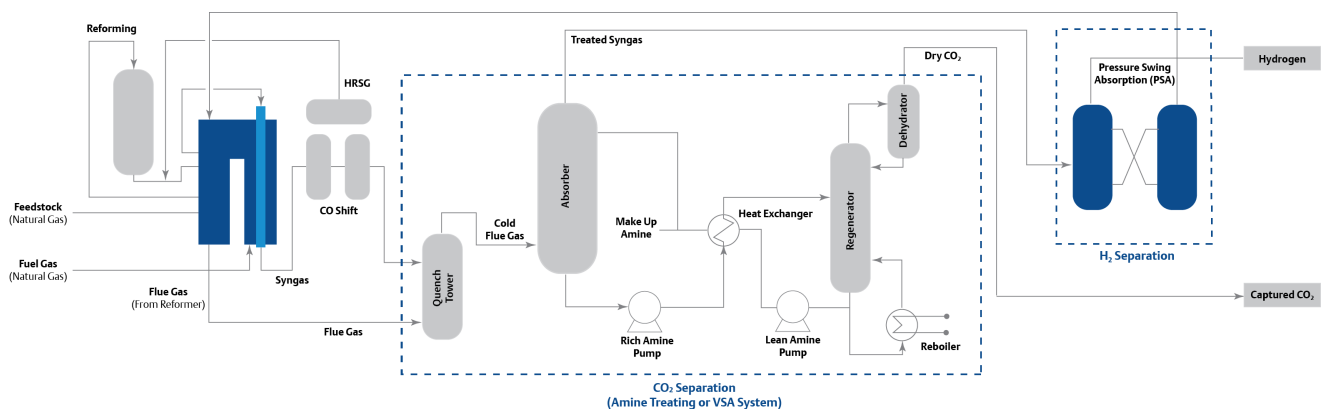


Figure 2: SMR combines methane and steam at very high temperatures to create hydrogen, CO₂, and CO. Shift converters change CO to CO₂, which is removed in the amine section. Hydrogen purity is controlled in the pressure swing adsorber unit downstream.

Natural gas is desulfurized and preheated, then mixed with high-pressure steam and heated further in the presence of a catalyst inside a fuel gas-fired reformer. The heat and catalyst decompose the methane (CH_4) and steam (H_2O) to create a synthesis gas (syngas) composed of hydrogen, carbon dioxide (CO_2), and carbon monoxide (CO). Shift converters react any remaining CO and water (H_2O) into CO_2 and hydrogen.

The purified syngas mixture then enters the amine absorber, where circulated amine liquid absorbs the CO_2 . The hydrogen leaves the top of the absorber to be further purified in a pressure swing adsorber (PSA), while the CO_2 -laden amine is heated and depressurized in the amine regenerator to separate the CO_2 from the liquid. The CO_2 is then released and vented, and the lean amine is cooled and returned to the amine absorber to process more syngas.

Grey hydrogen SMR production units do not capture carbon dioxide, as shown in Figure 2, but instead simply vent the flue gas and amine carbon dioxide production to atmosphere. A blue hydrogen unit adds carbon dioxide recovery equipment to capture and ultimately store the CO_2 produced by the SMR. These extra process steps add capital and operating costs, but they allow an existing SMR unit to operate with a far reduced carbon footprint.

The chief advantages of SMR over ATR units are their well-understood operations and abundant presence worldwide. The additional cost of adding a carbon dioxide capture unit to an SMR is relatively small when compared to building a new plant. The disadvantage of an SMR is that complete carbon capture is rather difficult. The relatively concentrated and clean CO_2 leaving the amine unit is easy to capture, but the less concentrated and impure CO_2 associated with the flue gas is not so easily scrubbed and recovered.

Conversion of SMR systems to blue hydrogen production is relatively straightforward. The CO_2 from the amine unit is further scrubbed, pressurized, and liquified to transfer it to a carbon storage facility. If flue gas is ducted to the amine unit as shown in Figure 2, it may require further processing steps to clean the gas. Most SMR plants converted to produce blue hydrogen tend to focus on the carbon dioxide generated in the amine section, while venting the flue gas since it is so much more difficult and expensive to recover.

2.2 Blue hydrogen production using ATR

ATR is a newer process gaining traction in the blue hydrogen design arena. It utilizes many of the same steps as SMR, but it is more fuel efficient and creates a single concentrated CO_2 stream, rather than two as with SMR. Figure 3 shows a process diagram of ATR.

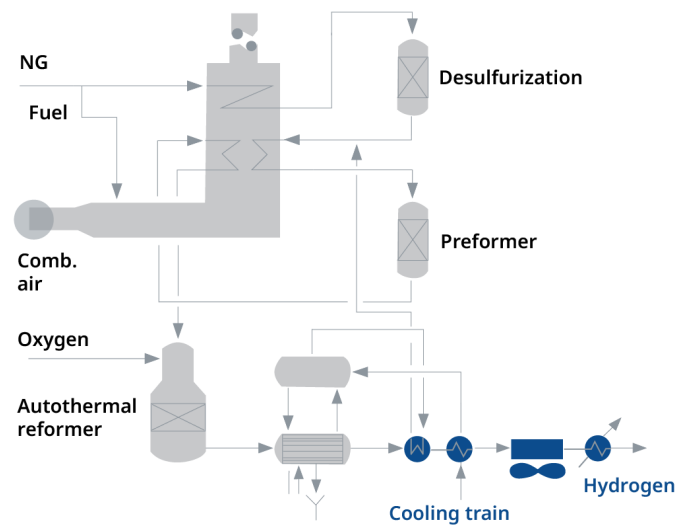


Figure 3: ATR combines methane and steam, and it then adds pure oxygen to create syngas at very high temperatures. The resulting syngas feeds amine and hydrogen purity sections, similar to the SMR process

Natural gas is desulfurized and preheated, and then mixed with high-pressure steam and heated further in the presence of a catalyst. This gas is then burned with pure oxygen to create a very high-temperature syn gas. The difference between ATR and SMR is that the initial ATR steps require very little fuel, if any, with the bulk of the energy coming from the oxygen injection step. This reduces energy requirements and generates a single, pure, and concentrated CO₂ stream that is easily captured.

Downstream of the autothermal reformer, as shown in Figure 3, the SMR and ATR processes are essentially the same. The shift converters react any remaining CO and water into CO₂ and hydrogen, and the amine section absorbs the CO₂ from gas stream before the hydrogen is purified in the PSA.

The chief advantage of ATR units is they are more efficient than SMR for blue hydrogen production, and they make it possible to capture much more of the greenhouse gases than SMR. The disadvantage of ATR is the requirement of an oxygen source or an air separation unit. Also, far fewer ATR plant designs exist, so the technology is less mature and only now being brought into production. However, ATR is a promising and likely-preferred technology for future designs intended to produce blue hydrogen as it has been specifically designed for this service. There are several ATR plants in various stages of design and early construction across the globe.

3 Valves, regulators, and relief valves in blue hydrogen production

Whether using SMR or ATR technology, the blue hydrogen process poses a number of challenges for the automated valves, regulators, and relief valves that help control and protect the process. This section identifies those difficult process applications, and it offers a range of solutions to address those needs.

3.1 Hydrogen/synthesis gas isolation valves, regulators, and relief valves

The presence of hydrogen in the hot syn gas stream around the reformers, and in the final product, creates significant challenges for control equipment. Hydrogen embrittlement can degrade the mechanical integrity and performance of the valves, and this can result in increased emissions and inefficiencies. High pressures and temperatures are also common, and the various gas components require a range of materials of construction to suit each application.

Properly selected manual or automated block valves must include the correct materials of construction, carry an API 607 certified firesafe rating, and may require SIL 3 certification for shutdown applications (Figure 4).

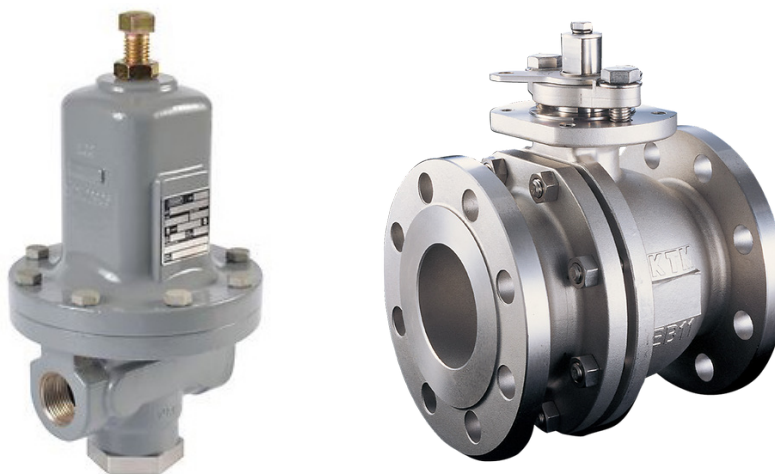


Figure 4: In hydrogen and syn gas service, the proper materials of construction are critical. This Fisher MR-95 regulator (left) is available with a wide variety of internal materials. The KTM series (right) offers many body styles and a broad range of materials of construction, packing types, and certifications.

In this application, a good solution is the KTM ball valve with durable E-Seats for low temperature applications, and with Metaltite™ materials for high temperature applications. KTM valves have the required API and SIL certifications, offer live-loaded low-emission packing and a variety of body styles, and have a proven track record in high-pressure and hydrogen service.

Depending on specific conditions and pipe sizes, a double eccentric C-ball valve or a triple offset metal-to-metal seated butterfly valve may also serve as isolation valve alternatives. Both valves are suitable for a wide range of temperatures, pressures, and fluid conditions, and both are inherently fire-resistant. These valves are discussed in more detail in section 3.3 below.

The wide range of material requirements can be a problem for regulator selection due to the limited range of options. Fortunately, some models, like the Fisher MR-95 regulator, can be specified in stainless steel, Monel, Hastelloy, and nickel-aluminum bronze to provide control across a wide range of pressures from 5 to 150 PSI.

High-capacity relief valves are often required for these processes, and these safety valves must seal tightly to avoid losing product. Additionally, the relief valves may operate close to their pressure setpoints, making a tight seal even more difficult to achieve and maintain. Enhanced seal tightness pilot relief valves, like the Anderson Greenwood™ 400/700/800 series, work well in these applications. These pilot-operated relief valves have very high capacity, and newer models allow a valve to operate within 2% of its setpoint with minimal leakage.

Properly selected manual or automated block valves must include the correct materials of construction, carry an API 607 certified firesafe.

3.2 Carbon capture control valve selection

Whether SMR or ATR is used, the general processing steps are relatively similar between the two plant designs once the syngas has been produced. The key control valves associated with the carbon capture portion of the process are shown in Figure 5 below. Specific challenges and key performance parameters will be discussed for each valve type.

Properly selected manual or automated block valves must include the correct materials of construction, carry an API 607 certified firesafe rating, and may require SIL 3 certification for shutdown applications (Figure 4).

Overview: Valves in Carbon Capture

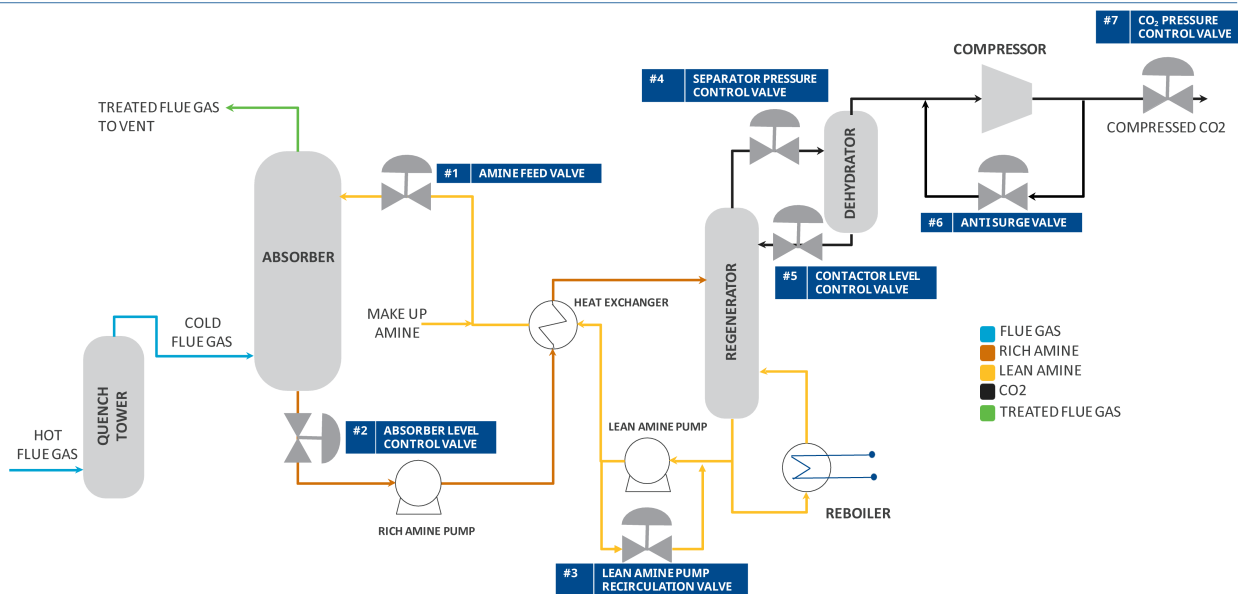


Figure 5: This diagram shows the critical control valves associated with the carbon capture portion of the process. Each valve location faces different process conditions and has its own set of difficulties.

3.2.1 Amine feed valve (#1)

To efficiently scrub CO₂ from the syngas, the lean amine feed valve must provide a consistent flow of amine to the top of the absorber, despite a high pressure drop and cavitating conditions. The best valve for this application will be a single-seated 316SS valve with hardened Alloy 6, anti-cavitation trim, and Enhanced ENVIRO-SEAL™ packing. A good choice for this application would be a Fisher™ ET or EWT valve (Figure 6).

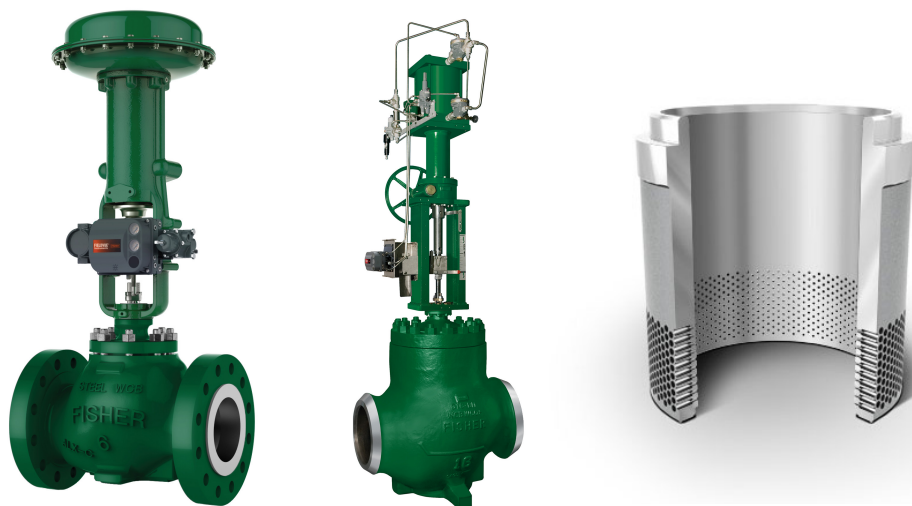


Figure 6: The lean amine feed valve is prone to cavitation and some level of corrosion. A 316 stainless Fisher ET (left) or EWT (middle) control valve with hardened anti-cavitation trim, like Cavitrol™ III (right), is a good choice for this application.

3.2.2 Absorber level control valve (#2)

This critical valve controls the liquid level in the carbon dioxide absorber and passes supersaturated, rich amine liquid to the amine regenerator. Even though the amine has not yet been pressurized or heated, the pressure drop across this valve tends to create cavitation and off-gassing, and the valve is subject to high levels of corrosion and erosion from crystallization in the solvent solution.

In this application, the same Fisher ET or EWT 316SS valve with a hardened Alloy 6 trim will work, but a noise-reducing Whisper I or III trim may be advised. Sizing this valve can be difficult due to the potential for two-phase flow, so consultation with an experienced automation valve provider is recommended to assist with body and trim size selection.

3.2.3 Lean amin pump recirculation valve (#3)

The challenge of this application is the valve remains closed most of the time, but it must instantly open as required to maintain pump flow during low flow conditions and avoid expensive pump damage. Tight shutoff is necessary since any leakage will reduce pump efficiency, and because the amine remains heated the valve is prone to cavitation.

The best valve for this application will be similar to the lean amine application (#1) described above. The addition of a high-diagnostic positioner can detect impending problems and alert staff should valve performance begin to degrade with respect to leakage.

3.2.4 Dehydrator control valves (#4 and #5)

The dehydrator is an important component of the carbon dioxide processing area since CO₂ pipelines will have a maximum water content specification (<100 ppm). Water in CO₂ will create long-term corrosion issues throughout the transportation network, so this specification is rigidly enforced.

In this area of the process, water content is higher, creating corrosion issues. There are also very high pressure drops, creating cavitation and high noise challenges. Proper selection of the material of construction and the body style is important.

The separator pressure control valve (#4) will be subject to high noise, so an attenuation trim like Whisper or Whisper Flo will be required. Depending on specific process design details, the dehydrator level control valve (#5) may experience cavitation and require an anti-cavitation trim. For either valve, a Fisher ET/HPT single-seated control valve will work well (Figure 7).



Figure 7: Dehydrator valves require 316SS bodies with 316SS or Alloy 6 trims to prevent corrosion, such as this single-seated Fisher ET or HPT (shown) valve. Valves around the CO₂ dehydrator may see noise and/or cavitation, and thus require low noise or anti-cavitation trims.

3.2.5 Antisurge Valve (#6)

Captured carbon dioxide must eventually be pressurized and liquefied to facilitate pipeline transport. This process starts with large, multi-stage centrifugal compressors, which receive the incoming, dehydrated CO₂ and compress it to higher pressures. Centrifugal compressors are prone to a catastrophic condition called surge that occurs when either the compressor suction or discharge are restricted. Under these conditions, the gas flow through the compressor can reverse many times a second, destroying the turbine blades, bearings, and seals.

To avoid a low flow condition and the surge it creates, an antisurge valve is installed in parallel with the compressor. This valve will open to recycle discharge pressure back to the suction to maintain a minimum flow through the compressor. The challenge associated with an antisurge valve is that it remains normally closed but must open very quickly (often within a second or two) to pass a substantial portion of the compressor capacity through the valve. Antisurge valves tend to be large, so moving a very big valve that quickly with no overshoot is not easy.

Antisurge valves require a carefully designed trim to handle the very high flow, high pressure drop, and noise conditions. They also need oversized actuators with pneumatic boosters and high-capacity positioners to allow the valve to stroke very quickly and accurately. Antisurge valve performance is critical for compressor protection because if the antisurge fails to perform as required, the compressor will likely require months and significant expense to repair.

Depending on the specific process flows and pressure drops, a Fisher E/EW EA, or FB single-seated globe or angle valve may be required (Figure 8). Specialized, oversized actuators with high-capacity volume boosters and high-performance, high-diagnostic positioners are the norm. The valve must have very tight shutoff and then instantly open to pass high flow rates under high pressure drop conditions, so low noise trims are often required.



Figure 8: An anti-surge control valve, like this Fisher Optimized easy-e™ EWT, is a critical component of gas compressor operations. High-diagnostic positioners with oversized actuators and volume boosters are typically required to meet the demanding response times.

3.2.6 Carbon dioxide flow/pressure control valve (#7)

Most captured carbon dioxide will eventually be injected into a pipeline for transport. This part of the process will typically operate in the supercritical regime under very high pressures. Carbon dioxide is a strong solvent under these conditions, and it can enter and catastrophically damage certain elastomers. The valve may also see very high pressure drops during injection operations.

Full bore 600# class valves, such as the Fisher V260, and 900# class valves, such as the Fisher V280, are commonly used for these applications (Figure 9). O-ring and elastomer components must be carefully specified, and single- or double-stage noise attenuators may be necessary in applications with a very high pressure drop.



Figure 9: Pipeline applications typically require high-pressure, full-bore valves, such as the Fisher V260 (left) and V280 (middle). Applications with high pressure drop and excess noise often require single or multistage attenuation trims, such as the Cavitrol Hex (right).

3.3 PSA isolation valves

The valves around the PSAs are subjected to very challenging service conditions. These valves are continuously cycled and must maintain virtually zero leakage and low emissions while ensuring isolation performance, despite high pressure and vacuum conditions, elevated temperatures, and the presence of erosive powdered bed media.

Compared to other automated valve designs, the triple offset Vanessa™ Series 30,000 TOV (Figure 10), provides a smaller footprint and less weight, improved operability, reduced fugitive emissions, and a longer valve life for this difficult application.

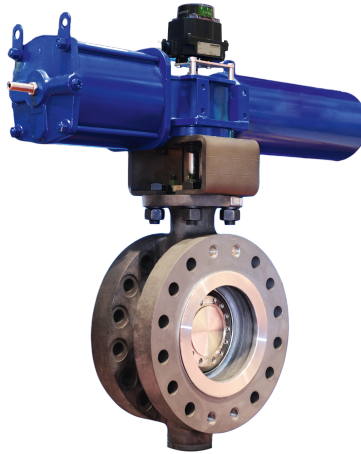


Figure 10: The metal-seated Vanessa Series 30,000 TOV provides zero leakage performance despite the reverse and variable pressures, extreme temperatures, and particulates present in PSA service.

Vanessa Series 30,000 TOV utilizes Stellite® grade 21 as a standard for valve body welding overlay to achieve higher resistance to galling, abrasion, erosion, and corrosion. This feature—combined with a solid seal ring, reinforced trim components, and live loaded packing—makes this valve the preferred choice for this application as it provides essentially zero leakage despite very difficult service conditions.

Another option for PSA isolation valves is the AEV™ 2XC double eccentric C-ball valve (Figure 11). It utilizes a double offset to create a zero-leakage seal that operates independently of applied pressure.

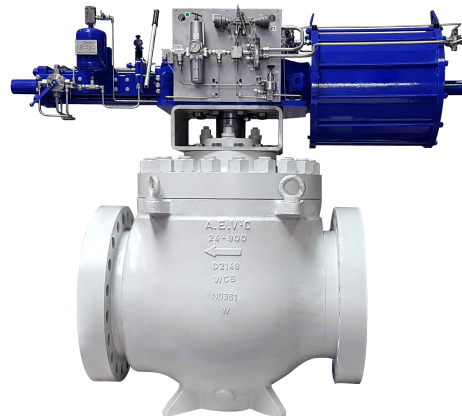


Figure 11: Double eccentric C-ball valves provide zero leakage, even in severe service applications, such as pressure swing adsorbers. The valves offer top entry and a hardened chromium carbide ball for long life. (AEV 2XC C-ball valve shown.)

A camming effect moves the C-ball away from the seat during the opening stroke to minimize wear when abrasives are present. The combination of fixed metal seats, mechanical sealing independent of process pressure, low wear, and a low emission design also works well in these difficult conditions.

3.4 Remote pipeline valve actuators

Some automated pipeline valves may be installed in remote locations where instrument air is not available. In such applications, electric actuators, or actuators driven from pipeline pressure, are required (Figure 12). Lower torque requirements can be satisfied with modern electric actuators, with or without spring fail capability.



Figure 12: When air is not available, advanced electric actuators with or without spring fail assist are available (Bettis™ XTE top). For high torque applications, zero emission options, like the Shafer™ ECAT SHO (bottom), use pipeline gas pressure to drive actuator hydraulics.

Remote pipeline applications requiring high torque or involving multiple valves can utilize zero-emission hydraulic actuating systems, like the Shafer ECAT SHO. This unit utilizes pipeline pressure to drive hydraulic valves, and the pipeline gas is injected back into the pipe at the end of stroke, so there are no emissions.

3.5 Carbon dioxide storage injection valves

During storage injection operations, the pressure may be very high, with some valves requiring class 1500, and even class 2500, pressure ratings. High noise and high pressure drop conditions are common, so low noise trims are commonly specified. High-capacity positioners and volume boosters may be necessary to meet fast stroking speed requirements. For these applications, high-pressure globe valves, such as the Fisher HP or EH with Whisper™ III or Whisper Flo trims, are a good option (Figure 13).

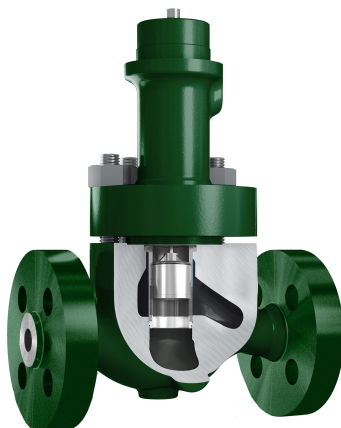


Figure 13: Carbon dioxide injection applications often require 1500 or 2500 class valves with noise attenuating trims. High-speed actuator and positioner components may be necessary for some applications.

4 Key takeaways

The key advantage of blue hydrogen compared to traditional hydrogen production methods is the capture and storage of carbon dioxide. The main technologies used to produce blue hydrogen are SMR and ATR.

SMR has been in use for decades, so it is very well understood, with many units operating worldwide, but its emissions are more difficult to capture than those produced by ATR. ATR is a newer technology and there are relatively few units operating worldwide, but its emissions are very simple to capture. This makes ATR the technology of choice for new blue hydrogen projects, but SMR will continue to be the most widely used technology for blue hydrogen production due to the large number of existing units.

When specifying the critical automated valves, regulators, and relief valves around a blue hydrogen plant, there are several process areas that pose significant challenges. The array of options can be overwhelming, but the details and design choices truly matter and will have lasting and positive impacts on the plant's reliability and profitability.

- Any gas steam containing hydrogen, such as product gas or syn gas, poses a risk for hydrogen embrittlement. Valves, regulators, and relief valves in these services must be specified carefully when selecting materials of construction. KTM ball valves, MR-95 regulators, and Anderson Greenwood 400/700/800 valves can be a good option.
- Many of the valves around the amine section are subject to cavitation, off-gassing, high noise, and high pressure drops and occasionally erosion. Valves with anti-cavitation trims and hardened internals are the norm. The best valve will vary depending on the specific application, but Fisher ET and EWT with low noise or anti cavitation trims work well in this application.
- Valves around the CO₂ dehydrator section will see high pressure drops and corrosion. Fisher ET or HPT valves with Alloy 6 internals work well in that application.
- If there are any antisurge valves, the user would be wise to consult their automation vendor. Antisurge valves are typically customized designed for the requirements of the specific application and require very specialized actuator components.

- Valves around the PSA face some of the most punishing conditions in the plant. The valves must maintain essentially zero leakage despite very high cycle rates, reversed pressure differential, high temperatures, and erosive dust. The Vanessa Series 30,000 TOV is well suited for this application and the double excentric AEV XC C-ball valve is a good alternative.
- Pipeline valves typically require full bore valves with Class 600 and even Class 900 pressure ratings, and with specialized internal soft goods suitable for high pressure carbon dioxide service. The Fisher V260 and V280 ball valves are good choice for this pipeline service.
- If actuated valves must be installed in remote areas with no access to instrument air, spring fail-safe electric actuators like the Bettis RTS are a good option. If the torque or speed of response requirements exceed the capability of electric actuators, zero emission hydraulic systems powered by pipeline pressure, such as the Shafer ECAT SHO, are available.
- Carbon dioxide injection valves can require class 1500 and even class 2500 valves. In these applications, high pressure globe valves, like the Fisher HP or EH with high-capacity positioners and low noise trims, work well.

Hydrogen process units have been operating for decades, but not at the scale envisioned in the future. Nonetheless, Emerson has extensive experience with these units, with much of their expertise applicable to the new processes described in this White Paper, namely the carbon capture and transport required to convert grey to blue hydrogen.

When designing the systems required to convert grey to blue hydrogen, operating companies would be wise to consult with a supplier that has extensive experience with hydrogen handling, along with the ability to apply this expertise worldwide at the scale required.

Emerson

19200 Northwest Fwy
Houston, Texas 77065 USA
T: +1 800 558 5853
+1 972 548 3574
www.Emerson.com

Neither Emerson, Emerson Automation Solutions, nor any of their affiliated entities assumes responsibility for the selection, use or maintenance of any product. Responsibility for proper selection, use and maintenance of any product remains solely with the purchaser and end user.

The contents of this publication are presented for information purposes only, and while effort has been made to ensure their accuracy, they are not to be construed as warranties or guarantees, express or implied, regarding the products or services described herein or their use or applicability. All sales are governed by our terms and conditions, which are available on request. We reserve the right to modify or improve the designs or specifications of our products at any time without notice.

