GE Oil & Gas

Carbon Capture & Sequestration

CO_2 management systems for higher plant performance and lower emissions

Carbon capture & sequestration (CCS)

Carbon dioxide (CO_2) is a natural byproduct of fossil-fuel processing, including refineries and petrochemical plants, power generation from coal, biomass, oil and natural gas. For perspective, a 500 MW power plant could emit about 4 million tons of CO_2 per year. In the past, CO_2 would be burned as waste, but it is now captured and stored for greater control of greenhouse gasses and other pollutants caused by flaring. Recent technological advances are enabling injection of CO_2 back into the earth, not only as a storage method, but as a means of re-pressurizing oil and gas reservoirs in order to increase their recovery rates. But there are many complex challenges involved in effectively and safely transporting and storing CO_2.

GE Oil & Gas solutions

CCS is the only emission-reduction method that enables continued use of fossil fuels. We have therefore invested considerably to advance the science behind CO_2 management. We also leverage extensive domain expertise in compression and pumping technologies from decades of proven solutions for related areas such as urea and liquefied natural gas. In an age when CO_2 management is not negotiable, GE Oil & Gas has the comprehensive capabilities to make it safer, easier and more cost effective in any situation.

Facing the future head-on

Analysts continue reminding the industry that the inexpensive and easy oil is gone. While this is true, GE Oil & Gas continues its longstanding tradition of pushing technological boundaries to make more out of finite global resources.

Sour and acid gas requires the most advanced materials, efficient designs and safety precautions. With an average recovery rate of 34% in oil fields, a 1% increase would result in approximately three years of additional production. We know how important every small step can be.

Our goal is to maximize opportunity and minimize risk at every point along the way.

All our new technologies are evolved from existing products with years of proven in-field performance, coupled with new developments from our Global Research Centers that are extensively tested in both laboratory and in-field environments before being launched for our customers to use.

Making CCS more efficient and productive

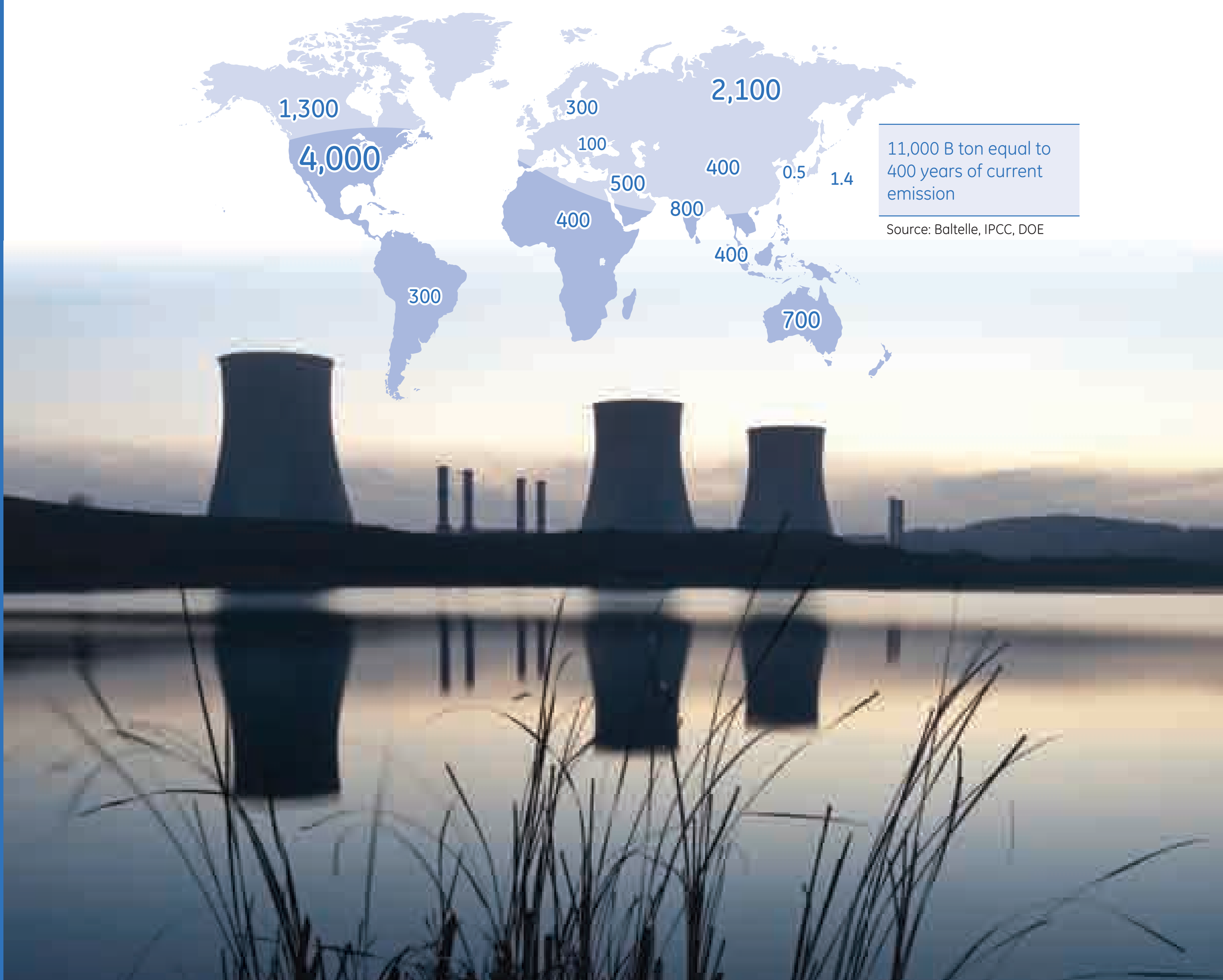
To date, much of the industry's CCS research has focused on separating carbon from either the fuel or post-combustion exhaust streams. This is critical because CO_2 separation is the most energy-intensive process step in CCS.

But separation isn't the only area where significant progress can be made. Closer examination shows that CO_2 compression and transportation can account for overall power plant efficiency drains of 6-10%. Since CO_2 compression is a parasitic energy consumer, any measure of reduced compression workload directly translates into a net improvement in plant performance.

This is where we have focused our attention – customizing complete compression trains for the unique characteristics of CO_2 so they operate more efficiently and contribute to the plant's overall performance.

Worldwide CO_2 storage potential

Potential storage capacity (B ton CO_2)



Pushing the boundaries of CO_2 technology

The primary challenge with CO_2 is that its pressure and temperature can be near atmospheric conditions for separation and capture, but must be much higher to reach the supercritical phase required for efficient transportation and storage. At that state, CO_2 exhibits properties of both a liquid and a gas, making it exponentially difficult to control. It can also be extremely corrosive in the presence of free water and contaminants such as H_2S. These factors have significant impacts on engineering design and material composition of compression train equipment.

Thermodynamics

The starting point in our CO_2 compression analysis was to establish an accurate simulation model of the thermodynamic characteristics. Although there are many mathematical models available for the equation state of pure CO_2 in low-pressure conditions, very few are applicable to the high pressures and gas mixtures found in CCS. In a certain range of pressure and temperature, CO_2 presents a strong gradient, meaning that even a small uncertainty in pressure will result in high performance errors.

GE Oil & Gas has spent the past 30 years advancing technologies and processes for CO_2 handling, including refinement of equation of state. Through extensive testing and experimentation, our current model is capable of 550 bar for pure CO_2 – validated to within 2% of expected value. Deep knowledge of equation of state and gas mixture enables us to design compressors and pumps with a strong prediction of each stage behavior across the full pressure range.

Rotordynamics

When pressure is above 200 bar, the density of CO_2 is over 300 kg/m^3 – an extremely high value that can jeopardize machine stability. In addition to design accommodations such as honeycomb balance piston and various damper devices, we are developing advanced measurement techniques for rotor and stator interaction across the seals at high pressure.

Aerodynamics

Using aggressive 3D CFD and careful monitoring of relative impeller velocity deceleration, we have designed a new family of impellers specifically for CO_2 compression.

The first stages use a Mixed Flow impeller design with a raked-angle exit section to better control secondary flows and optimize blade load. This enables efficient handling of higher volume flow without the need for a larger compressor. Due to the high compressibility of CO_2, our last stages have low flow coefficient impellers with very high head. This design reduces the number of stages and achieves more robust rotordynamics.

Dense-phase pumping

CO_2 pumping requirements are significantly different from those of centrifugal pumps for conventional hydrocarbon or water applications.

The low density of supercritical CO_2, together with high differential heads needed for high discharge pressure, requires the highest possible rotation speed – making rotordynamic assessment the most critical aspect. Our CO_2 pump designs include swirl brakes and magnetic bearings for dense phase acid gas pumping at high rotating speeds.

CO_2 management system optimization

The operating envelope for CO_2 injection is very broad in terms of volumetric flow and delivery pressure. It ranges from several thousand m^3/h at relatively low pressures, up to a few hundred m^3/h at extremely high pressures of 700-800 bar.

GE Oil & Gas over 30 years of proven experience in closely related compression and pumping applications, and is a leading developer of new technologies specific to CO_2 management.

We offer a range of customizable configurations, depending on site conditions that include delivery pressure, temperature, cooling sources, gas composition and contaminant type.

Pumping is viable at relatively low pressures and temperatures – in general, when density is higher than 600 kg/m^3.

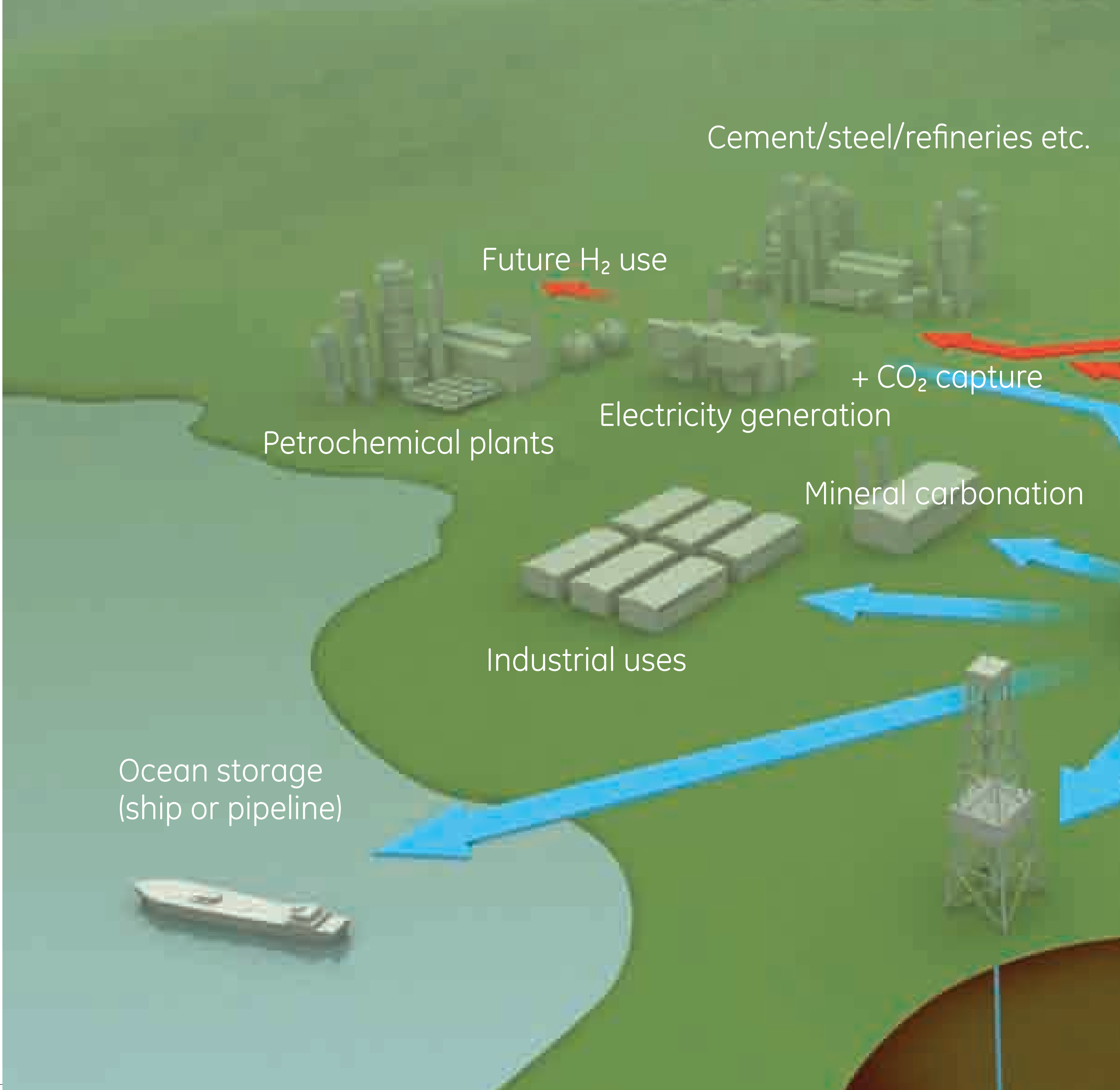
Where possible, inclusion of a pump reduces the train's total absorbed power by 10%.

For transportation of CO_2 in supercritical phase, it is advantageous to have a lower specific volume – allowing smaller piping and, hence, lower capital cost.

Pressure	Configuration options
< 200 bar	In-line compressors Integrally geared compressors + pump
> 200 bar	In-line compressors + HP pumps Integrally geared compressors with MP pump + HP pumps

Proven solutions for pure and mixed CO_2

Covering all the angles
for CCS and



EOR

Gas re-injection & water flooding

- Unique re-injection compressor experience
- Injection pump capabilities
- Water treatment technology
- System integration capabilities

CO_2 and steam/thermal injection

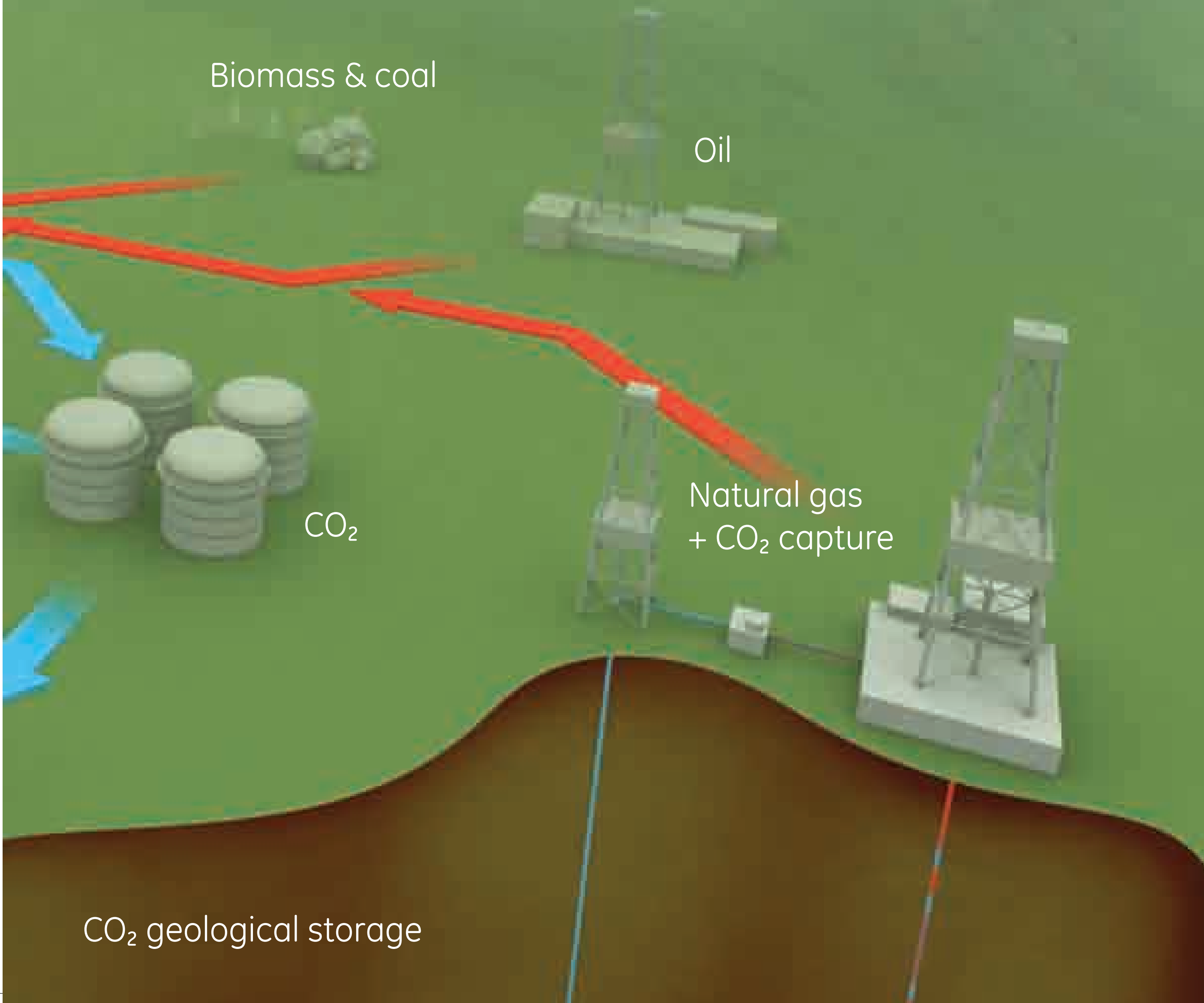
- CO_2 compressor experience
- Compressor and pump optimization
- SAGD water treatment technology
- System integration capabilities

Products for CO_2 compression

- Reciprocating Compressors
- Centrifugal pumps
- Centrifugal compressors
- Integrally geared compressors

Sour/acid compression mapping

- Centrifugal pumps up to 4 MW and 650 bar
- Seal-less compressors up to 15 MW and 250 bar
- Centrifugal compressors up to 30 MW and 800 bar



Integrally geared compressors

The high pressure ratio of CO_2 compression results in significantly high temperatures. However, since less energy is required to boost the pressure of a cool gas, the main advantage of an integrally geared centrifugal compressor is that coolers can be installed after each stand-alone stage. Our design features a bull gear and from one to four high-speed pinions, with one or two impellers mounted on each pinion shaft. Stand-alone stages also optimize impeller speed and allow for impellers with higher peripheral speed and compression. Each stage can be fitted with inlet guide vanes to eliminate the need for recirculation for partial loads. The net result is very high efficiency – requiring less work than an in-line compressor.

Optimized solution for CCS and EOR re-injection, transportation and storage

- Reduced compression train absorbed power
- Optimized high compression ratio and wide range of flow rates
- Optimum rotor balance for low vibration level
- Advanced seal system options available
- Easily accessible components for maintenance
- Available in multi-shaft models
- Direct or gear (integral or separate) driven with fixed or variable-speed drivers
- Oil-free gas delivery system
- Automatic capacity control and safety system to reliably match any operating condition
- Auxiliary system to meet international standards and customer specifications

a product of
ecomagination℠

In-line centrifugal compressors

Since 1971, fertilizer plants and pipelines have benefited from our proven OEM compression experience. We have supplied more than 200 units with typical pressures in the range of 200 bar. Our heavy involvement in urea applications is the most applicable to the new frontiers of CCS and EOR. Typical train arrangement includes a steam turbine or electric motor driving a low-speed, horizontally split compressor and a high-speed barrel compressor through an increasing gearbox. The same configuration can be used with a pump for CCS or EOR service because inlet and discharge pressures will be roughly the same as for fertilizer service. Our use of the Power Density approach reduces footprint and weight, while enhancing efficiency and increasing rotation speed. For CCS and EOR, where gas mixtures may include H2S and water, we use primarily stainless steel for improved resistance to corrosion and stress corrosion cracking (SCC).

Integrated Compressor Line (ICL)

GE's ICL is a fully integrated compression system, incorporating a high-speed electric motor drive and a centrifugal compressor in a single sealed casing. The product line was designed to address specific customer needs for production and environmental performance in applications such as gas storage, pipeline compression and upstream or downstream clean dry gas services.

The zero-leakage design makes both operation and maintenance easy by eliminating several components - there is no gearbox, no lube oil system, no external motor-cooling system, no seal gas system and no auxiliaries. It is 40-60% smaller, 50% lighter, 3 dB quieter and requires 50% fewer maintenance days than a traditional VSDS compressor.

CO_2 compressor & pump integrated system

Pumps

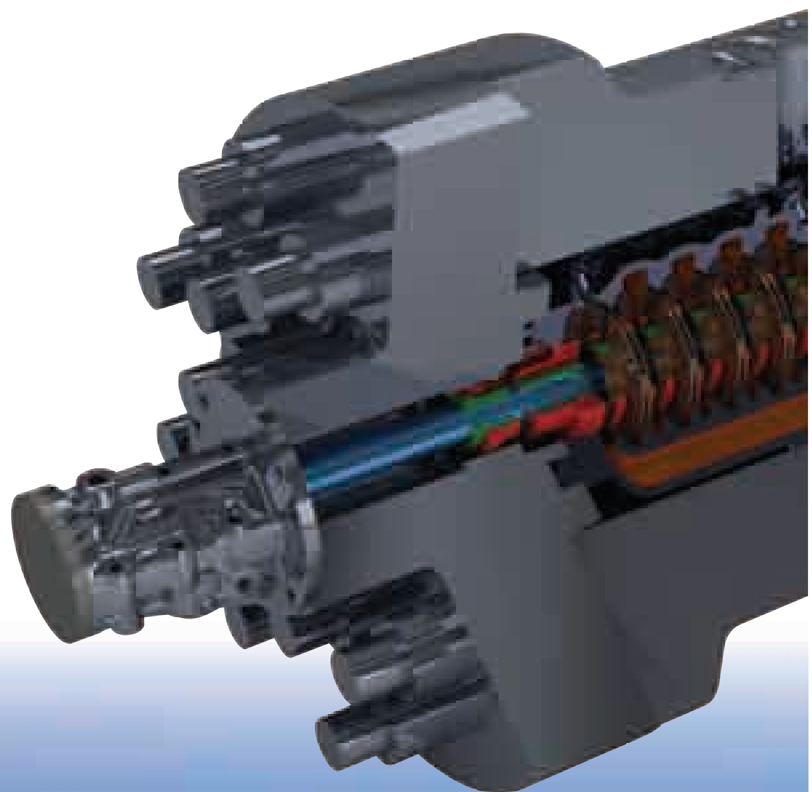
GE's installed fleet of over 1,000 multistage centrifugal pumps for liquefied gas applications already includes most of the technology needed for CO_2 pumping, because of similar viscosity, density and compressibility. This reference fleet has been an exceptional resource in our development of our high-pressure CO_2 injection pumps.

Our DDHF multistage barrel pump was selected as the best fit for CO_2 applications. Its opposing back-to-back impeller configuration provides the best overall efficiency compared with in-line rotor configurations. This is because the central balancing bushing can reduce internal leakages better than larger-diameter balancing drums. Two available sealing technologies are available: dry gas seals for optimized power consumption in small-footprint applications; and wet seals where power and footprint are of less importance.

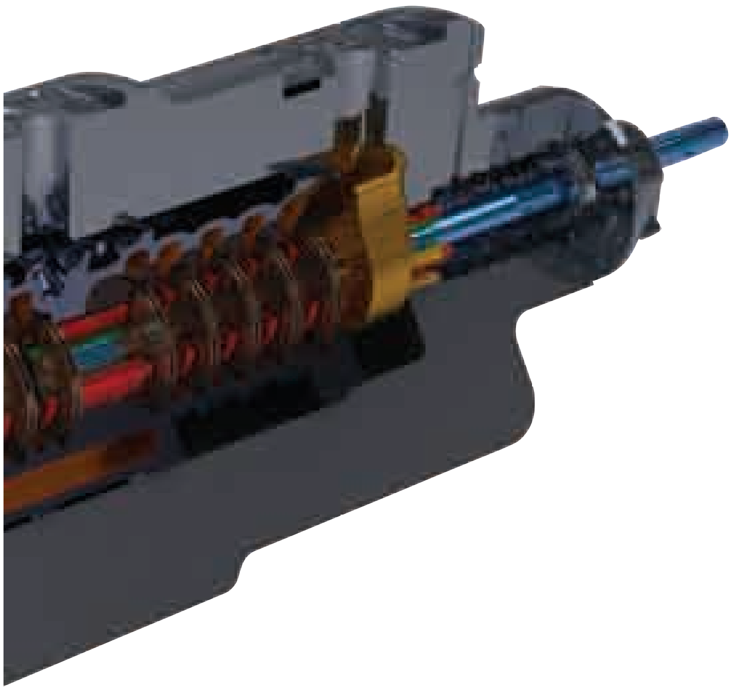
We have also optimized the overall compressor-pump train, including selection of the intermediate pressure between the last compression stage and the pump suction. This decreases total absorbed power and cost – whether total life cycle cost or cost per unit of CO_2 re-injected underground.

Structural design and material selection have been derived from the well-proven experience of GE CO_2 compressors. To maximize availability and the mean time between maintenance (MTBM), a monitoring and smart diagnostics system was developed with algorithms specifically designed for CO_2 applications.

DDHF centrifugal



pump



Pump spotlight: Re-injection pilot

This reservoir is located 4-5 km below the ocean floor and required new technologies to address the salt thickness of 2 km.

Very high suction pressure make mechanical seals the most critical component. A triple-seal arrangement was necessary to split the total pressure differential in smaller steps. Assembly and water testing was completed in late 2009.

- Suction pressure: 30 MPa
- Rated discharge pressure: 54 MPa
- Barrel casing design pressure: 67 MPa
- API 10000 rating class

Impeller modifications have improved stall characteristics with the compressible mixture. Careful rotordynamic assessment and internal bearing designs have achieved damping factors to guarantee stable operation at critical speeds.

From inlet to outlet, pressure increases from 30 MPa to 54 MPa, while temperature rises from 40°C to 76°C. With the field's gas composition, the temperature increase makes the total polytropic transformation very close to an iso-density transformation, limiting the variation of volumetric flow rate between inlet and outlet. A spare pump is under testing with a mixture of supercritical gases in simulated held conditions.

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