Forward Thinking
Advanced compression solutions for CO₂, N₂, propylene and vapor
Exceptional challenges, extraordinary solutions. We live in an amazing time. It is a time of incredible wealth, unsurpassed technical knowledge and ability, and unforeseen dynamic forces. Our progress fuels itself. The more we achieve, the more energy and resources we require, and the more we produce.

This cycle represents an extraordinary challenge: While we are consuming and producing more and more goods and energy, we need to proportionally decrease our impact on the environment. It is an incredible race, with technical challenges of remarkable variety and complexity. These challenges call for new and forward thinking solutions. We have to work smarter, cleaner, and more efficiently in order to meet the challenge of creating more prosperity while protecting our environment and safeguarding our future.

With advanced CO$_2$, N$_2$, propylene and vapor compression technology, MAN Diesel & Turbo is at the core of many progressive engineering solutions that combine environmentally conscious thinking with operational efficiency. On the following pages, we will show you some of these extraordinary solutions with focus on CO$_2$ applications and the MAN Diesel & Turbo products they employ.
Compression of CO$_2$, N$_2$, propylene and vapor has a long tradition in modern industrial processes and furthermore plays an increasing role in the present discussion of the world wide climate change. Especially in refinery and food industry applications it is used and a common good since several decades. Nowadays numerous industrial procedures require them not in a gaseous but in a compressed state at a specific pressure and temperature.

CO$_2$ is being used in many different industries, and most applications require its compression. Due to the impact of CO$_2$ emissions on the world climate, CO$_2$ compression technologies are an industry focus, now more than ever.

In CCS or EOR, the traditional approach to CO$_2$ compression has been to use high-speed reciprocating compressors. This technology shows several limits, among them the significant restriction of volume flows.

For this reason centrifugal type compressor systems have become state of the art for future CO$_2$ projects. Among centrifugal type compressors, there are two technologies, namely ‘single-shaft centrifugals’ and ‘multi-shaft integrally geared centrifugals’; MAN Diesel & Turbo manufactures both types.

MAN Diesel & Turbo provides compression solutions for the whole range of CO$_2$, N$_2$, propylene and vapor related applications, with single machines or complete train solutions including prime mover, auxiliaries and control system – all backed by the industry leading ‘MAN PrimeServ’ service plans.

Air separation and the extraction of oxygen from air is a pivotal process on the path to ‘clean coal’. MAN Diesel & Turbo is leading in this segment and offers a comprehensive product portfolio for a broad range of technical approaches.

MAN Diesel & Turbo is your partner of choice when it comes to CO$_2$ related industrial applications. No matter which technology will turn out to be the method of choice in the following years, we will put our extensive knowledge and experience to work for you. Together we can achieve profitable efficiency in the service of a clean planet.
The ever growing demand for energy worldwide, combined with increasingly strict environmental regulations have created the need for clean and sustainable technologies for power generation and industrial applications. Carbon Capture and Storage (CCS) labels a group of technologies which all serve one goal: to prevent the atmospheric release of carbon dioxide from thermal power generation.

Regardless of the CO₂ separation method employed, each process requires the compression of CO₂ for future transport and storage.

**Spotlight IGCC:**
**Efficient power with ultra-low emissions**
This type of power plant uses a technology that turns coal into gas, with a gasification unit that has been optimized for its use in combined cycles. IGCC plants feature significantly reduced sulfur dioxide, particulates and mercury emissions, and are highly efficient energy producers. When combined with CCS, IGCC plants achieve spectacularly low emissions. MAN Diesel & Turbo compressors find an important application in this forward thinking technology.

**CO₂ Separation/Gasification**
Before CO₂ can be compressed with MAN Diesel & Turbo technologies for storage or EOR applications, it needs to be separated from gas mixture. The main processes which can achieve this separation are described below.

**Pre-Combustion**
Integrated Gasification Combined Cycles (IGCC) convert fuels such as coal to a synthetic gas at elevated pressures. After the conversion of carbon monoxide to carbon dioxide in shift reactors, the CO₂ can be separated from the syngas. Due to the elevated partial pressure of the CO₂ in the gas stream, this is mainly achieved by absorption processes employing physical solvents. The captured CO₂ can then be released from the solvent by simple depressurization.
Oxyfuel
The combustion of fossil fuels with almost pure oxygen is another effective method for CO₂ capture. The concentration of the CO₂ in the exhaust gas is about five times higher than produced when combusting with air. The lighter and the heavier gas components are separated from the CO₂ stream in different stages of a cryogenic purification process.

Post-Combustion
In post-combustion CO₂ capture, the exhaust gas of a conventional power plant or other processes in which fuel is burned at atmospheric pressure is treated with a chemical solvent to dissolve the carbon dioxide. The CO₂ is then released by thermal regeneration of the solvent.

Storage
If there is no economically feasible use for the separated carbon dioxide, it needs to be safely removed to avoid negative environmental impact. The safest option is to store CO₂ underground. The gas is compressed to a supercritical fluid state and passed into deep geological formations. Different physical and chemical mechanisms prevent it from moving back into the atmosphere. Usually, an impermeable layer of rock provides a natural seal for the gas.

Power Plant Vapor Compression by MAN
- Vapor recompression is used to increase overall plant efficiency
- Water injection cooling, enabling higher pressure ratio, which results in improved efficiency

MAN Refrigeration in Industrial Applications
- Refrigeration processes are used in all kind of industrial applications
- Flexible/maximum effectiveness due to variable speed, per stage feed-in possible
- Compact design, resulting in high Mach-numbers (protects impellers)

Our compression solutions are mission-critical elements in safe storage, and have proven their long-term effectiveness, safety and reliability in many projects.
Enhanced Oil Recovery (EOR) techniques are applied when the amount of oil in a field has decreased to a level where no more can be recovered with conventional extraction methods like water injection. Oil and water do not mix. When water is used to push oil through a reservoir, it leaves a significant residue behind.

Instead, CO₂ flooding is a significantly more effective method. CO₂ and oil mix above a pressure known as the minimum miscibility pressure (MMP). At or above the MMP, CO₂ acts as a solvent, cleanly sweeping the reservoir, leaving only very little residue behind. At pressures below the MMP, CO₂ also assists oil production by swelling the oil and reducing its viscosity. This technique can also be used in natural gas fields to recover additional gas from exploited fields. The elimination of CO₂ from the atmosphere is a welcome side effect. If CO₂ is not available N₂ production and compression is a further option for EOR.

**Uniquely powerful**
For a particularly challenging project, the Dakota Gasification Company, in Beulah, ND, turned to MAN Diesel & Turbo for their compression needs. In 2006, MAN Diesel & Turbo delivered the third unit of an 8-stage integrally geared compressor for compressing CO₂ to 187 bar – a record achievement for this technology in this industry. Two prototypes of this RG type compressor had already been in continuous operation for the same customer since 2001. Their outstanding service record was the deciding factor for Dakota Gas in placing their trust in MAN Diesel & Turbo. The delivery consisted of a full package, including compressor core unit, driver, process gas...
coolers, lube oil system, process piping, auxiliaries, and the Turbolog control system. In this project, the CO₂ is compressed to 187 bar, and fed into a 205 mile long pipeline that runs north into Canada and ends in the Weyburn oil field. Here, the compressed CO₂ is injected into the field. The results at Weyburn have been spectacular – currently 28,000 barrels of oil are produced every day. This represents an 18,000 barrel per day increase over the 10,000 barrels a day that would be produced without the carbon dioxide flood.

MAN Diesel & Turbo’s 8-stage integrally geared compressors are a high performance solution that have stood the test of time and can easily meet the demands of even more demanding compression applications in the future.

At a Glance – CO₂ Compression Applications

**CO₂ Separation/Gasification**

Power plant with CCS-technology:
- Pre-combustion decarbonization
- Post-combustion or oxyfuel combustion decarbonization

**Transport**

- Compressor station
- Injection wellhead
- Oil well

**Enhanced Oil Recovery (EOR)**

- Recoverable oil
- Oil field
- Saline aquifer
Enhanced Oil or Gas Recovery (EOR, EGR)

Carbon Capture and Storage (CCS)

Buffer storage

Unmineable coal seam

Depleted oil or gas field

Saline aquifer

CO₂ injection

Recoverable oil or gas
For most CO₂ and N₂ compression applications, integrally geared centrifugal compressors have emerged as state of the art. This technology offers several clear advantages:

- Optimum impeller flow coefficient, since the optimum speed can be selected for each pair of impellers
- Axial inflow to each stage
- Shrouded or unshrouded impellers can be used
- Small hub/tip ratio
- Intercooling possible after each stage (impeller)
- External connection after each stage results in more flexibility in selecting the pressure level for the dehydration system, if applicable
- Practically no limit to the possible number of stages in one machine (pressure ratio of 200 possible on a single frame)
- Can be direct-driven by a 4-pole electric motor on the bull-gear, or a steam turbine on one of the pinions
- Inlet Guide Vane (IGV) for flow control
MAN Diesel & Turbo’s integrally geared centrifugal compressors feature a multi-stage arrangement allowing up to 5 pinions. All shafts are equipped with maintenance-free tilting pad bearings. The RG compressor can contain up to ten impellers. This enables a very compact design.

Continuously improved and refined, the underlying design of these compressors has existed for over 30 years. There are multiple references for their impressive performance and reliability track record.

Units can be built up to 10 stages (5 pinions)
Can be equipped with all current sealing systems
In full accordance with API 617
Intervals between overhaul comparable to in-line designs
This successful RG Design is becoming more and more popular for refrigeration and vapor applications as well.
Extreme high pressure:  
RB type barrel compressors

The right compressor for every application, and all pressure requirements – MAN Diesel & Turbo offers a comprehensive portfolio of products and solutions.

**Type RB**
This type of compressor is mostly applied for applications in the oil & gas industry, where it can handle a wide variety of gases, including toxic gases. For CO₂ applications, we recommend barrel type centrifugal compressors in cases where extreme high pressures of more than 200 bar, and up to 1,000 bar are required.

**Components**
- Exterior housing with integral inner casing

**Features**
- Covers, seals and bearing housing
- Variable nozzle position

**Up to 20 bar**
- Integradly Geared: Type RG
- Axial: Type AR, AV
- Isotherm: Type RIKT
- Screw: Type CP, SKUEL

**20 to 250 bar**
- Integradly Geared: Type RG
- Barrel: Type RB

**Above 250 bar**
- Barrel: Type RB
Low pressure, high volume flow: isotherm and axial compressors

In addition to gear type and barrel compressors, there are some CO₂ applications where the use of isotherm (Type RIKT) and axial compressors become necessary. Particularly in cases where high volumetric flows and low pressures are involved, these compressors find application.

**Type RIKT**
Isotherm compressors are single-shaft centrifugal compressors with integrated cooling.
- Low energy consumption
- Low noise emissions
- Extremely reliable
- Compact construction

**Axial compressors**
Axial compressors can be used for volume flows of up to 1,400,000 m³/h and pressures of up to 20 bar.
A complete train solution from MAN Diesel & Turbo is more than the sum of its parts. The elements of components, testing, assembly, and service seamlessly combine to achieve unsurpassed levels of performance, efficiency and reliability.

**Typical scope of supply**
- Compressor unit including gears
- Driver
- Couplings
- Sealing system
- Control equipment
- Water or air intercoolers
- Lube oil system
- On skid process piping
- Testing

**Drivers**
The most commonly used drivers for integrally geared and barrel compressors are electric motors, but steam and gas turbines are also sometimes employed.

**Control and safety equipment**
A complex machine train places significant demands on the control and protection systems in terms of quality and flexibility. These systems control an extremely diverse and complex set of processes and functions, from start-up to emergency shutdown. The electronic control and protection systems delivered by MAN Diesel & Turbo have become a recognized standard of quality.
Anti-surge control

In the performance characteristics of a turbo compressor, the surge line is the dividing line between ranges of stable and unstable operation. Reduction of the volume flow rate beyond this line results in the separation of flow from the blading, causing the gas to flow periodically from the discharge to the suction end of the compressor – a phenomenon referred to as compressor surging. The resulting extreme load reversals and temperature fluctuations in the gas handling components of the machine must be avoided. This is the task of the anti-surge control system which, by controlled opening of the blow-off or by pass valves, always keeps the compressor flow rate in the stable range of the performance characteristic.

MAN Diesel & Turbo’s electronic control and protection system is based on Simatic S7 hardware. This system called turbolog incorporates components which greatly improve the dynamic response of the controller and thus allows the distance between the blow-off line and the surge line to be minimized – surging is safely prevented under all operating conditions. In addition to anti-surge control, an independent surge detector is provided on MAN Diesel & Turbo compressors. During surging, the mass flow rate temporarily drops to zero and the temperature suddenly rises. Both values are measured by the surge detection system, and if one of them passes a limiting level, the blow-off valves are opened and, if necessary, the machine train is shut down.

Flow control (typically IGV)

To protect the machine train against overspeed, and to allow the flow rates of the train and thereby the pressures in the process to be controlled, MAN Diesel & Turbo uses a protection system based on Simatic S7 hardware. This system provides control far exceeding the requirements of NEMA specification SM 23, class D.

Depending on the specific requirements, it is designed for any of the following functions:
- Combined control of speed and extraction pressures
- Back-pressure control
- Inlet pressure control
- Power output control.
MAN Diesel & Turbo owns and operates different test stands for turbomachinery in order to execute factory acceptance tests. Test centers for compressors, steam turbines and gas turbines, as well as for individual components are integrated into the different shop locations. Individual machines and machine trains are completely assembled in the assembly bay and subsequently transferred to the adjacent test stand.

After the machinery has been erected on the foundation and has been connected to the permanent piping systems (steam, air, water, oil), many different kinds of tests according to DIN/VDI/ASME/API can be conducted:

- Mechanical testing of individual turbo machines
- Mechanical testing of complete machine trains
- Thermodynamic testing with air and other gases in open or closed loop systems or on site
- High pressure testing
- R&D testing

The drivers used during testing are either those supplied under a particular contract or the various test stand drivers which are available, i.e.:

- An 18 MW condensing steam turbine
- One 12 MW and several 7 - 2.5 MW variable speed motors
In total, MAN Diesel & Turbo operates 24 test stands on an area of 10,840 m². Modules up to 600 tonnes are by no means an exception; Cranes with a crane hook height of 13 meters, guarantee the necessary flexibility in the machine assembly and testing.

Test stands include a water cooling circuit and a 20 MW electrical power supply in addition to the steam supply (50 bar, 500°C, 55 t/h).
MAN Diesel & Turbo has delivered several integrally geared compressors with up to 10 stages for CO₂, N₂, Propylene and vapor applications. References include:

3 x 8-Stage CO₂ compressor RG80-8 for coal gasification plant in North Dakota. The CO₂ from this plant is used for EOR in the Weyburn oilfields in Canada

- 2 units commissioned in 1998, with an additional train in 2005
  - Pressure from 1.1 to 187 bara
  - Massflow ≈ 34 kg/s
  - Impeller diameters 800 – 115 mm
  - Pinion speed 7,350 – 26,600 rpm
  - Driven by fixed-speed synchronous electric motor

10-Stage CO₂ compressor RG56-10 in Russia

- Commissioned in 1992
  - Pressure from 1 to 200 bara
  - Massflow ≈ 13 kg/s
  - Impeller diameters 550 – 90 mm
  - Pinion speed 26,000 – 48,000 rpm
  - Driven by fixed-speed synchronous electric motor

8-Stage CO₂ compressor RG40-8 in Slovakia

- Commissioned in 2002
  - Pressure from 1.1 to 150 bara
  - Massflow ≈ 8 kg/s
  - Impeller diameters 400 – 95 mm
  - Pinion speed 8,000 – 41,000 rpm
  - Driven by variable speed asynchronous electric motor

8-Stage CO₂ compressor RG56-8 in CIS

- Commissioning in 2011
  - Pressure from 1.1 to 150 bara
  - Massflow = 16 kg/s
  - Impeller diameters 500 – 95 mm
  - Pinion speed 8,000 – 36,000 rpm
  - Driven by steam turbine

8-Stage CO₂ compressor RG71-8 in Canada

- Pressure from 1.68 to 174 bara
  - Massflow = 39 kg/s
  - Impeller diameters 741 - 142 mm
  - Pinion speeds 7,830 - 25,600 rpm
  - Driven by fixed-speed synchronous electric motor

8-Stage N₂ compressor RG50-8 in Northern Europe

- Pressure from 1.07 to 76 bara
  - Massflow = 11.5 kg/s
  - Impeller diameters 515 - 167 mm
  - Pinion speeds 14,000 - 29,950 rpm
  - Driven by fixed-speed asynchronous electric motor

4-Stage Propylene compressor RG71-4 in India

- Pressure from 1.14 to 20.17 bara
  - Massflow = 74 kg/s
  - Impeller diameters 730 – 510 mm
  - Pinion speeds 7,550 – 9,200 rpm
  - Driven by fixed-speed asynchronous electric motor

3-Stage Vapor compressor RG100-3 in Scandinavia

- Pressure from 0.4 to 2.7 bara
  - Massflow = 11.5 kg/s
  - Impeller diameters 980 – 670 mm
  - Pinion speeds 9,200 – 12,100 rpm
  - Driven by fixed-speed asynchronous electric motor