Gasification Technologies

We offer the right process for every feedstock and end-to-end solutions for every application.
The Business Area Industrial Solutions of thyssenkrupp is a world leader for planning, construction and service in the field of industrial plants and systems. Together with our customers we develop solutions at the highest level and deliver efficiency, reliability and sustainability throughout the entire life cycle. Our global network, with around 19,000 employees at 70 locations, enables us to provide turnkey solutions worldwide which set new benchmarks with their high productivity and particularly resource conserving technologies.

We are at home in many different industries. Along with chemical, fertilizer, coking, refinery, cement and other industrial plants, our portfolio also includes equipment for open-cast mining, ore processing and transshipment, as well as associated services. In the naval sector, we are a leading global system supplier for submarines and surface vessels. As an important system partner to our customers in the automotive, aerospace and battery industries, we optimize the value chain and improve performance.
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Syngas applications

The raw gas produced by gasification needs to be treated before it can be used for the production of downstream products, such as hydrogen, SNG, ammonia, methanol, liquid fuels, electricity or direct reduction gas (DRI).

There are various process routes available for obtaining the desired syngas composition, which may be a mixture of carbon monoxide and hydrogen or either pure hydrogen or carbon monoxide alone.

Hydrogen, for example, can be used in the refinery industry to achieve lighter and cleaner liquid fuels or for new applications such as fuel cells for power generation or cars.

Hydrogen-rich syngas can be produced via the “sour” CO shift process. In this case, the CO in the raw gas produced by gasification is shifted with steam to form hydrogen and carbon dioxide before the sour gas components are removed.

A number of processes are available for desulphurisation and carbon dioxide removal, such as: MDEA, aMDEA, Genosorb, Selexol, Sulfinol, Rectisol.

For the production of ammonia synthesis gas, a liquid nitrogen process can be used for the final cleaning and to obtain the correct mixture of hydrogen and nitrogen.

thyssenkrupp Industrial Solutions offers all of these process stages and can provide optimised solutions for complete production plants for e.g. fertilisers or liquid fuels as well as for combined hydrogen and electric power generation with or without carbon dioxide capture, or for direct reduction in the steel industry (DRI).
Our experience in gasification

Our gasification history
Different technologies for different applications

- **TGP**
  - 1953: TGP-License
  - 1959: Las Palmas, Spain
  - 1960: Lissabon, Portugal
  - 1971: Rhodes, Australia

- **TCGP**
  - 1973: Start Development
  - 1978: Demoplant Holten, Germany
  - 1986: Oberhausen, Ger.

- **PRENFO®**
  - 1974: Pressurised Entrained Flow: Start of Development
  - 1980: Demoplant, Hamburg, Germany
  - 1982: Essen, Germany
  - 1998: PuertoLlano, Spain
  - 2011: KEPCO-Uhde Inc.
  - 2014: BioThue, France

- **Koppers-Toetzek**
  - 1941: Koppers-Toetzek
  - 1988: Katue, Zambia

- **HTW**
  - 1926: Winkler Process
  - 1973: Fluidised Bed Gasification: Start of Development
  
  - 1978: Frechen, Ger.
  - 1985: Berrenrath, Ger.
  - 1988: Oulu, Finland
  - 1993: Kolnra
  - 2000: SHi, Japan
  - 2002: Veszprem, Cz.
  - 2017: Värmland, S.
Gasification by Uhde

Why gasification? Gasification processes offer a number of upstream and downstream advantages to customers faced with rising oil prices and dwindling energy reserves as well as a need to meet increasingly stringent environmental requirements. With proper preparation a variety of carbon-based materials can be easily gasified to produce synthesis gas (syngas) for the subsequent production of chemicals, liquid fuels, electricity or direct reduction gas (DRI). Gasification is particularly clean and efficient.

Gasification is also flexible with respect to feedstock quality and the use of mixed feedstocks. The gasification of low-value or waste materials is an attractive option. Even otherwise problematic materials can be gasified together with the main feedstock.

As coal is much more abundant than oil and gas and global availability ensures security of supply and relative price stability for the foreseeable future, coal will play an ever greater role in power generation, the chemical industry (e.g. in India, China and Africa) and in the production of liquid fuels (gasoline, diesel, etc.).

Gasification technology offers environment-friendly, efficient solutions for these applications. In power generation, for example, gasification can achieve high electrical efficiencies and also forms a basis for Carbon Capture and Storage (CCS).

thysenkrupp Industrial Solutions’ proprietary HTW™ and PRENFLO® technology provide tailor-made gasification solutions optimised for the respective project-specific application:

- HTW™: fluidised-bed gasification
- PRENFLO® with Steam Generation (PSG): entrained-flow gasification
- PRENFLO® with Direct Quench (PDQ): entrained-flow gasification

What is gasification?
Gasification is mainly a high-temperature partial oxidation process for converting carbonaceous materials into a synthesis gas composed mainly of carbon monoxide and hydrogen.

A number of chemical reactions are involved, some exothermic and some endothermic:

**Exothermic:**
\[
\begin{align*}
C + \frac{1}{2}O_2 &\rightarrow CO \\
C + O_2 &\rightarrow CO_2
\end{align*}
\]

**Endothermic:**
\[
\begin{align*}
C + CO_2 &\rightarrow 2 CO \\
C + H_2O &\rightarrow CO + H_2
\end{align*}
\]

During the gasification process, the sulphur present in the feedstock reacts to produce mainly hydrogen sulphide (H₂S) and carbonyl sulphide (COS):

\[
\begin{align*}
S + H_2 &\rightarrow H_2S \\
S + C + \frac{1}{2}O_2 &\rightarrow COS
\end{align*}
\]

Sulphur can be readily recovered in its elemental form or as sulphuric acid, both marketable commodities.

**Worldwide Gasification Capacities 2013-2019 (GWth)**

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Source: STM (Worldwide Gasification Database)
Uhde’s gasification technologies are all based on dry feeding principle, and are thus able to handle all types of coal (hard coal, lignite, anthracite, high-ash coals, coals with high-ash melting points) as well as petroleum coke, char and biomass (e.g. wood, chicken litter, sewage sludge, olive residues, etc.).

In addition to the main product (syngas), gasification produces by-products of economic value. The gasification of solids produces: bottom ash, fly ash and, after subsequent gas treatment, elemental sulphur or sulphuric acid.

**Range of feedstocks**

Our gasification technologies are suitable for a wide range of feedstocks, such as:

- Petroleum coke
- Anthracite coke
- Hard coals (with low and high ash contents)
- Brown coal, lignite
- Biomass
- Wastes

**Different feedstocks require different gasification technologies**

![Technology decision tree](image)

**Technology decision tree**

- **Feedstock**
  - Low Rank Fuels
    - Lignite
    - Peat
    - Biomass
  - High Rank Fuels
    - Hard Coal
    - Petcoke
    - Residues

- **Reactivity**
  - High
    - Ash Softening Point
      - High
      - Low
  - Low

- **Ash Content**
  - High
  - Low

- **Product Gas**
  - H₂ rich / Chemicals
  - CO rich / Power

- **Technology**
  - HTW
  - PRENFLO PDQ
  - PRENFLO PSG
  - Oil gasification
The PRENFLO® (PRessurised ENtrained-FLOw) process, which operates at elevated pressure, can be used to gasify all types of solid feedstocks (coal, petroleum coke and biomass). It is a further development of the Koppers-Totzek process developed in the 1940s, which operates at atmospheric pressure.

PRENFLO® can look back on more than two decades of operating experience, providing a wealth of lessons learnt which have formed the basis for subsequent successful applications.

**Flow diagram of the PRENFLO® (PSG) process**

**Main process data:**
- Gasification pressure: 40 bar and higher
- Gasification temperature: > 2,000 °C
- Gas temperature at outlet of gasifier: 1,350 - 1,600 °C
- Carbon conversion: > 99%
- Typical raw gas composition:
  - CO + H₂ > 85 vol. %
  - CO₂: 2-4 vol. %
  - CH₄ < 0.1 vol. %

1. Cyclone filter
2. Lock hopper
3. Feed bin
4. PRENFLO® gasifier
5. Slag crusher/collector (if required)
6. Slag lock hopper
7. Waste heat boiler
8. Steam drum
9. Filter
10. Fly ash lock hopper
11. Fly ash feed bin
12. Scrubber
13. Quench gas compressor
Process description
First, the feed dust is prepared in the feed preparation unit. Approximately 80% of the dust is smaller than 0.1 mm. This feed dust is then gasified in the PRENFLO® gasifier using oxygen and steam as gasification agents. The gasification temperature is higher than the ash melting temperature, which allows the coal ash to be removed as slag. The cooled-type gasifier is equipped with multiple, horizontally arranged burners.

In the PRENFLO® Process with Steam Generation (PSG), the raw gas produced, which contains mainly carbon monoxide and hydrogen, is cooled in the waste heat boiler, generating steam. The gas is then dedusted in a candle filter and further treated in a Venturi scrubber.

The slag from the gasifier can be used as a construction material and the fly ash from the candle filter as a base product in the cement industry.

PRENFLO® technology is used at the world’s largest single train, solid-feedstock-based IGCC power plant in Puertollano, Spain. This plant operates with a mixture of petroleum coke and coal.

Single train capacity upto 1,200 MWth

Main features of the PSG process:
- Entrained-flow
- Dry dust feed for high efficiency
- Multiple burners with high availability and long lifetime
- Horizontally arranged burners for high carbon conversion
- Membrane wall with long lifetime
- Waste heat boiler for efficient heat recovery
- Operates above ash melting point
The PRENFLO® (PRessurised ENtrained-FLOw) Direct Quench (PDQ) process is an optimised design of the proven PSG gasification process for chemical applications (e.g. ammonia, methanol, hydrogen, synthetic fuel) and IGCC plants with Carbon Capture and Storage (CCS), where hydrogen-rich syngases are required. It combines the technologically advanced dry feed system, multiple burners and membrane wall of the PRENFLO® PSG process with a proprietary water quench system which saturates the raw syngas with water for subsequent gas treatment.

Capital-intensive systems, such as the waste heat boiler system, the dry fly ash removal system and the quench gas compressor, are therefore no longer required.

Main process data:

Gasification pressure: 40 bar and higher
Gasification temperature: > 2,000°C
Gas temperature at outlet of gasifier/quench: 200 - 250°C
Carbon conversion: > 99%

Typical raw gas composition:
CO + H₂ > 85 vol. %
CO₂ 6 - 8 vol. %
CH₄ < 0.1 vol. %
**Process description**

First, the feed dust is prepared in the feed preparation unit. Approximately 80% of the dust is smaller than 0.1 mm. This feed dust is then gasified in the PRENFO® gasifier using oxygen and steam as the gasification agent. The gasification temperature is higher than the ash melting temperature, which allows the coal ash to be removed as slag. The cooled-type gasifier is equipped with multiple, horizontally arranged burners.

The raw gas produced, which contains mainly carbon monoxide and hydrogen, is quenched with water in the gasifier/direct quench and then cleaned in a scrubber.

The filter cake from the slurry filtration system is mainly recycled to the gasifier via the feed preparation unit.

The slag from the gasifier can be used as a construction material.

**Single train capacity upto** 1,200 MWth

**Main features of the PDQ process:**

- Entrained-flow
- Dry dust feed for high efficiency
- Multiple burners with high availability and long lifetime
- Horizontally arranged burners for high carbon conversion
- Membrane wall with long lifetime
- Full water quench for syngas saturation
- Shorter supply and construction schedule
- Lower investment cost
- Operates above ash melting point
The HTW™ process
Perfect fit for waste, biomass and low rank coal

The fluidized-bed gasification process was developed in the 1920’s in Germany by Fritz Winkler. Commercial-scale Winkler gasifiers were operated in over 40 applications around the world. In the 1970’s, thyssenkrupp Industrial Solutions together with Rheinische Braunkohlenwerke AG commenced with the development of a pressurised version of the Winkler gasifier—the High-Temperature Winkler (HTW™) gasification process. The HTW™ process enables shorter residence time, higher reaction velocity, higher reactor throughput for larger plant capacity, higher carbon conversion rate, higher plant efficiency and improved syngas quality. In 1978, the HTW™ pilot plant started-up in Frechen, Germany, with a pressure of 10 bar. The operating experience gained therein laid the foundation for the design and construction of the HTW™ commercial-scale plant at Berrenrath, which started-up in 1986 to convert Rhenish brown coal into methanol. The Berrenrath plant achieved plant availabilities of over 8,000 hours per year. In 1988, another commercial HTW™ gasification plant started-up for Kemira in Oulu, Finland. This plant converted 100% biomass (peat) into ammonia. Within the further development of the HTW™ process for IGCC applications, and the later engineering for the KoBra IGCC plant at Hürth, an additional 25 bar HTW™ gasification plant started-up in 1989 at Wesseling. In the mid-1990’s the HTW™ plant at Wesseling was operated using air instead of oxygen as reactant. Carbon conversion efficiencies up to 95% could be achieved. Around the same time, the HTW™ plant at Berrenrath ran a programme to add up to 30% of MSW/plastic wastes as feedstock to the gasifier. Due to the excellent results, Sumitomo Heavy Industries selected the HTW™ process for a municipal solid waste gasification plant that started up in Japan in Niihama in 2000.

Main process data:
Gasification pressure: 1.5 - 30 bar
Gasification temperature: 700 - 1,200 °C (below ash softening point)
Carbon conversion: > 95%
**Process description**
In the fluidized bed, a high material and energy transfer rate is achieved and this ensures a uniform temperature distribution throughout the gasifier. The temperature is maintained below the ash softening point.

Screw conveyers or gravity pipes are used for supplying the feedstock to the HTW™ gasifier. Due to the gasifier pressure, both the feeding system as well as the bottom ash removal have to be performed by lock-hopper systems. The gasification agents, steam and oxygen (or air) are injected at the bottom of the gasifier (here they serve simultaneously as fluidizing agents for the fluidized bed) and they are also introduced into the fluidized bed as well as above the fluidized bed, into the so-called post-gasification zone in order to improve the gas quality and the conversion rate due to the temperature increase.

**Single train capacity upto 700 MWth**

<table>
<thead>
<tr>
<th>Gasification Agent</th>
<th>Oxygen + Steam</th>
<th>Air</th>
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</thead>
<tbody>
<tr>
<td>Feedstock</td>
<td>Low Ash Lignite</td>
<td>High Ash Lignite</td>
</tr>
<tr>
<td>CO vol.%</td>
<td>29.4</td>
<td>20</td>
</tr>
<tr>
<td>H₂ vol.%</td>
<td>29.5</td>
<td>15</td>
</tr>
<tr>
<td>CO₂ vol.%</td>
<td>18.8</td>
<td>8.1</td>
</tr>
<tr>
<td>CH₄ vol.%</td>
<td>4.0</td>
<td>1.7</td>
</tr>
<tr>
<td>N₂+Ar vol.%</td>
<td>0.5</td>
<td>46.5</td>
</tr>
<tr>
<td>H₂O vol.%</td>
<td>17.5</td>
<td>8.5</td>
</tr>
<tr>
<td>H₂S vol. ppm</td>
<td>1,000</td>
<td>1,000</td>
</tr>
<tr>
<td>NH₃ vol. ppm</td>
<td>1,500</td>
<td>750</td>
</tr>
</tbody>
</table>

**Main features of the HTW™ process:**
- Fluidised bed
- Operates below ash softening point
- Dry feeding system
- Cyclone
- Post-gasification zone for tar destruction
- Multiple oxygen nozzles for optimum distribution
Major Projects

ELCOGAS S.A.
Puertollano, Spain
Capacity: 181,000 Nm³/h of raw gas (PRENFLD® gasification)
Coal-to-Liquids (MTG)
Jincheng Anthracite Coal Mining, Shanxi, China
Capacity: 2,600 barrels per day

Gasification plant for the production of ammonia and methanol
Modderfontein, South Africa
Capacity: 90,000 m³ (Vn)/h (dry) CO + H₂

Gasification plant for the production of oxo gas
Oberhausen, Germany
Capacity: 83,000 m³ (Vn)/h (dry) CO + H₂

PRENFLO® demonstration plant
Fürstenhausen, Germany
Capacity: 4,200 m³ (Vn)/h (dry) CO + H₂

Gasification of peat for the production of ammonia
HTW™ Syngas plant
Kemira Oy, Oulo, Finnland
Capacity: 300 t/day NH₃
Coal-to-Liquids
Wesseling, Germany
Capacity: 100 barrels per day

Elcogas IGCC Plant
Puertollano, Spain
Capacity: 183,000 m³ (Vn)/h (dry) CO + H₂

Methanol-to-Gasoline (MTG)
In combination with Uhde’s gasification technologies, different process routes for the production of liquids from coal or other carbonaceous feedstocks, i.e. the Methanol-to-Gasoline (MTG) route or the Fischer-Tropsch synthesis route, can be supplied.

Coal-to-Liquids
Wesseling, Germany
Capacity: 100 barrels per day

Elcogas IGCC Plant
Puertollano, Spain
Capacity: 183,000 m³ (Vn)/h (dry) CO + H₂
HTW™ Gasification

On the basis of the preliminary tests in a bench-scale plant at Aachen Technical University, a pilot plant has been set up by Rheinbraun in their coal processing factory Wachtberg at Frechen near Cologne in order to test the HTW™ process. This project was subsidized by the Federal Ministry for Research and Technology (BMFT).

thyssenkrupp Industrial Solutions was responsible for the engineering, supervision of civil works and erection activities and for commissioning the plant.

thyssenkrupp Industrial Solutions and Rheinbraun engineers jointly perform the tests and evaluate the results.

The pilot plant was commissioned in summer 1978.

The test programme covered the evaluation of the process design parameters, in particular:

• Gasification under pressure
• Gasification at evaluated temperature
• Improving the carbon conversion rate
• Improving the gas quality

The plant concept

In view of the good results obtained in the pilot plant, Rheinische Braunkohlewerke AG decided to install a demonstration plant for the gasification of lignite. The plant started up in 1986 to produce synthesis gas suitable for methanol production, which was transported by pipeline to the methanol synthesis plant of Union Rheinische Braunkohlen Kraftstoff AG to demonstrate the feasibility of methanol production from lignite.

The Berrenrath plant demonstrated excellent performance, high availability, a robust operation and the ability to co-feed solid waste upto 50%.
thyssenkrupp Industrial Solutions is a full service technology, engineering and contracting company. We offer our customers a wide range of cost effective, safe and environment-friendly solutions.

### Range of Services
#### Uhde Technologies

<table>
<thead>
<tr>
<th>Ammonia &amp; Urea</th>
<th>Hydrogen &amp; Nitrates</th>
<th>Electrolysis</th>
<th>Organic chemicals / Polymers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synthesis gas generation</td>
<td>Synthesis gas generation</td>
<td>Electrolysis</td>
<td>Organic chemicals</td>
</tr>
<tr>
<td>Steam reforming</td>
<td>Steam reforming</td>
<td>Chlor-alkali electrolysis</td>
<td>Ethylene dichloride (EDC)</td>
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<td>Autothermal reforming</td>
<td>Autothermal reforming</td>
<td>HCl electrolysis</td>
<td>Vinyl chloride (VCM)</td>
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<td>Combined autothermal reforming (CAR®)</td>
<td>Chlorate electrolysis</td>
<td>Vinyl acetate monomer (VAM)</td>
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<td><strong>Synthesis gas products</strong></td>
<td><strong>Bleaching chemicals / Others</strong></td>
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<td>Ammonia</td>
<td>Hydrogen</td>
<td>Chlorine dioxide (ClO₂)</td>
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<td>Carboxymethylcellulose (CMC)</td>
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<td>Engineering plastics</td>
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**Mineral acids**
- Nitric acid
- \( N₂O / NOx \) abatement
  - (DeNOx, De-N₂O₈, EnviNOx®)

**Nitrogenous fertilisers**
- Ammonium nitrate
  - (HDAN, LDAN), CAN, UAN, ASN, AS
- **Phosphate Fertiliser**
  - DAP, NP, NPK
Refining Technologies

Oil refining
Crude oil processing
Atmospheric distillation
Vacuum distillation

Catalytic processing
Hydrotreating,
hydrodesulphurisation,
hydrocracking
Catalytic reforming
Fluid catalytic cracking (FCC)
Isomerisation
Alkylation, dimerisation

Ethers
Methyl / ethyl tertiary butyl ether (MTBE, ETBE)
Selective hydrogenation
Oxygenate removal
Tertiary amyl methyl ether (TAME)
Dimethyl ether (DME)

Other processes and offsites
Gas-to-liquids
(product upgrading)
Hydrogen / synthesis gas
Gas / LPG separation
Thermal cracking
Visbreaking
Bitumen and asphalt
Offsite facilities

Lube oil, waxes and white oil
Solvent extraction
Propane deasphalting
Solvent dewaxing
Wax deoiling
Lube oil hydrofinishing
Lube oil hydrocracking
Wax hydroisomerisation
Catalytic dewaxing
Wax / white oil hydrogenation
Lube oil blending

Aromatics and derivates
Extractive distillation (BTX)
using the Morphylane® process
Reformate hydrogenation
Pyrolysis gasoline hydrogenation
Coke-oven light oil hydrotreating
Catalytic reforming
Xylene isomerisation
Disproportionation
Toluene dealkylation
Divided wall column fractionation
Styrene extraction

Olefins and solvents
Alcohols
Isopropanol (IPA)
Secondary butanol (SBA)
Ketones
Methyl isobutyl ketone (MIBK)
Methyl ethyl ketone (DMK)
C4 olefins
Butene concentration
(Butenex®, Molsieve)

Gas Technologies

Gasification
(PRENFLO® & HTWM®)
Coal / petcoke gasification
(PRENFLO®)
Oil / residue gasification
Biomass gasification
Partial oxidation

Synthesis gas applications
Gas treatment for synthesis
gas, hydrogen
Sulphur recovery
Coal-to-liquids (methanol-to-
gasoline, Fischer-Tropsch)
Ammonia, methanol
DME, DRI

Olefins
Propane dehydrogenation
(STAR process®, STAR catalyst®)

Coke Plant Technologies

Coke oven batteries
Gas treatment plants
Coke quenching facilities
Coal / coke handling
Heat-recovery coke plants
Emission control systems
thyssenkrupp Industrial Solutions is dedicated to providing its customers with a wide range of services and to supporting them in their efforts to succeed in their line of business. With our worldwide network of subsidiaries, associated companies and experienced local representatives, as well as first-class backing from our head office, thyssenkrupp Industrial Solutions has the ideal qualifications to achieve this goal.

We at thyssenkrupp Industrial Solutions place particular importance on interacting with our customers at an early stage to combine their ambition and expertise with our experience.

Whenever we can, we give potential customers the opportunity to visit operating plants and to personally evaluate such matters as process operability, maintenance and on-stream time.

We aim to build our future business on the confidence our customers place in us.

thyssenkrupp Industrial Solutions provides the entire spectrum of services associated with a process-oriented EPC contractor from a single source.

Our large portfolio includes:

• End-to-end process solutions
• Licensing of gasification and downstream technologies, incl. the basic engineering package (BEP)
• Front-end engineering design (FEED)
• Feasibility studies
• Cost estimates
• Engineering, procurement, construction
• Commissioning and start-up support
• Training of operating personnel
• After-sales services.

The policy of the thyssenkrupp Industrial Solutions group and its subsidiaries is to ensure utmost quality in the implementation of our projects. Our head office and subsidiaries worldwide work to the same quality standard, certified according to: DIN/ISO 9001/EN29001.

We remain in contact with our customers even after project completion. Partnering is our byword.

By organising and supporting technical symposia, we promote active communication between customers, licensors, partners, operators and our specialists. This enables our customers to benefit from the development of new technologies and the exchange of experience as well as troubleshooting information.

We like to cultivate our business relationships and learn more about the future goals of our customers. Our after-sales services include regular consultancy visits which keep the owner informed about the latest developments or revamping options.

thyssenkrupp Industrial Solutions stands for tailor-made concepts and international competence.

For more information contact one of the thyssenkrupp Industrial Solutions offices near you, visit:

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