

Enhanced Cryogenic Air Separation

A proven Process applied to Oxyfuel

Future Prospects

Dr.-Ing. Gerhard Beysel
1st Oxyfuel Combustion Conference
Cottbus, Sept 8th, 2009

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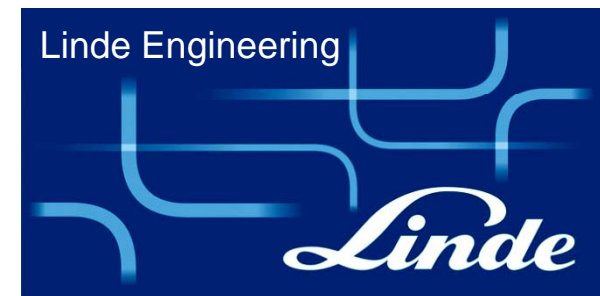
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- 1 Introduction**
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- 3 Potentials for Power Savings and Cost Reduction**
- 4 Potentials for Large Capacities and Oxygen Demand for New Applications**
- 5 Innovative Improvements at Cryogenic Air Separation**

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The Divisions



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(Headquarter Munich, Germany)

50 000 employees

2006

Sales 17 billion US\$

Linde Engineering Division Product Lines & Key Plant Types

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Olefin Plants



Products:

- Ethylene
- Propylene
- Butadiene
- Aromatics
- Polymers

Natural Gas Plants



— Products:

- LNG
- NGL
- LPG
- Helium
- NRU

Hydrogen and Synthesis Gas Plants



— Products:

- H₂/CO/Syngas
- Ammonia
- Gas removal
- Gas purification

Air Separation Plants



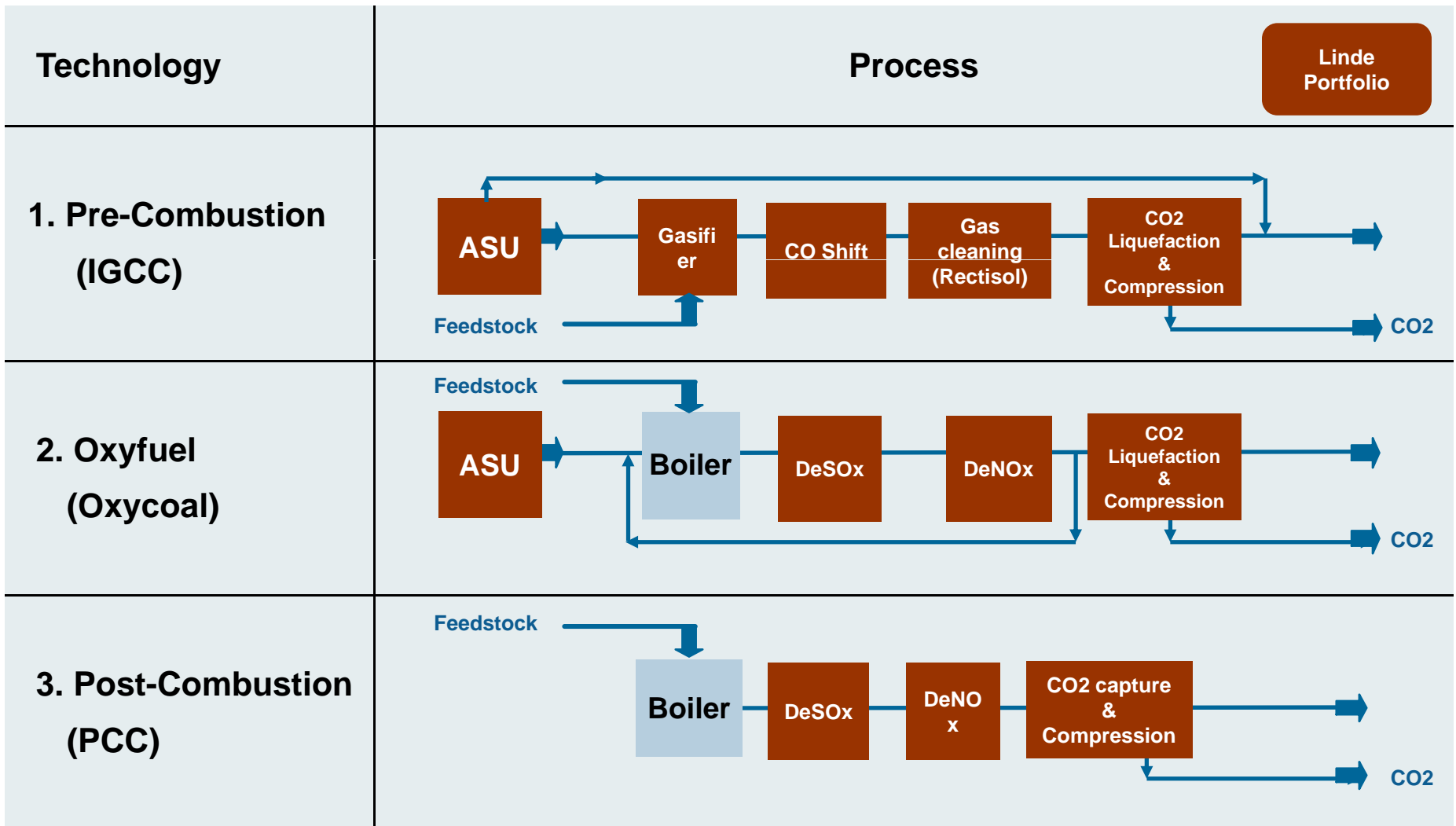
— Products:

- Oxygen
- Nitrogen
- Rare gases

Carbon Capture Technologies (CCS)

- From the ASU Perspective -

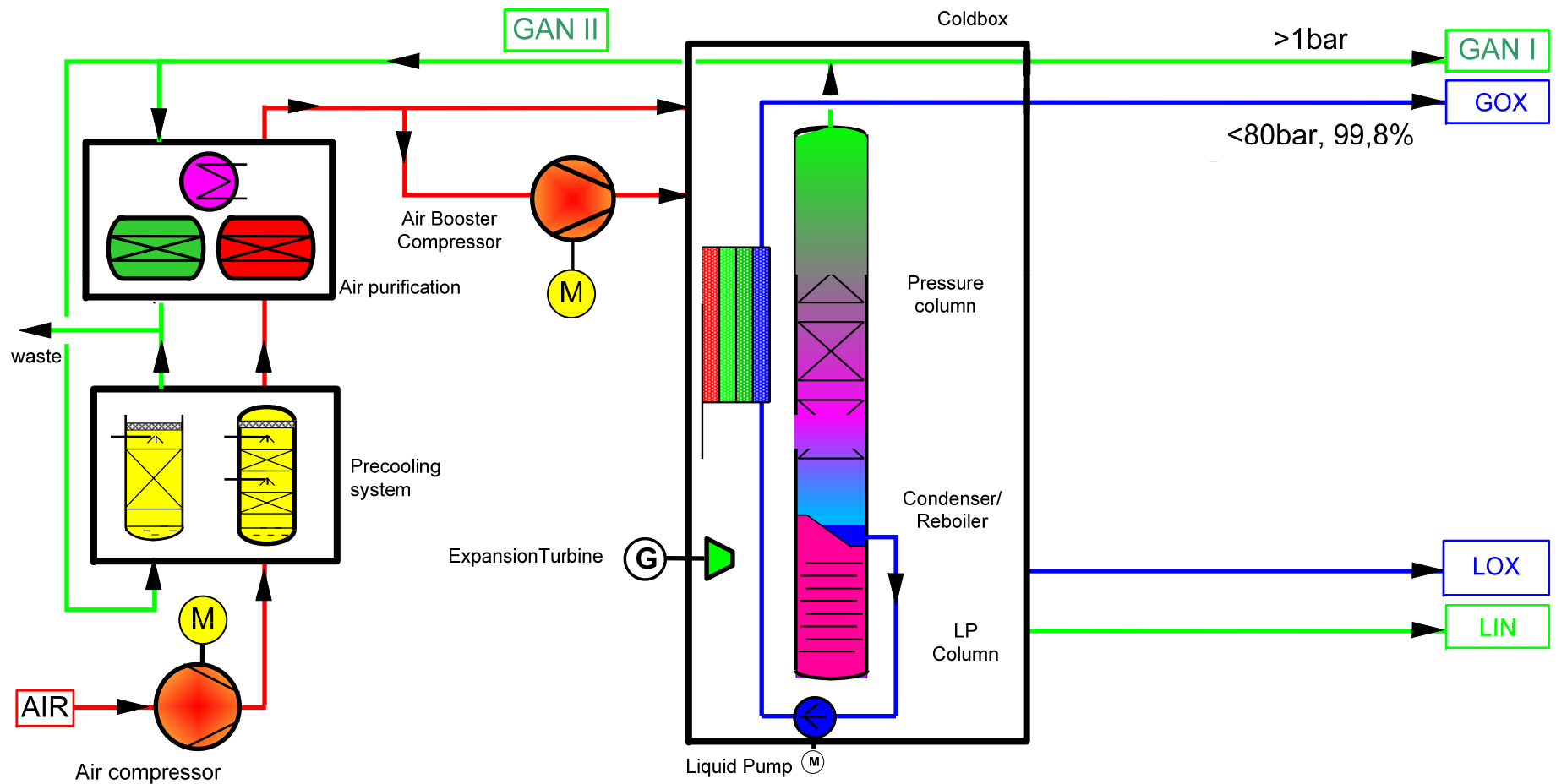
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Air Separation Plants

Simplified Air Separation Process

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Air compression,
-precooling and -purification

heat exchange, refrigeration,
rectification and internal compression

product
distribution

Alternative Air Separation Technologies



Cryogenic Air Separation (ASU)

- the principles invented one century ago (Dr. Carl von Linde)
- developed for large volumes of oxygen and nitrogen with high purities
- commercialized for industrial application in a wide range
- the source for Industrial Gas Companies supply schemes
- Continuous development and improvement , >25% power saving possible

Polymeric Membranes and Moleculare Sieves (PSA, VSA)

- advantageous for small volumes - at lower purities
- produced at ambient temperatures and as needed on-site

Oxygen Production by Chemical Air Separation (MOLTOX)

- Developed and pilot tested by Air Products with DOE funding in early 1990s
- >40% power saving predicted, compared with cryogenic processes
- Status and future of the process unknown (material- and corrossion problems)

High Temperature Ceramic Membranes (ITM)

- Developed and pilot testing (5t/d) since 2005 by Air Products with DOE funding
- 150 tpd under development;
- >30% power saving predicted

Alternative Air Separation Technologies

- Potentials to Reduce Power Consumption and Cost



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High ++

Polymeric Membranes and Molecular Sieves (PSA, VSA)

- advantageous for small volumes - at lower purities
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medium+

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?

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High ++

Alternative Air Separation Technologies - Potentials to Supply Large Product Flows



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low

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Typical Oxygen Demand for New Applications



New Applications		Capacity [MW]	Oxygen [tons/day]
IGCC	(demo)	250 - 300 MW	- 2.000 ¹⁾
IGCC, Oxyfuel	(demo)	300 - 600 MW	2.000 - 5.000 ¹⁾
CTL, Polygeneration	(project)	1500 MW	25.000 ¹⁾
GTL	(demo)	12.000 bpd	2.500 ²⁾
GTL scale)	(commercial	35.000 bpd	7.000 ²⁾
GTL scale)	(commercial	140.000 bpd	30.000 ²⁾

Cryogenic ASUs: Single train sizes with a capacity of 5.000 tons/d are available
capacities < 7.000 ton/d under development

¹⁾ Low purity oxygen <95%

²⁾ High purity oxygen >99,5%

Cryogenic Air Separation – Capacity Increase

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1902 :
5 kg/h
(0,1 ton/day)



2006 :
1,250 Mio kg/h
(30.000 ton/day)

Air Separation Plants – Shell „Pearl“ GTL Project Qatar 30.000 tons/day Oxygen

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Air Separation Plants – Shell „Pearl“ GTL Project Qatar 30.000 tons/day Oxygen

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Large Tonnage ASU Coldbox Shipment for „Pearl“ GTL project

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Tonnage Air Separation Plants Mega Plants for new Applications

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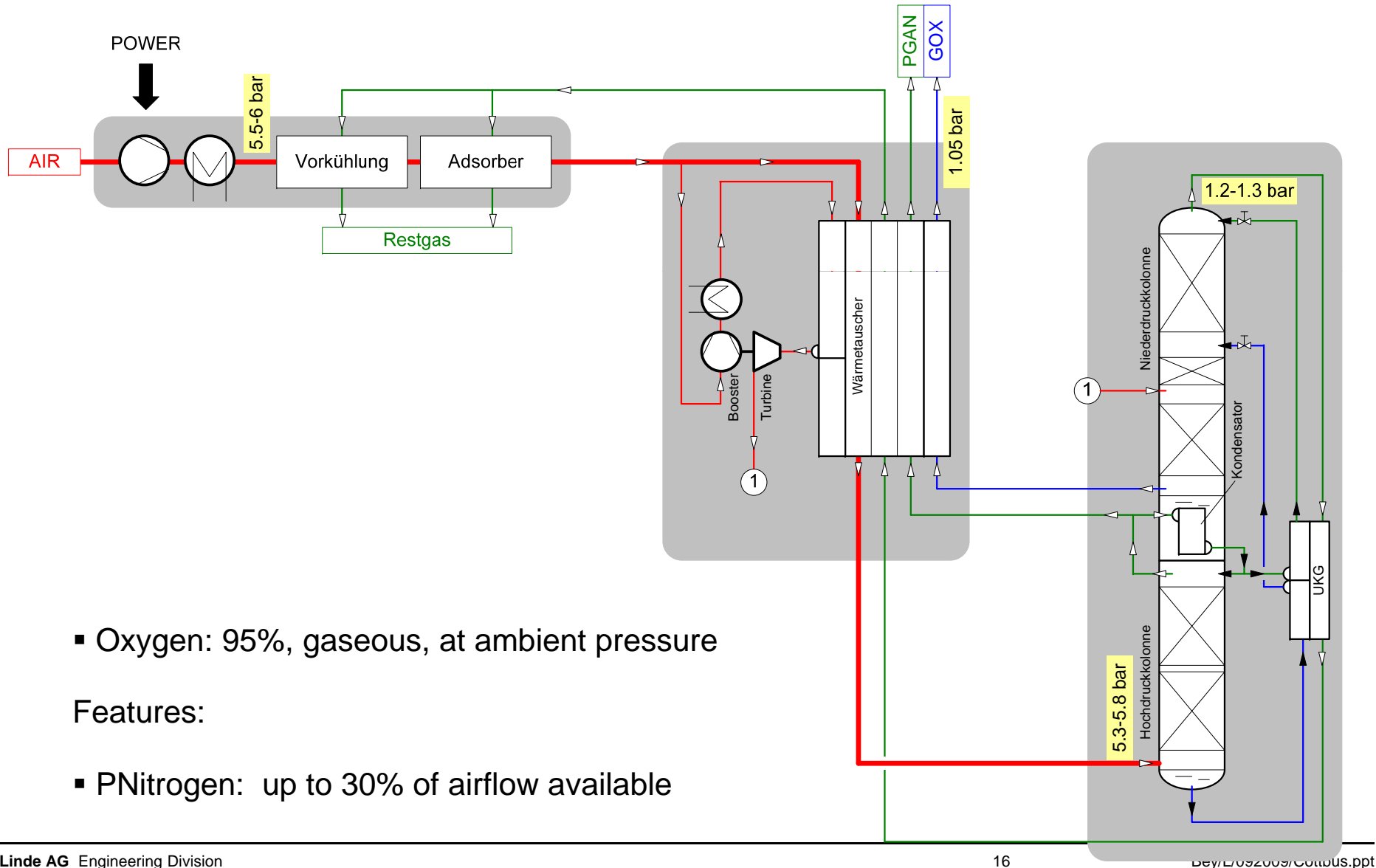
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Cryogenic Air Separation Process Optimization

Air Separation Process Conventional Design (mit Einblaseturbine)

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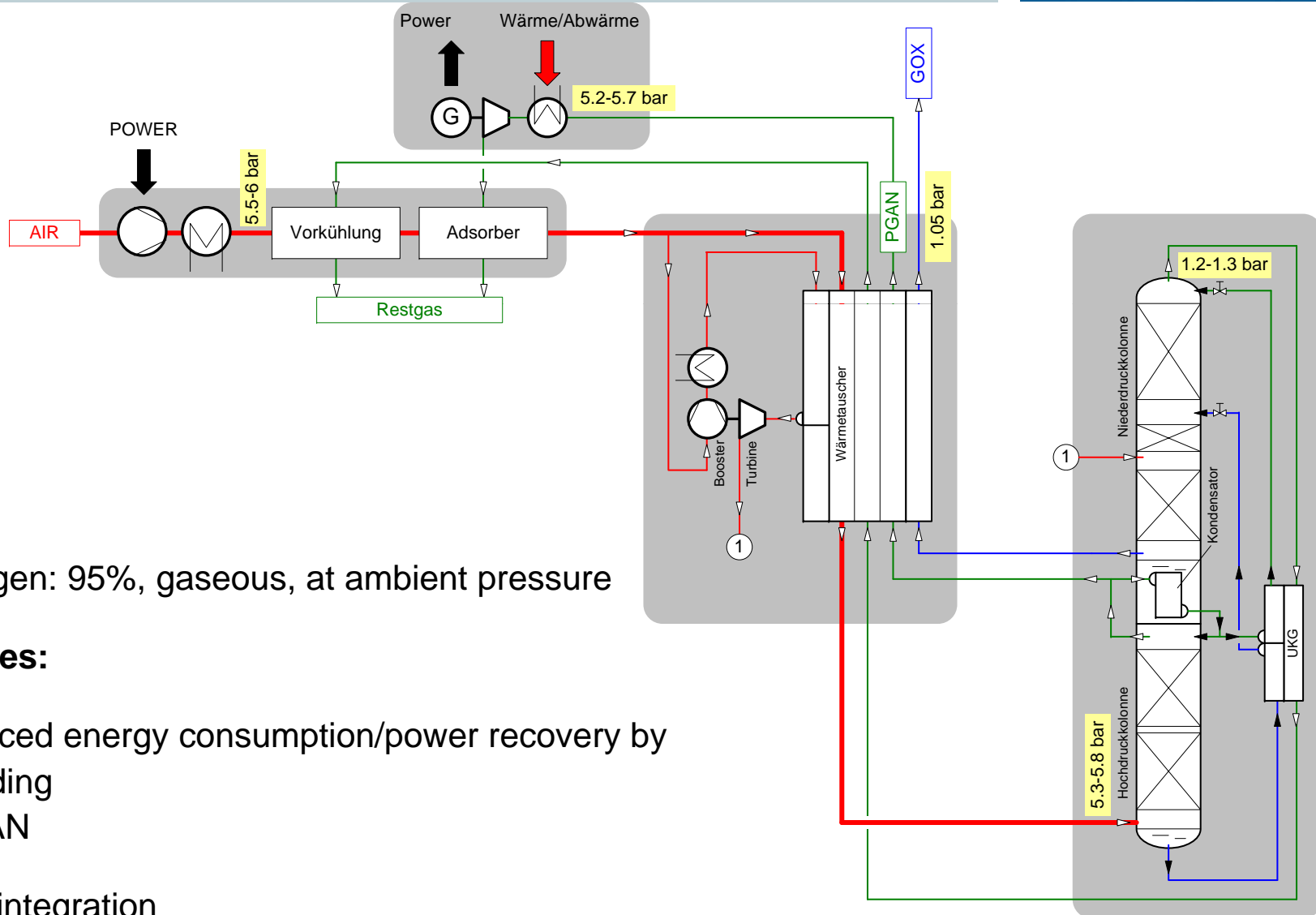


- Oxygen: 95%, gaseous, at ambient pressure

Features:

- PNitrogen: up to 30% of airflow available

Air Separation Process Advanced Alternative Design (mit warmer PGAN-Turbine)

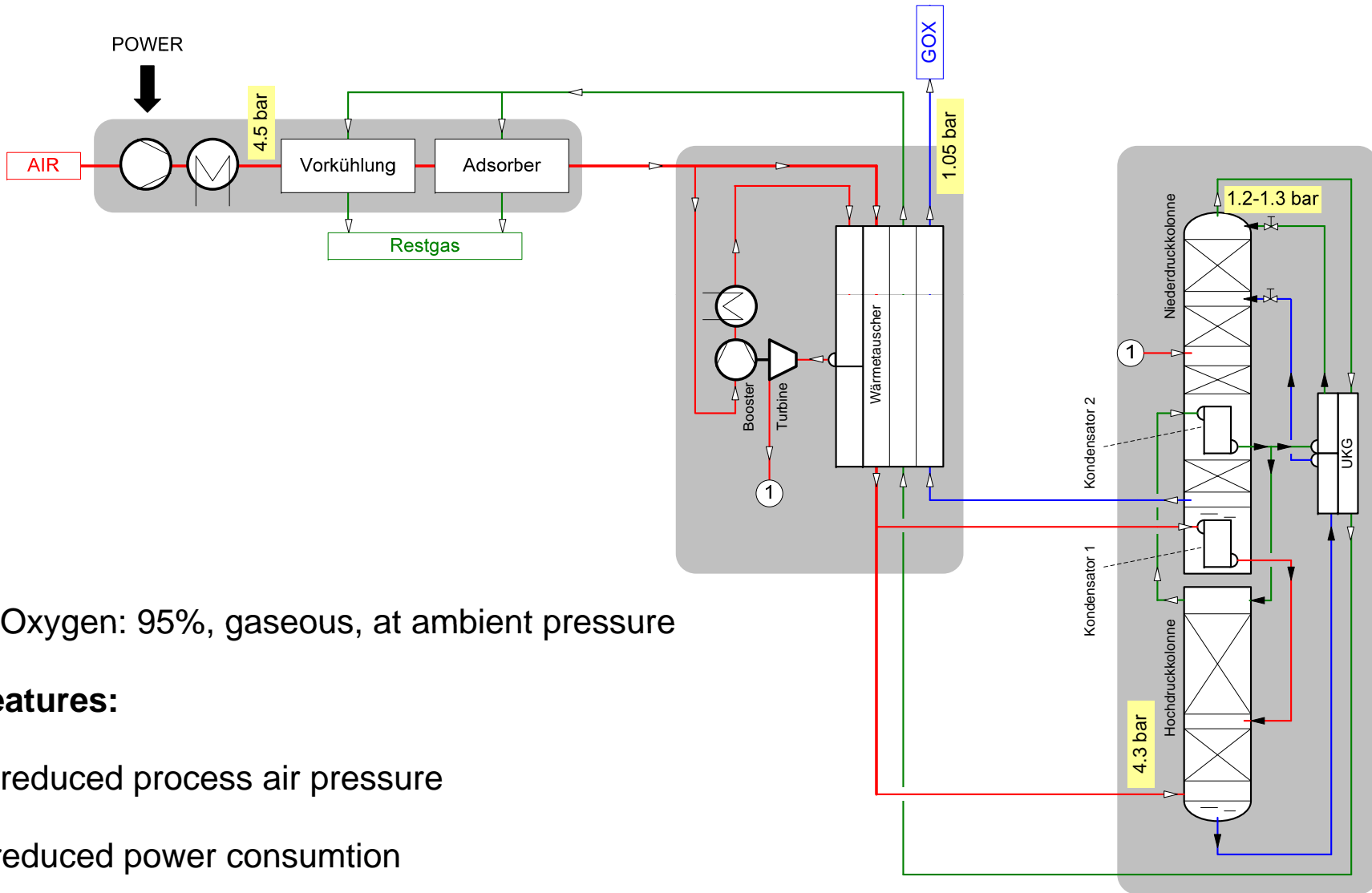


- Oxygen: 95%, gaseous, at ambient pressure

Features:

- reduced energy consumption/power recovery by expanding PGAN
- heat integration

Air Separation Process Advanced Alternative Design (“Dual Reboiler”- Design)

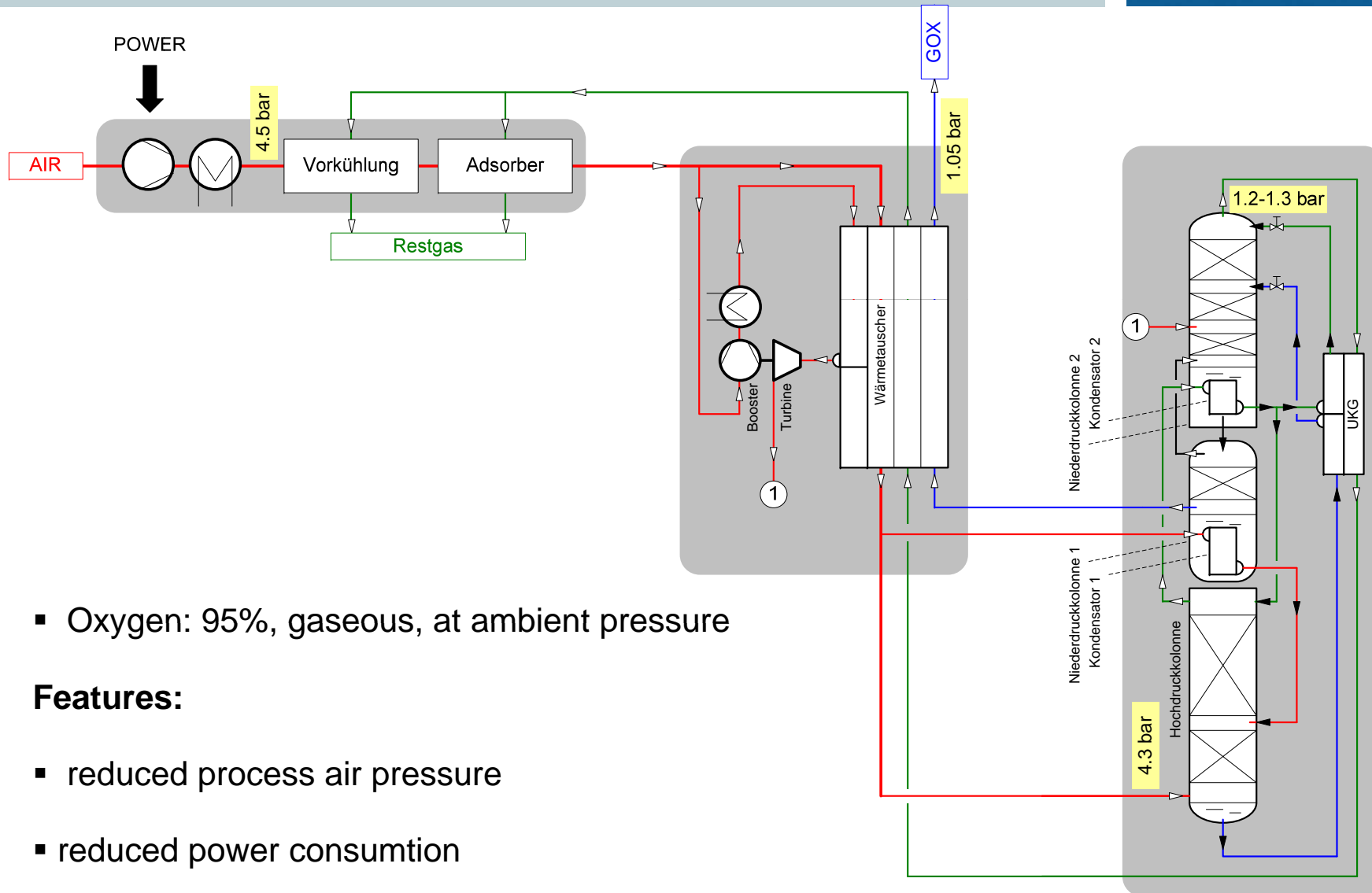


- Oxygen: 95%, gaseous, at ambient pressure

Features:

- reduced process air pressure
- reduced power consumption

Air Separation Process Advanced Alternative Design (3-column Design)



- Oxygen: 95%, gaseous, at ambient pressure

Features:

- reduced process air pressure
- reduced power consumption

Air Separation Units Cryogenic Oxygen / Specific Energy Consumption



Conventional Process Schemes / - Applications

kWh/Nm ³ ¹⁾	kWh/Nm ³ ²⁾	kWh/t (metric ton) ³⁾	kWh/t (short ton) (= 907,2 kg) ³⁾
Conversion Figures:			
1	0,95	699	635
0,35 kWh/Nm³	0,33 kWh/Nm³	245 kWh/t	222 kWh/t
Conventional ASU, Oxygen Purity >99.5%			



¹⁾ used by ASU vendors (Linde et al) and commonly used for process calculation
= 1,429 kg

²⁾ used by Gas Companies

³⁾ 1 Nm³

Air Separation Units Cryogenic Oxygen / Specific Energy Consumption



Advanced Process Schemes for New Applications, e.g. IGCC, Oxyfuel, IGSC

kWh/Nm ³ ¹⁾	kWh/Nm ³ ²⁾	kWh/t (metric ton) ³⁾	kWh/t (short ton) (= 907,2 kg) ³⁾
Advanced, energy optimized ASU, 95 % Purity Oxygen			
0,25	0,237	175	159



Power consumption reduced by > 25% !!

Above Figures are related to 100% Oxygen (contained Oxygen), normal ambient conditions for design: 20°C, 15°C CW, 60% rel. humidity, at sea level

Air Separation Plants Mega Plants for new Applications

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Power Plant Specific Requirements and their consequences

Air Separation Units for Power Plants Specific Requirements

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Specific Power Plant Requirements:

- **lowest possible power consumption**
- **CAPEX and OPEX optimization**
- **operation range from 60 to 105%**
- **load change > 2% per minute**
- **oxygen purity 95%**
- **low product pressure**

Differences between Power Plant Standards and conventional Industrial Gases Standards

Air Separation Units

Specific Requirements for Power Plants

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If project specific requirements:

- Design margin of 5%,
- turndown to 63%,
- design for maximum ambient conditions,
- liquid production

are not to be considered for design,

potential for further power saving of 8%.

Air Separation Units for Power Plants

Air Compression Efficiency

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Impact of Turndown Requirement on Main Air Compressor Efficiency

(For a typical ASU)

Turndown	Power at motor terminal Comparison	Additional power	
75 to 80%	18 500 kW		100 %
63%	19 100 kW	+ 600 kW	103 %
56%	19 500 kW	+ 1000 kW	105 %

Air Separation Units for Power Plants

Air Compression Efficiency

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Impact of Different Ambient Air Temperatures

Ambient Air Temperature	-17°C	9°C	30°C	33°C
Effective Air Volume Flow	91%	100%	107%	109%

plus 5% design margin

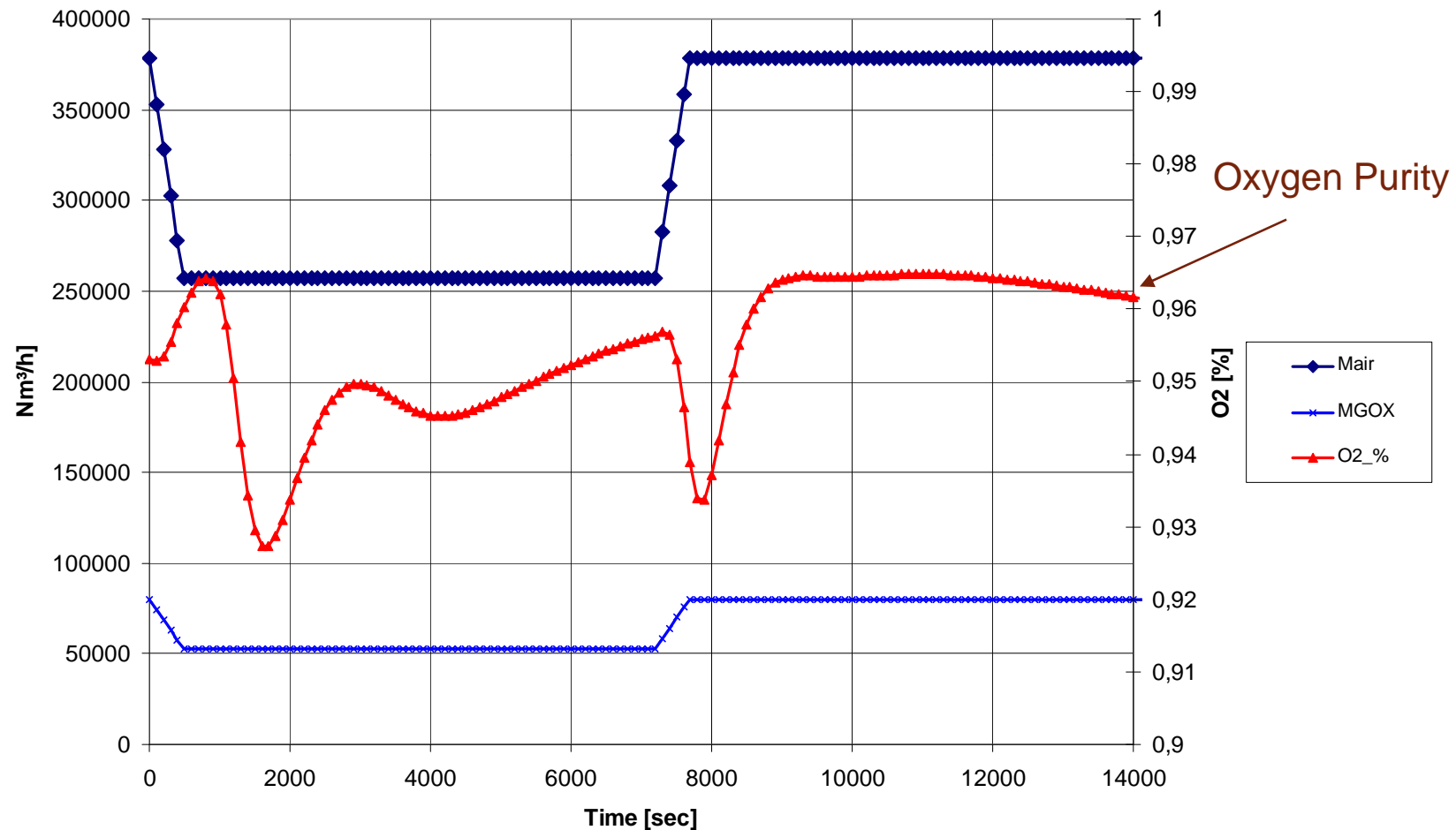
plus turndown requirement

Load change scenario: Ramping of process parameters

→ Target > 2%/min – fluctuation of oxygen purity?



Load change scenario - conventional process scheme considered
ramping > 4 %/min



Air Separation Units for Power Plants Summary, Low Power Consumption



Steps to low power consumption of ASU:

- ✓ apply highly efficient air separation process
- ✓ select appropriate compressor model
- ✓ identify possibilities for power/heat integration
- ✓ pick advantageous driver option
- ✓ check operations requirements carefully (turn down, design margin, etc.)

Advanced Cryogenic Air Separation - innovative improvements for new applications



- Advanced Structured Packings instead of sieve tray columns available
reducing pressure drop , increasing turndown capacity
- Advanced process control systems, ALC (AutomaticLoadChange) available
Dynamic Simulation
- Compressors with higher efficiency, larger turndown range development
- High efficient Heat Exchangers available
- Advanced process schemes ¹⁾ available

1) Large Scale Low Purity Oxygen Requirement (e.g. 95%) - is a novelty in Cryogenic ASU applica

➔ leads to a step change energy reduction compared to traditional applications !

Linde Engagement in CCS – Oxyfuel

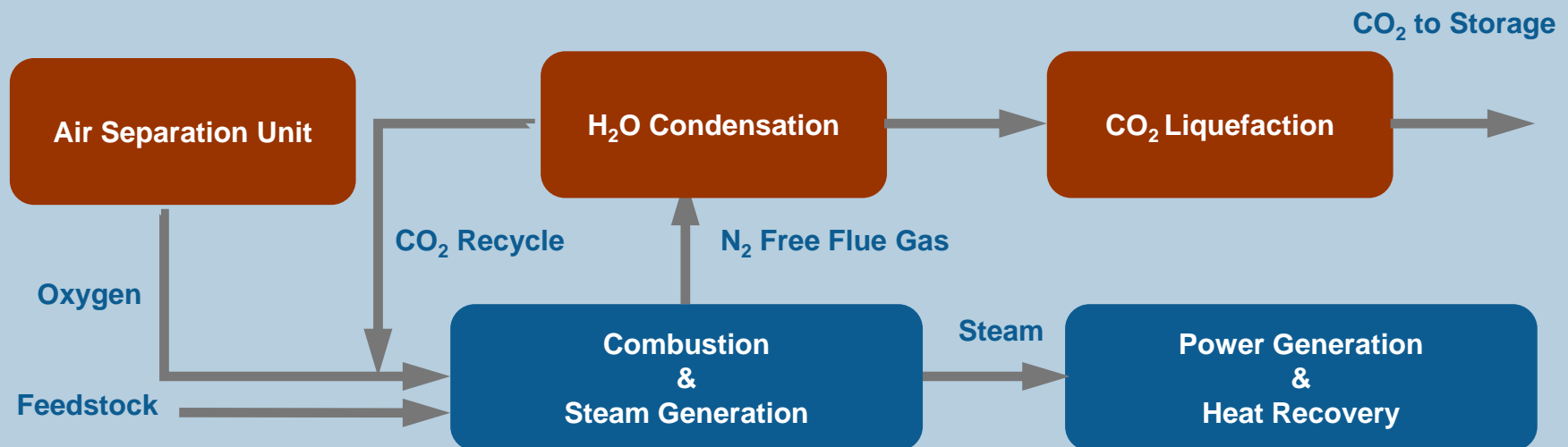
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Linde has built an air separation plant and a CO₂ purification and liquefaction plant for Vattenfall's first oxyfuel pilot plant for coal-based power generation with CO₂ capture.

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Portfolio

Oxyfuel Combustion



Groundbraking Ceremony May 2006

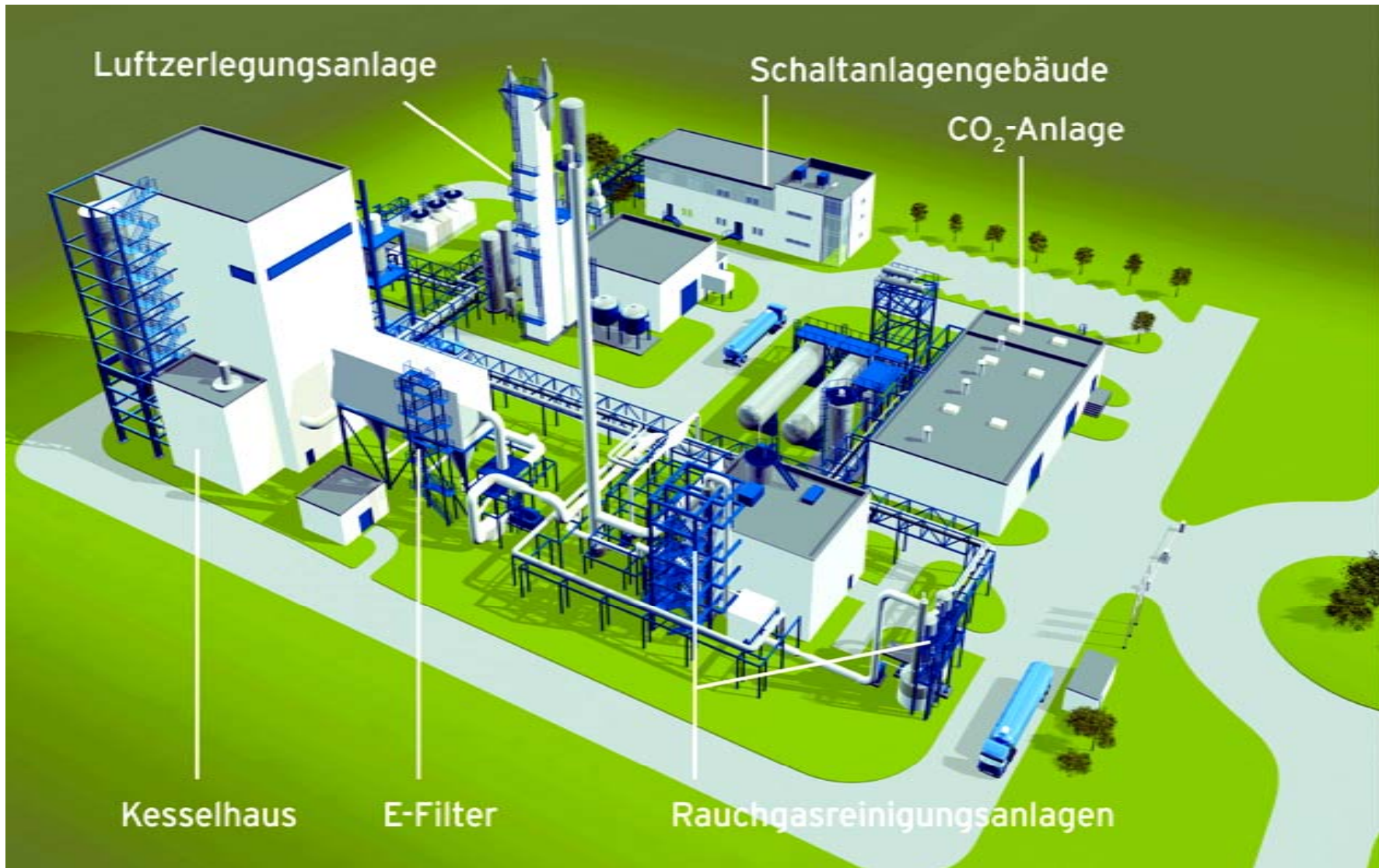
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Oxyfuel Pilot Plant Schwarze Pumpe – 3-D Model

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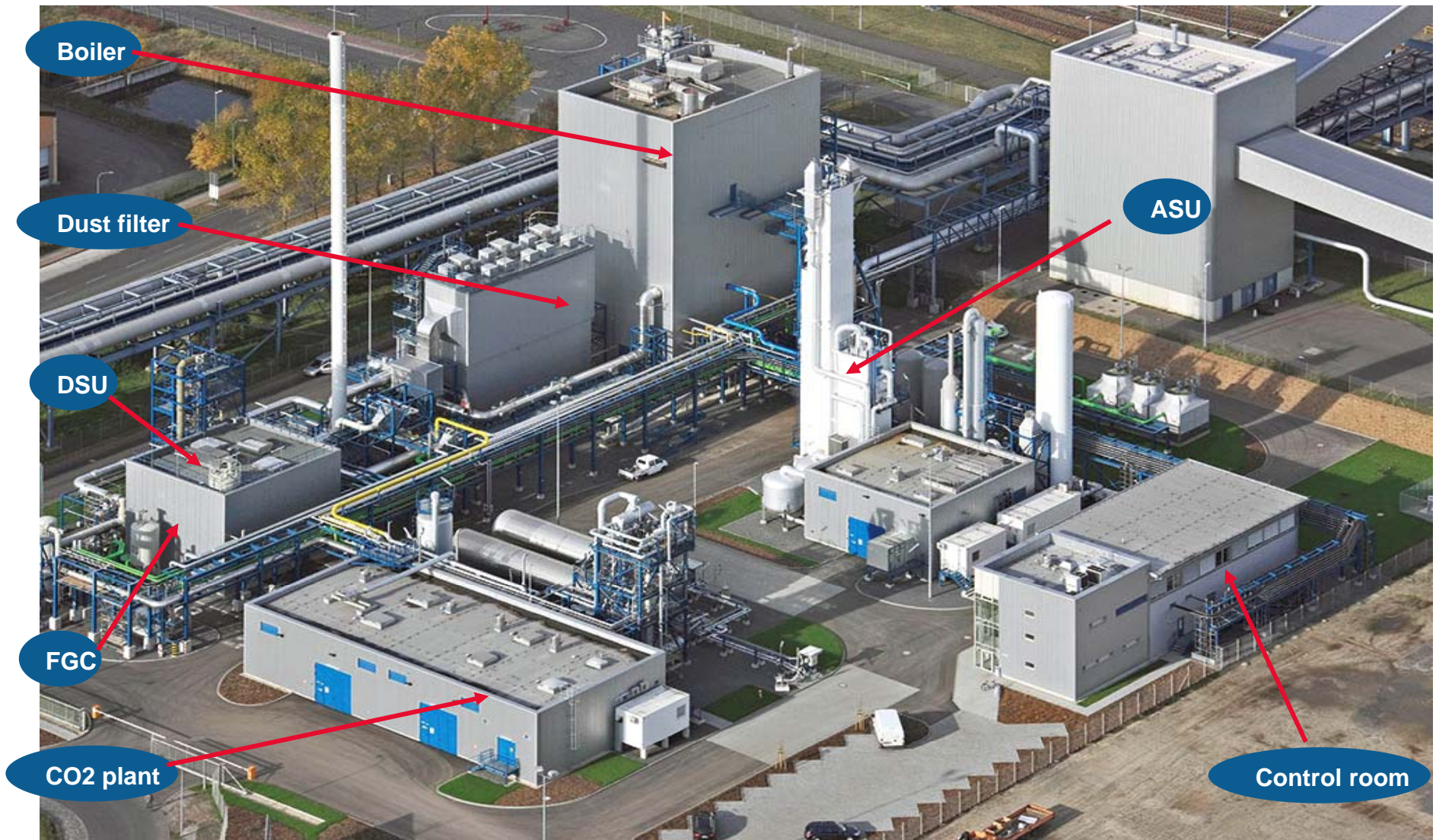
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Oxyfuel Pilot Plant Schwarze Pumpe Official Inauguration and start-up: Sept. 9th 2008

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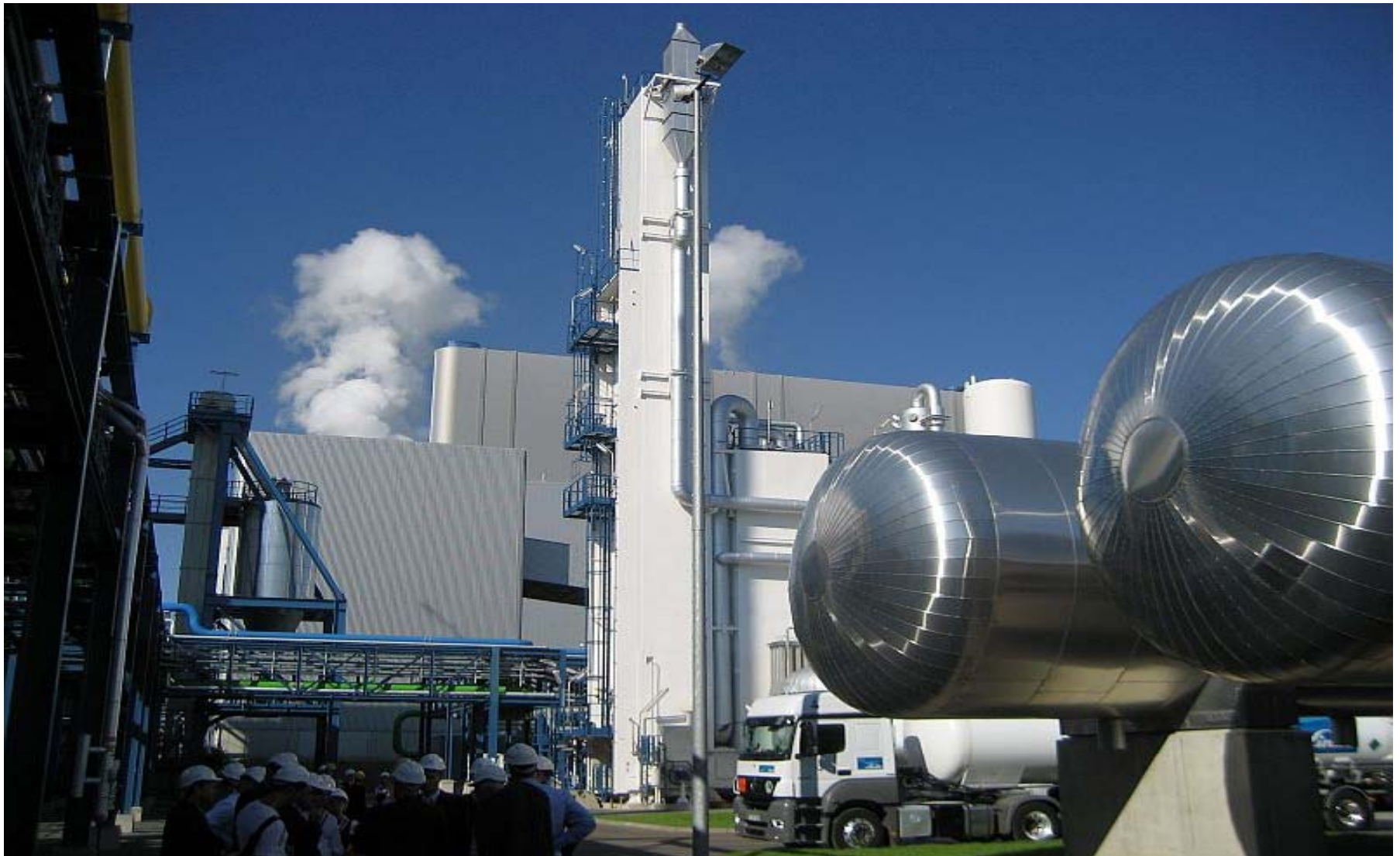
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Vattenfall Oxyfuel Powerplant Schwarze Pumpe Linde Scope: ASU, CO2 Plant; Technologiepartnership

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Vattenfall Oxyfuel Powerplant Schwarze Pumpe ASU with LCO2 Tank

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Vattenfall Oxyfuel Powerplant Schwarze Pumpe CO2 Plant with LCO2 Tanks

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„Coal or petcoke gasification, Oxygen for CO2-free power generation, Hydrogen for refinery applications, LNG, and Gas To Liquids, are all energy related development trends where Linde is engaged and offers appropriate technologies and know-how.“

Linde - the Pioneers of Air Separation – we are able to respond to the challenge of producing cleaner fuel & energy for the growing worldwide demand.

(Dr. Aldo Belloni , CEO-Linde)

**Thank you
for your attention.**

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