AGENDA

1. The Linde Group - a leader in Industrial Gases and Engineering
2. Clean Energy - a growth driver at Linde
3. Linde project portfolio for cleaner steel production
4. Indicative off gas utilization case study
5. Summary & Outlook
1 The Linde Group - a leader in Industrial Gases and Engineering
Linde R&D and Innovation Structure

The Linde Group

- Linde Engineering
- Innovation Management
  - Andreas Opfermann
- Linde Gas
- LE R&D (&LEDD)
  - Hubertus Winkler
- Clean Energy Technology
  - Harald Ranke
- Application Development
  - Volker Häckh
The Linde Group - a leader in Industrial Gases and Engineering

Megatrend: Clean energy

- Challenge: meeting increasing energy needs while reducing greenhouse gas emissions
- Linde supports application of sustainable energy technologies, such as photovoltaics, hydrogen and biofuels
- Working on solutions to lower the ecological impact of fossil fuels, e.g. CCS, EOR and LNG
2 Clean Energy - a growth driver at Linde
Long-term growth drivers opportunity areas are identified

- Maturing oil fields
- High oil price outlook

- Indigenous coal reserves
- Carbon reduction (with CCS/U)

- Sustainable spread between oil and NG
- Transition to carbon reduced fuels

- Regulations
- Public funding schemes

- Indigenous availability
- Large reserves

- Transition to sustainable energy
- Regulations incentives
- Hydrogen Mobility
2 Clean Energy - a growth driver at Linde
Clean Energy has three growth horizons

- Hydrogen as fuel
- Green Hydrogen
- Biomass conversion
- Energy storage, CCU
- Heat recovery

- OxyFuel
- PCC
- CO₂ networks
- Solar-/Geothermal

- CO₂ & N₂ EOR, NRU
- Clean coal
- Merchant LNG

Technology development
Business development

Play new businesses
Exploit technologies & business models
Leverage Linde competence

Technology platforms, demonstrations & partnerships
Business models, financing, lobbying & technology differentiation
Market insights, industry expertise & opportunity development

Scouting & Screening
Development, M&A
Sales next to core business
Linde is adopting a dual approach to the development of relevant technologies for the steel industry:

In countries like Germany, with public concerns regarding CCS, Linde is looking at converting CO and hydrogen containing fuel gases into usable by-products. The concepts could also be applied in regions where sequestration sites are not available or accessible.

In parallel with this, Linde is selling and developing technologies that exploit oxy-fuel combustion to lower high caloric fuels consumption, lower energy consumption, or to generate flue gas streams suitable for CCS.
3 Linde project portfolio for cleaner steel production
Measures to reduce CO2 footprint

Carbon Capture from flue gases

Fuels & Chemical utilization

- Oxygen plant
- Power plant
- Renewable E-power
- Energy storage

Blast furnace
Lime furnace
External coke
SNG/methanisation
TGR
BioGas
Expanded oxyfuel combustion

BOF and Ladle metallurgy
Continuous casting
Reheating and rolling

Natural gas

Sales
Development
Screening
3 Linde project portfolio for cleaner steel production
Ecologic efficiency - today’s double bind

Linde approach during screening & scouting:
Evaluate core process technologies in strategic partnerships

IRR

Optimum technology

CO2
13.47 €/t↑

Environmental acceptance
↓ CO2,e-Footprint

BAT

Affordable compromise
### 4 Indicative off gas utilization case study
Measures to reduce CO2 footprint - summary I

<table>
<thead>
<tr>
<th>Technology</th>
<th>Accessible Mio. t CO2</th>
<th>Impact of process step ∆ t CO2 / t steel</th>
<th>Abatement costs ∆ € / t saved CO2</th>
</tr>
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<tbody>
<tr>
<td>NG replacement, e.g. blast furnace</td>
<td></td>
<td></td>
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<tr>
<td>• BioGas</td>
<td>1,00</td>
<td>-0,05</td>
<td>350</td>
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<tr>
<td>• SNG via H2O electrolysis</td>
<td></td>
<td>+0,20</td>
<td>n.a.</td>
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<td>Regenerative Power</td>
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<td>• ASU by Geothermal Power</td>
<td>0,23</td>
<td>-0,17</td>
<td>110</td>
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<td>Chemical utilization Off-Gases</td>
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<td>MeOH/DME &amp; downstream</td>
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<tr>
<td>• Lean Design</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>• Full reduction potential</td>
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</tbody>
</table>
4 Indicative off gas utilization case study
Application case following state of the art ISM

Characteristic data

- 20 Mio. t CO2
- 12 Mio. t steel
- 70 MW Power export reimbursed

KPI
1,60 t CO2/t steel

Gas flows

- Coke Oven: 100% 160,000 m³
- Converter: 100% 100,000 m³
- Blast furnace: 100% 2,000,000 m³
- NG import

Relevant cases for further analysis
4 Indicative off gas utilization case study
Framework for Life Cycle Analysis and economics

Integrated metallurgical plant
Stand alone POx + MeOH plant

Integrated MeOH plant

Product marketing
Fe, ...
Power*
MeOH
BTX, NH3, Sulfur

*Power balanced for zero import/export

Feedstock supply
- Ores
- Coal
- PetCoke
- Charge
- Natural Gas...

A
Integrating
B

Industry bridging integration:
Steel + Chemistry/Fuel
4 Indicative off gas utilization case study
Case definition - main process steps

COG is used completely, CG is adjusted

**H₂:CO = 2:1**

Coke oven

1. Coke oven
2. Purification (compression)
3. Purification (compression)
4. CH₄ import

Converter

1. Converter
2. Purification (compression)
3. Purification (compression)
4. CH₄ import

COG-CH₄

**COG-CH₄**

Dry reforming

**COG-CH₄**

H₂O reforming

**COG-CH₄**

H₂O reforming

MeOH reactor

MeOH reactor

MeOH reactor

MeOH reactor

Not converted components are combusted, further downstream according to customer requirements
4 Indicative off gas utilization case study
CO2-footprint “well to gate” - schematic

Zero-footprint

Feedstock black coal

Process emissions other operational units

Off Gases to power plant

NG feedstock

MeOH transport

CH4 to MeOH

Combust.

COG + CG to MeOH

Residual gases combustion

Scaling: Product capacity

Fe

Power*

MeOH

CO2-emission

Fe

Power = 0

MeOH *credits

IMPROVEMENT
4 Indicative off gas utilization case study
Lean concept

Zero-footprint

A

Feedstock black coal

1.14

12.3

Process emissions other operational units

9.1

Off Gases to power plant

NG feedstock supply

CH4 to MeOH

Power plant CH4 combustion

Power plant residual gas

1.14

12.3

0.15

8.3

CO2-emissions

Σ 20.5 Mio. t/a

Σ 22.3 Mio. t/a

Σ 20.9 Mio. t/a

Σ 20.1 Mio. t/a

COG + CG to MeOH

ISBL and well to gate with dedicated results!
4 Indicative off gas utilization case study
Eco-efficiency for Methanol production

Margin to ME import
[€/t MeOH]

SR: CH₄ import to convert CO + CO₂
No reforming
Steam reforming
SR: CH₄ import to convert all CO
Dry reforming

% Improvement CO₂ footprint ISBL

Bubble size represents:
CAPEX

Sensitivity credits • 1:1 to 1:2
4 Indicative off gas utilization case study
Eco-efficiency for Methanol production – CAPEX size effects

Advantage since reformer redundant

Larger compressor erodes advantage of smaller reformer

Indicative specific CAPEX

MeOH Green Field
MeOH Integrated

MeOH plant size [Mta]
4 Indicative off gas utilization case study
Eco-efficiency for Methanol production - findings

Chemical utilization is an opportunity to reduce the CO2 emissions, it is add-on!

Optimum Scenario “Full COG use, no reforming” with potential return
Revenues instead of abatement costs also for enhanced MeOH production (reforming cases)

Strengths
• Manageable investment, flexible downstream to even more upgrade
• Increasing CO2 certificated prices expected ➔ favor the proposed route
• In principle available now

Challenges
• Purification of COG and CG to catalyst specifications
• Impact on energy balance, especially consumption of COG
Linde’s steel activities besides CCS

Steel companies´ deeper involvement in fuel/chemicals business

Linde has re-identified the Off Gas utilization for fuels chemicals production as a field of substantial business opportunities.

Next, CE-T shifts from screening to development activities. Linde feels open-minded for collaborations, e.g. site studies.

Smart washing concepts and robust catalysts to be further developed and tested before skimming the full potential.

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Questions?

CE is not just a slogan. It is a must and it is a perfect fit with Linde’s business!
Main assumptions

NG Footprint: German Bundestag, 2007
Power: GUD with 0,37 t CO2/MWh
Bio-methane: Wuppertal-Institut
Efficiency electrolysis 65% to 70%
CO2: 0 to 80 €/t
Efficiency Methanisation 75 to 85%

NG 2.4 cent / kWh
Bio-methane 6 cent / kWh