IEAGHG I&S Workshop CCS

Cleaner steel production

LeadIng.

THE LINDE GROUP

Düsseldorf, 8th November 2011

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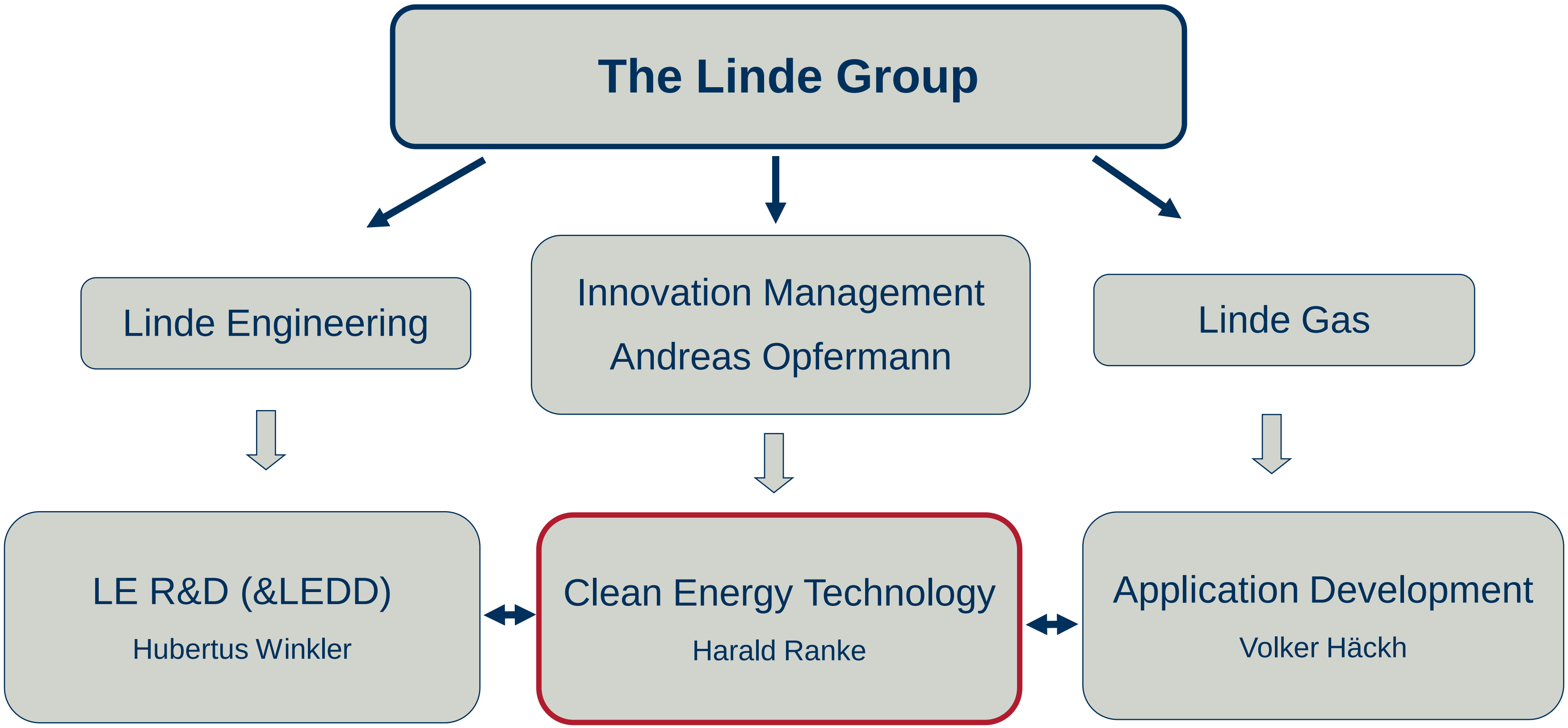
AGENDA

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



1 The Linde Group - a leader in Industrial Gases and Engineering

Megatrend: Clean energy

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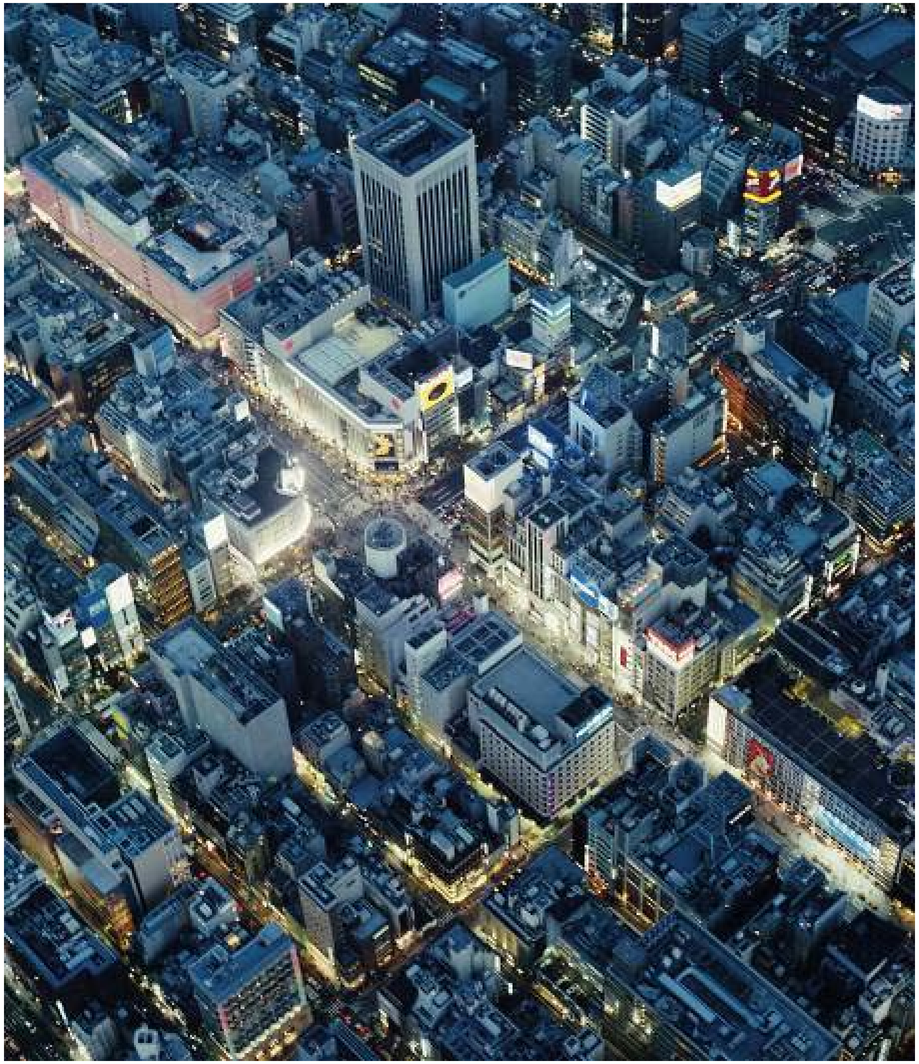
- Challenge: meeting increasing energy needs while reducing greenhouse gas emissions
- Linde supports application of sustainable energy technologies, such as photovoltaics, hydrogen and biofuels
- Working on solutions to lower the ecolo-gical impact of fossil fuels, e.g. CCS, EOR and LNG



2 Clean Energy- a growth driver at Linde

Long-term growth drivers opportunity areas are identified

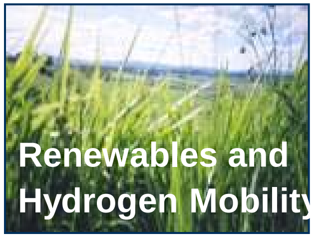
- Maturing oil fields
- High oil price outlook

- Regulations
- Public funding schemes

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

- Indigenous availability
- Large reserves

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



- Transition to sustainable energy
- Regulations incentives
- Hydrogen Mobility

2 Clean Energy- a growth driver at Linde

Clean Energy has three growth horizons

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Technology development | Business development

Play new businesses	Exploit technologies & business models	Leverage Linde competence
— Hydrogen as fuel — Green Hydrogen — Biomass conversion — Energy storage, CCU — Heat recovery	— OxyFuel — PCC — CO_2 networks — Solar-/Geothermal	— CO_2 & N_2 EOR, NRU — Clean coal — Merchant LNG
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**

3 Linde project portfolio for cleaner steel production

Top view on CCS and (steel) industry

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Linde is adopting a dual approach to the development of relevant technologies for the steel industry:

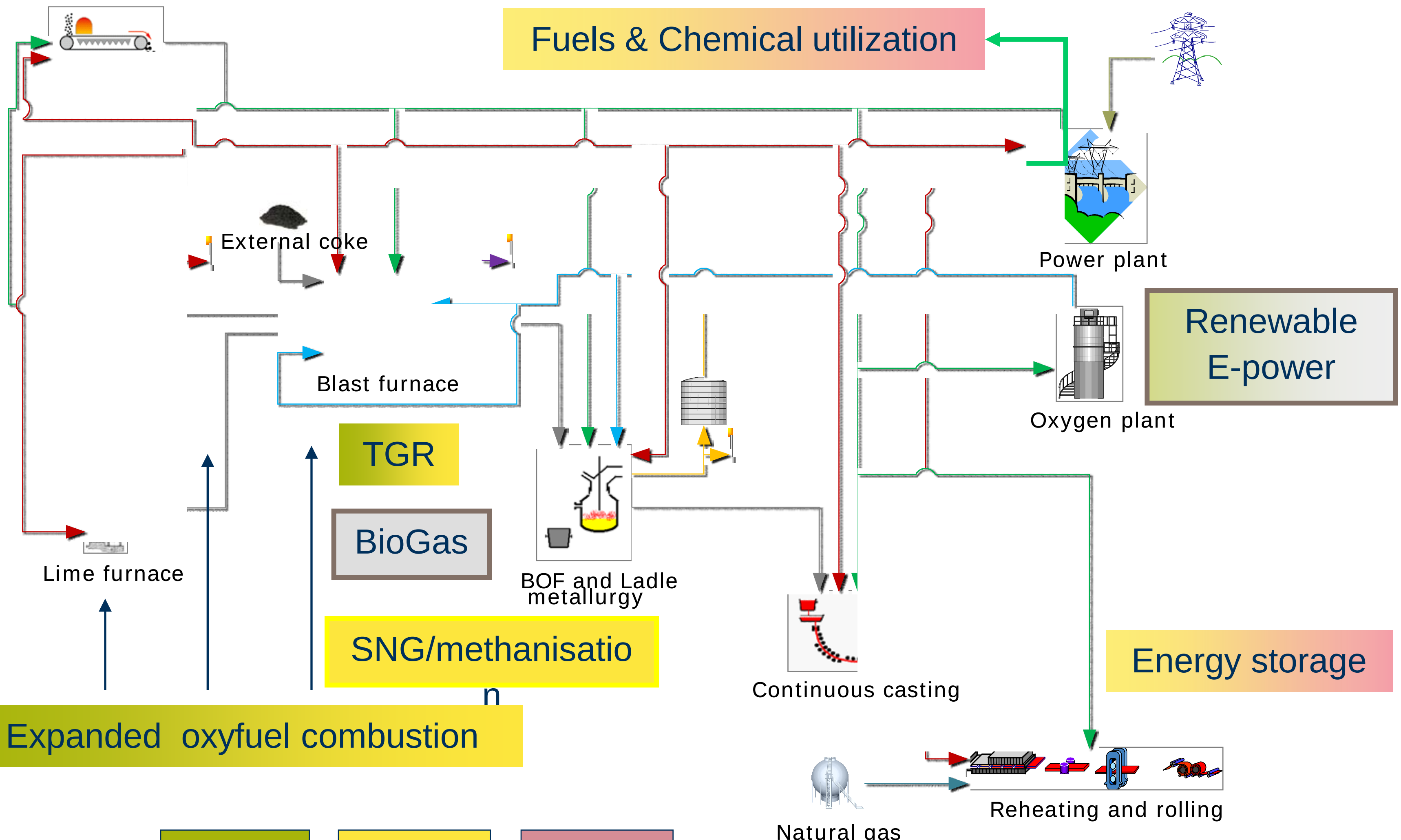
In countries like Germany, with public concerns regarding CCS, Linde is looking at converting CO and hydrogen containing fuel gases into usable by-products. The concepts could also be applied in regions where sequestration sites are not available or accessible.

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



Sales | Development | Screening

3 Linde project portfolio for cleaner steel production

Ecologic efficiency - today's double bind

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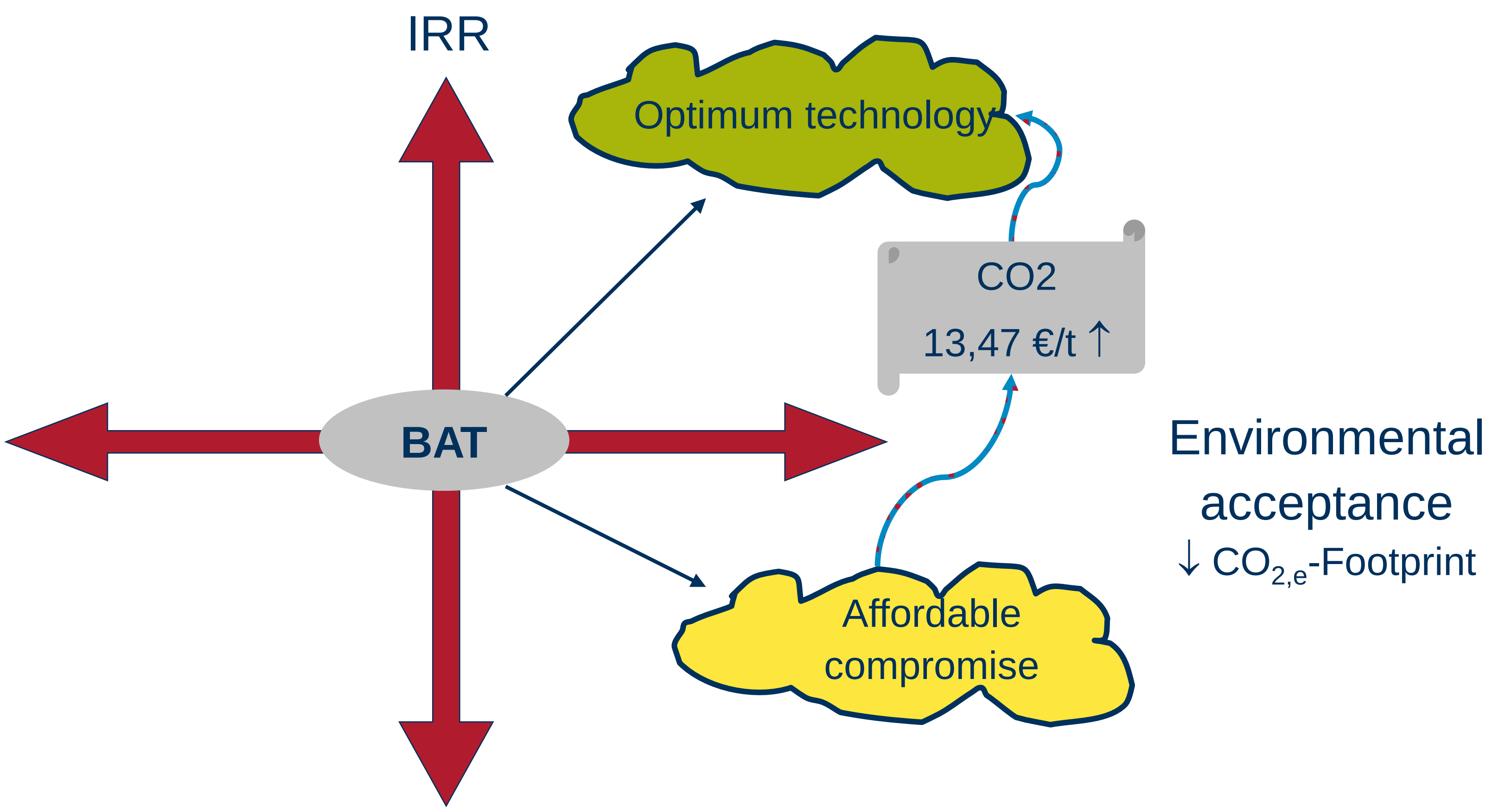

Linde approach during screening & scouting:

Evaluate core process technologies in strategic partnerships

4 Indicative off gas utilization case study

Measures to reduce CO2 footprint - summary I

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Technology	**Accessible** **Mio. t CO2**	**Impact of process step** **Δ t CO2 / t steel**	**Abatement costs** **Δ € / t saved CO2**
…			
NG replacement, e.g. blast furnace •BioGas •SNG via H2O electrolysis	1,00	-0,05 +0,20	350 n.a.
Regenerative Power • ASU by Geothermal Power	0,23	-0,17	110
…			
Chemical utilization Off-Gases **MeOH/DME & downstream** • Lean Design • Full reduction potential			

4 Indicative off gas utilization case study

Application case following state of the art ISM

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Characteristic data

20 Mio. t CO_2

12 Mio. t steel

70 MW Power export reimbursed

KPI

1,60 t CO_2/t steel

Gas flows

Coke Oven	Converter	Blast furnace	NG import
100%	100%	100%	
160.000 m^3 i.N.	100.000 m^3 i.N.	2.000.000 m^3 i.N.	

Relevant cases for further analysis

4 Indicative off gas utilization case study
Framework for Life Cycle Analysis and economics

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Feedstock supply

Ores
Coal
PetCoke
Charge
Natural Gas…

A

Integrated metallurgical plant → **Stand alone POx + MeOH plant**

B

Integrated metallurgical plant → **Integrated MeOH plant**

Industry bridging integration:

Steel + Chemistry/Fuel

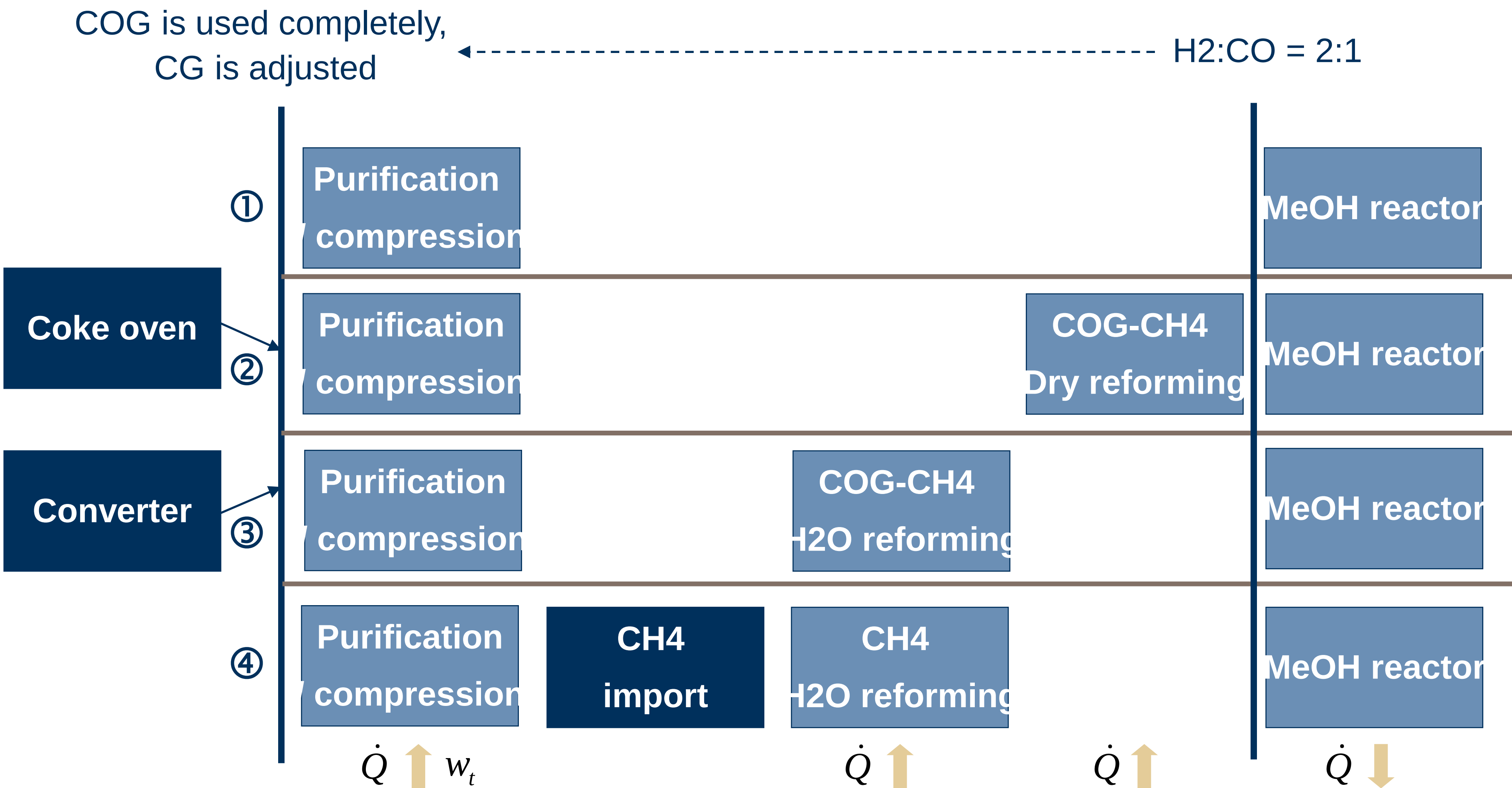
Product marketing

Fe, …
Power*
MeOH
BTX, NH3, Sulfur

*Power balanced for zero import/export

4 Indicative off gas utilization case study

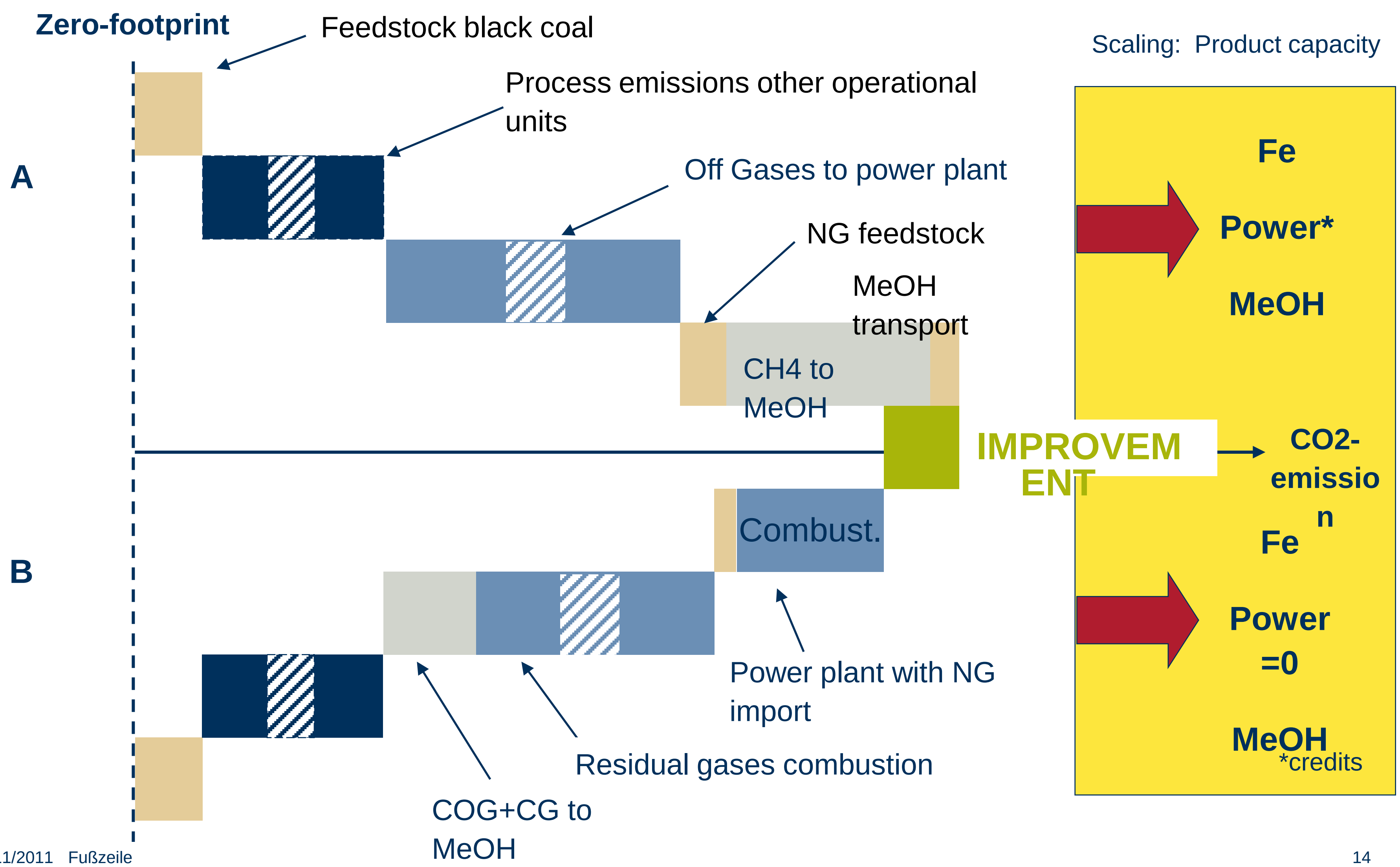
Case definition - main process steps



Not converted components are combusted, further downstream according to customer requirements

4 Indicative off gas utilization case study

CO2-footprint “well to gate” - schematic



4 Indicative off gas utilization case study

Lean concept

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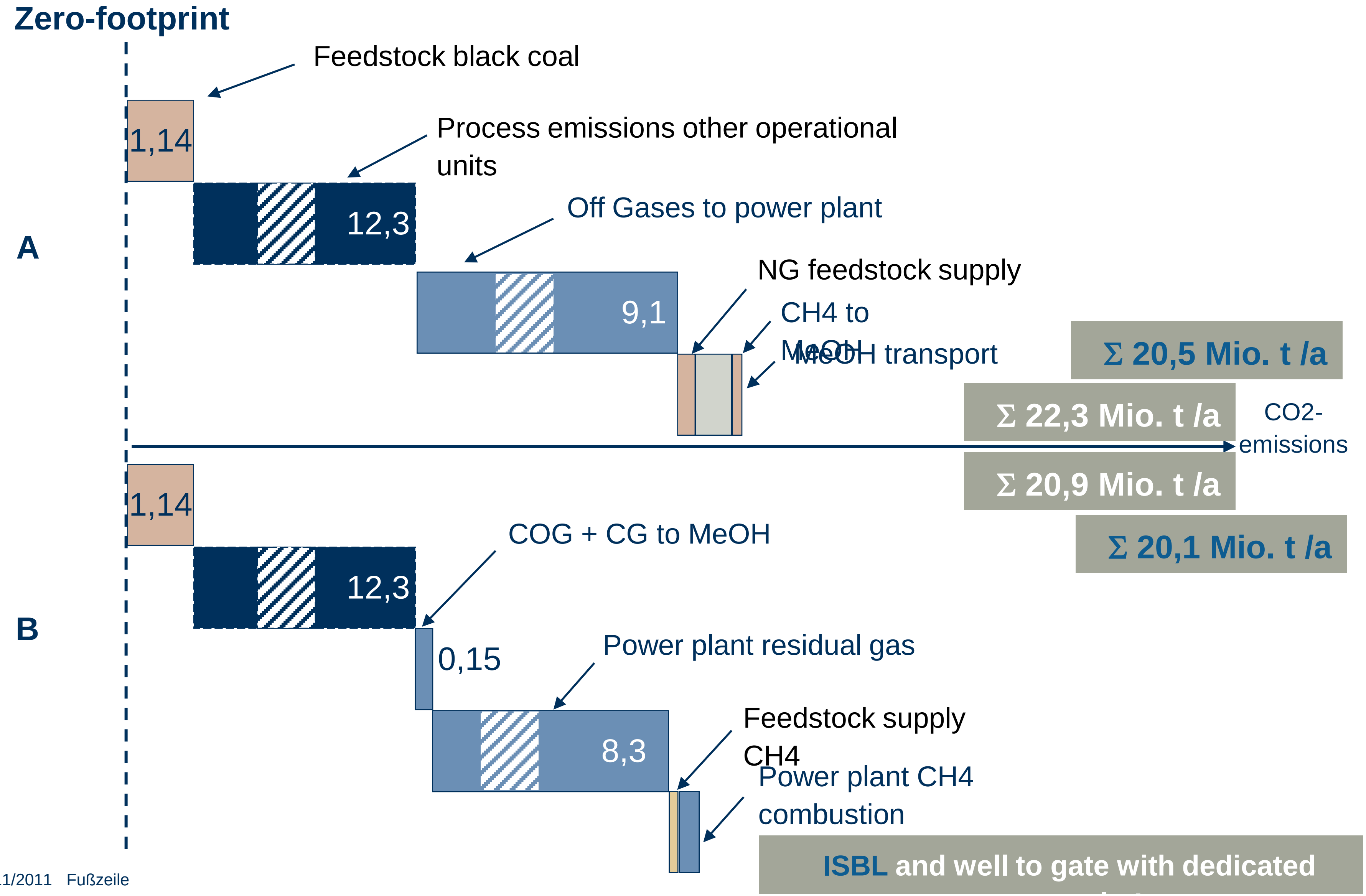
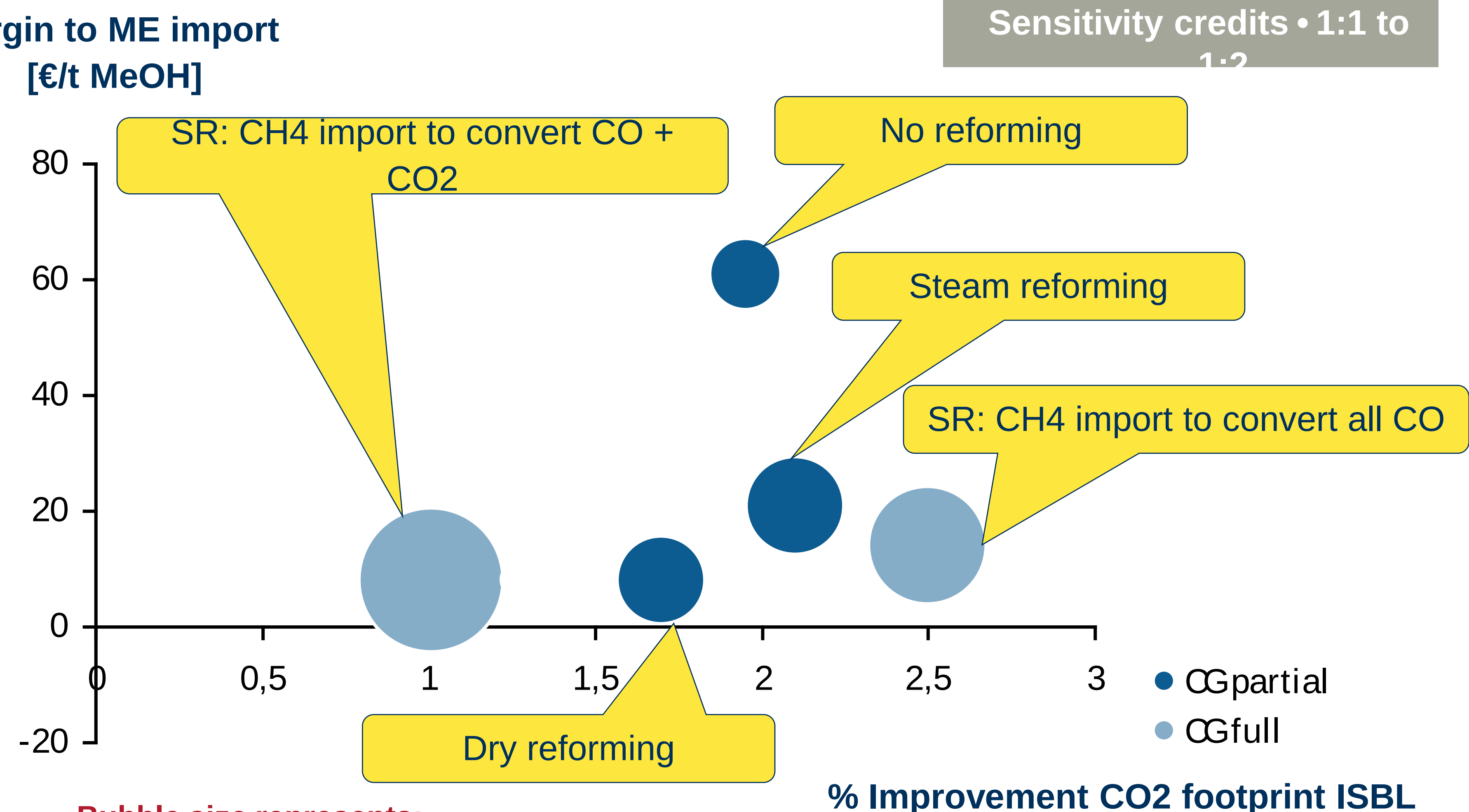


4 Indicative off gas utilization case study

Eco-efficiency for Methanol production

Sensitivity credits • 1:1 to 1:2



Bubble size represents: CAPEX

4 Indicative off gas utilization case study

Eco-efficiency for Methanol production – CAPEX size effects

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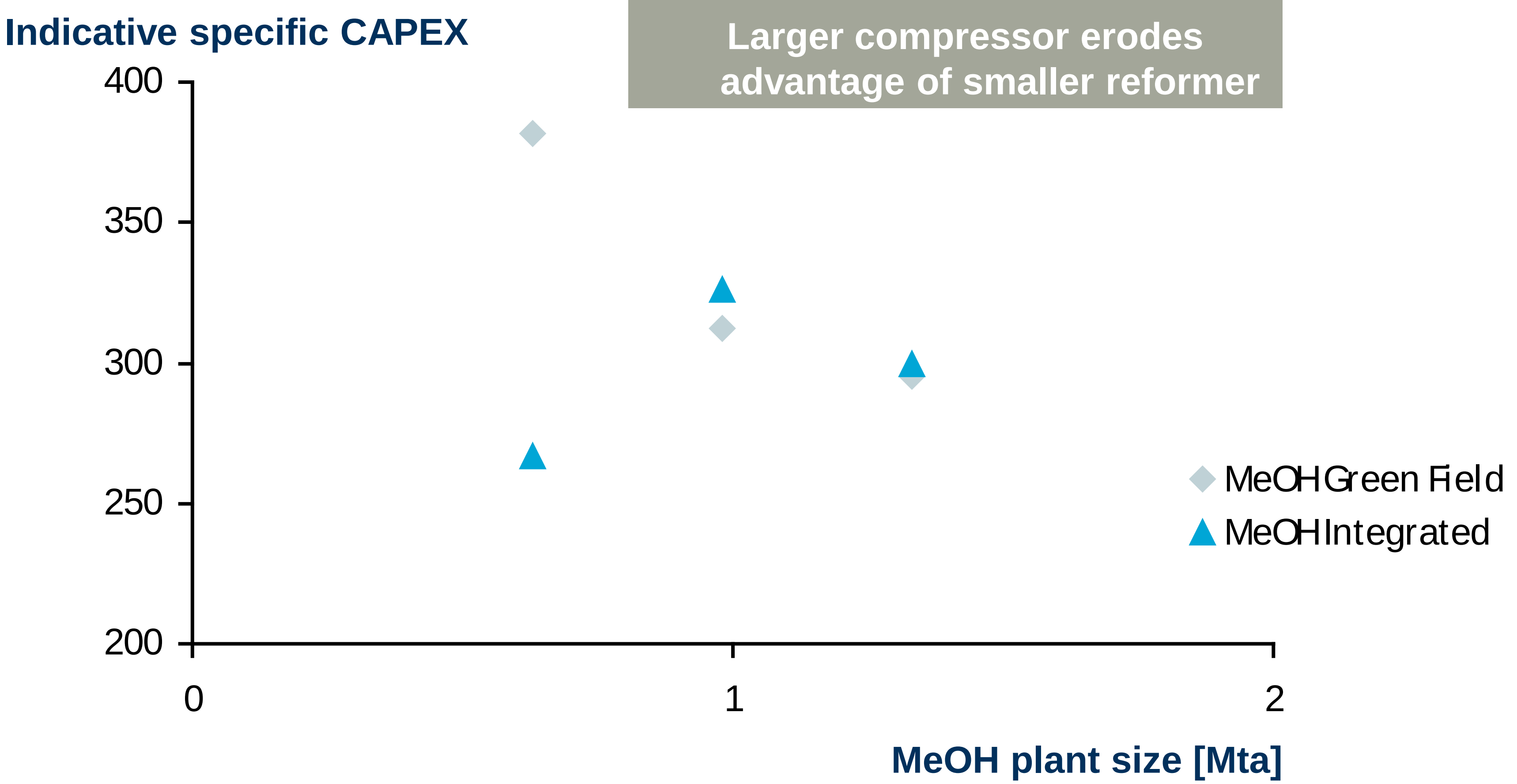
Advantage since reformer redundant

Larger compressor erodes advantage of smaller reformer



4 Indicative off gas utilization case study

Eco-efficiency for Methanol production - findings

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Chemical utilization is an opportunity to reduce the CO_2 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 CO_2 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

6 Summary & outlook

Linde's steel activities besides CCS

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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.

Steel companies´ deeper involvement in fuel/chemicals business

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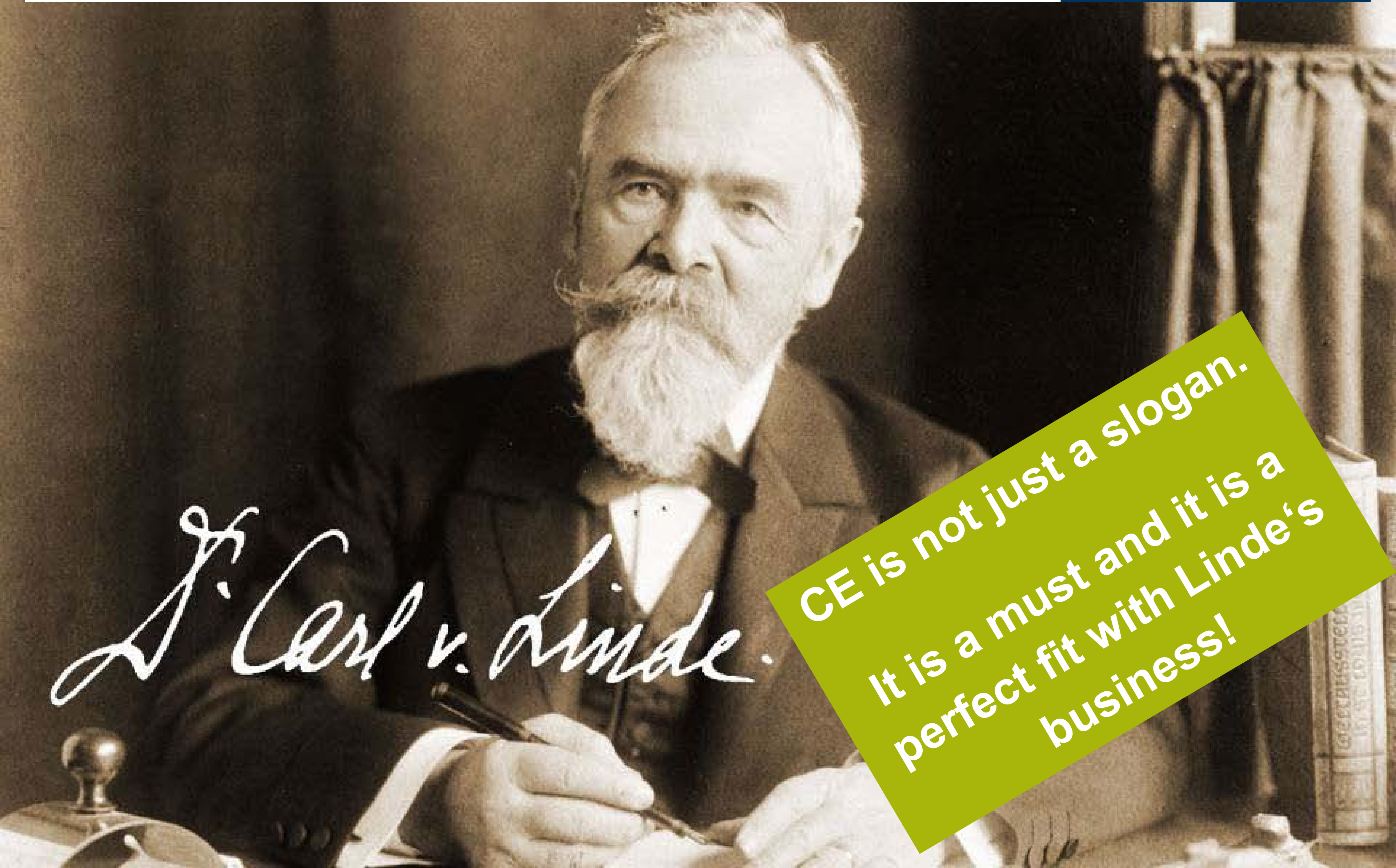
Questions?


Dr. Carl v. Linde.
CE is not just a slogan.
It is a must and it is a perfect fit with Linde‘s business!

BioGas & SNG

Main assumptions

NG 2,4 cent / kWh

Bio-methane 6 cent / kWh

Main assumptions

NG Footprint: German Bundestag, 2007

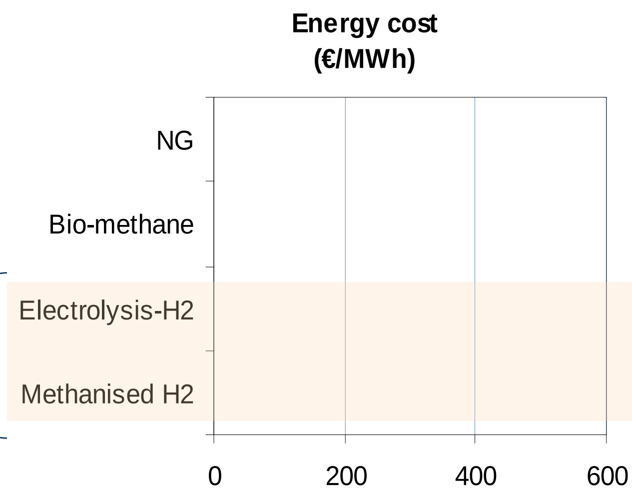
Power: GUD with 0,37 t CO_2/MWh

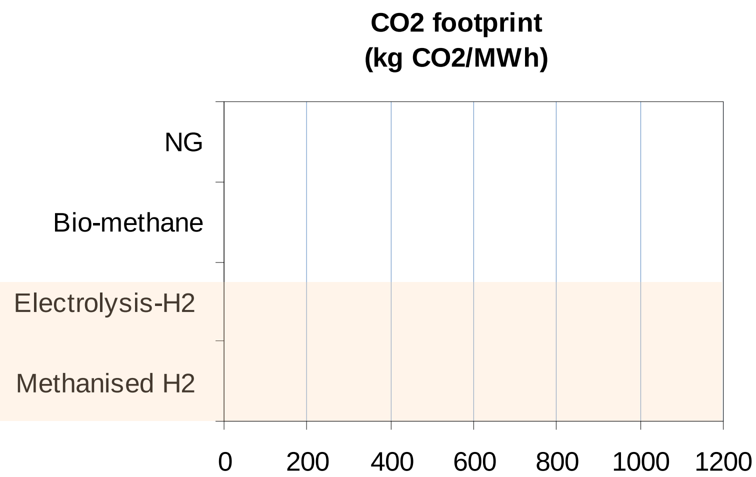
Bio-methane: Wuppertal-Institut

Efficiency electrolysis 65% to 70%

CO_2: 0 to 80 €/t

Efficiency Methanisation 75 to 85%





Linde Study 2011