Hydrogen Applications Today and Tomorrow

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Jens Luehring, Head of Americas and CFO

Industrial usage of hydrogen today

A wide range of markets and applications

Total production sufficient to fuel ~ **300,000,000** fuel cell cars!

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Hydrogen

Refineries ~30%

- Hydrocracking
- Hydrotreating

Chemical Industry ~63%

- Ammonia 53% (Urea, Fertilizers)
- Methanol 8%
- Polymers 2% (Caprolactam, AdipicAcid → Nylon)
- Polyurethanes (MDI and TDI as Precursor for)

Metal & Glass Processing ~6%

- Direct Reduction of Iron Ore
- Forming & Blanketing Gas
- Float glass production

Others ~1%

- Rocket Fuel
- Semiconductor Industry (incl. Photovoltaic)
- Food processing
- Generator cooling

Upcoming use of hydrogen as an energy carrier

Many new opportunities in mobility, power and heat

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Hydrogen energy & decarbonization

Six things Linde is doing today

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- Production of certified green H_2 from bio-methane and renewable power
- R&D of new green & CO2 reduced H2 production technologies, H_2 recovery from blast furnace gas

Green H_2 production

- Energiepark Mainz – world's largest PEM electrolysis plant
- Development of processes for „E-Chemistry"/ „E-Fuels"
- Driving systematic investigation & implementation of Power-to-X options

Power-to-X / Sector coupling

- *OASE® blue:* Highly efficient CO2 absorption from power plants and industry processes
- Development of technologies and applications for Utilisation of captured CO2

Carbon Capture & Utilization

Development of new applications for hydrogen, e.g.

- Portable H2 fuel cell solution (HyMera)
- Solutions for hydrogen as a transport fuel (forklifts, buses, trains, ships) & energy carrier
- H2Bike: H2 powered E-bike

H_2 applications

- In-house technology „ionic compressor" and „cryo pump"- more than 150 HFS equipped
- Active driver of H2Mobility in several world regions

H_2 Fueling Stations

- „BeeZero": world's #1 car-sharing with FCEV
- 50 Hyundai FCEVs in Munich
- Easy access for the public
- Target: „Customer experience", public acceptance of maturity and ease of handling

H_2 Carsharing

Deep dive: Energiepark Mainz

A global showcase for sector coupling

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Key facts

- Connected to a wind-farm (8 MW)
- 6.3 MW peak electrolyser stacks (each 2.1 MW)
- 800 kg storage (25 MWh)
- 200 tons target annual output from 2017 onwards
- Injection in local gas grid and multi-use trailer-filling
- Budget: total 17 m€, funding: ~50% (BMWi)

Objectives

1. **Local grid integration** by storing fluctuating renewable power
2. Provision of **ancillary services in the electricity grid Testing** and further development of **megawatt class PEM** electrolysis
3. Intelligent and **efficient H_2 conditioning, storage and handling**, smart management structure
4. **Research** of effects of the **increased H2 concentrations in NG gas grid** and end devices

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Thanks for your attention.

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Linde covers the entire hydrogen value chain
Value creation by proprietary technology and operation

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Production

Conventional
(e.g. SMR)

Renewable
(e.g. electrolyser)

Conditioning

Compression

Liquefaction

Delivery/supply

CGH_2 distribution/storage

LH_2 distribution/storage

Pipeline distribution

Onsite Electrolysis

Industrial use

- Desulphurization of fossil fuels
- Metal sintering and annealing
- Ammonia synthesis for fertilizers
- Plastics and solvent production
- Hydrogenation of oils

→ Wide range of required volumes

→ Typically low to medium pressure (from 1 to 50 bars)

Refuelling / Mobility

Ionic compressor

350 bar

700 bar

LH_2 only

Cryo pump

300 bar
CcH_2/LCH_2

Hydrogen value chain | Infrastructure

H_2 infrastructure initiatives in USA, Europe, and Japan

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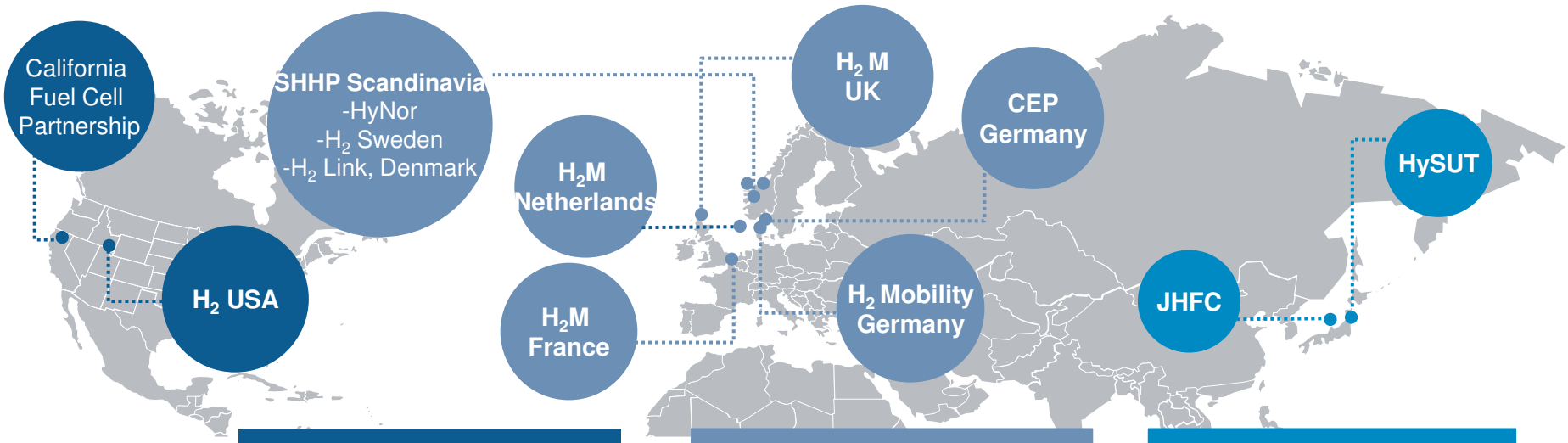

	North America	Europe	Asia
H_2 infra-structure	– California H_2 Stations Road Map: By 2016: 51 stations	– 50 HFS Program of BMVI (NIP) – EU: Clean Power for Transport Directive, Alternative Fuels Strategy, FCH JU, CEF	– Japanese NEV funding 2016: > 80 stations – Regional Korean HFS roll-out initiatives
H_2 as fuel	– **Hot Spot California:** CARB Advanced Clean Cars Programm/ZEV regulations – First commercial market for **utility fleet vehicles (FLT)**	– **Hot Spot Germany**: Focus of German OEMs due to funding structure (NIP,CEP): **H2Mobility** – Various other projects in UK, Benelux, Scandinavia, etc.	– **Hot Spots Japan & Korea:** Focus of OEMs due to funding structure (esp. METI in Japan) – **China: growing activities**

SHHP: Scandinavian Hydrogen Highway Partnership, JHFC: Japan Hydrogen & Fuel Cell Demonstration Project, HySUT: The Research Association of Hydrogen Supply/Utilization Technology, CARB: California Air Resources Board, ZEV: Zero Emission Vehicle, BMVI: Federal Ministry of Transport and Digital Infrastructure (DE), NIP: National Innovation Programme (DE), FCH JU: Fuel Cell and Hydrogen Joint Undertaking (EU), CEF: Connecting Europe Facility, CEP: Clean Energy Partnership (DE), NEV: New Energy Vehicle, METI: Ministry of Economy, Trade and Industry (JP)

Hydrogen value chain | Hydrogen as a fuel

Fuel Cell Electric Vehicles (FCEV) best alternative

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Emission targets in major markets*

Benefits of Fuel Cell Electric Vehicles (FCEV)

- Zero emission tank–to-wheel
- With renewable hydrogen: near zero emission well-to-wheel
- Current ranges: 500 - 600 km
- Refuelling time: 3 – 4 min
- Silent driving like battery electric vehicles (BEV)

Hyundai ix35 FCEV
Start of production: Feb. 2013

Toyota „Mirai“ FCEV
Start of production: Dec. 2014

Honda FCEV “Clarity”
Start of production: 2016

* Source: icct 2014

Hydrogen as a fuel | H_2 mobility

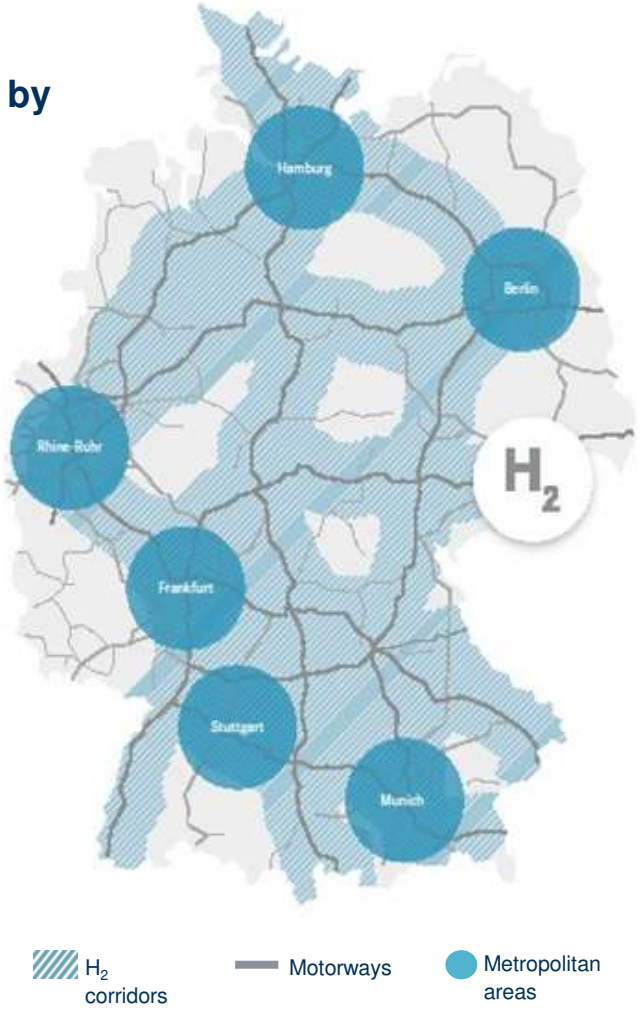
Hydrogen refuelling infrastructure in Germany

Action plan for the construction of a hydrogen refuelling network in Germany by 2023

~400 stations — will Germany´s publichydrogen refueling network cover by 2023

~90 kilometres — lie between the H_2 fuelling stations on the motorways around the metropolitan areas by

>10 H_2 fuelling stations — will be available in each metropolitan area from 2023



H_2 Mobility Goals

- **Synchronize HRS roll-out with FCEV ramp-up**
- Create a common structure to **de-risk HRS deployment**
- **100 hydrogen refuelling stations** in the next **four years**
- **200 to 400 hydrogen refuelling stations by 2023,** distributed all over the country
- **250,000 FCEVs** on the roads in 2023
- **350 MEUR** planned investments

Hydrogen as a fuel | Bee Zero

World‘s first hydrogen car sharing model

Targets

H_2 as fuel

Create awareness and bring “H_2-as-fuel” closer to the customer

Technology

Demonstrate validity of the technology and foster market development

Learning

Leverage learning experience for future H_2 projects

Data

Collect data and learn about user behaviour

Conclusion & Outlook

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Energy applications @ Linde

—Well positioned due to unique competences and broad energy application portfolio

—Linde covering the full value chain creates competitive advantages

Next steps and key success factors

—Focused technology development and staged infrastructure build-up

—Stringent cost and product management e.g. for hydrogen fuelling stations

Bringing innovation to the market

—Innovations in the field of environment and resources will focus on:

- —Emission reduction & carbon footprint
- —Advanced energy conversion & clean fuels
- —Challenging feedstocks

Energiepark Mainz | Solving the storage problem

Hydrogen – Interconnector between energy-systems

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Power generation

- Increasing amount of volatile energy feeding into the power grid
- Power-generation exceeds demand in local grid and in transmission systems
- Conventional power-plants are still necessary as safeguards but low operating hours affect operating results

Renewables need energy storage

- From a renewable power share of 30-50% and above, overgeneration (i.e. curtailment) and load ramping become critical and hinder further deployment
- Only storage can take up overgeneration, provide back-up capacity and ramping
- But: No single technology can fulfill all requirements

Power-to-Gas / hydrogen has unique strengths

Better than any other storage type, hydrogen can:

- create cross-links from renewable electricity to other sectors (fuels, chemicals)
- store large amounts of energy at reasonable costs (~170 GWh in one typical salt cavern ≙ ~ 2 hours of electricity consumption of Germany)
- facilitate seasonal storage (weeks to months)

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Energiepark Mainz | Hydrogen in the energy system

A multitude of options for usage

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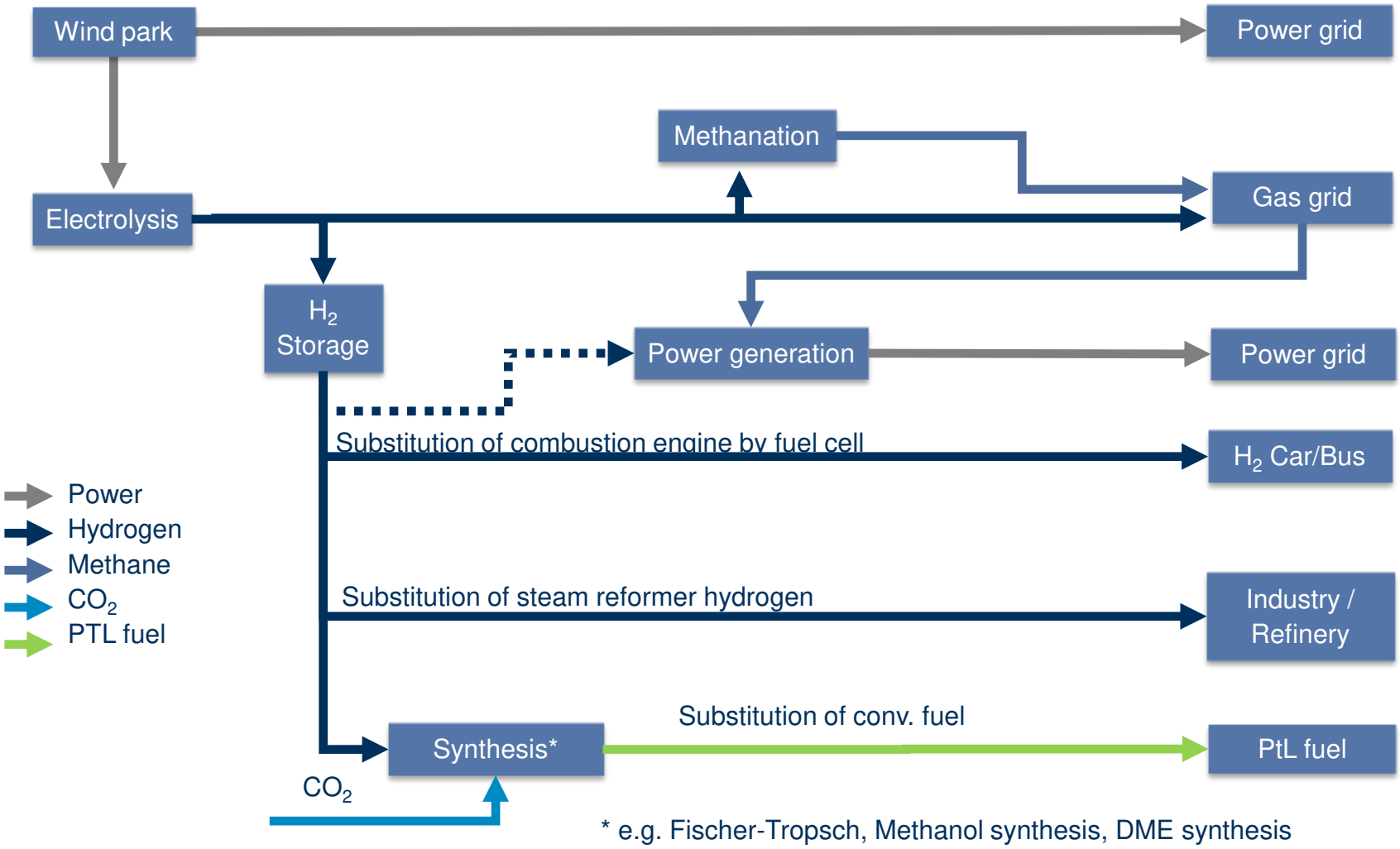

* e.g. Fischer-Tropsch, Methanol synthesis, DME synthesis

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The Linde Group profile
Organisational structure

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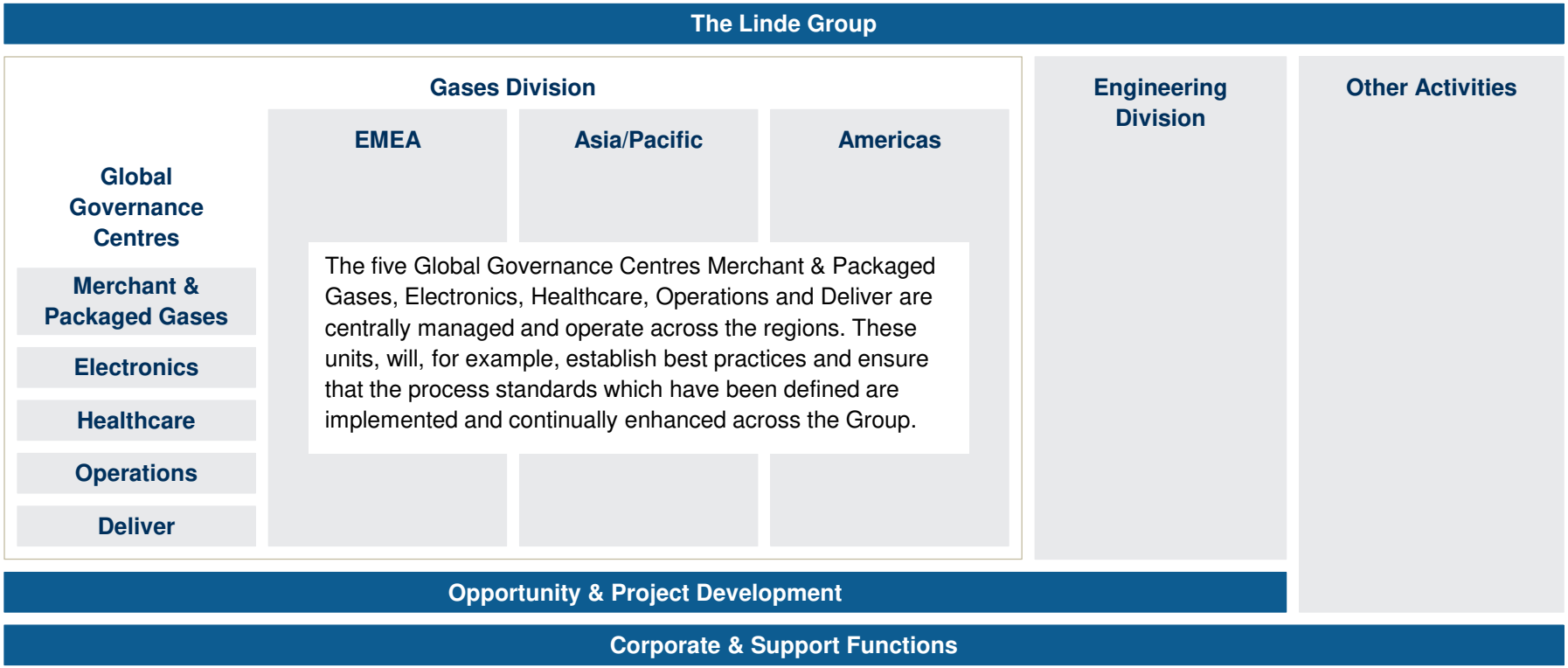
Organisation of The Linde Group



The Group comprises three divisions: Gases, Engineering and Other Activities (the logistics services company Gist). The Healthcare product unit belongs to the Gases Division, which is divided into three reportable segments: EMEA (Europe, Middle East and Africa), Asia/Pacific and the Americas.

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Gases Division

Wide range of products, services and applications

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Gases

Air Gases
- Nitrogen (N_2)
- Oxygen (O_2)
- Argon (Ar)
- Rare Gases
  Krypton (Kr)
  Neon (Ne)
  Xenon (Xe)

Other Gases
- Acetylene (C_2H_2)
- Helium (He)
- Propane (C_3H_8)
- Carbon Dioxide (CO_2)
- Carbon Monoxide (CO)
- Hydrogen (H_2)

Specialty Gases
- Pure Gases
- Specialty Gas Mixtures

Medical Gases
- Medical Oxygen
- Nitric Oxide (NO)
- Nitrous Oxide (N_2O)

Services

Administrative Efficiency | **Process Know-how** | **Quality and Safety** | **Supply Reliability**

Applications

Healthcare | **Chemistry & Energy** | **Metallurgy & Glass** | **Manu-facturing** | **Retail** | **Food & Beverages** | **Electronics** | **Other**

Linde gases are used, for example, in the energy sector, steel production, chemical processing, environmental protection and metal fabrication, as well as in glass production, food processing and electronics. The company is also a leading global supplier of premium healthcare products and services for patients with respiratory disorders.

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Engineering Division

Leading market position in a lot of segments

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Air Separation Plants	Hydrogen and Synthesis Gas Plants	Petrochemical Plants	Natural Gas Plants
			

Providing plants for Linde Gas and third party customers

Providing plants for chemical industry and energy-related industries

With around **1,000 process engineering patents and applications** and about **4,000 completed plant projects,** Linde Engineering is supporting the energy and environment megatrend and leveraging customer relationships for gas projects.

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