Clean Technologies by Linde

Krish R. Krishnamurthy
iSEE Congress
Champaign, IL
September 14, 2016

THE LINDE GROUP

Linde

Linde is involved in the clean energy business worldwide: Some examples

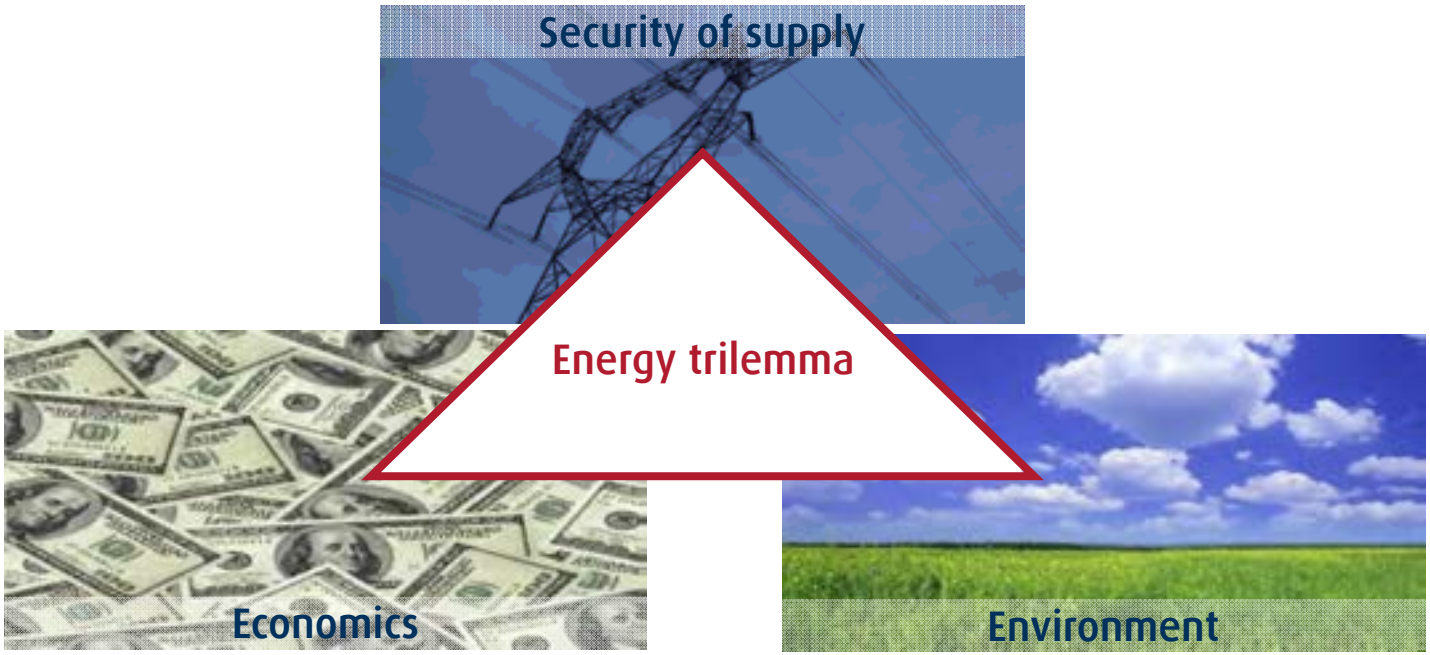
THE LINDE GROUP

Energy Generation and Use: A changing landscape
The energy trilemma

THE LINDE GROUP

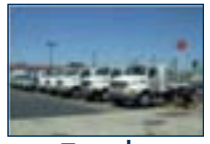
— Balancing the growing global energy demand with the need to conserve natural resources is a major challenge. Successful solutions must be economically viable.

— Tomorrow's power supply will be dominated by a steady increase of efficiency and a smart utilisation of new technologies.



Linde adds value along the entire NG/LNG value chain

THE LINDE GROUP

Upstream	Production/Sourcing	Distribution	Customers
 World-scale LNG	 Terminal	 Trucking	 Marine
 Floating LNG	 LNG plants	 Shipping	 Truck
 Biogas	 3rd party	 Storage	 Industry
 Stranded gas		 Fuelling	 Utilities
 Pipeline			

Hammerfest LNG plant, Norway
CO_2 reinjection via subsea pipeline

THE LINDE GROUP

World's first industrial project to deliver CO_2 separated onshore back offshore and injected into a reservoir

- Europe's first export facility for liquefied natural gas (LNG)
- Terminal and process plant on Melkøya island outside Hammerfest in northern Norway
- Annual LNG export: 5.67 billion Nm^3
- CO_2 content: 5.0% to 8.0%
- CO_2 captured in onshore plant, conveyed back with subsea pipeline, stored underground
- Emission reduction of more than 50%
- Norwegian CO_2 tax = 50 €/t

Small- and mid-scale LNG plants and offloading terminals

THE LINDE GROUP

Description

— Increasing importance of small- and mid-scale LNG plants
— Size makes them ideal for sites near industrial parks and cities, keeping them close to the customer
— Compared with fossil fuels such as diesel, petrol and oil, natural gas reduces carbon dioxide emissions by around 20 percent

Scope

— Linde a one-stop provider for entire LNG terminals, supplying everything from the LNG production plant to the storage tanks for trucks and ships, and from the on-site storage units to the on-board relique-faction units and liquid-to-gas converters

Reference projects

— Baltic Sea's first LNG terminal in Nynäshamn (S)
— Australia's first LNG plant in Dandenong
— Stavanger (N), Kwinana (AUS), Shan-Shan and Ji Munai (PRC), Lysekil (S), Emden (D, under construction)

Serving the shale gas boom

Enhanced natural gas extraction with the help CO_2 and LIN

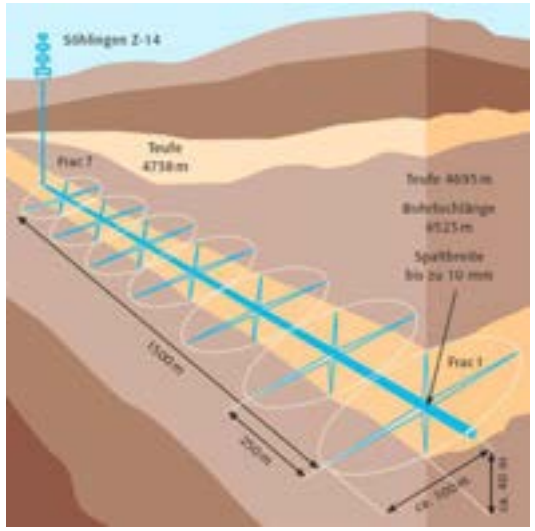
THE LINDE GROUP

Description

- Advances in horizontal drilling and hydraulic fracturing (fracking) have made huge reserves of North American natural gas economically feasible to extract
- Carbon dioxide (CO_2) and liquid nitrogen (LIN) are commonly used during the fracking process as energized fluids offering unique characteristics and economics
- Depending on the reservoir, fracking with CO_2 and/or LIN can substantially reduce water consumption and requires less or no chemical additives

Scope

- Linde serves as a supplier of energized fluids and field service supported by a national CO_2 and LIN supply network
- Extensive industry relationships
- Engineering Division has been awarded contracts worth around USD 1.3 bn for the supply of NG plants from the US since 2010



Chesapeake ENERGY · Williams · PEMEX · dcp Midstream · ONEOK · devon

Biogas as environmentally friendly vehicle fuel

THE LINDE GROUP

Description

— Biogas is captured, cleaned and either compressed or liquefied → environmental friendly fuel

— Reducing methane emissions, 25 times more harmful to the atmosphere than CO_2

Scope

— Linde engineers and builds plants to capture, purify and liquefy gas from landfills, biomass or animal waste

— Tailored solutions to reuse gas by customer, retail of waste stream gas to other industries

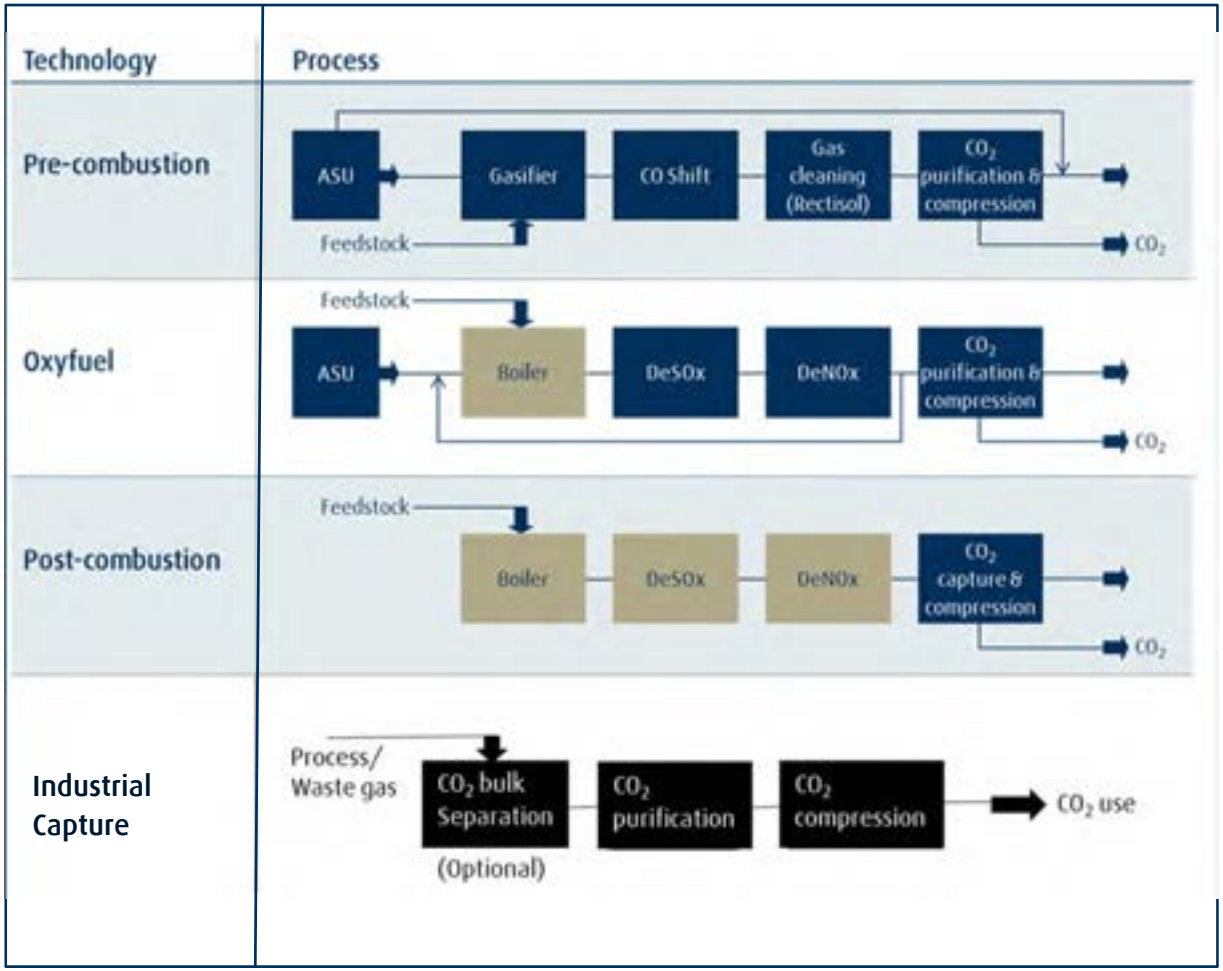
Reference projects

— Altamont, CA, USA: JV with US company Waste Management Inc.: landfill gas generated via fermentation is processed to fuel 300 refuse collection trucks in California

— Contributing in a collaborative effort in Stockholm, Sweden, supplying up to 11 biogas fuelling stations

Linde has options in all carbon capture pathways through commercial products or technology/solution development

THE LINDE GROUP



Solvent based post-combustion CO_2 capture is currently a leading option:

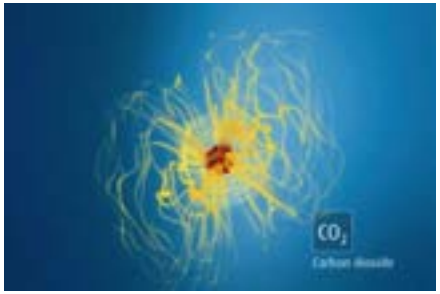
- Applicable to new or retrofit plants
- Capture all or part of flue gas
- Applied at large scale in other applications
- Novel solvents (e.g. OASE® blue) are stable in presence of flue gas contaminants & oxygen
- Significant progress made toward the capture cost goal

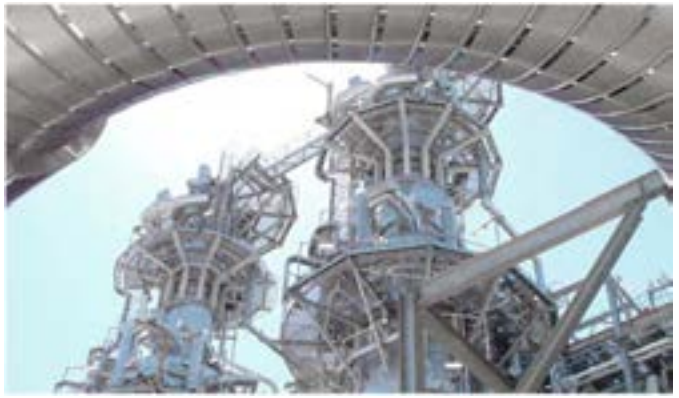
BASF / Linde post-combustion CO_2 capture partnership

Delivering total solutions with confidence

BASF We create chemistry

THE LINDE GROUP





BASF Solvent/Process Expertise

- Basic Design Package
- Process performance
- Emissions performance

Linde Engineering Expertise

- Process optimization
- Basic/Detailed Engineering
- Package/EPC wrap

PCC capture

Founded	1865
Sales (2015)	€70.5 billion
Employees	~112,000

Founded	1879
Sales (2015)	€17.9 billion
Employees	~64,000

BASF OASE® blue technology roadmap

Adopted and optimized for PCC applications

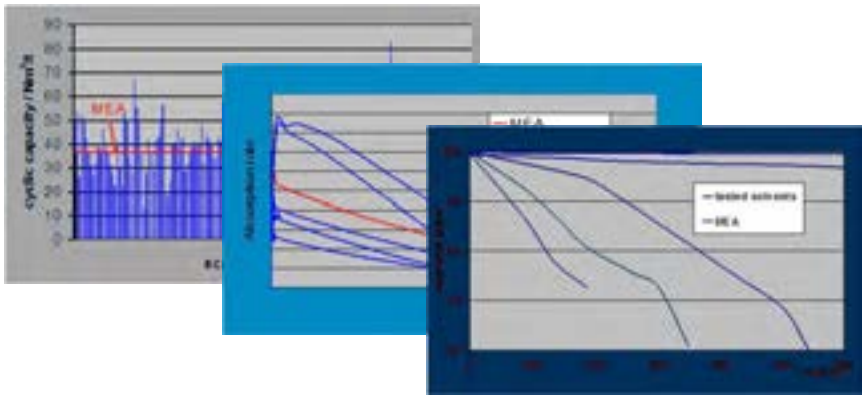
BASF We create chemistry

THE LINDE GROUP

Equilibria

Kinetics

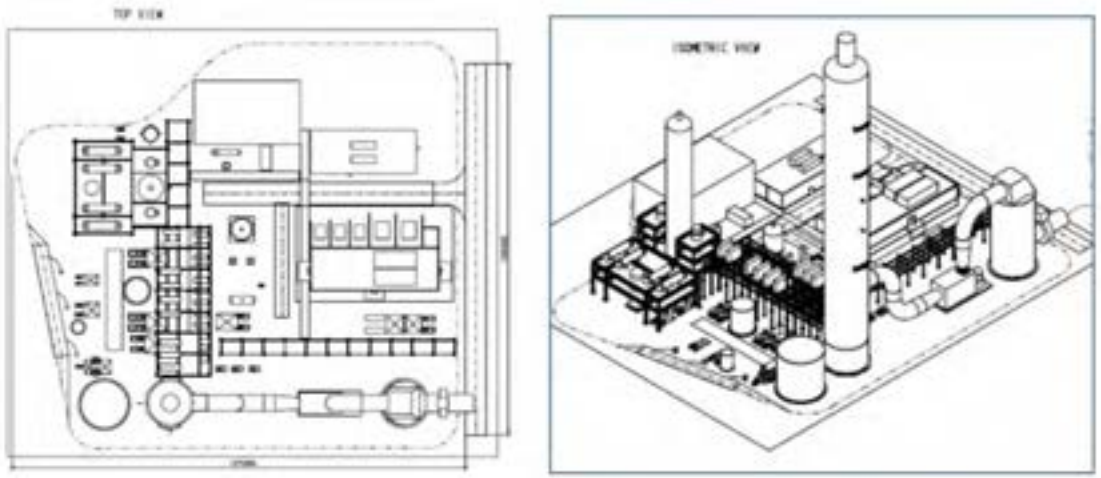
Stability



Lab. & Mini plant (2004)	Pilot: 0.45 MWe (2009)	Pilot: 1.5 MWe (2014)	Large Pilot (proposed): 15 MWe (2016-2020)
— Ludwigshafen, Germany — Solvent selection & performance verification	— Niederaussem, Germany — Process opt., materials & emissions testing	— Wilsonville, AL (NCCC) — Design improvements, emissions confirmation	— Abbott power plant, UIUC, Champaign, IL — Full value chain demo.

CAPTURING CARBON FROM ABBOTT POWER PLANT

PHASE 1 COMPLETED & PHASE 2 PROPOSAL IN EVALUATION BY DOE/NETL FOR 15 MWe CAPTURE FACILITY



Layout of Linde's 15 MWe Carbon Capture Plant at UIUC

Linde 1.5 MWe Capture Plant at National Carbon Capture Center

- **Strong Illinois team led by University: University of Illinois, Linde, BASF, Affiliated Engineers, ACS**
- **Vigorously Tested, Proven, and Matured Carbon Capture Technology from Linde/BASF**
- **Phase 1 (Project Definition and {Pre-FEED)**
- **Phase 2 (build & test) is a $75 Million project; Phase 2 proposal submitted March 31, 2016**
- **Syndicated public / private partnership for Phase II with $58.5 Million from DOE/NETL and the remaining from the University and private sector companies**
- **Phase 3 plans by University to set up a CO2 utilization Research Center**

PRAIRIE RESEARCH INSTITUTE · ACS · Linde · BASF · NETL · AEI Affiliated Engineers · ENERGY

Linde Covers The Entire Hydrogen Value Chain

THE LINDE GROUP

Large-Scale Production

Conventional
(e.g. SMR)

Green
(e.g. BTH)

On-site Supply & Storage

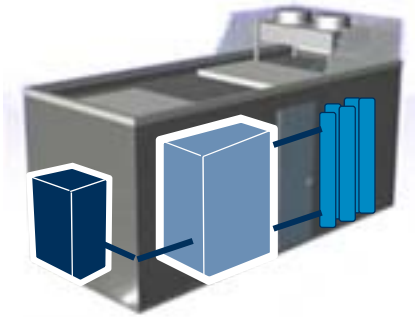
CGH2 storage

LH2 storage

Onsite SMR

Onsite Electrolyzer

Compression/Transfer



Ionic compressor

Cryo pump

Dispenser

350 bar

700 bar

Linde hydrogen refueling solutions
Reference projects prove technological maturity

THE LINDE GROUP

Linde reference projects

Key facts

- More than 80 hydrogen stations equipped in 15 countries
- Over 1,000,000 successful refueling events
- Leading supplier of hydrogen fuelling technologies
- Cover the entire hydrogen value chain

Key learnings

- Technological maturity reached
- High level of standardisation reached
  - Standardised fuelling protocol
  - Standardised H_2 quality
- User-friendly fuelling process
  - 3 min / fuelling
  - Touch & feel like conventional stations
  - Integration into existing infrastructure

How is Linde Playing a Part?

An economical environmentally friendly solution is here today

THE LINDE GROUP

BMW, Spartanburg, SC
Largest H2 Fueling station in the world
fueling >350 FLTs
Approaching ~ 1 TPD

West Sacramento Station

1st truly retail hydrogen station in operation

THE LINDE GROUP

— Credit Card Ready (No user Agreements)

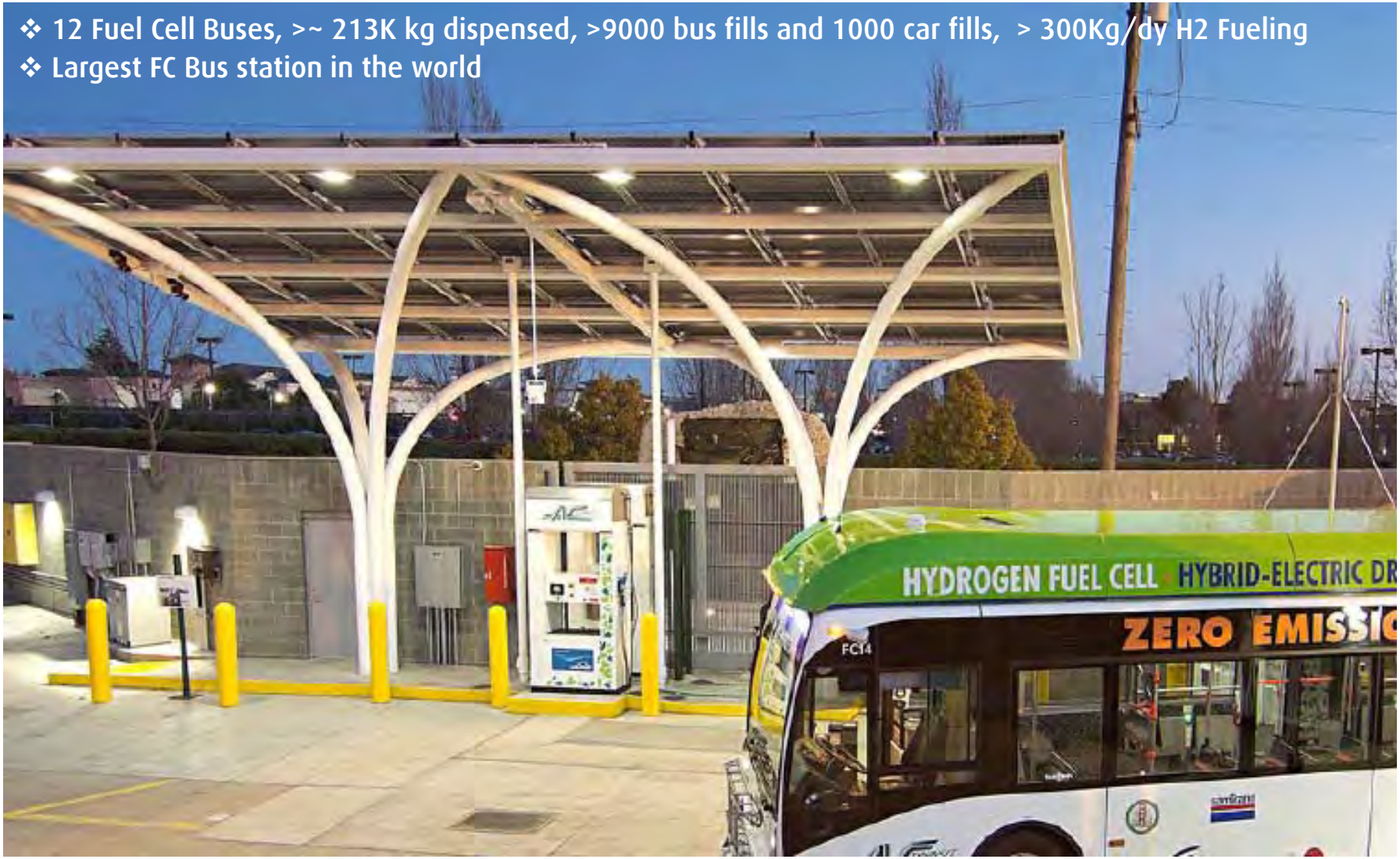
— DMS Approved for sale by KG

—SAE J2601 Compliant

AC Transit – Emeryville, CA (SF Bay Area)
Linde Hydrogen Fueling Stations

THE LINDE GROUP

- 12 Fuel Cell Buses, >~ 213K kg dispensed, >9000 bus fills and 1000 car fills, > 300Kg/dy H2 Fueling
- Largest FC Bus station in the world



World's 1st Hydrogen Fuel Cell Car Share Program by Linde

THE LINDE GROUP

ENERGIE PARK MAINZ

Project overview and key facts

Project scope and key facts

Development of an decentralized hydrogen energy storage plant

- Location: Mainz (Germany)
- Partners Stadtwerke Mainz, Linde, Siemens, RheinMain University
- Connected to a wind-farm (8 MW)
- 6 MW peak electrolyzer (3 stacks, each 2 MW)
- 1000 kg H_2 storage (33 MWh)
- 200 tons H_2 target annual output
  - Injection in local gas grid
  - Multi-use trailer-filling
- Budget: total 17 m€
- Funding: ~50% (BMWi)
- Timeline: 4 years (10/2012 – 12/2016)

Source: Energiepark Mainz

ENERGIE PARK MAINZ

Project overview and key facts

Electrolysis

- Three electrolysis units (SILYZER 200)
- Electrical power consumption:
  - 1.3 MW continuos
  - 2.0 MW time limited peak load
- H_2 output pressure level of up to 3.5 MPa
- Highly dynamic operation over a broad load range (ramp speed 10% per sec.)
- Widely adjustable DC power supply

Source: Energiepark Mainz

Thank you for your attention.

LeadIng.

THE LINDE GROUP

CLEAN
TECHNOLOGY
BY LINDE