


Clean Energy for Steel Decarbonization

Accelerating the Energy Transition

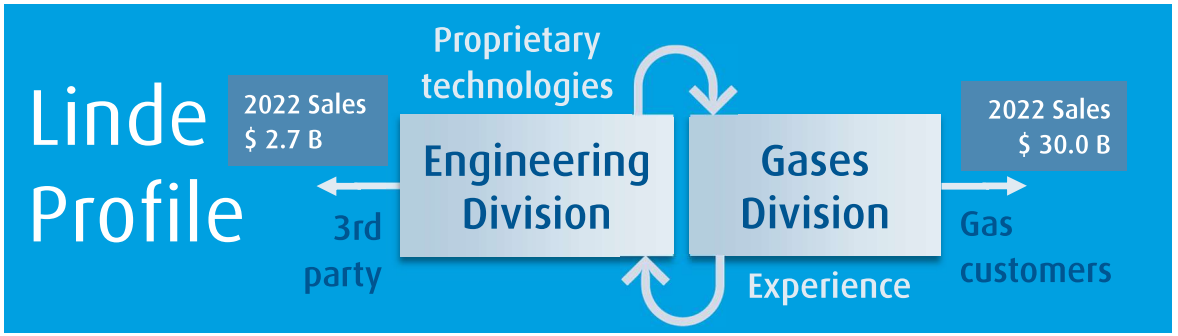
Overview | January 2024

Making our world more productive

Linde Background

World's Largest Industrial Gases Company

- Sales at $33 B (2022)
- Market Capitalization at **$190 B**
- Activities in 100+ Countries
- Integrated Gases and Engineering Divisions



Growth through Clean Energy

- World leading supplier of Hydrogen
  - Sales >$3 B; Capacity 8000 t/d
  - Active Across the Whole Value-chain
- ~**$2B** backlog in Clean Energy projects
- Invest **$8-10B** in Clean Energy over 2-3 years; **$50B** over next decade

AOD Process
75% of global stainless-steel production

~25% of argon sales

CoJet®
Industry standard for chemical energy in EAF

>170 installations

REBOX®
Oxy-Fuel combustion in reheat furnaces

>180 installations

Developing step-change technologies for steel production

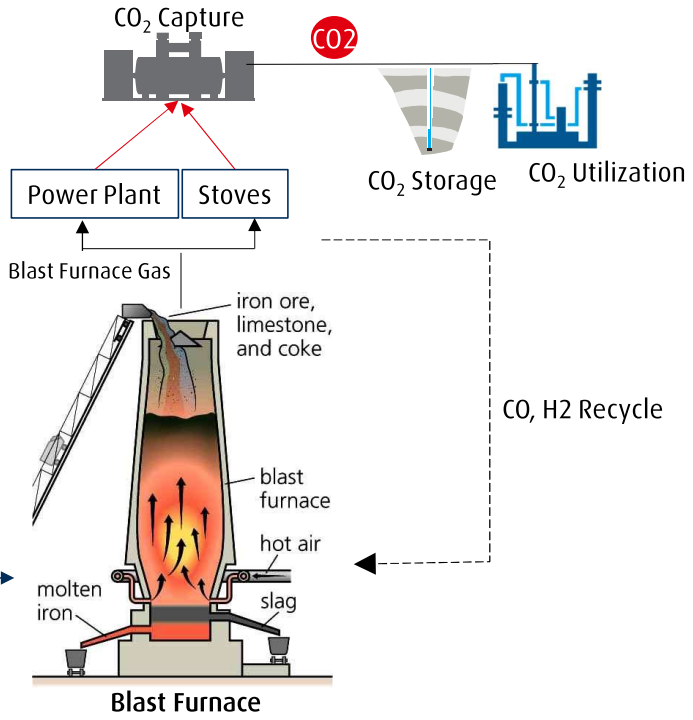
Decarbonization Solutions for Ironmaking

CCUS and H2/Low C Fuels are primary solutions

CCUS

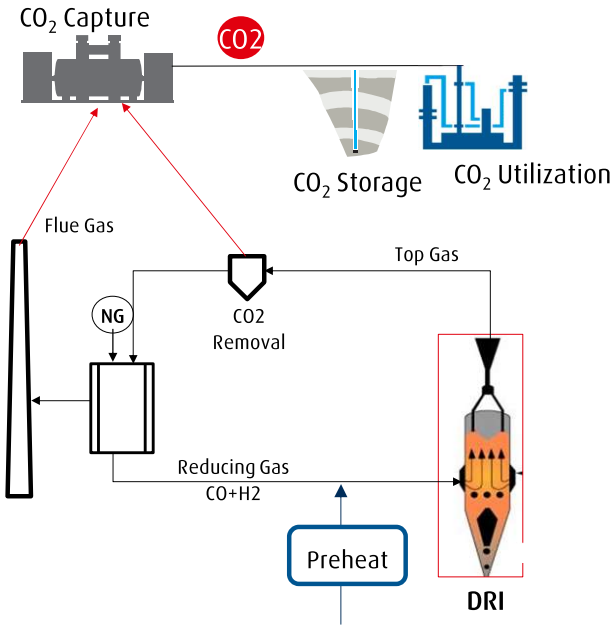
H2
Low C Fuels

Blast Furnace



H2 **H2 Injection**
Max 25 kg/t
~15% decarb

DRI Plant



H2 Injection
H2 Max 54-70 kg/t
100% Decarb
H2 can be blended in steps
- Up to 30%, 70%, 100%

Linde Offerings for Steel Decarbonization

Hydrogen Supply

- Blue H2 SMR/ATR...w/CCS
- Green H2 Electrolysis
- Ammonia & methanol Plants
- Liquefaction
- Underground storage
- Pipelines

CO_2 Capture

- Compression & pretreatment
- OASE © BLUE
- HISORP© CC
- Cryogenic Separation
- Logistics & distribution
- Storage (CCS)

Low Carbon Fuels

Linde's **H**ot **O**xygen **T**echnology produces **Syngas** from Biomass, MSW, Pyoil, Plastics, Coke Oven Gas, etc ...

Oxy-Fuel Combustion

Oxy-Fuel burners and technology to convert air-fired furnaces to oxy-fuel
Fuel savings, production increase and emissions reduction

Hydrogen Production Methods

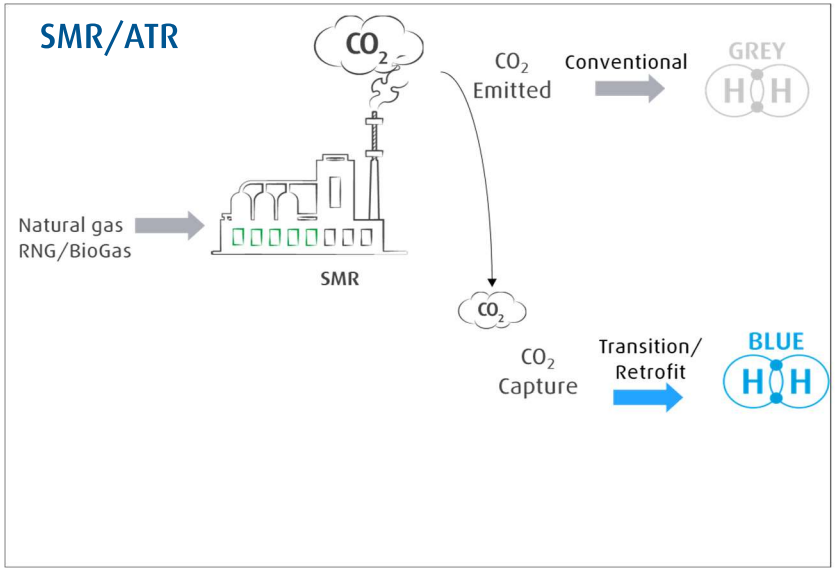
Methane Reforming (SMR[1] or ATR[2])

Feedstock	Natural Gas
Product	Grey H2 – CO2 is emitted Blue H2 – CO2 is captured (CCS)
Scale	Large scale up to 700 TPD (300 MMSCF/d)
Status	Mature, efficient and reliable

[1] Steam Methane Reformer, [2] Autothermal Reformer

Electrolysis

Feedstock	Renewable power (55 kwh/kg)
Product	Green H2 with renewable power
Scale	Modular: 2/5 MW modules 35 MW under construction; 200+ MW planned
Status	Technology ramping up



Carbon Intensity
(kg CO_2/kg H_2)

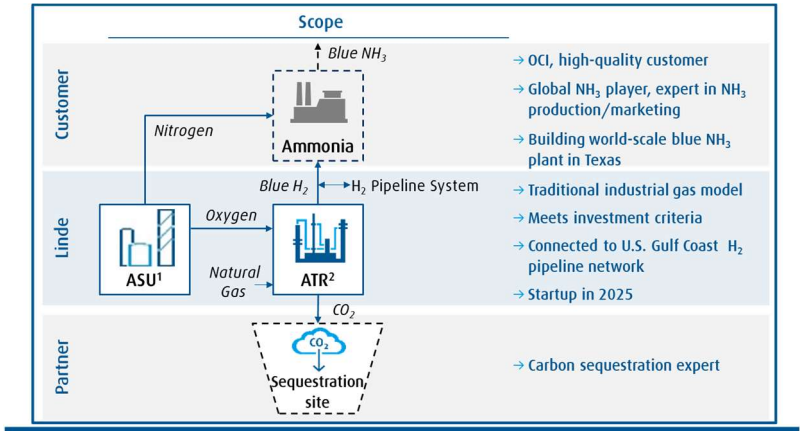
8-12

2-4

<0.45

Linde Hydrogen Projects

Blue H2 Project in US Gulf Coast: $1.8B Investment



World-Scale Low Carbon Project - More Wins to Come

Blue H2 Project in Europe

Equinor and Linde sign agreement on H2M Eemshaven hydrogen project

January 8, 2024: Equinor and Linde have signed a project development agreement to develop the H2M Eemshaven low carbon hydrogen project in the Netherlands as partners.

Equinor will secure access to carbon transport and storage capacity and offer low carbon hydrogen to the market. Linde will build, co-own and operate the hydrogen production and carbon capture and transfer facility.

Green H2 Projects

Linde is executing projects representing **>400 MW** of electrolyzer capacity utilizing technology from **five** different OEMs, with the largest unit being 100 MW

Linde Leuna Chemical Complex

- 24 MW capacity
- Planned production start in 2022
- Built, owned and operated by Linde
- Linde also operates 2 x SMRs and 10tpd liquid hydrogen plant.

Shell REFHYNE project

- 10 MW electrolyzer system (modular approach 5 x 2MW)
- H2 purification to 5.0 purity, suitable for load and grid balancing
- Phase II to be initiated soon – 100 MW concept

Cummins to Supply 35MW Electrolyzer System to Linde for Green Hydrogen Production in Niagara Falls, New York

December 12, 2022 08:00 AM Eastern Standard Time

Linde to Increase Green Hydrogen Production in California

January 31, 2023

Woking, UK, January 31, 2023 – Linde (NYSE:LIN; FWB:LIN) announced today plans to increase its green hydrogen production capacity in Ontario, California, in response to growing demand from the mobility market.

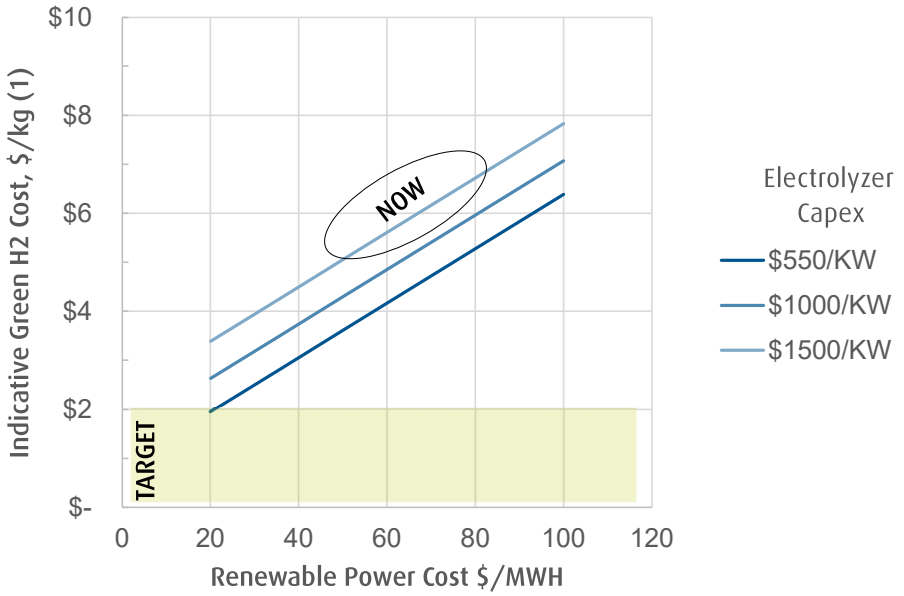
Linde will build, own and operate the first of several planned five-megawatt PEM (proton exchange membrane) electrolyzers to increase its hydrogen capacity. Following this initial investment, the new

Two 100 MW electrolyser contracts signed with Linde Engineering

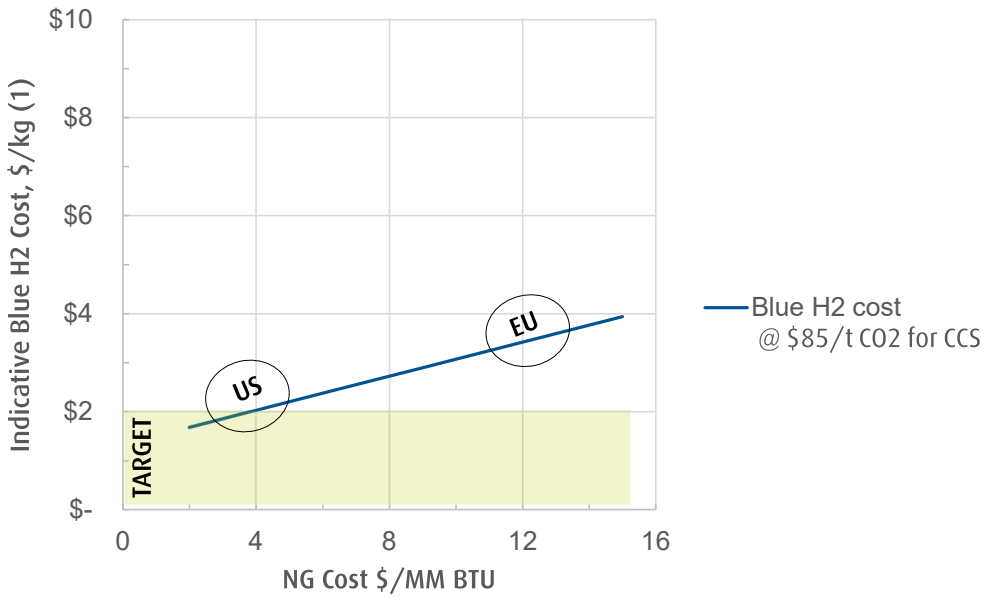
31 January 2023

H2 Cost Evolution

GREEN HYDROGEN



BLUE HYDROGEN



H2 preferentially produced in regions with lowest cost renewable power, or CCS opportunities
Can lead to dislocation of production sites

(1) Does not include compression, storage, transport, etc.

Linde Offerings for Industrial Decarbonization

Hydrogen Supply

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Green H2 Electrolysis

Ammonia & methanol Plants

Liquefaction

Underground storage

Pipelines

CO_2 Capture

Compression & pretreatment

OASE © BLUE

HISORP© CC

Cryogenic Separation

Logistics & distribution

Storage (CCS)

Low Carbon Fuels

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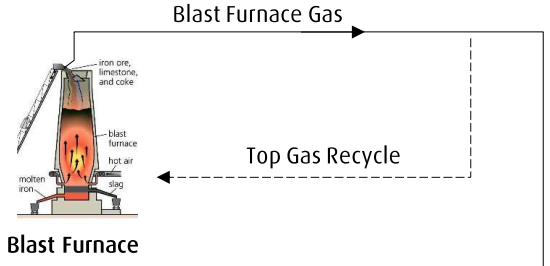
Oxy-Fuel Combustion

Oxy-Fuel burners and technology to convert air-fired furnaces to oxy-fuel
Fuel savings, production increase and emissions reduction

CO2 Capture from Steel Mills

Capture technology available for different flue gas streams

Integrated Mill

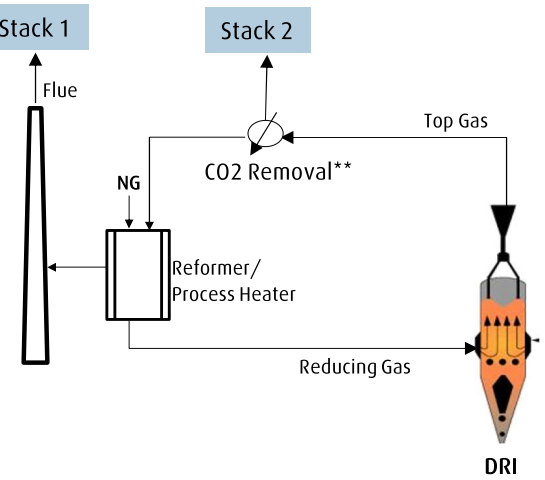


CO2 t/t	1.0 t/t	0.4 t/t	0.6 t/t
% CO2	18.5%	29%*	24%
Flow, Nm3/h 2.5 Mtpa BF	800,000	215,000	400,000
LINDE CO2 Technology	OASE Blue HISORP CC	HISORP CC	HISORP CC

* Can be doubled with oxy-fuel stoves

Direct Reduction Plant

CO2 t/t	0.24 t/t	0.36 t/t
% CO2	9%	90-95%
Flow, Nm3/h 2.5 Mtpa DRI	355,000	50,000
LINDE CO2 Technology	OASE Blue HISORP CC	CO2 Processing Unit



** CO2 Removal is optional in Midrex flow sheet. In this case, all the CO2 will be emitted in the flue (Stack 1)

CO_2 / H2 Purification Technology Portfolio

OASE BLUE
Solvent (Amine) Systems

Amine Unit for Syngas - DRI

- Amines (e.g. BASF OASE white)
- > 50 commercial units built
- Significant operating experience

Amine Unit for Flue Gas – BFG, DRI

- BASF solvent OASE® Blue
- Linde EPC and operation
- 30 tpd Demonstration at National Carbon Capture Center
- 250 tpd demo planned
- Ready for commercialization

HISORP CC
Adsorbent (PSA) Systems

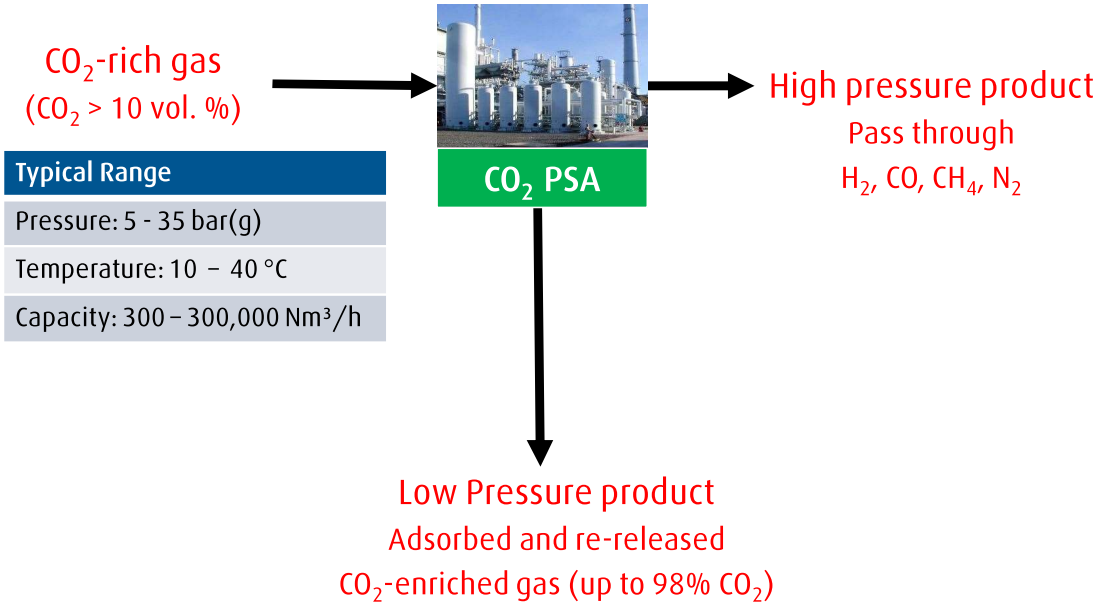
CO_2 PSA for Syngas - DRI

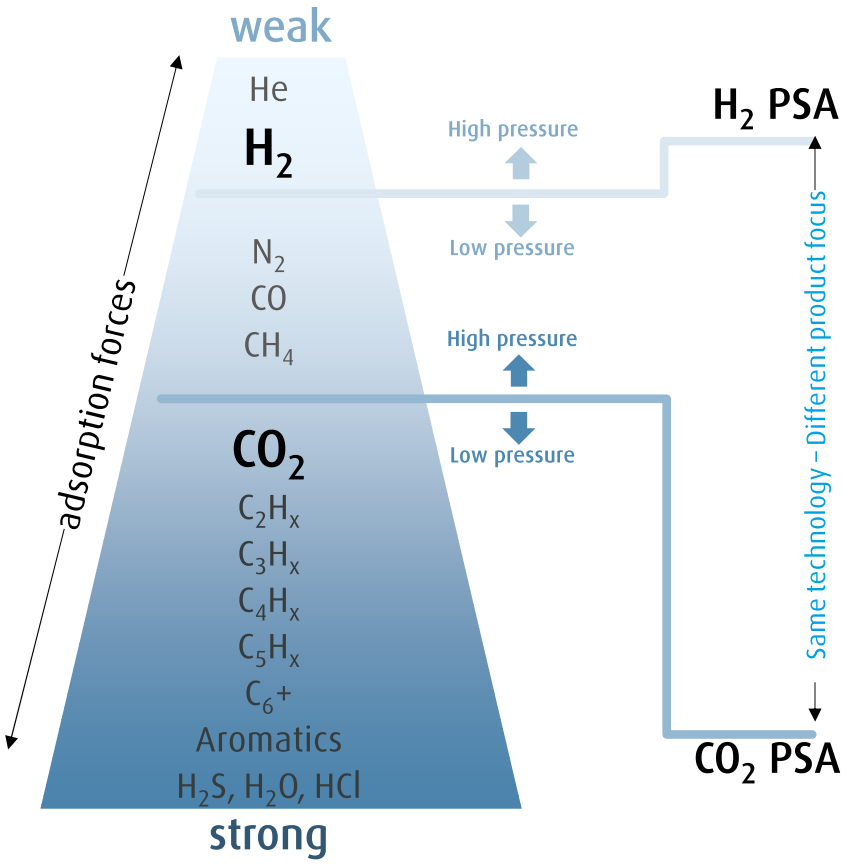
- Requires power; no steam
- No secondary CO2 emissions, washing agents
- Dry CO2 outlet at pressure; less post-treatment

H_2 PSA for Coke Oven Gas

- Recovery of H2, CH4, N2, O2,...
- Iron & steel industry applications
- No steam required

PSA[1] Gas Separation Technology





[1] Pressure Swing Adsorption

HISORP Adsorptive CO_2 removal in DRI production.

Features

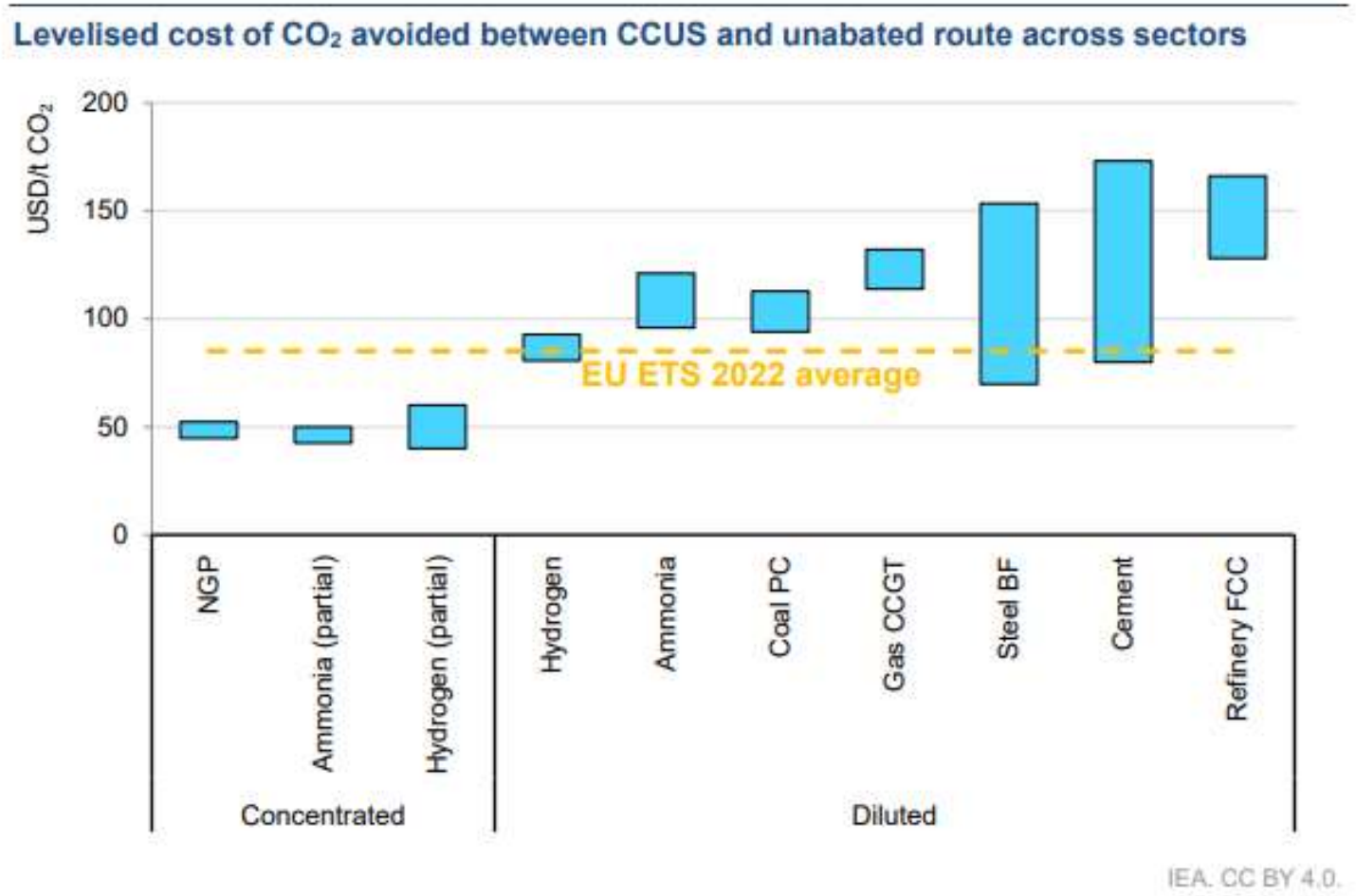
TRL 9

- CO_2 capture rate >95% @ <400* kWh/ton CO2
- 100% renewable power possible
- No steam requirement (= no secondary CO_2 emissions)
- No washing agents
- Dry CO2 output. Less post-treatment
- Optimum solution for retrofit

Linde References (selected)

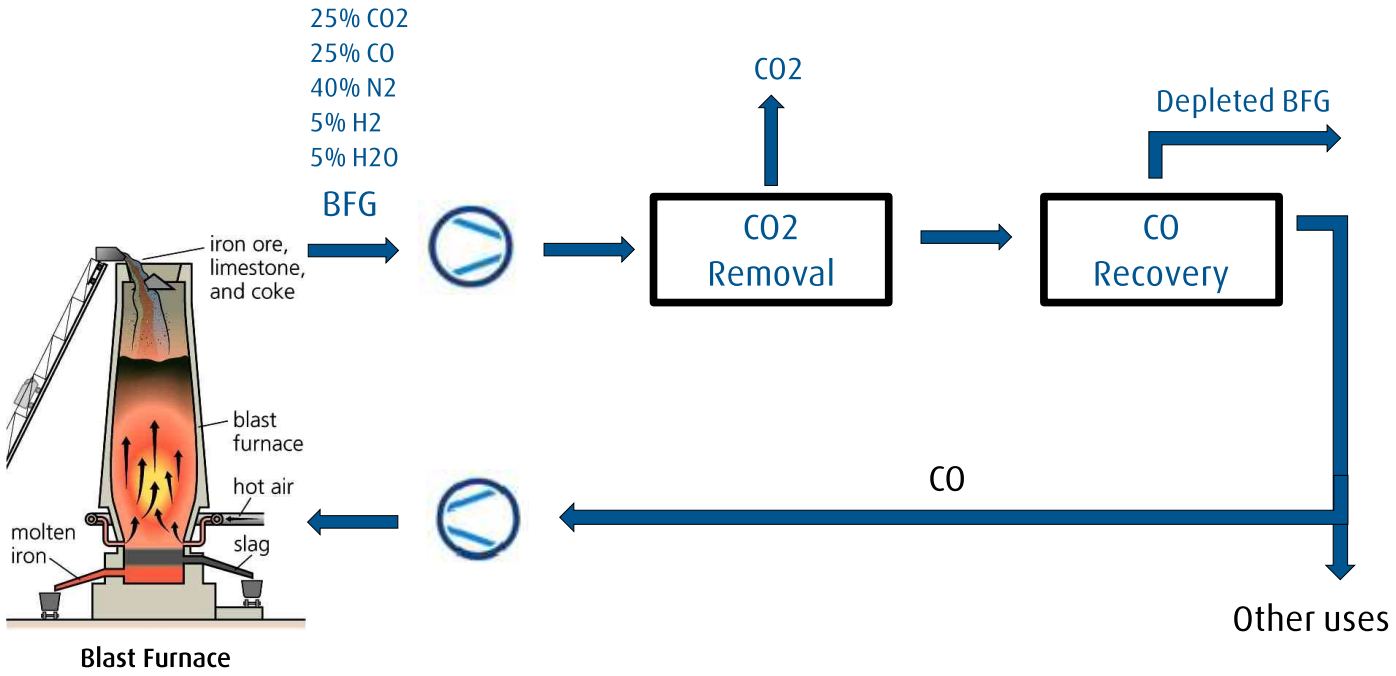
DRI Process	PSA capacity [Nm3/h]
COREX/MIDREX	500.000
Finex	105.000
HYL	165.000
COREX	320.000
COREX	320.000

Carbon Capture Cost



Carbon Recycling/Utilization

Combined CO2 Removal and CO Recycle – Under Evaluation



Blast Furnace

Large Scale CO2 Utilization Requires H2

Ethanol (Gas Fermentation)

$6CO + 3H_2O \rightarrow C_2H_5OH + 4\ CO_2$

$2CO + 4\ H_2 \rightarrow C_2H_5OH + H_2O$

$2\ CO_2 + 6\ H_2 \rightarrow C_2H_5OH + 3\ H_2O$

LanzaTech

Methanol (CO_2 Hydrogenation)

$CO + 2\ H_2 \rightarrow CH_3OH$

$CO_2 + 3\ H_2 \rightarrow CH_3OH + H_2O$

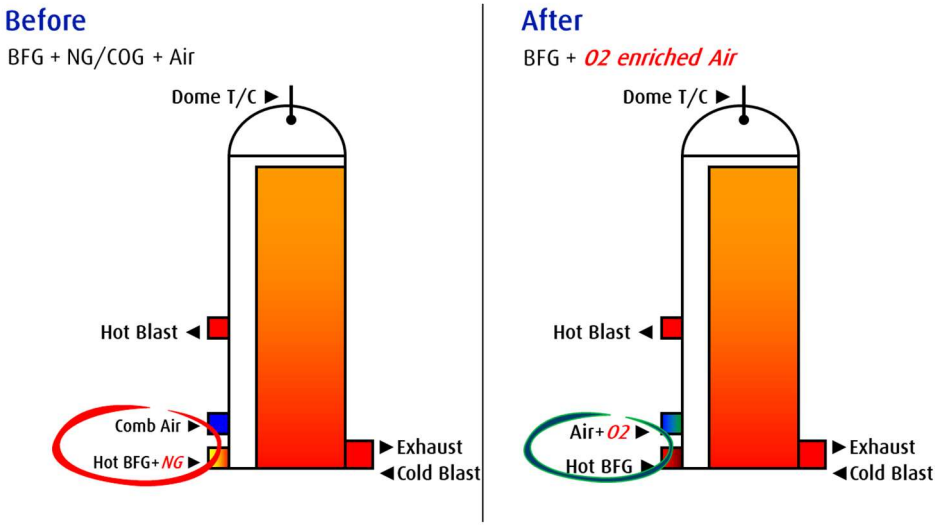
Methanation

$CO_2 + 4\ H_2 = CH_4 + 2\ H_2O$

Blast Furnace Decarbonization
Oxygen in Blast Furnace Stoves

STOVE OXYGEN ENRICHMENT

Oxygen enrichment of combustion air

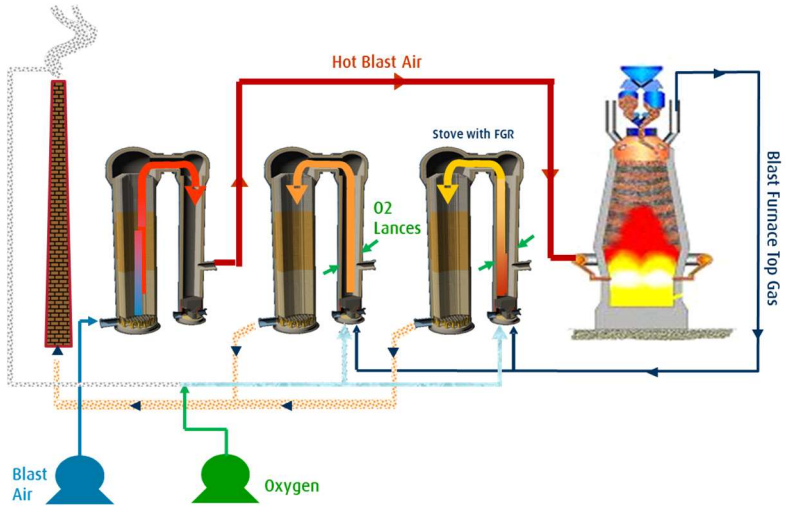


- Save/eliminate natural gas or coke oven gas
- Raise blast temperature → save coke in blast furnace
- De-bottleneck plugged stoves

20+ Installations Worldwide

FLUE GAS RECIRCULATION – Under Evaluation

Conversion of stoves to 100% Oxy-Fuel. Concentrate CO2 emissions for capture.



- Flue gas is recycled to moderate oxy-fuel flame temperature, use its sensible heat
- CO2 concentration in flue gas is doubled over ~40%
- **~30% of Integrated mill's CO2 emissions contained in a single flue gas for capture and sequestration. Specific CO2 emissions reduction by 0.6 t/t.**

Oxy-Fuel Stoves: Illustrative Heat & Mass Balance.

	BFG Nm3/h	COG Nm3/h	AIR Nm3/h	Oxygen Nm3/h	Flue Recycle Nm3/h	Energy Input From Combustion GJ/h	Flame Temp. °C	Flue Mass Flow kg/min	Flue Gas %O2	Flue Gas %CO2
AIR-FUEL	34000	2400	34200	0	0	145	1347	1539	1	23
OXYGEN ENRICHED	40200	1200	26800	1300	0	145	1347	1545	1	27
OXY FUEL WITH FLUE RECYCLE	44700	0	0	6220	14490	139	1347	1541	1	41

- Flame Temperature, Flue Gas Mass Flow and Excess Oxygen all Held Constant.
- Blast furnace gas consumption increases as COG consumption decreases.
- Combustion energy required 4% lower when sensible heat of flue gas recovered.
- CO_2 mass flow and concentration in flue gas DOUBLED for oxy-fuel combustion.
- Heat transfer coefficient increased by replacing non-radiating N_2 with highly radiating CO_2.
- Incremental oxygen requirement is ~60% of that needed by the ULCOS TGRBF.

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Hydrogen Supply

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Green H2 Electrolysis

Ammonia & methanol Plants

Liquefaction

Underground storage

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Low Carbon Fuels

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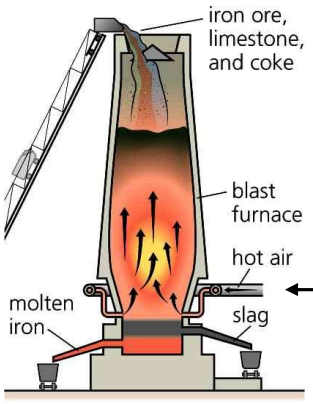
Oxy-Fuel Combustion

Oxy-Fuel burners and technology to convert air-fired furnaces to oxy-fuel
Fuel savings, production increase and emissions reduction

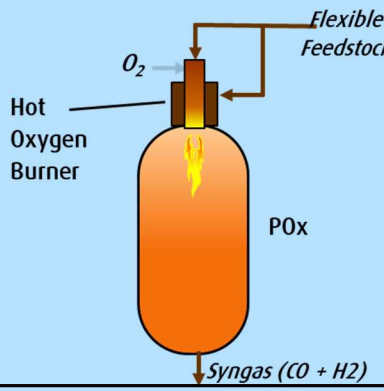
Gasification of Low Carbon Fuels
Partial Oxidation with Linde's Hot Oxygen Technology



Blast Furnace

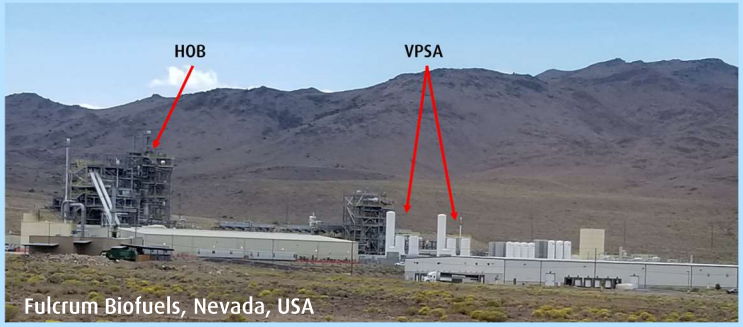
- Maximize injectant levels, coke replacement
- Achieve CO2 savings without cost penalty
- Maximize BF decarbonization, asset utilization

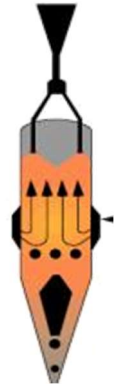
Linde's Hot Oxygen Technology
External Gasification of low carbon feedstocks



- Biomass/Pyoil
- Municipal Solid Waste
- Plastics
- Coke oven gas
- Natural Gas
- Etc.

- Efficient, small-scale gasifier to generate *hot* syngas
- Up to 35,000 Nm^3/h syngas per unit



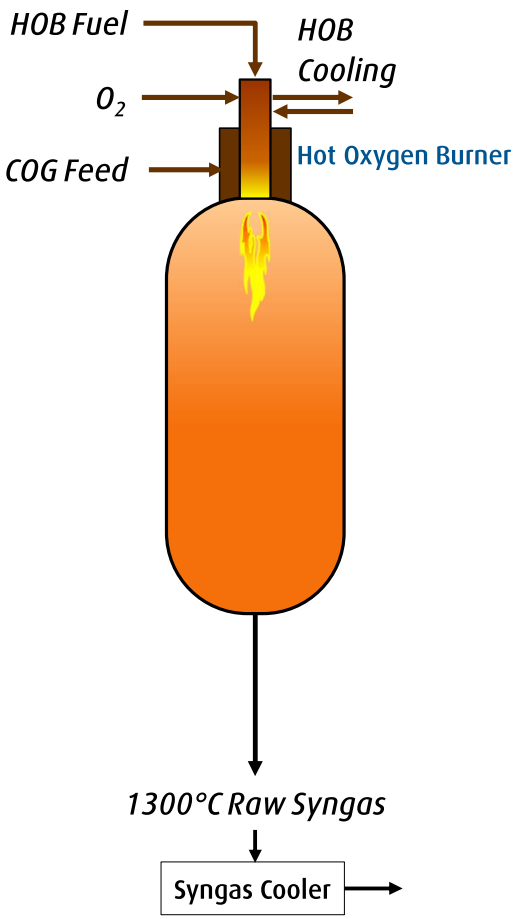


DRI

- Alternate approach to decarbonization of DRI
- Advantages over H2:
  - Cost/economics
  - Source of carbon for DRI

Syngas from Coke Oven Gas

For use in DRI or BF



Typical COG Analysis

Heating Value: ~4200 Kcal/Nm3

1. H2 55%
2. CO 7%
3. CO2 3%
4. **CH4 25%**
5. **HHC 5%**
6. **BTX 1%**
7. H2O 4%

Partial Oxidation (POx) Burns Off Components

- Too much Methane
- Too much Heavy Hydro-Carbon
- Too much BTX/Tar

Residual (mg/Nm3): H2S <500; Naphthalene < 230; NH3 < 50; HCN < 1000; dust <5; moisture saturated 24C

	COG	POx unit				Dried syngas
		Feed	*HOB Fuel*	*O2*	Product	
	Linde battery limit					***Linde battery limit***
Pressure (barg)	5.0	5.0	5.0	5.0	2.9	2.9
Temp (°C)	250	250	250.0	25.0	1311.3	26.7
Flowrate (Nm3/h)	20,000	18,913	1,087	4,208	29,293	24,928
Gas composition (vol%)						
H2	52.10%	52.10%	52.10%		52.34%	61.50%
O2	0.50%	0.50%	0.50%	100.00%		0.00%
H2O	1.40%	1.40%	1.40%		14.90%	0.00%
CH4	24.40%	24.40%	24.40%		3.14%	3.69%
CO	8.60%	8.60%	8.60%		22.71%	26.68%
CO2	3.90%	3.90%	3.90%		2.20%	2.58%
C2H4	1.70%	1.70%	1.70%			0.00%
N2	7.00%	7.00%	7.00%	0.00%	4.71%	5.54%
C3H8	0.30%	0.30%	0.30%			0.00%
C6H6	0.10%	0.10%	0.10%			0.00%
Total	100.0%	100.0%	100.0%	100.00%	100.00%	100.00%

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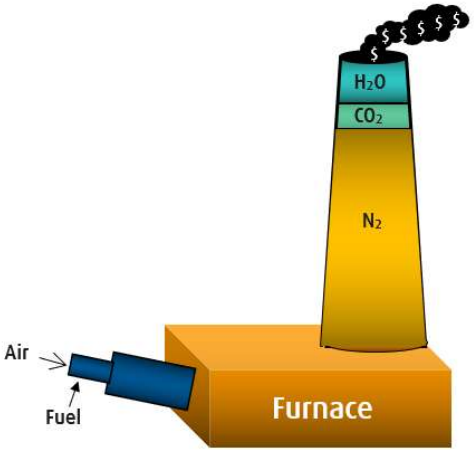
Oxy-Fuel Combustion for Energy Efficiency

Cost-effective approach to decarbonization

Air Based Combustion

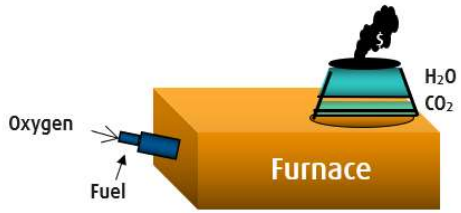


N2 in air is heated and emitted in flue gas → Energy is wasted

Oxygen Based Combustion

- 80% lower flue gas volume
- *Up to* 50% fuel and CO2 savings*
- *Up to* 90% NOx reduction*
- Lower capital for flue gas treatment
- Fuel substitution: low C / low value fuels
- On-demand production increase

*depending on baseline conditions



Eliminates heat up of N2 in air → fuel savings

Oxy-Fuel Combustion has been applied to:

- Steel Reheating
- Non-ferrous processing
- Glass melting
- Rotary kiln processes
- Etc.

Hydrogen Combustion

H2 Combustion Characteristics

- Burners can be easily converted to H2
- H2 requires **3.3x** the volumetric flow of NG
- **Hydrogen combustion is different**
  - Luminosity
  - Water vapor content

Customers interested in impact on:

- Heat transfer
- NOx
- Product quality

Air-Fuel ⇨ **Oxy-Fuel** ⇨ **Oxy-H2**

10-40% CO2 savings

Full Decarbonization

H2 Burners

Customer Demos

Ovako first in the world to heat steel using hydrogen

Together with Linde Gas AB, Ovako has conducted a full-scale trial using hydrogen to heat steel before rolling. The trial was performed with good results in one of the company's pit furnaces at the Hofors rolling mill in Sweden. This historic development for the steel industry proves that carbon dioxide emissions from rolling can be eliminated provided the right financial support and infrastructure are in place.

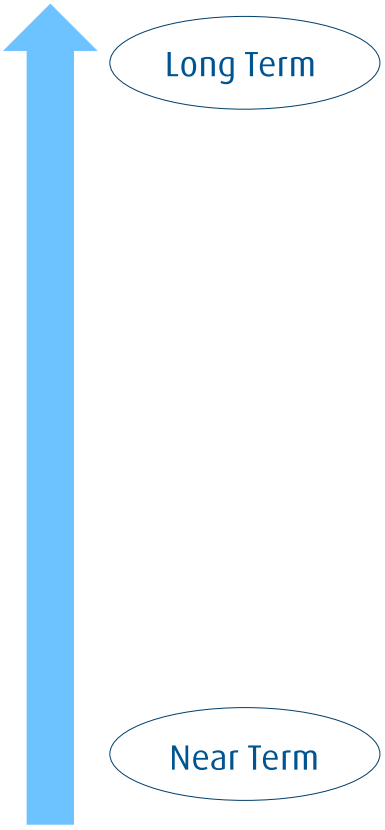
"Hydrogen can be used simply and flexibly, with no impact on steel quality, which would mean a very large reduction in the carbon footprint."
Göran Nyström, EVP, Head of Technology and Marketing at Ovako

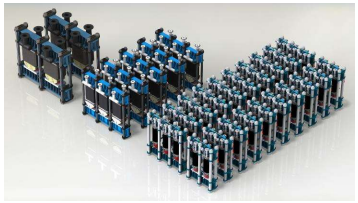
World First as 100% Hydrogen Glass Fired at Pilkington UK

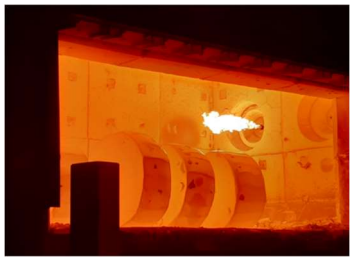
The ground-breaking 'HyNet Industrial Fuel Switching' project, led by Progressive Energy, with hydrogen being provided by BOC, will provide confidence that low carbon hydrogen from HyNet can replace natural gas. This is believed to be the first large-scale demonstration of 100% hydrogen firing in a live float (sheet) glass production environment anywhere in the world.

Summary

1. Hydrogen Supply
2. CO2 Capture
3. Low Carbon Fuels
4. Oxy-Fuel Combustion







Thank you for your attention.

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Making our world more productive