2023 WSA Breakthrough Technology Conference

MIDREX Flex™: Minimizing technology risks in the transition to carbon-free steelmaking

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MIDREX

Presentation outline

01 About Midrex

02 Low CO_2 ironmaking with Midrex Technologies

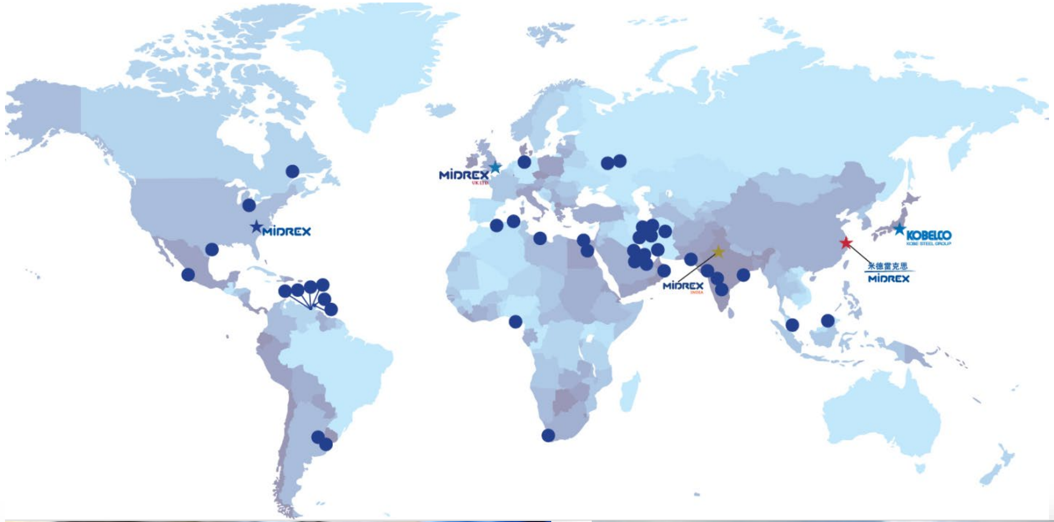
03 Viability of using Hydrogen as a reductant

- Process Design
- Equipment Design
- DRI and HBI quality

04 Conclusions

About Midrex

- Headquartered in Charlotte, NC (USA)
  Research and Development Technology Center in Pineville, NC (USA)
- Midrex has a unique blend of existing and new technologies to create the sustainable future of iron & steel
- Our DR plants produce low CO_2 metallics for captive steel production (DRI) or for export to steelmakers around the world (HBI)



50+
Years of commercial operation

20+
Countries with MIDREX® Plants

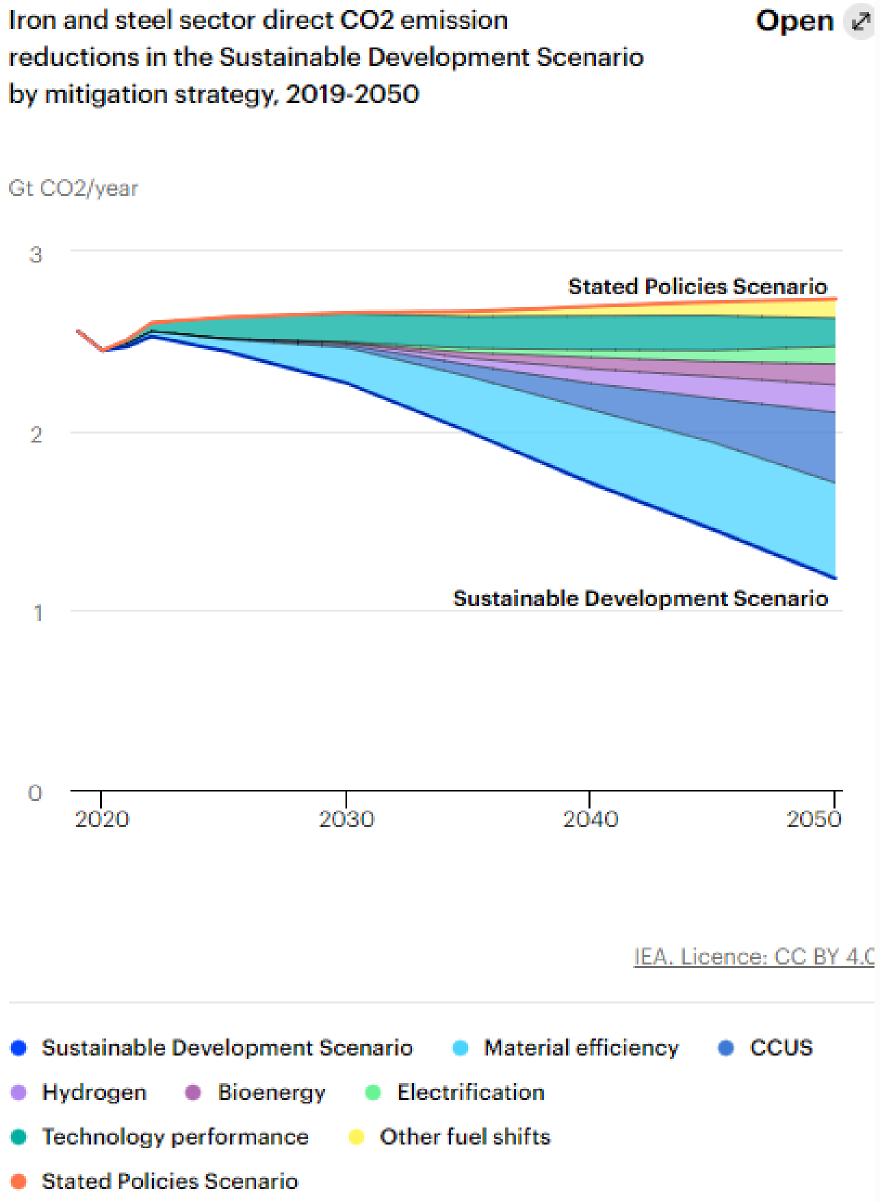
Process
MIDREX Plants Produce about 80% of the World's Low CO_2 DRI

R&D
State-of-the-Art Research and Development

HQ
Charlotte, NC Headquarters + Global Offices

A generational Challenge

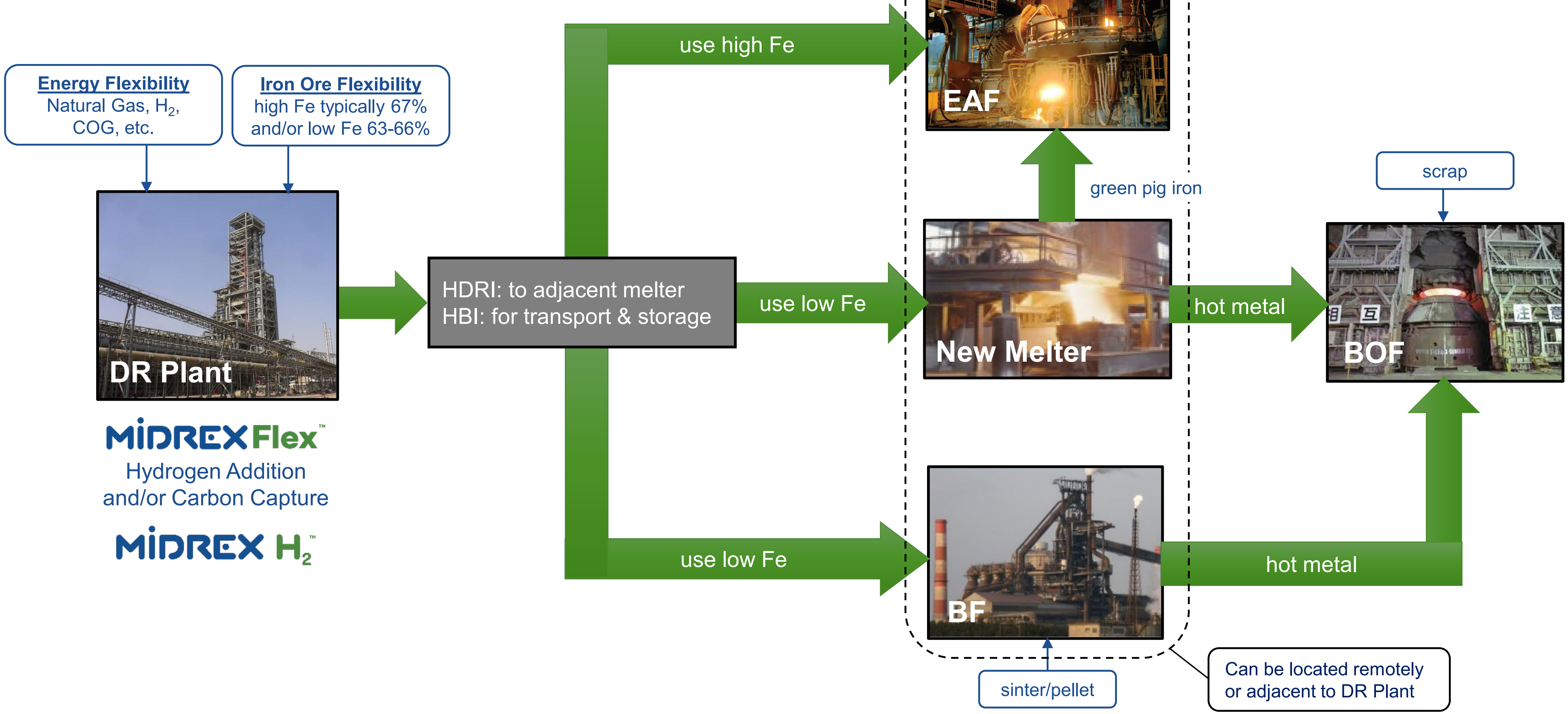
- The Iron & Steel industry is responsible for around 7% of global CO_2 emissions (2.6 Gt CO_2 emissions annually)
- To meet global and climate goals set by the IEA Sustainable Development Scenario (SDS), CO_2 emissions from the Iron & Steel industry must decrease by more than 50% by 2050
- The reduction in CO_2 emissions will come from implementation various technologies, including energy efficiency improvements and CCUS (carbon capture, utilization, and storage)
- In the long-term, bio-energy, hydrogen and process electrification will play a prominent role in decarbonizing the steel industry
- There are many scenarios and roadmaps, but ALL included DRI/HBI with Natural Gas and Hydrogen



Source: IEA Iron and Steel Technology Roadmap 2020

Flexibility of Low CO_2 Metallics

- Very high Technology Readiness
- Iron Ore and Energy Flexibility through the 30-year transition
- Compatible with existing integrated plants and future metallic hubs



Viability of using H_2 as reductant

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- Hydrogen should only be used as reductant, not as fuel
- MIDREX already uses Hydrogen for direct reduction (up to 80%)
- Our R&D and Engineering teams have been working for over 5 years on **Technical Risk mitigation** for the transition from Natural Gas to H_2-based DRI / HBI
  1. Process Design:
     - 100% H_2
     - NG → H_2 transition
  2. Equipment Design
  3. DRI and HBI Quality:
     - Furnace sticking and disintegration
     - Product quality for steelmakers

H_2 Reduced HBI
Produced at the Midrex Tech Center

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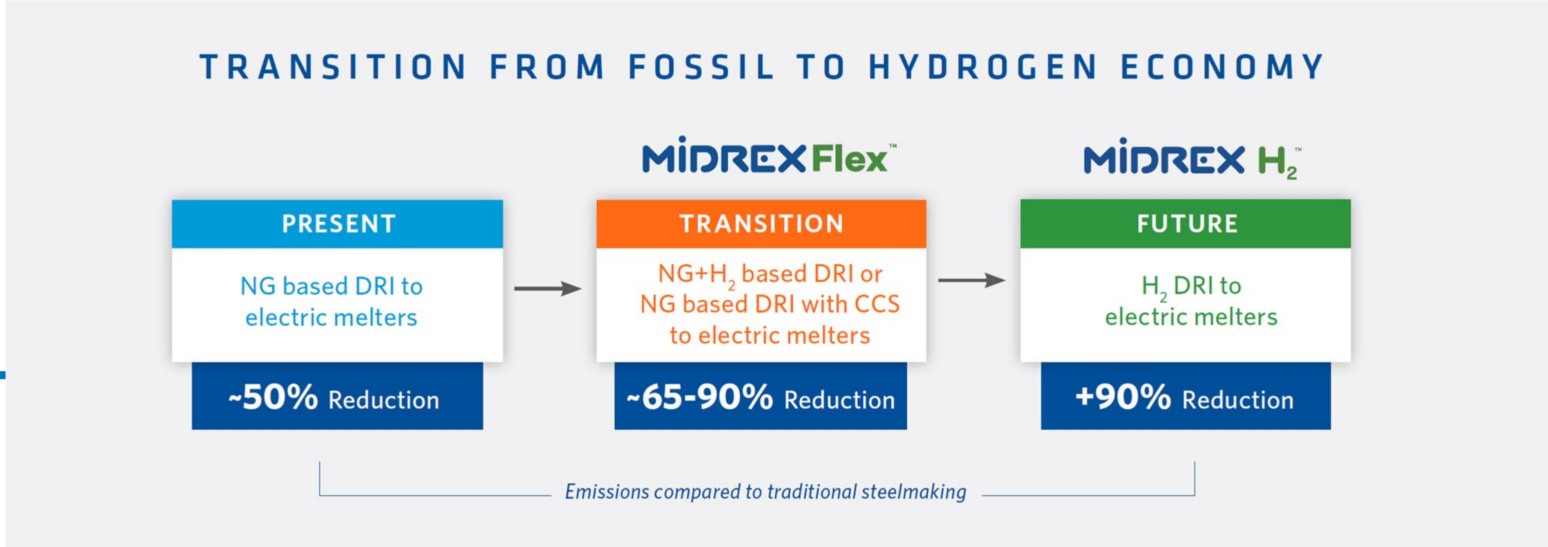
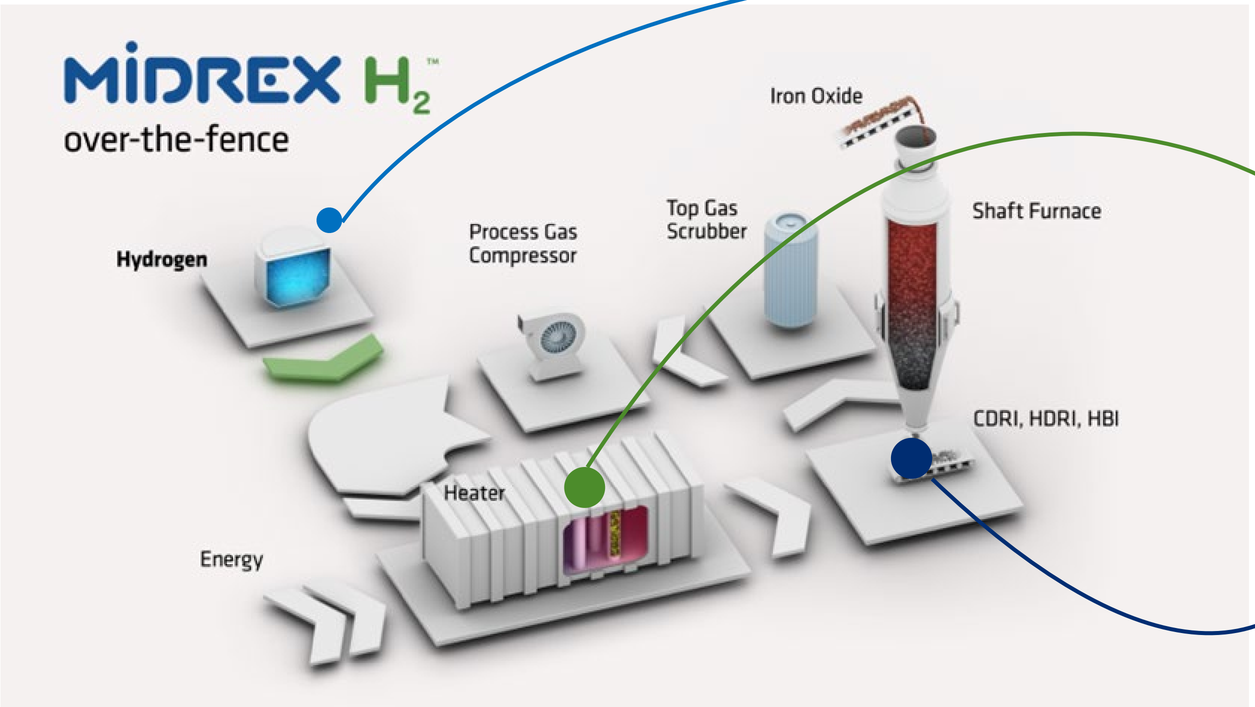
1- Process Design



MIDREX H_2™: The Future Today



1 Optimized for 100% H2

The MIDREX H2 plant can operate without any fossil fuel input. Hydrogen recovery in the Top Gas Fuel maximizes the process efficiency

2 Electrical Heater

Strong collaboration with Midrex's partner, Tutco Sureheat, allows for the application of direct electric heating to the Process Gas.

3 Product Quality

Ready to deliver maximum CO2 reduction with 0% carbon DRI, or deliver carbon-containing DRI for the downstream user. Special attention to the electric heater design and Top Gas Fuel hydrogen recovery allows for this flexible operation while avoiding undesirable side reactions.

MIDREX H_2™: Electric gas heating

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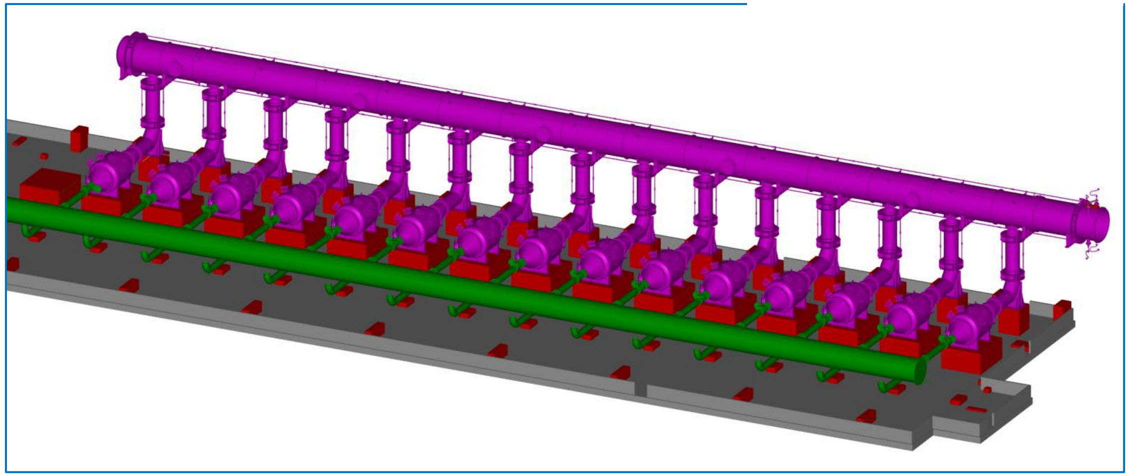
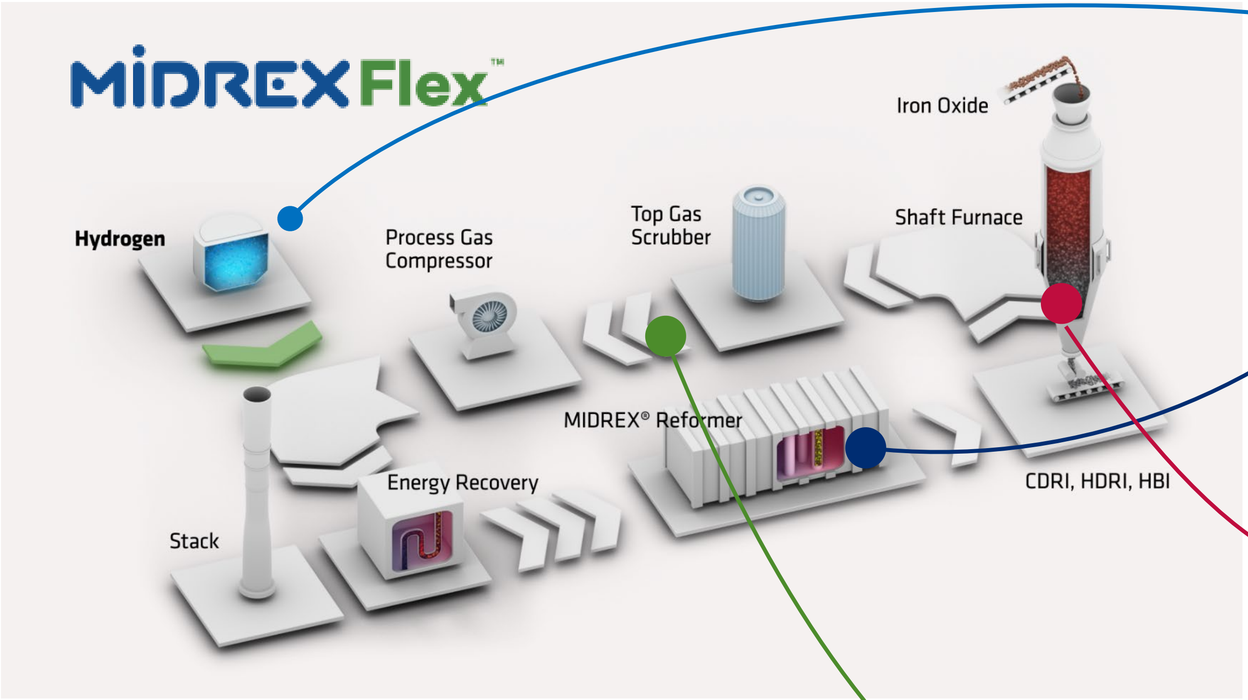
Electric Heater:

- Provides sensible heat energy for reducing gas via direct electrical heating (increased efficiency compared to gas-fired route).
- Modular Design:
  - 15 electric heating vessels for 2 MTPA plant
  - Dedicated control panels
  - Over Temperature Protection ensures heater element safety
  - Provides reducing gas temperatures in excess of 900ºC
- No heat recovery system required

TUTCO HEATING SOLUTIONS GROUP



MIDREX Flex™: Solution for Hydrogen Transition



1 Hydrogen Ready

Use up to 100% H2 as the reductant. Midrex has solutions ready to address the plant performance for the entire range of required input compositions

2 Midrex Reformer

The Midrex Reformer ensures optimum reducing gas conditions throughout the entire range of the transition.

3 Midrex Shaft Furnace

Delivers consistent product quality throughout the transition. The influence of endothermic hydrogen reduction is mitigated by the Reformer and uniform burden movement that is a result of the proprietary shaft furnace flow aid equipment.

4 Carbon Capture & Storage

Carbon capture and storage can be applied to several different process streams. CO2 capture of 50% to nearly 100%. Available for addition to existing faculties or new installations.

Design Goals for Midrex Flex and the Natural Gas to H_2 Transition

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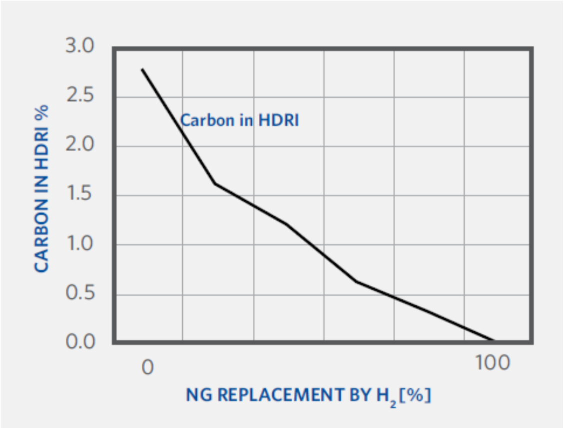
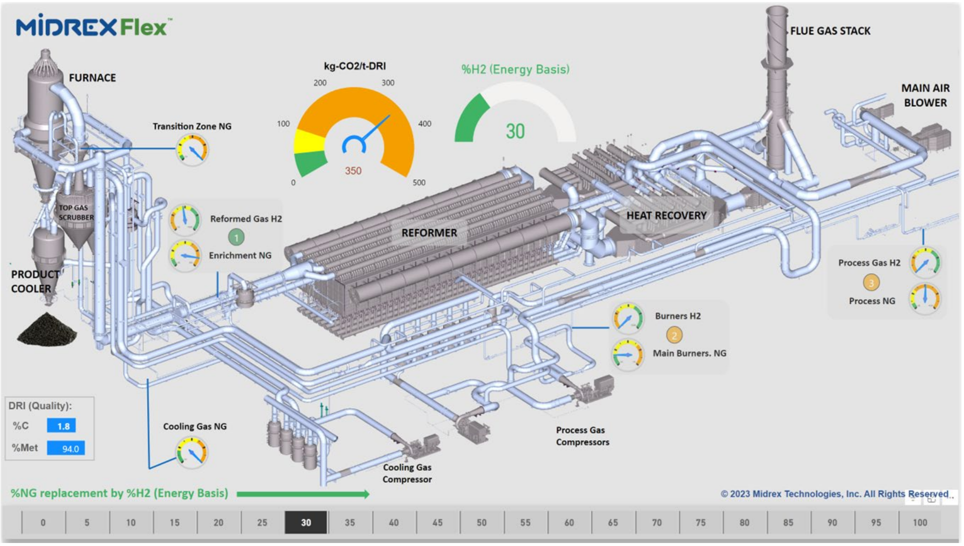


Major impacts of increasing hydrogen content:

- Reduction by hydrogen is endothermic
- Reduction by hydrogen is kinetically faster ***at the same temperature***, but reaction kinetics is very strongly influenced by the bed temperature
- Lighter molecule
- Heat transfer properties
- Less carburization

Operational Targets:

- Maintain plant productivity across the full NG→H_2 transition range, while minimizing equipment modifications / additions
- Maximize the DRI carbon at each point across the full transition range by maintaining the transition zone NG flow as far into the H_2 transition as possible
- Maintain optimum reducing gas quality to the reduction furnace by maximizing H_2 addition downstream of the reformer
- Maintain the required amount of thermal mass flow to support the increasing endothermic reduction load in the shaft furnace



2- Equipment Design

Impact of Hydrogen on equipment design (in existing or new MIDREX-Flex™ plants)

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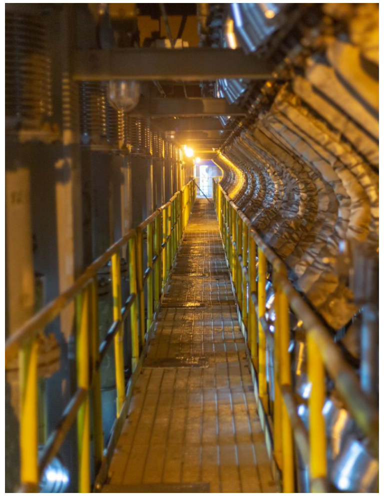
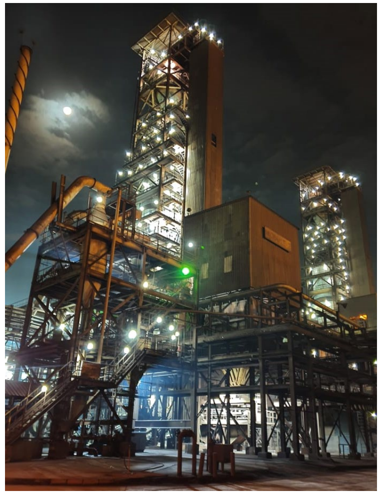
<u>Operational changes:</u> **Higher H_2/CO ratio**

- Lighter molecular weight of the reducing gas; changes in heat transfer properties
- Favors endothermic reduction: increased reducing gas flow to maintain the energy balance in the shaft furnace
- Increased cold water demand and reduction in hot water demand

<u>Equipment changes:</u>

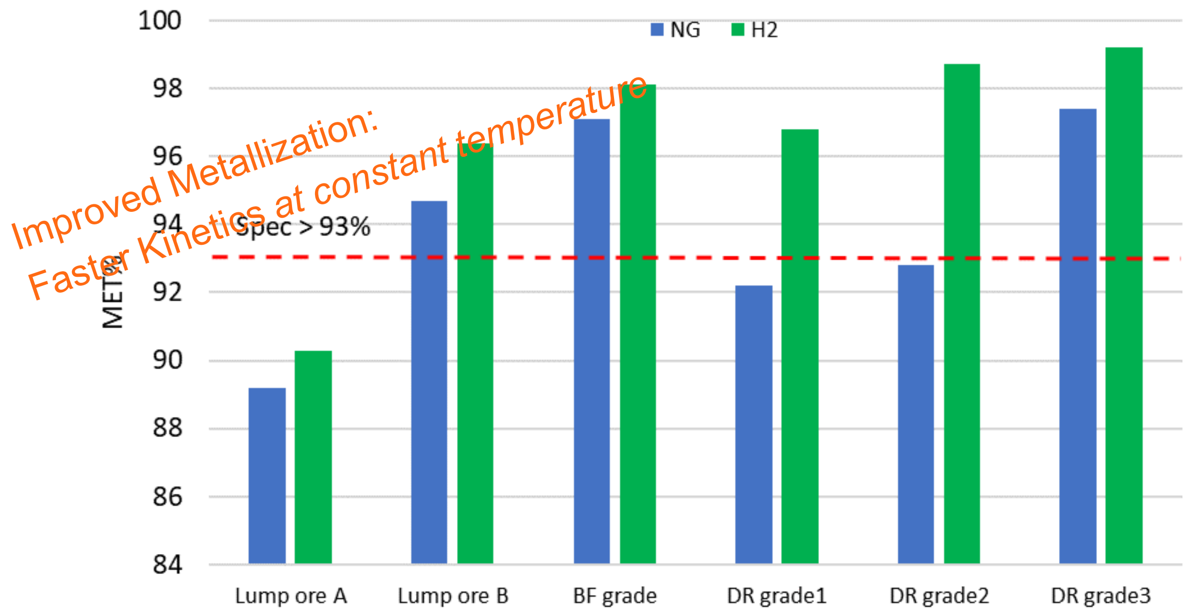
- **Furnace**: no fundamental changes
  - Bustle gas temperature and temperature profiles are maintained
  - PG gas flow per ton increases, utilization decreases (productivity is maintained)
  - Existing refractory is suitable for H_2 operation
  - Seal legs do not require any modifications
- **Reformer**: no fundamental changes
  - Reforming load decreases with higher %H_2
  - Existing burner design capable of TGF to H_2 transition
- **Compression**:
  - Additional compressor may be needed to maintain the energy balance of the furnace (on a plant-by-plant basis)
- **Heat recovery**:
  - Piping modifications on a plant-by-plant basis
- Additional **water treatment** capacity needed from more water generated by reduction with H_2

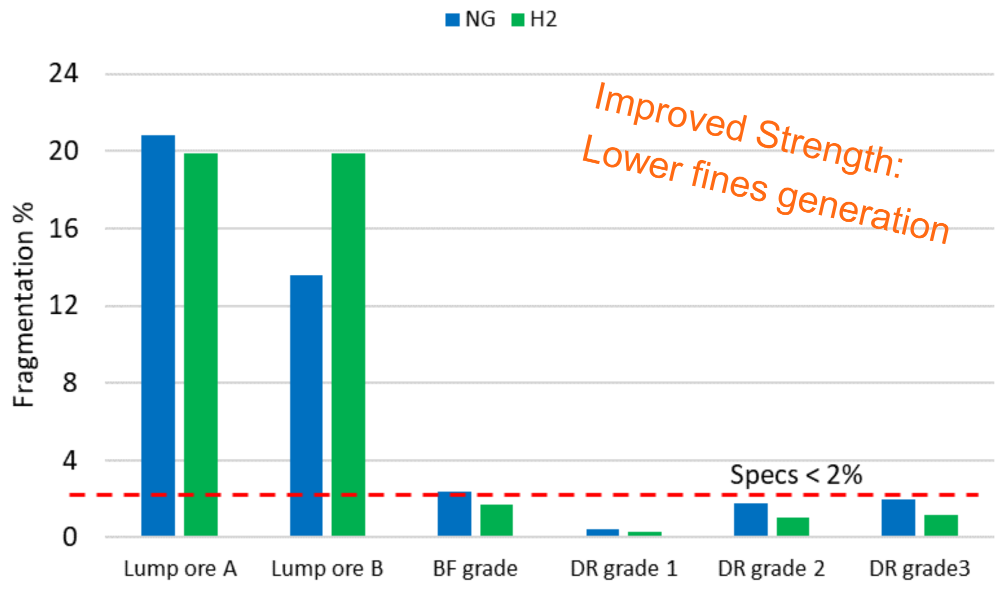




3- DRI and HBI Quality

Evaluation of H_2-reduced DRI

- Physical and chemical characteristics of DRI reduced under Natural Gas (NG) and H_2 reduction conditions
- Linder Test (ISO-11257): measure of reduction degree and degradation index
  - It is a comparative test only: absolute values have little meaning
  - NG conditions: 36% CO, 5% CO_2, 55% H_2, 4% CH_4
  - H_2 conditions: 100% H_2
  - 760 °C for 5 hours





Evaluation of H_2-reduced HBI

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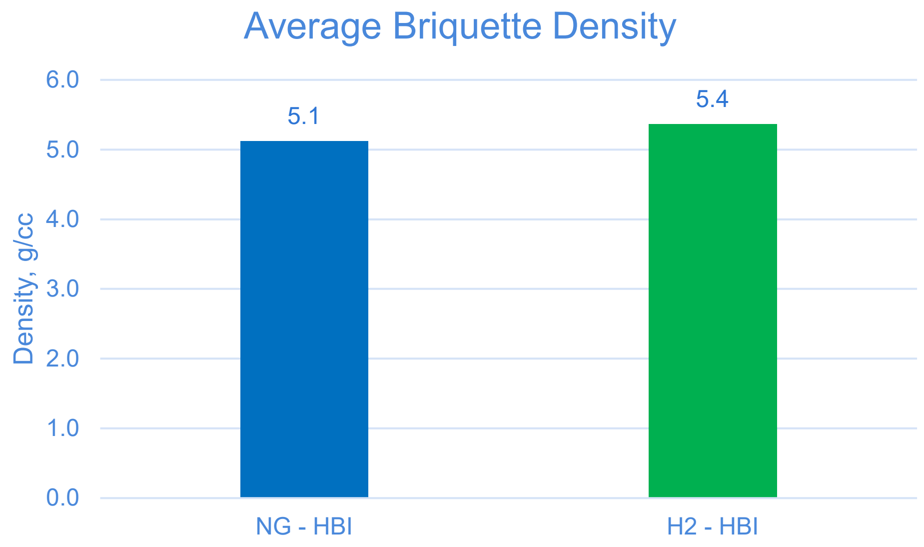
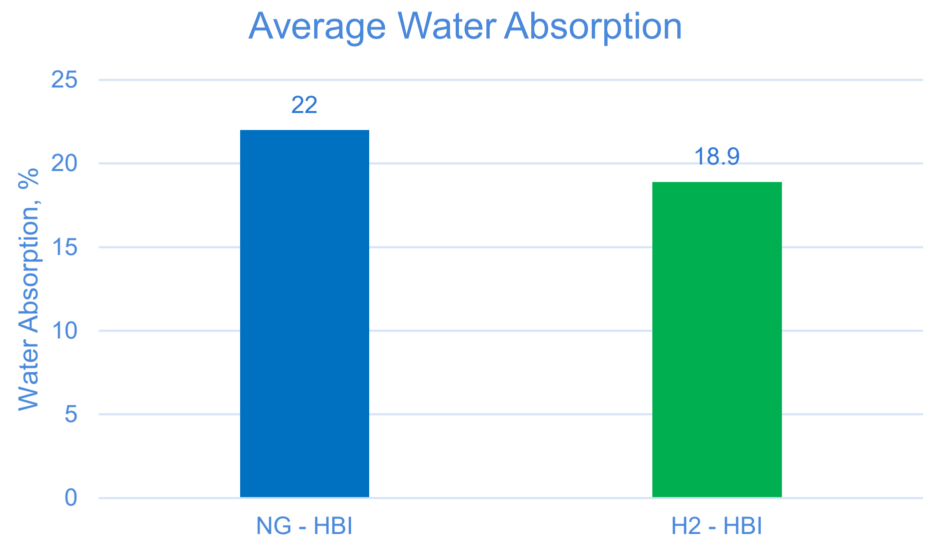
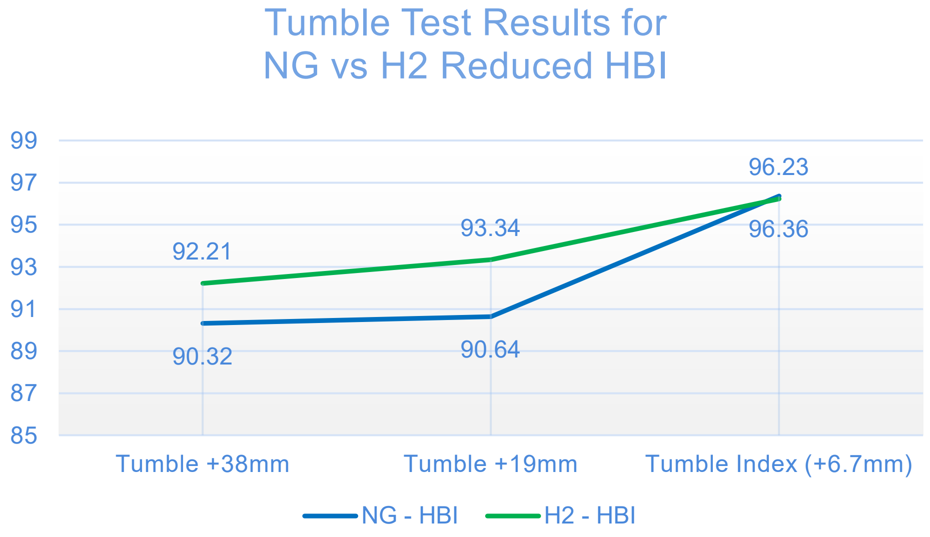
HBI reduced and briquetted at the Midrex Tech Center:

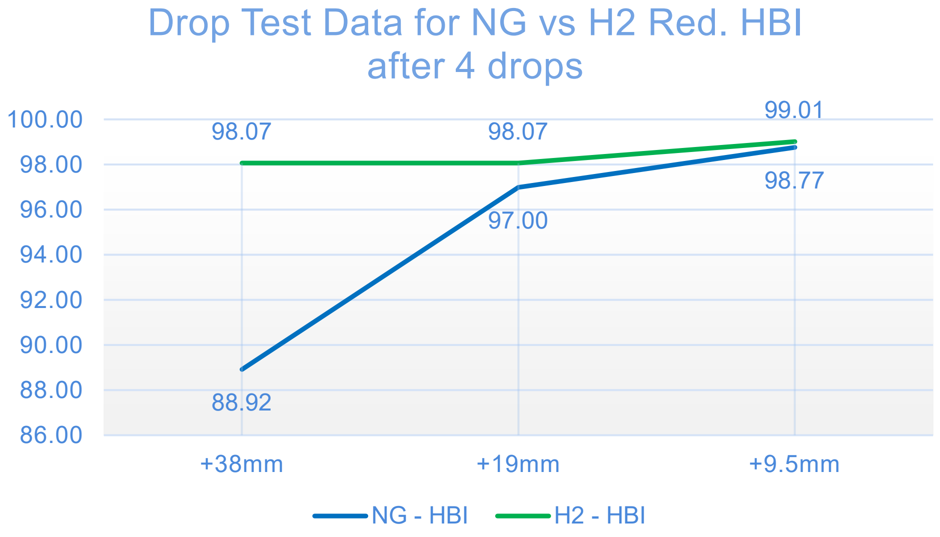
- Approximately 400 kg of DR-grade oxide pellets reduced with
  - H_2+CO syngas (simulating NG base reduction)
  - H_2/N_2 mixed gas (simulating hydrogen reduction)
- Resulting DRI from each trial reheated above 750°C and briquetted in a Köppern commercial-scale briquetting machine
  - Each briquette run was approx. 2 minutes
  - HBI size ~110 cm^3

Physical properties of H_2-reduced HBI









Conclusions

- Direct Reduction has great promise for leading the transition to decarbonize our industry
  - Natural-gas based DRI has already nearly half of the carbon footprint as pig iron
  - Various options for further decarbonization:
    - Carbon capture
    - displacement of NG by hydrogen
    - 100% Hydrogen
- Step-wise transition has minimal technical risks on process and equipment
- Similar or improved properties (fragmentation and clustering) under H_2 reducing conditions
- H_2 reduction does not have adverse effects on DRI / HBI quality (other than carbon)
- Green iron & steel using H_2 is happening now
  - Full scale, green H_2 DR plants are being executed now
  - Direct electrification is necessary, incl. electric heaters

Midrex selected by H2 Green Steel

Midrex and Paul Wurth, an SMS Group company, to supply the **world's first commercial 100 percent hydrogen direct reduced iron (DRI) plant**.

MIDREX H_2™ **Plant will have 2.1 million tons per year** of hot DRI/hot briquetted iron.

The configuration includes the **latest innovation from Midrex**, an electric heater for the recirculating hydrogen gas.

H2 Green Steel's purpose is to decarbonize hard-to-abate industries, starting with steel. Its process will remove **up to 95 percent of carbon emissions** compared to traditional steelmaking

Location: Boden, northern Sweden.
Timing: The plant is expected to begin production in 2025 and ramp up during 2026.

MIDREX Flex™

thyssenkrupp

Location: Duisburg, Germany
Contracted: March 2023
Schedule: Start-up planned for the end of 2026

- Midrex and Paul Wurth will engineer, supply, and construct a direct reduction plant for thyssenkrupp Steel Europe AG
- 2.5 million t/y of HDRI will be used in new electric smelters provided by SMS
- Flexibility to operate at different ratios of natural gas and H_2, up to 100% H_2
- The hydrogen-based DRI plant is a major step in thyssenkrupp's conversion of its integrated steelworks to a climate-neutral production site

Sources:
thyssenkrupp - engineering.tomorrow.together.
thyssenkrupp Steel Selects MIDREX Flex™ for Immediate CO2 Emissions Reduction - Midrex Technologies, Inc.

3D model of planned thyssenkrupp Steel Duisburg plant complex

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Kobe Steel & Mitsui Announce DRI Project in Oman; 5 Million Tons Using MIDREX® Technology

Kobe Steel, Ltd. and Mitsui & Co., Ltd. have signed a memorandum of understanding (MoU) to manufacture and sell direct reduced iron (DRI).

The plant will utilize MIDREX Flex™ technology, which allows for initial operation on natural gas with transition to up to 100% hydrogen.

KOBELCO | MITSUI & CO.

Location: Duqm, Sultanate of Oman
Production: This Low-CO_2 Iron Metallics Project to produce **5 millions tons of DRI** with future expansion plans under study

Tosyali Algérie Contracts 2nd MIDREX® Plant

Tosyali Algérie will add a second **2.5 Mt/y MIDREX Plant capable of operating with increased percentages of hydrogen**.

HDRI will be fed via a hot transport conveyor to a new 2.4 Mt/y EAF melt shop with downstream facilities to produce flat products.

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Q&A

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