DECARBONIZING ROADMAP FOR IRON AND STEEL MANUFACTURING

National Science Foundation

Energy Research Center Workshop

27 February 2023

Association for Iron and Steel Technology (AIST)

✦ 15,500 members from more than 70 countries with 22 Member Chapters and 29 Technology Committees

MISSION

to advance the technical development, production, processing and application of iron and steel

Steel is one of the world's most sustainable materials

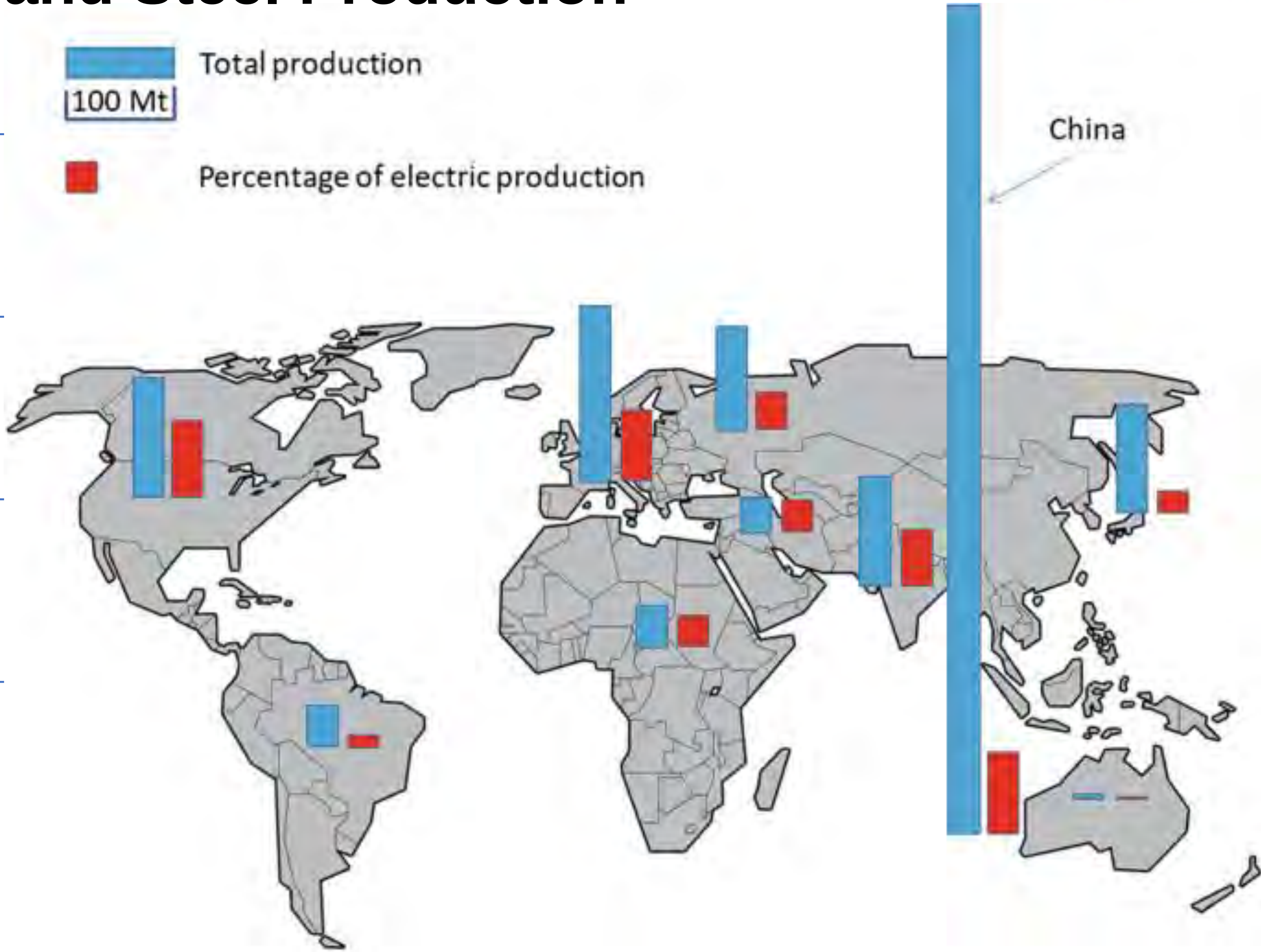
The Global Iron and Steel Production

In the U.S. 72% of all steel produced was via EAF process.

Global EAF steel production is approximately 30%

The BF/BOF process emits 1,800 kg CO_2/ton crude steel.

EAF process emits 600 kg CO_2/ton crude steel.



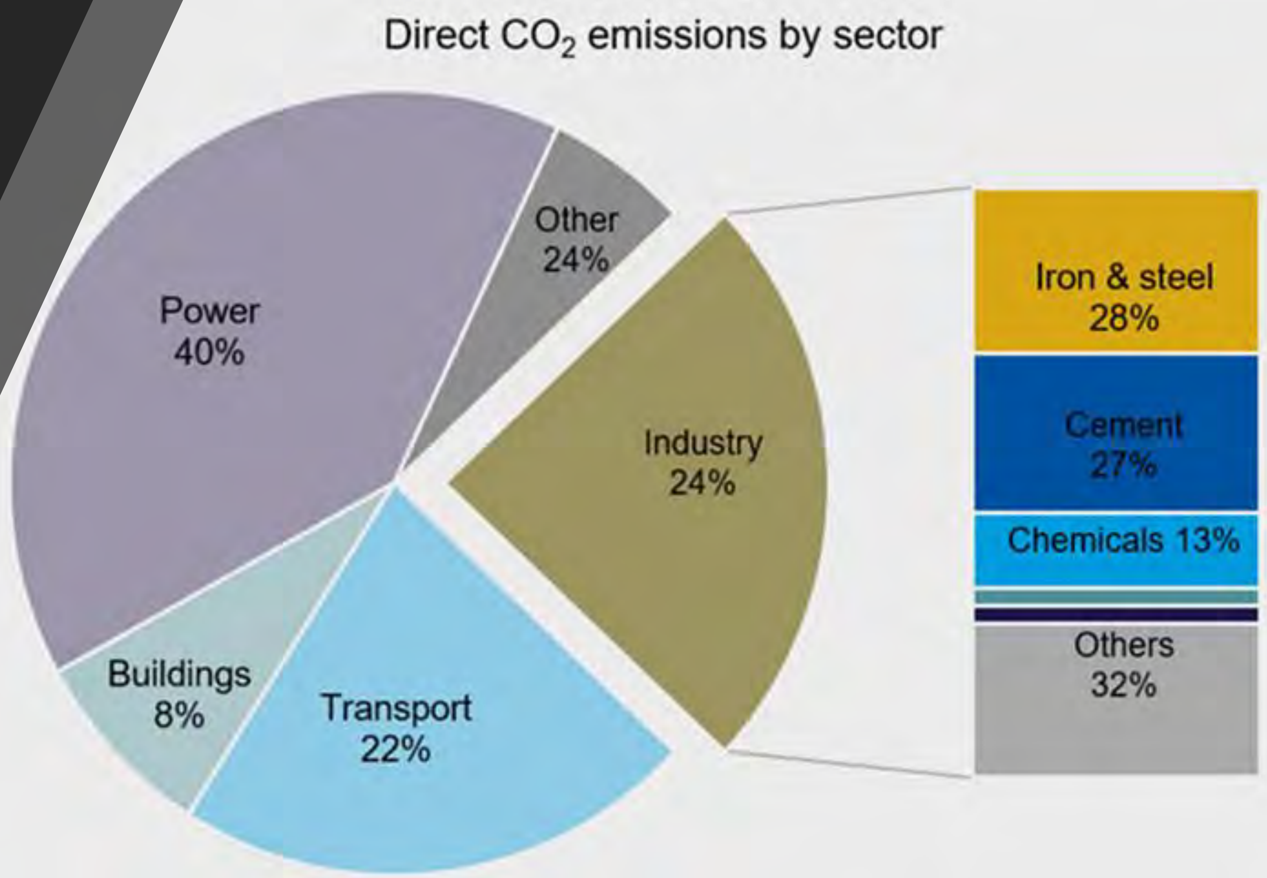
Industry – Academia – Technology Suppliers

WORKING TOGETHER to support RD&D

Moving Innovations into Commercial Applications

Global Challenges

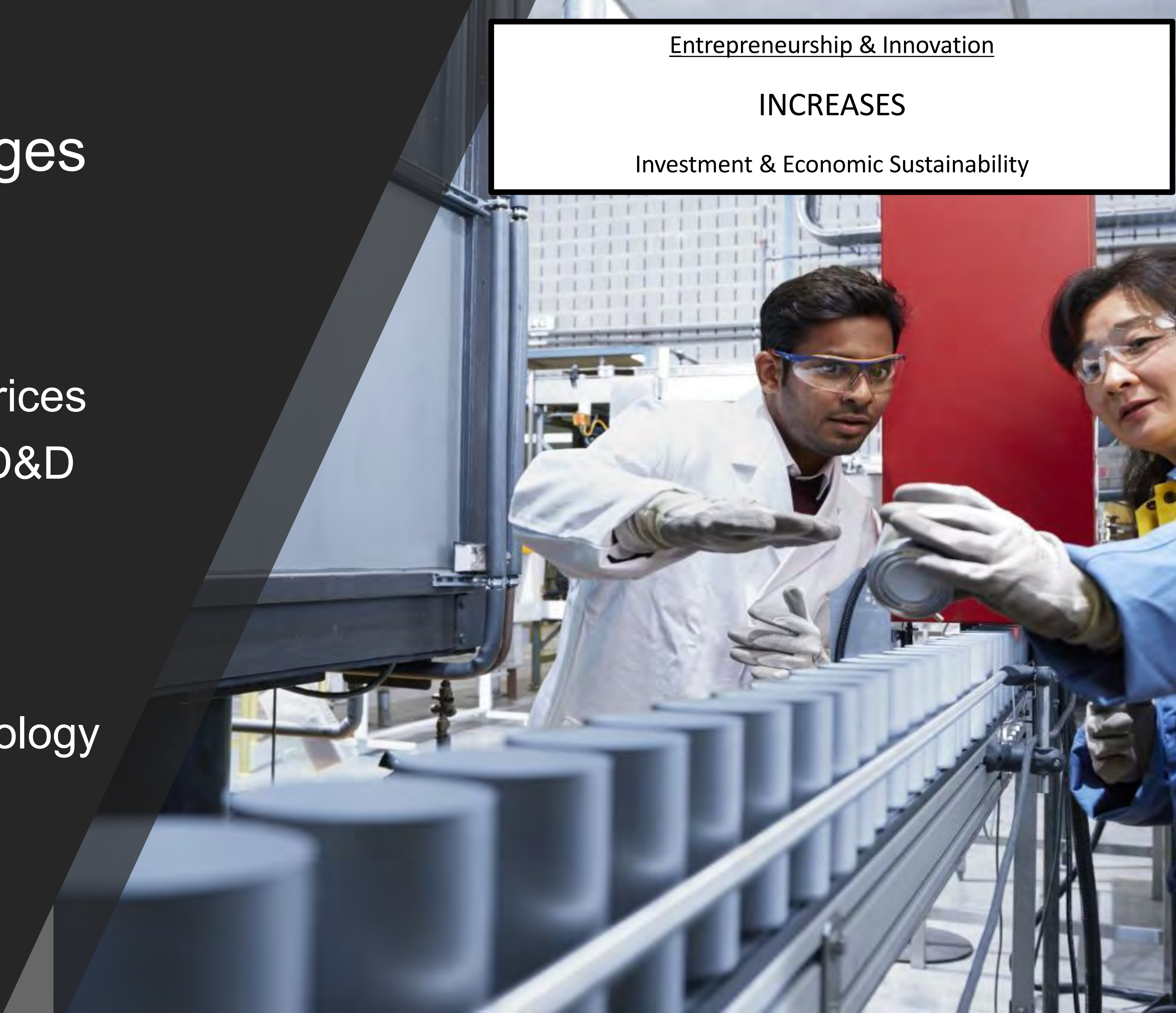
- Global steel production contributes significantly to the emission of CO_2, accounting for 7% of all CO_2 emissions.
- Mounting global decarbonization expectations
- Global demand for high-quality metallic feedstock.
- Steel Scrap quality and availability
- Global steel overcapacity (approaching 40% today)
- Trade and free market.



Economic Challenges

✦Narrow profit margins
✦Varying raw material prices
✦Underinvestment in RD&D
✦Foreign Trade
✦Alternative Materials

→ Need to de-risk technology innovations.



<u>Entrepreneurship & Innovation</u>

INCREASES

Investment & Economic Sustainability

Workforce Challenges

- ✦ Few metallurgy institutes and universities in the U.S.
- ✦ Shrinking talent pool
- ✦ Attract and educate a skilled and diverse workforce.
- ✦ Workforce attrition and capabilities, both physical and digital, are outdated when compared to other sectors.

→ There is a need to reduce the skills gap and increase diversity and equity.

<u>Community Colleges – Trade Schools – Universities</u>

PROVIDE INFRASTRUCTURE

Develop a SKILLED, DIVERSE and INCLUSIVE Workforce

Technical Challenges

- ✦Cutting-edge technologies to achieve carbon neutrality are at the RD&D stage.
- ✦The 4th Industrial Revolution (Industry 4.0)
- ✦Challenges with modern steelmaking

→ We must identify the pathways to merge smart solutions with advanced processes.

<u>Smart Solutions & Advanced Processing</u>

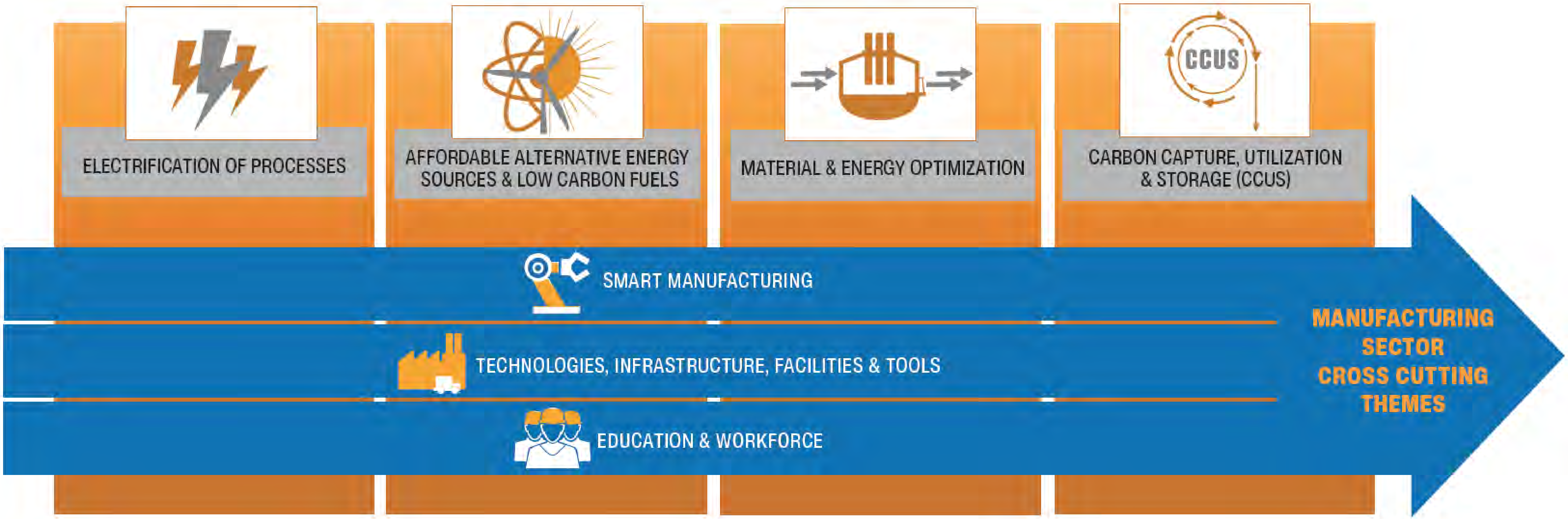
PROVIDES

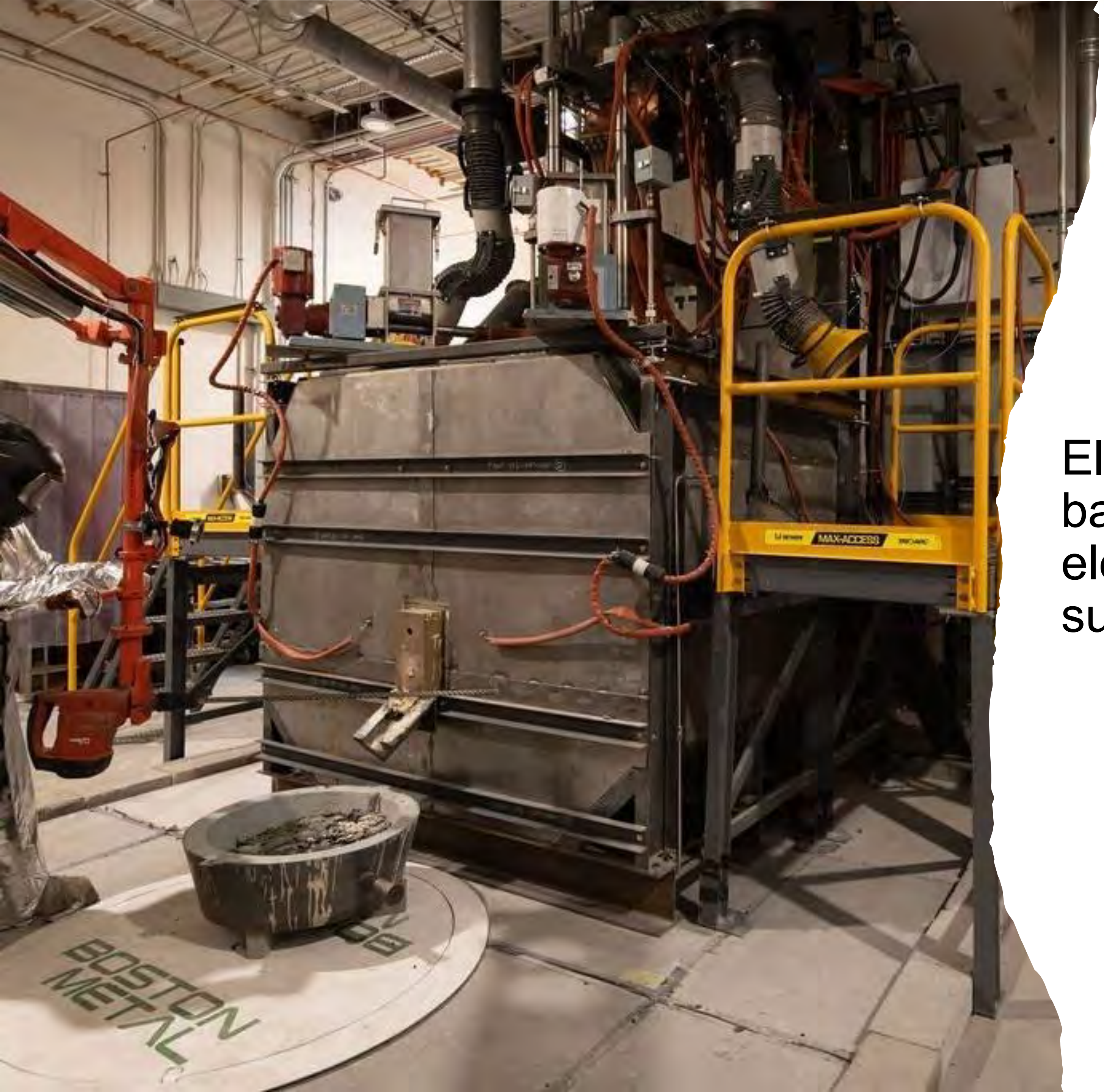
Raw Material & Energy Flexibility
Lower Emissions
Near-net-shape Manufacturing
Lighter, Higher-performing Products

DECARBONIZING ROADMAP FOR IRON AND STEEL MANUFACTURING:

- Industry has started addressing several areas within the steel manufacturing value chain to achieve cost improvements and reductions in emissions and efficiency.
- However, many of these efforts are still not commercially deployable and will require further insights that can only come through enhanced innovation, research and development.
- Four key technology themes and three cross-cutting themes identified:

AIST Decarbonization Themes



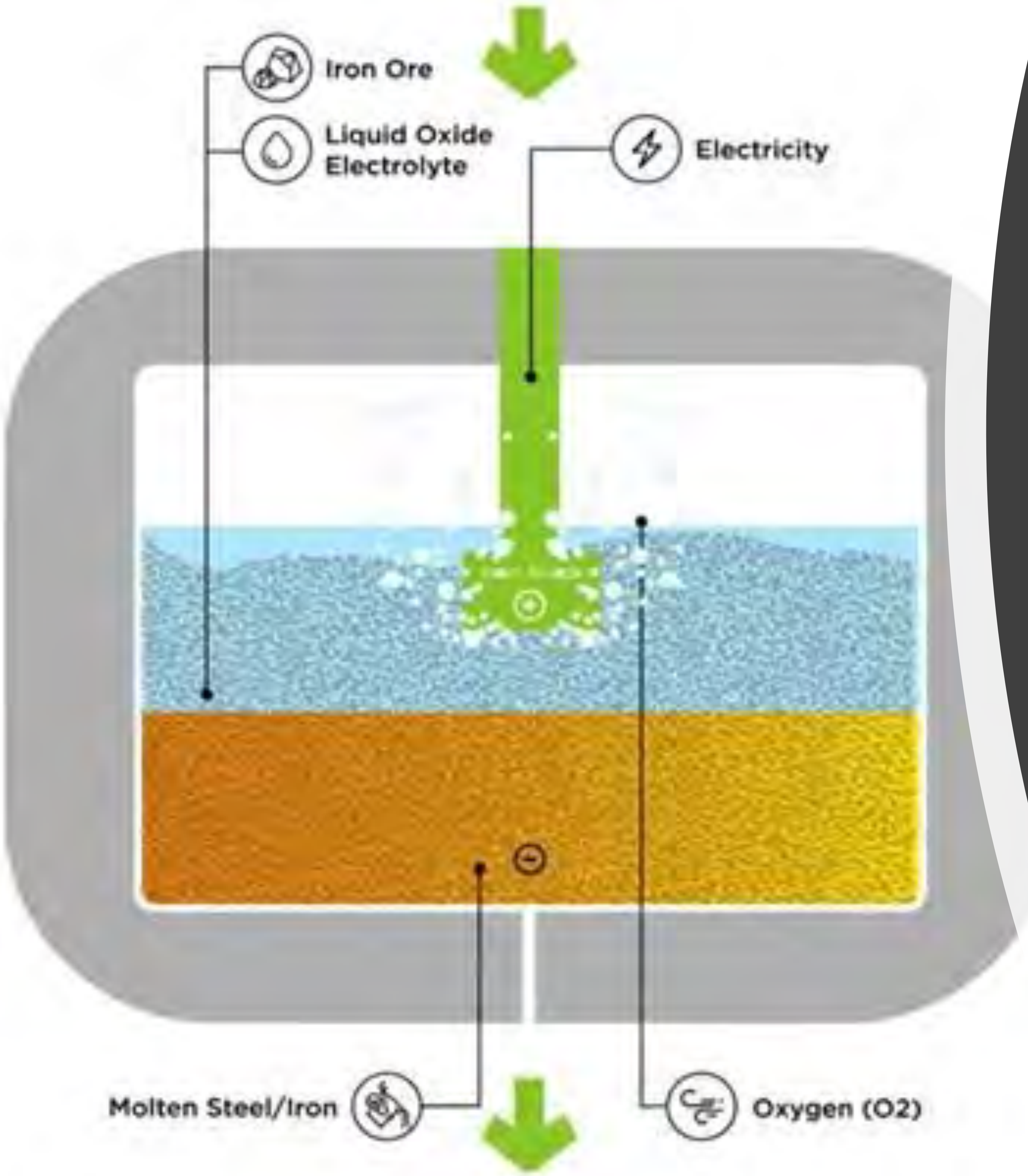


Theme 1- Electrification of processes

Electrification to replace fossil-fuel based processes and equipment with electric power from renewable sources such as solar, wind or hydro.

Key Technologies

- Molten oxide electrolysis
- Scaling up electric induction furnaces
- Optimized EAF-DRI process route
- Diode laser technology
- Electrification of Pelletizing of iron ore
- Electrification of reheat and other downstream processes
- Recovery and re-use of off-gas and waste steam to electricity



Main Challenges

- More investments need to be directed to support process integration and optimization of electrification of industrial processes.
- Challenges with replacing BF with DRI / EAF production routes at integrated steel mills.
- Challenges and knowledge gaps in electrolysis reactor for steelmaking include limitations with scale-up.

Theme 2 - Alternative energy sources and low carbon fuels

The most considered alternative has been H_2 based on its potential to be produced at scale.

Hydrogen, as a replacement for carbon, can act as a reducing agent as well as an energy source for reheating.

Key Technologies

- Hydrogen based DRI & Green Electricity EAF process.
- Hydrogen replaces pulverized coal in BF.
- Hydrogen production and storage.
- Biofuels Coke Making and BF.
- Utilizing suppressed combustion for EAF production.
- Hydrogen in Reheat furnaces.

Main Challenges

- Costs for natural gas and CO_2 certificates will remain at high levels.
- Future design and technologies for steelmaking will need to adjust dramatically.
- Water, wind, solar panel requirements to produce Green H_2.
- Storage and transportation of Green H_2.
- What is the capital cost, and can it be scaled?

Main Challenges

- The challenge with intermittent renewable power (solar/wind) is the lack of sufficient energy storage and ability to operate fossil free operation during downtimes.

- Co-locating near continuous renewable power sources, e.g., hydro-electric or geothermal stations or nuclear power.

- There is a risk of overdependence on clean electric power.

- EAF facilities to collaborate with local utility company to integrate locally generated green electricity.

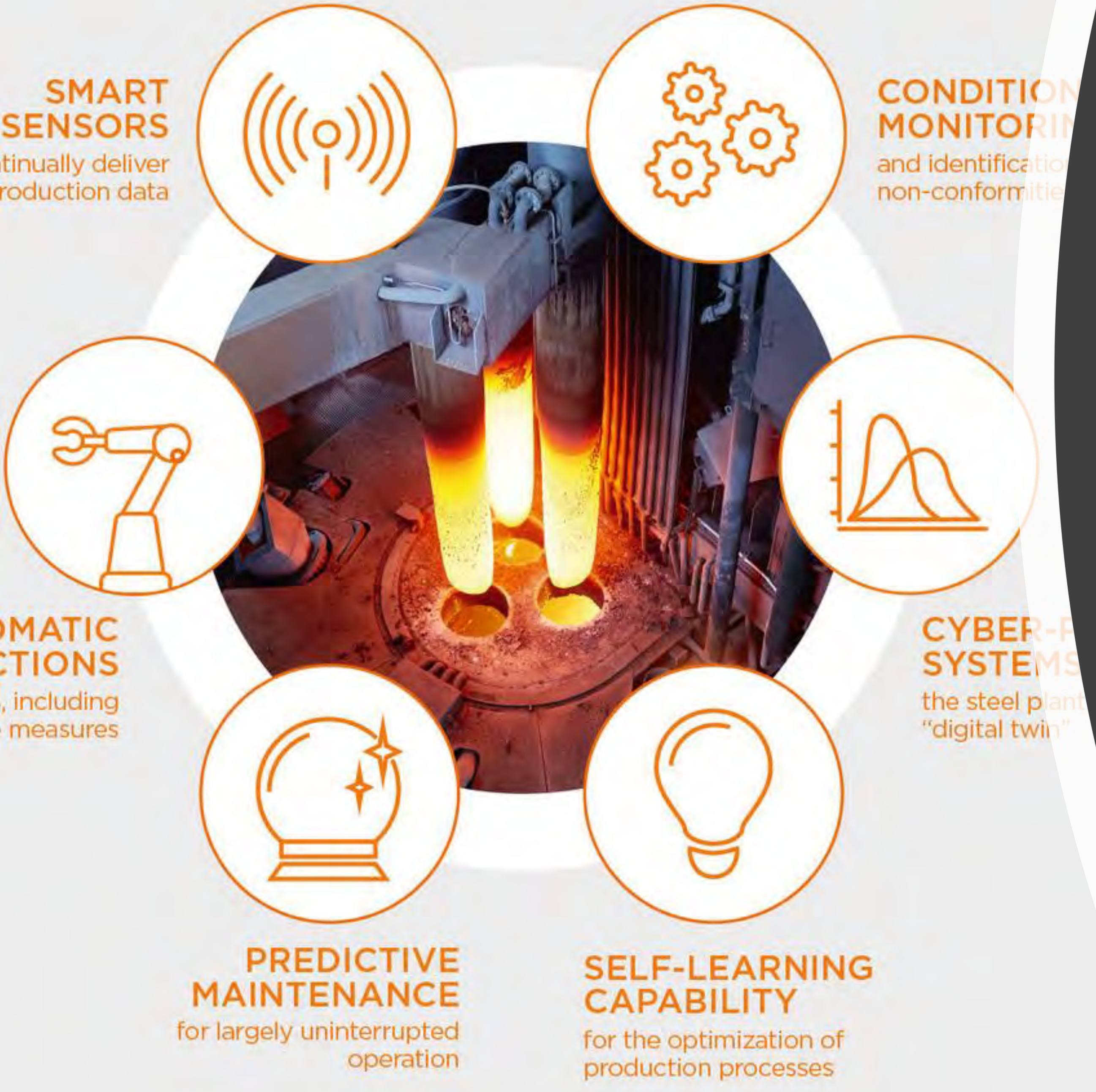
- Grid balancing using large-scale low-cost battery storage, such as FORM energy’s iron air battery, or supplemental power generation using natural gas may provide full or partial solutions.

Theme 3 - Material and energy optimization

Scrap and low-grade iron ore must be optimized to achieve quality demands.

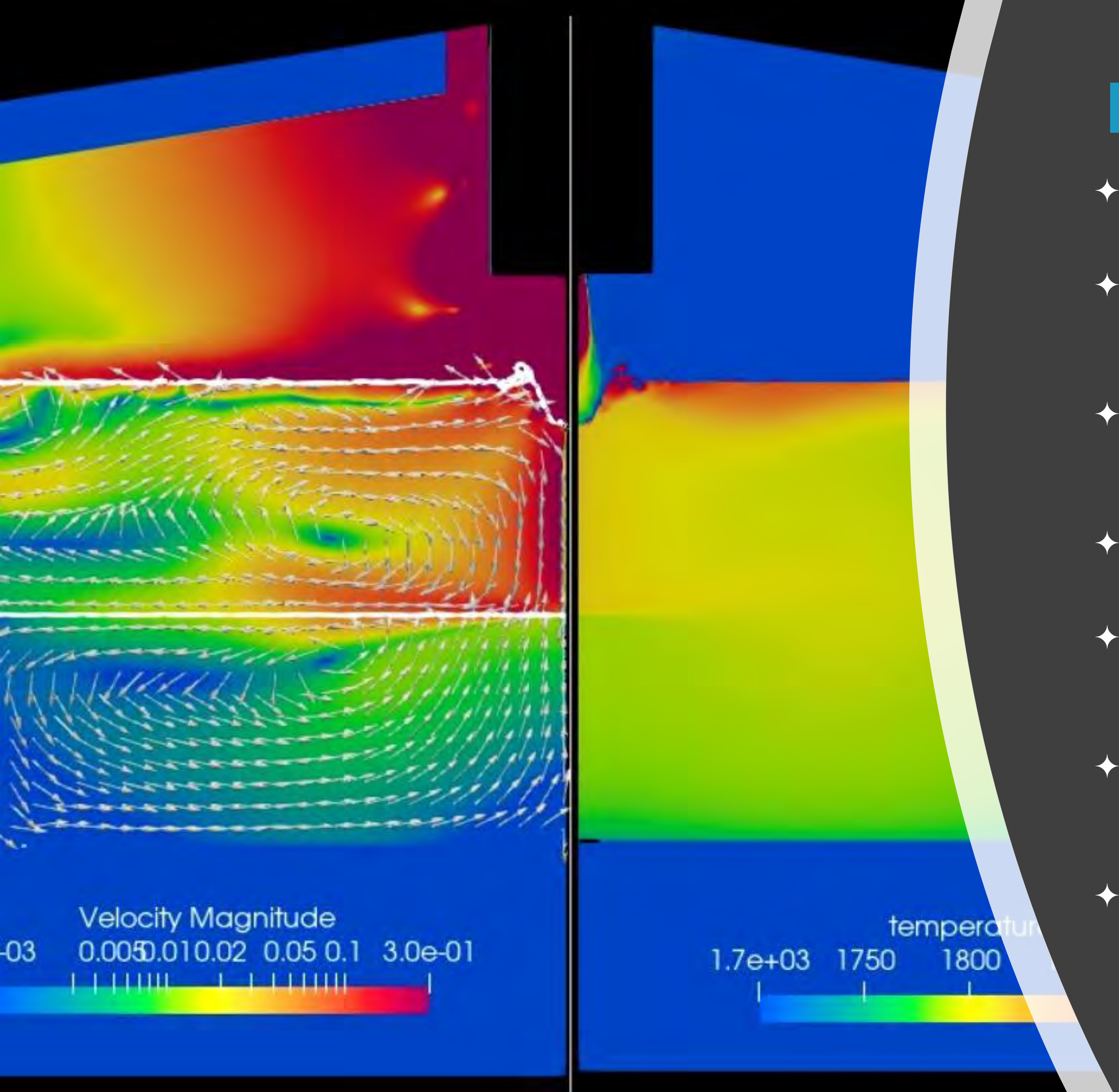
New steel development will impact decarbonization by increasing efficiency of material usage (lightweighting, performance and strength)

Recovery and re-use of off-gas waste heat in the steel industry provides significant energy and cost savings.



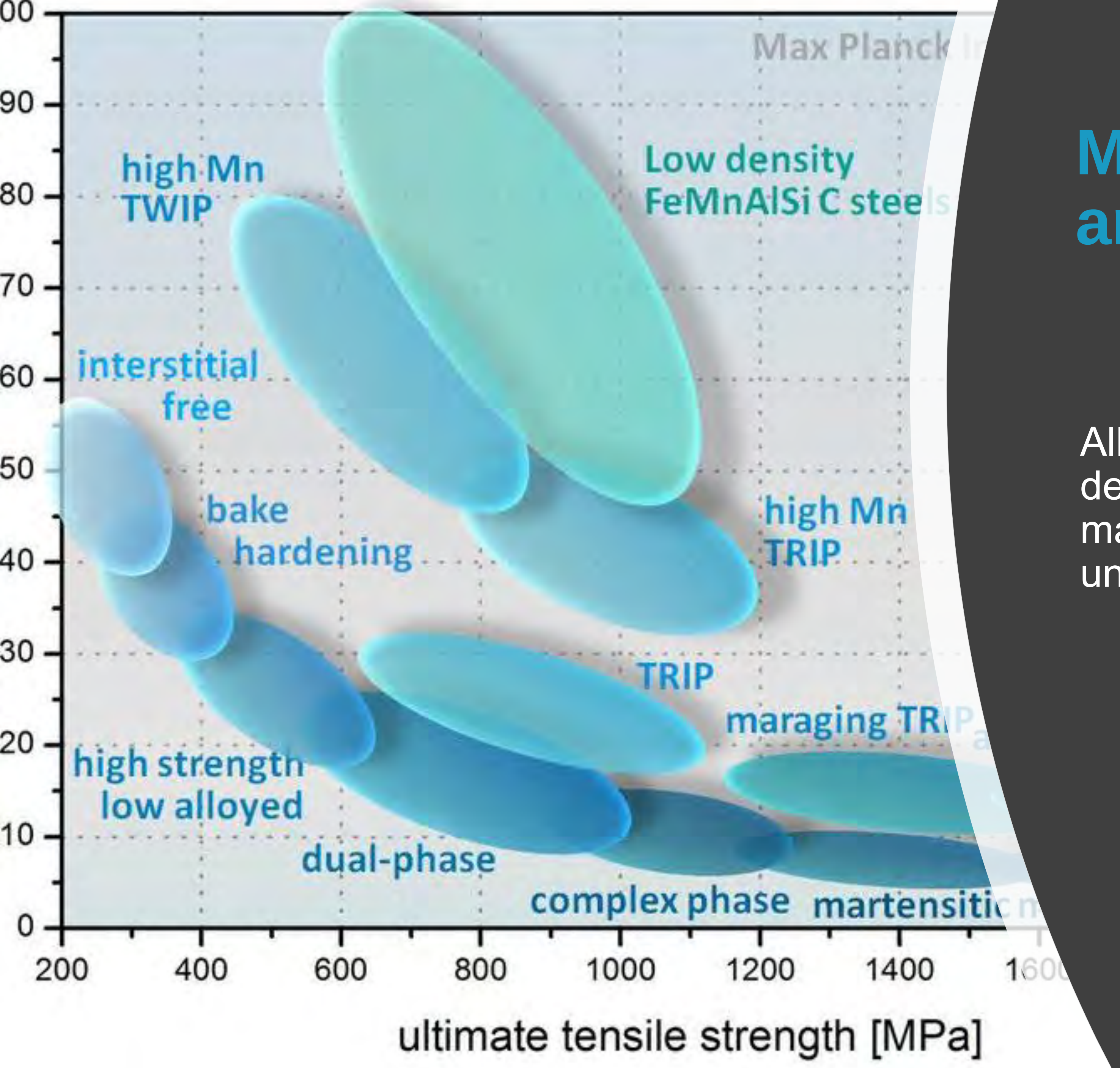
Key Technologies

- Alloy production that is less carbon intensive
- Utilize steel scrap for steelmaking
- Energy optimization in all processes
- Smart manufacturing
- Material and energy recovery from slag
- Recovery and re-use of off-gas and waste steam



Main Challenges

- How can C-free iron be melted and processed?
- Adaptation of digitalization and smart sensors at harsh conditions to provide real-time feedback.
- Recovering post-combusted heat emitted from the EAF.
- Near-net-shape cast products
- Recycling of steel scrap - sorting and separation technologies to pre-separate residuals from scrap
- Technologies for removing residuals in the liquid steel
- Feedstock flexibility



Material Performance and Alloy Development

Alloy development will impact decarbonization by increasing efficiency of material usage (lightweighting, performance under harsh conditions, etc.)

Theme 4 - Carbon capture and utilization and storage (CCUS)

Carbon capture and storage (CCS) processes must separate CO_2 from the exhaust gas streams before the subsequent transportation and storage.

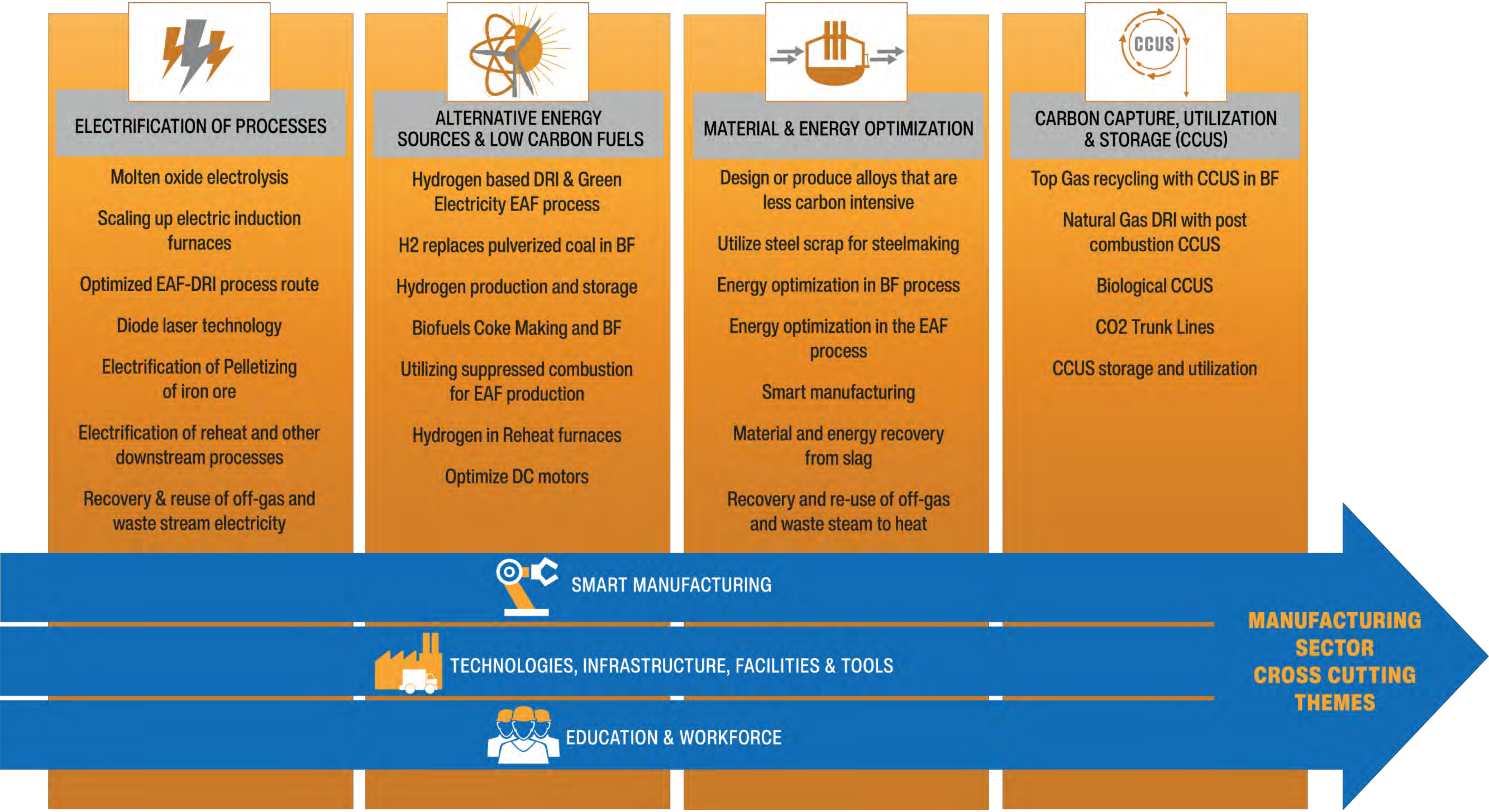
Commercial-scale transport of gaseous and liquid carbon dioxide emissions uses tanks, pipelines and ships.

Key technologies

- Blast Furnace Top Gas recycling with CCUS
- Natural Gas DRI with post combustion CCUS
- Biological CCUS
- CO_2 Trunk Lines
- CCUS storage and utilization.

Main Challenges

- Enabling infrastructure such as shared transport pipelines and storage sites.
- Economically viable and widely accessible.
- Targeted RD&D projects towards next-generation CCUS technologies
- Standards and regulation for high CO_2 capture rates, as well as developing best-practice monitoring of CCUS.
- Financial incentives and regulatory frameworks



ELECTRIFICATION OF PROCESSES
Molten oxide electrolysis
Scaling up electric induction furnaces
Optimized EAF-DRI process route
Diode laser technology
Electrification of Pelletizing of iron ore
Electrification of reheat and other downstream processes
Recovery & reuse of off-gas and waste stream electricity
ALTERNATIVE ENERGY SOURCES & LOW CARBON FUELS
Hydrogen based DRI & Green Electricity EAF process
H2 replaces pulverized coal in BF
Hydrogen production and storage
Biofuels Coke Making and BF
Utilizing suppressed combustion for EAF production
Hydrogen in Reheat furnaces
Optimize DC motors
MATERIAL & ENERGY OPTIMIZATION
Design or produce alloys that are less carbon intensive
Utilize steel scrap for steelmaking
Energy optimization in BF process
Energy optimization in the EAF process
Smart manufacturing
Material and energy recovery from slag
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CARBON CAPTURE, UTILIZATION & STORAGE (CCUS)
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CO2 Trunk Lines
CCUS storage and utilization
SMART MANUFACTURING
TECHNOLOGIES, INFRASTRUCTURE, FACILITIES & TOOLS
EDUCATION & WORKFORCE
MANUFACTURING SECTOR CROSS CUTTING THEMES

Decarbonizing the Steel Industry by 2050

- Electrification
- Alternative energy sources
- Material & energy optimization
- CCUS

Impact on Carbon Reduction

2020	2030	2040	2050
	• Design or produce alloys that are less carbon intensive		• Molten oxide electrolysis • Chemical and Hydro Metallurgy
• Biofuel in Coke making and BF	• Scaling up electric induction furnaces • H2 replaces pulverized coal in BF • Hydrogen based DRI & Green Electricity EAF process • Hydrogen production and storage	• Utilizing steel scrap for steelmaking	
	• Energy material optimization in the EAF process • Energy and material optimization in the BF process	• Diode laser technology	• Optimized EAF-DRI
• Recovery and re-use of off-gas and waste steam to electric power • Optimize DC motors • Recovery and re-use of off-gas and waste steam to heat • Material and energy recovery from slag	• Electrification of reheat and other downstream furnaces • Electrification of Pelletizing of iron ore • Smart manufacturing • Utilizing suppressed combustion for EAF production • Top Gas recycling with CCUS in BF	• Hydrogen usage in Reheat furnaces • Biological CCUS • CO2 Trunk Lines • Natural Gas DRI with post combustion CCUS	• CCUS storage and utilization

Workforce Development: Manufacturing Challenges

Workforce development is taking on increasing importance as manufacturers not only must fill more than 500,000 current openings but also define new careers involving robotics, automation and AI.

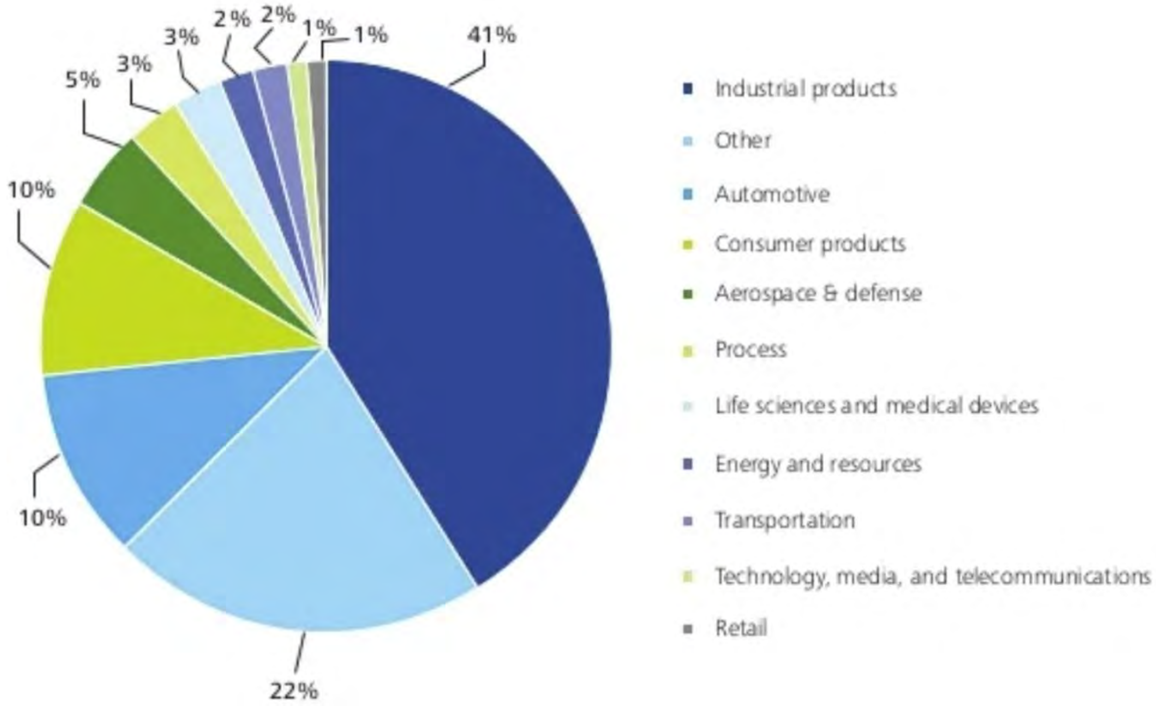
Manufacturers are seeking people with the right skills for the advanced manufacturing jobs of today and tomorrow and finding ways to upskill their current staff.

2021 Manufacturing Talent Study: Key Takeaways

Deloitte and The Manufacturing Institute

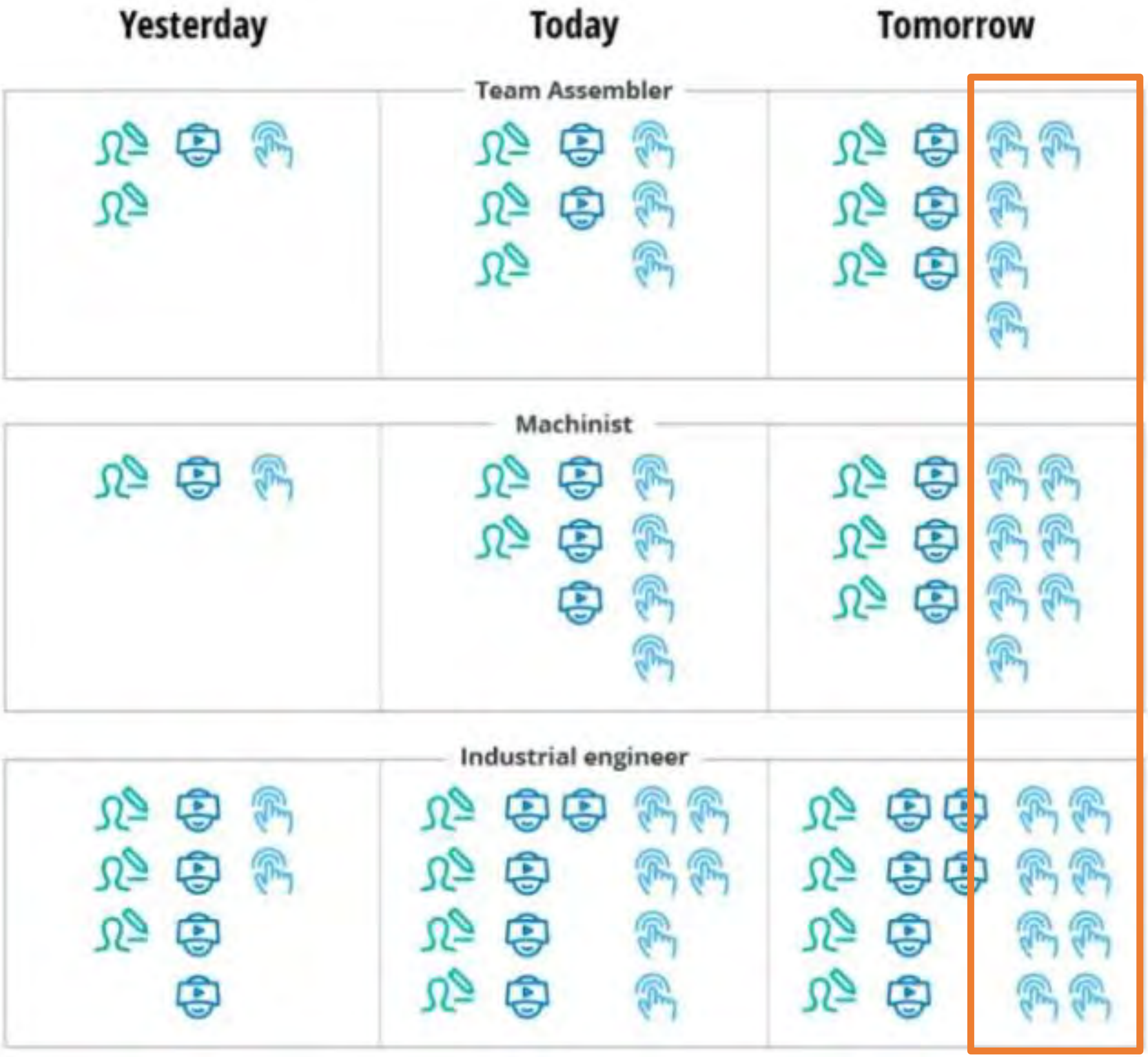
- ✦**83%** of manufacturing companies have experience a moderate to critical shortage of skilled production workers.
- ✦US manufacturing is expected to have **2.1 million** unfilled jobs by 2030.
- ✦The pace of digital transformation in the manufacturing industry will likely continue to redefine work for humans.
- ✦Diversity, equity, and inclusion (DEI) is an imperative for manufacturers.

Survey Audience:



2021 Manufacturing Talent Study: Key Takeaways

The changing nature of skills, roles and jobs



Human capabilities

- Basic digital learning agility
- Management of resources
- Decision-making/problem-solving
- Ability to handle multiple teams and team members
- Advanced digital skills such as process twin development and testing

Specialized skills

- Understanding and working with state-of-the-art robotics and automated equipment
- Data analysis
- Proficiency with advanced manufacturing technologies
- Automated process monitoring and control
- Production process proficiency
- Leveraging digital systems

Technology skills

- Understanding of connected equipment and industrial control software
- Computer aided manufacturing (CAM)
- 6-sigma DMAIC or DFSS certified
- Advanced customer data analytics
- Advanced computer skills and knowledge of document and spreadsheet products
- Working knowledge of statistical analysis

Other challenges within the manufacturing workforce

- ✦ Aging workforce (ave. age of 55) with need for new, young talent to replace retirements

- ✦ Reduced federal funding and increasing costs of university education.

- ✦ The steel industry is unfairly perceived by society as a dirty, unsafe workplace with hazards.

AIST Efforts To Reduce The Skills-gap

- ✦ Grants to university professors for ferrous metallurgy programs
- ✦ College scholarships and program grants from AIST total over US$750,000 per year
  - ✦ Our goal is to reach $1M by 2024.
- ✦ Steel Internship Program (Scholarships and Internships)
  - ✦ $7,500 Scholarship plus paid Internship in Steel
- ✦ Women in Steel Initiative
- ✦ Young Professionals' program

THANK YOU!!