Role of Advanced Steelmaking Technologies in Global Climate Change Mitigation

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Based on work with
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Global Trade Analysis Project

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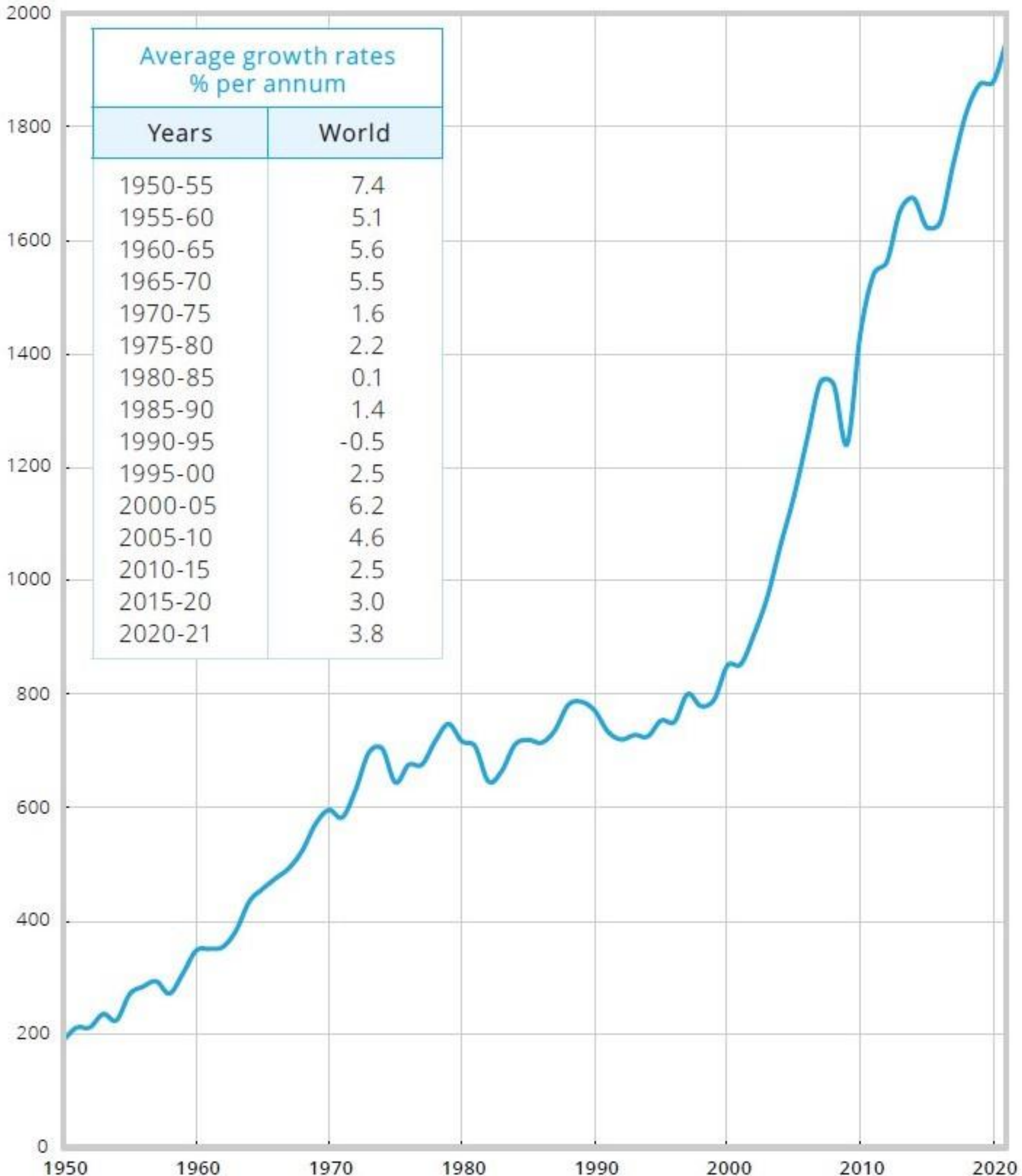
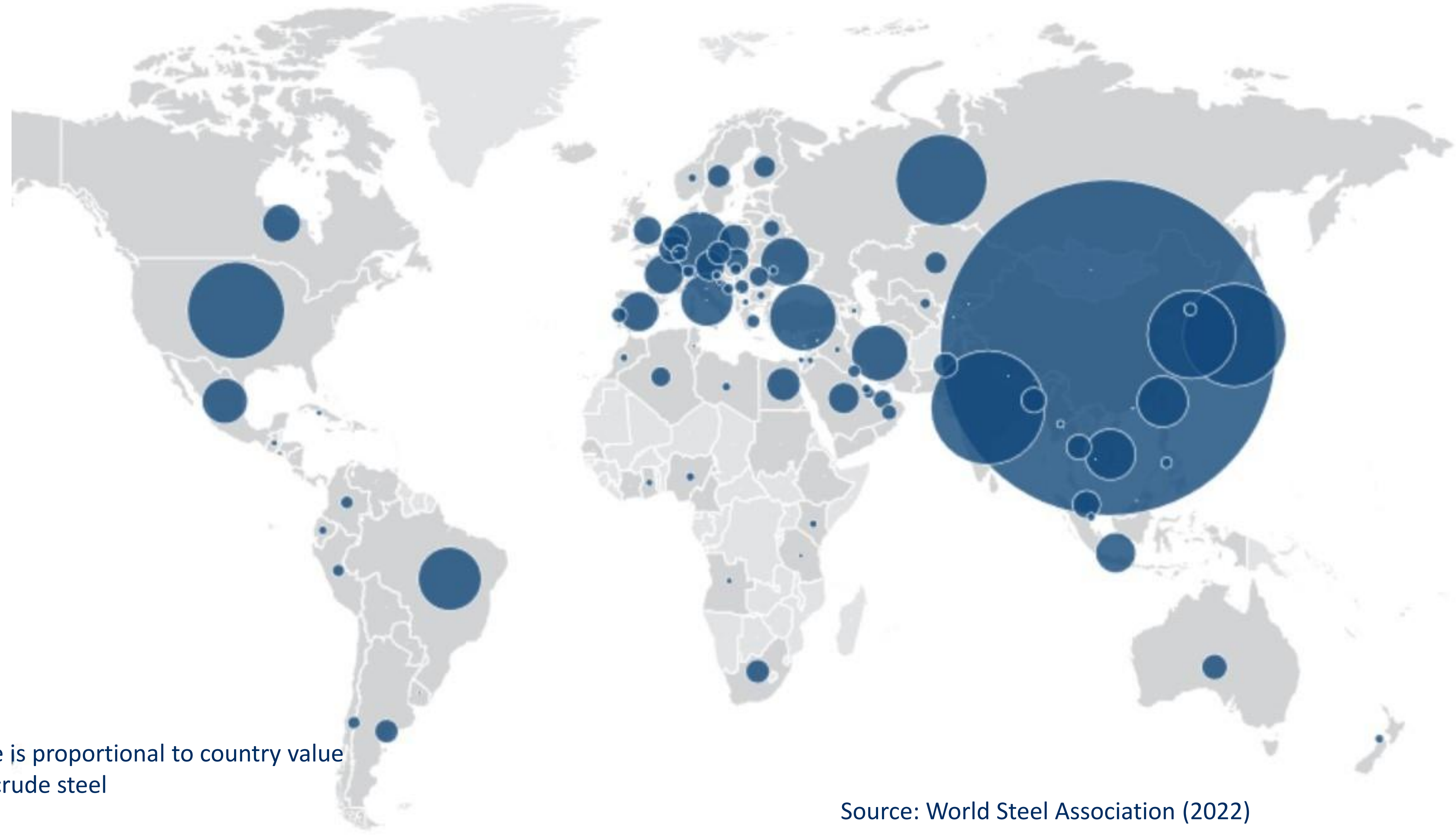
Global crude steel production, Mt



Average growth rates % per annum	
Years	World
1950-55	7.4
1955-60	5.1
1960-65	5.6
1965-70	5.5
1970-75	1.6
1975-80	2.2
1980-85	0.1
1985-90	1.4
1990-95	-0.5
1995-00	2.5
2000-05	6.2
2005-10	4.6
2010-15	2.5
2015-20	3.0
2020-21	3.8

Source: World Steel Association (2022)

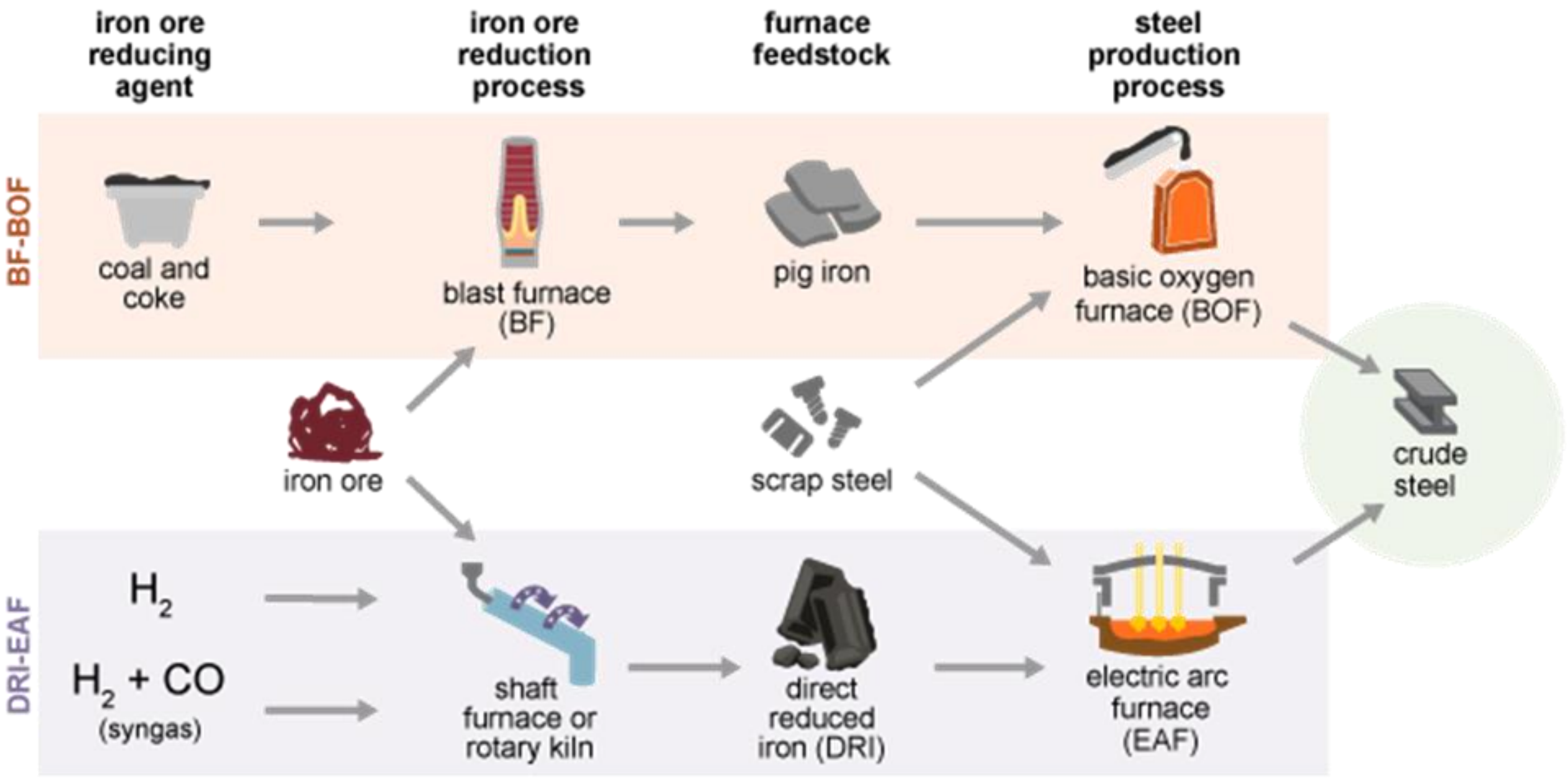
Global steel production is dominated by China



Circle size is proportional to country value in Mt of crude steel

Source: World Steel Association (2022)

Steelmaking



Source: U.S. Energy Information Administration (EIA)

Note: Electric arc furnaces (EAFs) can (and currently usually do) use pure scrap steel and generally use only 20%–25% of the energy that BFs use to produce steel. DRI is used to supplement the scrap steel in EAFs to produce purer steel.

		Share of production	
	Mt crude steel	BF-BOF	DRI-EAF
World	1953	0.72	0.28
China	1033	0.90	0.10
India	118	0.44	0.56
Japan	96	0.76	0.24
USA	86	0.30	0.70
Russia	76	0.66	0.34
Korea	70	0.68	0.32
Turkey	40	0.32	0.68
Germany	40	0.70	0.30
Brazil	36	0.77	0.23
Iran	28	0.10	0.90
Italy	24	0.18	0.82
Taiwan	23	0.62	0.38
Vietnam	23	0.66	0.34
Ukraine	21	0.93	0.08
Mexico	18	0.23	0.77
Top 15 countries	1732	0.75	0.25
Top15 without China	699	0.54	0.46
Rest of the world	221	0.45	0.55
EU		0.59	0.41

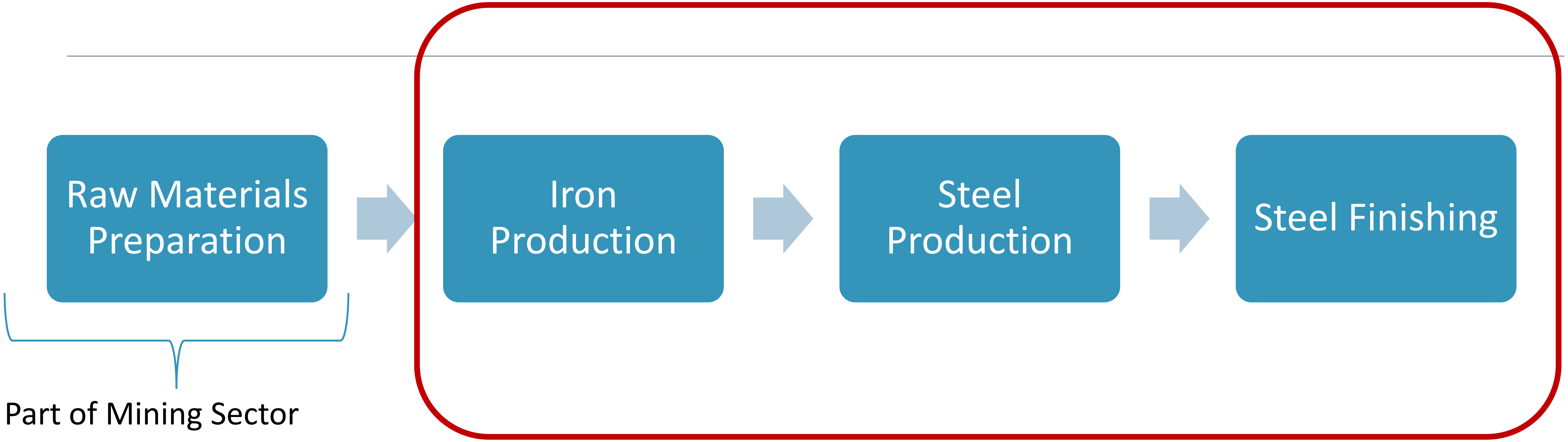
Top 15 producers and shares of production process

China: 90-10
India: 50-50
USA: 30-70
EU: 60-40
Germany: 70-30
Italy: 20-80

World: 70-30

Source: World Steel Association (2022)

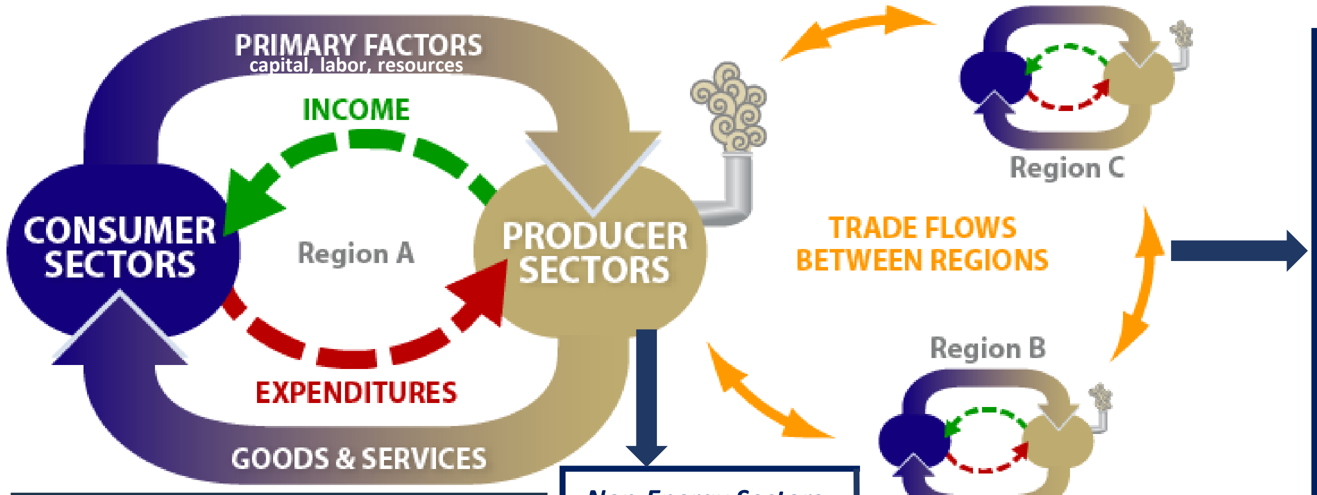
Boundaries for Iron & Steel Production

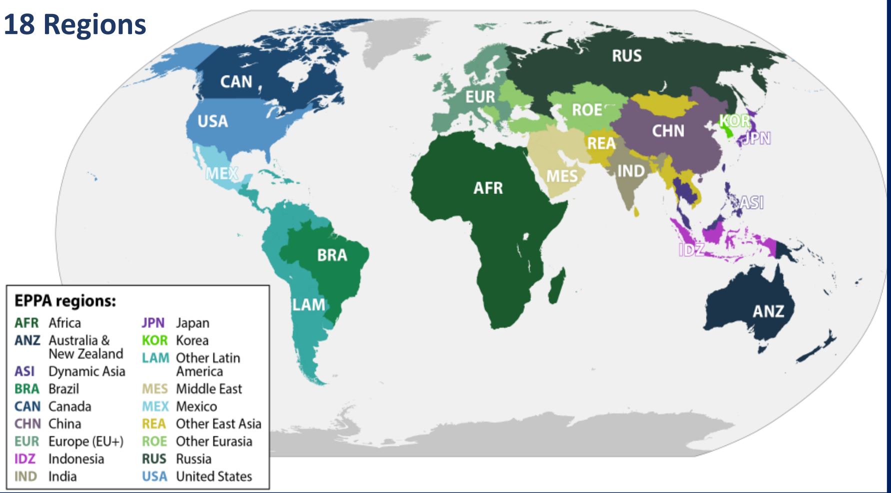


% of Total	Preparation (e.g. iron ore pelletization)	Iron Production (DRI)	Steel Production (EAF)	Steel Finishing (Hot Rolling)
Energy Usage	16%	62%	13%	8%
Direct + Indirect CO2 Emissions	21%	50%	23%	6%

MIT Economic Projection and Policy Analysis (EPPA) Model

Multi-sector, multi-region computable general equilibrium (CGE) model of the world economy for energy, economy and emissions projections





Technical Features
Written in GAMS using MSPGE
Based on GTAP Database
Calibrated to current economic and energy levels based on IMF and IEA
Documented in peer-reviewed literature
Publicly Available Version
2100+ (in 5-year steps)

Full Input-Output Data for Every Region

		INTERMEDIATE USE by Production Sectors (1, 2, ...j..., n)	FINAL USE: Private Consump.	FINAL USE: Government Consumption	FINAL USE: Investment	FINAL USE: Export	OUT-PUT
Domestic Production	1, 2, :, i, :, n	A	B				C
Imports	1, 2, :, i, :, n	D	E				F
Value added:	-labor, -capital, - natural resources	G	H				I
INPUT		J					

Non-Energy Sectors
Crops
Livestock
Forestry
Food
Energy-Intensive Industry
- Iron & Steel
- Cement
- Chemicals
- Non-Ferrous Metals
- *+ low-carbon options*

Manufacturing
Service
Commercial Transport
Household Transport
- ICE (gasoline & diesel)
- Plug-in Electric
- Battery Electric
- Hydrogen

Energy Sectors
Crude Oil
Refined Oil
Liquid Fuel from Biomass
- Current Generation
- Advanced Biofuel

Oil Shale
Coal
Natural Gas (conv., shale, tight)
Electricity
- Conv. Fossil (coal, gas, oil)
- Adv. Fossil (NGCC, Adv Coal)
- Coal with CCS
- Coal + Bio Co-firing w/ CCS
- Gas with CCS
- Gas with Advanced CCS
- Nuclear
- Advanced Nuclear
- Hydro
- Solar
- Wind
- Renewables with Backup
- Biomass
- Biomass with CCS

Synthetic Gas (from Coal)

New Technologies Continually Added

Regions and sectors can be added for special studies

Key Inputs
Policy Assumptions
Population Growth
Capital/Labor Productivity Growth
Energy Efficiency Improvements
Technology Costs
Rate of Technology Penetration
Elasticities of Substitution
(related to labor, capital, energy, fuels, etc.)
Fossil Fuel Resource Availability
Urban Pollutant Initial Inventories & Trends
Land Productivity

Key Outputs
GDP
Consumption
Emissions (GHGs, Air Pollutants)
Primary/Final Energy Use
Electricity Generation
Technology Mix
Commodity and Factor Prices
Sectoral Output
Land Use
At global and regional levels

Key Features
Global Coverage & International Trade
Economy-Wide Coverage & Inter-Industry Linkages
Feedbacks Across Regions & Sectors
Theory-Based (microeconomics with full input-output data)
Endogenous Prices, Investments & Capital Accumulation
GDP and Welfare Effects
Policies (emissions limits/prices, sector/technology regulations…)
Distortions (taxes, subsidies, etc.)
Accounting for Physical Quantities (energy, electricity, land)
Links to MIT Earth System Model (MESM)

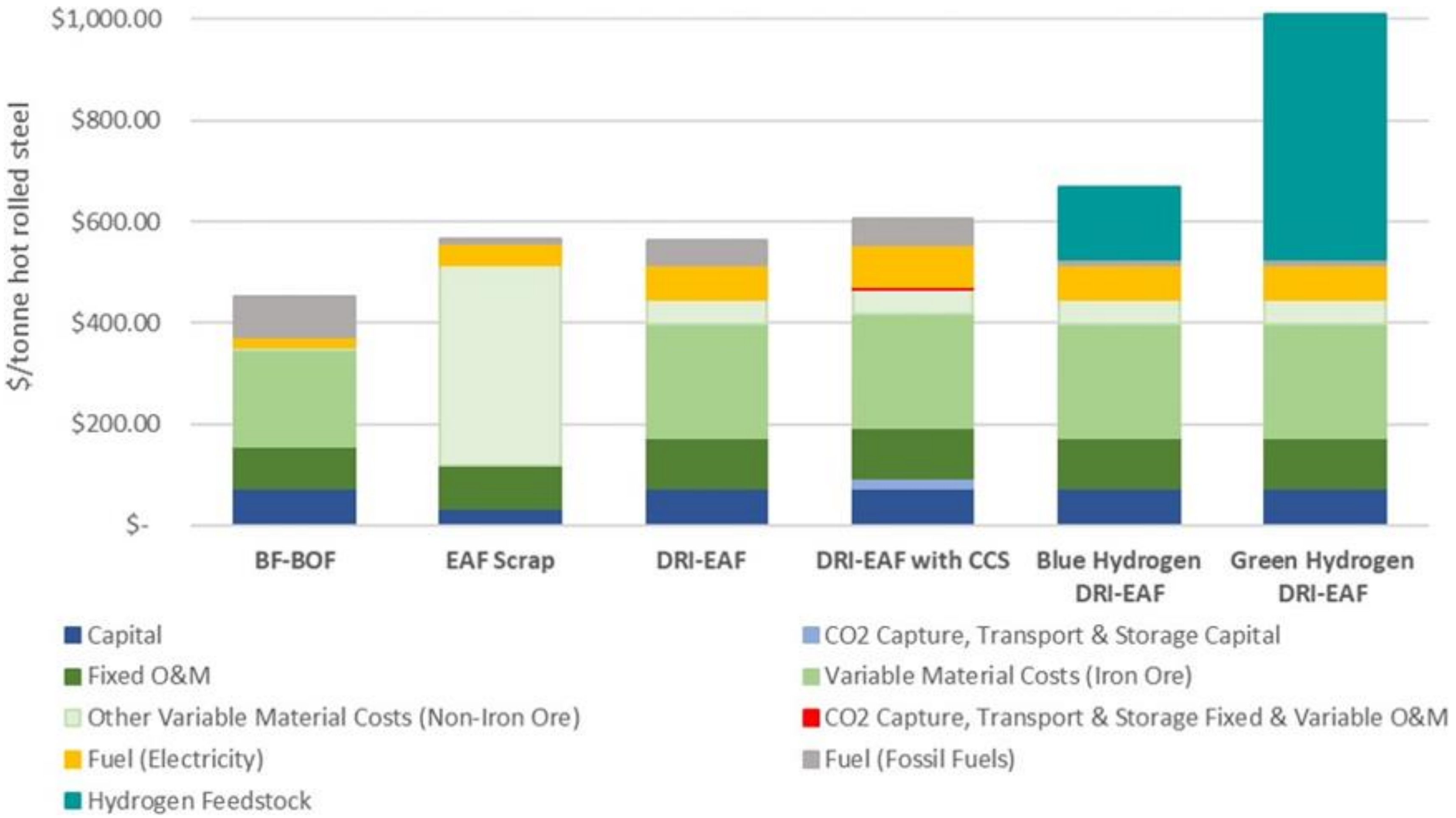
Key Equations
Firms maximize profit: choose technology, level of output and inputs subject to production functions and costs

Household maximize welfare: choose savings and consumption subject to budget constraint

Equilibrium Conditions: Market-Clearing, Zero-Profit, Income Balance

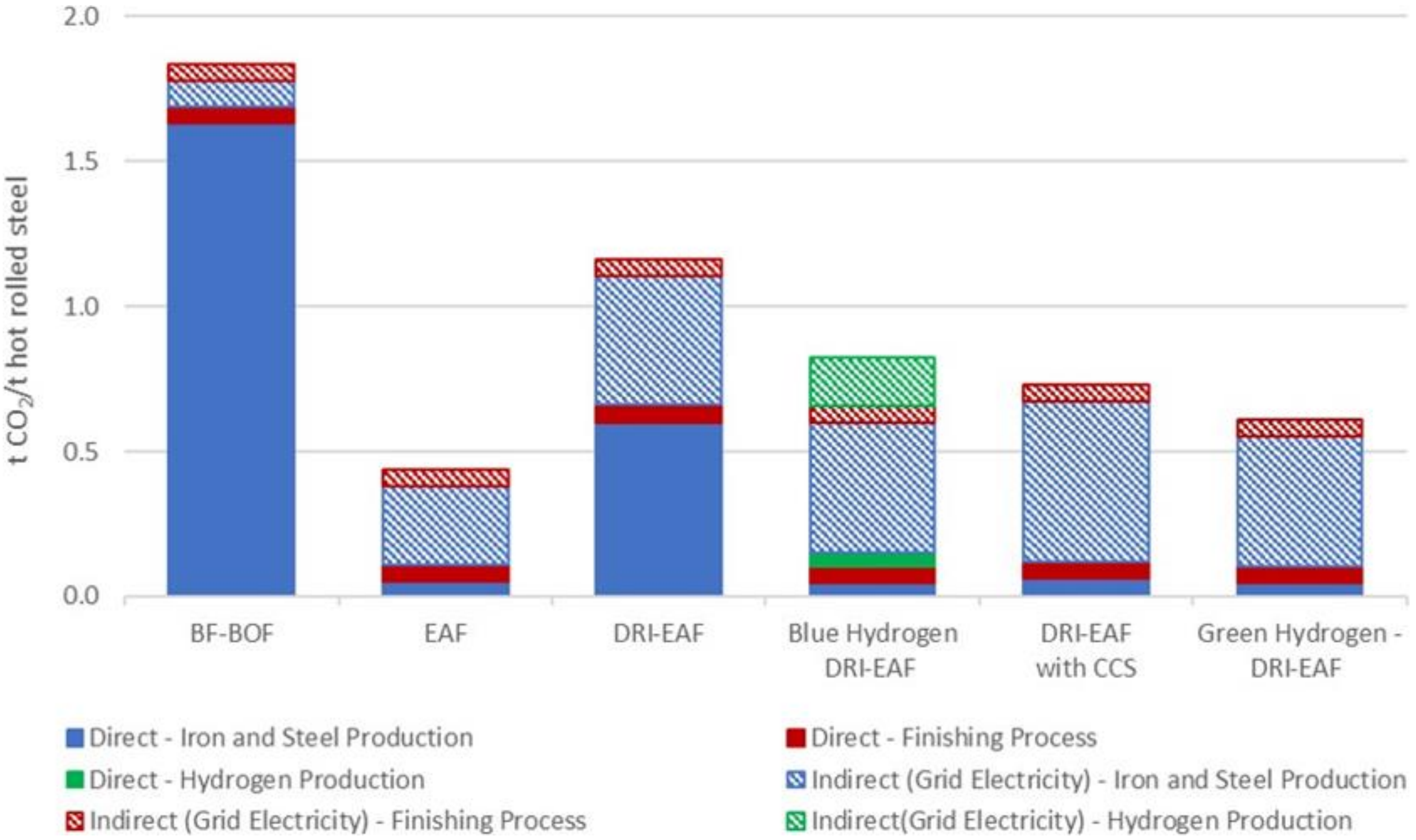
https://globalchange.mit.edu/research/research-tools/human-system-model

Steel Production Costs and Input Shares



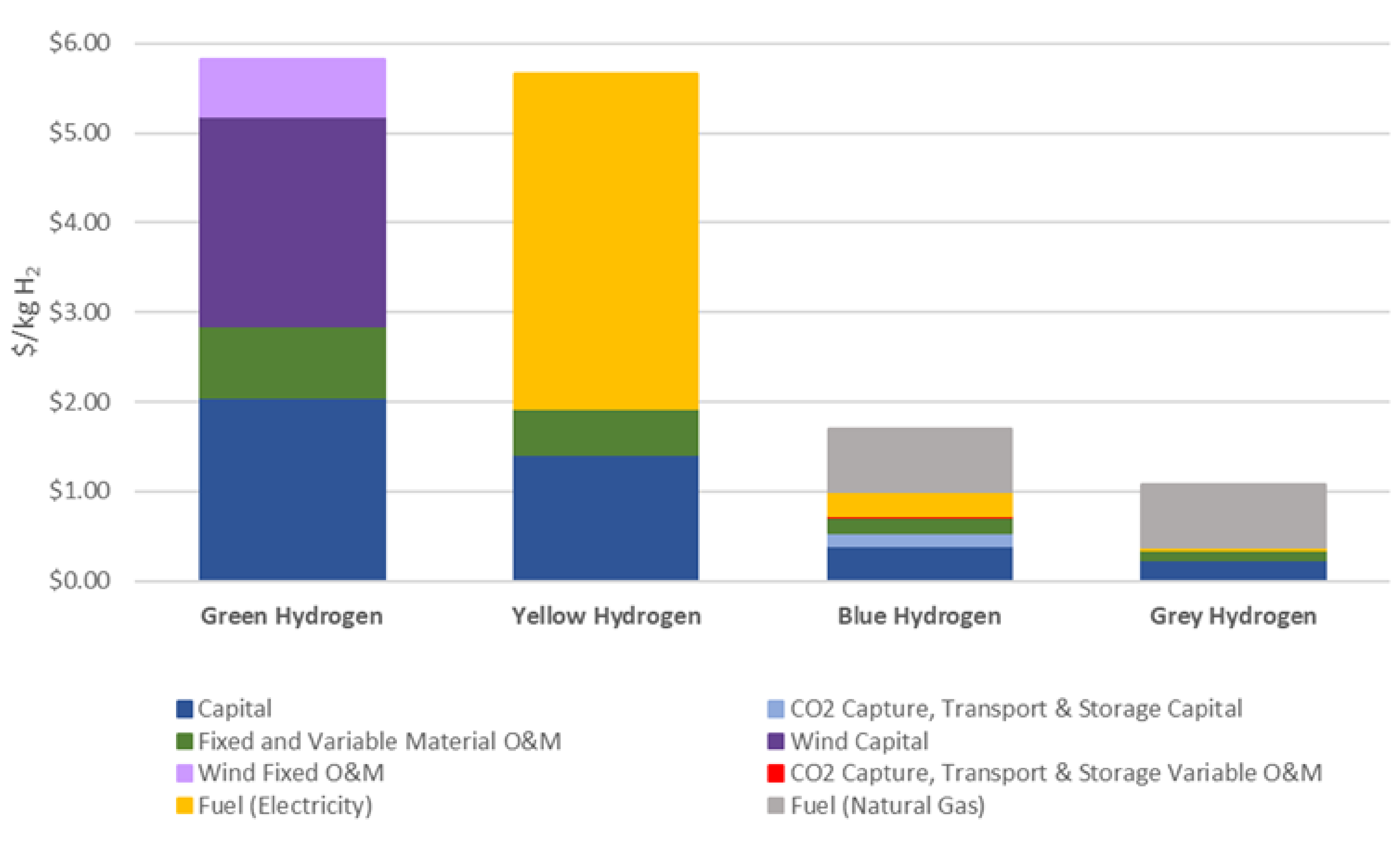
Benavides et al. (2022). Emission Mitigating Emissions in the Global Steel Industry: Representing CCS and Hydrogen Options in Integrated Assessment Modeling. International Journal of Greenhouse Gas Control, 131, 103963. https://globalchange.mit.edu/publication/18065

Emission Intensity for Steel Production Pathways



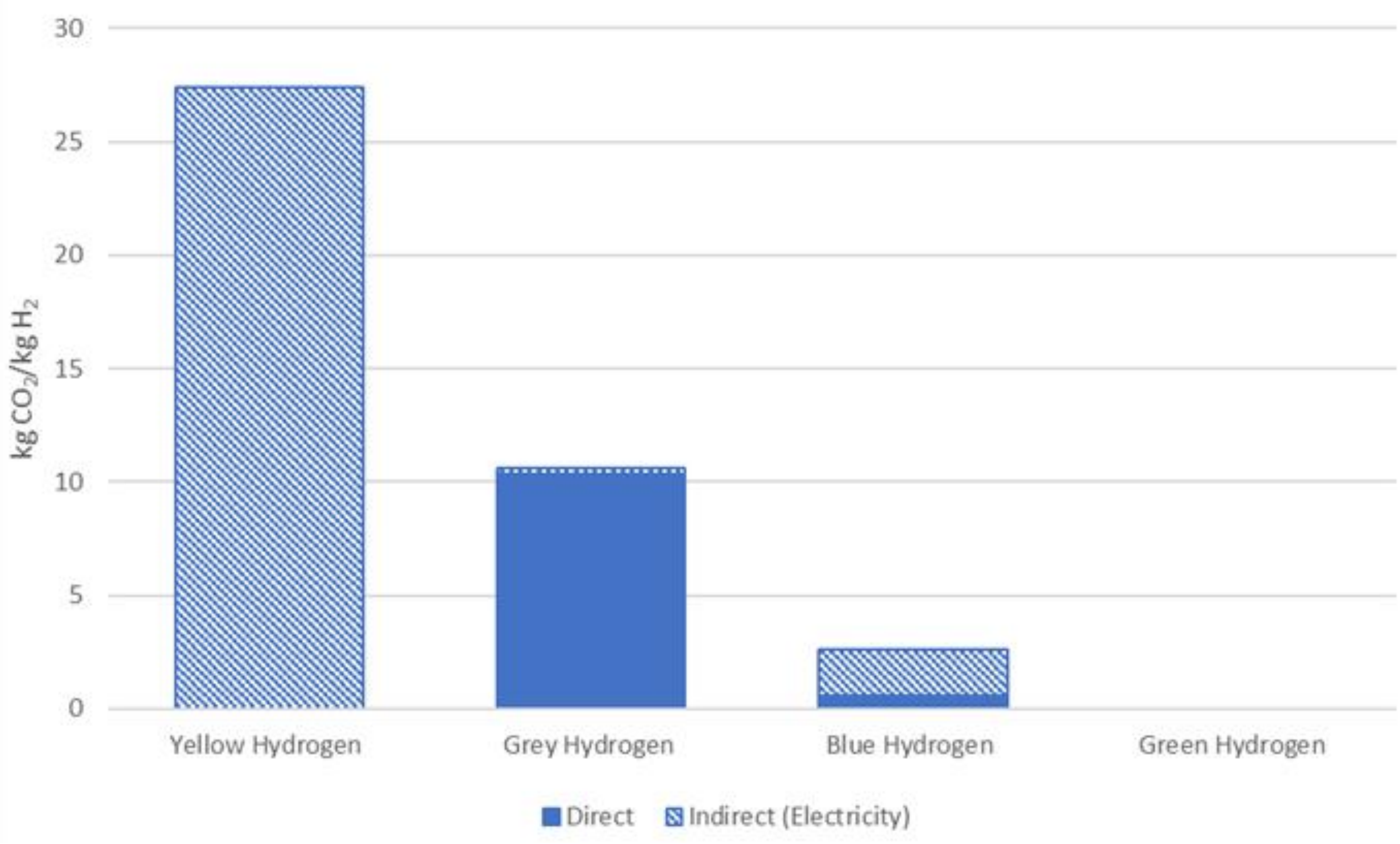
Source: Benavides (2023)

Hydrogen Production Cost



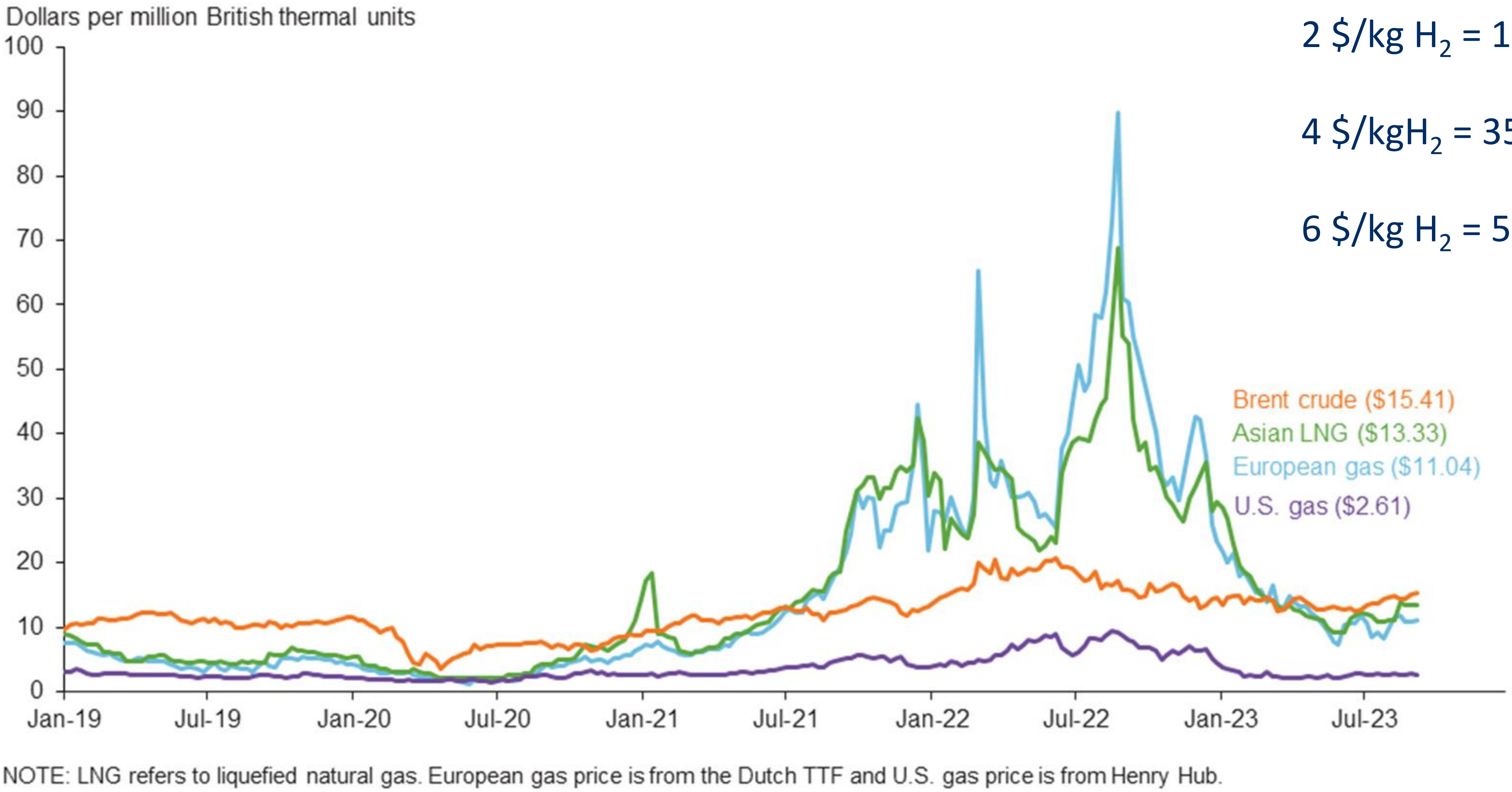
Source: Benavides et al (2022)

Hydrogen Emission Intensity



Source: Benavides et al (2022)

Cost of H_2 in \$/kg and an equivalent natural gas price



2 \$/kg H_2 = 17.60 \$/MMBTU

4 \$/kgH_2 = 35.10 \$/MMBTU

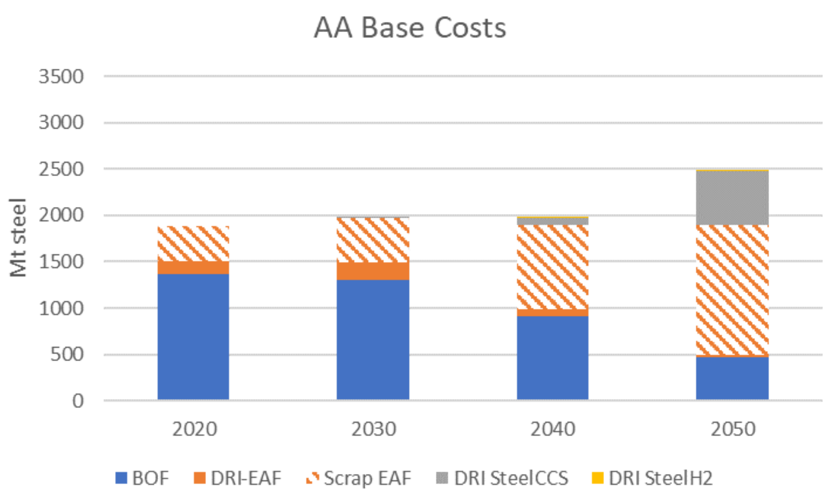
6 \$/kg H_2 = 52.70 \$/MMBTU

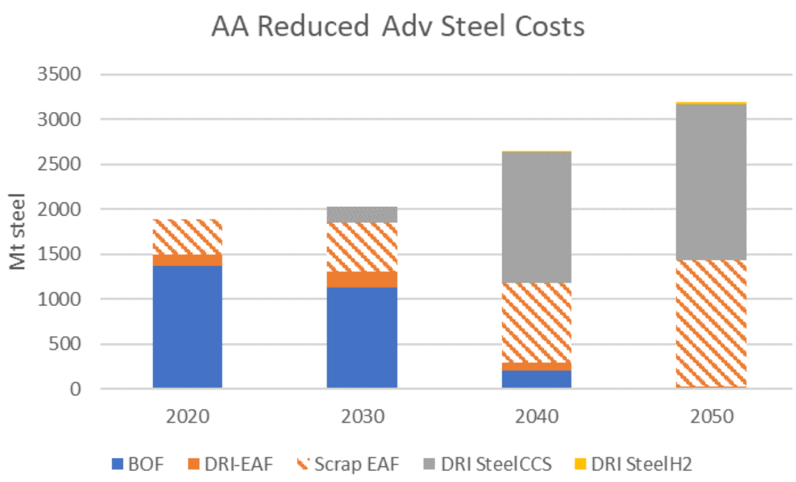
Figure Source: Federal Reserve Bank of Dallas (2023)

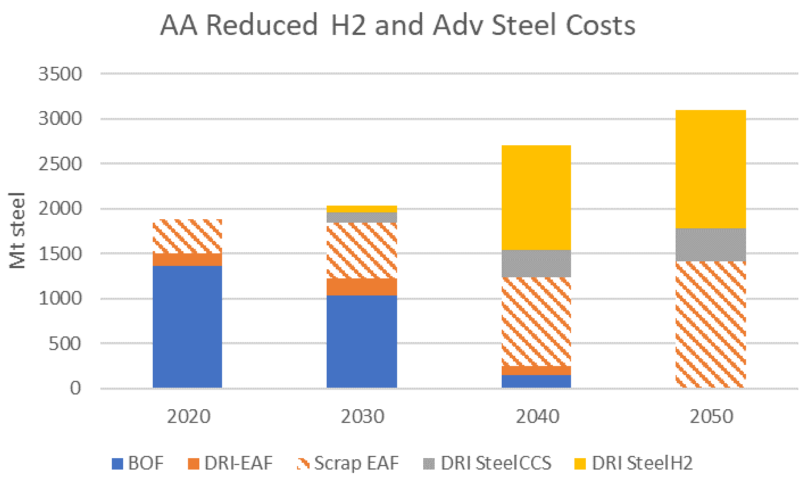
Table 1. Scenarios for 2020-2050

Scenario Name	Climate Policy	Advanced Steel Production Non-Energy Input Costs	H_2 Production Costs
Reference	Current Trends	Base Costs	Base Costs
AA Base Costs	Accelerated Actions	Base Costs	Base Costs
AA Reduced Cost of Advanced Steel Production	Accelerated Actions	**Reduced Costs**	Base Costs
AA Reduced Cost of Advanced Steel and H_2 Production	Accelerated Actions	**Reduced Costs**	**Reduced Costs**

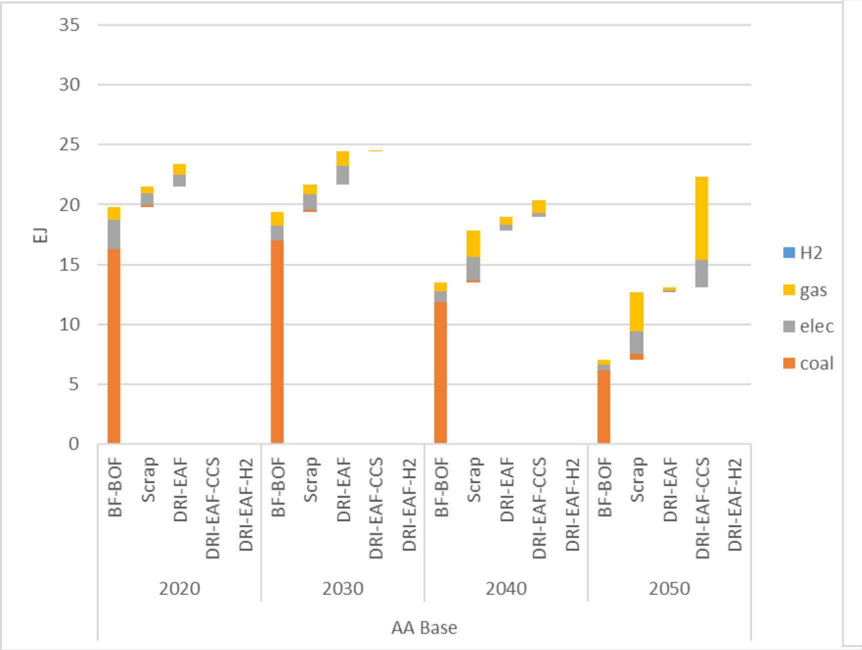
Global steel production by process

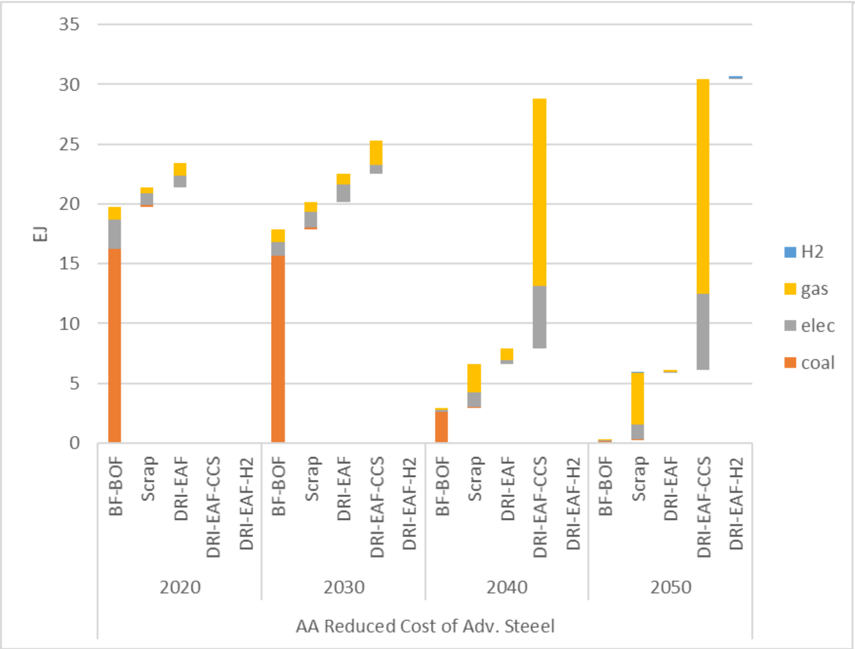


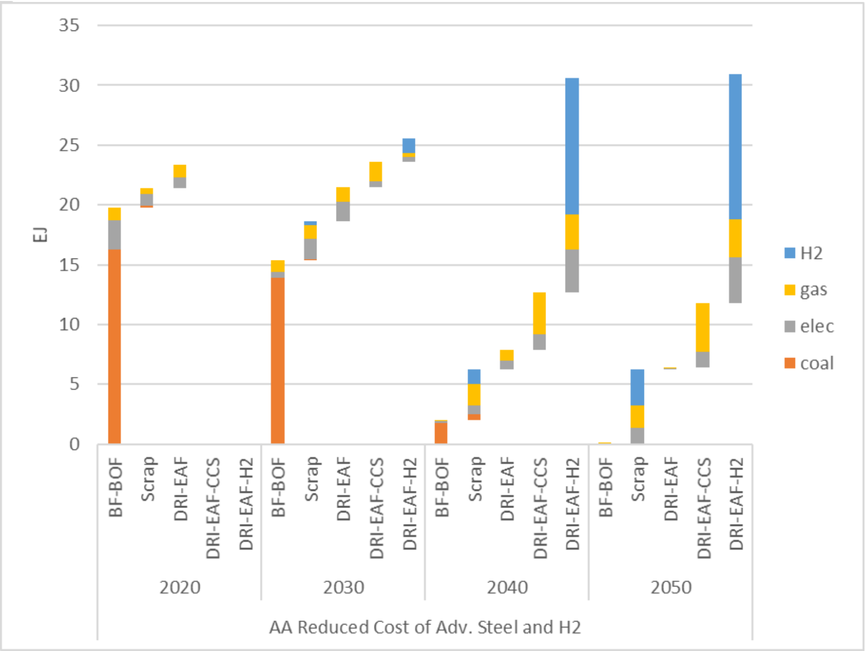




Energy consumed by global iron and steel production by process and type of energy input

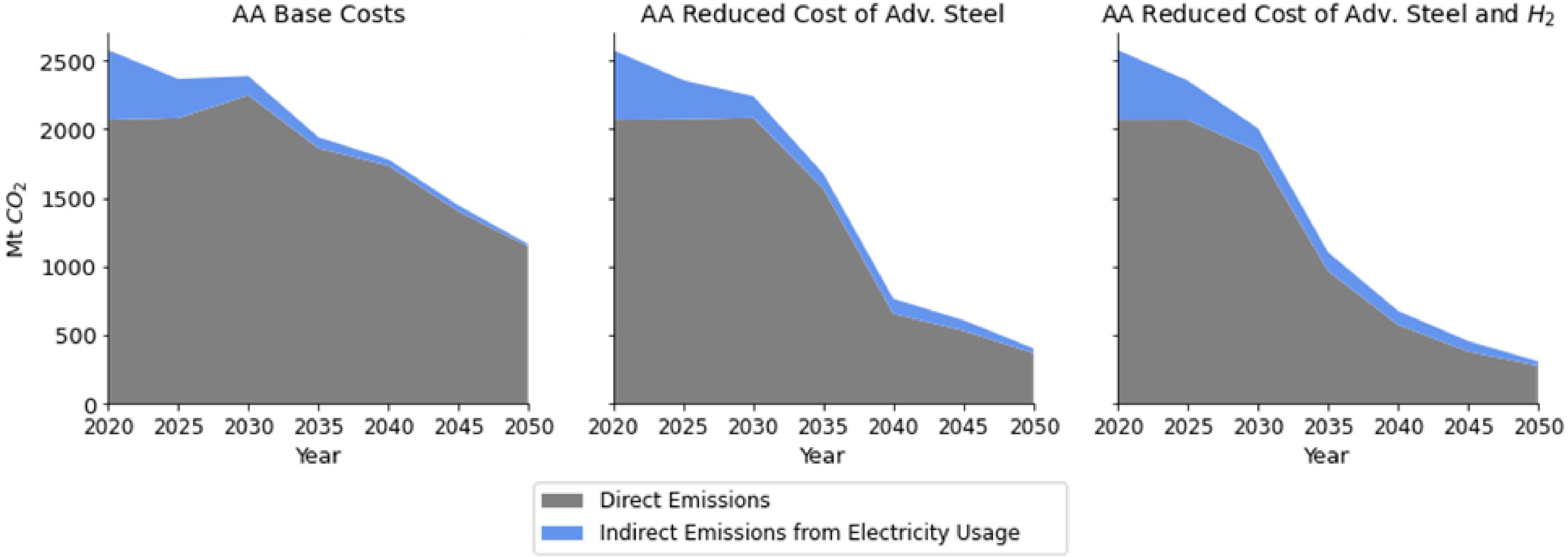




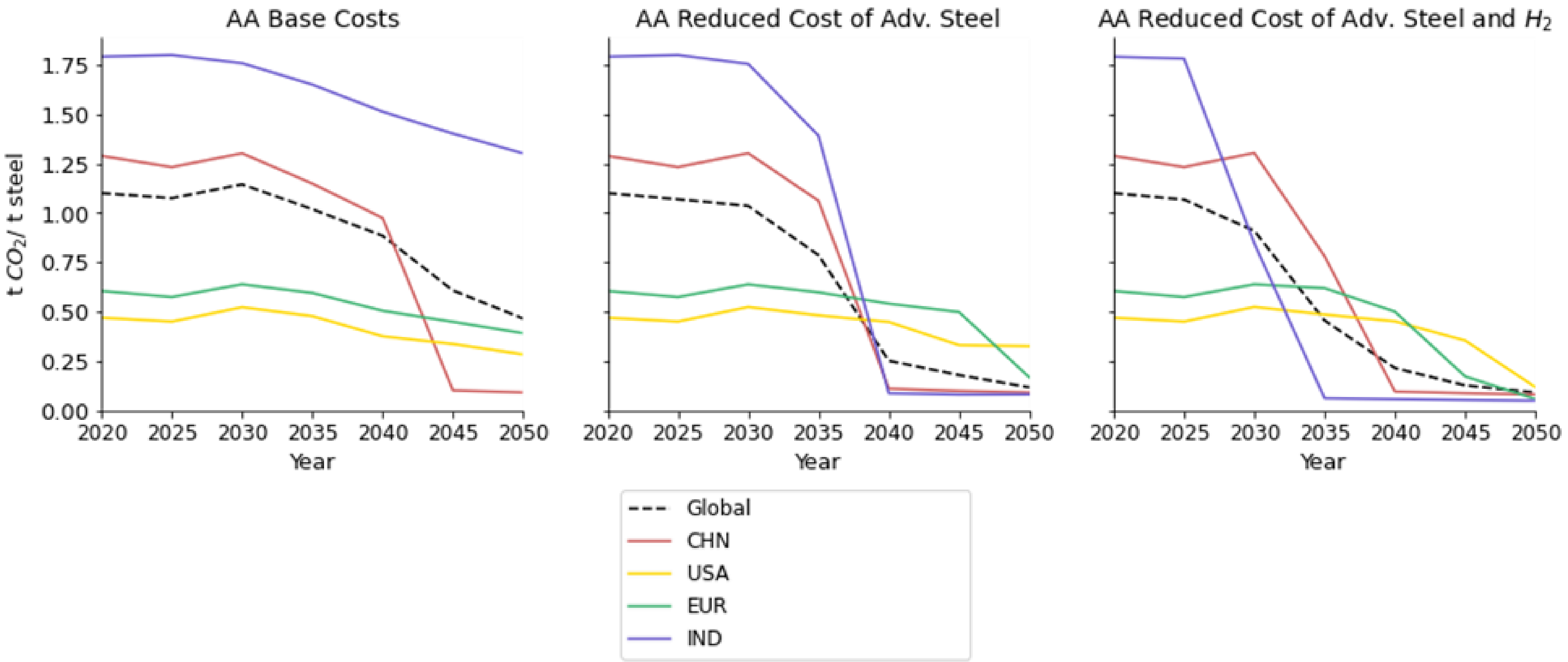


Energy Usage [GJ/tonne hot rolled steel]	BF-BOF	DRI-EAF	Scrap-based	DRI-EAF with CCS	Hydrogen-based DRI-EAF
Coal	15.3	0	0.6	0	0
Natural Gas	1.1	12.9	1.7	12.9	3
Electricity	1	3.6	2.3	4.4	3.6
Hydrogen	0	0	0	0	11.5
Total	17.4	16.5	4.6	17.3	18.1

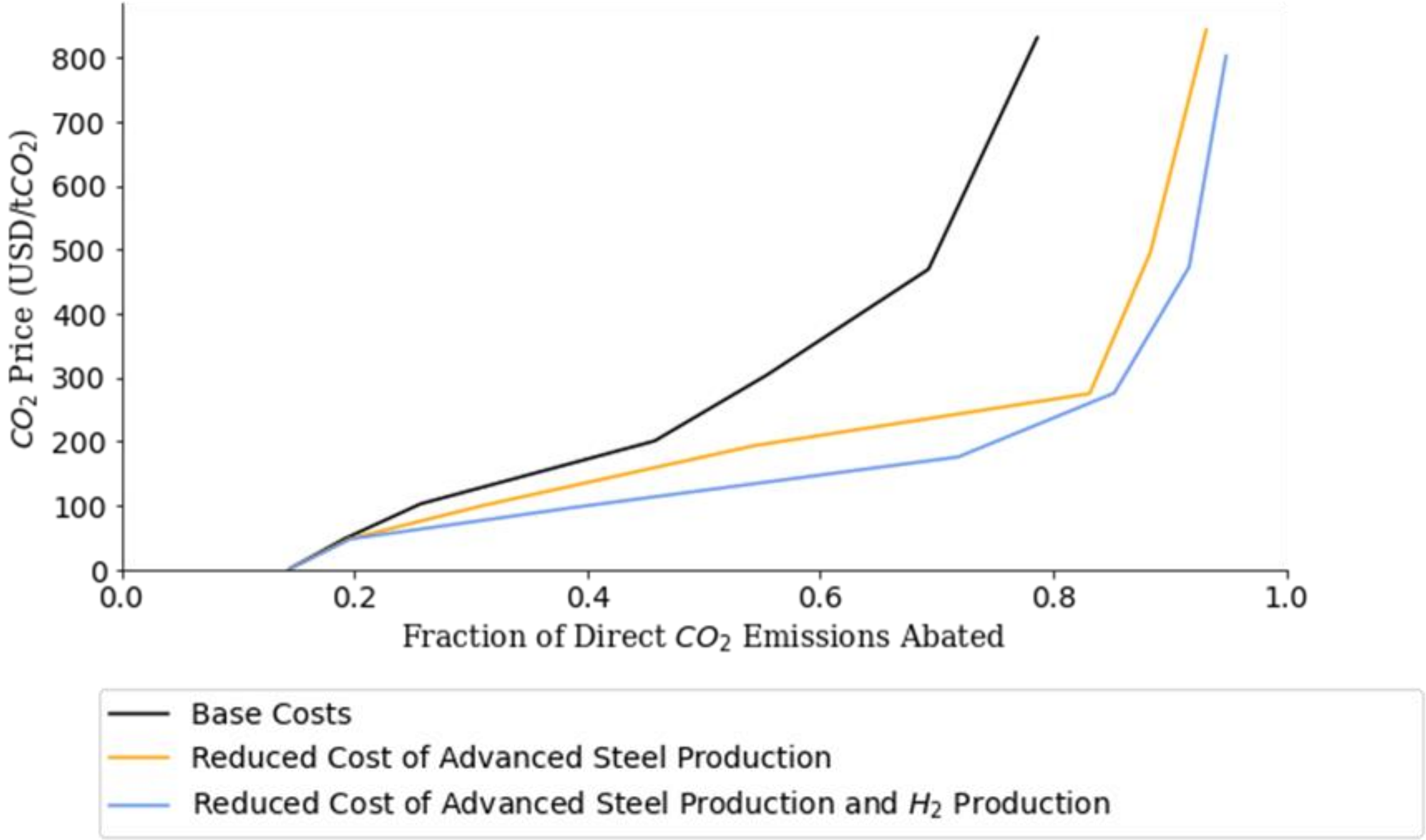
Global emissions from steel production



Direct CO_2 Emission Intensity of iron and steel production



Abatement of direct CO_2 emissions from iron and steel production relative to the Reference case



Concluding remarks

Substantial CO_2 emission mitigation in steelmaking can be done at carbon prices lower than \$200-250/tCO_2

Electrification and scrap use are the primary pathways for steel decarbonization

CCS is less costly option than hydrogen for steel decarbonization

H_2 production costs must reduce significantly to compete

Steel decarbonization pathways are region specific

Thank you

Questions or comments?
Please contact Sergey Paltsev at paltsev@mit.edu