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Green iron and steel offer MENA a chance to shine

Green hydrogen – not carbon capture – is the key to beating growing global competition

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Key Findings

The Middle East and North Africa (MENA) region is well equipped to produce cheap green hydrogen due to its excellent solar resources, but exports look inefficient and expensive.

MENA should instead prioritise using green hydrogen domestically to become a global leader in the emerging green iron trade, where it already enjoys a significant advantage due to its established use of direct reduced iron (DRI).

The COP28 climate conference is expected to see widespread advocacy for carbon capture and storage, but the technology's poor record means it, and consequently blue hydrogen, is not an alternative to green hydrogen.

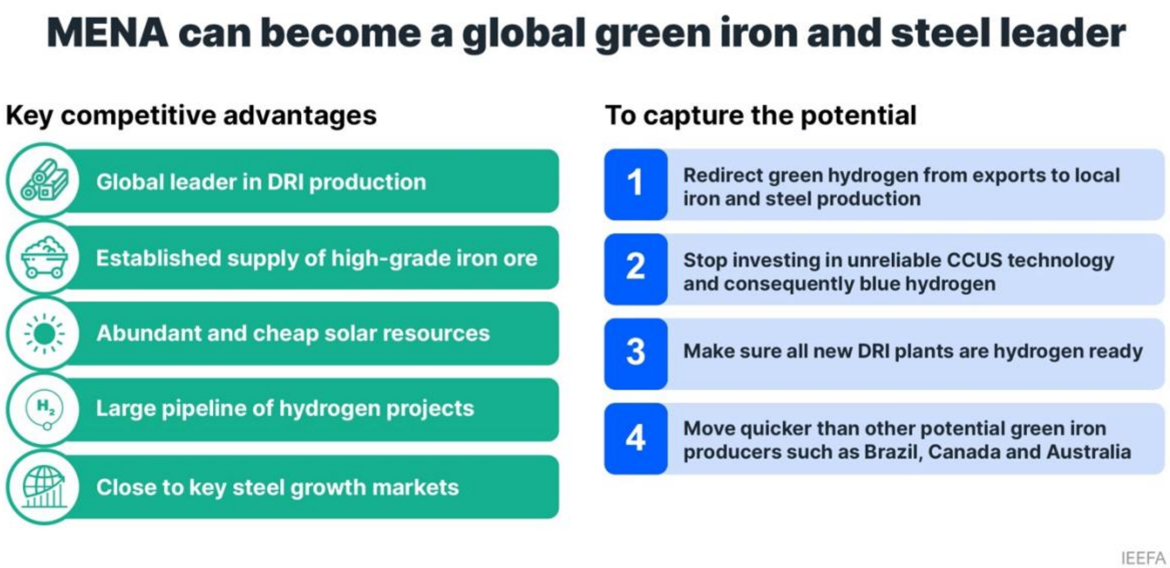
As the global steel sector decarbonises, the MENA region is well placed geographically to supply the key and emerging markets for green iron and steel. But global green iron competition is already growing.

Executive Summary

The Middle East and North Africa (MENA) region has a significant opportunity to marry its direct reduced iron (DRI)-based steelmaking leadership with its green hydrogen potential. This could place MENA as a global leader in green steel and the emerging green iron trade. The region is well situated to supply the key steel growth market of India and green steel demand centres like Europe.

The steel technology transition is accelerating, and steelmakers are already starting to shift from blast furnace-based production towards DRI technology that can run on green hydrogen. Until now, the focus of steelmakers has been on importing iron ore and metallurgical coal for blast furnaces. Going forward, steelmakers that have access to direct reduction-grade (DR-grade) iron ore and cheap green hydrogen – or the green iron made from them – will have an advantage.

As the global steel sector decarbonises, iron production looks set to dislocate from steel production. More iron ore will be processed in places with excellent renewable energy resources that can produce cheap green hydrogen, with the resultant iron shipped to centres of steel demand. MENA can be a global leader in the emerging green iron trade, but global competition is growing.



MENA's green steel advantage

MENA's steel sector has a major advantage as it is already based on DRI using gas rather than coal. The region has an established, growing source of DR-grade iron ore – a commodity in limited supply that makes up just 3%-4% of total global iron ore trade. Vale, the world's largest producer of DR-grade iron ore, is planning green iron "Mega Hubs" in the Middle East that will supply iron ore pellets to co-located DRI plants to produce hot briquetted iron (HBI) for local consumption and export.

Gas-based steelmaking via DRI has lower emissions than the coal-consuming blast furnaces that dominate steelmaking in most other regions, but it can only be made truly 'green' by switching to green hydrogen as its cost falls over the rest of this decade. MENA's excellent solar resources will allow the region to produce cheap green hydrogen in the near future. Planned green hydrogen production in the region has expanded substantially.

The current focus of green hydrogen projects is on exports. However, exporting green hydrogen appears to be inefficient and expensive. More future green hydrogen production should be earmarked for domestic use to produce green steel. Global steelmakers seeking decarbonisation options will increasingly seek imports of green iron, shipped as HBI. Future DRI-based steel plants in MENA should be built 'hydrogen-ready' for conversion to green hydrogen at the earliest opportunity.

As well as Vale, Rio Tinto – the world's largest iron ore producer – envisages a future where iron ore exports are replaced by exports of green iron as HBI from locations where cheap green hydrogen can be produced. In October 2023, ING's global steel lead and head of metals, mining and fertilisers stated: "I expect significant iron production to move to places like Northern Europe, Southern Europe and the Middle East and North Africa regions. Steel companies in Europe, Korea and Japan will have to make difficult strategic choices about where to produce iron going forward."

Steelmakers in South Korea and Japan are already considering the import of HBI from places such as the Middle East, planning projects that would initially use gas before switching to green hydrogen as it gets cheaper. To cut emissions in the interim, some of these projects are considering carbon capture utilisation & storage (CCUS).

Carbon capture should be viewed with scepticism

IEEFA cautions that CCUS increases project risk and has a growing history of significant underperformance. The focus of future MENA iron and steel projects should be on early adoption of locally produced green hydrogen. The Middle East is home to the world's only industrial-scale steel CCUS project, at Emirates Steel Arkan's Al Reyadah project in the UAE. However, this does not fully decarbonise the operation – only 30% of carbon dioxide was captured in 2022. The captured carbon is used for enhanced oil recovery (EOR) thereby enabling the release of more carbon emissions. EOR will grow increasingly unacceptable to steel buyers, who will increasingly demand green steel and will not want fossil fuels in their supply chains.

Some nations may push for an increased role for CCUS at the COP28 climate conference in November 2023. However, CCUS's poor track record strongly suggests it is not a key solution for steel sector decarbonisation. A September 2022 IEEFA report found that underperforming carbon capture projects far outnumber successful projects globally, by large margins, with both the technology and regulatory framework found wanting. In its 2023 update to its Net Zero Roadmap, the IEA stated: "The history of CCUS has largely been one of underperformance."

Concerns about CCUS's role in steel decarbonisation also apply to production of 'blue hydrogen'. CCUS proponents often claim or assume high rates of carbon capture are feasible – sometimes up to 95%. However, the historical performance of CCUS across various industries suggest such high capture rates are not even close to achievable on a sustained basis. Potential importers like Japan and South Korea will eventually need to recognise that blue hydrogen is not as clean as is claimed.

Stricter definitions of phrases like 'green steel', 'near-zero emissions steel' and 'low-carbon steel' can be expected in the near future. Although MENA steel production currently has relatively low carbon intensity by global standards, gas-based DRI won't meet the definition of 'green steel' and the like for long. This will also apply to steelmakers employing CCUS either directly or via use of blue hydrogen.

Europe's carbon price is already seeing it taking a lead in steel sector transformation and green steel demand. A truly low-carbon local steel industry would give MENA further advantage over other regions as Europe's carbon border adjustment mechanism comes into force. The import of green HBI is likely to be crucial to Europe's efforts to decarbonise its steel sector, and MENA is ideally placed geographically to supply it. MENA is also well positioned to supply India, the key steel demand growth market globally. Decarbonisation of India's steel industry will occur later than Europe but likely happen faster than expected given the historical speed of technology transitions.

Global green iron competition is already rising

Despite MENA's numerous advantages when it comes to developing a truly green steel sector, it faces growing competition from other countries. Its primary competition in the emerging green iron/HBI trade comes from iron ore mining nations – Australia, Brazil and Canada – which all have access to strong renewable and/or hydro power resources.

Australia is the world's largest exporter of iron ore by far, but the vast majority of its production is of lower-grade, blast furnace-grade ore. Despite this, POSCO is planning a major investment in Western Australia to produce HBI for export, and is co-developing a green hydrogen project to supply it. Japan's Nippon Steel is also considering a green steel investment in Australia or Brazil. Brazil supplies most of the world's DR-grade iron ore and has abundant clean energy resources for the production of green steel and HBI. In addition to Nippon Steel, H2 Green Steel is eying Brazil and has agreed with Vale to study the potential for a green iron hub there. H2 Green Steel is also exploring a €3-€6 billion project in Canada, which is also a producer of DR-grade iron ore. Rio Tinto has separately agreed to supply H2 Green Steel's green steel plant under development in Sweden with iron ore from its Canadian operations.

Early green hydrogen adoption can help meet domestic emissions targets

Growing global competition in the nascent green iron exports sector is further indication that the steel technology transition away from fossil fuels is accelerating. With some nations in the MENA region keen to diversify away from oil and gas, the development of a truly green steel industry is an opportunity to help achieve this. Steelmaking developments in the region should be built hydrogen-ready as far as possible, and the region should make the most of its advantage in low-cost renewable energy by adopting green hydrogen for iron and steel production as quickly as possible.

By moving quicker than other potential green iron producers, the MENA region can become a global leader in green iron exports. The early adoption of green hydrogen can also decarbonise steel made for domestic use.

MENA's steel sector is already expanding, with numerous plans for new DRI-based plants in Saudi Arabia, Oman and the UAE that will initially run on gas and transition towards hydrogen on unspecified timelines. Although gas-based DRI is less carbon-intensive than coal-based blast furnaces, this expansion will still add to MENA nations' domestic carbon emissions at a time when pressure to increase emissions reduction ambition is increasing.

A refocus from green hydrogen exports towards more domestic use can help the region achieve its domestic emissions reduction targets as well as positioning its steelmakers for the global iron and steel sector of the near future.

Introduction

Having supplied fossil-based energy for major energy-consuming nations for decades, the Middle East and North Africa (MENA) region is now at the crossroads of transition. Nearly 52% of the world's oil reserves and 43% of gas reserves are in the MENA region.[1] While countries in the region want to maintain their position in the global energy market, they are also seeking to diversify their economies away from over-reliance on oil and gas. Much of this diversification will be based on the region's world-leading renewable energy resources.

These renewable energy resources will allow the region to become a producer of cheap green hydrogen in the near future. MENA has seen substantial growth in planned green hydrogen projects for the region, with most of the focus on exports.

The outlook of declining green hydrogen costs has helped accelerate the global steel technology transition away from coal. With carbon capture utilisation and storage (CCUS) for coal-consuming blast furnaces looking increasingly unlikely to play a major role in steel decarbonisation, global steelmakers are turning to direct reduced iron (DRI)-based steelmaking that can run on green hydrogen.[2]

MENA has a head start in this transition as the world's DRI-based steelmaking leader, based on the region's abundant gas. The region hosts half of the world's DRI plants, positioning it as a potential major player in the decarbonisation of the iron and steel industry if it gives increasing focus to domestic utilisation of green hydrogen in steelmaking, rather than exports.

Around the world, there is a growing understanding that global steel decarbonisation will require some shift in ironmaking to regions able to produce green hydrogen more cheaply. In the near future, green iron and steel production will shift to areas that provide a competitive advantage of cheap clean energy, have access to high-grade iron ore, and are well-positioned in global trading networks. A global trade in low-carbon iron, exported as hot briquetted iron (HBI), is starting to emerge.

The MENA region has the potential to become a leading contender in steel decarbonisation, but global competition is already starting to grow from other regions with strong clean energy resources and access to high-grade iron ore.[3]

[1] IEMed. Energy Transition and Prospects for Producing Countries in the MENA Region. 2023.
[2] IEEFA. No, metallurgical coal is not a critical material…and carbon capture won't save it. 3 July 2023.
[3] IEEFA. Australia faces growing green iron competition from overseas. 1 September 2023.

DRI capacity in the MENA region

The MENA region offers a distinct advantage for the production of green iron and steel due to several key factors, including competitive renewable electricity, existing DRI-based steelmaking facilities, increasing supply of DR-grade iron ore, and lower labour costs. These factors play a crucial role in differentiating MENA's position in the green iron and steel industry.[4]

> **MENA is already a hub for DRI with nearly 46% of total global production.**

MENA is already a hub for DRI with nearly 46% of total global production. In 2022, the MENA nations produced 58.48 million tonnes (Mt) DRI. The region has retained its share in global production unchanged since 2021, with an increase in production in all countries except Bahrain and the United Arab Emirates (UAE).[5]

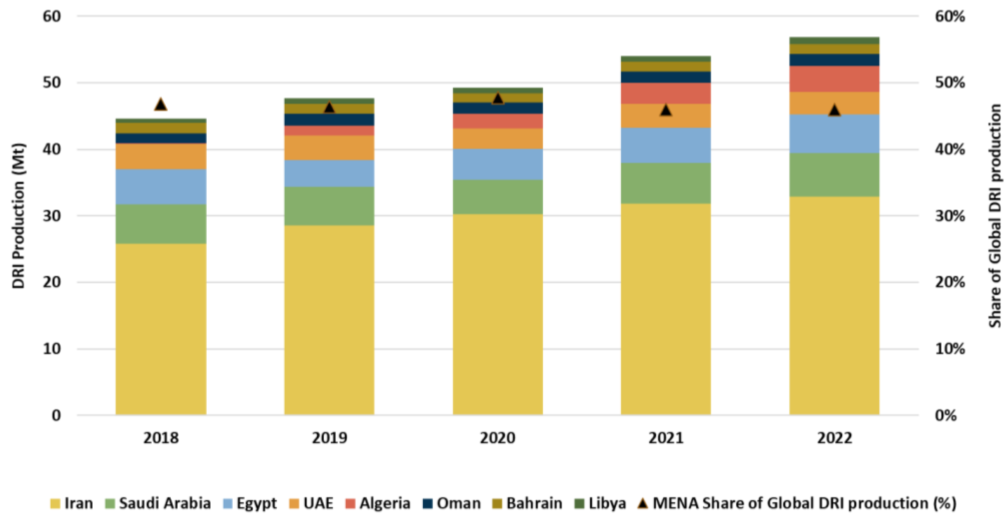
Table 1: MENA crude steel and DRI production in 2022 (Mt)

Country	Crude Steel Production	Share of Electric Furnace %	Share of Basic Oxygen Furnace %	DRI Production 2022*	Number of DR Shafts*
Iran	30.6	91.8	8.2	32.90	42
Saudi Arabia	9.1	100	-	6.48	7
Egypt	9.8	100	-	5.82	6
UAE	3.2	100		3.45	3
Algeria	3.5	80	20[e]	3.88	3
Oman	3	100	-	1.82	1
Bahrain	1.17	100	-	1.42	1
Libya	0.74	100	-	1.1	3
Qatar	1	100	-	1.62	1

*Source: Worldsteel & Midrex**
Qatar Steel Sustainability Report 2021. Arab Iron and Steel Union (Libya Crude Steel Production) and Knoema (Bahrain Crude Steel Production)

[4] IEEFA. Green steel opportunity in the Middle East and North Africa. 14 September 2022.
[5] Midrex. World Direct Reduction Statistics 2022. 12 September 2023

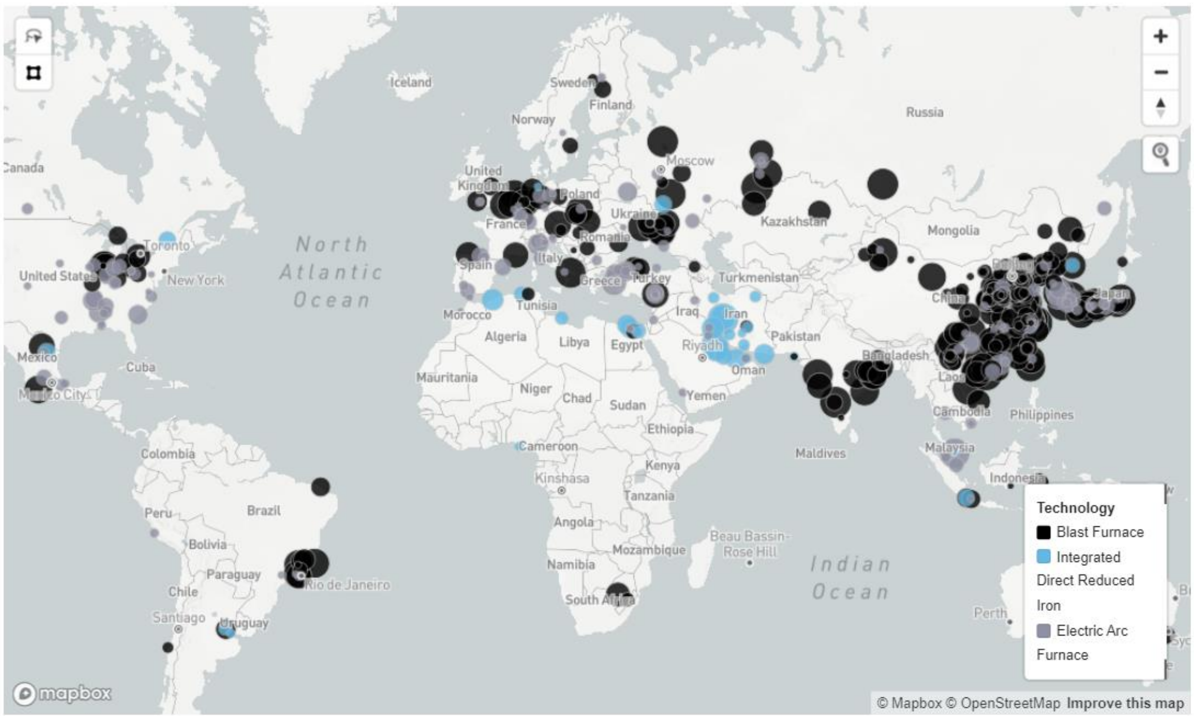
Figure 1: MENA region DRI production in 2018-2022 (Mt)



Source: Midrex Statistics 2022

DRI-electric arc furnace (EAF)-based steelmaking dominates in the MENA region due to the availability of abundant gas in the region. With the exception of a few legacy blast furnaces, nearly all nations in the region adopted EAFs fed with DRI or scrap or a combination of both. Steelmakers in the MENA region have a smaller carbon footprint than their global rivals on average, and their prominent position in DRI opens up exciting opportunities for producing cost-competitive, truly green steel if they can adapt early to green hydrogen.

Figure 2: MENA region leads in DRI-based steelmaking



Source: Agora Global Steel Transformation Tracker

Furthermore, the region stands as a prime candidate to become an export hub for green iron metallics, with the capacity to supply high-grade feedstock such as DRI and HBI for steelmakers looking to meet carbon emissions goals around the globe.[6]

Recent studies show that locating hydrogen (H_2)-based steelmaking facilities in advantageous locations – typically characterised by robust and reliable solar resources, supplemented by wind energy, and with access to high-quality iron ore – is especially crucial in the short term.[7]

MENA's renewables potential

Producing green iron and steel without renewables is impossible. The steel sector is energy-intensive and to decarbonise the whole value chain a considerable amount of renewable energy is required.

During the shift from traditional steelmaking to the green steel value chain, electricity emerges as the primary cost determinant influencing the expense of producing green hydrogen. This alternative reducing agent serves as a substitute for fossil fuels such as coal and natural gas. Additionally, electricity serves as the energy source for various electric furnace variants applicable in the melting process. The availability of cost-effective renewable resources, with limited seasonal variability, leads to a reduction in the dimensions of the electrolyser and hydrogen storage units. Consequently, this reduction notably lowers the capital expenditure (CAPEX) for green iron and steel production facilities.

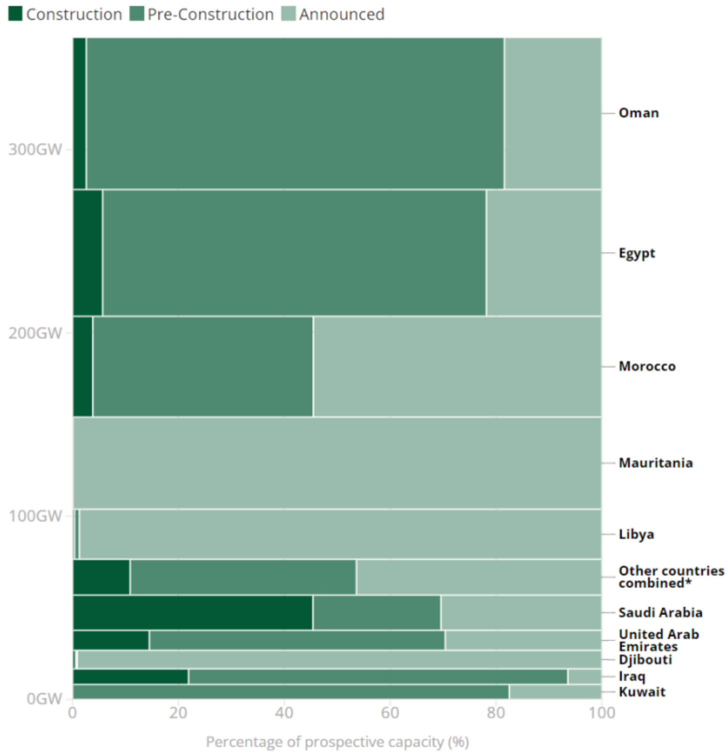
Current capacity and prospective projects

The Middle East has one of the lowest renewables share in the electricity mix among other regions, amounting to 5%, compared with a global average of 38.2%.[8] However, a 15% jump in renewables capacity just in 2022 bodes well for significant change in this area.[9] The International Energy Agency (IEA)'s *Renewables 2022* report shows that the renewables capacity is rising in MENA faster than previous expectations, and anticipates the region maintaining its rapid growth.[10]

The region is blessed with reliable solar irradiation and has the highest photovoltaic power potential worldwide.[11] In a September 2023 briefing, Global Energy Monitor (GEM) found that the MENA region has a prospective, large-scale renewable energy capacity of 361 gigawatts (GW), of which 23GW is under construction, 171 GW is in the preconstruction stage, and the remainder has been announced. Of this prospective capacity, 60% is earmarked for green hydrogen production according to GEM, with most of that production focused on exports.[12]

[6] IEEFA. MENA, a potential new hub for green steel and green iron metallics. 8 December 2022.
[7] Devlin, A., Kossen, J., Goldie-Jones, H. et al. Global green hydrogen-based steel opportunities surrounding high quality renewable energy and iron ore deposits. *Nat Commun* 14, 2578 (2023). https://doi.org/10.1038/s41467-023-38123-2.
[8] Reuters. Column: Middle East starts cleaning up its power act with renewable push. 6 April 2023.
[9] IRENA. RENEWABLE ENERGY STATISTICS 2023. Page 6.
[10] IEA. Renewables 2022. December 2022.
[11] World Bank. Global Photovoltaic Power Potential by Country. June 2020.
[12] Global Energy Monitor. MENA grows renewables by half but clings to risky hydrogen and gas. September 2023.

Figure 3: MENA's prospective solar and wind capacity



Source: Global Energy Monitor

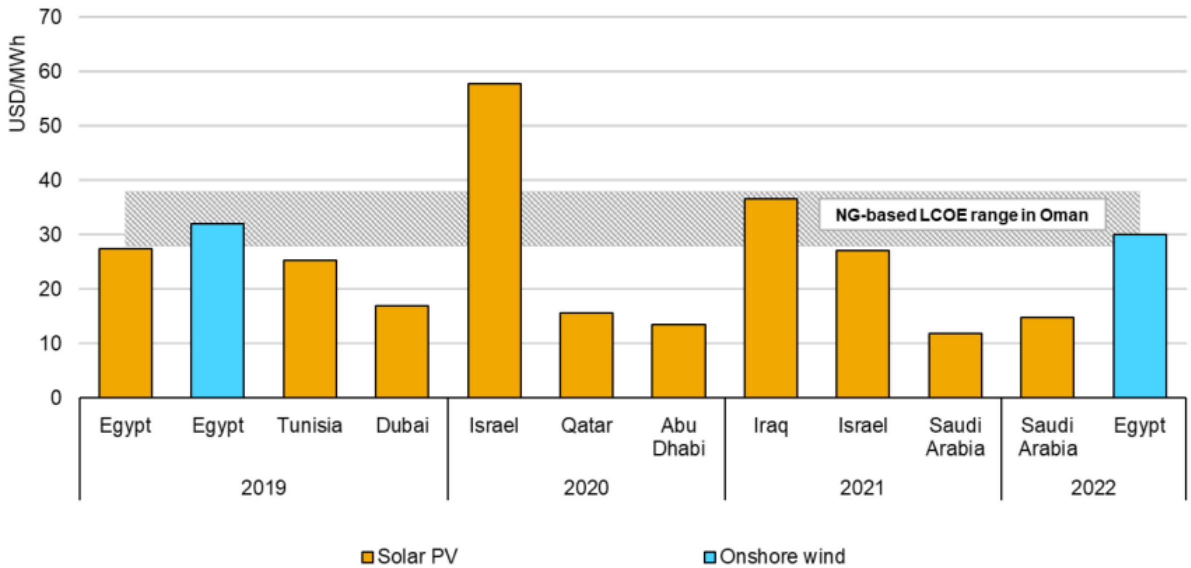
Renewable energy costs

Renewable electricity is already cost-competitive in MENA. The most recent Independent Power Producer (IPP) contracts show that MENA has some of the cheapest renewable prices in the world. Solar photovoltaic (PV) costs based on IPP contracts are three times cheaper than the global average.[13]

Figure 4 shows that the bid prices for solar PV technology in some Middle Eastern countries are well below two US cents per kilowatt hour (kWh) in recent years, which is below the natural gas-based levelised cost of electricity (LCOE) in Oman.[14]

[13] MEED. Middle East & Africa Hydrogen Projects. 16 November 2022. Page 8.
[14] IEA. Renewable Hydrogen from Oman. June 2023. Page 36.

Figure 4: Renewables' bid price vs LCOE of gas-fired power plants in Oman



Source: IEA
Notes: Assumed natural gas price USD 3.7/GJ.

In 2021 the lowest offer for the 600MW Al Shuaiba project in Saudi Arabia was US$0.0104/kWh which was a new record at that time.[15]

In June 2023, UAE-based company Masdar Clean Energy submitted US$0.0162/kWh for the sixth phase of the Mohammed bin Rashid Al Maktoum Solar Park with a capacity of 1.8 GW.[16] The price for Phase 5 was US$0.0169/kWh for 0.9 GW capacity.[17]

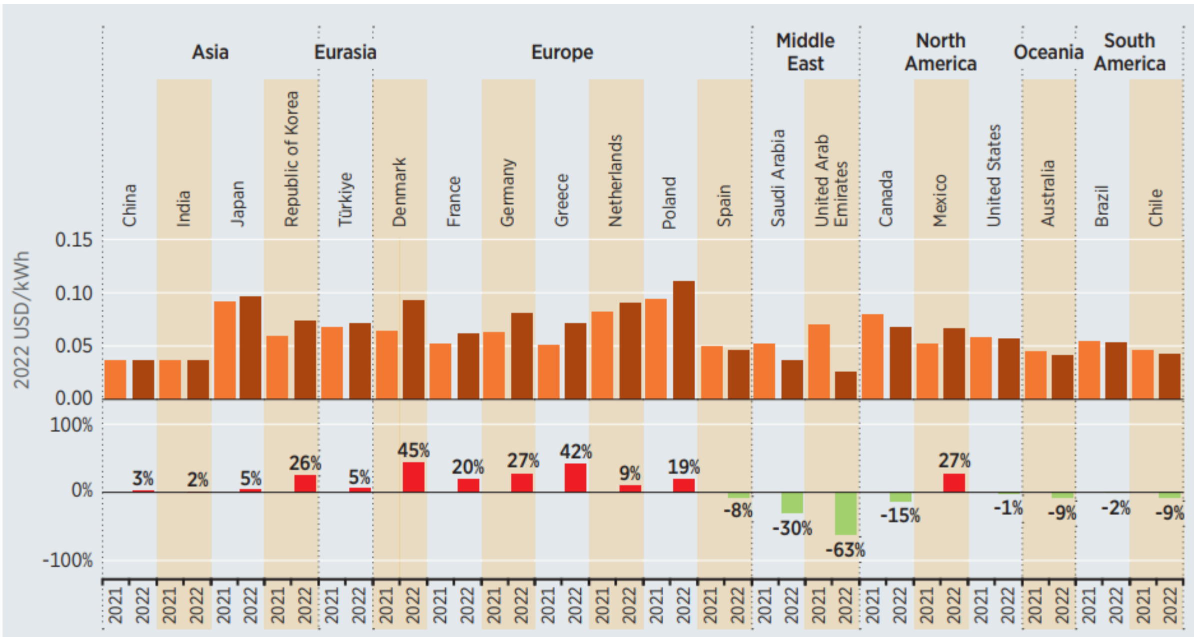
More renewable projects with higher capacities are in the pipeline. Saudi Arabia is developing its largest solar projects with a capacity of 2.6GW, which is backed by US$2.2 billion in funds and expected to be operational by 2025.[18]

In 2022, the global weighted average LCOE of onshore wind was US$0.033/kWh, and for solar PV it was US$0.049/kWh. While MENA's onshore wind LCOE was near the global average range (with Egypt as a reference point), it has the most cost-competitive solar PV costs globally. According to IRENA, the cost decline for the UAE and Saudi Arabia from 2021 has been impressive, reaching 63% and 30% respectively, and making them the nations with the cheapest solar LCOE worldwide.[19]

> **MENA has the most cost-competitive solar PV costs globally.**
> **IRENA 2022**

[15] PV magazine. Saudi Arabia's second PV tender draws world record low bid of $0.0104/kWh. 8 April 2021.
[16] Government of Dubai. DEWA receives the lowest bid of USD 1.62154 cents per kWh of MBR solar park's 6th phase. 07 June 2023.
[17] Government of Dubai. Mohammed bin Rashid Al Maktoum Solar Park. Page last updated on 17 April 2023.
[18] S&P Global. Saudi Arabia moves ahead with its largest solar power project. 20 August 2023.
[19] IRENA. Renewable Power Generation Costs In 2022. August 2023. Page 112.

Figure 5: Utility-scale solar PV weighted average LCOE trends in Top 20 utility-scale markets, 2021-2022



Source: IRENA

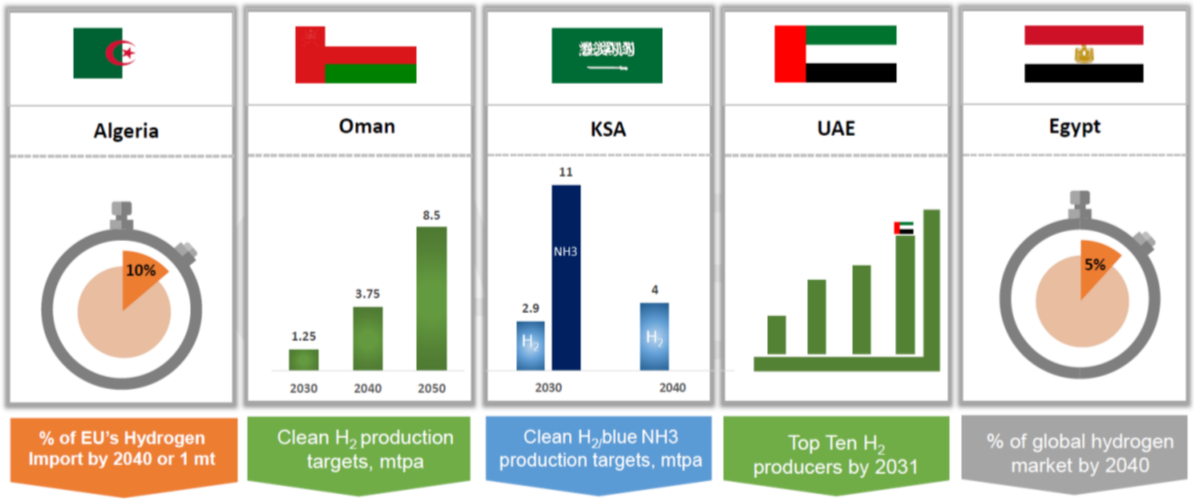
Green hydrogen in MENA

The location of future DRI and HBI export hubs will be determined to a large extent by the availability of cheap green hydrogen, which will soon outcompete blue hydrogen (hydrogen produced from fossil fuels with carbon capture) on cost as well as emissions. Wood Mackenzie sees the Middle East (as well as Australia) as being best placed to benefit from being "in the top echelon for solar irradiance".[20]

Several countries in the MENA region have taken the lead in becoming early adopters of green hydrogen production, setting ambitious goals to become significant exporters of this emerging energy source. Figure 6 illustrates the targets in some MENA countries. Appendix 2 presents the main hydrogen projects in MENA countries.

[20] Wood Mackenzie. Metamorphosis: how decarbonisation is transforming the iron and steel industry. October 2023.

Figure 6: Hydrogen ambitions and targets in selected MENA countries



Source: OAPE[21]

Saudi Arabia

In addition to reaching 50% renewable energy by 2030, Saudi Arabia also has ambitions in both blue and green hydrogen production with plans to produce 2.9 million tonnes per annum (Mtpa) by 2030 and 4 Mtpa by 2035.[22,23] IEEFA expects blue hydrogen to play little role in global decarbonisation, given carbon capture technology's long history of underperformance, and the fact that cost declines for green hydrogen will see it outcompete blue hydrogen by the end of the decade.[24,25,26]

The NEOM Green Hydrogen Project in Saudi Arabia is currently the largest green hydrogen project in the world. In May 2023, the company that is building the project at Oxagon completed financial close at a total investment value of US$8.4 billion. The project will produce green hydrogen which will be converted to ammonia for transportation by the end of 2026, backed by 4 GW of solar and wind capacity.[27]

South Korean steelmaking giant POSCO, in partnership with Korea Electric Power Corp (KEPCO) and three other Korean companies, has entered into a Memorandum of Understanding (MoU) with Saudi Arabia's Public Investment Fund (PIF). This agreement aims to develop a 1.2 Mtpa green hydrogen and ammonia facility in Saudi Arabia, with an investment of US$6.5 million. The construction of the plant is anticipated to take place between 2025 and 2029.[28]

[21] OAPEC. Hydrogen Opportunities in MENA Accelerating Exports. 21 June 2023.
[22] Kingdom of Saudi Arabia. A Sustainable Saudi Vision 2030.
[23] Alarabiya News. NEOM's green hydrogen plant will secure Saudi Arabia's clean energy transition. 31 May 2023.
[24] IEEFA. Blue hydrogen: Not clean, not low carbon, not a solution. 12 September 2023.
[25] IEEFA. Carbon capture: a decarbonisation pipe dream. 1 September 2022.
[26] Bloomberg New Energy Finance. Green Hydrogen to Undercut Gray Sibling by End of Decade. 9 August 2023.
[27] NEOM. NEOM green hydrogen company completes financial close at a total investment value of USD 8.4 billion in the world's largest carbon-free green hydrogen plant. 22 May 2023.
[28] Reuters. South Korea, Saudi to boost ties on energy, defence; $30 bln in deals signed. 17 November 2022.

In another agreement, Japanese power producer Jera will collaborate with the PIF to study the opportunities for green hydrogen and ammonia production in Saudi Arabia for export markets including Japan.[29]

In October 2023, Saudi Arabia and India signed an MoU covering a range of energy collaborations including green hydrogen.[30]

Oman

Oman could become the largest exporter of hydrogen in the Middle East this decade, according to the IEA. Oman announced its own 2050 net zero emissions target in 2022, and more use of green hydrogen domestically rather than for export could help it achieve this aim. The IEA predicts that the cost of producing green hydrogen in Oman in 2030 could be as low as US$1.6/kg, cheaper than Australian production (Figure 7).[31]

Oman has pledged to meet the net zero emission target by 2050, and as part of this target it envisages producing 1 Mt of renewable hydrogen by 2030, with further aims for 3.75 Mt and 8.5 Mt by 2040 and 2050 respectively.[32]

The country is blessed with solar irradiation and onshore wind that make renewables the best long-term option to produce electricity despite having access to cheap fossil fuels. IEA projections suggest that Oman could potentially export 0.67 Mtpa of hydrogen by 2030, while the UAE and Saudi Arabia are expected to follow closely with exports of nearly 0.22 Mtpa and 0.18 Mtpa respectively.[33]

To reach the target by 2030, more than 50 terawatt hours (TWh) of captive renewable capacity will be needed, which entails faster development in the energy system and more investment in infrastructure.[34]

In March 2023, Hydrogen Oman (Hydrom) signed six term-sheet agreements with developers such as BP and Green Energy Oman to invest in green hydrogen projects. The agreements include seven years for the development and establishment and 40 years for operating the projects.[35]

Hydrom also has a strategy for land allocation to various projects through auctioning. The initial round of Phase A took place in April 2023. In June 2023, Hydrom granted three blocks for developing green hydrogen projects totalling more than US$20 billion of investment. The first of two blocks in Hydrom's Phase A Round 1 public auction process (Z1-01) was awarded to a consortium led by Copenhagen Infrastructure Partners (CIP), and the other two with Green Energy Oman and BP were awarded following the commercial term sheets in March.[36]

Three projects will produce 0.5 Mtpa green hydrogen from 11.5 GW of installed renewable energy capacity. The CIP-led consortium plans to establish a green hydrogen production capacity of

[29] Argus. Japan's Jera, Saudi Arabia to study green H2, NH3. 20 July 2023.
[30] ET Energyworld. India, Saudi Arabia ink pact on green hydrogen, electrical interconnections. 9 October 2023.
[31] IEA. Renewable Hydrogen from Oman. June 2023. Page 7.
[32] IEA. Oman's huge renewable hydrogen potential can bring multiple benefits in its journey to net zero emissions. 12 June 2023.
[33] IEA. Renewable Hydrogen from Oman. June 2023. Page 18.
[34] Ibid.
[35] Oman News Agency. Agreements Worth Over RO 20 Billion for Green Hydrogen Projects in Oman Inked. 14 March 2023.
[36] Oman News Agency. Three Agreements Worth $20 Billion Signed to Develop Green Hydrogen Projects in Oman. 1 June 2023.

0.2 Mtpa, supported by 4.5 GW of renewable energy to supply a green steel plant located in the Port of Duqm, within the Special Economic Zone at Duqm (SEZAD).[37]

POSCO and Engie are leading a consortium that won the second land auction of the first round, planning to produce 0.22 Mtpa green hydrogen and 1.2 Mtpa green ammonia in Duqm.[38] POSCO has stated that the project will be South Korea's largest overseas green hydrogen development. Production will be utilised in steelmaking and power production in South Korea, and some hydrogen will be used domestically in Oman.[39]

The Hyport Project is another green hydrogen project in Oman, under an agreement signed with Hydrom. The project, from a consortium consisting of OQ Alternative Energy, and DEME Concessions, was awarded land following the commercial term sheets agreement in March. [40]

Hydrom intends to conduct a second round of land allocation for hydrogen projects in its pursuit of an ambition to produce 1 Mtpa of green hydrogen by 2030. During this round, three blocks of land will be allocated in the Dhofar region in the south of Oman.[41]

Table 2: Land block awards by Hydrom for large-scale green hydrogen projects

Consortium	Green Hydrogen Capacity (Mtpa)	Renewable Capacity (GW)	Location (Block)
Copenhagen Infrastructure Partners (CIP), Blue Power Partners (BPP) and Al Khadra, part of Oman's Hind Bahwan Group	0.2	4.5	Duqm (Z1-01) Auction
Oman's integrated Energy Company OQ, Shell Oman, Kuwait's state-backed energy investor EnerTech (ETC), InterContinental Energy (ICE) and Golden Wellspring Wealth for Trading (GWWT)	0.15	4	Duqm (Z1-04)
BP Oman	0.15	3.5	Duqm (Z1-03)
POSCO and Engie, Samsung Engineering, Korea Southern Power, Korea East-West Power and Thailand's state-run petroleum exploration and production firm PTTEP	0.22 (will be converted into 1.2Mtpa ammonia for export)	5	Duqm (Z1-02) Auction
OQ Alternative Energy, and DEME Concessions NV	0.07	2	Hyport Duqm

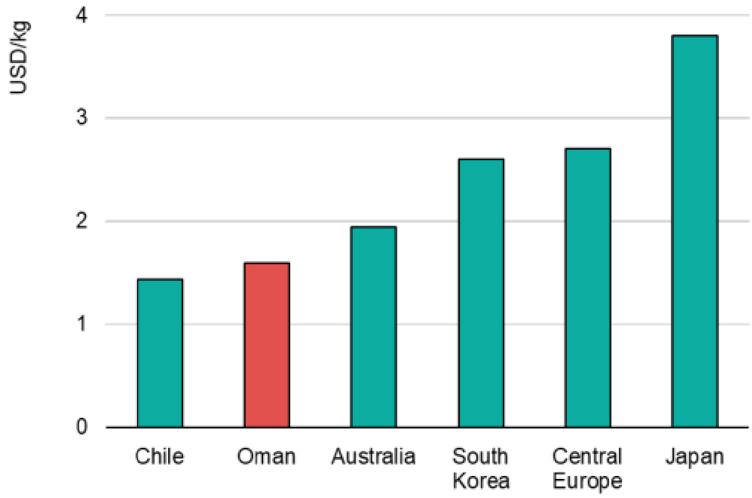
Source: Oman's Ministry of Energy and Minerals, Press releases

The country also intends to build a 2,000km hydrogen pipeline network around the country that connects not only the hydrogen hubs in the south but also the industrial zones in the north. In the

[37] Ibid.
[38] Oman News Agency. Hydrom Signs Two Agreements Awarding Green Hydrogen Projects in Oman. 21 June 2023.
[39] S&P Global. Oman awards green hydrogen/ammonia project to South Korea's top steelmaker POSCO, France's Engie. 22 June 2023.
[40] Oman News Agency. Hydrom Signs Two Agreements Awarding Green Hydrogen Projects in Oman. 21 June 2023.
[41] Hydrom Oman. Auction Phase A.

long term the capital city Muscat and neighbouring countries including UAE will be connected to this network project, which may cost up to US$3 billion.[42]

Figure 7: Renewable hydrogen production costs in selected potential export countries and import markets in 2030



Source: IEA
Notes: Technical lifetime 25 years; electrolyser: 69%; electrolyser CAPEX USD320/k/We; annual OPEX 3% of CAPEX, WACC 3.55-5% depending on the country.

United Arab Emirates

The UAE's national hydrogen strategy envisages production of 1.4 Mtpa of low emissions hydrogen by 2031, comprising 1 Mtpa of green hydrogen and 0.4 Mtpa of blue hydrogen. In the long-term UAE aims to scale up to 7.5 Mtpa and 15 Mtpa by 2040 and 2050 respectively.[43] The UAE intends to establish two hydrogen hubs named "oases" that can reduce the 2031 emissions by 25%, in sectors including heavy industry. Three more "oases" will be developed by 2050.[44]

The UAE also plans to invest up to US$54 billion by 2030 to triple its supply of renewable energy.[45]

Egypt

During the COP27 climate summit, Egypt – the summit's host – signed eight different framework agreements for low-carbon hydrogen and ammonia projects. The agreements were signed with well-known industry partners such as TotalEnergies and Fortescue Future Industries (FFI).[46]

[42] Argus. Oman sets out plans for H_2 pipeline network. 15 September 2023.
[43] The United Arab Emirates' Government portal. National Hydrogen Strategy.
[44] Hydrogen Insight. UAE targets 15 million tonnes of green hydrogen production by 2050 as it approves national H2 strategy. 4 July 2023.
[45] Associated Press. UAE announces plans to invest $54B in energy and triple renewable sources. 5 July 2023.
[46] Hydrogen Central. COP27 – Egypt Signs Eight Framework Agreements for Hydrogen Projects, Including an $8 Billion Green Hydrogen Factory. 16 November 2022.

The agreements were followed by more than 20 MoUs for producing green hydrogen, Egypt's prime minister Mostafa Madbouly said. The country has a project pipeline worth more than US$83 billion for millions of tonnes of green hydrogen capacity.[47]

Morocco

Morocco hopes to capture up to 4% of the global demand for green hydrogen. Based on the calculations in the country's roadmap, it is estimated that the green hydrogen industry and its derivatives in Morocco could meet a demand of between 13.9 and 30.1 TWh in 2030, which could reach between 153.9 and 307.1 TWh in 2050.[48]

A new report by the Moroccan Economy and Finance Ministry shows the intention of the government to invest more than US$60 billion in hydrogen and ammonia projects in the next few years.[49]

Algeria

Algeria is hoping to supply green hydrogen to Europe via pipeline.[50] Green hydrogen transportation via pipeline looks to have a significant cost benefit over transport by ship (Figure 15). However, the proposal involves the conversion of existing gas pipelines and there are significant questions over the viability of such projects.[51]

In addition, several green hydrogen initiatives are currently in development in countries including Algeria and Mauritania, though they are still in the early stages of planning. A list of the Hydrogen and Ammonia projects in the MENA region is available in Appendix 2.

Green hydrogen production costs

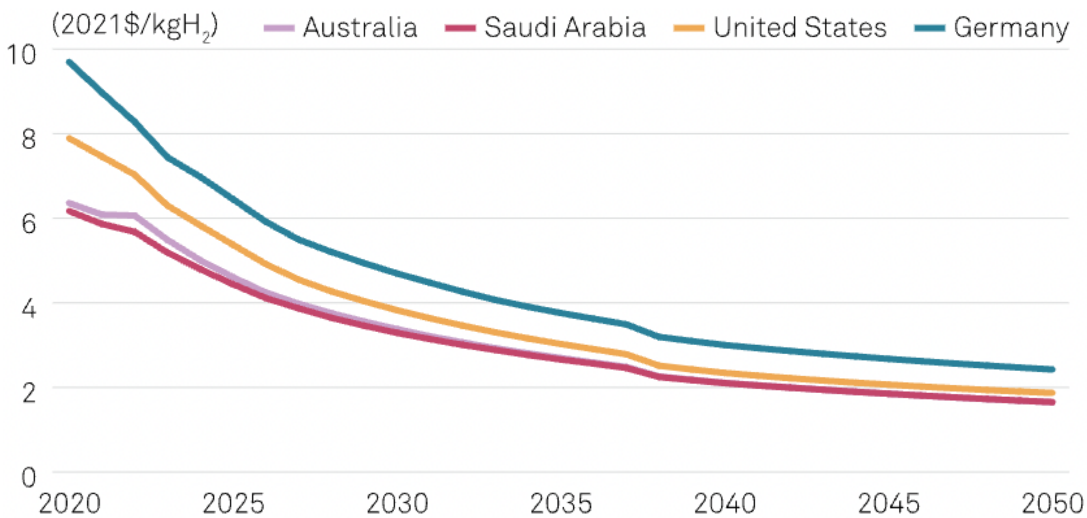
Although hydrogen production via electrolysis is relatively expensive now, it is forecast that the cost will decline quickly as electrolyser production capacity ramps up and the cost of wind and solar power continues its downward trend.

Bloomberg New Energy Finance (BloombergNEF) sees the current cost of green hydrogen at US$4.5-US$12/kg, while the cost of grey hydrogen (produced from gas) is US$0.98-US$2.93. Blue hydrogen (produced from gas and with some carbon emissions captured) costs US$1.8-US$4.7/kg. However, S&P Platts assessed the cost of green hydrogen produced in Saudi Arabia at US$3.22/kg in September 2023.[52] S&P sees Saudi Arabia outcompeting nations including Australia, Germany and the U.S. as green hydrogen costs fall substantially (Figure 8).

BloombergNEF finds that producing green hydrogen in a new plant will be cheaper than grey hydrogen in many countries by 2030. Green hydrogen will also outcompete blue hydrogen according to BloombergNEF: "Using Western-made alkaline systems, green hydrogen beats out blue hydrogen by 2030 in all but a handful of modelled markets."[53]

[47] Hydrogen Insight. Egypt has an $83bn pipeline of green hydrogen projects that could produce millions of tonnes of green ammonia. 3 August 2023.
[48] Green Hydrogen Organisation. Morocco.
[49] ZAWYA. Morocco to invest heavily in green hydrogen projects. 17 August 2023.
[50] Bloomberg. Algeria Is in Talks to Send Green Hydrogen to Germany Via Pipeline. 24 October 2023.
[51] IEEFA. A gas pipeline in disguise? Known unknowns about H2Med. 8 December 2022.
[52] S&P Global. Middle East's clean hydrogen capacity plans double year on year. 25 September 2023.
[53] BloombergNEF. Green Hydrogen to Undercut Gray Sibling by End of Decade. 9 August 2023.

Figure 8: Forecast decline in cost of green hydrogen

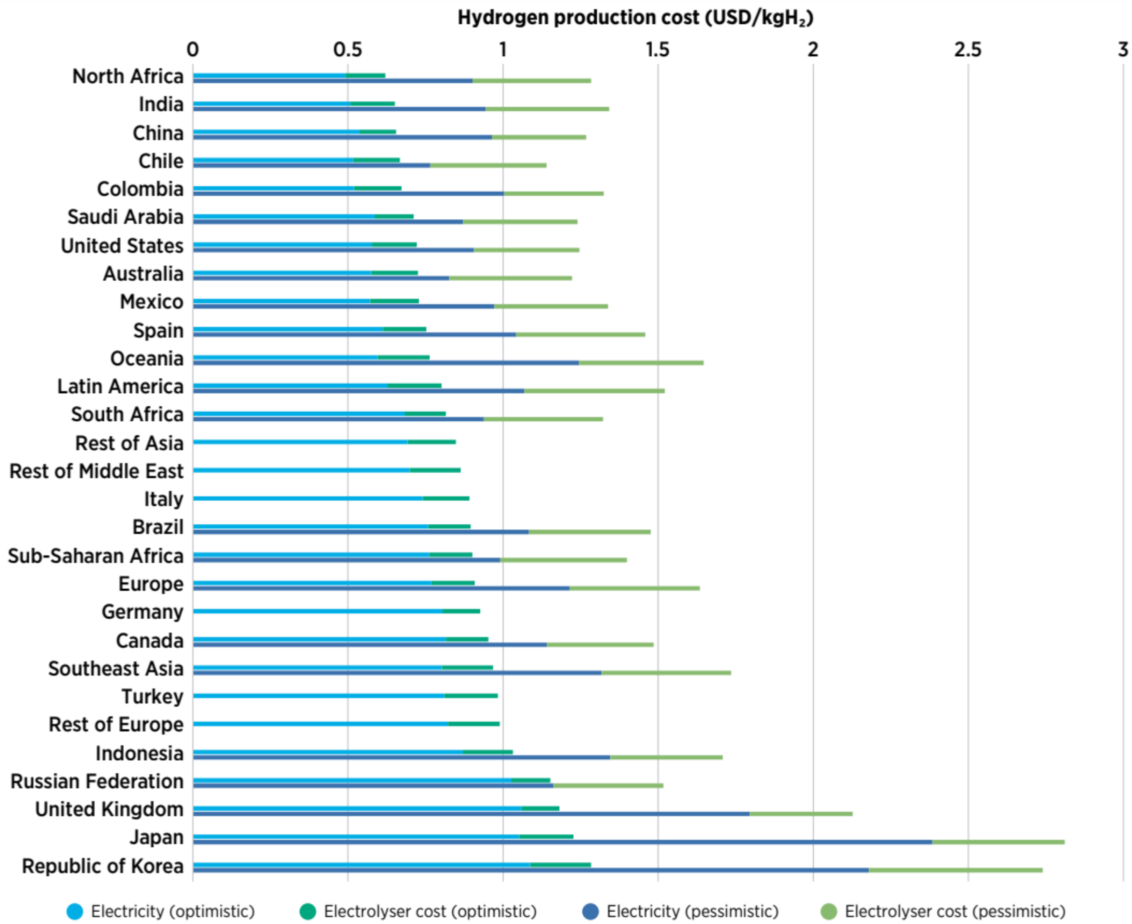


Source: S&P Global Commodity InsightsNote: Levelised cost of hydrogen

After 2030, the cost of green hydrogen will continue its decline. The widespread availability of cheap renewables, with costs ranging from US$10 to US$20 per MWh, will emerge as the primary cost-driving factor in numerous regions, leading to the attainment of low green hydrogen production costs. According to IRENA projections, achieving the production of green hydrogen at a cost below US$1.5/kg is feasible by 2050, even under pessimistic assumptions. MENA nations will be highly competitive on cost compared to key steel-consuming countries like Japan, South Korea and in Europe, as well as steel demand growth regions like South-East Asia (Figure 9).[54]

[54] IRENA. Global hydrogen trade to meet the 1.5°c climate goal. Part I. July 2022. Page 53.

Figure 9: Levelised cost of hydrogen by 2050 (US$/kg)



Source: IRENA[55]

Green hydrogen exports: Inefficient and costly

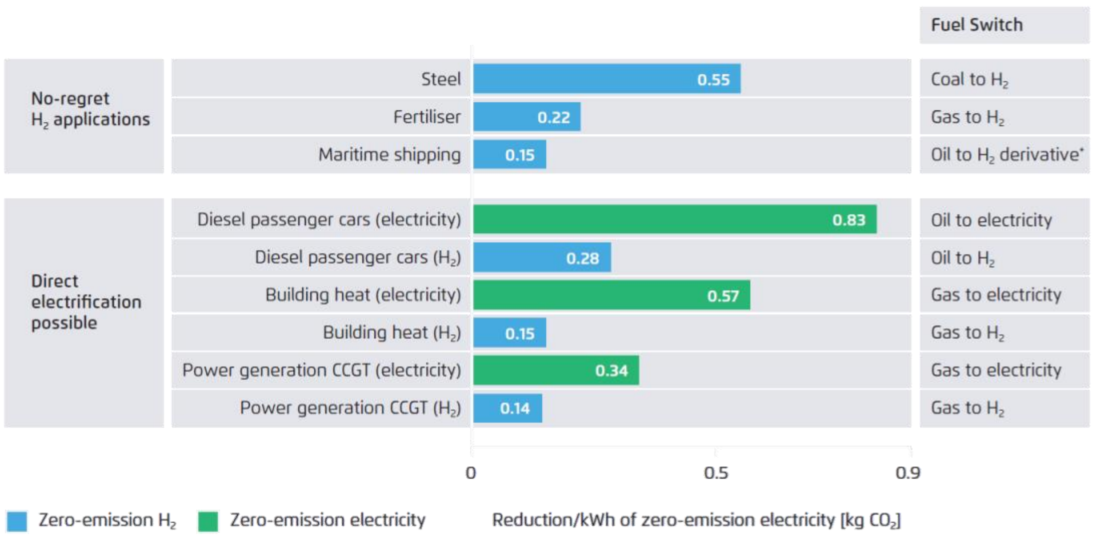
Proponents of green hydrogen exports point to the many decarbonising applications it can have across energy systems. However, many of the proposed uses for green hydrogen – such as decarbonising domestic heating, road transport and power generation – look far more likely to be achieved via electrification and the use of now well-established wind and solar power backed up by battery storage.[56] Sectors where it looks like green hydrogen will make a significant impact in decarbonisation include fertiliser production and steel production via DRI.

While green hydrogen can help reduce emissions in the iron and steel sector, not all regions will be able to produce it at the same low cost. As a result, there has been a push to transport cheap, green

[55] IRENA. Global hydrogen trade to meet the 1.5°c climate goal. Part I. July 2022. Page 53.
[56] Hydrogen Insight. Liebreich: 'Hydrogen is starting to look like an economic bubble – and here's why'. 13 October 2022.

hydrogen to these regions. However, the efficiency and cost of transporting hydrogen over long distances looks like a major challenge.

Figure 10: Steel has the highest CO_2 mitigation potential of H_2 applications



Agora Industry and Wuppertal Institute (2023) based on concept developed by RMI (2022) and authors' calculations in Agora Energiewende (2023). Note: We assume 2.1 t CO_2/t of crude steel for a world average conventional BF-BOF plant and an electricity requirement of 3.84 MWh/t of crude steel for the DRI-EAF route that runs on 100% renewable H_2. *For maritime shipping based on RMI 2022, we assumed that ammonia replaces heavy fuel oil in a 39% efficient internal combustion engine. All other assumptions are retrieved from Agora Energiewende (2023).

Source: Agora Industry

Hydrogen transportation barriers

Hydrogen shipping poses challenges such as low efficiency, high pressures, and the need for extreme temperatures during conversion and reconversion. All of these inefficiencies and losses add costs to the hydrogen value chain.

Hydrogen is the lightest element and has a very low volumetric energy density compared with other sources of energy. This is problematic when it comes to transporting and storing it. The small hydrogen molecule can leak easily, and compressing it for transportation and storage poses a real engineering challenge.

Due to these characteristics, it is not possible to transport hydrogen as easily as oil and liquefied natural gas (LNG). Hydrogen can be liquefied at -253°C (compared with -162°C for LNG). The colder the temperature required for liquefaction, the greater the cost.[57] It also requires 2.5 deliveries to transport the same amount of energy as one cargo of LNG.[58]

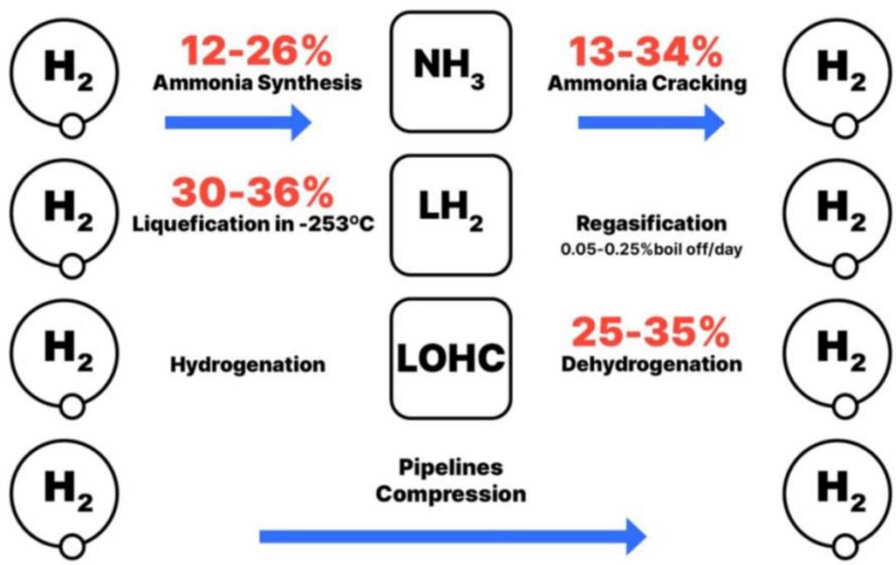
Almost all of the available technologies for hydrogen conversion and reconversion to gaseous form, including conversion to ammonia for shipping, consume considerable energy that leads to higher costs. While hydrogen liquefaction consumes 30%-40% of its energy content, LNG needs less than

[57] Bloomberg. There Won't Be a Saudi Arabia of the Green Hydrogen Age. 17 May 2023.
[58] BloombergNEF. Hydrogen for Beginners. 8 September 2021.

10% – another argument for keeping hydrogen in gaseous form to avoid energy loss.[59] Provaris Energy, a leading company in green hydrogen shipping technologies, has highlighted the significant challenges involved in transporting hydrogen. It has emphasised that converting hydrogen to a liquid form or into ammonia for shipping can result in a loss of up to half of the hydrogen's energy content. This makes it inefficient for end users that require gaseous hydrogen, according to Provaris chief executive Martin Carolan.[60]

Figure 11 illustrates the energy consumption involved in the conversion to hydrogen carriers (i.e. ammonia (NH_3), liquified hydrogen (LH_2) and liquid organic hydrogen carriers (LOHC)) and subsequent reconversion to hydrogen again. This is represented in terms of the equivalent energy contained in the hydrogen.[61] Although these processes typically utilise electricity and other heat sources in practice, representing them in terms of the equivalent energy in hydrogen provides an understanding of the efficiency associated with different transportation alternatives.

Figure 11: Hydrogen carriers' energy consumption in conversion and reconversion



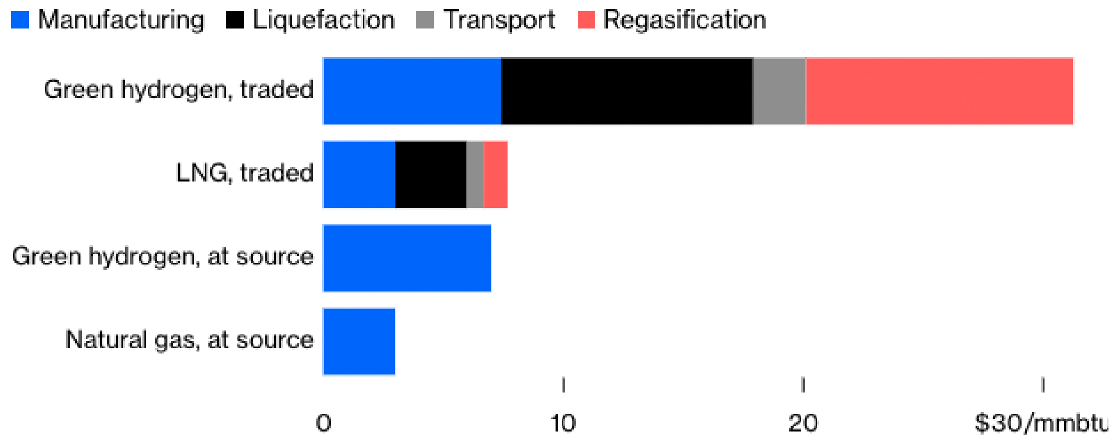
Source: IRENA
Note: As an example, to convert ammonia to hydrogen via an ammonia cracking process, high temperatures and low pressures are required. The energy consumption of this process is 4-11kWh per kilogram of hydrogen, which is equivalent to the heat of 13-34% of that hydrogen when it's combusted.
**Percentages calculated based on energy contained in hydrogen*

By 2030, hydrogen transportation via hydrogen carriers is projected to add an additional cost of US$2.5 to US$4.5 per kilogram of hydrogen delivered.[62] Assuming 51kg of hydrogen for one tonne of steel, this translates to an additional US$128 to US$230 per tonne of crude steel.[63] While the

[59] BloombergNEF. Liebreich: The Unbearable Lightness of Hydrogen.12 December 2022.
[60] Australian Financial Review. Hydrogen exports yet to clear technical hurdles, shipper warns. 22 May 2023.
[61] IRENA. Global hydrogen trade to meet the 1.5°C climate goal: Part II – Technology review of hydrogen carriers. 27 April 2022. Pages 22-23.
[62] IRENA. Global hydrogen trade to meet the 1.5°C climate goal: Part II – Technology review of hydrogen carriers. 2022. Page 11.
[63] Journal of Cleaner Production. Assessment of hydrogen direct reduction for fossil-free steelmaking. December 2018.

technology is maturing and holds the potential to alleviate high costs in the value chain in the coming decades, hydrogen transportation still represents an extra cost for steelmakers.

Figure 12: Transportation costs make importing green hydrogen expensive, even at US$1/kg production cost



Source: BloombergNEF. Hydrogen Council, Deloitte, Bloomberg Opinion calculations.
Note: Based on hydrogen conversion via ammonia. Assumed hydrogen production cost of $1 per kilogram. Converted to mmbtu at a rate of 7.44kg/mmbtu.

The current state of the hydrogen transportation value chain indicates that it is not yet fully developed, requiring significant investments in infrastructure at ports, dedicated vessels for each type of hydrogen carrier, new conversion plants at the production region, and reconversion facilities near steel mills.

In regions where the cost of hydrogen production is higher compared with countries with abundant renewable resources, the transportation costs pose a significant challenge in making it economically viable. The difference in hydrogen production costs between countries with strong and weak renewable sources has been projected to be US$0.82/kg in 2030 and US$0.52/kg in 2050.[64] However, these cost differentials are not sufficient to justify the transportation of hydrogen over long distances.

Export green iron not green hydrogen

Given that the shipping of green hydrogen appears to be expensive, there should be more focus in MENA on using green hydrogen domestically in sectors where it makes sense to do so, such as steelmaking (Figure 10).

In October 2023, Erik van Doezum, ING's global steel lead and head of materials, mining and fertilisers, stated: "I expect significant iron production to move to places like Northern Europe, Southern Europe and the Middle East and North Africa regions. Steel companies in Europe, Korea and Japan will have to make difficult strategic choices about where to produce iron going forward."[65]

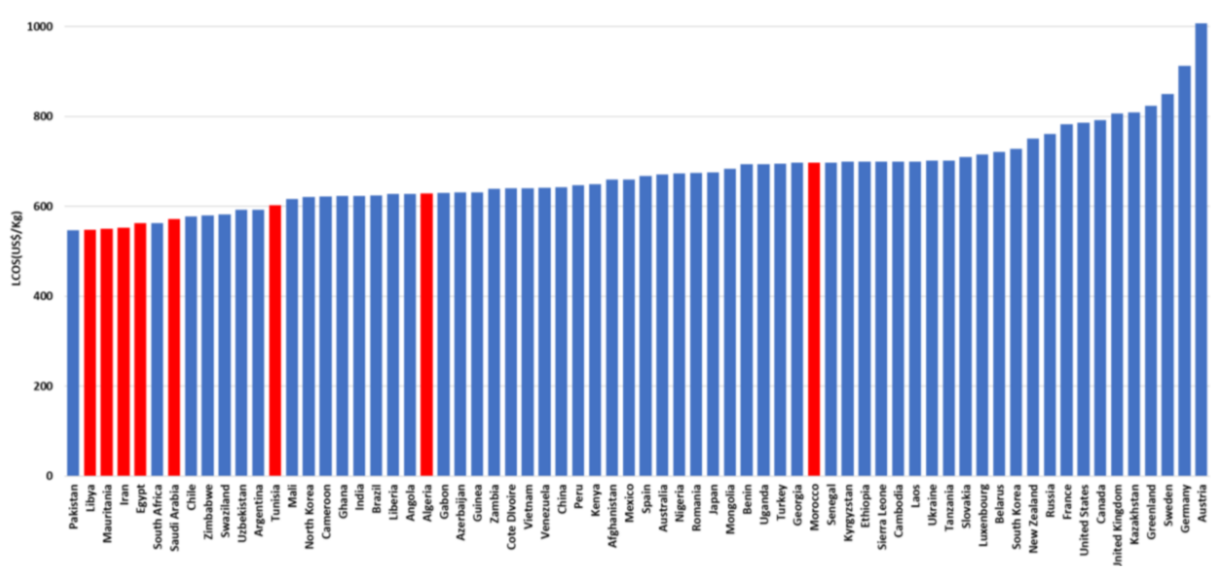
[64] BloombergNEF. Hydrogen: The Economics of Transportation and Delivery. 17 October 2019.
[65] Fastmarkets. Green steel panel | Five key questions answered by experts: LME Week. 13 October 2023

Wood Mackenzie has made clear that rising demand for green steel will transform the steel value chain, stating: “Future green DRI hubs will be determined by how close they are to low-carbon hydrogen production, particularly given the uncertainties around how traded hydrogen will be transported and stored.”

Major steelmakers in key markets like Europe, China, Japan and South Korea are now weighing up whether to produce green DRI domestically or import it in the form of HBI. Wood Mackenzie states: “Future green DRI producers in regions such as the Middle East may seek to go further down the value chain and produce their own green metallics for export.”[66]

A 2023 academic study analysed more than 300 global locations in 68 different countries to assess opportunities for cost-competitive steelmaking using green hydrogen by 2050. Renewable energy resources, access to high-quality iron ore, and low workforce wages were found to contribute to competitiveness of green hydrogen-based steelmaking. Countries within the MENA region emerged at the forefront of this list, primarily attributable to their cost-effective deployment of renewable energy systems (Figure 13).[67]

Figure 13: Projected H_2-DRI-EAF LCOS by 2050(US$/kg)



Source: Nature Communications – Devlin et al.

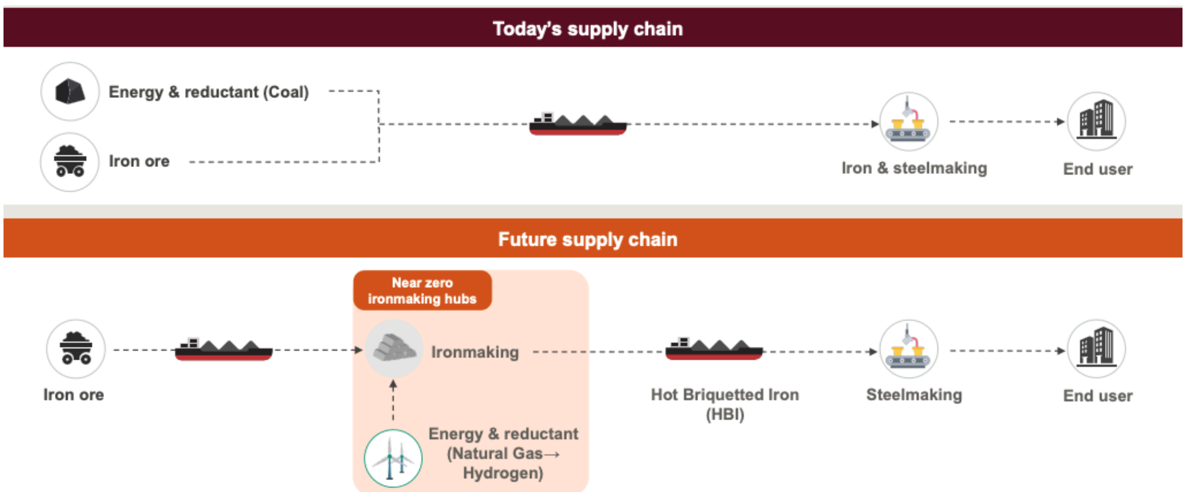
The MENA region could export green steel made using green hydrogen. However, many nations are likely to be reticent to fully offshore their steelmaking capacity and may strategically prefer to import green iron that could be processed into steel domestically via EAFs that could be powered by renewable energy. This replacement of the import of iron ore with the import of green iron is now being considered by some major steelmakers.

According to H2 Green Steel executive vice president Kajsa Ryttberg-Wallgren, it is crucial for the future to prioritise the production of green iron in regions with competitive advantages. Breaking the

[66] Wood Mackenzie. Metamorphosis: how decarbonisation is transforming the iron and steel industry. October 2023.
[67] Devlin, A., Kossen, J., Goldie-Jones, H. et al. Global green hydrogen-based steel opportunities surrounding high quality renewable energy and iron ore deposits. *Nat Commun* 14, 2578 (2023). https://doi.org/10.1038/s41467-023-38123-2.

traditional ironmaking process within the steel value chain is unavoidable, especially considering the impracticality of producing DRI in many EU countries given the available renewable energy resources and the cost of importing green hydrogen. Ryttberg-Wallgren highlighted the strategy employed by Kobe Steel, which is planning to import green iron from H2 Green Steel's Swedish plant, avoiding the expense of hydrogen imports. Noting that cost was key in a low-margin industry, she stated: "You will be out of cost. So they want to buy green iron, or HBI [hot briquetted iron, blocks of sponge iron] from places in the world where it makes sense to produce it."[68]

Figure 14: Ironmaking likely to dislocate from steelmaking, moving to advantaged energy locations, with near-zero hubs emerging



Source: Rio Tinto

Furthermore, studies on green hydrogen investment primarily focus on addressing the significant risks associated with the green hydrogen economy. Alongside tackling technical hurdles related to production, storage, transmission and distribution, lenders and sponsors are particularly concerned about securing long-term offtake agreements and effectively managing the demand side for end users.[69]

Local consumers have the ability to organise the purchase agreements for green hydrogen. By converting the green hydrogen into valuable products instead of exporting it in liquid or other derivative form, it is possible to reduce the risks involved with hydrogen production and transportation.

Green iron and steel projects are now being backed by banks and credit guarantors.[70] The demand for green steel is experiencing a significant surge, primarily driven by car makers and white goods producers aiming to reduce carbon emissions throughout their value chain.

[68] Hydrogen insight. 'Coal-based steel will have an advantage over hydrogen-derived green steel due to EU carbon allowance scheme'. 26 June 2023.
[69] BCG. Breaking the Finance Barrier for Hydrogen and Carbon Capture. 21 February 2023.
[70] IEEFA. Green finance has begun to flow into green steel funding. 11 November 2022.

Hot Briquetted Iron

HBI is a compressed form of DRI that is compacted at the discharging point of DRI shaft furnaces. It is an established product that does not react with oxygen in the atmosphere, making it safe for shipping. Compared with DRI, HBI has a higher density, making it more efficient for transportation and storage purposes.[71] HBI is a bulk export product that can be shipped in a similar way to iron ore.

Moreover, it has better mechanical strengths, making it a better option for transport and storage.[72] HBI has the highest quality among the iron ore metallics with a metallisation rate above 90%. As a result, it is the best ore-based metallic that can be used in EAFs to produce high-quality steel.

Another benefit of trading reduced iron rather than iron ore is the reduced shipping costs for end-users. During the reduction process, iron ore loses its oxygen content, resulting in an average weight that is nearly 30% lower than that of iron ore pellets.[73]

The export of HBI is a well-established pathway. In 2021, 8 Mt of gas-based HBI was shipped overseas and a further 15 Mt was transported by trains and inland vessels.[74] HBI production and transportation offer energy efficiency and eliminate energy losses that may occur when hydrogen and iron ore pellets are transported separately. Green iron exports would take the form of HBI created from DRI that has been produced using green hydrogen (H_2-DRI) powered by renewables.[75]

Japan's Renewable Energy Institute has found that the import of HBI made via hydrogen-based DRI can be one of three key pillars of the decarbonisation of the nation's steel sector. HBI imports would help eliminate the need for unnecessary hydrogen import infrastructure investment, reducing the cost of zero-carbon steelmaking, and helping to keep the Japanese steel industry competitive.[76]

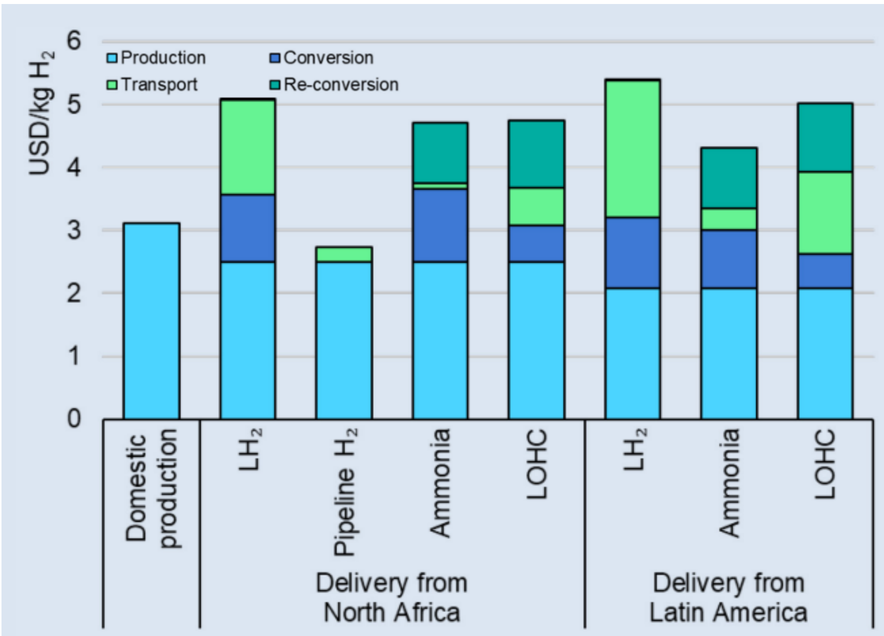
Recently, a report by Australia's CSIRO outlined a potential scenario for ironmaking in Australia with the steelmaking process completed in Japan and South Korea. According to the analysis, using natural gas and then green hydrogen to reduce iron ore and produce DRI in Australia (specifically in Pilbara region) results in a more sustainable value chain with lower total carbon emissions compared with performing these processes in Japan and South Korea. By shifting from blast furnace and basic oxygen furnace technology, which relies on iron ore fines (Fe=57% sinter feed), to the H_2-DRI-EAF route that uses green DR-grade pellets, a carbon dioxide (CO_2) reduction of 80% is achievable.[77] It is also potentially cost-competitive in the short term and becomes increasingly competitive as the cost of green hydrogen declines.

The CSIRO report also addressed the high cost of shipping hydrogen from Australia to these countries, highlighting it as an unfeasible option. However, producing H_2-DRI in Australia is a financially viable solution when compared with exporting both iron ore and green hydrogen to Japan and South Korea for green steel production.[78] The cost gap between producing green steel in Japan or South Korea through imported H_2-DRI and using imported hydrogen and iron ore is projected to exceed US$200 per tonne of steel in some scenarios.

[71] IIMA. Hot Briquetted Iron (HBI).
[72] Australian Financial Review. How Sweden's dash for green steel could trigger a Pilbara revolution. 9 December 2022.
[73] Energy Transitions Commission. Unlocking the First Wave of Breakthrough Steel Investments. April 2023.
[74] Agora Industry. 15 Insights on the Global Steel Transformation. June 2023. Page 22.
[75] Primetals. The new age of HBI. 28 February 2023.
[76] Renewable Energy Institute. The Path to Green Steel: Pursuing Zero-Carbon Steelmaking in Japan. February 2023.
[77] CSIRO. Low emissions steel transition: Value chain considerations to support accelerated transition. February 2023.
[78] Ibid.

The IEA has also highlighted that the hydrogen trade incurs additional costs related to conversion, transportation and reconversion. Figure 15 illustrates the prices of hydrogen in north-west Europe from domestic production and various exported hydrogen pathways. Except for pipelines, which require proximity to end-users, the other pathways are more expensive.[79]

Figure 15: Supply costs of hydrogen in north-west Europe compared to imports



Source: IEA, Global Hydrogen Review 2023

MENA is well placed to meet growing green iron and steel demand

Geographically, the MENA region is well located to export iron to Europe, currently the global leader in steel decarbonisation thanks in large part to its meaningful carbon price. The introduction of the EU's Carbon Border Adjustment Mechanism (CBAM), which was initiated in October 2023 and will see importers into the EU begin paying for embedded emissions from 2026, may benefit sources of lower-carbon-intensity iron and steel like the Middle East in the short term. But CBAM will also likely drive an even faster transition towards truly green steel, necessitating a shift from gas-based to green-hydrogen-based DRI to maintain that advantage. In addition, other countries are likely to respond to CBAM with their own carbon prices and border adjustment mechanisms.

Wood Mackenzie foresees that mature markets with carbon prices such as the EU will shift away from importing carbon-intensive steel from the likes of China and India and towards importing green DRI to supply local EAFs. However, Wood Mackenzie does not see China and India falling too far behind – they are already investing in EAF technology for which DRI from the MENA region could be a key material.[80]

[79] IEA. Global Hydrogen Review 2023. September 2023. Page 103.
[80] Wood Mackenzie. Metamorphosis: how decarbonisation is transforming the iron and steel industry. October 2023.

India's Tata Steel has recently begun construction of a new EAF in India and is planning several more across the country.[81,82] India's steel technology transition away from coal looks likely to happen faster than many expect, but this will happen within the context of significant demand growth. India will be the key steel demand growth territory now that Chinese steel demand is entering permanent decline, and the Middle East is well placed geographically to serve it.[83]

Rising demand for low-carbon steel is being led by one the steel industry's most significant customers – car manufacturers.[84] The shift from internal combustion engines to electric vehicles (EVs) is reducing car industry emissions, and the next decarbonisation phase for car manufacturers will come via purchasing of low-carbon steel and aluminium.

However, demand for low-carbon MENA automotive steel won't just come from overseas.

Saudi Arabia has plans to become a significant hub for car manufacturing as it seeks to diversify its economy away from over-reliance on oil. With the global automotive sector shifting quickly to EVs, the Saudi push will be EV-based and is aiming for production of 500,000 cars a year by 2030. Of this target, 170,000 cars will come via production of the new Ceer brand being developed in partnership with BMW and Foxconn, with sales planned to begin in 2025.[85] The nation's push into the car industry is being led by its US$600bn Public Investment Fund (PIF), which already owns 60% of US-based EV maker Lucid, which plans to begin manufacturing in Saudi Arabia.[86]

In October 2023, the PIF signed a joint venture agreement with Hyundai Motor Company to set up a US$500m automotive plant in Saudi Arabia with production expected to commence in 2026. The PIF will own 70% of the venture and Hyundai 30%.[87]

However, car makers and other drivers of low-emissions production going forward will increasingly want clear standards about what actually constitutes 'green steel'. Stricter definitions of phrases like 'green steel', 'near-zero emissions steel' and 'low-carbon steel' can be expected. Although MENA steel production is currently relatively low carbon intensity compared with most global production, gas-based DRI won't meet the guidelines of what constitutes 'green steel' and the like for long.

MENA's steel capacity expansion is underway

The MENA region presents an appealing destination for companies engaged in energy-intensive and high-emission processes. In the iron and steel sector, several industry leaders are actively investing in the region with the aim of transforming it into a hub for lower-carbon iron metallics. In the near future, such investments could be paired with cheap green hydrogen to produce truly green steel.

The notion of producing green iron through DRI and exporting it as HBI has gained traction. In light of mounting pressure to lower emissions, several prominent steelmakers and iron ore miners are exploring opportunities to tap into this promising market (Table 3).

[81] Times of India. Groundbreaking for Tata Steel's EAF plant held in Ludhiana. 23 October 2023.
[82] The Hindu. Tata Steel plans EAF plants to recycle steel in South India too. 5 July 2023.
[83] IEEFA. As Indian steel production takes off, its metallurgical coal demand will disappoint Australian miners. 29 September 2023.
[84] The National. Why car makers are excited about green steel. 3 October 2023.
[85] Financial Times. Saudi Arabia goes electric to launch homegrown car industry. 12 February 2023.
[86] Reuters. EV maker Lucid to raise $3 billion, mainly from Saudi PIF. 1 June 2023.
[87] Public Investment Fund. PIF and Hyundai Motor Company Sign Joint Venture Agreement to Establish New Automotive Manufacturing Plant in Saudi Arabia. 23 October 2023.

Table 3: Green iron and steel projects in MENA

	Co-operating Companies	Plant Description	End User
UAE	Emirates Steel Arkan, ADP, ITOCHU and JFE Steel	DRI/HBI in Abu Dhabi	JFE Steel, other Asian steelmakers
OMAN	Vulcan Green Steel (Part of the Jindal Group)	5Mt H_2-DRI plant	Middle East, Europe and Japan
	Kobe Steel, and Mitsui & Co. and OPAZ	5Mt of H_2 ready DRI/HBI	Asia and Europe market
Saudi Arabia	Aramco and Baosteel and PIF	Integrated steel plate mill, 1.5Mt (H_2 ready DRI-EAF)	Middle East market
	ESSAR Group and Saudi Arabia's NIDC	4Mt H_2 ready flat steel integrated mill	Saudi Arabia and Middle East market
Vale and Saudi Arabia's NIDC, Emirates Steel Arkan and Oman's MOCIIP		Three mega hubs in Saudi Arabia, UAE and Oman[88] (Including 4 Mtpa in Ras Al Khair industrial city)	Domestic consumption in the region

Source: Companies' press releases. IEEFA.
The National Industrial Development Center (NIDC), Ministry of Commerce, Industry and Investment Promotion (MOCIIP), Public Authority for Special Economic Zones and Free Zones (OPAZ), Public Investment Fund (PIF)

United Arab Emirates

Emirates Steel Arkan, the largest steel producer in the UAE, has formed a collaborative partnership with JFE Steel and Itochu Corporation. They aim to establish an ironmaking facility within the UAE, focused on producing low-emission iron materials like HBI for international export. This collaboration will adopt gas-based DRI technology, though a later switch to hydrogen is being considered. Additionally, there are plans to use CCUS technology, with the captured CO_2 being used in enhanced oil recovery (EOR) processes.[89] Production via DRI is intended to begin in the second half of 2025.[90]

According to the MoU, Itochu will take charge of providing high-grade iron ore, while Emirates Steel Arkan will oversee the production of iron ore metallics. JFE Steel, along with other steel manufacturers from Asia, will be the ultimate users of these materials. Developer Abu Dhabi Ports (ADP) has joined the venture to provide land, logistics, and probably in the future a specific jetty for receiving iron ore and shipping final products.[91]

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[88] Vale. Vale signs agreements to develop Mega Hubs in the Middle East and provide decarbonization solutions for steelmaking. 1 November 2022.
[89] JFE Steel Corporation. JFE Steel, Emirates Steel and Itochu to Study Building Supply Chain of Ferrous Raw Material for Green Ironmaking with Low-carbon Emission. 1 September 2022.
[90] Itochu Corporation. Decarbonization of the Steel Industry: Supply Chain of Ferrous Raw Material for Green Ironmaking with Low Carbon Emission. 1 September 2022.
[91] Argus Media. Japanese, UAE firms expand low-carbon iron alliance. 19 July 2023.

Oman

Japan's Kobe Steel and trading house Mitsui have entered into a MoU to investigate the viability of producing DRI in Oman and exporting it as HBI using Kobe Steel's MIDREX DRI technology. Their objective is to achieve an initial DRI output of 5 Mtpa, utilising natural gas as the primary reducing agent. Subsequently, they will consider a shift to hydrogen or CCS to lower emissions.[92] The proposed DRI plant is planned to be operational from 2027.[93]

Mitsui and Kobe Steel have considered the abundant renewable energy resources of Oman in considering the proposed project location, which will be close to planned green hydrogen developments. The plant will also have access to iron ore pellet supply from Vale's Oman operations. It is expected that the project will export HBI to Europe and Asian markets.[94]

This is not the only low-carbon DRI plan in Oman. Vulcan Green Steel – a sister company to Oman-based Jindal Shadeed Iron and Steel – plans to invest US$3 billion in an integrated greenfield H_2-DRI-EAF plant with an annual capacity of 5Mt. The plant will be located in the Special Economic Zone at Duqm, adjacent to green hydrogen facilities that can directly supply the DRI plant with green hydrogen, reducing transportation costs, though the plant will initially be based on gas.[95] The company is targeting low-carbon steel demand in the Middle East, Europe and Japan.[96]

Jindal Shadeed currently is operating a 2.4Mtpa steel plant based on DRI-EAF technology. To complete the upstream of the value chain, the company is developing a 6Mtpa pelletising plant, which was scheduled to be operational by the end of this year. [97]

Saudi Arabia

Aramco, China Baowu and Saudia Arabia's PIF have signed a shareholders' agreement to establish an integrated steel plate manufacturing complex in Saudi Arabia's Ras al-Khair Industrial City. The collaboration aims to leverage Aramco's energy expertise, China Baowu's advanced steel capabilities, and the PIF's financial strength. China Baowu will own 50% of the venture with the two Saudi partners owning 25% each.[98] The project, aligned with Saudi Arabia's economic diversification efforts, will have a steel plate production capacity of up to 1.5 Mtpa. It will feature an H_2-ready DRI-EAF pathway that, as with other new DR plants, will commence operations using natural gas.[99]

Essar Group is developing a green steel plant in Ras Al Khair as well – the 'Green Steel Arabia' project. The integrated plant is to include two 2.5Mtpa H_2-ready DRI plants, a 4Mtpa hot strip mill and 1 Mtpa in cold rolled coil capacity, totalling US$4.5 billion of investment. The plant initially will be

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[92] Kobelco. Kobe Steel to accelerate feasibility study of Low-CO_2 Iron Metallics Project in Oman. 10 April 2023.
[93] Fastmarkets. Mitsui's move into green metallics sets tone for steel's future in Middle East. 6 June 2023.
[94] Fastmarkets. Mitsui-Kobe Steel joint venture cements Middle East as vital DRI hub, but further efforts required. 2 May 2023.
[95] Green Steel World. Vulcan Green Steel master plan manifests sustainability and resilience. 28 February 2023.
[96] Bloomberg. Jindal Shadeed Group Plants $3 Billion Green Steel plant in Oman. 4 December 2022.
[97] International Mining. Metso Outotec to add to Grate Kiln iron ore pellet reference list with Oman order. 20 May 2022.
[98] Quartz. China and Saudi Arabia are teaming up on steel decarbonization. 8 May 2023
[99] Aramco. Aramco, Baosteel and PIF sign agreement to establish first integrated steel plate manufacturing complex in Saudi Arabia. 1 May 2023.

using gas with the ability to switch to hydrogen in the future and is expected to start production by 2027.[100,101]

During the September 2023 G20 summit, Desert Technologies, a Saudi solar PV company, signed an MoU on the development of renewable energy infrastructure for the project, encompassing both energy generation and storage solutions.[102] Essar plans to cater to Saudi and regional demand across a number of industries including automotive demand.

Iron ore supply in MENA

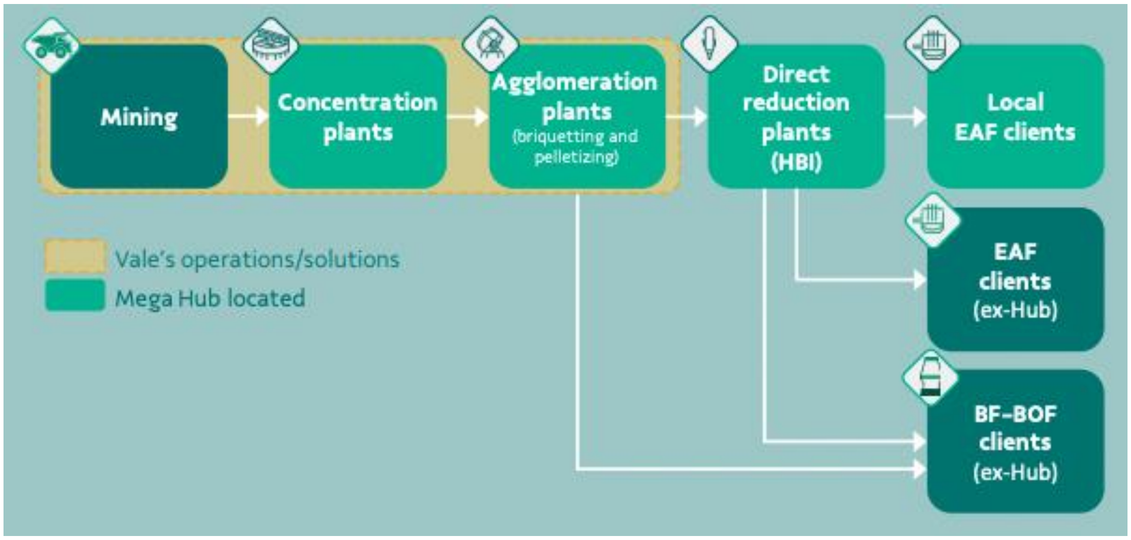
Given the steel industry in the Middle East is already based on DRI, the region has a well-established DR-grade iron ore supply which is now set to expand. Vale – the world's largest supplier of high-grade iron ore – is currently engaged in expanding its facilities in the region to solidify its regional strategy. The company already operates a pelletising plant with a capacity of 9 Mt in Oman and has a distribution centre there that has the capability to manage up to 40 Mt of iron ore and pellets annually. [103]

Steelmaking via DRI-EAF requires high-quality iron ore, which makes up a small proportion of the iron ore traded globally. Vale forecasts that a DR-grade demand-supply gap of around 70 Mtpa could emerge by 2030, though it is intending to fill much of that gap itself.[104] Any future expansion in DRI capacity must be carefully coordinated with the expansion of iron ore supply.

As part of its expansion plans in the Middle East, Vale is planning to build iron ore "green briquette Mega Hubs" in Oman, Saudi Arabia and the UAE.[105,106] Under the Mega Hubs concept, Vale will supply iron ore fines to the hubs where they will be beneficiated and agglomerated into pellets and briquettes of suitable high grade for DRI operations. The pellets and briquettes will be supplied to DRI-based operations located within the hubs for the production of HBI. The resulting HBI will be either supplied to EAF operations within the hubs for processing into steel or transported to external customers (Figure 16).[107]

[100] Essar. Essar returns to steel biz with $8-bn investment. 6 March 2023.
[101] Essar. Foulath Subsidiary, Bahrain Steel, Signs LOI for Iron Ore Pellet Supply to Essar Group's KSA Green Steel Project. 17 August 2023
[102] Essar. Essar Group and Desert Technologies sign MOU for developing renewable energy solutions for Essar's KSA Green Steel Arabia Project. 11 September 2023
[103] SteelOrbis. Vale assumes full control of Oman pellet plant. 15 February 2023.
[104] Vale. Iron Solutions webinar: Decarbonization of steel and impacts in iron ore supply. 14 April 2023.
[105] S&P Global. Brazil's Vale, Saudi Arabia's NIDC sign MOU for iron ore pellet plant. 1 November 2022.
[106] Vale. Iron Solutions webinar: Decarbonization of steel and impacts in iron ore supply. 14 April 2023.
[107] Fastmarkets. Inside Vale's green briquette megahubs and how they will work. 18 November 2022.

Figure 16: Vale's Mega Hubs Concept



Source: Vale.

Recognising the MENA region as one that has a high potential to increase low-carbon DRI production, Vale has decided to amplify its investments in this area to meet the demands of the expanding market.[108] The company's plan is to increase its high-grade agglomerates from 32 Mtpa in 2022 to 100 Mtpa by the end of this decade.[109]

In alignment with this strategic trajectory, Vale has entered into a MoU with Saudi Arabia's National Industrial Development Centre (NIDC) to explore the establishment of a pelletising plant with a capacity of 4 Mtpa in Ras Al Khair industrial city. The plant's objective is to manufacture high-quality pellets. The anticipated investment for this project is approximately US$1.1 billion.[110]

In September 2023, Vale entered into an agreement with Essar to supply iron ore to its 'Green Steel Arabia' project. Vale's Regional Director Andre Figueiredo stated that the agreement to supply 4 Mt of high-grade iron ore per year "signifies our long-term commitment to meet the growing demand for raw material by the steel industry; especially in the Middle East".[111] Bahrain Steel has also signed a Letter of Intent (LOI) to supply Essar's project with iron ore.[112]

Within the MENA region, Iran and Mauritania are the two primary large-scale iron ore mining nations, while Algeria, Egypt, and Tunisia engage in smaller-scale iron ore production.

Iran is the largest miner and producer of various iron metallics in the region, with most of its production capacity dedicated to captive steelmaking plants. Iran's iron ore reserves are estimated to be approximately 2.7 billion tonnes.[113]

[108] Vale. Iron Solutions webinar: Decarbonization of steel and impacts in iron ore supply. 14 April 2023.
[109] Vale. The BMO 32nd Global Metals & Mining Conference. 27 February 2023.
[110] S&P Global. Brazil's Vale, Saudi Arabia's NIDC sign MOU for iron ore pellet plant. 1 November 2022
[111] Essar. Vale International enters into an LOI for supplying iron ore agglomerates to Essar Group's KSA Green Steel Project. 7 September 2023.
[112] Essar. Foulath Subsidiary, Bahrain Steel, Signs LOI for Iron Ore Pellet Supply to Essar Group's KSA Green Steel Project. 17 August 2023.
[113] USGS. U.S. Geological Survey, Mineral Commodity Summaries. January 2023.

Mauritania, currently the second-largest iron ore producer in Africa, possesses 1.5 billion tonnes of reserves, which has attracted the attention of major mining and steel producers seeking to tap into its raw material potential. Emirate Steel Arkan entered into a preliminary agreement with Mauritania's mining company SNIM in February 2022. This strategic partnership aims to explore avenues for new investments, ensuring a reliable supply of iron ore pellets. The two entities are currently evaluating the feasibility of establishing a pelletising plant.[114]

Subsequently, major global steel producer ArcelorMittal has entered into a non-binding MoU with SNIM to assess the prospects of establishing iron ore pellet and DRI production in Mauritania.[115] Mauritanian green hydrogen production is also a distinct possibility in the near future. Oil major BP is actively exploring various avenues for advancing green hydrogen initiatives in Mauritania. With a history of collaboration in gas projects, these two countries are now seeking to extend their partnership into the realm of green hydrogen.[116] In October 2023, the EU announced an initiative to support the development of a green hydrogen industry in Mauritania.[117]

Western Algeria boasts another substantial iron ore deposit known as Gâra Djebilet, which holds reserves of 3.5 billion tonnes. Much like other major iron ore reserves in Africa, such as Simandou, the remote location of this deposit necessitates the development of critical infrastructure, including railway and road networks. Algeria, having commenced production from this iron ore reserve with an initial output target of 2 to 3 Mtpa, now aims to significantly boost its iron ore production to a range of 40 to 50 Mtpa.[118]

Meanwhile, Saudi Arabia has launched a mining fund to invest in essential metals including copper, nickel, lithium and iron ore outside of the MENA region. Manara Minerals is a joint venture between Saudi state-owned miner Ma'aden and the PIF, which is prepared to invest up to US$15 billion in international assets to secure strategic material supply for the coming decades.[119] Mining investment is seen as a key element of Saudi Arabia's 'Vision 2030', an initiative designed to diversify the nation's economy away from oil and gas. In July 2023, Manara agreed to acquire a 10% stake in Vale's base metals unit – its first major investment in the global mining sector.[120]

[114] National Business. Emirates Steel explores JV option with Mauritanian mining company SNIM. 1 March 2022.
[115] ArcelorMittal. ArcelorMittal signs MoU with SNIM to evaluate the opportunity to jointly develop a pelletisation plant and DRI production plant in Mauritania. 25 May 2022.
[116] BP. bp and Mauritania to explore green hydrogen at scale. 8 November 2022.
[117] European Commission. Global Gateway: EU launches a Team Europe Initiative to develop green hydrogen in Mauritania and accelerate its energy transition. 24 October 2023.
[118] ZAWYA. Algeria to produce 40-50mln tonnes of iron in 2026. 18 April 2023.
[119] Financial Times. Saudi Arabia launches mining fund in effort to reduce oil dependency. 12 January 2023.
[120] Vale. Vale announces strategic partnership with Manara Minerals and Engine No. 1 to accelerate growth of energy transition metals business. 27 July 2023.

CCUS is no alternative to green hydrogen

It is already becoming apparent that CCUS will not play a major role in the decarbonisation of blast furnace-based steelmaking.[121] Agora Industry has compiled data that shows that steelmakers are backing hydrogen-ready DRI technology, not CCUS. While the 2030 pipeline of hydrogen-ready DRI plants has reached 84 Mt, projects for CCUS on blast furnace-based steel plants totals just 1 Mt.[122]

Amongst the numerous reasons why CCUS for blast furnaces looks unfeasible is a lack of carbon storage options close to integrated steel plants and the cost of transporting carbon. The MENA region may have some CCUS opportunity for DRI-based steelmaking given the availability of storage locations. Indeed, the region is home to the first (and only) industrial-scale CCUS installation at a steel plant – Emirates Steel Arkan's Al Reyadah project.

The Al Reyadah CCUS facility has a nominal capacity for capturing 0.8 Mt of CO_2 annually. This facility was commissioned in 2016 with the primary objective of capturing CO_2 and transporting it approximately 43km away for use in EOR operations. Despite the fact that Emirate Steel Arkan has operated this plant for more than six years, detailed performance data remains undisclosed to the public. However, Emirates Steel Arkan disclosed that only 30% of the CO_2 produced by the DRI plant was captured in 2022.[123]

Emirates Steel Arkan's new HBI export project with JFE Steel and Itochu also intends to use CCUS for EOR.[124]

EOR enables the production and combustion of more fossil fuels, so this is clearly not a solution for emissions reduction or the development of a truly green steel industry. Even when captured carbon is not used for EOR, emissions still occur because the track record of CCS demonstrates that the technology only captures a fraction of total carbon emitted. Demand for green steel is rising, led by car manufacturers, and it seems highly likely that steel customers will increasingly want accurate standards that define green steel and will not want fossil fuels to be part of their supply chains.

Some nations look likely to push for an increased role for CCUS at the COP28 climate conference in November 2023.[125] However, the technology's poor track record over decades strongly suggests that it isn't going to be a key decarbonisation solution. A September 2022 IEEFA report found that underperforming carbon capture projects considerably outnumber successful projects globally, and by large margins, with both the technology and regulatory frameworks found wanting.[126]

Another major CCUS project disappointment can now be added to the growing list of carbon capture failures. Occidental Petroleum's Century project was to become the world's largest carbon capture facility when built in 2010. Captured carbon was to be used for EOR. The project never reached the level of capture it was designed for. Between 2018 and 2022, the capture rate was only 10% of its designed capacity. Occidental quietly sold the project in 2022 for a fraction of its construction cost.[127]

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[121] IEEFA. No, metallurgical coal is not a critical material…and carbon capture won't save it. 3 July 2023.
[122] Agora Industry. 15 Insights on the Global Steel Transformation. June 2023.
[123] Emirates Steel Arkan. Investor Presentation. March 2023.
[124] JFE Steel Corporation. JFE Steel, Emirates Steel and Itochu to Study Building Supply Chain of Ferrous Raw Material for Green Ironmaking with Low-carbon Emission. 1 September 2022.
[125] Financial Times. Saudi leads push to elevate carbon removal in UN climate science report. 21 March 2023.
[126] IEEFA Carbon capture: a decarbonisation pipe dream. 1 September 2022.
[127] Bloomberg. An Oil Giant Quietly Ditched the World's Biggest Carbon Capture Plant. 23 October 2023.

A September 2023 report on carbon capture costs by BloombergNEF stated that, though the technology was expected to play a role in steel decarbonisation, “we have yet to see meaningful projects announced, reflecting steelmaker’s preference towards other low-carbon solutions, such as hydrogen, in the short term.”[128]

Bloomberg NEF’s 2023 CCUS Outlook report, released in November, highlights a significant expansion in CCUS capacity by 2035 based on announced projects. However, it makes clear that CCUS plants will only be capturing 1.1% of current global annual emissions from industrial processes and fossil fuel combustion. BloombergNEF also sees that a lack of transport and storage capacity will be a major bottleneck holding back CCUS development.[129]

In its 2023 update to its Net Zero Roadmap, the IEA stated: “The history of CCUS has largely been one of underperformance.” The IEA significantly reduced the expected role of CCUS in steel production in the new update. In the original 2021 version of the roadmap, the IEA expected CCUS equipped processes to account for 6% of primary steel production by 2030 and 57% by 2050. In the 2023 update this has dropped to 3% and 37% respectively. IEEFA expects that the IEA will continue to scale down its expectations for steel CCUS as other technologies – most prominently green hydrogen-based DRI – leave it further behind.

Unlike modular solar and wind installations, each CCUS facility is different, meaning it is harder to find cost reductions as experience with the technology grows. As a result, after five decades of deployment, CCUS has not seen the significant price declines that renewable energy has.

Steelmakers in MENA will be better off backing the falling cost of green hydrogen production rather than working on uncertain and risky CCUS technology that will not produce sufficiently low-emissions steel for their customers in the future.

> **Steelmakers in MENA will be better off backing the falling cost of green hydrogen production rather than working on uncertain and risky CCUS technology that will not produce sufficiently low-emissions steel for their customers in the future.**

Blue hydrogen is not a solution

Concerns about the role CCUS can play in steel decarbonisation also apply to the production of blue hydrogen. Blue hydrogen is most commonly made from methane with some of the resulting carbon emissions captured. The Middle East is leading blue hydrogen and ammonia export developments with shipments destined for Asia.[130] However, countries like Japan and South Korea will eventually need to recognise that blue hydrogen is not as clean as its proponents claim.[131]

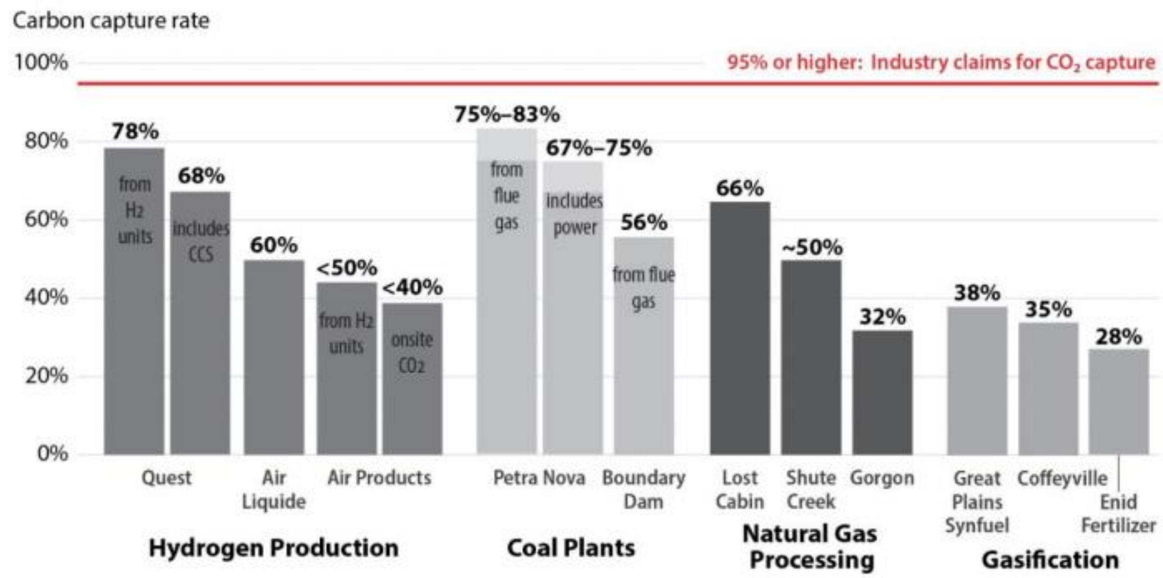
CCUS proponents often claim or assume very high rates of carbon capture are achievable, sometimes claiming up to 95%. However, there is no evidence from the historical performance of

[128] BloombergNEF. Carbon Capture Cost Breakdown: Industrial Sources. September 2023.
[129] BloombergNEF. CCUS Market Outlook 2023: Announced Capacity Soars by 50%. 6 November 2023
[130] S&P Global. Middle East’s clean hydrogen capacity plans double year on year. 23 September 2023.
[131] Nikkei Asia. Japan and South Korea must recognise blue hydrogen is not clean. 28 November 2022.

CCUS installations across various industries that such high capture rates are even close to achievable on a sustained basis. Most existing CCUS facilities do not publish data that would allow independent determination of actual capture rates. However, Figure 17 shows capture rates for the few projects where data is publicly available.[132]

A key academic study found that blue hydrogen may only produce 9%-12% less total greenhouse emissions than grey hydrogen.[133] Even if very high rates of carbon capture were achievable, blue hydrogen would still be a source of emissions via upstream methane leakage and emissions from methane used to power its energy-intensive production.

Figure 17: Real-world carbon capture rates at commercial-scale hydrogen production, coal-fired power plants, natural gas processing and gasification facilities



Source: IEEFA analysis based on publicly available data.

It seems possible that blue hydrogen capture rates may rise in the future. However, at the same time, green hydrogen costs are expected to decline significantly. BloombergNEF finds that green hydrogen will outcompete blue hydrogen on cost by the end of the decade: "Using Western-made alkaline systems, green hydrogen beats out blue hydrogen by 2030 in all but a handful of modelled markets."[134] Wood Mackenzie forecasts that green hydrogen will dominate all other hydrogen sources combined, "We expect the green hydrogen market to dwarf all others, so that they account for less than 20% of the total hydrogen market by 2050."[135] Sumitomo-Mitsui Banking Corporation sees green hydrogen closing the price gap with blue hydrogen before moving on to outcompete grey hydrogen; it sees the NEOM Green Hydrogen Project in Saudi Arabia as a model for other such projects going forward.[136]

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[132] IEEFA. Blue Hydrogen: Not Clean, Not Low-Carbon, Not a Solution. September 2023
[133] Energy Science & Engineering. *Howarth and Jacobson*. How green is blue hydrogen? 12 August 2021.
[134] BloombergNEF. Green Hydrogen to Undercut Gray Sibling by End of Decade. 9 August 2023.
[135] Wood Mackenzie. Decoding the hydrogen rainbow. November 2023
[136] S&P Global. Clean hydrogen industry's scale, investments advance globally: Sumitomo. 27 October 2023.

Global green iron competition is already rising

The MENA region has a significant opportunity to become a global green iron and steel leader, with a burgeoning green iron export industry, if it can become an early adopter of green hydrogen in the sector. There is already early interest in investment in DRI production and export projects in the region. However, as Wood Mackenzie notes, other countries such as Australia and Brazil also have an opportunity here and steelmakers and iron ore producers are already eyeing low-carbon iron developments in these locations.[137] Global competition to lead the iron and steel industry into a restructured technological and trade environment is already growing.

In Australia, the key iron ore mining centre in the Pilbara region is well suited to the production of green hydrogen because of both its renewable energy resources and the presence of existing road and power infrastructure.[138] Australia, the world's largest iron ore producer and exporter, and specifically the giant iron ore miners in the Pilbara can play a major role in green iron production if they act fast.[139]

However, most Pilbara iron ores have a distinct disadvantage compared with higher-grade ores in other parts of the world.[140] DRI-based iron and steelmaking processes currently require a high grade of iron ore with at least 67% Fe content. Most of the Pilbara's commercial deposits contain between 56% and 62% Fe.[141]

Australia's big iron ore miners are developing technology that would allow the use of lower-grade Pilbara iron ore in DRI-based operations. Rio Tinto has been investigating the use of a melting step that could see Pilbara iron ore used in DRI-based steelmaking, with Australian steelmaker BlueScope since 2021.[142] BHP is working with Hatch to design a pilot electric smelting furnace (ESF) that can allow the use of BHP's Pilbara iron ore in a DRI-based process.[143] Fortescue is working with Mitsubishi Corp and Primetals Technologies on the use of its iron ores in the latter's HYFOR DRI process for net zero carbon ironmaking.[144]

The Minerals Resources Institute of Western Australia (MRIWA) recently found that a shift towards the production and export of HBI is a natural extension of Western Australia's current place in the global steel value chain and would allow the state to capture additional value without the infrastructure investment to produce steel itself.[145]

Green hydrogen-based HBI will be cost-competitive with its fossil fuel-based equivalent before green steel, according to MRIWA, such that green iron exports (in the form of HBI) can be an aspirational target for Western Australia in the medium term. The MRIWA finds that green hydrogen-based HBI

[137] Wood Mackenzie. Metamorphosis: how decarbonisation is transforming the iron and steel industry. October 2023.
[138] International Journal of Hydrogen Energy. *Changlong Wang, Stuart D.C. Walsh, Zhehan Weng, Marcus W. Haynes, Daisy Summerfield, Andrew Feitz*. Green steel: Synergies between the Australian iron ore industry and the production of green hydrogen. 18 May 2023.
[139] IEEFA. Opportunities and challenges for the Pilbara amid the accelerating steel technology transition. 27 March 2023.
[140] IEEFA. Iron ore quality a potential headwind to green steelmaking: Technology and mining options are available to hit net-zero targets. 28 June 2022.
[141] Minerals Research Institute of Western Australia. Western Australia's Green Steel Opportunity. 19 June 2023.
[142] Rio Tinto. Rio Tinto and BlueScope to explore low carbon-steelmaking pathways. 29 October 2021.
[143] BHP. BHP and Hatch commence design study for an electric smelting furnace pilot. 23 March 2023.
[144] Fortescue. Fortescue, Primetals Technologies, and voestalpine to jointly evaluate groundbreaking green ironmaking plant. 20 December 2022.
[145] Minerals Research Institute of Western Australia. Western Australia's Green Steel Opportunity. 19 June 2023.

will become economic once green hydrogen reaches A$4/tonne (in today's dollars). It finds the current delivered price for green hydrogen in Western Australia is A$7/tonne.

In its assessment of options for the Western Australian iron ore industry to position itself for a decarbonising steel sector, the MRIWA finds that, "pathways which involve the development of intermediate iron products, such as HBI, are the most prospective for Western Australia."[146]

Major global steelmakers are already considering shifting iron production to Western Australia. POSCO is planning a US$40bn investment in Australia with US$28bn earmarked for green hydrogen production and a further US$12bn for the production and export of green HBI.[147] In December 2022, the Western Australian government granted POSCO a land lease within the Boodarie Strategic Industrial Area for its HBI project, and in October 2023 plans for the development were submitted for environmental approval.[148,149] POSCO is also developing a major green hydrogen project in Western Australia with Engie to supply the green steel project.[150]

Nippon Steel has also stated that it is considering both Australia and Brazil as possible green iron ore steel project locations.[151]

In addition, China Baowu Group – the world's largest steelmaker – is considering a major green iron project in Western Australia.[152] However, in a sign of the growing competition Australia faces as steelmakers start thinking about the offshoring of green iron production, China Baowu is also looking at South America, the Middle East and Africa as possible green iron/steel investment destinations.

Brazil is the most likely South American country that China Baowu is considering. As the world's largest producer of high-grade iron ore, Brazil is the natural destination for green iron investment in South America and possesses significant potential to solidify its position due to its abundant resources.

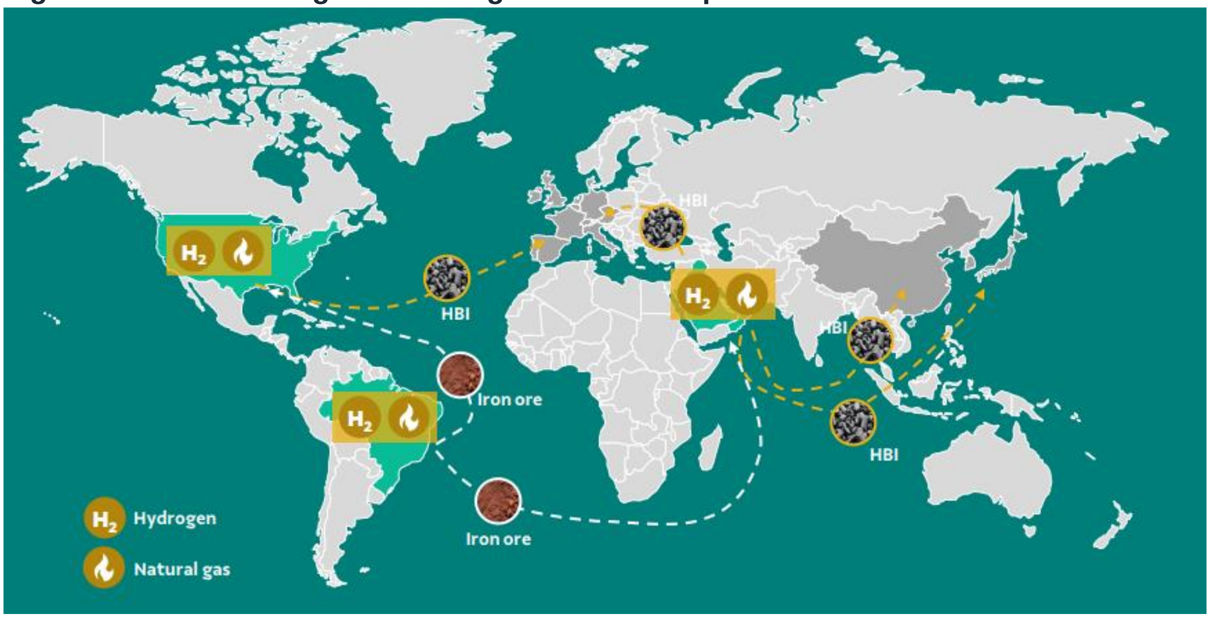
Vale – the world's leading producer of DR-grade iron ore – projects that by 2030, global DRI/HBI production will increase 55% to 200 Mtpa, and demand for seaborne DR-grade iron ore will more than double to 110 Mtpa.[153] Vale sees DR-grade ore demand continuing to rise beyond 2030 while demand for benchmark 62% (blast furnace-grade) iron ore has now entered permanent decline. The suitability of Brazil's high-grade iron ore for the type of low-carbon DRI-based iron and steelmaking that will become increasingly prevalent is already being demonstrated. In May 2023, Vale announced it had signed a MoU with GravitHy to jointly evaluate a hydrogen-based DRI plant in France. The intention is to begin production as soon as 2027, with Vale supplying the DR-grade iron ore. The DRI produced is planned to be used directly or traded globally as HBI.[154]

In addition to planning 'Mega Hubs' in the Middle East where Vale's high-grade iron ore fines will be agglomerated and used to produce iron for domestic use and export, the company is also considering similar developments in both Brazil and North America (Figure 18).

[146] Minerals Research Institute of Western Australia. Western Australia's Green Steel Opportunity. 19 June 2023.
[147] POSCO. POSCO Group CEO, Jeong-woo Choi, Meets the Prime Minister of Australia, Anthony Albanese, to Discuss Future Eco-friendly Projects. 7 December 2022.
[148] POSCO. POSCO promotes the preemptive acquisition of low-carbon steel raw materials in Australia. 7 March 2023.
[149] The West Australian. Plans for Gina Rinehart-backed Pilbara hot briquette iron plant lobbed to EPA by South Korea's Posco. 9 October 2023.
[150] RenewEconomy. Engie and Posco pursue huge green hydrogen project in Pilbara to feed green steel. 15 October 2023.
[151] Bloomberg. Green Steel Challenges Could Trigger Overseas Push for Posco. 25 September 2023.
[152] Australian Financial Review. World's biggest steel maker looks to WA for massive green investment.12 May 2023.
[153] Vale. Iron Solutions webinar Decarbonization of steel and impacts in iron ore supply. 14 April 2023.
[154] Vale. Vale and GravitHy sign MoU to develop a plant dedicated to direct reduction iron ore briquettes production. 9 May 2023.

In September 2023, Vale signed an agreement with the Port of Açu to investigate development of a Mega Hub in Brazil that will produce HBI via gas-based DRI that could later switch to green hydrogen. Vale CEO Marcello Spinelli stated: "We believe that Brazil has great potential to be a hub for low-carbon steelmaking. We have high-quality iron ore, abundant natural gas reserves and the potential to develop green hydrogen. As a Brazilian company, Vale seeks to partner with ventures that contribute in this direction. We want to be the driving force behind Brazil's 'neo-industrialisation', which will be based on green industry."[155]

Figure 18: Potential regions for Mega Hubs development



Source: Vale

Also in September 2023, it was announced that Vale and H2 Green Steel will together examine the development of green industrial hubs in Brazil and North America in which green hydrogen and green iron would be produced using Vale's iron ore.[156] China Baowu has also reportedly held talks with Vale about future cooperation on mineral resources and low-carbon metallurgical technology.[157]

H2 Green Steel is also eyeing Canada as a location to produce green iron, based on its high-grade iron ore and access to clean energy. In August 2023, Rio Tinto announced a multi-year agreement to supply DR-grade iron ore pellets to H2 Green Steel in Sweden; which is aiming to produce steel using green hydrogen from 2025. This will be supplied from Rio's Canadian iron ore operations. The deal will also see Rio buy and on-sell HBI from H2 Green Steel.[158]

Then in October 2023, it was reported that H2 Green Steel was in talks with Canadian governments about a potential €3-€6 billion investment for a plant in Quebec. The focus is likely to be the production of truly green iron using green hydrogen, which would then be exported.[159]

[155] Vale. Vale and Port of Açu sign agreement to develop a Mega Hub for the decarbonisation of steelmaking. 26 September 2023.
[156] Vale. Vale and H2 Green Steel sign agreement to study the development of green industrial hubs in Brazil and North America. 6 September 2023.
[157] Reuters. China Baowu wants new models of cooperation with Vale. 4 August 2023.
[158] Rio Tinto. Rio Tinto and H2 Green Steel partner to accelerate the green steel transition. 9 August 2023.
[159] Bloomberg. Swedish Industrialists Explore $6 Billion Green Steel Project in Canada. 9 October 2023.

Although the MENA region has numerous advantages when it comes to low-carbon steel production and the potential to lead global growth in green iron exports, steelmakers and iron ore miners are also looking at other locations. Furthermore, some of these plans involve early adoption of green hydrogen in ironmaking. The fast-developing green iron trade is starting to look like a race between competing regions. The MENA region has a chance now to increase its ambition and push for early green hydrogen use in its steel sector to meet the growing demand for truly green iron and steel.

MENA's iron and steel opportunity

The growing global competition in the nascent green iron exports sector is further indication that the steel technology transition away from fossil fuels is accelerating. With some nations in the MENA region keen to diversify away from over-reliance on oil and gas, the development of a truly green steel industry based on green hydrogen rather than gas or blue hydrogen is an opportunity to help achieve this. Steelmaking developments in the region should be built hydrogen-ready as far as possible, and the region should make the most of its advantage in low-cost renewable energy by adopting green hydrogen for iron and steel production as quickly as possible.

By moving quicker than other potential green iron producers such as Brazil, Canada and Australia, the MENA region can become a global leader in green iron exports to key regions of growing demand. The early adoption of green hydrogen can also decarbonise steel made for domestic use.

MENA's steel sector is already expanding with numerous plans for new DRI-based plants that will initially run on gas. Although gas-based DRI is less carbon-intensive than the coal-based blast furnaces that dominate steelmaking globally, this expansion will still add to MENA nation's domestic carbon emissions at a time when pressure to increase emissions reduction ambition is increasing ever more.[160]

A refocus from green hydrogen exports towards more domestic use can help the region achieve its domestic emissions reduction targets, as well as positioning its steelmakers for the global iron and steel sector of the near future.

> **A refocus from green hydrogen exports towards more domestic use can help the region achieve its domestic emissions reduction targets, as well as positioning its steelmakers for the global iron and steel sector of the near future.**

[160] S&P Global. Saudi Arabia could achieve net-zero before 2060: energy minister. 9 October 2023.

Appendix 1

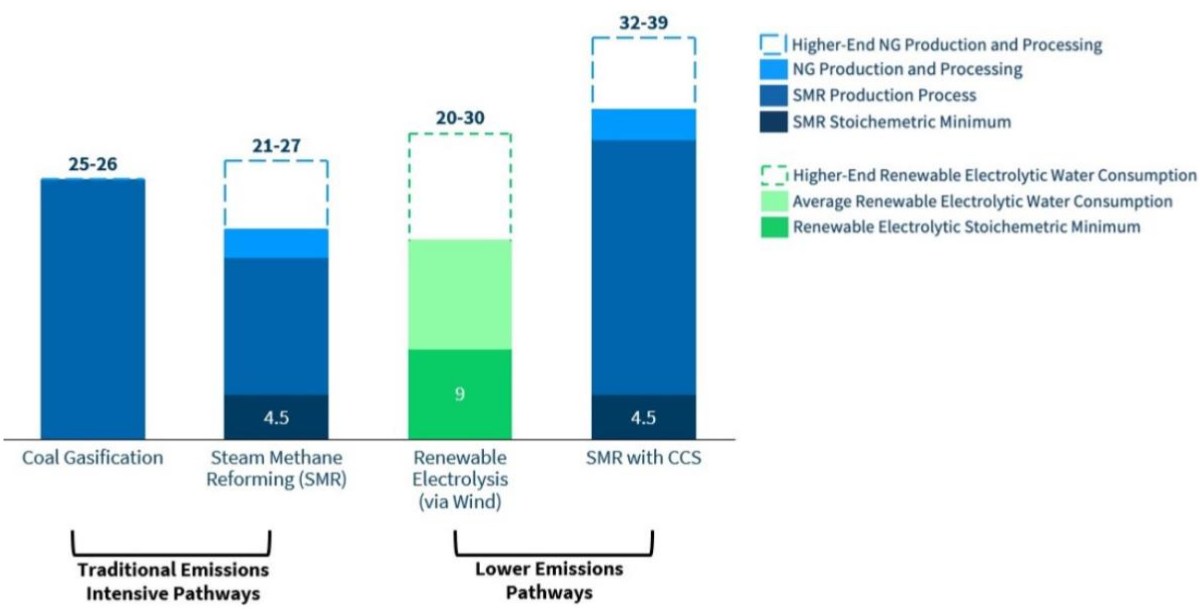
Potential headwinds

Water scarcity

The MENA region faces significant water scarcity challenges, making the provision of fresh water for various industrial purposes a key task. Concerns have arisen regarding the feasibility of utilising electrolysis-based technology to produce green hydrogen in this water-scarce environment.

In essence, the environmental impact of generating green hydrogen remains relatively minimal when compared with alternative methods of hydrogen production. From a technical standpoint, the production of one kilogram of hydrogen typically requires nine litres of fresh water. Accounting for all aspects such as cooling and purification, the water consumption falls within the range of 20-30 litres per kilogram, which is on par with conventional fossil fuel-based technologies, and notably better than the water-intensive process associated with blue hydrogen production using steam methane reforming (SMR) coupled with CCUS (Figure 19).[161] In its 2023 World Energy Outlook, the IEA noted that, though an increase in green hydrogen production in the Middle East would lead to higher water demand, this would be offset by lower demand resulting from reduced need for fossil fuels.[162]

Figure 19: Water consumption of various hydrogen production pathways (litres /kg H_2)



Source: RMI

[161] RMI. Hydrogen Reality Check: Distilling Green Hydrogen's Water Consumption. 2 August 2023.
[162] IEA. World Energy Outlook 2023. October 2023.

> **Although an increase in green hydrogen production in the Middle East would lead to higher water demand, this would be offset by lower demand resulting from reduced need for fossil fuels.**

Assuming production of one kilogram of hydrogen requires 20 litres of water, and 51kg of hydrogen is needed for one tonne of steel, the hydrogen value chain could potentially add one cubic metre to the water requirement for green steel production. Compared with the current average water consumption for steel mills, which is four cubic metres per tonne, and considering the water scarcity in MENA, supplying water for the integrated plant based on H_2-DRI-EAF needs precise planning.[163] Furthermore, producing iron with green hydrogen emits water as a byproduct that can be reused to reduce the total water consumption.

While the MENA region does indeed offer significant potential for cost-effective hydrogen production, a considerable area of that region is unsuitable due to its pronounced water scarcity.[164] In arid regions like MENA, freshwater resources are limited, necessitating a heavy reliance on desalination technology to extract salt from seawater for various uses. To address the water demand in MENA's steel industry, there is potential for harnessing wastewater usage and advancing water recycling systems as primary solutions.

However, there are already plans to increase seawater desalination capacity in the Middle East to tackle water security. New hydrogen production plans in Oman are based on production from desalinated water.[165]

CAPEX challenges

As with the energy transition in other sectors, deep steel decarbonisation entails new investment in renewables and hydrogen. Given the intermittent nature of renewables and the continuous demand for electricity and hydrogen in steel mills, it is essential to oversize both renewable energy sources and electrolysers. Additionally, battery and hydrogen storage facilities are necessary to ensure a consistent supply of electricity and hydrogen, thereby allowing the plant to operate continuously without interruptions. The incorporation of these oversizing measures results in an increased capital cost for the construction of new steel plants.

The construction of renewable energy capacity sufficient to supply green hydrogen for steel is the larger part of required investment. The Minerals Research Institute of Western Australia (MRIWA) has found that scaling up the power facilities (including 50/50 solar and wind plus batteries) required to produce green hydrogen for one million tonnes of crude steel in Australia requires A$5.6 billion (nearly US$3.5 billion), which is more than the total investment needed for a pelletising facility, DRI shaft furnace, EAF and hydrogen electrolysers.[166]

[163] Emirate Steel Arkan. Sustainability report 2022. Page 100; and ArcelorMittal. ArcelorMittal Integrated Annual Review 2022. Page 37.
[164] IRENA. Global hydrogen trade to meet the 1.5°c climate goal. Part III. July 2022. Page 40.
[165] IEA. World Energy Outlook 2023. October 2023.
[166] MRIWA. Western Australia's green steel opportunities. 20 June 2023.

However, current green hydrogen plans in the MENA region are focused on exports– an approach that appears to be structurally challenged on cost. If more of the planned production from these projects was earmarked for domestic use, this would decrease the amount of new renewable energy capacity required.

Project finance

As it stands, green hydrogen and ammonia projects are being held back by a lack of offtake agreements required for them to be bankable, in part because potential off-takers will want to wait for the cost of green hydrogen production to come down as expected.[167]

The NEOM Green Hydrogen Project in Saudi Arabia achieved financial close in May 2023 with US$6.1 billion of non-recourse financing from 23 financial institutions.[168] This came on the back of a 30-year offtake agreement covering all of the plant's production. However, in this case the off-taker is Air Products, one of the project's joint venture participants.

Increased focus on domestic offtake for planned green hydrogen capacity may help underpin off-taker demand. Key sectors such as local fertiliser and chemical producers, refineries, and steel companies are well positioned to utilise the available green hydrogen capacity in MENA.

Green iron and steel projects are now backed by banks and credit guarantors.[169] The demand for green steel is experiencing a significant surge, primarily driven by car makers and white goods producers aiming to reduce carbon emissions throughout their value chain.

Last year, European financial institutions provided support to H2 Green Steel which is developing an industrial-scale steel project based on green hydrogen. The company has successfully secured supply contracts spanning various industries for a duration of up to seven years. H2 Green Steel has presold 1.5 Mt of its total capacity of 2.5 Mt, with producers like Cargill and others around the world engaging the company for green steel supply.[170,171] Mercedes, one of the early investors in H2 Green Steel, has now signed a binding supply contract for 50 Kt of green steel per annum.[172] In November 2023, H2 Green Steel signed an agreement with Porsche to supply the carmaker with green steel from 2026.[173]

An expansion in the steel industry in the MENA region is already underway, though this is largely limited to countries like Saudi Arabia, Oman and the UAE. These nations not only have an existing and expanding iron ore supply, but they are also considered lower-risk investment destinations than other nations in the region, such as in North Africa.

The Weighted Average Cost of Capital (WACC) can account for 20-50% of LCOE in utility-scale PV projects according to the IEA.[174]

[167] S&P Global. Blue ammonia prices firm, lack of green offtake deals hampers FIDs. 20 October 2023.
[168] NEOM. NEOM Green Hydrogen Company completes financial close at a total investment value of USD 8.4 billion in the world's largest carbon-free green hydrogen plant. 22 May 2023.
[169] IEEFA. Green finance has begun to flow into green steel funding. 11 November 2022.
[170] H2GreenSteel. H2 Green Steel has pre-sold over 1.5 million tonnes of green steel to customers. 10 May 2022.
[171] H2GreenSteel. Cargill and H2 Green Steel sign multi-year offtake contract to supply near zero-emission steel. 19 June 2023.
[172] H2GreenSteel. Mercedes-Benz and H2 Green Steel announce agreements in both Europe and North America. 7 June 2023.
[173] Porsche. Porsche plans to use CO2-reduced steel in some of its vehicles starting in 2026. 2 November 2023
[174] IRENA. World Energy Transitions Outlook 2022.

Table 4: Real after-tax WACC assumptions for 2021

Country	Solar PV	Onshore Wind
Algeria	11%	11.4%
Egypt	8.8%	8.8%
Iran	11.40%	11.5%
Iraq	9.60%	9.60%
Israel	3.70%	5.0%
Jordan	8.20%	8.20%
Kuwait	5.30%	5.30%
Lebanon	21.00%	21.0%
Morocco	6.70%	6.10%
Saudi Arabia	6.20%	6.2%
Tunisia	9.3%	9.3%
United Arab Emirates	5.60%	5.60%
Yemen	17.20%	17.20%

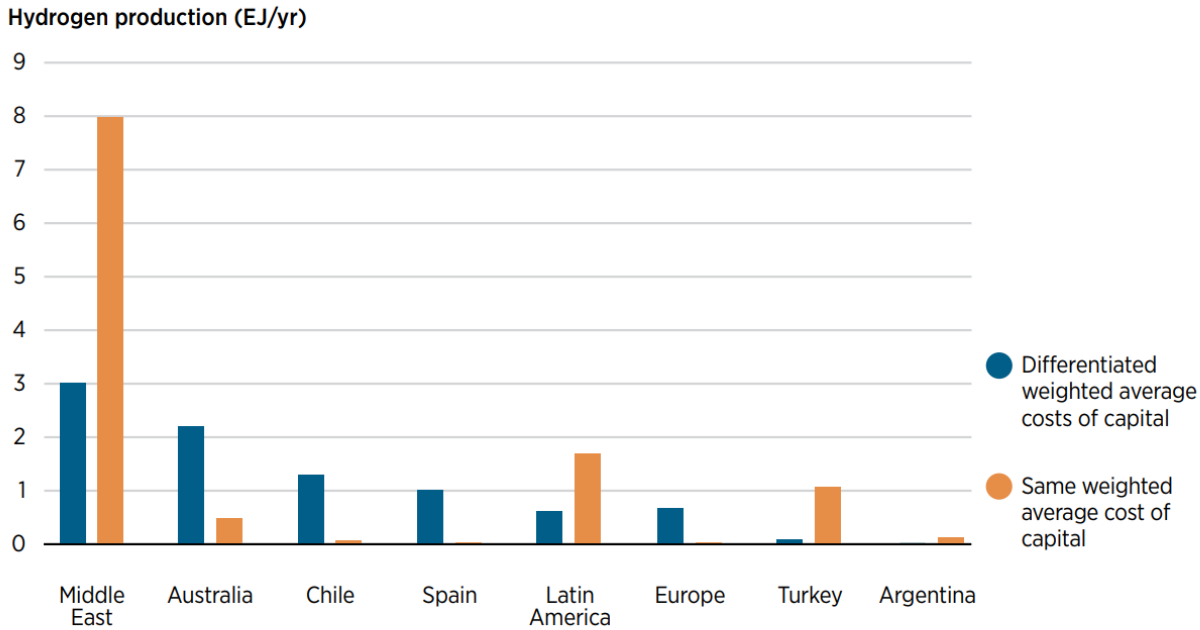
Source: IRENA.[175]

IRENA conducted a sensitivity analysis on the impact of the WACC on hydrogen trade. To achieve this, it simulated a scenario where the WACC remained constant across all countries and regions to highlight the quality of resources rather than the cost of project financing.

In this scenario, the Middle East (excluding Saudi Arabia) would nearly triple its hydrogen production. On the other hand, countries like Australia and Chile might experience substantial reductions in hydrogen output as their advantage in lower cost of capital is removed and their distance from potential export markets has a greater impact.[176] (Figure 20)

[175] IRENA. The cost of financing for renewable energy: data appendix.
[176] IRENA. World Energy Transitions Outlook 2022. Page 239

Figure 20: Difference in green hydrogen production in selected locations in 2050 due to changes in WACC



Source: IRENA.

Despite challenges regarding the cost of capital, renewable energy in North Africa is on the rise and there are plans for green hydrogen production. Europe has been turning to North Africa to help it reduce its reliance on energy imports from Russia, with plans for more fossil fuel and renewable electricity imports. Green hydrogen may also now be added to the list.

However, as it stands the usual model of European resource extraction from African nations looks set to continue and it is unclear that North African nations will be able to do what some nations in the Middle East can do – using domestic resources to export value-added materials such as green iron and steel.

Fossil fuels still dominate MENA power grid

Despite MENA's excellent renewable energy resources, the region's power systems remain dominated by fossil fuel-based electricity generation. According to data from Ember in 2021 (figures for 2022 are not available for all MENA nations), the MENA region had a weighted average CO_2 emission of 509 gCO_2/kWh, whereas the global average was 442 gCO_2/kWh. Within the EU and G7, the averages were lower at 262 and 343 gCO_2/kWh, respectively.[177]

Meanwhile, potential competitors to the MENA region in early green iron and steel production have much greener power grids that will allow projects to produce green hydrogen by using grid power, thereby avoiding the need for substantial investment in dedicated renewable energy capacity.

[177] Ember. Yearly electricity data. 12 September 2023.

Companies like H2 Green Steel and Vale are developing and planning green iron and steel projects in Sweden, Quebec and Brazil that have significant hydro power generation.

In Australia, the most advanced green steel plan is in the state of South Australia, where the power grid is now dominated by wind and solar generation. South Australia is targeting 100% renewable energy by 2030 but recently achieved 99.8% net renewable power generation over a seven-day period.[178] In October 2023, the South Australian government named preferred partners for a 250MW hydrogen electrolyser – the biggest of its type in the world – which will connect to the grid and use excess renewable electricity in the middle of the day to make hydrogen.[179] Some of the hydrogen is to be supplied to a local steelmaker that plans to shift from blast furnace-based production to green hydrogen-DRI.[180]

> **Although renewable energy capacity is expanding in the region, the dominance of fossil fuels in MENA power grids means that green hydrogen can only be produced via dedicated solar or wind installations, not off the grid as in other geographies.**

Although renewable energy capacity is expanding in the region, the dominance of fossil fuels in MENA power grids means that green hydrogen can only be produced via dedicated solar or wind installations, not off the grid as in other regions. This increases investment requirements. Where other MENA steel plant power demand outside of green hydrogen production is served by the grid, this will also entail Scope 2 carbon emissions. With the growing focus on renewables for green hydrogen production, the MENA region cannot neglect wind and solar additions for grid decarbonisation as well.

178 RenewEconomy. South Australia grid operates at 99.8 per cent wind and solar over past seven days. 27 October 2023.
179 RenewEconomy. South Australia names winners of world-leading hydrogen tender in race to 100 pct renewables. 22 October 2023.
180 Liberty Steel. LIBERTY Steel in Whyalla announces the phase out of coal-based steelmaking with purchase of a low carbon emissions electric arc furnace. 4 April 2023.

Appendix 2

Table 5: MENA Hydrogen Projects

Country	Project Name	Status	Date Online	Announced Size	Product
Djibouti	Amea Power - Ammonia project	Concept	--	1 GW or 700 kt NH_3/y	Ammonia
	MoU CWP - Ministry of Energy and Natural Resources	Concept	--	--	H_2
	MoU Fortescue Future Industries-Djibouti	Concept	--	--	H_2
Egypt	ACME SCZONE Green Ammonia Plant	Concept	--	2.2 Mt H_2/y (production)	Ammonia
	Ain Sokhna ammonia project	Feasibility study	2027	800 kt NH_3/y production	Ammonia
	Ain Sokhna plant, Suez Canal Economic Zone (SCZone), phase 1	Feasibility study	2026	140kt NH_3/y using 25kt H_2/y production	Ammonia
	Ain Sokhna plant, Suez Canal Economic Zone (SCZone), phase 2	Concept	--	350kt NH_3/y production	Ammonia
	BP Green hydrogen project	Concept	--	--	H_2
	EBIC - Ammonia plant	Feasibility study	2024	100MW	Ammonia
	EEHC - Siemens MoU	Concept	--	100-200 MW	H_2
	Egypt Ministry of Electricity and Renewable Energy	Feasibility study	--	--	H_2
	Fortescue Future Industries - Egypt	Concept	--	9.2GW	H_2
	Globeleq green hydrogen project, completion	Concept	--	3.6GW	H_2
	Globeleq green hydrogen project, phase 1	Concept	--	100MW	Ammonia
	Jindal - Suez Canal Economic Zone authority green steel project	Concept	--	5 Mt steel/y (production)	H_2
	KIMA - Aswan electrolyser	Decommissioned	2000	165MW	Ammonia
	Maersk SCZONE	Feasibility study	--	480kt H_2/y production	H_2
	Masdar Hassan Allam green hydrogen, phase 1	Feasibility study	2026	100 kt MeOH/y production	MeOH
	Masdar Hassan Allam green hydrogen, phase 2	Concept	2030	4GW electrolysis, 2.3 Mt NH_3/y	Ammonia
	Petrofac Ain Sokhna Ammonia project	Feasibility study	--	125 kt NH_3/y production	Ammonia
	ReNew Power - Egypt MoU, Ammonia phase 1	Concept	2025	100 kt NH_3/y production	Ammonia
	ReNew Power - Egypt MoU, Ammonia phase 2	Concept	2029	1.1 Mt NH_3/y production	Ammonia
	ReNew Power - Egypt MoU, Hydrogen, phase 1	Concept	2025	20 t H_2/y production	H_2
	ReNew Power - Egypt MoU, Hydrogen, phase 2	Concept	2029	200 kt H_2/y production	H_2
	Scatec e-Methanol	Concept	--	60 MW electrolyser - 40 kt MeOH/y	MeOH
	Scatec Green Ammonia	Concept	2025	1 Mt NH_3/y production	Ammonia
	Total Eren, Enara green ammonia, phase 1	Concept	--	300 kt NH_3/y production	Ammonia

	Total Eren, Enara green ammonia, phase 2	Concept	2030	1.5 Mt NH_3/y production	Ammonia
	Votalia - Taqa Arabia	Concept	--	100MW	H_2
			--	1GW	H_2
	Waste-to-hydrogen East Port Said	Feasibility study	2026	300 kt H_2/y	H_2
Iran	Taleghan solar hydrogen energy system	Operational	2009	0.2MW	H_2
Jordan	Ammonia project Jordan	Concept	--	530MW or 200k t NH_3/year	Ammonia
Lebanon	Power plant in Lebanon for a Power Plant Cooling application	Operational	2018	0.114MW	H_2
Mauritania	Aman - Green Hydrogen Project - phase 1	Feasibility study	2030	--	Ammonia
	Aman - Green Hydrogen Project - phase 2	Feasibility study	2035	10 Mt NH_3 production	Ammonia
	Mauritania - Green Ammonia project - phase 1	Concept	2028	400MW or 0.28-0.3 Mt NH_3 production	Ammonia
			--	10GW or 8 Mt NH3 production	Ammonia
	Mauritania & BP- Nassim project	Concept	--	10 Mt NH_3 production	H_2
	Project Nour	Feasibility study	2030	1.2 MtH_2/year capacity	H_2
Morocco	Amun, phase 1	Concept	--	--	H_2
	Amun, phase 2	Concept	--	--	H_2
	Guelmim-Oued Noun project	Concept	2027	--	H_2
	HEVO-Morocco	Feasibility study	2026	31kt H_2/y production	Ammonia
	Masen - KfW	Feasibility study	2025	100MW	H_2
	OCP Group Ammonia project	Concept	2027	1 Mt NH_3/y production	Ammonia
	OCP Group demo project	FID/Construction	--	4t NH_3/day production	Ammonia
	Saipem and Alboran Hydrogen (1 plant)	Concept	--	--	H_2
Oman	BP Alternative Energy Investments project, Duqm	Feasibility study	--	150 kt H_2/y production	H_2
	BP Alternative Energy Investments projects, Dhofar	Feasibility study	--	150 kt H_2/y production	H_2
	Green Hydrogen and Chemicals SPC, phase I (former ACME-Scatec Oman)	FID/Construction	2025	320MW	Ammonia
	Green Hydrogen and Chemicals SPC, phase II (former ACME-Scatec Oman)	Concept	--	1.2Mt NH_3/y production	Ammonia
	Green Hydrogen Oman (GEO), phase 1 (former Oman-Al Wusta green H_2 project)	Feasibility study	2028	150 kt H_2/y production	Ammonia
	Green Hydrogen Oman (GEO), phase 2 (former Oman-Al Wusta green H_2 project)	Feasibility study	2038	14GW	Ammonia
	H2 Industries waste to hydrogen plant	Concept	--	67 kt H_2/y	H_2
	H2Oman (Dhofar)	Concept	2030	1 Mt NH_3/y production	H_2
	Hydrogen project Duqm area	Concept	--	200 kt H_2/y production	H_2

	Hyport@Duqm, phase 1	Feasibility study	2026	500MW	Ammonia
	Hyport@Duqm, phase 2	Concept	--	1.5GW	Ammonia
	Omifco ammonia capture	Concept	--	3500t NH_3/d	Ammonia
	POSCO green ammonia plant	Feasibility study	2030	220kt H_2/y (production)	Ammonia
	SalalaH2	Feasibility study	2024	400MW	Ammonia
	Sohar Port, phase 1	Concept	2024	35MW	H_2
	Sohar Port, phase 2	Concept	--	350MW	H_2
	Sumitomo Oman	Concept	2025	0.3-0.4 kt H_2/y	H_2
	Sur hydrogen cluster	Feasibility study	2030	1.3GW	H_2
	Vale steel project	Concept	--	--	H_2
Saudi Arabia	KEPCO, Korea Southern Power, KNOC, Samsun, Posco	Concept	--	1.2Mt NH_3/d (production)	Ammonia
	NEOM Green Hydrogen Project	FID/Construction	2026	2GW - 650t H_2/d - 1.2Mt NH_3/y	Ammonia
United Arab Emirates	Abu Dhabi CCS Phase 1: Emirates Steel Industries - Al Reyadah CCUS	Operational	2016	800000 t CO_2/y	H_2
	Bee'ah waste-to-hydrogen	Concept	--	--	H_2
	Brooge Renewable Energy's (BRE) renewable ammonia plant	FID/Construction	--	600 kt NH_3/y production	Ammonia
	Engie - Masdar - Fertiglobe Abu Dhabi	Concept	2025	200MW	Ammonia
	Green hydrogen Project, Mohammad Bin Rashid Solar Park	Operational	2021	1.25MW	H_2
	Khalifa Industrial Zone Abu Dhabi (KIZAD) - phase 1	Feasibility study	2024	35kt NH_3/y production	Ammonia
	Khalifa Industrial Zone Abu Dhabi (KIZAD) - phase 2	Feasibility study	2026	200kt NH_3/y production	Ammonia
	Masdar City green H_2	FID/Construction	--	1000t H_2/y	Various
	MoU ADNOC, ENEOS, Mitsui, phase 1	Concept	--	200kt H_2/y, 50kt H2/y	H_2
	MoU BP - ADNOC	Concept	--	--	H_2
	MoU IHI-Enoc	Concept	2028	200kt NH_3/d (production)	Ammonia
	NWTN - CMEC Middle East green hydrogen plant	Concept	--	20MW	H2
	TA'ZIZ blue ammonia	FID/Construction	2025	1000 kt NH_3/y	Ammonia
	TAQA & Abu Dhabi Ports	Concept	--	100kt H_2/y capacity	Ammonia
	TAQA-Emirates Steel Green H_2	Concept	--	--	H_2

Source: IEA.[181]

[181] IEA. Hydrogen Production and Infrastructure Projects Database. (Last Updated October 2023)

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