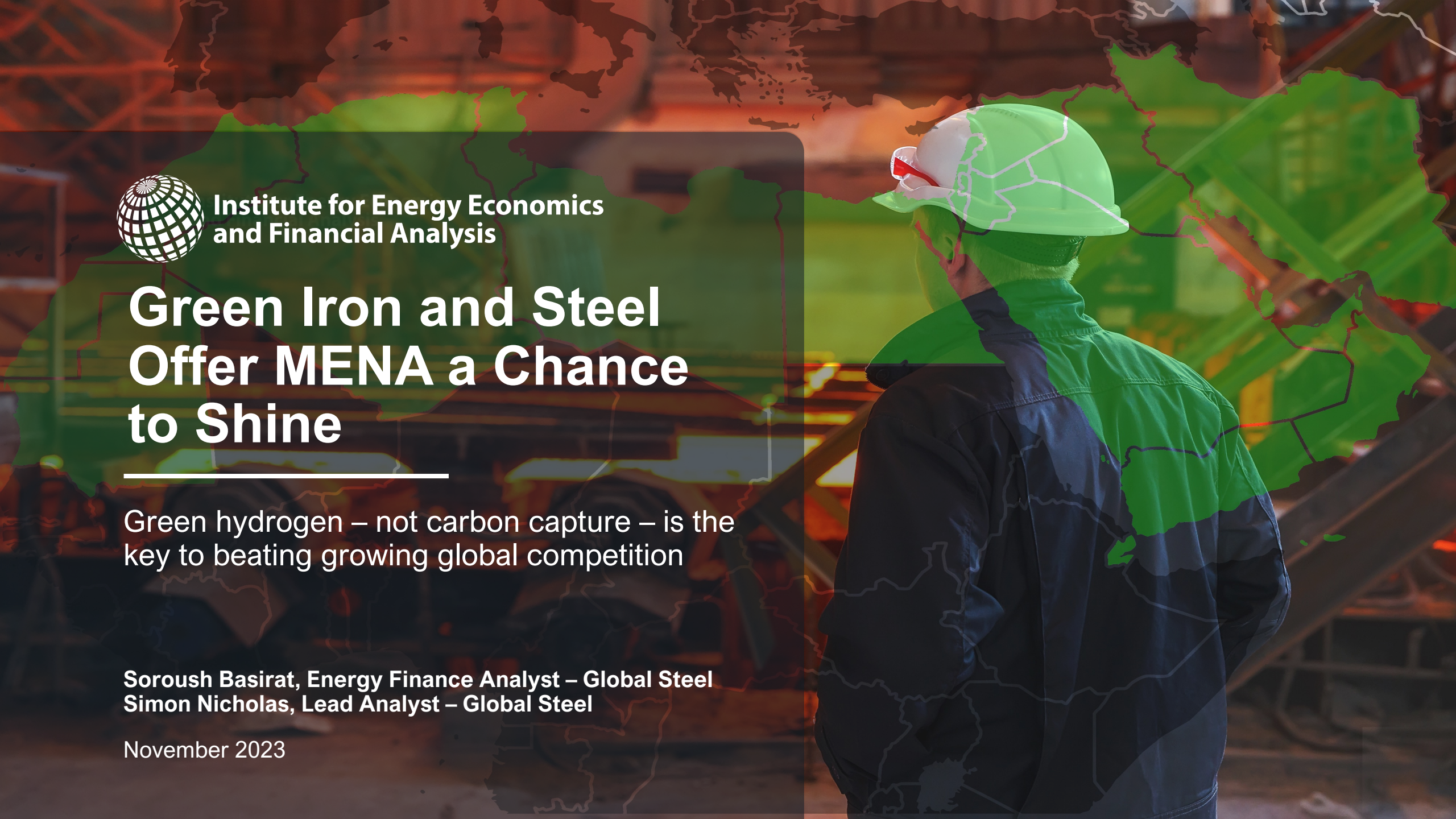

Institute for Energy Economics and Financial Analysis

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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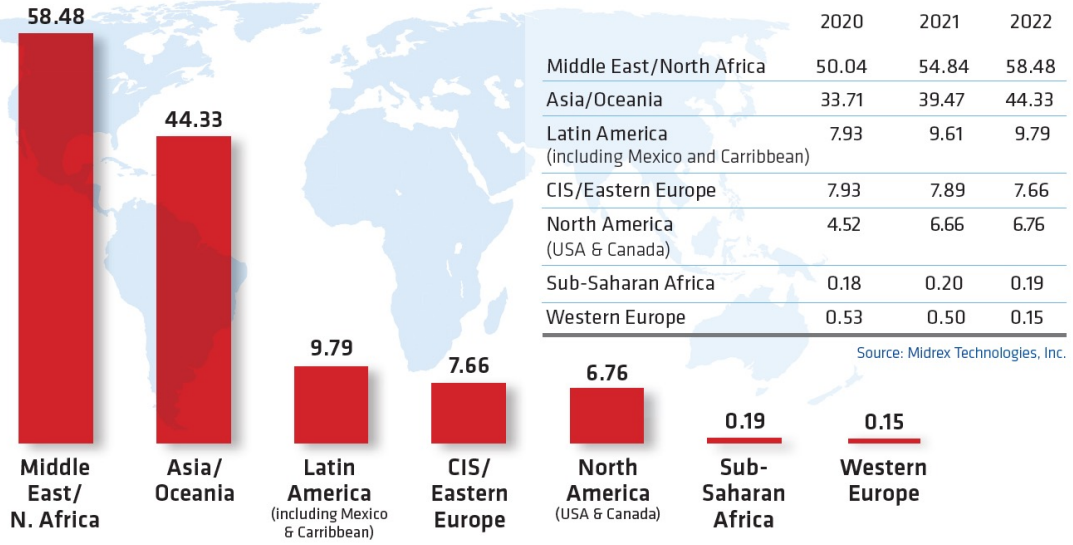
November 2023

Key Messages

- 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) technology.
- The poor record of Carbon Capture, Utilisation & Storage (CCUS) 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.

MENA Is a Hub for DRI Production

2022 World DRI Production by Region (Mt)



	2020	2021	2022
Middle East/North Africa	50.04	54.84	58.48
Asia/Oceania	33.71	39.47	44.33
Latin America (including Mexico and Carribbean)	7.93	9.61	9.79
CIS/Eastern Europe	7.93	7.89	7.66
North America (USA & Canada)	4.52	6.66	6.76
Sub-Saharan Africa	0.18	0.20	0.19
Western Europe	0.53	0.50	0.15

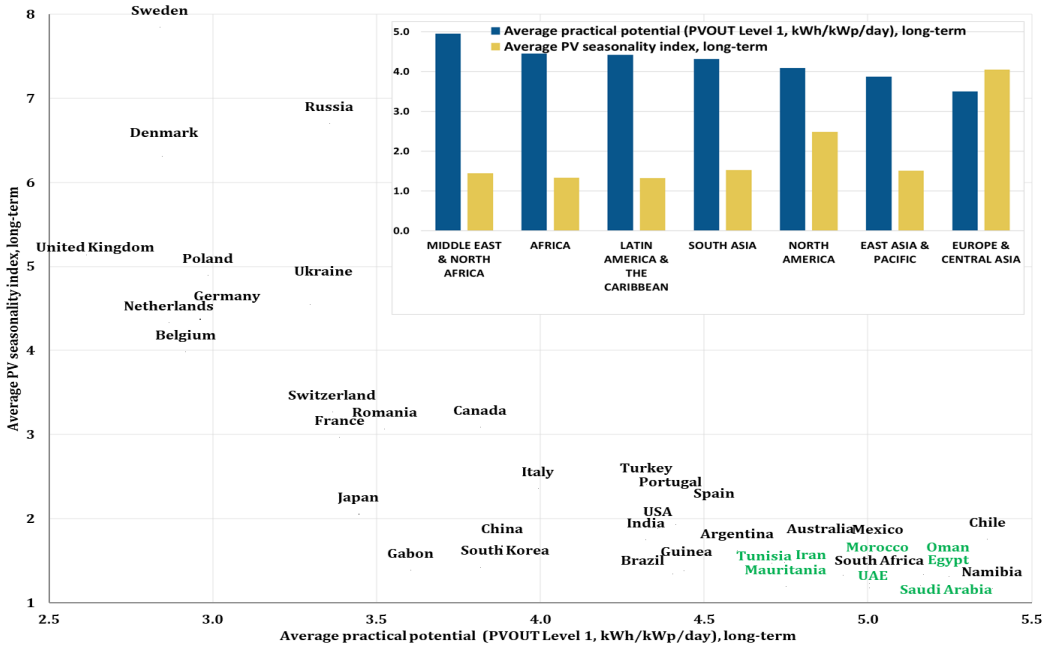
Source: Midrex Technologies, Inc.

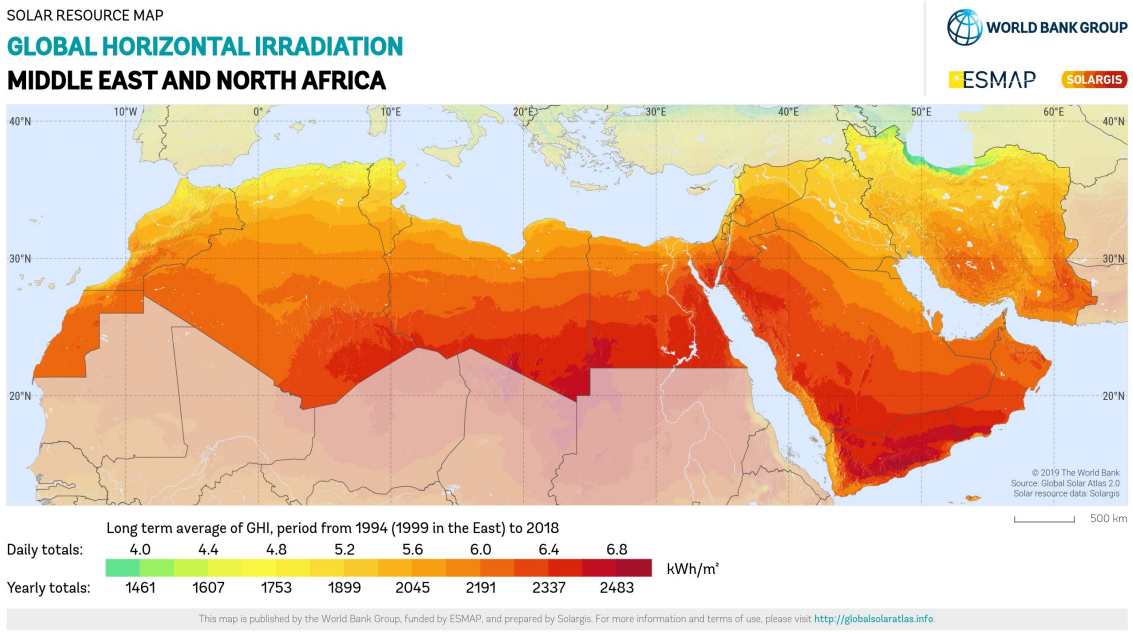
Country	Crude Steel Production	Electric Furnace %	Basic Oxygen Furnace %	DRI Production 2022	Number of DR Shafts
Iran	30.6	91.8	8.2	32.90	42
Saudi Arabia	9.1	100	-	6.48	7
Egypt	9.8	100	-	5.82	6
UAE	3.2	100		3.45	3
Algeria	3.5	80	20[e]	3.88	3
Oman	3	100	-	1.82	1
Bahrain	1.17	100	-	1.42	1
Libya	0.74	100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

- MENA is the world's leading DRI-based steelmaking leader, driven by the region's abundant gas resources.
- The region produced nearly 46% of total global DRI in 2022.
- MENA has an established, growing source of direct reduction (DR)-grade iron ore.
- Steelmakers in the MENA region have a smaller carbon footprint than their global rivals on average.
- By increasing focus on domestic utilisation of green hydrogen in steelmaking, rather than hydrogen exports, the MENA region can be a leader in steel sector decarbonisation.

MENA Renewable Energy Potential

Practical PV potential versus PV Seasonality

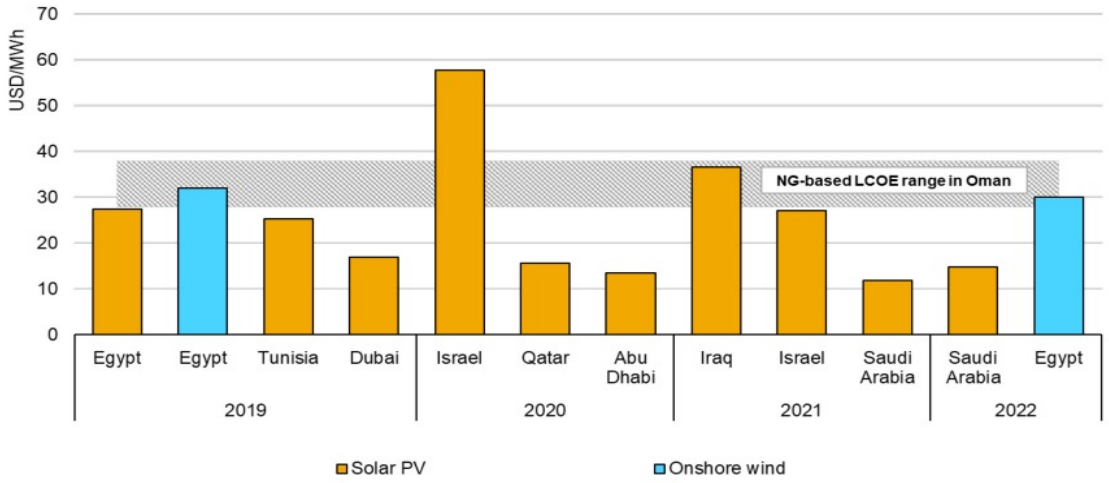




- The region boasts reliable solar irradiation and has the highest photovoltaic (PV) power potential worldwide with limited seasonal variability.
- The steel sector is energy-intensive, and to decarbonise the whole value chain would require a considerable amount of renewable energy.
- As the global steel 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, such as MENA.

MENA Renewable Energy Cost

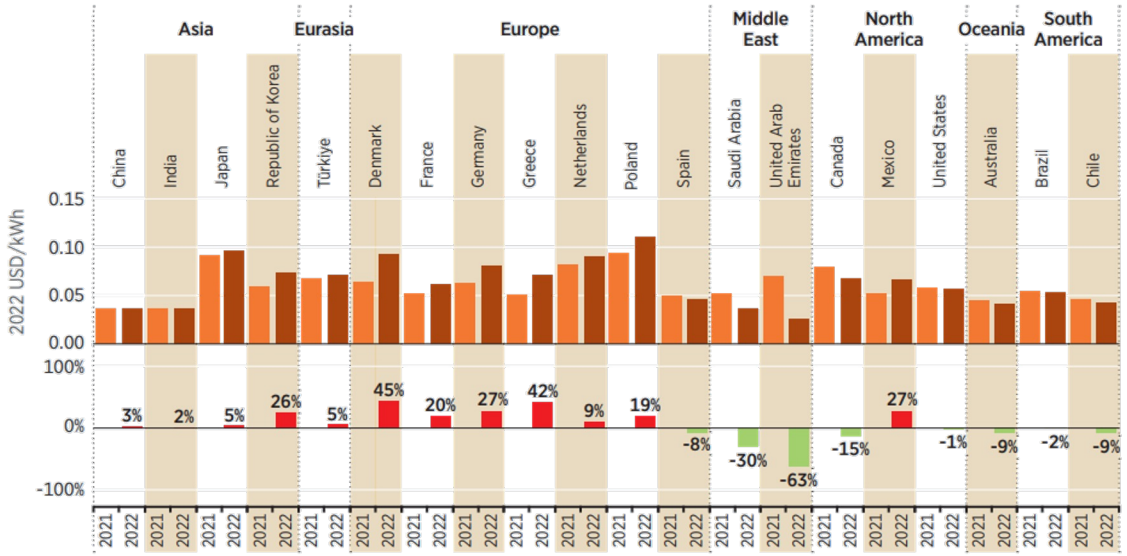
Renewables' bid price vs LCOE of gas-fired power plants in Oman



Notes: Assumed natural gas price USD 3.7/GJ.

Source: IEA

Utility-scale solar PV weighted average LCOE trends in top 20 utility-scale markets, 2021-2022



Source: IRENA

- Renewable electricity is already economically viable in MENA, and it has the most cost-competitive solar PV globally.
- 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.
- 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 levelised cost of electricity (LCOE) for solar worldwide.
- These renewable energy resources will allow the region to become a producer of cheap green hydrogen in the near future.

MENA Green Hydrogen Targets

Saudi Arabia

Ambitions in both blue and green hydrogen production, with plans to produce 2.9 Mtpa by 2030 and 4 Mtpa by 2035.

UAE

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, up to 7.5 Mtpa and 15 Mtpa by 2040 and 2050 respectively.

Egypt

Up to 8% of the global demand for green hydrogen by 2050.

Oman

1 Mtpa of renewable hydrogen by 2030, with further aims for 3.75 Mtpa and 8.5 Mtpa by 2040 and 2050 respectively.

Morocco

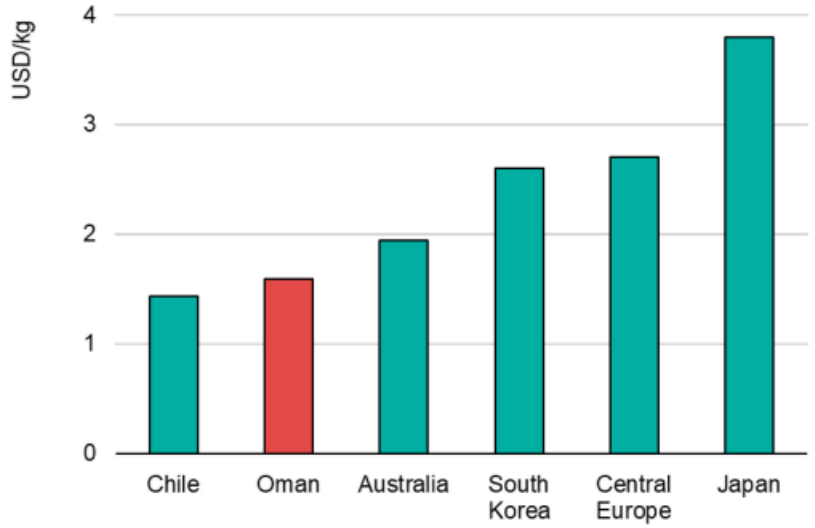
Up to 4% of the global demand for green hydrogen by 2030.

Algeria

Aims to provide European market with 10% of its needs by 2040.

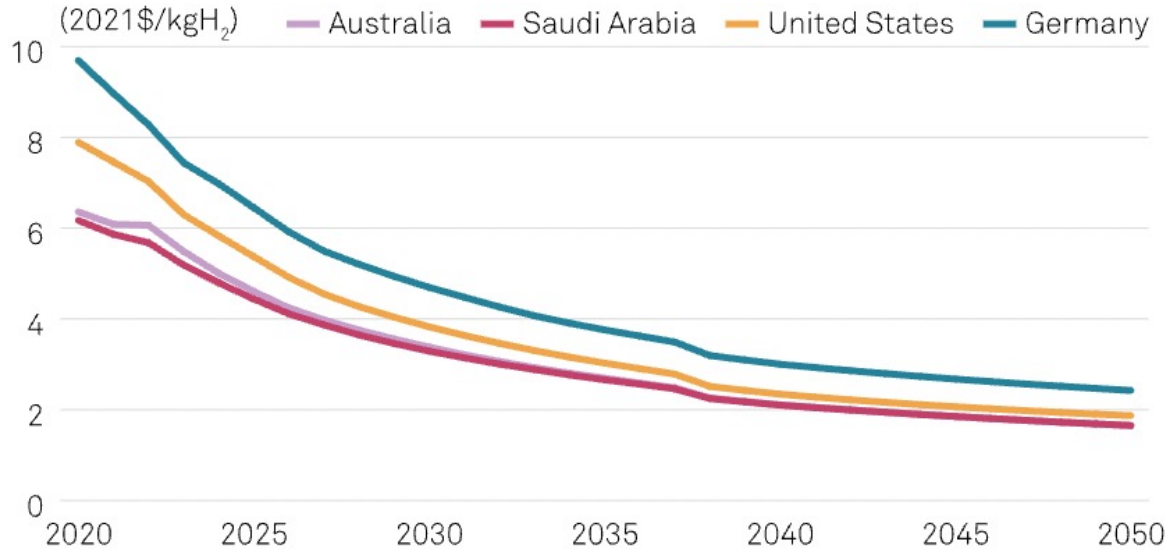
MENA Hydrogen Production Cost

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.

Forecast decline in cost of green hydrogen

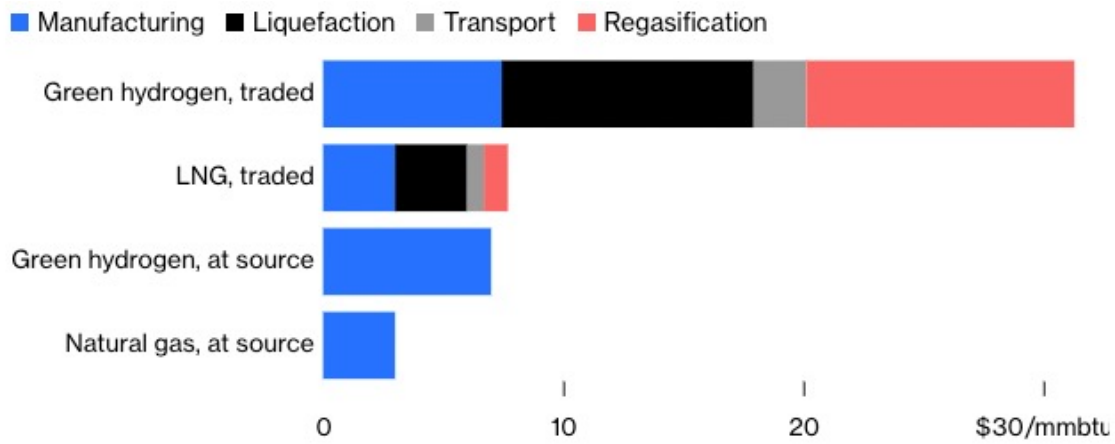


Source: S&P Global Commodity

- S&P Platts assessed the cost of green hydrogen produced in Saudi Arabia at US$3.22/kg in September 2023. S&P sees Saudi Arabia outcompeting nations including Australia, Germany and the U.S. as green hydrogen costs fall substantially.
- According to IRENA projections, achieving the production of green hydrogen at a cost below US$1.5/kg is feasible by 2050, and MENA nations will be highly competitive on cost compared to key steel-consuming nations.

Green Hydrogen Exports: Inefficient and costly

Transportation costs make importing green hydrogen expensive



Source: BloombergNEF. Hydrogen Council, Deloitte, Bloomberg Opinion calculations.

According to IRENA, hydrogen transportation via hydrogen carriers is projected by 2030 to add an additional cost of US$2.5 to US$4.5 per kilogram of hydrogen delivered.

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 to produce green iron in the form of hot-briquetted iron (HBI).

> **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.**
>
> Wood Mackenzie, October 2023

Green Iron and Steel Projects

	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 (Including 4 Mtpa in Ras Al Khair industrial city)	Domestic consumption in the region

DRI-based plants in Saudi Arabia, Oman and the UAE will initially operate on gas and shift to green hydrogen when economically viable.

Emirates Steel Arkan is considering CCUS in its initial stages when using gas. However, as it transitions to green hydrogen, the CCUS facility will become obsolete.

CCUS Is No Alternative to Green Hydrogen

MENA is home to the first (and only) industrial-scale CCUS installation at a steel plant – Emirates Steel Arkan's Al Reyadah project. The 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 Enhanced Oil Recovery (EOR) operations.

Underperforming carbon capture projects considerably outnumber successful projects globally, and the technology's poor track record over decades strongly suggests that it is not going to be a key decarbonisation solution.

We have yet to see meaningful projects announced, reflecting steelmaker's preference towards other low-carbon solutions, such as hydrogen, in the short term.

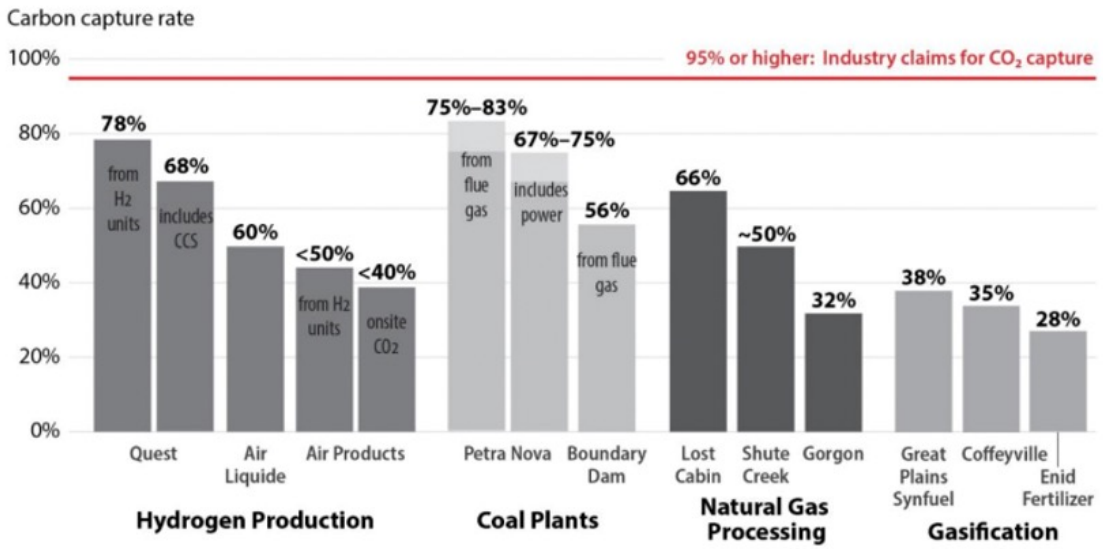
BloombergNEF carbon capture costs 2023

The history of CCUS has largely been one of underperformance

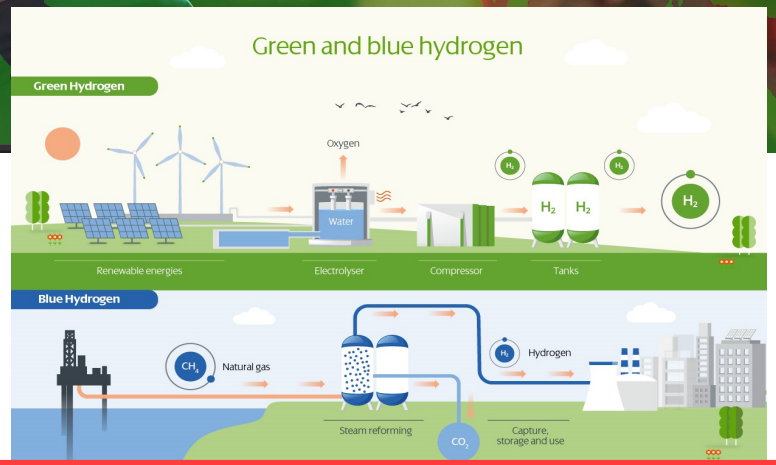
IEA Net Zero Roadmap 2023

Blue Hydrogen Is Not a Solution

Blue hydrogen is most commonly made from methane with some of the resulting carbon emissions captured. CCUS proponents often assert 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 CCUS installations across various industries that confirms that capture rate.



Source: IEEFA analysis based on publicly available data.



Using Western-made alkaline systems, green hydrogen beats out blue hydrogen by 2030 in all but a handful of modelled markets.

BloombergNEF 2023

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.

Wood Mackenzie 2023

Takeaways for MENA

- 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.

- MENA nations should cease investments in CCUS technology, given its history of failing to meet targets. Blue hydrogen is not a viable option, as it relies on CCUS technology. In the near future, green hydrogen is expected to surpass all other forms of hydrogen production.

- All new DRI plants should be hydrogen-ready, and existing in-situ DRI capacity in the MENA region should progressively transition to readiness for increased hydrogen consumption.

- 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.

Thank You

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