

## **MARKETS AND PROFITABILITY**

# **Market Insights: Hydrogen - 2022**

August 2022



This Report was prepared by NexantECA Energy & Chemicals Advisory ("NexantECA"). Except where specifically stated in this Report, the information contained herein is prepared on the basis of information that is publicly available and contains no confidential third party technical information to the best knowledge and belief of NexantECA. The information has not been independently verified or otherwise examined to determine its accuracy, completeness or financial feasibility. Neither NexantECA, Subscriber nor any person acting on behalf of either shall have any liabilities for any loss or damage arising from or connected to the use of any information contained in this Report. NexantECA does not represent or warrant that any assumed conditions will come to pass.

The Report is for Subscriber's internal use only and shall be kept strictly confidential. The Report should not be otherwise reproduced, distributed or used without first obtaining prior written consent by NexantECA. Each Subscriber agrees to use reasonable effort to protect the confidential nature of the Report.

Copyright © by NexantECA (BV) Ltd. 2022. All rights reserved.



## Contents

1	Executive Summary .....	1
2	Introduction.....	12
2.1	Overview .....	12
2.2	Increased Focus on Decarbonization.....	12
2.2.1	Reducing GHG Emissions .....	12
2.2.2	Basics of Hydrogen .....	14
2.2.3	Emphasis on Hydrogen in Decarbonization.....	16
2.3	Different Colours of Hydrogen.....	17
2.3.1	Hydrogen Colour Palette.....	17
2.3.2	Terminology for Hydrogen Technologies .....	18
2.4	Viable Pathways for Hydrogen Production .....	19
2.4.1	Various Pathways and Routes .....	19
2.4.2	Pathways and Routes for Green Hydrogen .....	20
2.4.3	Differentiation of Main Hydrogen Production Pathways .....	21
2.4.4	Potential Barriers for Hydrogen Production .....	22
2.4.5	Qualitative Comparison of Grey, Blue, and Green Blue Hydrogen.....	22
2.4.6	GHG Emissions and Footprint .....	23
2.4.7	Are Grey, Blue, and Green Hydrogen So Different? .....	24
2.4.8	Pricing of Grey, Blue, and Green Hydrogen .....	25
2.5	Hydrogen Grades .....	25
2.6	Hydrogen End-Use Applications .....	26
2.6.1	Overview of Applications .....	26
2.7	Limitations of This Report .....	28
2.7.1	Major Underlying Current Events .....	28
3	Market Drivers and Challenges .....	30
3.1	Overview .....	30
3.2	Key Drivers .....	30
3.2.1	Global Stakeholders' Macro Market Outlook – Driven by "Net Zero" Emissions .....	30
3.2.2	Overall Hydrogen Supply and Demand .....	31
3.2.3	Regulatory Framework and Policy .....	32
3.2.4	Hydrogen Policy Overview – Initiatives and Projects in Various Countries .....	33
3.2.5	Key Role for Low Carbon Hydrogen Hubs and Clusters .....	37
3.2.6	Key Success Factors for Low Carbon Hydrogen Projects .....	46
3.3	Key Challenges and Barriers .....	46
3.3.1	Policy and Framework.....	46
3.3.2	Certification of Hydrogen.....	47
3.3.3	Low Carbon and Zero Carbon Hydrogen Production .....	47
3.3.4	Hydrogen Logistics.....	48
3.3.5	Natural Gas Blending .....	49



3.3.6	Project Financing .....	50
3.4	Potential “Top-Down” Market Scenarios for Hydrogen Supply to 2050 .....	53
3.4.1	Transformation to Being an “Energy Carrier” .....	53
3.4.2	Decarbonized Supply .....	53
3.4.3	Potential Blue Hydrogen Only Scenario.....	53
3.4.4	Potential Green Hydrogen Only Scenario .....	54
3.4.5	Potential Combined Blue and Green Hydrogen Scenario .....	54
3.4.6	Potential Sensitivities .....	55
4	Market Outlook .....	57
4.1	Overview .....	57
4.2	Global .....	57
4.2.1	Global Supply by Sources .....	57
4.2.2	Global Green Hydrogen Supply by Region.....	60
4.2.3	Key Assumptions .....	61
4.3	Global Demand by End-Use .....	61
4.3.1	Established Demand .....	61
4.3.2	Energy Transition Applications.....	61
4.3.3	Estimates.....	62
4.3.4	Key Assumptions .....	64
4.4	Global Market by Region.....	64
4.4.1	Key Assumptions .....	67
4.4.2	Asia Pacific.....	68
4.4.3	North America .....	73
4.4.4	South America .....	75
4.4.5	Europe.....	78
4.4.6	Middle East.....	82
4.4.7	Africa .....	85
5	Hydrogen Pricing .....	89
5.1	Overview .....	89
5.1.1	Paradigm Shift.....	89
5.1.2	The “Black Box”.....	89
5.2	Industry Approach and Methodology .....	90
5.2.1	Limitations .....	90
5.2.2	Quantifying Costs .....	90
5.2.3	COP Estimates.....	91
5.2.4	Estimating LCOH .....	93
5.3	Hydrogen Production Costs .....	95
5.3.1	Overview .....	95
5.3.2	Price Impact of Natural Gas .....	95
5.3.3	Impact of LCOH on Grey/Blue Hydrogen.....	95
5.3.4	Impact of LCOH on Green Hydrogen.....	96
5.3.5	Ranges of LCOH for Grey, Blue, and Green Hydrogen.....	96
5.4	Market Pricing .....	97



5.4.1	Industrial Hydrogen .....	97
5.4.2	Hydrogen for Vehicle Use .....	97
6	Comparative Costs of Hydrogen .....	98
6.1	Overview .....	98
6.2	Assumptions .....	98
6.2.1	Typical Characteristic Syngas Compositions .....	98
6.2.2	Pricing Basis.....	99
6.3	Grey, Blue, and Green Hydrogen.....	100
6.3.1	Overview .....	100
6.3.2	Comparison of Hydrogen Production via SMR, ATR, and POX .....	100
6.3.3	Green Hydrogen Production via Electrolysis .....	102
6.3.4	Results of Comparative Analysis .....	102
6.4	LCOH - Grey, Blue, and Green Hydrogen Projects .....	104
6.4.1	Highlights of Results .....	104
6.4.2	European Project Studies .....	105
6.4.3	USDOE Project Studies .....	106
6.4.4	Linde Group Project Studies .....	106
7	Conclusions .....	107
7.1	Market Drivers and Challenges.....	107
7.2	Market Outlook .....	108
7.2.1	Supply .....	108
7.2.2	Demand.....	110
7.3	Hydrogen Pricing.....	112
7.4	Comparative Costs of Hydrogen (Grey, Blue, and Green) .....	112



## Figures

Figure 1	Focus on Energy Transition.....	13
Figure 2	Different Colours of Hydrogen .....	18
Figure 3	Various Pathways and Routes .....	19
Figure 4	Commercial and Developmental Routes for Green Hydrogen.....	21
Figure 5	Differentiation of Main Hydrogen Production Pathways.....	21
Figure 6	GHG Footprint for Grey Hydrogen, Blue Hydrogen and Fossil Fuels .....	24
Figure 7	Major End Use Applications for Hydrogen .....	27
Figure 8	NEOM Location Map in Saudi Arabia.....	34
Figure 9	Air Products Hybrid Low Carbon Products Process and Distribution.....	35
Figure 10	Air Products Hybrid Green/Blue Hydrogen in Saudi Arabia .....	35
Figure 11	Air Products Supply/Value Chain for Ammonia-Hydrogen.....	36
Figure 12	Air Products Ammonia based HRS .....	36
Figure 13	Agreement Structure for Ammonia-HRS .....	36
Figure 14	UK's Largest Hubs and Clusters by Industrial CO <sub>2</sub> Emissions.....	38
Figure 15	Announced Low Carbon Hydrogen Projects in Europe.....	39
Figure 16	H2H Saltend Project, UK .....	40
Figure 17	Air Products "Net-Zero" Hydrogen Energy Complex, Alberta .....	42
Figure 18	Air Product Large-Scale Blue Hydrogen Complex in U.S. Gulf Coast .....	44
Figure 19	Air Products Blue Hydrogen Delivery in U.S. Gulf Coast .....	44
Figure 20	Routing of Air Products Blue Hydrogen Pipeline in U.S. Gulf Coast.....	45
Figure 21	Cross-Section of Proposed Carbon Sequestration Plan .....	45
Figure 22	Potential Sensitivities for Decarbonized Hydrogen Scenario .....	56
Figure 23	Global Hydrogen Supply from Grey, Blue, and Green Sources - Historical and Outlook .....	58
Figure 24	Global Hydrogen Supply from Grey, Blue, and Green Sources – Estimate (2022) .....	58
Figure 25	Global Green Hydrogen Capacity by Region - Outlook .....	60
Figure 26	Global On-Purpose Hydrogen Demand by End-Use .....	63
Figure 27	Global On-Purpose Hydrogen Demand by End-Use – Estimate (2022) .....	63
Figure 28	Global On-Purpose Hydrogen Demand by Region .....	66
Figure 29	Global On-Purpose Hydrogen Demand by Region – Estimate (2022) .....	66
Figure 30	China On-Purpose Hydrogen Demand by End-Use .....	69
Figure 31	China On-Purpose Hydrogen Demand by End-Use – Estimate (2022) .....	70
Figure 32	Asia Pacific (Excl. China) On-Purpose Hydrogen Demand by End-Use .....	71
Figure 33	Asia Pacific (Excl. China) On-Purpose Hydrogen Demand by End-Use – Estimate (2022) .....	71
Figure 34	North America On-Purpose Hydrogen Demand by End-Use.....	74
Figure 35	North America On-Purpose Hydrogen Demand by End-Use – Estimate (2022) .....	75
Figure 36	South America On-Purpose Hydrogen Demand by End Use .....	77
Figure 37	South America On-Purpose Hydrogen Demand by End-Use – Estimate (2022).....	77
Figure 38	Western Europe On-Purpose Hydrogen Demand by End-Use.....	79
Figure 39	Western Europe On-Purpose Hydrogen Demand by End Use – Estimate (2022) .....	80
Figure 40	Central & Eastern Europe On-Purpose Hydrogen Demand by End-Use.....	81



---

Figure 41	Central & Eastern Europe On-Purpose Hydrogen Demand by End-Use – Estimate (2022) .....	82
Figure 42	Middle East On-Purpose Hydrogen Demand by End Use .....	84
Figure 43	Middle East On-Purpose Hydrogen Demand by End Use – Estimate (2022).....	84
Figure 44	Africa On-Purpose Hydrogen Demand by End Use.....	87
Figure 45	Africa On-Purpose Hydrogen Demand by End-Use – Estimate (2022) .....	87
Figure 46	Integrated Costs and Techno-Economic-Financial Analysis .....	91
Figure 47	Overview of U.S. DOE's H <sub>2</sub> A Analysis and Modelling.....	94
Figure 48	Estimates for SMR and ATR (via Natural Gas) versus POX (via Coal) and Green Hydrogen .....	103
Figure 49	CO <sub>2</sub> Intensity for SMR and ATR (via Natural Gas) versus POX (via Coal).....	104
Figure 50	Comparative Costs of Projects for Grey, Blue, and Green Hydrogen .....	105
Figure 51	Global Hydrogen Supply from Grey, Blue, and Green Sources - Historical and Outlook .....	109
Figure 52	Global Green Hydrogen Capacity by Region .....	109
Figure 53	Global On-Purpose Hydrogen Demand by End-Use.....	110
Figure 54	Global On-Purpose Hydrogen Demand by Region .....	111
Figure 55	Comparative Costs of Projects for Grey, Blue, and Green Hydrogen.....	113



## Tables

Table 1	Liquid Hydrogen's Physical and Chemical Properties.....	14
Table 2	Qualitative Comparison of Grey, Blue, and Green Hydrogen .....	23
Table 3	Challenges and Characteristics by Storage and Transport Pathway.....	48
Table 4	Key Hydrogen Structural Market Parameters.....	50
Table 5	Integrated Hydrogen Value Chain - Benefits and Challenges.....	51
Table 6	Key Risks and Mitigants Along Zero Carbon Hydrogen Value Chain .....	51
Table 7	Mitigation of Volume Risk and Price Risk.....	52
Table 8	Global Hydrogen production - Historical and Outlook .....	59
Table 9	Global Green Hydrogen Capacity by Region – Outlook.....	61
Table 10	Global On-Purpose Hydrogen Demand by End Use .....	64
Table 11	Global Hydrogen Demand by Region.....	67
Table 12	China On-Purpose Hydrogen Demand by End Use.....	70
Table 13	Asia Pacific (Excl. China) On-Purpose Hydrogen Demand by End Use.....	72
Table 14	North America On-Purpose Hydrogen Demand by End Use .....	75
Table 15	South America On-Purpose Hydrogen Demand by End Use .....	78
Table 16	Western Europe On-Purpose Hydrogen Demand by End Use .....	80
Table 17	Central & Eastern Europe On-Purpose Hydrogen Demand by End Use .....	82
Table 18	Middle East On-Purpose Hydrogen Demand by End Use .....	85
Table 19	Africa On-Purpose Hydrogen Demand by End Use .....	88
Table 20	Comparative Summary of H <sub>2</sub> A versus H <sub>2</sub> FAST .....	94
Table 21	Ranges of Levelized Costs.....	96
Table 22	Ranges of Market Pricing of Hydrogen .....	97
Table 23	Typical Characteristic Syngas Compositions Based on Natural Gas Feedstock.....	98
Table 24	Prices for Raw Materials, Utilities, and Wages.....	99
Table 25	Case Matrix for Comparison of Hydrogen Production via SMR, ATR, and POX .....	100
Table 26	Hydrogen Purity Specifications .....	101
Table 27	Key Hydrogen Structural Market Parameters.....	108
Table 28	Ranges of Levelized Costs.....	112