

SPECIAL REPORTS

Hydrogen: Realistic Game Changer?

Table of Contents

A Report by **Nexant, Inc.**

Published Date: December 2018

www.nexantsubscriptions.com

Contents

1	Executive Summary	1
1.1	Introduction.....	1
1.2	Demand.....	3
1.2.1	Conventional End-Uses.....	3
1.2.2	New Applications and Ideas.....	3
1.3	Supply.....	5
1.3.1	Conventional Supply	5
1.3.2	New and Unconventional Supply	6
1.3.3	Current Station Infrastructure Status.....	6
1.3.4	Logistics Requirements	6
1.3.5	Regulatory Environment.....	6
1.4	Historic Market Dynamics.....	7
1.4.1	Demand.....	7
1.4.2	Supply	11
1.5	Cost Analysis.....	13
1.6	Future Demand Scenarios	14
1.6.1	Assumptions.....	14
1.6.2	Results	14
1.7	Conclusions, Limitations, and Recommendations	20
1.8	Conclusions.....	20
1.8.1	Demand.....	20
1.8.2	Supply	21
1.9	Limitations	22
1.9.1	Historic Market Analysis	22
1.9.2	Cost Model	22
1.9.3	Future Market Analysis.....	23
1.10	Recommendations	24
1.10.1	Analysis Covered in the Report.....	24
1.10.2	Analysis not Covered in this Report.....	24
1.10.3	Technical Research and Development Requirements for Widespread Adoption	25
1.10.4	Governmental and Regulatory Framework Requirements for Widespread Adoption.....	25
2	Introduction.....	27

2.1	Overview.....	27
2.2	Hydrogen Council.....	28
2.2.1	Introduction.....	28
2.2.2	Mission.....	28
2.2.3	Members.....	28
2.2.4	Roadmap.....	30
2.3	Contents of this Report.....	32
2.3.1	Background.....	32
2.3.2	Table of Contents.....	36
3	Demand.....	37
3.1	Introduction.....	37
3.2	Conventional End-Uses.....	39
3.2.1	Ammonia.....	39
3.2.2	Methanol.....	40
3.2.3	Refinery End Uses.....	41
3.2.4	Others.....	42
3.3	New Applications and Ideas.....	43
3.3.1	Introduction to Fuel Cell Technology.....	43
3.3.2	Road – Passenger Cars.....	47
3.3.3	Road – Buses.....	53
3.3.4	Road – Trucks.....	56
3.3.5	Road – Military Vehicles.....	58
3.3.6	Rail – Trains and Trams.....	60
3.3.7	Shipping.....	63
3.3.8	Energy Storage.....	64
3.3.9	Stationary Fuel Cell Applications.....	68
3.3.10	Others.....	70
4	Supply.....	72
4.1	Introduction.....	72
4.2	Conventional Supply.....	75
4.2.1	Reforming.....	75
4.2.2	Gasification.....	81
4.2.3	Conventional Electrolysis.....	86
4.2.4	Recently Announced Projects by Hydrogen Producers.....	90
4.3	New and Unconventional Supply.....	95
4.3.1	Other Electrolytic Processes.....	95
4.3.2	Photocatalytic Water Splitting and Artificial Photosynthesis.....	98
4.3.3	Thermocatalytic Processes.....	113
4.3.4	Mechano-catalytic Water Splitting.....	119
4.3.5	Biological Processes.....	122
4.3.6	Other Developments.....	128
4.4	Current Station Infrastructure Status.....	130
4.4.1	Introduction.....	130
4.4.2	Regional Overview.....	130
4.5	Logistics Requirements.....	133
4.5.1	Liquefaction Plants.....	133
4.5.2	Liquid and Gas Terminals.....	135
4.5.3	Hydrogen Delivery Pathways to Refueling Station.....	136
4.5.4	Liquid Delivery.....	136

	4.5.5	New Developments in Hydrogen Infrastructure	141
4.6		Regulatory Environment.....	143
	4.6.1	Introduction.....	143
	4.6.2	Policy Developments.....	143
5		Historic Market Dynamics.....	149
	5.1	Introduction.....	149
		5.1.1 Overview	149
		5.1.2 Methodologies	150
	5.2	Global	160
		5.2.1 Demand.....	160
		5.2.2 Supply	165
	5.3	North America	168
		5.3.1 Demand.....	168
		5.3.2 Supply	170
	5.4	South America.....	171
		5.4.1 Demand.....	171
		5.4.2 Supply	172
	5.5	Western Europe	174
		5.5.1 Demand.....	174
		5.5.2 Supply	176
	5.6	Central Europe	177
		5.6.1 Demand.....	177
		5.6.2 Supply	179
	5.7	Eastern Europe	180
		5.7.1 Demand.....	180
		5.7.2 Supply	181
	5.8	Middle East.....	183
		5.8.1 Demand.....	183
		5.8.2 Supply	185
	5.9	Africa	186
		5.9.1 Demand.....	186
		5.9.2 Supply	187
	5.10	East Asia	189
		5.10.1 Demand.....	189
		5.10.2 Supply	190
	5.11	South Asia	192
		5.11.1 Demand.....	192
		5.11.2 Supply	194
	5.12	South-East Asia.....	195
		5.12.1 Demand.....	195
		5.12.2 Supply	196
	5.13	Oceania	198
		5.13.1 Demand.....	198
		5.13.2 Supply	199
	5.14	Summary	201
		5.14.1 Demand.....	201
		5.14.2 Supply	205
6		Cost Analysis.....	208
	6.1	Introduction.....	208

6.1.1	Industrial Gas	208
6.1.2	Energy Carrier	209
6.2	Hydrogen Pathways	210
6.2.1	Overview	210
6.2.2	Broad Basis for Assessing Costs	210
6.3	Challenges and Limitations	212
6.4	Currently Available Tools and Methods	214
6.4.1	Hydrogen Analysis (H2A)	214
6.4.2	Hydrogen Financial Analysis Scenario Tool (H2FAST)	214
6.4.3	System Advisor Model (SAM)	215
6.4.4	Integration of Tools and Methods	215
6.5	High-Level Comparative Analysis	216
6.5.1	Overview	216
6.5.2	Cost Analysis	218
6.6	End-Use Case Analysis	223
6.6.1	Overview	223
6.6.2	Existing Key Gaps and Factors	224
6.6.3	Key Findings	224
6.6.4	Additional Research Areas and Gaps	229
6.7	Conclusions	231
7	Future Demand Scenarios	232
7.1	Introduction	232
7.2	Scenario Assumptions	232
7.2.1	Ammonia and Methanol	232
7.2.2	Refining	233
7.2.3	Other	233
7.2.4	Fuel Cell Electric Vehicles	234
7.3	Global	241
7.3.1	Demand	241
7.3.2	Supply Discussion	248
7.4	North America	250
7.4.1	Demand	250
7.4.2	Supply Discussion	253
7.5	South America	255
7.5.1	Demand	255
7.5.2	Supply Discussion	258
7.6	Western Europe	259
7.6.1	Demand	259
7.6.2	Supply Discussion	262
7.7	Central Europe	264
7.7.1	Demand	264
7.7.2	Supply Discussion	267
7.8	Eastern Europe	269
7.8.1	Demand	269
7.8.2	Supply Discussion	272
7.9	Middle East	273
7.9.1	Demand	273
7.9.2	Supply Discussion	276
7.10	Africa	277

	7.10.1 Demand	277
	7.10.2 Supply Discussion	280
7.11	East Asia	282
	7.11.1 Demand	282
	7.11.2 Supply Discussion	285
7.12	South Asia	287
	7.12.1 Demand	287
	7.12.2 Supply Discussion	290
7.13	South-East Asia.....	292
	7.13.1 Demand	292
	7.13.2 Supply Discussion	295
7.14	Oceania	296
	7.14.1 Demand	296
	7.14.2 Supply Discussion	299
7.15	Summary	300
	7.15.1 Assumptions	300
	7.15.2 Results	301
8	Conclusions, Limitations, and Recommendations	306
8.1	Conclusions	306
	8.1.1 Demand	306
	8.1.2 Supply	307
8.2	Limitations	308
	8.2.1 Historic Market Analysis	308
	8.2.2 Cost Model	308
	8.2.3 Future Market Analysis.....	309
8.3	Recommendations	310
	8.3.1 Analysis Covered in the Report.....	310
	8.3.2 Analysis not Covered in this Report	310
	8.3.3 Technical Research and Development Requirements for Widespread Adoption	311
	8.3.4 Governmental and Regulatory Framework Requirements for Widespread adoption	311
 Appendices		
A	References	314

Figures

Figure 1	2017 H ₂ Demand - Global	7
Figure 2	Historic H ₂ Demand - Global	8
Figure 3	2017 H ₂ Demand - Global	9
Figure 4	Historic H ₂ Demand - Global	10
Figure 5	2017 H ₂ Production - Global.....	11
Figure 6	Historic H ₂ Production and Capacity - Global	13
Figure 7	Global Hydrogen Scenario Demand Forecast by Application.....	15
Figure 8	Global Hydrogen Low Scenario Demand Forecast by Application, 2035	16
Figure 9	Global Hydrogen Medium Scenario Demand Forecast by Application, 2035	16
Figure 10	Global Hydrogen High Scenario Demand Forecast by Application, 2035.....	17
Figure 11	Global Hydrogen Scenario Supply Forecast by Source.....	19
Figure 12	Global Hydrogen Scenario Supply Comparison by Source	19
Figure 13	Traditional Energy and Refining Value Chains.....	33
Figure 14	Energy and Refining Value Chains with Limited Fossil Fuel.....	34
Figure 15	Global Hydrogen Supply by Source, 2017	35
Figure 16	Hydrogen Demand by End Use, 2017	37
Figure 17	Hydrogen Market Segments and Sub-Segments.....	38
Figure 18	End-Use of Ammonia and Its Derivatives	39
Figure 19	Global Ammonia Consumption by Application	40
Figure 20	Global Methanol Demand, 2017	41
Figure 21	Principle Behind Fuel Cells – (A) Negative Ion Conducting Electrolyte; (B) Positive Ion Conducting Electrolyte.....	43
Figure 22	Fuel Cell Stack Components.....	44
Figure 23	Most Common Materials Used in Different Fuel Cell Types	45
Figure 24	Types of Fuel Cells	46
Figure 25	General Fuel Cell System.....	46
Figure 26	FCEVs Demand by Country/Region, 2017	47
Figure 27	SWOT Analysis for Hydrogen Used to Power Passenger Vehicles	51
Figure 28	SWOT Analysis for Hydrogen Used to Power Buses.....	55
Figure 29	SWOT Analysis for Hydrogen Used to Power Trucks.....	57
Figure 30	SWOT Analysis for Hydrogen Used to Power Military Vehicle	59
Figure 31	SWOT Analysis for Hydrogen used to Power Rails	62
Figure 32	SWOT analysis for Hydrogen Used to Power Ships and Ferries	64
Figure 33	LOHC System	66
Figure 34	SWOT Analysis for Hydrogen Used for Energy Storage	67
Figure 35	SWOT Analysis for Hydrogen Used to Power Fuel Cell Applications	70
Figure 36	Global Hydrogen Supply by Source, 2017	72
Figure 37	Anatomy of a Simple Refinery.....	73
Figure 38	Shift to a Complex Refinery.....	74
Figure 39	Steam-Methane Reforming	76
Figure 40	Gasification Process Flow Diagram	83

Figure 41	Diagram of Hydrogen Production via Electrolysis	87
Figure 42	Process Flow Diagram of Hydrogen Production via Electrolysis	88
Figure 43	Electrolytic Water Splitting with LNBL’s Mo-oxo Metal Complex	96
Figure 44	SWOT Analysis for Other Electrolytic Processes Used for the Production of Hydrogen.....	97
Figure 45	PEC Hydrogen Production of TiO ₂ /Pt/SiNW Photocathode.....	100
Figure 46	Photosynthesis of Sunlight in Cyanobacteria	102
Figure 47	Ruthenium-based Water Oxidation Catalyst Developed by Jülich Institute	103
Figure 48	Proposed Photoelectrolysis Mechanism within a Nafion Membrane.....	107
Figure 49	Nafion-Coated Electrode	107
Figure 50	ASU Photoelectrochemical Cell for Water Splitting.....	109
Figure 51	Mechanism of the AIST Photocatalyst-electrolysis Hybrid System	111
Figure 52	SWOT Analysis for Artificial Photosynthesis Processes Used for the Production of Hydrogen.....	112
Figure 53	The Generation-2 CR5 Solar Thermochemical Reactor	113
Figure 54	Solar Rotary Reactor Configuration Lined with ZnO Particles	114
Figure 55	Solar Thermochemical Reactor Configuration with Cerium-oxide Particles.....	115
Figure 56	FSEC Hybrid S-NH ₃ Photothermochemical Water-Splitting Cycle	117
Figure 57	SWOT Analysis for Thermo Catalytic Processes Used for the Production of Hydrogen.....	119
Figure 58	H ₂ and O ₂ Produced by Deformation of ZnO Fibers or BaTiO ₃ Dendrites in Water.....	120
Figure 59	SWOT Analysis for Mechano-catalytic Process Used for the Production of Hydrogen	121
Figure 60	ORNL Integrated Pyrolysis-Microbial Electrolysis	124
Figure 61	Virent’s BioForming Process	126
Figure 62	SWOT Analysis for Biological Process Used for the Production of Hydrogen	127
Figure 63	Simplified Flow Diagram for Hydrogen Liquefaction Plant.....	134
Figure 64	Liquid Terminal for Use with Liquid Delivery.....	135
Figure 65	Liquid Terminal for Use with Gas Delivery.....	135
Figure 66	Liquid Hydrogen Distribution Scenario – Pathway 1	137
Figure 67	Liquid Hydrogen Distribution Scenario – Pathway 2	137
Figure 68	Liquid Hydrogen Distribution Scenario – Pathway 3	138
Figure 69	Compressed Hydrogen Distribution Scenario – Pathway 4.....	138
Figure 70	Compressed Hydrogen Distribution Scenario – Pathway 5.....	139
Figure 71	Compressed Hydrogen Distribution Scenario – Pathway 6.....	139
Figure 72	Compressed Hydrogen Distribution Scenario – Pathway 7	139
Figure 73	Transmission and Distribution Pipeline Arrangement	140
Figure 74	Pipeline Hydrogen Distribution Scenario – Pathway 8.....	140
Figure 75	Pipeline Hydrogen Distribution Scenario – Pathway 9.....	141
Figure 76	Pipeline Hydrogen Distribution Scenario – Pathway 9.....	141
Figure 77	Total Global Fuel Cell Passenger Cars in Operation, 2017	152
Figure 78	Average Mileage per Vehicle	153
Figure 79	Global Share of Final Energy Consumption in Rail Applications, 2017 estimate.....	155
Figure 80	Global Share of Non-electric Tracks (length) by Region.....	155

Figure 81	Global Share of Electric Tracks (length) by Region	156
Figure 82	Total Oil Based Final Energy Consumed in Rail, 2017 est.	157
Figure 83	Hydrogen Required to Displace Diesel in Rail Globally, 2017	158
Figure 84	Share of Global Shipping Fuel Consumption, 2017	159
Figure 85	Hydrogen Required to Displace Diesel/Fuel Oil in Shipping Globally, 2017	159
Figure 86	2017 H ₂ Demand - Global	160
Figure 87	Hydrogen Consumption for Hydrotreating of Various	161
Figure 88	Historic H ₂ Demand - Global	162
Figure 89	2017 H ₂ Demand - Global	163
Figure 90	Historic H ₂ Demand - Global	164
Figure 91	2017 H ₂ Production - Global.....	165
Figure 92	Historic H ₂ Production and Capacity	167
Figure 93	2017 H ₂ Demand – North America.....	168
Figure 94	Historic H ₂ Demand – North America	169
Figure 95	2017 H ₂ Production – North America.....	170
Figure 96	Historic H ₂ Production and Capacity – North America	170
Figure 97	2017 H ₂ Demand – South America.....	171
Figure 98	Historic H ₂ Demand – South America.....	172
Figure 99	2017 H ₂ Production – South America	173
Figure 100	Historic H ₂ Production & Capacity – South America	173
Figure 101	2017 H ₂ Demand – Western Europe	174
Figure 102	Historic H ₂ Demand – Western Europe	175
Figure 103	2017 H ₂ Production – Western Europe.....	176
Figure 104	Historic H ₂ Production & Capacity – Western Europe.....	176
Figure 105	2017 H ₂ Demand – Central Europe	177
Figure 106	Historic H ₂ Demand – Central Europe	178
Figure 107	2017 H ₂ Production – Central Europe.....	179
Figure 108	Historic H ₂ Production & Capacity – Central Europe.....	179
Figure 109	2017 H ₂ Demand – Eastern Europe	180
Figure 110	Historic H ₂ Demand – Eastern Europe	181
Figure 111	2017 H ₂ Production – Eastern Europe.....	182
Figure 112	Historic H ₂ Production & Capacity – Eastern Europe.....	182
Figure 113	2017 H ₂ Demand – Middle East.....	183
Figure 114	Historic H ₂ Demand – Middle East.....	184
Figure 115	2017 H ₂ Production – Middle East	185
Figure 116	Historic H ₂ Production and Capacity – Middle East.....	185
Figure 117	2017 H ₂ Demand – Africa.....	186
Figure 118	Historic H ₂ Demand – Africa.....	187
Figure 119	2017 H ₂ Production – Africa	188
Figure 120	Historic H ₂ Production & Capacity – Africa	188
Figure 121	2017 H ₂ Demand – East Asia.....	189
Figure 122	Historic H ₂ Demand – East Asia.....	190
Figure 123	2017 H ₂ Production – East Asia	191

Figure 124	Historic H ₂ Production & Capacity – East Asia	191
Figure 125	2017 H ₂ Demand – South Asia	192
Figure 126	Historic H ₂ Demand – South Asia	193
Figure 127	2017 H ₂ Production – South Asia.....	194
Figure 128	Historic H ₂ Production & Capacity – South Asia.....	194
Figure 129	2017 H ₂ Demand – South-East Asia.....	195
Figure 130	Historic H ₂ Demand – South-East Asia.....	196
Figure 131	2017 H ₂ Production – South-East Asia	197
Figure 132	Historic H ₂ Production & Capacity – South-East Asia	197
Figure 133	2017 H ₂ Demand – Oceania	198
Figure 134	Historic H ₂ Demand – Oceania	198
Figure 135	2017 H ₂ Production – Oceania.....	199
Figure 136	Historic H ₂ Production & Capacity – Oceania.....	200
Figure 137	2017 H ₂ Demand - Global	201
Figure 138	Historic H ₂ Demand - Global	202
Figure 139	2017 H ₂ Demand - Global	203
Figure 140	Historic H ₂ Demand - Global	204
Figure 141	2017 H ₂ Production - Global.....	205
Figure 142	Historic H ₂ Production and Capacity - Global	207
Figure 143	Basic Cost Build-Up.....	210
Figure 144	Key Categories, Inputs and Assumptions.....	214
Figure 145	Analysis of Hydrogen Pathways.....	215
Figure 146	Levelized Cost of Production for Ten Pathways.....	218
Figure 147	Levelized Cost of Compression, Storage and Distribution for Ten Pathways.....	219
Figure 148	Total Levelized Cost of Hydrogen for Ten Pathways	220
Figure 149	Normalized Capital Costs for Ten Pathways	221
Figure 150	Comparison of Ten Pathways' Levelized Costs and GHG Emissions	222
Figure 151	Equivalent Maximum Hydrogen Cost for each End-Use Case	227
Figure 152	Regional GDP Growth Rates	234
Figure 153	FCEV Cars' Share of Total Passenger Car Market, Medium Adoption	236
Figure 154	FCEV Trucks' Share of Total Commercial Vehicle Market, Medium Adoption	237
Figure 155	FCEV Buses' Share of Total Commercial Vehicle Market, Medium Adoption	237
Figure 156	Global Hydrogen Scenario Demand Forecast by Application.....	242
Figure 157	Global Hydrogen Low Scenario Demand Forecast by Application, 2035	242
Figure 158	Global Hydrogen Medium Scenario Demand Forecast by Application, 2035.....	243
Figure 159	Global Hydrogen High Scenario Demand Forecast by Application, 2035.....	243
Figure 160	Global Hydrogen Scenario Demand Forecast, by Region	244
Figure 161	Global Hydrogen Low Scenario Demand Forecast by Region, 2035.....	245
Figure 162	Global Hydrogen Medium Scenario Demand Forecast by Region, 2035	245
Figure 163	Global Hydrogen High Scenario Demand Forecast by Application, 2035.....	246
Figure 164	Global Hydrogen Scenario Supply Forecast by Source.....	249
Figure 165	Global Hydrogen Scenario Supply Comparison by Source	249
Figure 166	North America Hydrogen Scenario Demand Forecast by Application.....	250

Figure 167	North America Hydrogen Low Scenario Demand Forecast by Application, 2035	251
Figure 168	North America Hydrogen Medium Scenario Demand Forecast by Application, 2035	251
Figure 169	North America Hydrogen High Scenario Demand Forecast by Application, 2035.....	252
Figure 170	North America Hydrogen Scenario Supply Forecast by Source.....	253
Figure 171	North America Hydrogen Scenario Supply Comparison by Source	254
Figure 172	South America Hydrogen Scenario Demand Forecast by Application	255
Figure 173	South America Hydrogen Low Scenario Demand Forecast by Application, 2035.....	256
Figure 174	South America Hydrogen Medium Scenario Demand Forecast by Application, 2035	256
Figure 175	South America Hydrogen High Scenario Demand Forecast by Application, 2035	257
Figure 176	South America Hydrogen Scenario Supply Forecast by Source	258
Figure 177	South America Hydrogen Scenario Supply Comparison by Source	258
Figure 178	Western Europe Hydrogen Scenario Demand Forecast by Application	259
Figure 179	Western Europe Hydrogen Low Scenario Demand Forecast by Application, 2035	260
Figure 180	Western Europe Hydrogen Medium Scenario Demand Forecast by Application, 2035.....	260
Figure 181	Western Europe Hydrogen High Scenario Demand Forecast by Application, 2035.....	261
Figure 182	Western Europe Hydrogen Scenario Supply Forecast by Source.....	262
Figure 183	Western Europe Hydrogen Scenario Supply Comparison by Source	263
Figure 184	Central Europe Hydrogen Scenario Demand Forecast by Application	264
Figure 185	Central Europe Hydrogen Low Scenario Demand Forecast by Application, 2035	265
Figure 186	Central Europe Hydrogen Medium Scenario Demand Forecast by Application, 2035.....	265
Figure 187	Central Europe Hydrogen High Scenario Demand Forecast by Application, 2035	266
Figure 188	Central Europe Hydrogen Scenario Supply Forecast by Source	267
Figure 189	Central Europe Hydrogen Scenario Supply Comparison by Source.....	268
Figure 190	Eastern Europe Hydrogen Scenario Demand Forecast by Application.....	269
Figure 191	Eastern Europe Hydrogen Low Scenario Demand Forecast by Application, 2035	270
Figure 192	Eastern Europe Hydrogen Medium Scenario Demand Forecast by Application, 2035	270
Figure 193	Eastern Europe Hydrogen High Scenario Demand Forecast by Application, 2035.....	271
Figure 194	Eastern Europe Hydrogen Scenario Supply Forecast by Source.....	272
Figure 195	Eastern Europe Hydrogen Scenario Supply Comparison by Source	272
Figure 196	Middle East Hydrogen Scenario Demand Forecast by Application	273
Figure 197	Middle East Hydrogen Low Scenario Demand Forecast by Application, 2035.....	274
Figure 198	Middle East Hydrogen Medium Scenario Demand Forecast by Application, 2035	274
Figure 199	Middle East Hydrogen High Scenario Demand Forecast by Application, 2035	275
Figure 200	Middle East Hydrogen Scenario Supply Forecast by Source	276
Figure 201	Middle East Hydrogen Scenario Supply Comparison by Source	276
Figure 202	Africa Hydrogen Scenario Demand Forecast by Application	277
Figure 203	Africa Hydrogen Low Scenario Demand Forecast by Application, 2035.....	278
Figure 204	Africa Hydrogen Medium Scenario Demand Forecast by Application, 2035	278
Figure 205	Africa Hydrogen High Scenario Demand Forecast by Application, 2035.....	279
Figure 206	Africa Hydrogen Scenario Supply Forecast by Source	280
Figure 207	Africa Hydrogen Scenario Supply Comparison by Source	281
Figure 208	East Asia Hydrogen Scenario Demand Forecast by Application.....	282
Figure 209	East Asia Hydrogen Low Scenario Demand Forecast by Application, 2035.....	283

Figure 210	East Asia Hydrogen Medium Scenario Demand Forecast by Application, 2035	283
Figure 211	East Asia Hydrogen High Scenario Demand Forecast by Application, 2035.....	284
Figure 212	East Asia Hydrogen Scenario Supply Forecast by Source.....	286
Figure 213	East Asia Hydrogen Scenario Supply Comparison by Source	286
Figure 214	South Asia Hydrogen Scenario Demand Forecast by Application	287
Figure 215	South Asia Hydrogen Low Scenario Demand Forecast by Application, 2035	288
Figure 216	South Asia Hydrogen Medium Scenario Demand Forecast by Application, 2035.....	288
Figure 217	South Asia Hydrogen High Scenario Demand Forecast by Application, 2035	289
Figure 218	South Asia Hydrogen Scenario Supply Forecast by Source	291
Figure 219	South Asia Hydrogen Scenario Supply Comparison by Source.....	291
Figure 220	South-East Asia Hydrogen Scenario Demand Forecast by Application.....	292
Figure 221	South-East Asia Hydrogen Low Scenario Demand Forecast by Application, 2035.....	293
Figure 222	South-East Asia Hydrogen Medium Scenario Demand Forecast by Application, 2035	293
Figure 223	South-East Asia Hydrogen High Scenario Demand Forecast by Application, 2035.....	294
Figure 224	South-East Asia Hydrogen Scenario Supply Forecast by Source.....	295
Figure 225	South-East Asia Hydrogen Scenario Supply Comparison by Source	295
Figure 226	Oceania Hydrogen Scenario Demand Forecast by Application.....	296
Figure 227	Oceania Hydrogen Low Scenario Demand Forecast by Application, 2035	297
Figure 228	Oceania Hydrogen Medium Scenario Demand Forecast by Application, 2035	297
Figure 229	Oceania Hydrogen High Scenario Demand Forecast by Application, 2035.....	298
Figure 230	Oceania Hydrogen Scenario Supply Forecast by Source.....	299
Figure 231	Oceania Hydrogen Scenario Supply Comparison by Source	300
Figure 232	Global Hydrogen Scenario Demand Forecast by Application.....	301
Figure 233	Global Hydrogen Low Scenario Demand Forecast by Application, 2035	302
Figure 234	Global Hydrogen Medium Scenario Demand Forecast by Application, 2035	302
Figure 235	Global Hydrogen High Scenario Demand Forecast by Application, 2035.....	303
Figure 236	Global Hydrogen Scenario Supply Forecast by Source.....	305
Figure 237	Global Hydrogen Scenario Supply Comparison by Source	305

Tables

Table 1	Hydrogen Council Members.....	29
Table 2	Stationary Fuel Cell Applications	68
Table 3	Major Refinery Gasification/POX Unit.....	81
Table 4	Raw Syngas Characteristics	84
Table 5	Currently Available Industrial Electrolyzer Hydrogen Generators.....	89
Table 6	Emission-thresholds for light duty vehicles.....	144
Table 7	Alternative Fuel Requirements for Heavy Duty Vehicles	144
Table 8	Minimum Clean Vehicle Procurement Target per Member States and per Vehicle Segment.....	145
Table 9	Historic H ₂ Demand - Global	162
Table 10	Historic H ₂ Demand - Global.....	164
Table 11	Historic H ₂ Production and Capacity - Global	167
Table 12	Historic H ₂ Demand – North America	169
Table 13	Historic H ₂ Production and Capacity – North America	171
Table 14	Historic H ₂ Demand – South America.....	172
Table 15	Historic H ₂ Production and Capacity – South America.....	173
Table 16	Historic H ₂ Demand – Western Europe	175
Table 17	Historic H ₂ Production and Capacity – Western Europe	177
Table 18	Historic H ₂ Demand – Central Europe	178
Table 19	Historic H ₂ Production and Capacity – Central Europe	180
Table 20	Historic H ₂ Demand – Eastern Europe	181
Table 21	Historic H ₂ Production and Capacity – Eastern Europe	182
Table 22	Historic H ₂ Demand – Middle East.....	184
Table 23	Historic H ₂ Production and Capacity – Middle East.....	186
Table 24	Historic H ₂ Demand – Africa.....	187
Table 25	Historic H ₂ Production and Capacity – Africa	188
Table 26	Historic H ₂ Demand – East Asia.....	190
Table 27	Historic H ₂ Production and Capacity – East Asia	191
Table 28	Historic H ₂ Demand – South Asia	193
Table 29	Historic H ₂ Production and Capacity – South Asia.....	195
Table 30	Historic H ₂ Demand – South-East Asia.....	196
Table 31	Historic H ₂ Production and Capacity – South-East Asia	197
Table 32	Historic H ₂ Demand – Oceania	199
Table 33	Historic H ₂ Production and Capacity – Oceania	200
Table 34	Overview of Hydrogen Pathways	210
Table 35	Separate Cost Elements for Each Individual Segment	211
Table 36	Ten Hydrogen Production, Delivery, and Distribution Pathways	216
Table 37	Key Analysis Parameters	217
Table 38	Overview of End-Use Case Analysis	223
Table 39	Customer Side End-Use Case Analysis Assumptions	226
Table 40	Cost of Hydrogen Supply.....	228

Table 41	Integrated Economic Analysis	228
Table 42	Typical Example of Commercial Applications.....	229
Table 43	FCEV Cars – Medium Adoption	235
Table 44	FCEV Trucks – Medium Adoption.....	235
Table 45	FCEV Buses – Medium Adoption	236
Table 46	Percentage of Energy Required in Rail Applications from FCEV	238
Table 47	Percentage of Total Energy Required in Shipping from FCEV	239
Table 48	FCEV Cars – Fast Adoption	239
Table 49	FCEV Trucks – Fast Adoption.....	240
Table 50	FCEV Buses – Fast Adoption	240
Table 51	Percentage of Energy Required in Rail Applications from FCEV	240
Table 52	Percentage of Total Energy Required in Shipping from FCEV	241
Table 53	Global Hydrogen Scenario Demand Forecast by Application.....	244
Table 54	Global Hydrogen Scenario Demand Forecast, by Region	247
Table 55	North America Hydrogen Scenario Demand Forecast by Application.....	252
Table 56	South America Hydrogen Scenario Demand Forecast by Application	257
Table 57	Western Europe Hydrogen Scenario Demand Forecast by Application	261
Table 58	Central Europe Hydrogen Scenario Demand Forecast by Application	266
Table 59	Eastern Europe Hydrogen Scenario Demand Forecast by Application.....	271
Table 60	Middle East Hydrogen Scenario Demand Forecast by Application	275
Table 61	Africa Hydrogen Scenario Demand Forecast by Application	279
Table 62	East Asia Hydrogen Scenario Demand Forecast by Application.....	284
Table 63	South Asia Hydrogen Scenario Demand Forecast by Application	289
Table 64	South-East Asia Hydrogen Scenario Demand Forecast by Application.....	294
Table 65	Oceania Hydrogen Scenario Demand Forecast by Application.....	298

Nexant Inc.

SPECIAL REPORTS

Hydrogen: Realistic Game Changer?

Special Reports analyze issues of topical importance to the energy and chemicals industry. Each special report explores the subject matter in detail to provide an up-to-date and thorough understanding of the related issue allowing investment decisions and new business strategy to be formulated.

Contact Details:

Americas:

Marcos Nogueira Cesar, Vice President, Global Products, E&CA: Nexant Subscriptions
Phone: + 1-914-609-0324, e-mail: mcesar@nexant.com

Erica Hill, Client Services Coordinator, E&CA-Products
Phone: + 1-914-609-0386, e-mail: ehill@nexant.com

EMEA:

Anna Ibbotson, Director, Nexant Subscriptions
Phone: +44-207-950-1528, aibbotson@nexant.com

Asia:

Chommanad Thammanayakatip, Managing Consultant, Energy & Chemicals Advisory
Phone: +66-2793-4606, email: chommanadt@nexant.com

Nexant, Inc. (www.nexant.com) is a leading management consultancy to the global energy, chemical, and related industries. For over 38 years, Nexant has helped clients increase business value through assistance in all aspects of business strategy, including business intelligence, project feasibility and implementation, operational improvement, portfolio planning, and growth through M&A activities. Nexant has its main offices in San Francisco (California), White Plains (New York), and London (UK), and satellite offices worldwide.

Copyright © by Nexant Inc. 2018. All Rights Reserved.