

MARKETS AND PROFITABILITY

Sustainable Aviation Fuel (SAF)

November 2023



This Report was prepared by NexantECA, the Energy and Chemicals Advisory company ("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. 2023. All rights reserved.



Contents

1	Executive Summary	1
2	Introduction	11
2.1	Overview	11
2.2	Key SAF Technologies.....	13
2.2.1	Hydrotreated Vegetable Oil (HVO).....	13
2.2.2	Alcohol-to-Jet (ATJ)	14
2.2.3	Power-to-Liquid (PTL)	14
2.2.4	Biomass Gasification-Fischer Tropsch/Other Routes	15
2.3	SAF Blending Limits and Approved Pathways.....	16
2.4	Capacity Analysis Methodology	17
3	Market Outlook	19
3.1	Global	19
3.1.1	Market Overview	19
3.1.1.1	Consumption	19
3.1.1.2	Production	21
3.1.2	Market Drivers	23
3.1.2.1	Underlying Jet Fuel Consumption Patterns	23
3.1.2.2	Regulatory Policy and Aviation Sector Initiatives.....	27
3.1.2.3	Technological Progress	35
3.1.2.4	Other	36
3.1.3	Market Constraints	36
3.1.3.1	Feedstock Constraints	36
3.1.3.2	Development of Alternative Flight Modes	40
3.1.3.3	Green Premium Relative to Conventional Jet Fuel.....	40
3.1.3.4	Infrastructure	40
3.1.3.5	Other	41
3.1.4	Competitive Landscape.....	41
3.1.5	Supply Demand and Trade	45
3.1.5.1	Total SAF	45
3.1.5.2	HVO SAF	48
3.1.5.3	ATJ SAF.....	49
3.1.5.4	PTL SAF.....	50
3.1.5.5	Other SAF	51
3.2	Asia Pacific (excl. China)	52
3.2.1	Market Overview	52
3.2.2	Market Drivers	53
3.2.3	Market Constraints	54
3.2.4	Competitive Landscape.....	55
3.2.4.1	Existing Capacity.....	55
3.2.4.2	Firm Capacity Additions	55
3.2.4.3	Speculative Capacity Additions.....	57



3.2.5	Supply, Demand and Trade	61
3.2.5.1	Total SAF	61
3.2.5.2	HVO SAF	62
3.2.5.3	ATJ SAF	63
3.2.5.4	PTL SAF	63
3.2.5.5	Other SAF	64
3.3	China	65
3.3.1	Market Overview	65
3.3.2	Market Drivers	66
3.3.3	Market Constraints	66
3.3.4	Competitive Landscape	67
3.3.4.1	Existing Capacity	67
3.3.4.2	Firm Capacity Additions	68
3.3.4.3	Speculative Capacity Additions	69
3.3.5	Supply, Demand and Trade	72
3.3.5.1	Total SAF	72
3.3.5.2	HVO SAF	73
3.3.5.3	ATJ SAF	73
3.3.5.4	PTL SAF	74
3.3.5.5	Other SAF	74
3.4	North America	75
3.4.1	Market Overview	75
3.4.2	Market Drivers	77
3.4.2.1	United States (Federal): Renewable Fuels Standard (RFS)	77
3.4.2.2	United States (Federal): Blenders' Tax Credit (BTC)	78
3.4.2.3	United States (Federal): United States SAF Grand Challenge	79
3.4.2.4	United States (State-level): California, Oregon and Washington	81
3.4.2.5	Canada (Federal): Clean Fuels Regulation and Carbon Tax	83
3.4.2.6	Canada (Federal): Aviation Climate Action Plan 2022-2030	83
3.4.2.7	Canada (State-level): British Columbia LCFS	84
3.4.3	Market Constraints	84
3.4.4	Competitive Landscape	85
3.4.4.1	Existing Capacity	85
3.4.4.2	Firm Capacity Additions	86
3.4.4.3	Speculative Capacity Additions	90
3.4.5	Supply, Demand and Trade	92
3.4.5.1	Total SAF	92
3.4.5.2	HVO SAF	94
3.4.5.3	ATJ SAF	94
3.4.5.4	PTL SAF	95
3.4.5.5	Other SAF	95
3.5	South America	96



3.5.1	Market Overview	96
3.5.2	Market Drivers	97
3.5.3	Market Constraints	97
3.5.4	Competitive Landscape	98
3.5.4.1	Existing Capacity	98
3.5.4.2	Firm Capacity Additions	98
3.5.4.3	Speculative Capacity Additions	98
3.5.5	Supply, Demand and Trade	100
3.5.5.1	Total SAF	100
3.5.5.2	HVO SAF	101
3.5.5.3	ATJ SAF	101
3.6	Western Europe	102
3.6.1	Market Overview	102
3.6.2	Market Drivers	105
3.6.2.1	EU Policy	105
3.6.2.2	EU Climate Policy: 2001-2010 – RES/Biofuels Directives & Emissions Trading Scheme	105
3.6.2.3	EU Climate Policy: 2010-2020 – CARE & RED	106
3.6.2.4	EU Climate Policy: 2021-2030 – CEF/CEE & RED II to Fit for 55 & RED III	107
3.6.3	Market Constraints	111
3.6.4	Competitive Landscape	113
3.6.4.1	Existing Capacity	113
3.6.4.2	Firm Capacity Additions	115
3.6.4.3	Speculative Capacity Additions	119
3.6.5	Supply, Demand and Trade	124
3.6.5.1	Total SAF	124
3.6.5.2	HVO SAF	125
3.6.5.3	ATJ SAF	126
3.6.5.4	PTL SAF	126
3.6.5.5	Other SAF	127
3.7	Central Europe	128
3.7.1	Market Overview	128
3.7.2	Market Drivers	130
3.7.3	Market Constraints	130
3.7.4	Competitive Landscape	131
3.7.4.1	Existing Capacity	131
3.7.4.2	Firm Capacity Additions	131
3.7.4.3	Speculative Capacity Additions	131
3.7.5	Supply, Demand and Trade	133
3.7.5.1	Total SAF	133
3.7.5.2	HVO SAF	134
3.7.5.3	ATJ SAF	134
3.7.5.4	PTL SAF	135



	3.7.5.5	Other SAF	135
3.8		Eastern Europe	136
	3.8.1	Market Overview	136
	3.8.2	Market Drivers	137
	3.8.3	Market Constraints	137
	3.8.4	Competitive Landscape.....	137
	3.8.5	Supply, Demand and Trade	138
		3.8.5.1 Total SAF	138
		3.8.5.2 HVO SAF	139
		3.8.5.3 PTL SAF.....	139
3.9		Middle East.....	140
	3.9.1	Market Overview	140
	3.9.2	Market Drivers	141
	3.9.3	Market Constraints	142
	3.9.4	Competitive Landscape.....	143
		3.9.4.1 Existing Capacity.....	143
		3.9.4.2 Firm Capacity Additions	143
		3.9.4.3 Speculative Capacity Additions.....	143
	3.9.5	Supply, Demand and Trade	145
		3.9.5.1 Total SAF	145
		3.9.5.2 HVO SAF	146
		3.9.5.3 PTL SAF.....	146
3.10		Africa	147
	3.10.1	Market Overview	147
	3.10.2	Market Drivers	147
	3.10.3	Market Constraints	148
	3.10.4	Competitive Landscape.....	149
		3.10.4.1 Existing Capacity.....	149
	3.10.5	Supply, Demand and Trade	151
		3.10.5.1 Total SAF	151
		3.10.5.2 HVO SAF	152
4		Pricing Analysis and Trends.....	153
	4.1	Pricing Basis and Mechanism	153
	4.2	Price Build Up.....	156
	4.3	Price Forecast	159
5		Cost Competitiveness.....	161
	5.1	Methodology	161
		5.1.1 Sources	161
		5.1.2 Capital Cost Elements.....	161
		5.1.2.1 Inside Battery Limits Investment	161
		5.1.2.2 Outside Battery Limits Investment	162
		5.1.2.3 Other Project Costs.....	163
		5.1.2.4 Working Capital.....	164



5.1.3	Operating Cost Elements	165
5.1.3.1	Variable Cost.....	165
5.1.3.2	Direct Fixed Costs.....	166
5.1.3.3	Allocated Fixed Costs	166
5.1.3.4	Cash Cost	166
5.1.3.5	Depreciation	167
5.1.3.6	Return on Capital Employed (ROCE)	167
5.2	Costing Basis	168
5.2.1	Location Basis	168
5.2.2	Investment Basis	168
5.3	Comparative Economics	169
5.3.1	Prices	169
5.3.2	Cases Modelled	169
5.3.3	Comparative Economics	170
5.3.3.1	Regional Comparison	170
5.3.3.2	USGC	172
5.3.3.3	Western Europe	173
5.3.3.4	Southeast Asia.....	173
5.3.3.5	China.....	174
5.3.3.6	Brazil	174
6	Market Summary	175

Figures

Figure 1	SAF Value Chain	12
Figure 2	Simplified Routes to Renewable Fuels Production	13
Figure 3	HVO Value Chain	14
Figure 4	Well to Wake Carbon Emissions for Different SAF Pathways	16
Figure 5	Global Total SAF Demand by Region, 2023-e	20
Figure 6	Global Total SAF Demand by Region	20
Figure 7	Global Total SAF Production by Region, 2023-e	22
Figure 8	Global Total SAF Production by Region.....	22
Figure 9	Global Total Kerosene/Jet Fuel Demand by Region	25
Figure 10	Global Conventional Jet Fuel and SAF Demand.....	26
Figure 11	Global CO ₂ Emissions by Sector	27
Figure 12	Global Transport Sector CO ₂ Emissions by Type, 2022	28
Figure 13	Global Net Zero Targets	29
Figure 14	Summary of Key Policies Supporting SAF Demand	31
Figure 15	IATA Implied SAF Demand for Net Zero 2050	34
Figure 16	Total SAF Offtake Agreements by Airlines by Offtake Volume	35
Figure 17	Global HVO Feedstock Requirement & Production	39
Figure 18	Global SAF Capacity by Region, 2023-e.....	42
Figure 19	Global SAF Capacity by Producer, 2023-e	42
Figure 20	Global SAF Capacity by Region	43
Figure 21	Global SAF Capacity Growth.....	44



Figure 22	Global SAF Capacity by Pathway	45
Figure 23	Global Total SAF Supply, Demand and Net Trade	46
Figure 24	Global Total SAF Net Trade by Region	47
Figure 25	Global HVO SAF Supply, Demand and Net Trade	48
Figure 26	Global HVO SAF Net Trade by Region	48
Figure 27	Global ATJ SAF Supply, Demand and Net Trade	49
Figure 28	Global ATJ SAF Net Trade by Region	49
Figure 29	Global PTL SAF Supply, Demand and Net Trade	50
Figure 30	Global PTL SAF Net Trade by Region	50
Figure 31	Global Other SAF Supply, Demand and Net Trade	51
Figure 32	Global Other SAF Net Trade by Region	51
Figure 33	Asia Pacific (excl. China) Total SAF Demand Growth by Pathway	52
Figure 34	Asia Pacific (excl. China) Conventional Jet Fuel and SAF Demand	53
Figure 35	Asia Pacific (excl. China) SAF Capacity Growth	59
Figure 36	Asia Pacific (excl. China) SAF Capacity Growth by Pathway	60
Figure 37	Asia Pacific (excl. China) Total SAF Supply, Demand and Net Trade	61
Figure 38	Asia Pacific (excl. China) HVO SAF Supply, Demand and Net Trade	62
Figure 39	Asia Pacific (excl. China) ATJ SAF Supply, Demand and Net Trade	63
Figure 40	Asia Pacific (excl. China) PTL SAF Supply, Demand and Net Trade	63
Figure 41	Asia Pacific (excl. China) Other SAF Supply, Demand and Net Trade	64
Figure 42	China Total SAF Demand Growth by Pathway	65
Figure 43	China Conventional Jet Fuel and SAF Demand	65
Figure 44	China SAF Capacity by Operator, 2023-e	68
Figure 45	China SAF Capacity Growth	70
Figure 46	Asia Pacific (excl. China) SAF Capacity Growth by Pathway	71
Figure 47	China Total SAF Supply, Demand and Net Trade	72
Figure 48	China HVO SAF Supply, Demand and Net Trade	73
Figure 49	China ATJ SAF Supply, Demand and Net Trade	73
Figure 50	China PTL SAF Supply, Demand and Net Trade	74
Figure 51	China Other SAF Supply, Demand and Net Trade	74
Figure 52	North America Total SAF Demand Growth by Pathway	75
Figure 53	North America Conventional Jet Fuel and SAF Demand	76
Figure 54	RFS Volume Targets	78
Figure 55	United States SAF Grand Challenge Action Areas	80
Figure 56	LCFS Carbon Intensity Requirement	81
Figure 57	LCFS Credit Generation by Type	82
Figure 58	North America SAF Capacity by Operator, 2023-e	86
Figure 59	North America SAF Capacity Growth	91
Figure 60	North America SAF Capacity Growth by Pathway	92
Figure 61	North America Total SAF Supply, Demand and Net Trade	93
Figure 62	North America HVO SAF Supply, Demand and Net Trade	94
Figure 63	North America ATJ SAF Supply, Demand and Net Trade	94
Figure 64	North America PTL SAF Supply, Demand and Net Trade	95
Figure 65	North America Other SAF Supply, Demand and Net Trade	95



Figure 66	South America Total SAF Demand Growth by Pathway	96
Figure 67	South America Conventional Jet Fuel and SAF Demand	96
Figure 68	South America SAF Capacity Growth	99
Figure 69	South America SAF Capacity Growth by Pathway	99
Figure 70	South America Total SAF Supply, Demand and Net Trade	100
Figure 71	South America HVO SAF Supply, Demand and Net Trade	101
Figure 72	South America ATJ SAF Supply, Demand and Net Trade.....	101
Figure 73	Western Europe SAF Demand Growth by Pathway	102
Figure 74	Western Europe Conventional Jet Fuel and SAF Demand	103
Figure 75	Western Europe Total SAF Demand vs RefuelEU Mandates.....	104
Figure 76	Western Europe PTL SAF Demand vs RefuelEU Sub-Mandates	104
Figure 77	Western Europe SAF Capacity by Operator, 2023-e	115
Figure 78	Western Europe SAF Capacity Growth.....	122
Figure 79	Western Europe SAF Capacity Growth by Pathway	123
Figure 80	Western Europe Total SAF Supply, Demand and Net Trade.....	124
Figure 81	Western Europe HVO SAF Supply, Demand and Net Trade	125
Figure 82	Western Europe ATJ SAF Supply, Demand and Net Trade	126
Figure 83	Western Europe PTL SAF Supply, Demand and Net Trade	126
Figure 84	Western Europe Other SAF Supply, Demand and Net Trade.....	127
Figure 85	Central Europe Total SAF Demand Growth by Pathway	128
Figure 86	Central Europe Conventional Jet Fuel and SAF Demand.....	129
Figure 87	Central Europe Total SAF Demand vs RefuelEU Mandates.....	129
Figure 88	Central Europe PTL SAF Demand vs RefuelEU Sub-Mandates	130
Figure 89	Central Europe SAF Capacity Growth.....	132
Figure 90	Central Europe SAF Capacity Growth by Pathway	132
Figure 91	Central Europe Total SAF Supply, Demand and Net Trade	133
Figure 92	Central Europe HVO SAF Supply, Demand and Net Trade.....	134
Figure 93	Central Europe ATJ SAF Supply, Demand and Net Trade	134
Figure 94	Central Europe PTL SAF Supply, Demand and Net Trade	135
Figure 95	Central Europe Other SAF Supply, Demand and Net Trade	135
Figure 96	Eastern Europe Total SAF Demand Growth by Pathway	136
Figure 97	Eastern Europe Conventional Jet Fuel and SAF Demand.....	136
Figure 98	Eastern Europe Total SAF Supply, Demand and Net Trade.....	138
Figure 99	Eastern Europe HVO SAF Supply, Demand and Net Trade	139
Figure 100	Eastern Europe PTL SAF Supply, Demand and Net Trade	139
Figure 101	Middle East SAF Demand Growth by Pathway.....	140
Figure 102	Middle East Conventional Jet Fuel and SAF Demand	141
Figure 103	Middle East SAF Capacity Growth	144
Figure 104	Middle East SAF Capacity Growth by Pathway	144
Figure 105	Middle East Total SAF Supply, Demand and Net Trade	145
Figure 106	Middle East HVO SAF Supply, Demand and Net Trade	146
Figure 107	Middle East PTL SAF Supply, Demand and Net Trade	146
Figure 108	Africa SAF Demand Growth by Pathway	147
Figure 109	Africa Conventional Jet Fuel and SAF Demand	147



Figure 110	Africa SAF Capacity Growth	149
Figure 111	Africa SAF Capacity Growth by Pathway	150
Figure 112	Africa Total SAF Supply, Demand and Net Trade	151
Figure 113	Africa HVO SAF Supply, Demand and Net Trade	152
Figure 114	Historical D4 RIN Prices and SAF RIN Values	155
Figure 115	Historical Average Annual LCFS Credit Prices & Credit Price Cap	156
Figure 116	SAF Price Build Up via HVO Pathway in USWC	157
Figure 117	SAF & Fossil Kerosene/Jet Fuel Pricing by Key Region	158
Figure 118	USWC SAF Price Projections	159
Figure 119	NWE SAF Price Projections (pegged to US?)	160
Figure 120	SEA SAF Price Projections	160
Figure 121	Regional Competitiveness of HVO Technology by Region	170
Figure 122	Regional Competitiveness of ATJ Technology by Region	171
Figure 123	Regional Competitiveness of BG-FT Technology by Region	171
Figure 124	Regional Competitiveness of PTL Technology by Region	172
Figure 125	Overall Comparative Cost of Production, United States	172
Figure 126	Overall Comparative Cost of Production, Western Europe	173
Figure 127	Overall Comparative Cost of Production, Southeast Asia	173
Figure 128	Overall Comparative Cost of Production, Southeast Asia	174
Figure 129	Overall Comparative Cost of Production, Brazil	174
Figure 130	Porter 5 Force Analysis of SAF Producer	175

Tables

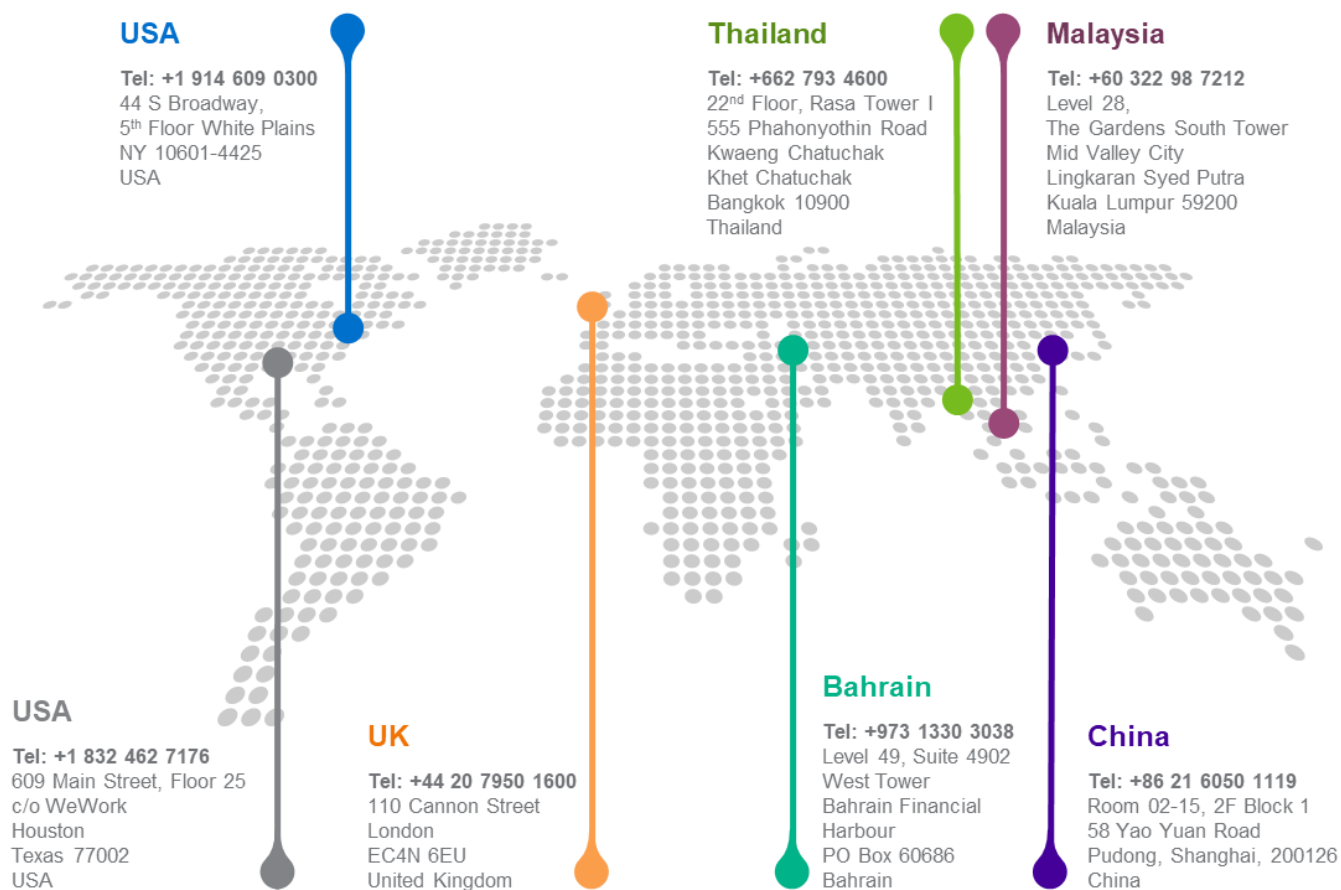
Table 1	SAF Approval Status under ASTM D7566	17
Table 2	Global Total SAF Demand by Region	19
Table 3	Global Total SAF Production by Region	21
Table 4	Selected Policy Options to Promote SAF Uptake	30
Table 5	Airlines with Announced SAF Commitment Targets	35
Table 6	Global SAF Supply, Demand and Net Trade	47
Table 7	Asia Pacific (excl. China) Firm SAF Capacity	57
Table 8	Asia Pacific (excl. China) Total SAF Supply, Demand and Net Trade	62
Table 9	China Firm SAF Capacity	69
Table 10	China Total SAF Supply, Demand and Net Trade	72
Table 11	North America Firm SAF Capacity	89
Table 12	North America Total SAF Supply, Demand and Net Trade	93
Table 13	South America Firm SAF Capacity	98
Table 14	South America Total SAF Supply, Demand and Net Trade	100
Table 15	RefuelEU Aviation Regulation Mandates	110
Table 16	Selected National Level SAF Mandates in Western Europe	111
Table 17	Western Europe Firm SAF Capacity	119
Table 18	Western Europe Total SAF Supply, Demand and Net Trade	125
Table 19	Central Europe Firm SAF Capacity	131
Table 20	Central Europe Total SAF Supply, Demand and Net Trade	133
Table 21	Eastern Europe Total SAF Supply, Demand and Net Trade	138



Table 22	Middle East Firm SAF Capacity.....	143
Table 23	Middle East Total SAF Supply, Demand and Net Trade	145
Table 24	Africa Total SAF Supply, Demand and Net Trade	151
Table 25	Raw Material Prices.....	169
Table 26	Utility Prices.....	169



NexantECA partners with clients to help them navigate the big global energy, chemicals and materials issues of tomorrow. We provide independent advice through our consulting, subscriptions and reports, and training businesses using expertise developed in markets, economics and technology through our fifty years of operation. We are entirely dedicated to supporting sustainable development of the industry and provide expert advice with efficiency, speed, and agility.



Disclaimer

This Report was prepared by NexantECA, the Energy and Chemicals Advisory company. Except where specifically stated otherwise in this Report, the information contained here is prepared on the basis of information that is publicly available, and contains no confidential third-party technical information to the best knowledge of NexantECA. Aforesaid information has not been independently verified or otherwise examined to determine its accuracy, completeness or financial feasibility. Neither NexantECA, Client nor any person acting on behalf of either assumes any liabilities with respect to the use of or for damages resulting from the use of any information contained in this Report. NexantECA does not represent or warrant that any assumed conditions will come to pass.