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Advanced Technologies for Blue Ammonia

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Table of contents

Abstract 10

1 Introduction 11

2 Summary 13

Commercial aspects 14

Technical aspects 14

Process summary 14

Process design summary 15

Process economics 16

Economics calculation modules for non-US regions 19

Environmental footprint 19

3 Industry status 21

4 Technology review 24

Blue ammonia 25

Technology 26

Hydrogen production 26

Ammonia synthesis 29

8 Rivers Capital LLC 29

$8RH_2$ ammonia synthesis process 29

$8RH_2$ technology 29

Casale SA 35

Casale SA's ammonia technology 36

Air Liquide — Blue ammonia technology with Cryocap™ (collaboration with KBR for synthesis loop) 38

Cryocap™ H_2 39

KBR ammonia synthesis 43

Johnson Matthey (JM) — LCH™ technology collaboration with thyssenkrupp Uhde's (Uhde) ammonia synthesis 45

JM — LCH™ technology 45

ATR-only LCH™ configuration 45

Uhde's ammonia synthesis 48

JM's LCH™ with Uhde's ammonia synthesis design selection criteria 49

5 Blue ammonia — $8RH_2$ and Casale SA's ammonia synthesis 50

Process overview 50

Description 51

Process description 53

Section 100 — Hydrogen production 53
Section 200 — Ammonia production 54
Process discussion 58
Feedstock and pretreatment 58
Reforming 58
Water-gas shift (WGS) 59
Nitrogen and oxygen generation 59
CO_2 capture and compression 59
Waste heat recovery 59
Refrigeration cycles 60
Ammonia storage 60
Material of construction 60
Cost estimates 64
Fixed capital costs 64
Production costs 65
6 Blue ammonia — Air Liquide's (Cryocap™ H_2) and KBR's ammonia synthesis 70
Process overview 70
Description 73
Process description 73
Section 100 — Hydrogen production 73
Section 200 — Ammonia production 74
Process discussion 80
Feedstock and pretreatment 80
Reforming 80
Water-gas shift (WGS) 80
Nitrogen and oxygen generation 80
CO_2 capture 80
Waste heat recovery 81
Refrigeration cycles 82
Ammonia converter 82
Ammonia storage 82
Material of construction 82
Cost estimates 86
Fixed capital costs 86
Production costs 87
7 Blue Ammonia — Johnson Matthey's LCH™and thyssenkrupp Uhde's high-pressure ammonia synthesis 92
Description 93
Process description 95

Section 100 — Hydrogen production 95
Section 200 — Carbon dioxide capture unit 96
Section 300 — Ammonia production 97
Process discussion 102
Feedstock and pretreatment 102
Design selection criteria 102
Reforming 102
Water-gas shift (WGS) 103
Nitrogen and oxygen generation 103
CO_2 capture and compression 103
Waste heat recovery 104
Refrigeration cycles 104
Ammonia storage 105
Material of construction 105
Cost estimates 108
Fixed capital costs 108
Production costs 109
Appendix A — Design and cost basis 114
Design conditions 115
Cost basis 115
Capital investment 115
Project construction timing 116
Available utilities 116
Production costs 117
Effect of operating level on production costs 117
Appendix B — Cited references 118
Appendix C — Process flow diagrams 122

Tables

Table 2.1 Process design summary for blue ammonia technologies 15
Table 2.2 Overall comparison of blue ammonia production processes — TFC investment 16
Table 2.3 Overall comparison of blue ammonia production technologies — Production cost ($/t) 17
Table 2.4 Carbon and water footprint 20
Table 3.1 Global announced blue ammonia projects 22
Table 4.1 Comparison of carbon capture efficiency 27
Table 4.2 Performance summary of various configuration of $8RH_2$ ammonia synthesis 32
Table 4.3 Performance of membranes 42
Table 4.4 Typical process parameters — LCH™ (ATR-only) 46
Table 4.5 Typical process parameters — ATR + GHR 47
Table 4.6 Process parameters for ammonia synthesis 49
Table 5.1 Blue ammonia — $8RH_2$ and Casale SA's ammonia synthesis: Design basis/assumptions 51

Table 5.2 Blue ammonia — 8RH$_2$ and Casale SA's ammonia synthesis: Mainstream flows 55
Table 5.2 Blue ammonia — 8RH$_2$ and Casale SA's ammonia synthesis: Mainstream flows (continued) 56
Table 5.2 Blue ammonia — 8RH$_2$ and Casale SA's ammonia synthesis: Mainstream flows (continued) 57
Table 5.2 Blue ammonia — 8RH$_2$ and Casale SA's ammonia synthesis: Mainstream flows (continued) 57
Table 5.2 Blue ammonia — 8RH$_2$ and Casale SA's ammonia synthesis: Mainstream flows (concluded) 58
Table 5.3 Blue ammonia — 8RH$_2$ and Casale SA's ammonia synthesis: Major equipment 61
Table 5.4 Blue ammonia — 8RH$_2$ and Casale SA's ammonia synthesis: Utilities summary 64
Table 5.5a Blue ammonia — 8RH$_2$ and Casale SA's ammonia synthesis: Total capital investment 66
Table 5.5b Blue ammonia — 8RH$_2$ and Casale SA's ammonia synthesis: Capital investment by section 67
Table 5.6a Blue ammonia — 8RH$_2$ and Casale SA's ammonia synthesis: Variable costs 67
Table 5.6b Blue ammonia — 8RH$_2$ and Casale SA's ammonia synthesis: Production costs 68
Table 6.1 Blue ammonia — Air Liquide's Cryocap™ and KBR's ammonia synthesis: Design basis assumptions 71
Table 6.2 Blue ammonia — Air Liquide's Cryocap™ and KBR's ammonia synthesis: Mainstream flows 76
Table 6.3 Blue ammonia — Air Liquide's Cryocap™ and KBR's ammonia synthesis: Refrigeration cycle details 82
Table 6.4 Blue ammonia — Air Liquide's Cryocap™ and KBR's ammonia synthesis: Major equipment 83
Table 6.5 Blue ammonia — Air Liquide's Cryocap™ and KBR's ammonia synthesis: Utilities summary 86
Table 6.6a Blue ammonia — Air Liquide's Cryocap™ and KBR's ammonia synthesis: Total capital investment 88
Table 6.6b Blue ammonia — Air Liquide's Cryocap™ and KBR's ammonia synthesis: Capital investment by section 89
Table 6.7a Blue ammonia — Air Liquide's Cryocap™ and KBR's ammonia synthesis: Variable costs 90
Table 6.7b Blue ammonia — Air Liquide's Cryocap™ and KBR's ammonia synthesis: Production costs 90
Table 7.1 Blue ammonia — JM's LCH™ and Uhde's high-pressure ammonia synthesis: Design basis/ assumptions 94
Table 7.2 Blue ammonia — JM's LCH™ and Uhde's high-pressure ammonia synthesis: Mainstream flows 98
Table 7.3 Blue ammonia — JM's LCH™ and Uhde's high-pressure ammonia synthesis: Refrigeration cycle details 104
Table 7.4 Blue ammonia — JM's LCH™ and Uhde's high-pressure ammonia synthesis: Major equipment 105
Table 7.5 Blue ammonia — JM's LCH™ and Uhde's high-pressure ammonia synthesis: Utilities summary 108
Table 7.6a Blue ammonia — JM's LCH™ and Uhde's high-pressure ammonia synthesis: Total capital investment 110
Table 7.7a Blue ammonia — JM's LCH™ and Uhde's high-pressure ammonia synthesis: Variable costs 112
Table 7.7b Blue ammonia — JM's LCH™ and Uhde's high-pressure ammonia synthesis: Production costs 112

Figures

Figure 2.1 Comparative analysis of blue ammonia net production cost versus CO_2 credit 18
Figure 2.2 Comparative analysis of blue ammonia net production cost vs. natural gas price 19
Figure 4.1 Main uses of ammonia — Conventional 24
Figure 4.2 Emerging uses of ammonia for decarbonization 25
Figure 4.3 Schematic for 8RH$_2$ technology 30
Figure 4.4 Flowchart for hydrogen production process — 8 Rivers Capital LLC 31
Figure 4.5 Oxy-fuel combustor — 8 Rivers Capital LLC 34
Figure 4.6 CO_2 convective reformer — 8 Rivers Capital LLC 35
Figure 4.7 Casale SA's ammonia synthesis loop 37
Figure 4.8 Casale SA's ammonia multibed converter 38
Figure 4.9 Air Liquide's autothermal reforming with Cryocap™ H_2 40
Figure 4.10 Schematic for cryogenic CO_2 separation — Air Liquide 41
Figure 4.11 KBR's conventional ammonia synthesis loop 44
Figure 4.12 KBR horizontal ammonia synthesis converter 45
Figure 4.13 Comparison of JM's LCH™ technology with SMR+CO_2 capture 48
Figure 4.14 Uhde's low-energy ammonia synthesis 48
Figure 5.1 Block flow diagram for blue ammonia — 8RH$_2$ and Casale SA ammonia synthesis 51

Figure 5.2 8RH$_2$ ammonia synthesis — Steam network 60
Figure 5.3 Effect of captured CO_2 price on ammonia production cost — 8RH$_2$ ammonia synthesis 69
Figure 6.1 Block flow diagram for blue ammonia — Air Liquide's Cryocap™ and KBR's ammonia synthesis 71
Figure 6.2 Blue ammonia — Air Liquide's Cryocap™ and KBR's ammonia synthesis: Steam network 81
Figure 6.3 Effect of captured CO_2 price on ammonia production cost — Air Liquide's Cryocap™ and KBR's ammonia synthesis 91
Figure 7.1 Block flow diagram for blue ammonia — JM's LCH™ and Uhde's high-pressure ammonia synthesis 93
Figure 7.2 Effect of captured CO_2 price on ammonia production cost — JM's LCH™ and Uhde's high-pressure ammonia synthesis 113

Appendix C Figures

Figure C1 Blue ammonia — 8RH$_2$ and Casale SA's ammonia synthesis: Section 100 hydrogen production (1 of 2) 123
Figure C1 Blue ammonia — 8RH$_2$ and Casale SA's ammonia synthesis: Section 200 ammonia production (2 of 2) 124
Figure C2 Blue ammonia — Air Liquide's and KBR's ammonia synthesis: Section 100 hydrogen production (1 of 2) 125
Figure C2 Blue ammonia — Air Liquide's and KBR's ammonia synthesis: Section 200 ammonia production (2 of 2) 126
Figure C3 Blue ammonia — JM's LCH™ and Uhde's high-pressure ammonia synthesis: Section 100 hydrogen production (1 of 3) 127
Figure C3 Blue ammonia — JM's LCH™ and Uhde's high-pressure ammonia synthesis: Section 200 Carbon dioxide capture (2 of 3) 128
Figure C3 Blue ammonia — JM's LCH™ and Uhde's high-pressure ammonia synthesis: Section 300 ammonia production (3 of 3) 129

Glossary

¢/lb	Cents per pound
¢/MMBtu	Cents per million British thermal unit
$/t	Dollars per metric ton
AFC	Allam-Fetvedt Cycle
ASU	Air separation unit
atm	Atmospheres
ATR	Autothermal reformer
bara	Bar absolute pressure
Bcm	Billion cubic meters
BFD	Block flow diagram
BFW	Boiler feed water
bhp	brake horse power
BLI	Battery limits investment
Btu	British thermal units
°C	Degree Celsius
CAP	Chilled ammonia process
Capex	capital expenditure
CCR	CO_2 convective reformer
CCS	Carbon capture and storage/sequestration
CCUS	Carbon capture utilization and storage/sequestration
CSIRO	Commonwealth Scientific and Industrial Research Organization
cP	Centipoise
cf/ft^3	Cubic feet
CW	Cooling water
DAC	Direct air capture
EJ	exajoule
EPC	engineering, procurement, and construction
EOR	Enhanced oil recovery
°F	Degree Fahrenheit
FID	Final investment decision
FOB	Freight on board
g	Grams
gal	gallons
Mgal	Thousand gallons
MPa	megapascal
G&A	General and administrative
GHG	greenhouse gases
GHR	Gas-heated reformer
gpm	Gallons per minute
h	Hours
HP	high-pressure
HHP	high high-pressure
HHV	High heating value
HTS	High-temperature shift
HVAC	Heating ventilation and air conditioning
IC	Internal combustion
ISBL	Inside battery limits
ITS	Isothermal shift
JM	Johnson Matthey
kg	Kilograms
$kgCO_2e$	Kilograms of carbon dioxide equivalent
kJ	Kilojoules
kPa	Kilopascals
kNm^3h	Kilo normal cubic meter per hour

kt	kilotons
KTPA	Kilotons per annum
kW	Kilowatt
kWh/Nm^3	Kilowatt-hour per normal cubic meter
lb	pound
lb/h	pounds per hour
lb/MMscf	Pounds per million standard cubic feet
LCH	Low-carbon hydrogen
LHV	Lower heating value
LP	low-pressure
LPG	Liquefied petroleum gas
LTS	Low-temperature shift
MDEA	Methyl diethanolamine
mgal	Thousand gallons
mlb	Thousand pounds
MMBtu	Million British thermal unit
MMlb/y	Million pounds per year
MMscfd	Million standard cubic feet per day
MMt	Million metric tons
MMt/d	Million metric tons per day
MMt/y	Million metric tons per year
mol%	Molar percent
MP	Medium-pressure
mPa	Megapascals
MWe	Megawatt-electric
NG	Natural gas
NNF	Normally no flow
OBBBA	One big beautiful bill act
OSBL	outside battery limits
Opex	operating expenditure
OSR	Oxygen secondary reformer
PDD-TFE	Perfluorodioxole–tetrafluoroethylene
PDMS	Polydimethylsiloxane
PEP	Process Economics Program
PFD	Process flow diagram
PGRU	Purge gas recovery unit
ppb	Parts per billion
ppm	Parts per million
ppmv	Part per million by volume
PSA	Pressure swing adsorption
psi	Pounds per square inch
psia	Pounds per square inch absolute
psig	Pounds per square inch gauge
ROI	Return on investment
s	Second(s)
S/C	Steam-to-carbon
scf	Standard cubic feet
scm	Standard cubic meter
SMR	Steam methane reformer
Sqft	square feet
SS	Stainless steel
t	Metric ton
t/d	Metric tons per day
t/y	Metric tons per year
TFC	Total fixed cost

U&S	Utility and storage
Uhde	thyssenkrupp Uhde
USGC	US Gulf Coast
vol%	Volume percent
w/w	Weight for weight
WGS	Water-gas shift

Abstract

Ammonia serves as a vital building block for various industrial processes, particularly in the production of fertilizers, chemicals, and explosives. However, traditional methods for producing grey ammonia are energy-intensive and heavily reliant on fossil fuels, contributing approximately 1% to 2% of the global greenhouse gas emissions.

As a result, low-carbon methods for ammonia production are gaining considerable attention for their potential to reduce carbon footprints. Additionally, ammonia is being recognized globally as a promising energy vector, primarily due to its ability to efficiently store and transport hydrogen, as well as its higher energy density compared to compressed hydrogen gas. With an established infrastructure for production, storage, and transportation, ammonia can act as a medium for renewable energy storage and long-distance transport, addressing the limitations of battery technologies and direct hydrogen use.

This increased interest is driving the development of new technologies and plant configurations for ammonia production. One such method is blue ammonia, which captures carbon dioxide from conventional steam methane reforming or autothermal reforming and the Haber-Bosch process. This approach provides a means to decarbonize existing ammonia and fertilizer operations by integrating carbon capture, utilization, and storage (CCUS) technology into these facilities.

This report focuses on the techno-economic analysis of advanced technology pathways aimed at reducing the carbon footprint associated with ammonia production. It presents an analysis of three commercial processes for producing blue ammonia:

- Blue ammonia — 8RH_2 and Casale SA's ammonia synthesis
- Blue ammonia — Air Liquide's (Cryocap™ H_2) and KBR's ammonia synthesis
- Blue ammonia — Johnson Matthey's (JM) (low-carbon hydrogen [LCH™] technology) and thyssenkrupp Uhde's (Uhde) high-pressure ammonia synthesis

In addition to covering the three processes mentioned, the report will provide an overview of the latest advancements in technologies and strategies being adopted by the industry to reduce the carbon intensity of ammonia production, with a focus on technology readiness. Along with the process technology, this report includes the process flow diagram (PFD), material balance, major equipment list with specifications, capital and operating expenditure, and the overall production cost for producing blue ammonia.

The production economics assessment in this report is based on a US Gulf Coast (USGC) location. However, an iPEP Navigator module (an Excel-based computer costing model developed by S&P Global) will be attached with this report to allow a quick calculation of the process economics for three other major regions: Germany, Japan, and mainland China. The module also provides production economics for every process to be reported in English or metric units in each region.

The technological and economic assessment of the processes is Process Economics Program's (PEP) independent interpretation of the companies' commercial processes based on information presented in the open literature, such as patents or technical articles. It may not reflect the actual plant configuration in whole or in part. We believe they are sufficiently representative of the processes and process economics within the range of accuracy necessary for economic evaluations of the conceptual process design.

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