PROVARIS

Media & ASX Announcement | 22 May 2023

New Hydrogen Supply Chain study highlights overwhelming benefits of compression for marine transport

HIGHLIGHTS:

- Provaris' latest report compares the delivery cost of hydrogen for three hydrogen energy vectors (compression, liquefaction, and ammonia) when integrated with a variable renewable energy profile to produce hydrogen.
- Energy use and losses across the entire supply chain (generation, production, and delivery) associated with liquefaction and ammonia exceed 40%, while compression remains below 20%.
- Compression is the most cost-effective option for regional transport distances from 500 to 4000 nautical miles with volumes of up to 500,000 tonnes per annum (tpa).
- Liquefaction and ammonia suffer from high levels of renewable energy curtailment, energy use in the conversion process (20-30% loss), and energy use in the conversion back to gaseous hydrogen upon delivery (5-30% loss).
- Compression is the most compatible with variable renewable generation profiles as it can fully "load follow", eliminating additional capex required for "battery and hydrogen storage" to manage variability.
- A bulk-scale hydrogen storage solution is required regardless of the hydrogen energy vector selected, and the recent launch of Provaris' proprietary H2Leo floating storage solution is a low-cost alternative for hydrogen storage.
- Compression is a compelling solution for regional green hydrogen trade to support the REPowerEU requirement for 10Mtpa imports by 2030.

SYDNEY: Provaris Energy Ltd (ASX.PV1) (Provaris, or **the Company)** is excited to announce the successful completion of its 2023 Hydrogen Marine Transport Comparison Report (the Report). The findings of the Report further solidify the numerous advantages of the compressed storage and maritime transport hydrogen supply chain and highlight that compression is a viable alternative and low-cost delivery method for the regional transport of hydrogen.

Martin Carolan, Provaris Managing Director and CEO commented: *"We are witnessing a remarkable increase in awareness and comprehension of some of the formidable challenges associated with delivering green hydrogen and the need for scalable solutions before 2030. Relying predominantly on ammonia supply chains to deliver hydrogen is not necessarily an efficient solution for governments and industries that require gaseous hydrogen to achieve emission reduction targets.*

Given the urgency to take immediate action and expedite the development of supply chains, compression emerges as a key enabler that can unlock the potential of renewable resources and deliver substantial volumes to regional markets while maintaining favourable economic returns. In contrast, the liquefaction and ammonia alternatives present less favourable economics.

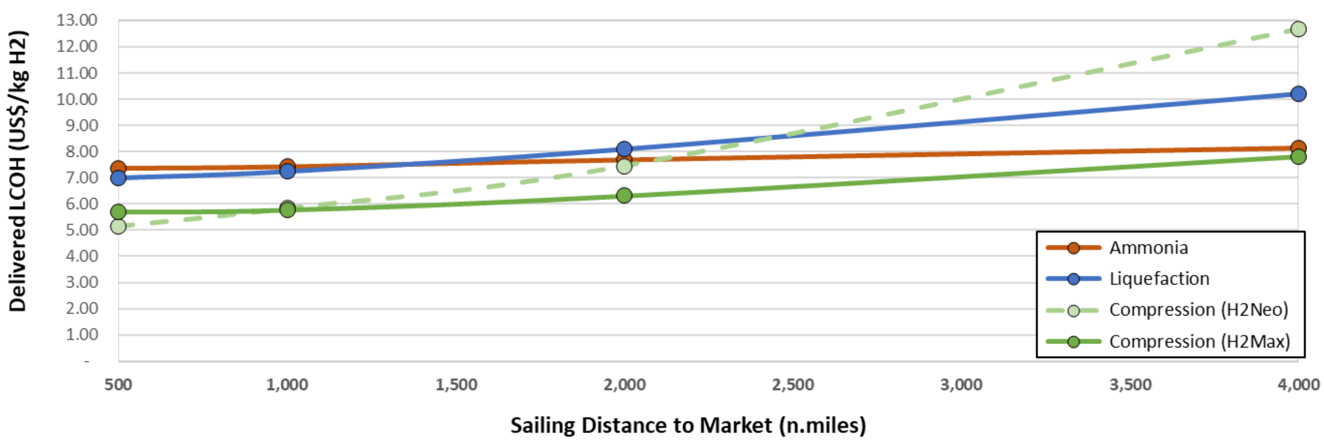
By embracing compression as a crucial element in our hydrogen infrastructure, we ensure a swifter realisation of emission targets for hard to abate sectors and effectively address the challenges we have ahead of us."

Garry Triglavcanin, Provaris Chief Development Officer added: *"A key objective of this Report was to understand and identify each of the components that together delivered the complete "generation, production and delivery" vector supply chain for marine transport as either compressed gas, liquefied, or ammonia, relying on renewable power generation.*

One of the key outcomes of the Report confirms that hydrogen produced from a renewable energy resource and delivered by marine transport either required: i) a process such as compression that was suitable to "load follow" the variability of the renewable generation profile; or ii) for liquefaction and ammonia, to the installation of a significant level of "battery and hydrogen storage" capacity to enable the hydrogen to be export ready. The latter was found to have a significant impact on the cost of producing green hydrogen."

Provaris has consistently emphasized the importance of understanding the overall efficiency of the complete hydrogen supply chain, from renewable electricity generation through to hydrogen production and delivery to the end customer. This Report precisely identifies the energy use and losses associated with each hydrogen energy vector (compression, liquefaction and ammonia) and the significant impact they have on the full delivered cost of hydrogen. Liquid Organic Hydrogen Carriers have not been considered in the comparison as they are considered only to be a viable alternative for specific production and use cases.

Figure 1: LCOH results for a combined solar/wind generation profile to deliver 100,000 tpa hydrogen



This comprehensive analysis underscores the compelling advantages of compression, the supply chain efficiency, and its potential to simplify and revolutionize regional transportation of hydrogen. Provaris is confident that these findings will drive further adoption and accelerate the hydrogen industry towards a sustainable and economic solution.

Importantly the report ratifies that Provaris' proprietary H2Neo (430t) and H2Max (2,000t) compressed hydrogen carriers and H2Leo compressed storage barge provide a highly competitive marine transportation (and storage) option for hydrogen, at scale over shipping distances of up to 4,000 nautical miles.

An extract of the Report is made available in the appendix of this ASX and Media announcement. Refer to page 4.

For further information on the details of this Report, please email info@provaris.energy

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This announcement has been authorised for release by the Board of Provaris Energy Ltd.

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About Provaris Energy

Provaris Energy Ltd (ASX: PV1) | www.provaris.energy

Provaris Energy Ltd (ASX: PV1) is developing a portfolio of integrated green hydrogen projects in the regional trade of Asia and Europe, leveraging our innovative compressed hydrogen bulk carrier. Our focus on value creation through innovative development that aligns with our business model of simplicity and efficiency. The choice to support all development phases of a project is in line with Provaris' strategic desire to develop and invest in profitable hydrogen projects across the value chain, establish an early-mover advantage for regional maritime trade of hydrogen, and to retain an equity position of these assets over the long term. With offices in Sydney, Perth and Oslo, the company's integrated approach to producing and transporting hydrogen can unlock a world of potential.

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Hydrogen Transport Comparison Report: Compression, Liquefaction and Ammonia

"Impacts on the levelised cost across the entire supply chain"

May 2023 | Report Extract

Author: Provaris Energy Ltd

For further information on the details of this Report, please email info@provaris.energy

BACKGROUND AND OBJECTIVES

In 2021, Provaris released the outcome of a Scoping Study which compared compression, liquefaction, and ammonia as marine transport (transport vectors) for hydrogen. The study made a key assumption that: *"each Vector had 24/7 access to a base load supply of both electricity (kWh) and hydrogen (kg) volumes"*.

However, in 2023, following the completion of Prefeasibility level studies for hydrogen projects produced from renewable energy sources, the assumption was replaced with *"each Vector sourced its hydrogen supply from an electrolyser, which is connected to a variable renewable energy source (either hydro, solar, wind or solar/wind). Therefore, hourly hydrogen production rates are based on load following the hourly generation profile of the renewable generation type and profile selected"*.

A primary objective of this Report was to comprehensively understand and identify all the components involved in the complete "generation, production and delivery" Vector supply chain, relying mostly (95%) on renewable generation. Provaris has revised the capital and operating costs and efficiency assumptions based on the latest up-to-date industry knowledge and Provaris' internal knowledge base.

This latest report specifically analyses the impact of renewable energy generation variability on the LCOH of each vector, considering short-term (hourly), daily, and seasonal (monthly) variations. To ensure a standardized analysis, the Levelised Cost of Electricity (LCOE) was set to 3.00c US$/kWh, allowing for a specific focus on the impact of variability rather than comparing LCOE between types.

THIS EXTRACT OF THIS REPORT INCLUDES:

1. **DELIVERY OF HYDROGEN IS ABOUT EFFICIENCY AND LOSSES IN THE PROCESS – NOT JUST THE ENERGY CONTENT OF THE CARRIER**
2. **COMPONENTS TO CREATE A REALISTIC HYDROGEN SUPPLY CHAIN**
3. **BENEFIT OF LOAD FOLLOWING THE RENEWABLE GENERATION**
4. **LCOH ANALYSIS ACROSS DIFFERENT GENERATION PROFILES**
5. **REQUIREMENTS FOR HYDROGEN STORAGE**
6. **APPENDIX A: Illustration of Supply Chain Efficiency for each Vector**
7. **APPENDIX B: Illustration of Supply Chain Vector Process – Compression, Liquefaction & Ammonia**
8. **APPENDIX C: LCOH Comparison Results for each Generation Profile: Solar, Solar/Wind, Wind, Hydro**

1. Delivery of Hydrogen is About Efficiency and Losses in the Process – Not Just the Energy Content of the Carrier

There is a long-standing perspective of the energy sector that a transport carrier of energy is solely determined by the energy content it can carry. This has carried over to the hydrogen sector and fails to consider the efficiency and losses inherent in hydrogen production, transportation, and distribution processes.

Provaris has consistently advocated that the efficiency of the entire value chain must be considered, not just the hydrogen energy content (MWh/m3) as shown in the table below. The entire value chain must be considered, not just the higher energy content (MWh/m3) of liquid hydrogen and/or ammonia as shown in the table below.

	Compressed H2 (250 bar)	**Liquid Hydrogen**	**Liquid Ammonia**
Energy Content	0.56 MWh/m^3	2.30 MWh/m^3	3.58 MWh/m^3

One of the issues this Report seeks to highlight is whether the scale-up of the hydrogen economy can ignore the costs and energy use/losses associated with the conversion and reconversion processes required for liquefaction and ammonia when the solution should be about lowering the cost of delivered hydrogen.

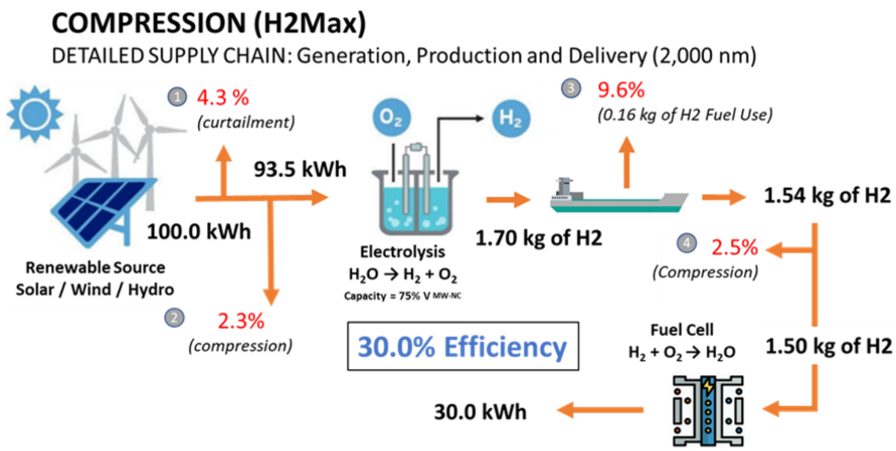
Highlighted in the table below, this Report has identified the energy use and losses associated with each hydrogen energy vector and results show that liquefaction and ammonia both exhibit energy use and losses exceeding 40%, while compression stands significantly lower at below 20%.

	Compress. H2 (250 bar)	**Liquid Hydrogen**	**Liquid Ammonia**
RE Curtailment (Load Following)	4.3%	15.0%	10.5%
Export Process Use	2.3%	16.7%	14.1%
Ship Use / Losses (2,000 n.miles)	9.6%	16.3%	4.7%
Delivery Process Use / Losses	2.5%	5.0%	28.5%
Cumulated Use/Losses	17.6%	43.7%	47.6%
Delivery Volume (% of Generated)	**82.4%**	**56.3%**	**52.4%**

In summary and as per the diagrams provided in appendix A, the overall efficiency levels from renewable generation to delivery (kWh energy) are shown in the table below and in Figure 3 is an illustration of the full supply chain efficiency for compression. Appendix a includes illustrations of all three vectors.

	Compressed H2 (250 bar)	**Liquid Hydrogen**	**Liquid Ammonia**
Total Supply Chain Efficiency	26.1 – 30.0%	20.5%	19.0%

Figure 3: Illustration of full supply chain efficiency for compression (refer to Appendix A for all vectors)



2. Components to Create a Realistic Hydrogen Supply Chain

This Report expands the analysis by including four additional components to create a more realistic hydrogen supply chain:

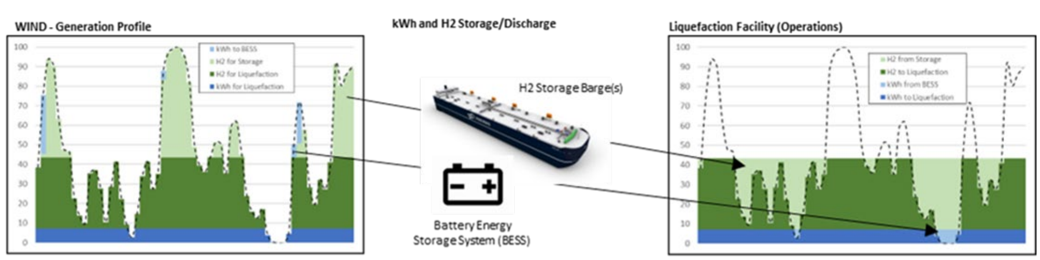
i. **Curtailment of renewable energy generated.** It is not commercially viable to design the project to use every single kWh of the 'variable' renewable energy generated, except in the case of hydro. "Load following" assumptions were made for each vector's different ability to adjust to variable hydrogen production rates and renewable energy generation.

Parameters (% of installed capacity)		Compression	Liquefaction	Ammonia
Load Following Capability		Full	None	Moderate
Operating Range	Max	100%	100%	100%
	Min	0%	100%	40%
Hourly Change	Up	100%	0%	5%
	Down	100%	0%	5%

These assumptions affected the size and capacity of each component in the supply chain to meet the required gaseous hydrogen volume for the customer. The solution to convert such "variable renewable power" to a semi "base load supply" is achieved via batteries (for electricity storage) and hydrogen storage vessels (for gaseous hydrogen storage).

Note: Storage is not related to loading a ship for export, but rather the storage of kWh and hydrogen to enable the Vector process to operate in accordance with their load following capabilities.

Figure 1 Illustration of an example for liquefaction which is understood to have no capability to load follow, requiring the conversion of variable wind generation profile to a flat profile.



ii. **Use of electricity in each Vector to either compress, liquefy or synthesis (for ammonia).** Energy usage assumed in this Report was as follows, with no material change from 2021.

Hydrogen Energy Vector		***Energy Use (Export)***
Compression	CGH2	1.3 kWh / kg H2
Liquefaction	LH2	11.0 kWh / kg H2
Ammonia	NH3	9.0 kWh / kg H2

iii. **Shipping distance and fuel usage** were derived for each vector to meet 'sustainable' green solutions. Each case was based on an assumed hydrogen fuel cell or ammonia fuelled engine (even though not currently available at such scale). Fuel use is based on 20 kWh per kg of hydrogen. The cargo use levels were calculated on speed and distance assumptions.

iv. **Delivery process and energy use** (loss) required for the unloading and reconversion for each Vector were updated, with an improvement observed for Ammonia cracking and purification. Industry debate still exists as the purity of a cracked H2 product achieving greater than 99.99%, which is below the requirement for fuel cell systems required for the mobility sector such as Heavy Duty Vehicles.

Hydrogen Energy Vector		***Energy Use (delivery)***
Compression	*CGH2*	*0.5 kWh / kg H2*
Liquefaction	LH2	5.0% of H2 Vol.
Ammonia	*NH3*	*28.5% of H2 Vol.*

3. Benefit of Load Following the Renewable Generation

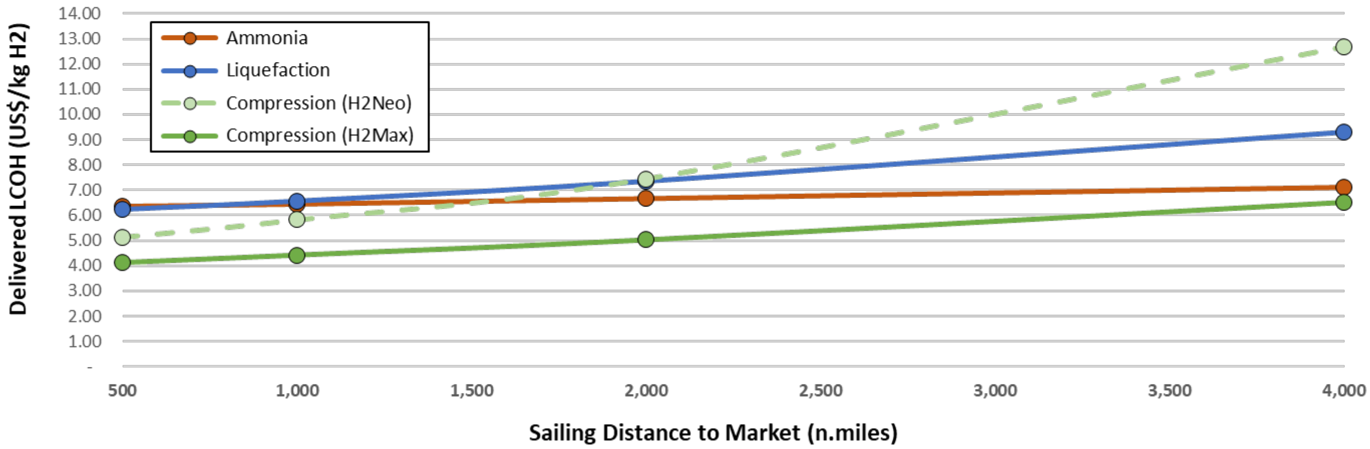
In the Report, compression demonstrated its remarkable capability to "100% load follow" a renewable generation profile, enabling seamless alignment with hydrogen production and eliminating the capital investment and associated costs in "battery and hydrogen storage". Scenarios up to 500,000 tpa also support an economic large scale delivery model.

This significant advantage directly translates into a substantial reduction in the Levelised Cost of Hydrogen (LCOH) as depicted in Figures 1 and 3, which showcase the impact on LCOH for delivered volumes of 100,000 tpa and 500,000 tpa.

The LCOH encompasses the full value chain, including production, loading, transport and discharge. Key findings of the Report highlight the following:

i. Compression emerges as the most cost-effective option for regional transport distances of less than 2,000 nautical miles for delivery of gaseous green hydrogen, leveraging the efficient H2Neo (430t) or H2Max (2,000t) capacity carriers.
ii. Even for transportation distances up to 4,000 nautical miles, compression remains a highly competitive transport alternative when utilising Provaris' advanced H2Max carrier.

Figure 2: LCOH results for a combined solar/wind generation profile to deliver 500,000 tpa hydrogen demonstrates economic advantages and scale of Compression.



4. LCOH Analysis Across Different Generation Profiles

The Report represents a significant milestone as it unveils the delivered LCOH for each transport vector when analysed across volumes, shipping distance and type or renewable generation profile.

By considering the energy efficiencies specific to each vector and incorporating the capital and operational costs associated with building, owning, and operating the entire supply chain, the Report provides valuable insights into the economic viability of different hydrogen delivery methods.

Together, the delivered LCOH was determined for a range of production volumes and shipping distances (refer to the table below).

Energy Vectors	Compression, Liquefaction, Ammonia
Delivered H2 Volume (tpa)	50,000, 100,000, 250,000, 500,000
Sailing Distance (n.miles)	500, 1,000, 2,000, 4,000
RE Type	Hydro, Solar, Wind, Solar/Wind

For each Renewable energy type, several hourly profiles have been analysed to determine the lowest LCOH for each Vector. For each run (volume, distance, energy source), the optimal electrolyser/vector capacity was also determined.

Capacities, capital and operating costs have been collated by Provaris from internal and public sources where available. LCOH results for the delivery of 50,000 tpa of gaseous hydrogen to a market, scaling to a growth scenario of 500,000 tpa, and transport ranges of 500 to 5,000 nautical miles. A full set of results are available in Appendix C.

Different hourly generation profiles have been analysed for each renewable generation type (solar only, wind only, and solar/wind mix) and compression was found to be the least sensitive to the generation profile, followed by ammonia, with liquefaction being the most sensitive, particularly to the wind only generation profiles.

The Table below provides an insight into the sensitivity that each vector has to the different generation profiles. The standard deviation of the best LCOH for each profile was determined (10 per renewable energy source) and then the standard deviation across those 10 results is shown in the table below.

LCOH Standard Deviation	**Compressed H2** H2Neo	H2Max	**Liquid Hydrogen**	**Liquid Ammonia**
Solar-Only Profiles	0.08	0.07	0.67	0.40
Wind-Only Profiles	0.11	0.10	1.26	0.80
Solar / Wind Profiles	0.11	0.10	0.77	0.50

Levelised cost analysis is based on a 6.0% discount rate, 30-year life, and 2.0% escalation of operating costs (refer to appendix C for full results of LCOH based on renewable generation type.

5. Requirements for Hydrogen Storage

The Report identifies a range of gaseous hydrogen storage volume required for liquefaction and ammonia, which differs based on the renewable energy sources and the scale of production (50,000 to 500,000 tpa).

Storage is required to provide a security of supply of gaseous hydrogen to the liquefaction or ammonia process during periods of low renewable energy generation.

The required hydrogen storage capacity levels shown in the table below take into account the availability of an external power supply (5% of annual total) during periods of extreme energy shortfall (i.e. a fossil fuel peaking plant).

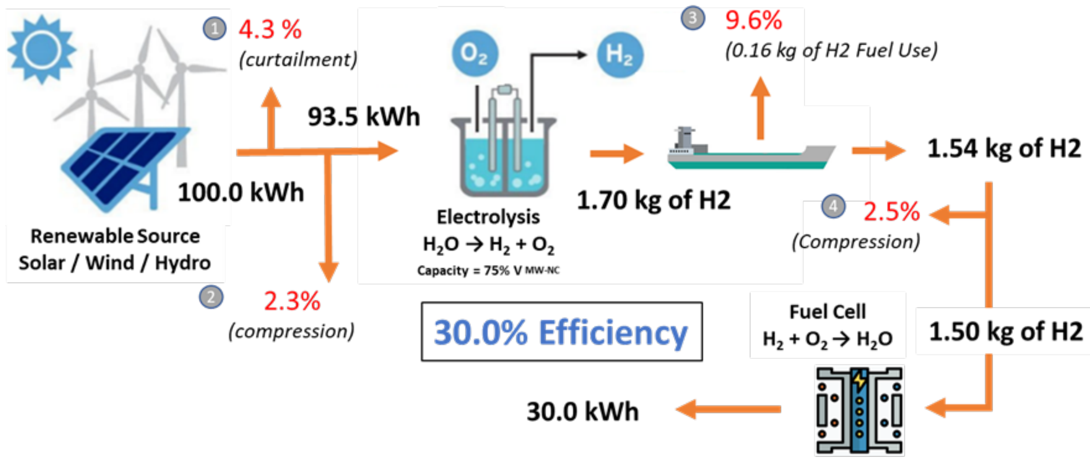
Hydrogen Storage Levels (tonnes)	Liquid Hydrogen	Liquid Ammonia
Solar Only	2,600 – 20,000	600 - 1,100
Wind Only	3,400 -20,000	1,400 – 6,000
Solar / Wind	1,300 – 20,000	600 – 3,000

For further information on the details of this Report, please email info@provaris.energy

Appendix A – Illustration of Supply Chain Efficiency for each Vector

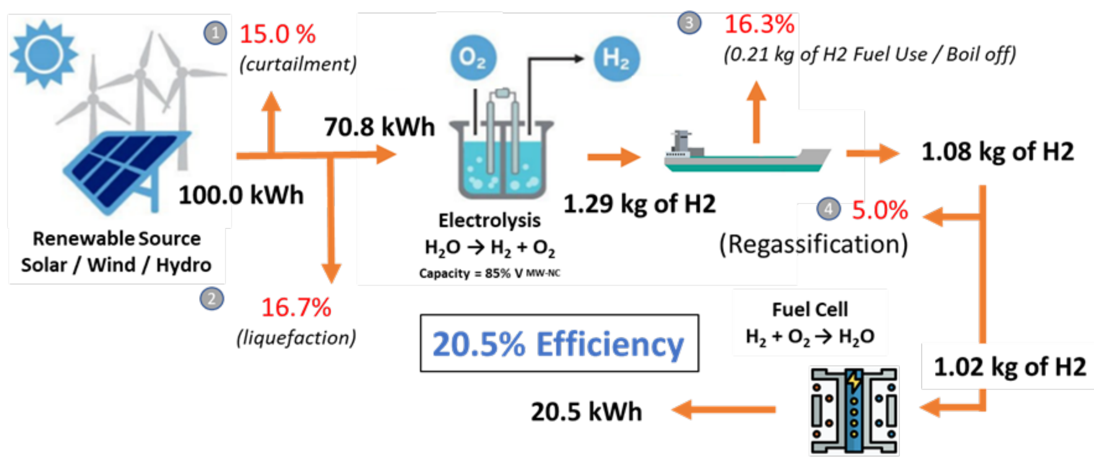
COMPRESSION (H2Max)

DETAILED SUPPLY CHAIN: Generation, Production and Delivery (2,000 nm)



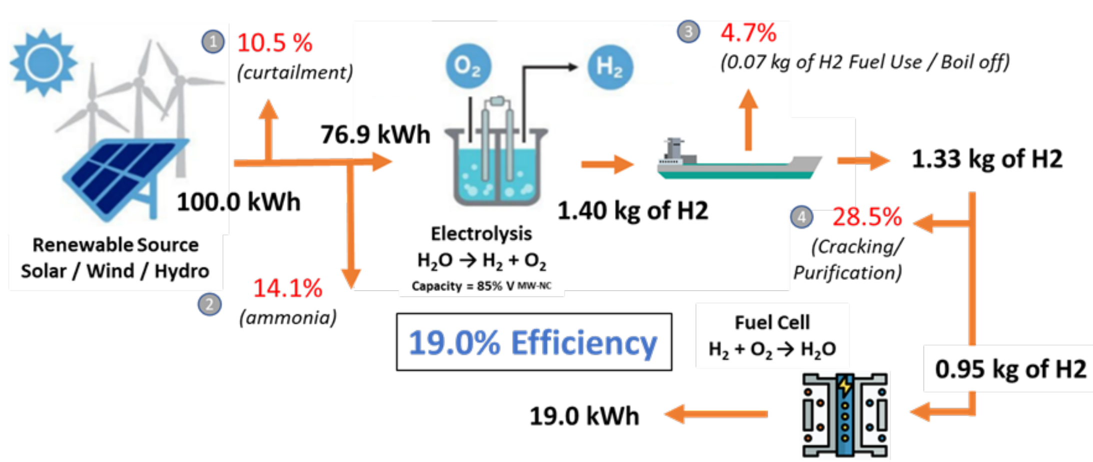
LIQUEFACTION

DETAILED SUPPLY CHAIN: Generation, Production and Delivery (2,000 nm)

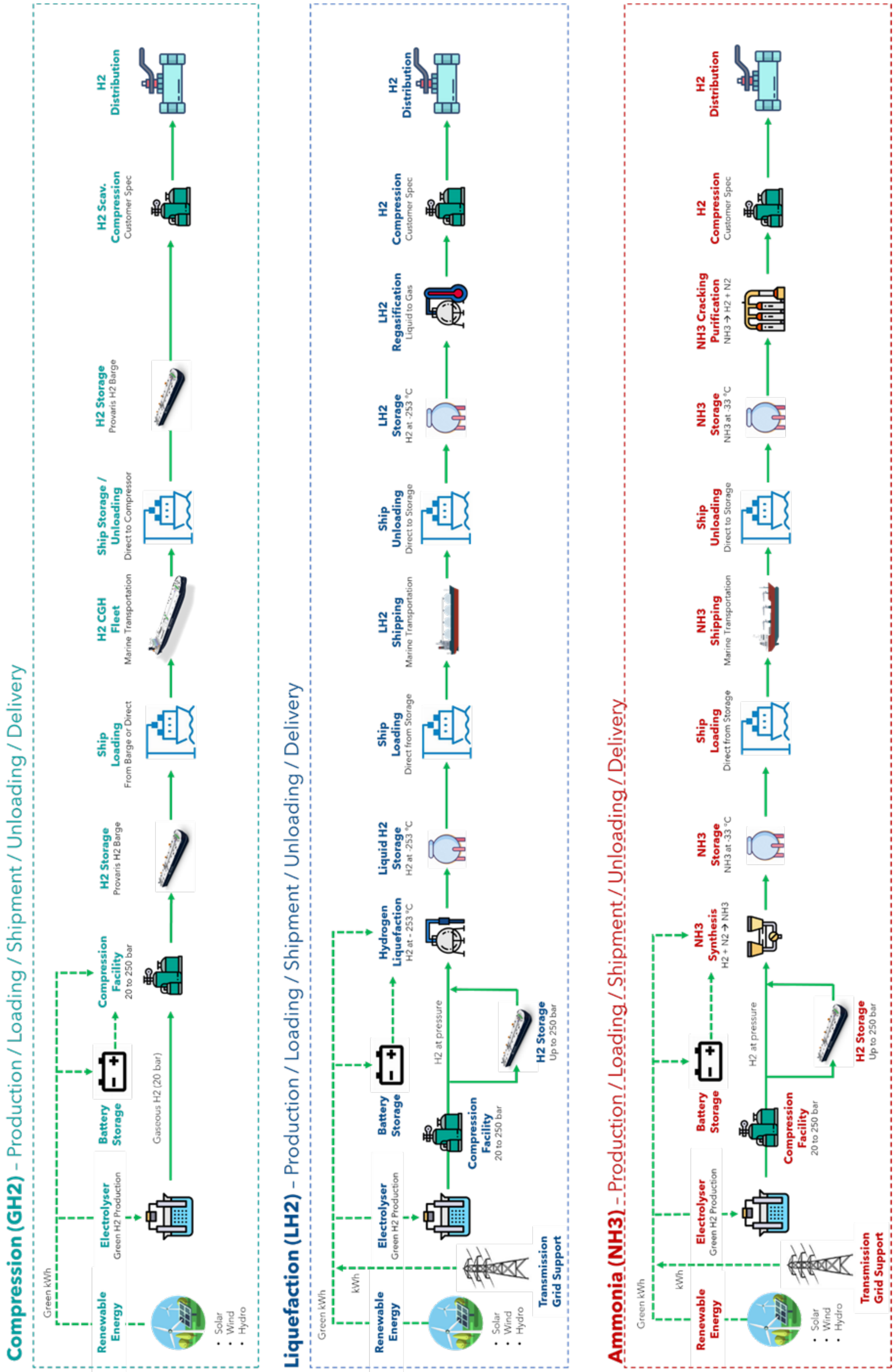


AMMONIA

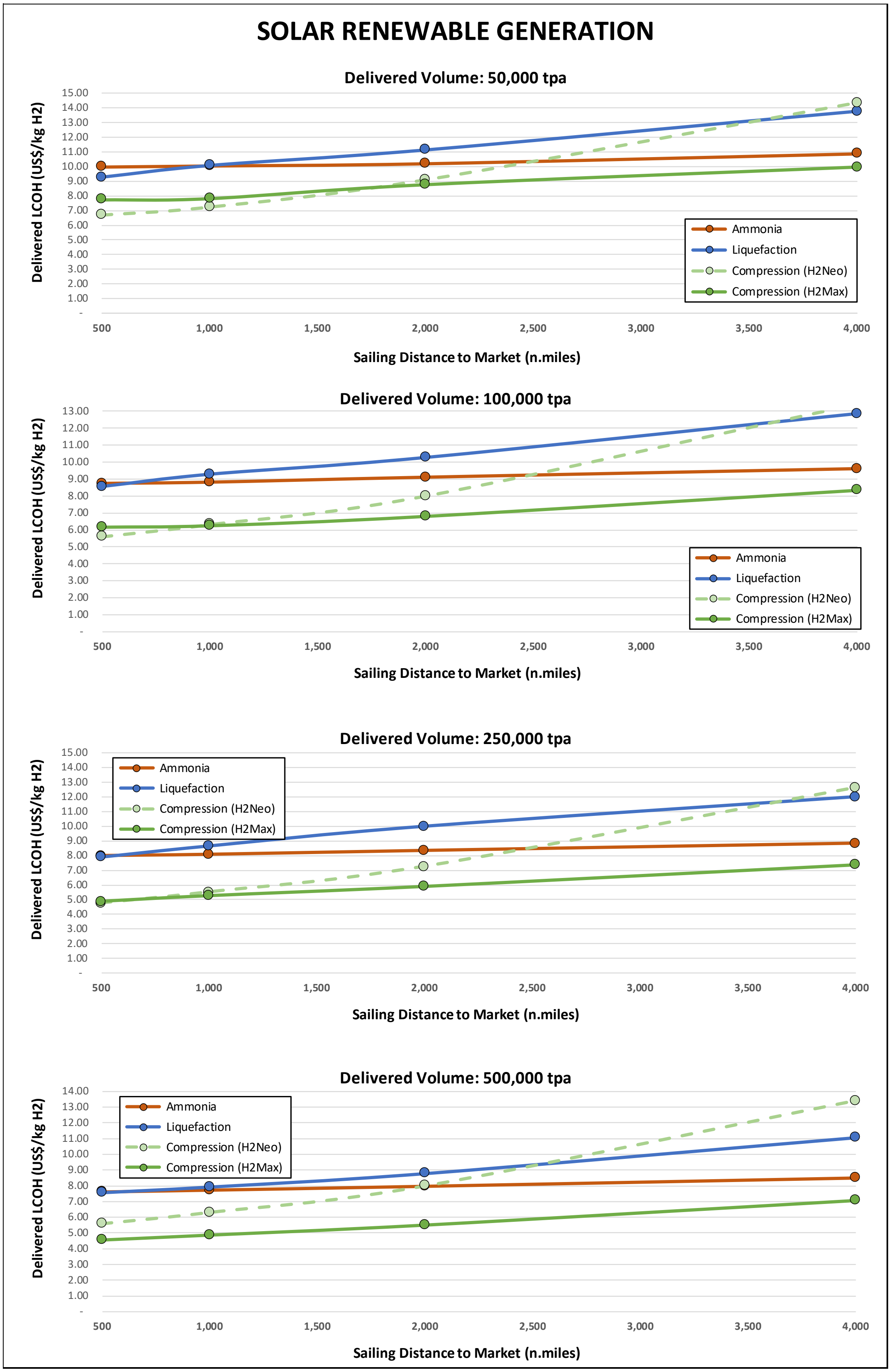
DETAILED SUPPLY CHAIN: Generation, Production and Delivery (2,000 nm)



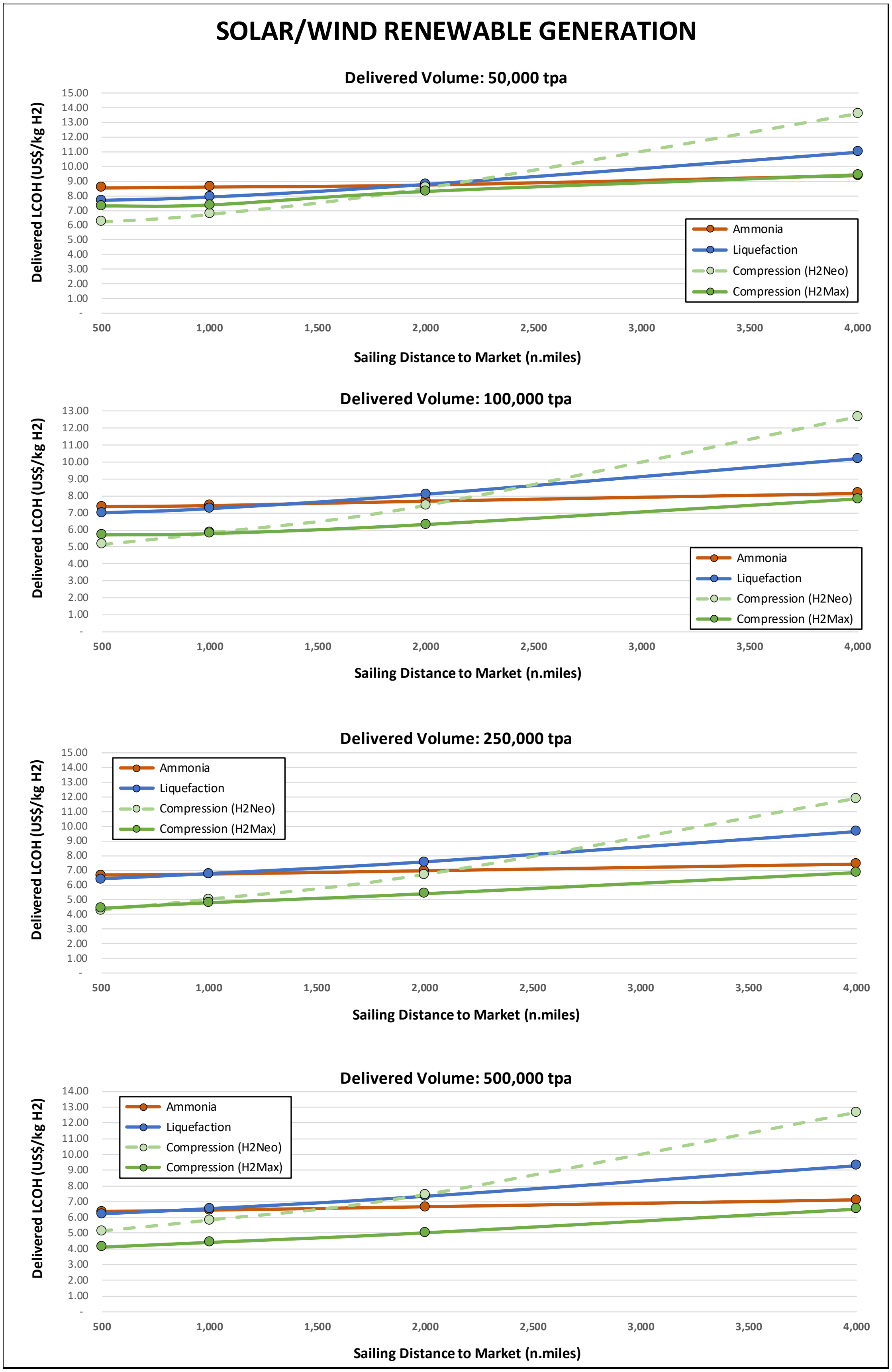
Appendix B – Illustration of Supply Chain Vector Process – Compression, Liquefaction & Ammonia



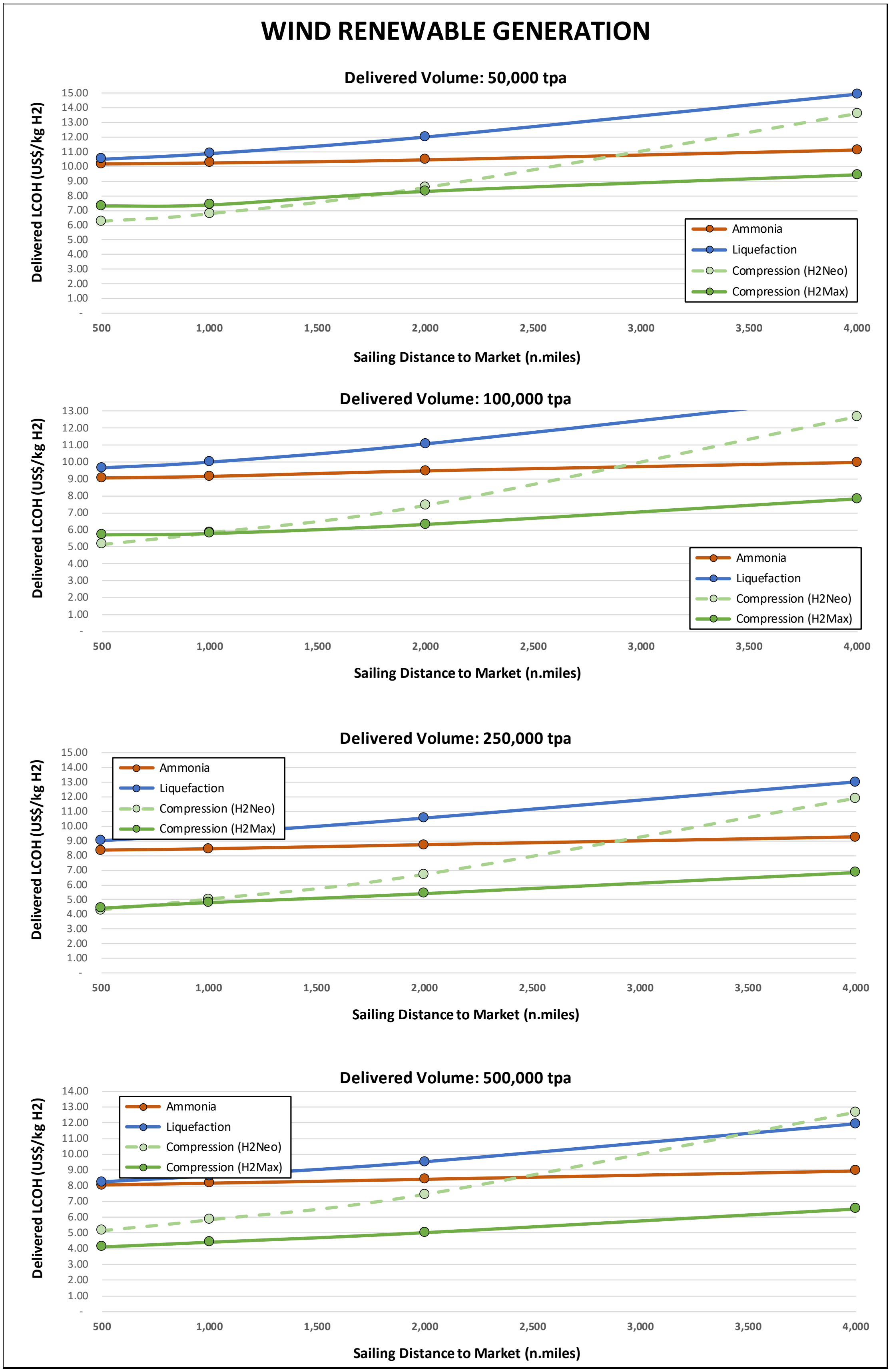
Appendix C – LCOH Comparison Results – Solar Only Renewable Resource



Appendix C – LCOH Comparison Results – Solar/Wind Mix Renewable Resource



Appendix C – LCOH Comparison Results – Wind Only Renewable Resource



Appendix C – LCOH Comparison Results – Hydro Renewable Resource