NAMIBIA - PORT OF ROTTERDAM HYDROGEN SUPPLY CHAIN

PRE - FEASIBILITY REPORT

Final Draft
28 May 2021

NamPower
Powering the Nation and beyond

Port of Rotterdam

TABLE OF CONTENTS

NamPower
Powering the Nation and beyond

Port of Rotterdam

EXECUTIVE SUMMARY

1. In the coming years Namibia has great potential to produce cost competitive green hydrogen for the European market, thanks to new wind and solar power potential. The Sperrgebiet area south of Lüderitz is one of the world's top 3 areas for wind production.

2. A staged development is proposed. A first stage will require 5.3 TWh of renewable power which will produce in the order of 100ktpa H2. Land area requirements are 30k Ha for wind and 2k Ha for solar parks. A following stage development could look at ten folding this production capacity and thus also the land requirements.

3. The price of hydrogen delivered in Rotterdam for the first stage would be reasonably competitive at a level of 3,3 EUR/kg. This is based on wind power production in the Sperrgebiet and ammonia as hydrogen carrier. Cost savings in local logistics and financing conditions as well as subsidies could improve competitiveness which is needed to ensure offtake. A detailed feasibility (FEED) should show what is the ultimate best option.

4. Note that this number was derived with PoR's cost model which approximates based on a number of assumptions. It is recommended to undertake detailed feasibility studies, preferably with specific technology providers, to update and confirm these results.

5. Namibia could produce 2 Mtpa of green H2. This volume could contribute a significant part approximately 10% - of the hydrogen expected in Rotterdam by 2050.

6. Northport in Walvis Bay has the best suitable port facilities, particularly for fast development. This could be a good location for a first project with minimal investment in the port facilities.

7. Lüderitz has very large potential because of the unique wind conditions south of Lüderitz, ample space and the opportunity to develop facilities in conjunction with new mining operations in South Namibia. The mining industry may be the first suitable local offtakers of green H2 to prove the concept in Namibia. Angra Point has 2 challenges that need to be overcome: first relating to accessibility of the Sperrgebiet and the nature reserve at Angra point.

8. A number of risks have been identified, the largest of which is probably the scale of investment for Namibia and the currency risk. Close structured cooperation with international partners and institutions will be key to materialize the potential for Namibia.

9. NamPower and the Port of Rotterdam have had a pleasant cooperation to date and established a strong relationship. Opportunities exist to continue to work together to bring together the right parties and build out the capabilities in order to establish a new green energy industry in Namibia with a large export potential, creating jobs and economic benefit for Namibia and reduce overall global CO2 emissions.

Note: NamPower did not have access to the PoR Cost Model.

LEGEND & DISCLAIMER

Legend:

PoR – Port of Rotterdam

LOHC – Liquid Organic Hydrogen Carrier

LCOH - Levelised cost of Hydrogen

SCDI - Southern Corridor Development Initiative

TWh - Terrawatt hour

Ha – Hectare

DWT - Deadweight ton (of a vessel)

Approximate conversion factors:

One kilogram of	approximately equals
Hydrogen	142 mega joules (upper heating value) 39.4 kilowatt hours 3.4 kilogram of crude oil 2.6 kilogram of natural gas
One liter of	**approximately equals**
Hydrogen, gas, 1 standard atmosphere @ 25°C (higher heating value)	0.33 liter of natural gas 0.00032 liter of crude oil
Hydrogen, liquified (higher heating value)	280 liter of natural gas 0.27 liter of crude oil

Disclaimer:

This report was produce by a joint team of NamPower & Port of Rotterdam. In view of the limitations due to COVID-19 no visits to Namibia were possible. All meetings were held virtually. Despite these limitations the joint team has worked together in a very pleasant way and been able to bring together the joint knowledge as well as brainstorm on solutions and visions.

Upon completion of this pre-feasibility study and the end of COVID-19 lockdowns we look forward to working physically shoulder to shoulder to take this assignment further and fill in the gaps that have been left in this pre-FS study.

1

THE WORLD IS GEARING UP

GREEN HYDROGEN PROJECTS ARE SPROUTING UP

HyDeal (Western Europe)
Completion: 2030
Capacity: 67 GW
CAPEX: ? US$bn
Production: 3,6 Mt/yr

North H2 (The Netherlands)
Start: 2027
Capacity: 10GW
CAPEX: 20 US$bn
Production: 1 Mt/yr

Aquaventus (Germany)
Start: 2025
Capacity: 10 GW
CAPEX: 20 US$bn
Production: 1 Mt/yr

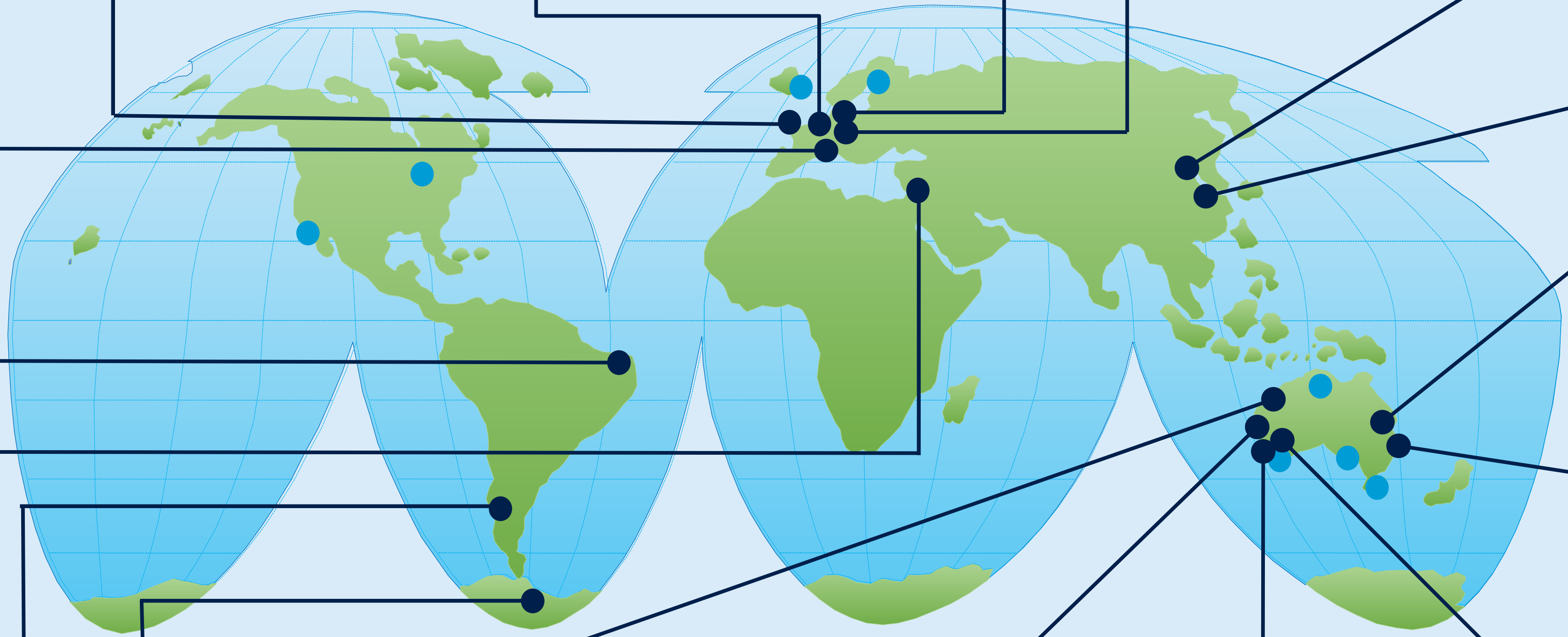
Copenhagen (Denmark)
Start: 2023
Capacity: 1.3GW
CAPEX: ? US$bn
Production: 250 kt/yr

Jingneng (China)
Completion: 2021
Capacity: 5GW
CAPEX: 3 US$bn
Production: 500 kt/yr

White Dragon (Greece)
Capacity: 1.5GW
CAPEX: 9.7 US$bn
Production: 250 kt/yr

Base One (Brazil)
Completion: 2025
Capacity: 3.4GW
CAPEX: 5.4 US$bn
Production: 600 kt/yr

NEOM-Helios (Saudi Arabia)
Start: 2025
Capacity: 4GW
CAPEX: 5 US$bn
Production: 240 kt/yr



Yellow Sea (China)
Completion: 2025
Capacity: 2GW
CAPEX: ? US$bn
Production: ? kt/yr

Pacific Solar (Australia)
Completion: ?
Capacity: 3.6GW
CAPEX: ? US$bn
Production: 200 kt/yr

H2 Hub Gladstone (Australia)
Start: 2023
Capacity: 3GW
CAPEX: 1.6 US$bn
Production: 5 kt NH3/day

HyEx (Chile)
Completion: 2024
Capacity: 1,6GW
CAPEX: 2 US$bn
Production: 124 kt/yr

HNH (Chile)
Completion: 2026
Capacity: 1.4GW
CAPEX: 3 US$bn
Production: 850 kt NH3/yr

AREH (Australia)
Completion: 2027
Capacity: 14GW
CAPEX: 36 US$bn
Production: 1.75 Mt/yr

Murchison (Australia)
Start: 2022
Capacity: 5GW
CAPEX: 12 US$bn
Production: ? kt/yr

HyEnergy (Australia)
Completion: 2030
Capacity: 8GW
CAPEX: ? US$bn
Production: ? kt/yr

Geraldton (Australia)
Completion: ?
Capacity: 1.5GW
CAPEX: ? US$bn
Production: ? kt/yr

Source: based on IEEFA, 'Great Expectations', (Aug 2020) , PoR Analysis and ReCharge News (May, 2021)

AMBITIOUS CLIMATE GOALS

GOALS OF BOTH COUNTRIES BASED ON PARIS AGREEMENT

The Port of Rotterdam has developed a total decarbonisation plan for its industrial complex, driven by the Paris Agreement and the Dutch climate law:

2030: 49% reduction of CO_2
2050: Climate neutral

Action Plan and Development Plan of the Namibian Government towards economic recovery and inclusive growth, outlining the objectives and aspirations of Namibia's long-term vision.

Including Paris climate goals and e.g.:

'Investigate the feasibility of Green Hydrogen and Ammonia as a transformative strategic industry'

Southern Corridor Development Initiative (SCDI)

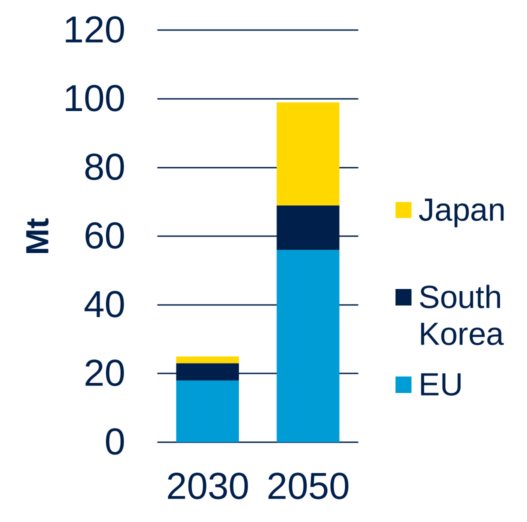
SUSTAINABLE DEVELOPMENT GOALS
8 DECENT WORK AND ECONOMIC GROWTH
7 AFFORDABLE AND CLEAN ENERGY
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
13 CLIMATE ACTION

NamPower Powering the Nation and beyond
Port of Rotterdam

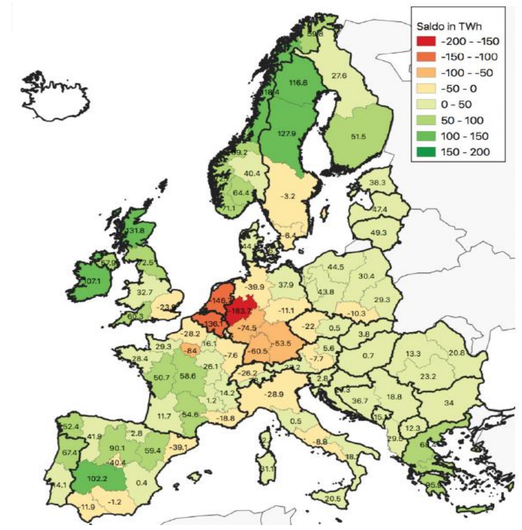
1 A HUGE NEW MARKET IS DEVELOPING

THE "HOCKEY STICK" GROWTH TREND

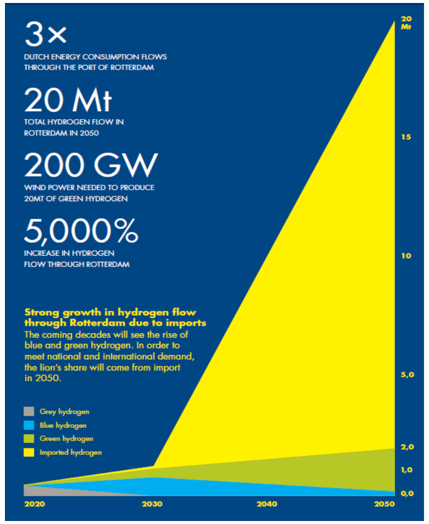
Global hydrogen demand



European demand



Rotterdam demand



Today - 2030

The first green and blue hydrogen proof of concept projects are being developed. Major scaling commencing 2027. Europe aims for development of 40GW renewable in- and 40GW outside Europe. First demand is also created in Korea, Japan and the US.

2030 - 2050

Rapid scale-up due to regulatory incentives (ETS, carbon border adjustments, more clear regulation of hydrogen trading and transport, timed to emerging EU backbone) aimed at achieving the next climate target.

2050 - onwards

Hydrogen will be an intrinsic part of our integrated energy system.

Source: Aurora Energy Research, 2020

1

THE H2 DEVELOPMENT ROADMAP

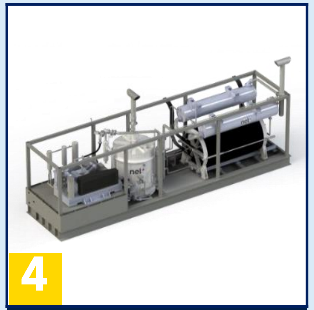
MOMENTUM IS RAPIDLY GROWING IN NAMIBIA TOWARD BECOMING AN EXPORTER OF GREEN ENERGY

SETTING THE STAGE

1 Start larger scale renewable projects

2 Real driver for Renewable ~30% of power growth

3 First national hydrogen masterplans



4 First hydrogen pilots for local use

5 First pilots for export

6 Hydrogen Industrial Port complex

Namibia today → Steps ahead

Largescale Export of H2

Port of Rotterdam's role:

- Assist with developing a vision and support with planning and determining requirements.
- Support finding partners and setting up pilot projects first locally and then export related.
- Support the development of Port Industrial Complexes, which are the main supply chain nodes.

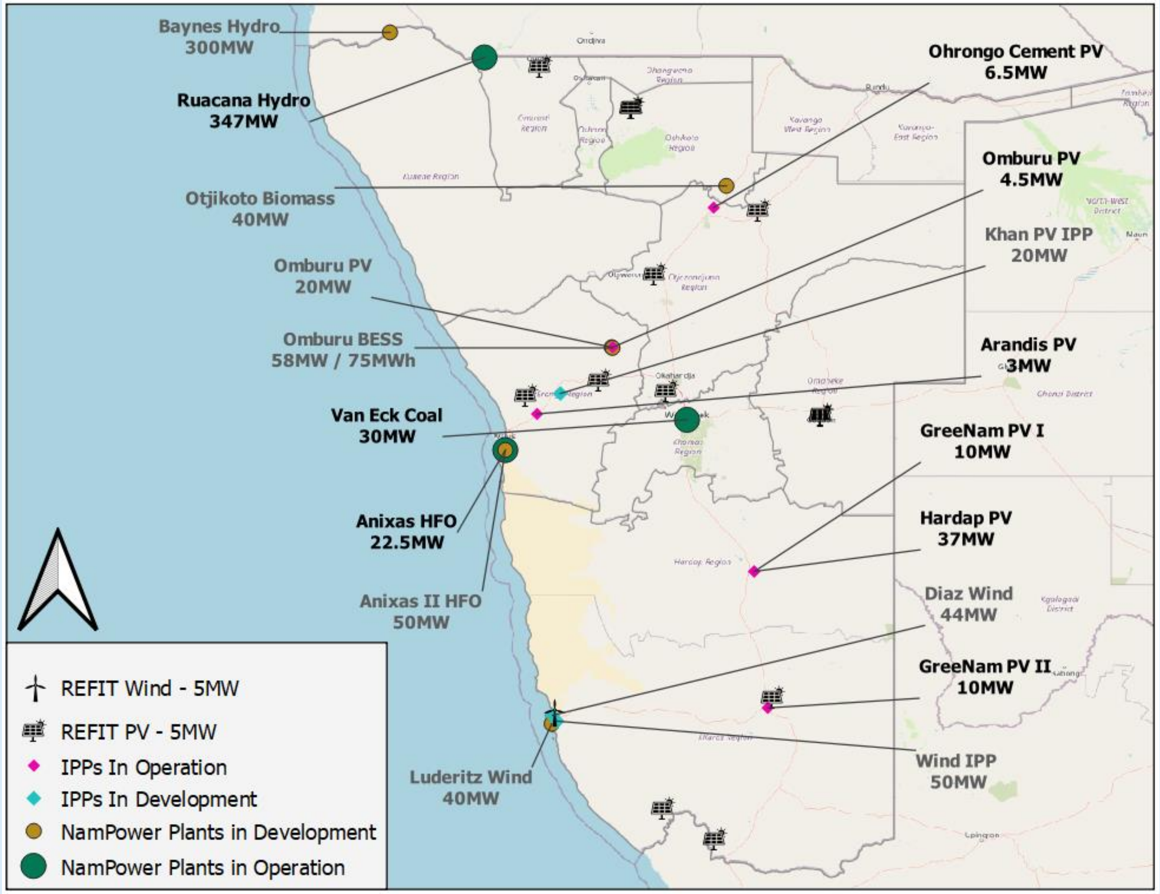
NamPower Powering the Nation and beyond

Port of Rotterdam

NAMIBIA'S SUCCESS STORY TO DATE

THE RENEWABLE POWER POTENTIAL IS ALREADY BEING EXPLORED

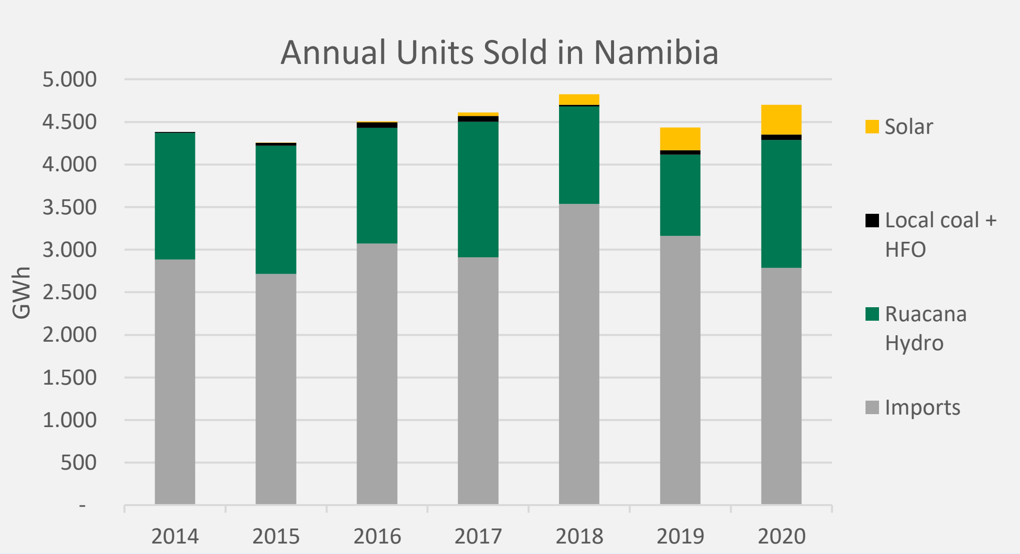
Generation projects



Maximum electricity demand was around 629MW in 2020, with an expected growth to 802MW by 2040.

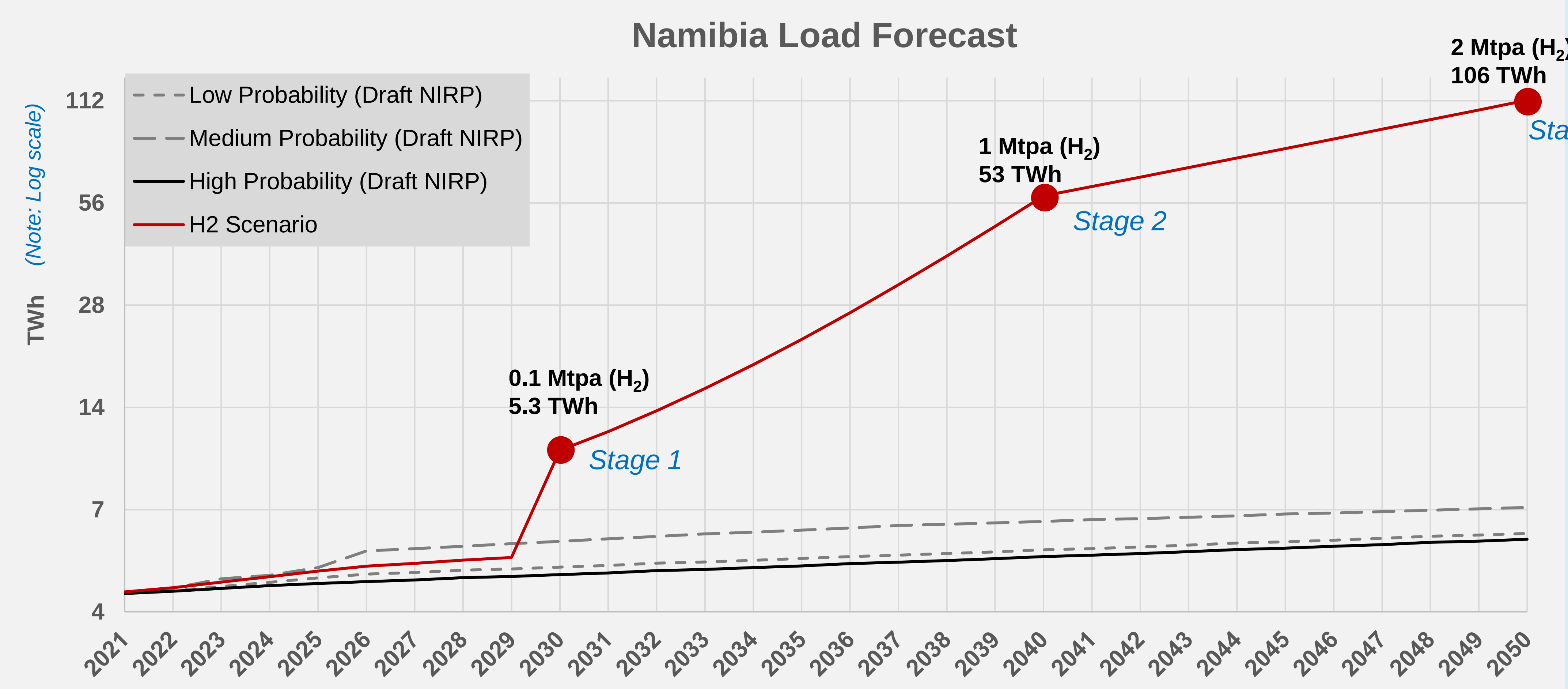
In 2015, the first renewable energy Independent Power Producer came online with a relatively small capacity of 4.5MW.

In 2020, the total commercial renewable energy plants installed has grown to 150MW with expected growth to 360MW by 2024. This excludes the participation in the Modified Single Buyer (MSB) market, which may have a potential participation of up to ~400MW of PV and wind power plants.



NamPower
Powering the Nation and beyond
Port of Rotterdam

NAMIBIA'S GROWTH AMBITIONS

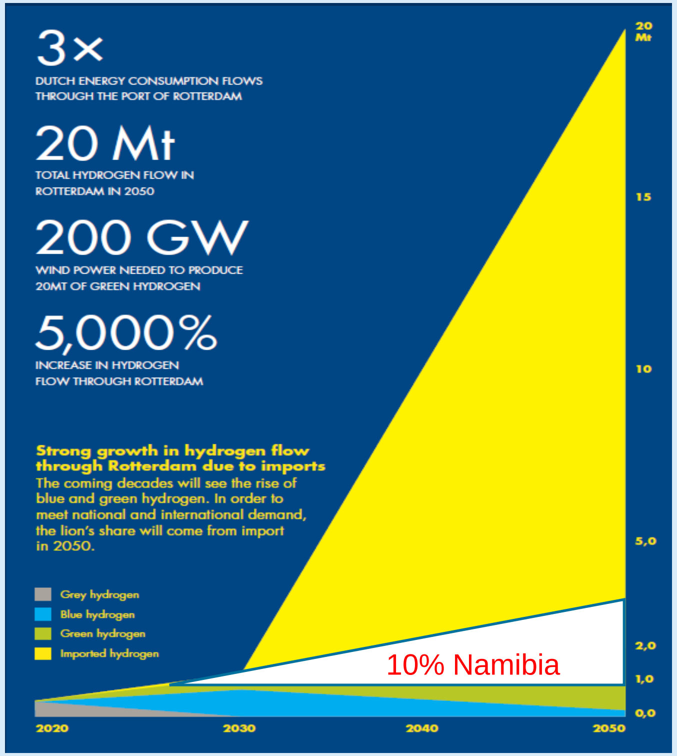


Source: Namibia National Integrated Resource Plan (NIRP) Load Forecast Report (14 April 2021 Draft)

NAMIBIA'S GROWTH AMBITIONS

NAMIBIA COULD FILL A SIGNIFICANT PART OF THE ROTTERDAM DEMAND

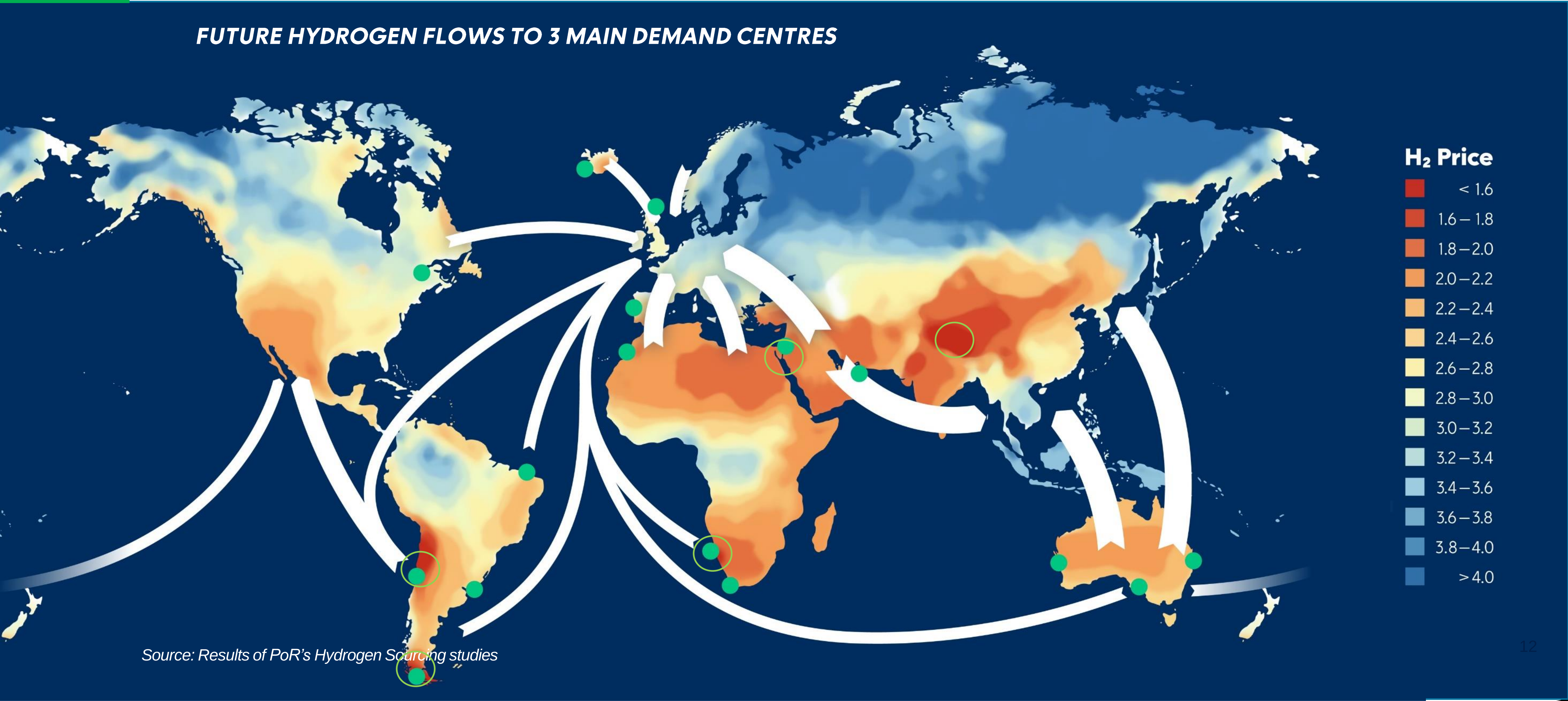
Year	2020	2030	2040	2050
Total Rotterdam demand	0.45 mtpa	1.2 Mtpa	10 Mtpa	20 Mtpa
- of which from import		0.3 Mtpa	8 Mtpa	18 Mtpa
- of which from Namibia		0.1 Mtpa	1 Mtpa	2 Mtpa
Namibia additional Power required		5.3 Twh	53 Twh	106 Twh
		stage 1	stage 2	stage 3



NAMIBIA’S UNIQUE POTENTIAL

ONE OF THE TOP 5 WIND LOCATIONS IN THE WORLD

H2 price



Source: Results of PoR’s Hydrogen Sourcing studies

A NEW GLOBAL SUPPLY CHAIN

FACING A CHICKEN AND EGG DILEMMA

H2 TRADE

1

Renewable Power
- Current capacity
- Future capacity

2

H2 Production
- Electrolyser
- Conversion

3

Local utilisation
- Heavy mobility
- Steel production

4

Local Logistics & Export
- Terminal business
- Industrial process

5

Shipping
- Shipping business
- Shipping fuel business

6

Import & Distribution
- Terminal business
- Industrial process

7

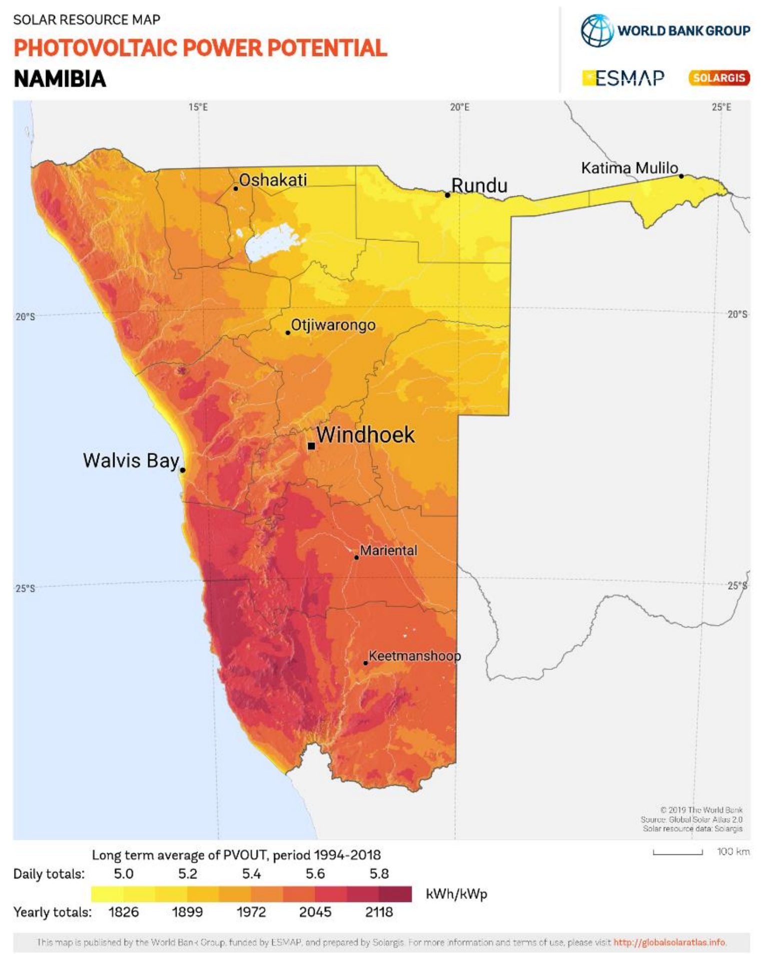
H2 usage
- Industry feedstock
- Mobility
- Industrial heating
- Power
- Urban use

LOGISTICS

The logistic infrastructure development will await actual trade, yet the trade will not be made if there is no logistic infrastructure. Only with an overall Vision presented in a national hydrogen masterplan, which is supported by all parties, will all supply chain components be developed simultaneously. **This is why NamPower and the Port of Rotterdam are jointly developing this pre-feasibility study with which we aim to support these developments.**

RENEWABLE POWER PRODUCTION

NAMIBIA'S POTENTIAL IN SOLAR



High values of Global Horizontal Irradiance (GHI) in the West of Namibia which is ideal for PV. However, the GHI rapidly declines nearing the coast due to a long stretching mist-band.

Source: Alensy, 10MW GreeNam PV Plant in Mariental, Namibia

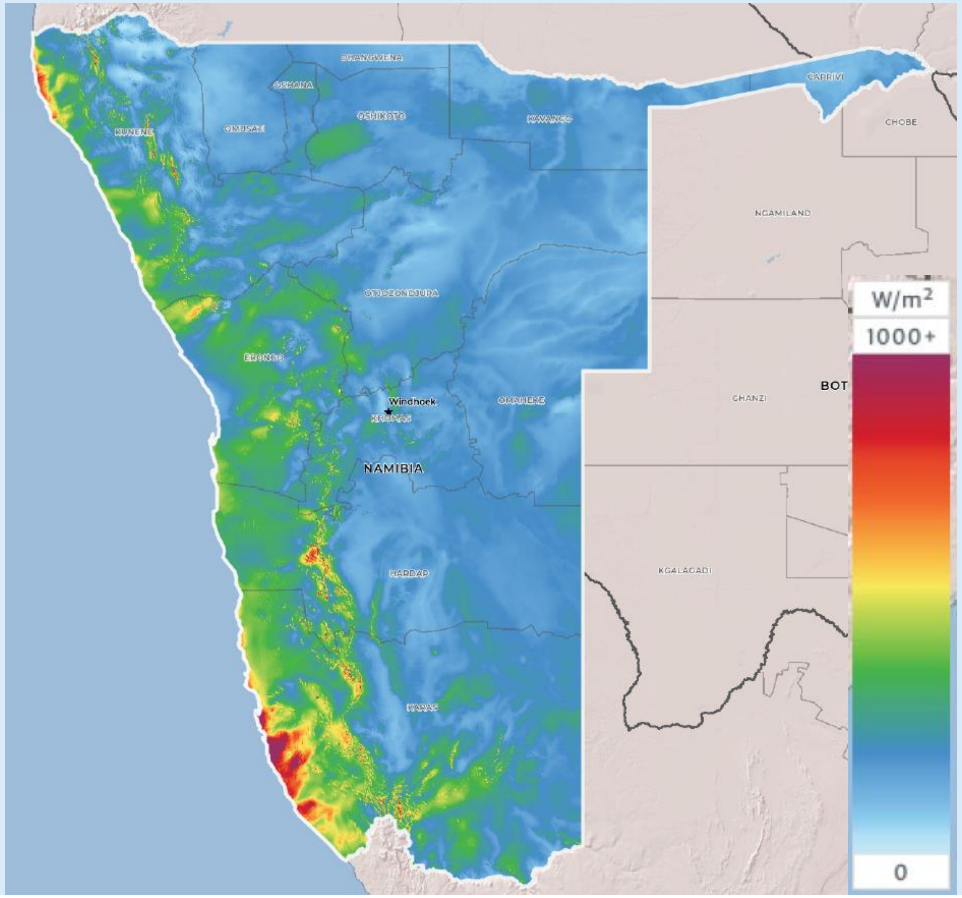
Source: SolarGIS

2

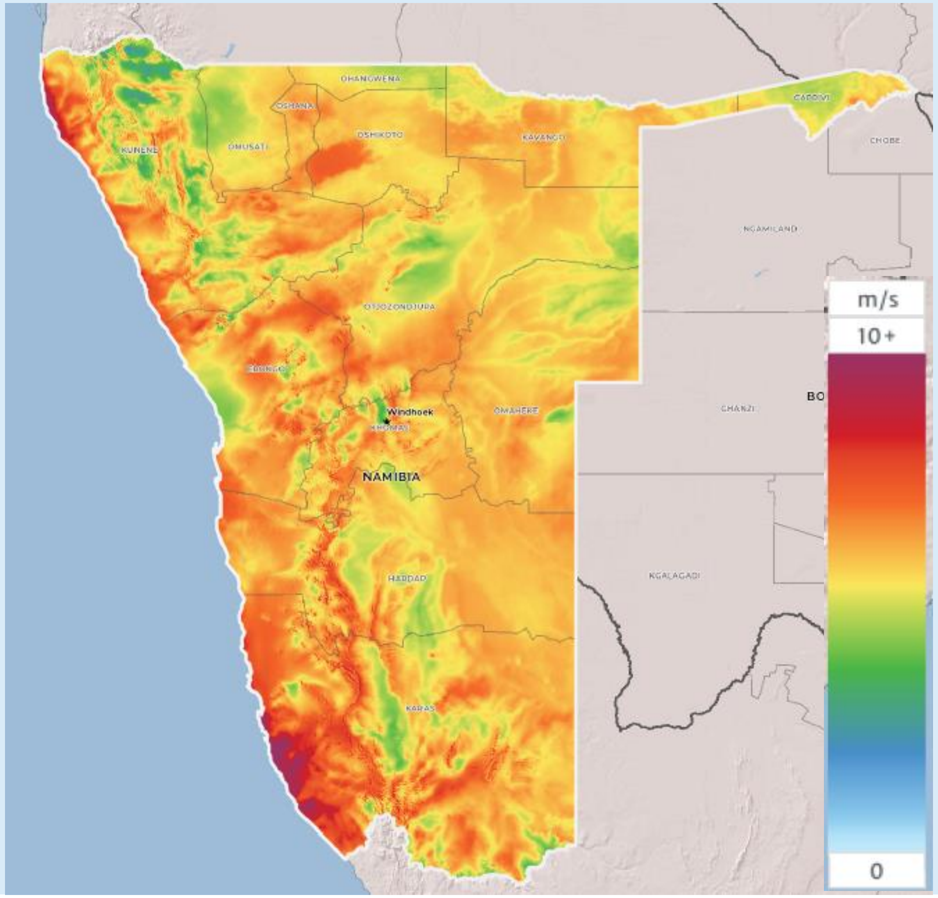
RENEWABLE POWER PRODUCTION

NAMIBIA'S POTENTIAL IN WIND

Namibia Mean Power Density Map



Namibia Mean Wind Speed Map



Strong capacity factors for wind can be found in the coastal areas north of Walvis Bay or south of Lüderitz.

Inland locations would require use of more land but could be combined with (cattle) farming.

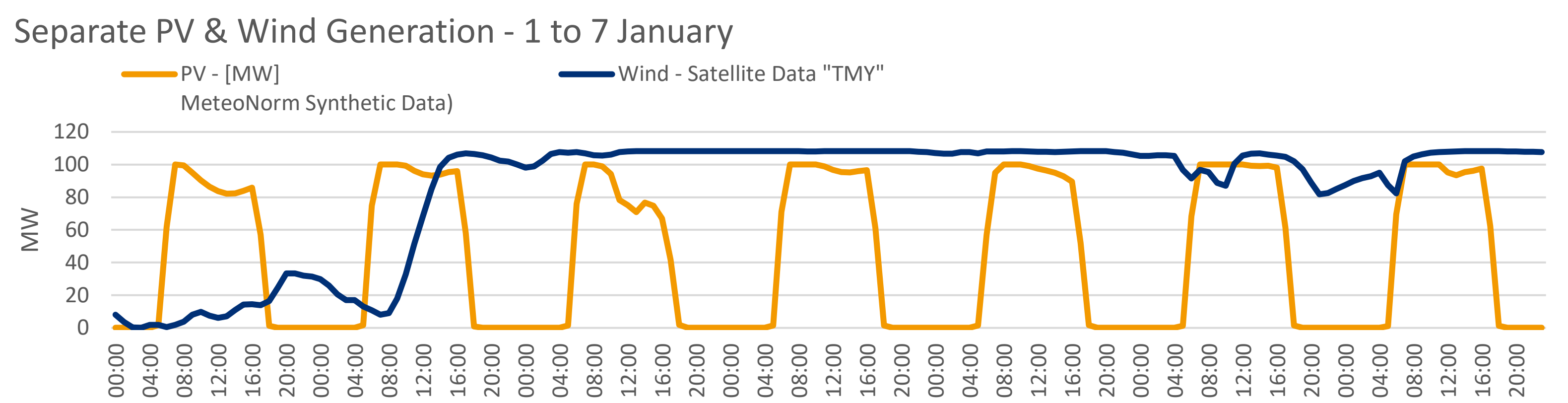
Source: Global Wind Atlas

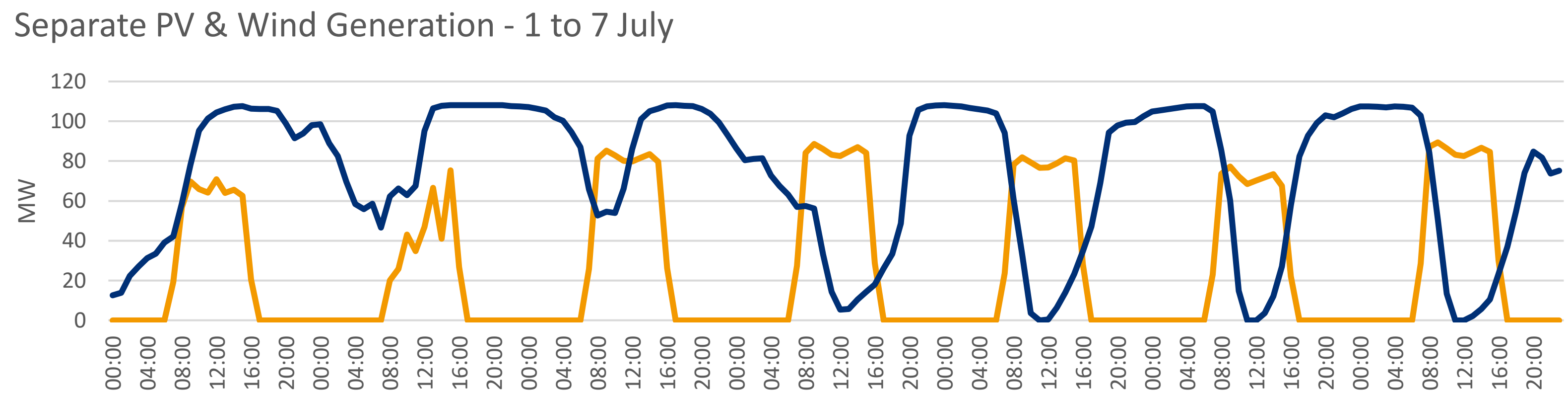
RENEWABLE POWER PRODUCTION

WIND AND SOLAR COMPLIMENT EACH OTHER VERY WELL

Semi-optimized scenario:
100MW PV plant (DC/AC ratio of 1.3) + 130MW Wind Plant:

- PV Capacity Factor (CF) = ~36%
- Wind CF (130MW) = ~49%
- **CF PV + Wind Combined (100MW) = 77%**
- Overlap Gx Loss = 23%





Both daily as well as seasonally the wind and solar production complement each other allowing for high-capacity factors of the electrolysers. During the day and in the summer the wind sags but the sun shines bright.

NamPower
Powering the Nation and beyond
Port of Rotterdam

RENEWABLE POWER PRODUCTION

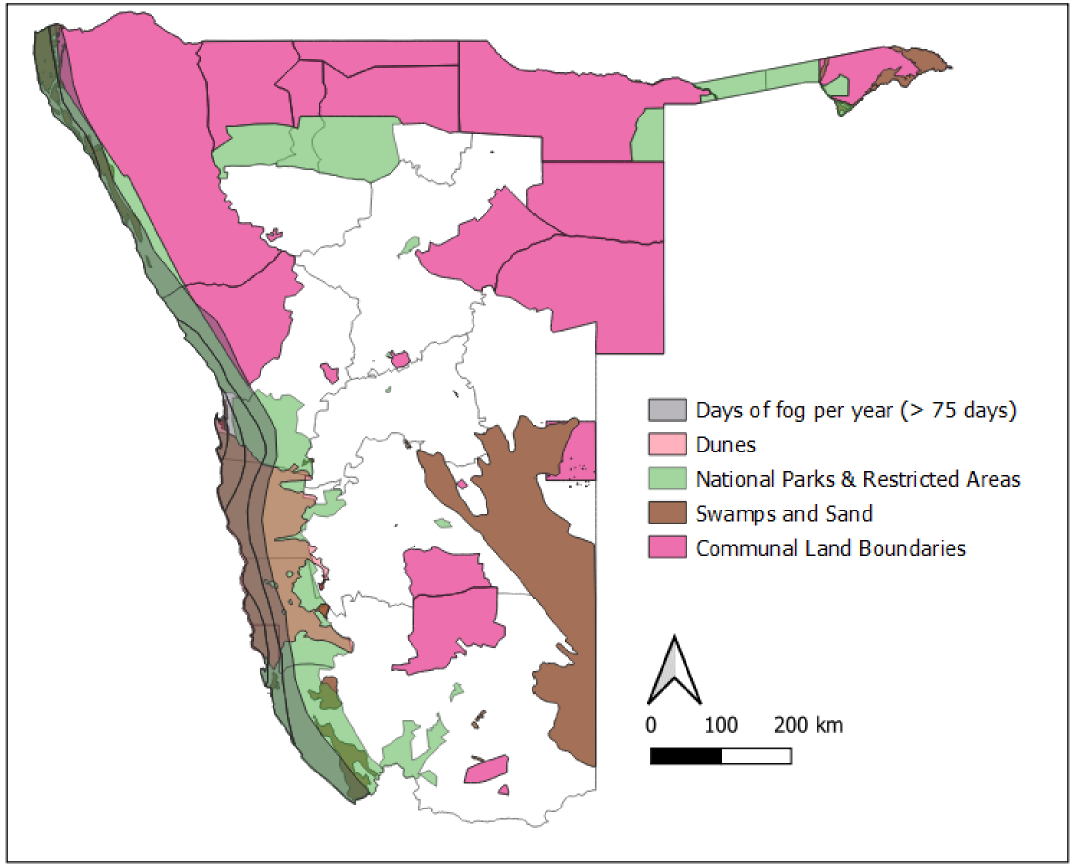
POTENTIAL AREAS

Restricted areas along the coast:

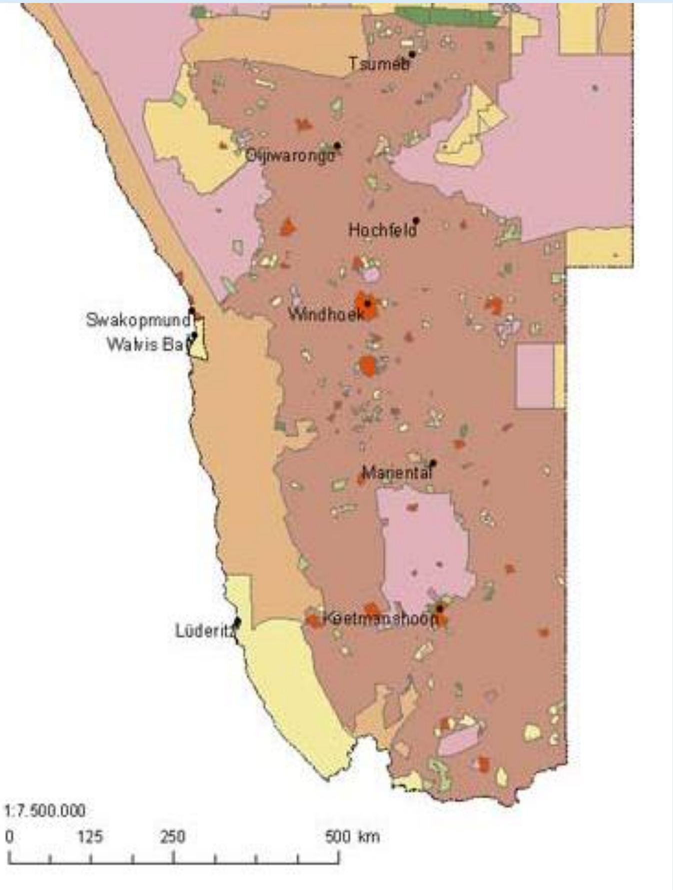
- North of Walvis Bay is the Skeleton Coast Park, a national (game) park.
- Between Walvis Bay and Lüderitz is Namibian's famous national park with wandering sand dunes.
- South of Lüderitz is the Sperrgebiet, which is currently exclusively allocated for diamond mining operations. The licenses are and held by Lewcor and Namdeb – latter a JV between Namibian government and de Beers. This area also contains unique flora & fauna and parts have been allocated for eco-tourism.

As seen in previous slides the Sperrgebiet in particular has high wind potential. Over recent months there has been significant interest in the development of wind power projects in this area. A detailed study is needed to determine how much land may really become available for RE production.

Conservation areas



Land uses



Source: Namibia Statistics Agency

2

RENEWABLE POWER PRODUCTION

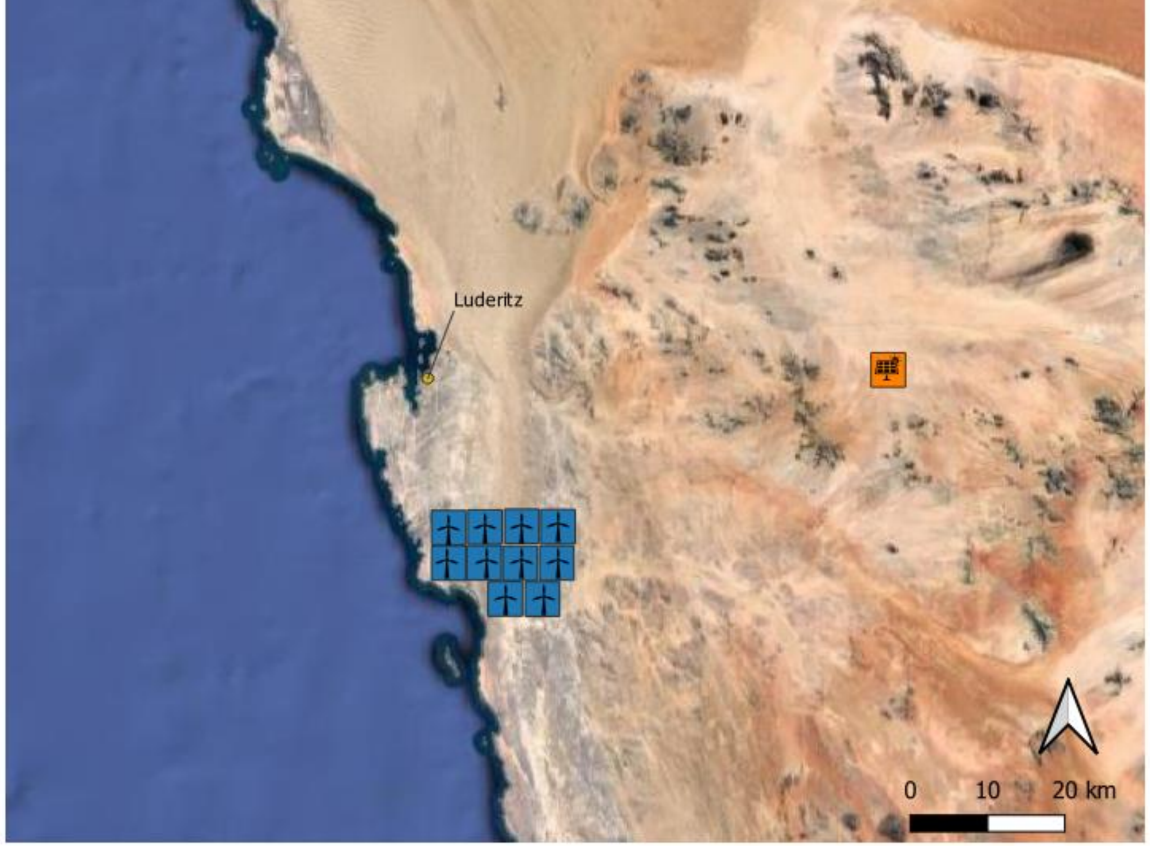
INDICATIVE LAND REQUIREMENTS: LÜDERITZ AREA

To Produce 5.3 TWh (~100ktpa H2) :

- 1 GW Solar installed: 2,500 Ha land (flat) = 5 x 5 km (yellow square)
- 1 GW Wind installed (Lüderitz): 25,000 Ha (flat) = 5 x 5 km (blue squares all together)
- 1 GW Electrolyzer: 15 Ha

(Note: these capacity ratios are high level estimates and will need to be optimised in a detailed FS or FEED)

Theoretical example 5.3 TWh wind- and solarpark in the Lüderitz Area



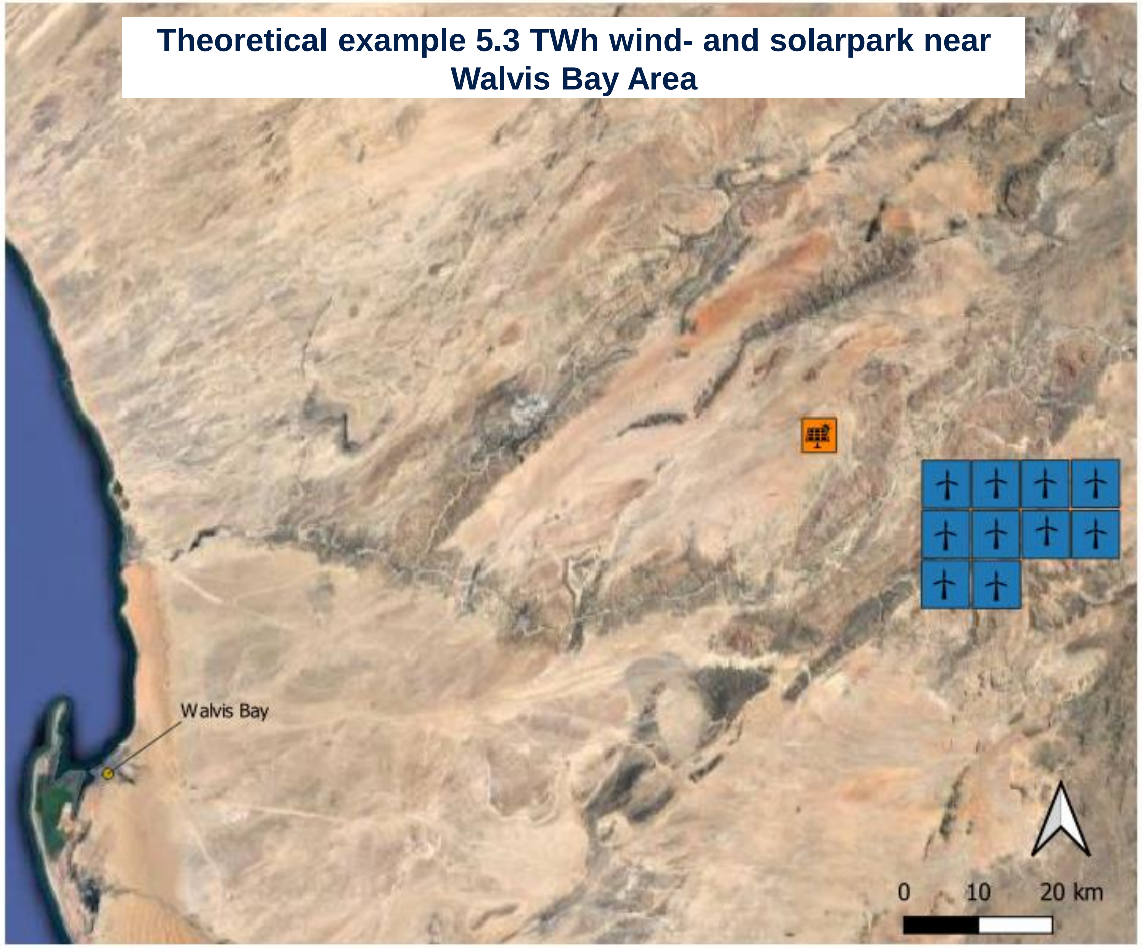
RENEWABLE POWER PRODUCTION

INDICATIVE LAND REQUIREMENTS: WALVIS BAY AREA

To Produce 5.3 TWh (~100ktpa H2) :

- 1 GW Solar installed: 2,500 Ha land (flat) = 5 x 5 km (yellow square)
- 1 GW Wind installed: 50,000 Ha (flat) = 7 x 7 km (blue squares all together)
- 1 GW Electrolyzer: 15 Ha

(Note: these capacity ratios are very rough. They will need to be optimised in a detailed FS or FEED)



2

LOCAL WATER PRODUCTION

POTENTIAL TO USE INNOVATION WATER DESALINATION TECHNOLOGY WITH WIND

DELFT OFFSHORE TURBINE

DOT

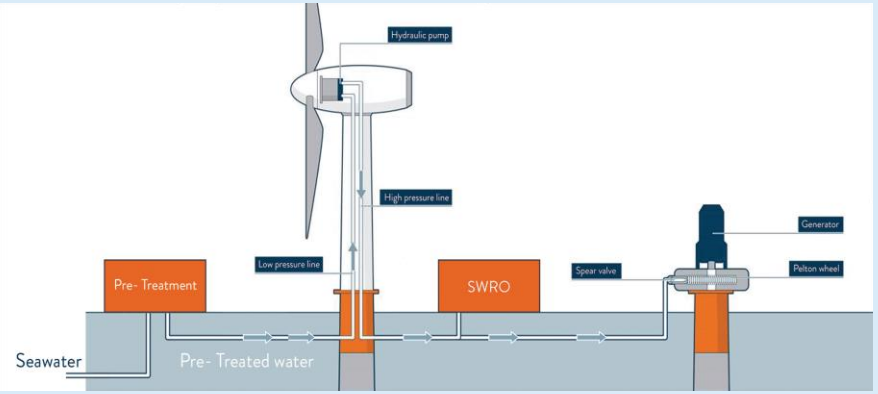
a PoR partner

- Replace generator with pump
- Reduce 50% of turbine weight

- Create high pressure (400 bar)
- Through composite pipeline

- Desalinate into fresh water
- Use high pressure directly
- Use hydro dam tech to make power

This concept also allows for peaks having and system balancing. During periods of low demand water is produced which is much easier to store



Current Testing @ the Port of Rotterdam

NamPower
Powering the Nation and beyond

Port of Rotterdam

LOCAL LOGISTICS

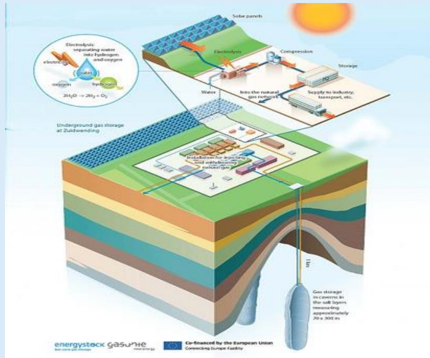
CONSIDERATIONS FOR POWER AND PIPE TRANSPORT & STORAGE

- **Transport by electrons or molecules**
  For large quantities it may be more cost-effective to transport energy as hydrogen rather than electricity. above ground pipelines. Buried pipelines are more expensive, yet unburied pipelines pollute visual aesthetics and may prevent animal migrations. Embrittlement of steel pipes could be an issue if high pressures (>70bar) are used for hydrogen transport but likely not necessary. Multi-layered flexible hoses can be used for smaller volumes

- **Distance between wind- and sunparks and port industrial complexes**
  In order to minimize losses it would be recommended to find an optimal balance between the distance from the sun- to the windparks and the industrial complex.

- **Connection to the grid or stand-alone**
  Exchange with the grid could lead to system optimizations. Either for supply to the electrolyser or as destination for curtailed renewable power. In later stages this may become more difficult due to scale.

- **Storage**
  In order to optimize the overall process it will be important to develop a number of buffer systems. These include storage systems for electricity, hydrogen and the hydrogen carrier. NamPower already initiated a largescale battery project. Hydrogen can either be stored in tanks – spheres for pressurized, cylinder tanks for LH2 – or in salt caverns, provided available in Namibia. For each hydrogen carrier there are storage solutions with specific advantages and disadvantages. To be studied in the next phase.



NamPower
Powering the Nation and beyond
Port of Rotterdam

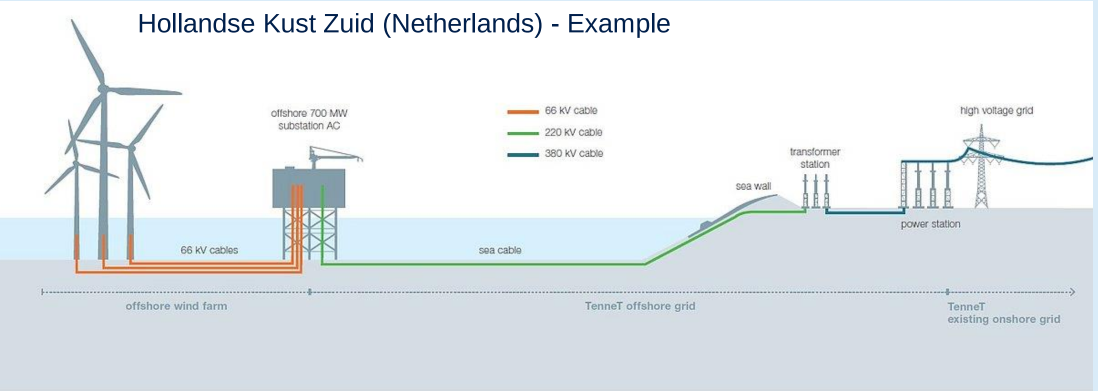
HYDROGEN & CARRIER PRODUCTION

FACILITIES AT THE RE PARK AND INDUSTRIAL PORT

Hydrogen production park:
- Windpark
- Transmission systems
- Demineralization plants
- Electrolyzer plants

Location of the Electrolyzer will depend on available space and preferred transport mode across Namibia (choice of gas transport means electrolyser close to windpark is beneficial) .

Port Industrial complex:
- Storage facilities
- Carrier production facilities
- industrial facilities for derivatives of H2 (eg. Fertiliser, methanol, etc)
- Marine export facilities (jetties)
- Logistics facilities
- Secondary and tertiary service industries



Stage 1 scenario

1GW offshore windpark: 30.000 Ha

Transmissionpark 5,5 Ha

1GW Electrolyzer: 17 Ha

Source: Electrolzyer park in Rotterdam (Artist impression)

NamPower
Powering the Nation and beyond

Port of Rotterdam

LOCAL UTILIZATION

Potential local uses of H2:

- **Mobility:**
  - Mining equipment
  - Trucks & busses
  - Marine Fuels
- **Power production (on-& off grid)**
- **Conversion of HFO IRCEs to H2**
- **Industry:**
  - Green pre-processed minerals, e.g. manganese
  - Ammonia for fertiliser
  - Green Methanol

- **In future:**
- Synthetic fuels
- Other green minerals (e.g. Steel)

Mining applications:
Mining companies in Southern Africa and globally are some of the front runners in hydrogen. For instance Anglo American has already developed green mining trucks and is running a pilot in South Africa.

Green Fertilisers
Namibia being an agricultural based economy could produce its own green fertiliser which creates independence of imports and possible "greener" products for which in Europe a market is expected to grow.

H2 CARRIER SELECTION FOR EXPORT

ALL CARRIERS REQUIRE SPECIAL HANDLING

LH2

- ✓ Less conversion
- ✓ Versatile product
- ✓ Possible use for cold energy at unloading port

- X A lot of energy needed to cool and keep cool below 250-degree, boil-off
- X All new infrastructure needed
- X Low volumetric density
- X Expensive and complex storage

AMMONIA

- ✓ Energy can be used directly in carrier
- ✓ Existing technology
- ✓ Dehydrogenation cost are lower
- ✓ Refrigerated ammonia has lower risk potential (see table)
- ✓ Foreseen to become one of the shipping fuels of the future

- X Highly toxic
- X Large scale cracking not yet proven
- X Substantial energy required to release hydrogen(dehydrogenation/cracking)
- X Compressed ammonia high risk contours

LOHC (DBT)

- ✓ Use of existing infrastructure & vessels
- ✓ Relatively safe and easy to handle

- X Practical dehydrogenation conversion around 98 %
- X Large energy requirement for dehydrogenation
- X Transport of product includes shipping a lot of material back and forth as well
- X Carrier still quite expensive.

LOHC (MCH)

- ✓ Use of existing infrastructure & vessels
- ✓ Carrier is existing chemical and easily available
- ✓ Easier to handle

- X Practical dehydrogenation conversion around 95%
- X Large energy requirement for dehydrogenation
- X Transport of produce includes shipping a lot of material back and forth as well
- X Carrier is toxic

Source table: Lloyd's Register – Hydrogen and Ammonia Infrastructure (2020)

H2 EXPORT CARRIER CHOICE

ENERGY DENSITY AFFECTS LOGISTICS REQUIREMENTS

Energy Density

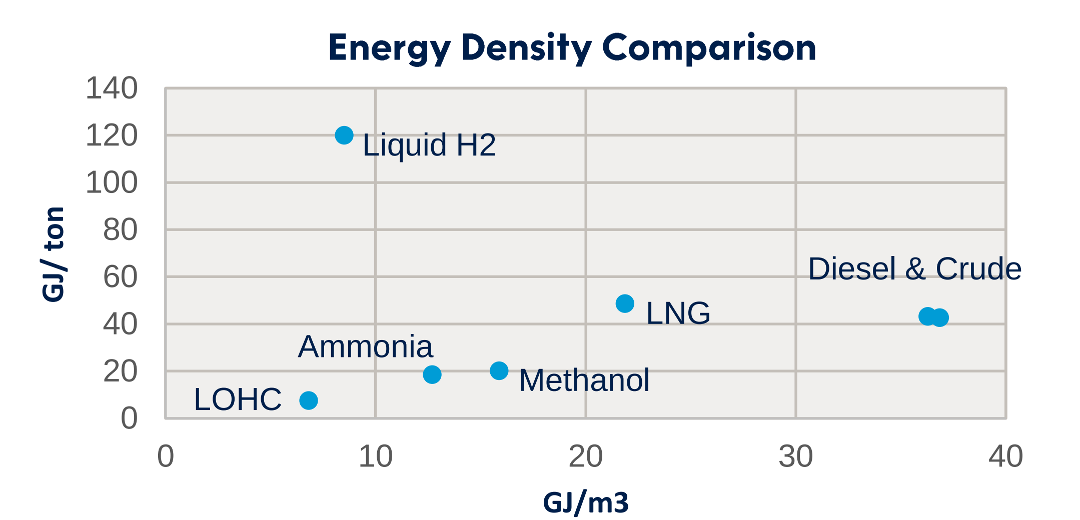
- Diesel is by far the most Energy dense per volume.
- Ammonia & Methanol require 2-3 more volume for the same amount of energy
- LH2 requires double the energy volume of Methanol and 4 times the volume of diesel
- LOHC requires double the volume of Ammonia and 6 times the same energy volume of diesel

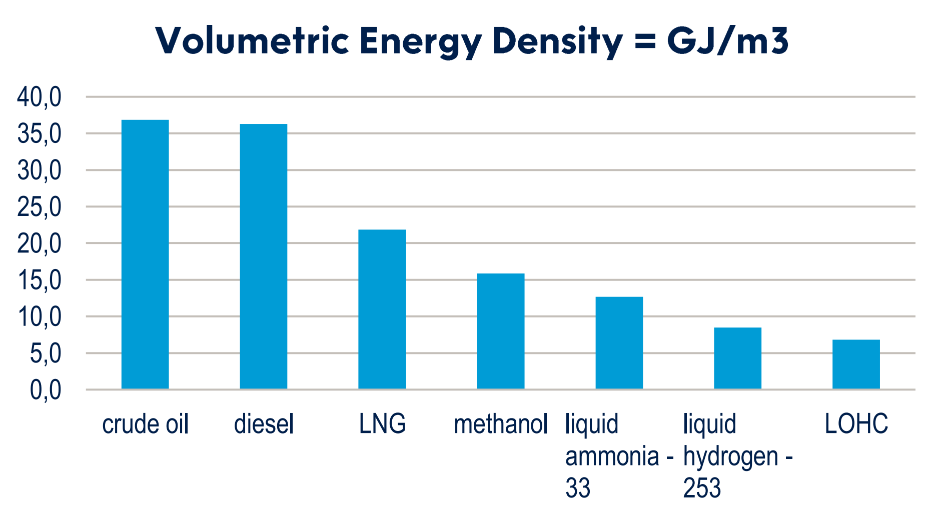
Storage Requirements

Comparing required storage volume per unit energy:

1 storage volume unit of diesel equals:

- 2,5 units of methanol
- 4 units of liquid hydrogen
- 3 units of Ammonia
- 6 units of LOHC





NamPower
Powering the Nation and beyond

Port of Rotterdam

2

VESSEL TYPE DEPENDS ON CARRIER

MINIMUM SIZE REQUIRED TO ALLOW FOR ECONOMIES OF SCALE

LH2

New	
Density	0,071
Type	LNG Tanker
DWT	9 800 t
Energy content of cargo	1 100 TJ/ 0,33 TWh
LOA	284 m
Width	43 m
Draught	11 m

AMMONIA

Bu Sidra	
Density	0,769
Type	VLGC/LPG Tanker
DWT	50 534 t
Energy content of cargo	990 TJ/0,26 TWh
LOA	225 m
Width	37 m
Draught	12 m

For LH2 the carrier is conceptual only. For all others existing vessels can be utilized.

LOHC (DBT)

Golden State	
Density	0,87
Type	Oil/Chemical
DWT	48 933 t
Energy content of cargo	370 TJ/ 0,1 TWh
LOA	183 m
Width	32 m
Draught	12 m

LOHC (MCH)

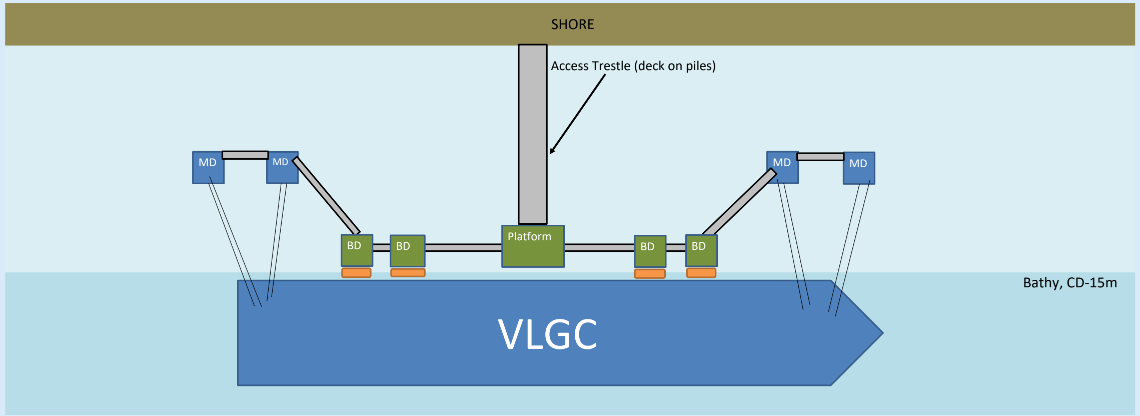
Manchac Sun	
Density	0,792
Type	Chemical
DWT	50 000 t
Energy content of cargo	300 TJ/ 0,1 TWh
LOA	186 m
Width	32 m
Draught	10,6 m

All vessels will need to run on zero-emission fuels so new engines will need to be integrated. These are expected to be on the market after 2025.

NamPower
Powering the Nation and beyond

Port of Rotterdam

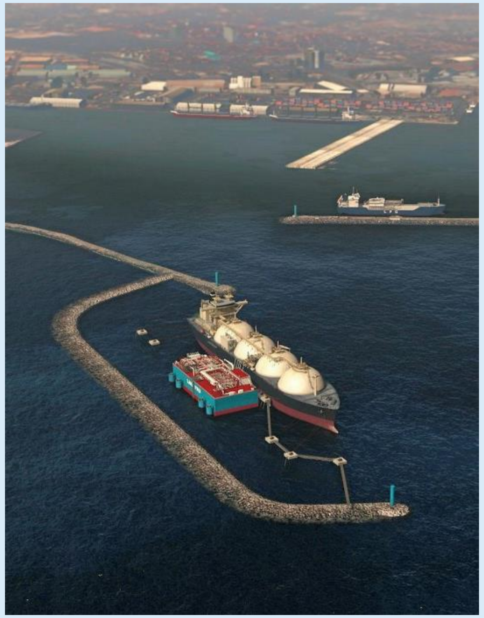
H2 EXPORT PORT REQUIREMENTS



Design requirements for standard export facilities:

1. Approach channel and turning circle 2x LOA
2. Marine structures: at least two jetties for stage 3
3. Berth line at ~15m water depth in order to minimize dredging
4. Design vessel: VLGC of 225 x 35m size
5. Onshore area outline of ~ 100 ha in comparatively flat area as per topo info of the area. Exact requirement depends on carrier.

Jetty Construction cost:
Total (order of magnitude) cost/jetty: $ 70M +/- 50% assuming multi-pile steel structures, hammered into the seabed consisting of loose material (gravel/sand); in case of hard rock, so called "rock socketing" is possible at higher cost.



Breakwater cost:
Heavily dependent on many factors such as wave climate, seabed material, turning circle and approach channel, etc. will need to be worked out in a FEED design

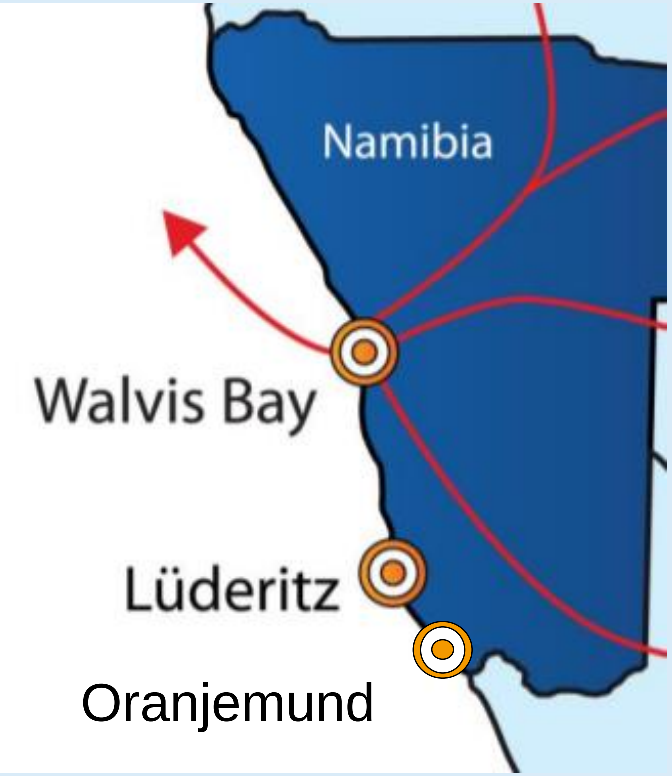
NamPower
Powering the Nation and beyond
Port of Rotterdam

H2 INDUSTRIAL PORT COMPLEX

LOCATION OPTIONS TO BE ASSESSED

4 Options considered

1. Walvis Bay - Northport
2. Lüderitz – Penguin Island
3. Lüderitz - Angra Point
4. Oranjemund – Uubvlei



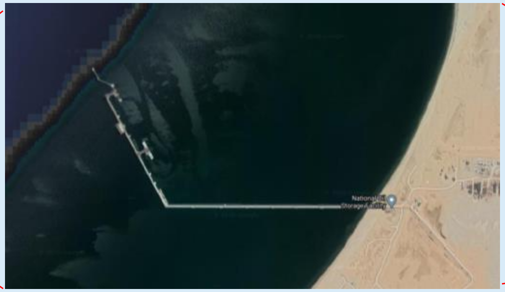
Assessment has been made with the professional support of:

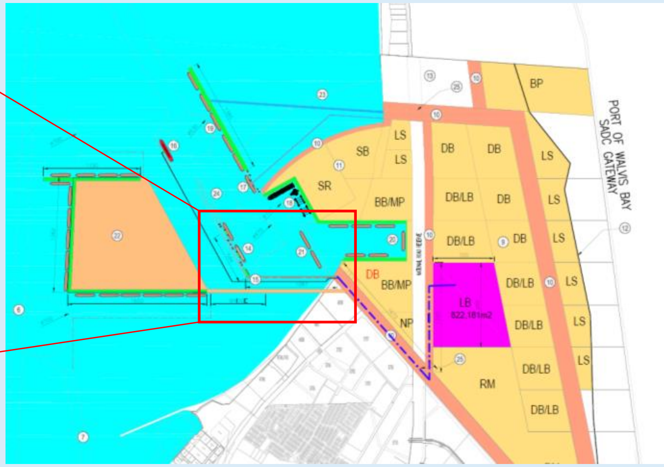
NAMPORT

2

PORT ASSESSMENT

WALVIS BAY - NORTHPORT



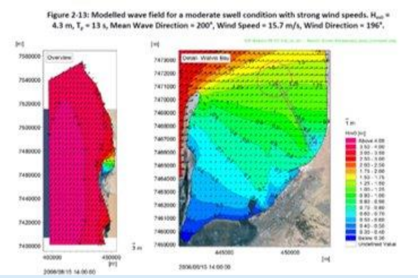


New container terminal will also free up other terminals in the existing port

Recently completed:
2 x 60,000dwt tanker berths
- 16 metre of water depth
- Low utilisation
- Jetties can be easily upgraded to allow for ammonia or hydrogen loadings.

The liquid bulk jetty is part of a larger masterplan for Northport development with multi-functional port facilities.

The Walvis Bay port is well protected from SW swells. The jetty orientation is such that downtime is minimal



Assessment Northport:

+ Existing berth with the right facilities and a lot spare capacity. Can be used right away.

+ No need for breakwater

+ Sufficient Port space available with adequate distance from any other activities/buildings

0 Hydrogen carrier production and storage facilities to be developed in a way not to hamper other future industrial developments.

0 Solar rich power production areas +/-70km from coastline, irrespective of location.

- Downside is the larger distance to the wind power production areas.

PORT ASSESSMENT

LÜDERITZ – PENGUIN ISLAND

Penguin Island
Greenfield development North of existing Lüderitz port
In the lee (downwind protected side) of the uninhabited island

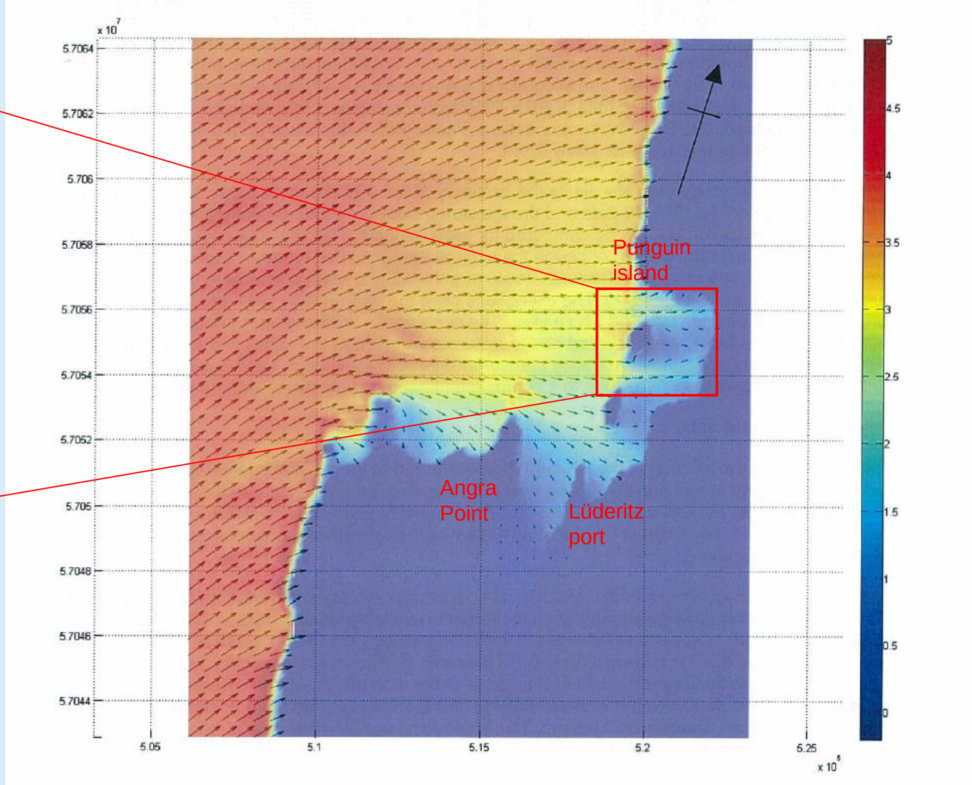


Figure 3: Preliminary result from SWAN SW 5m swell wave.

Assessment Penguin Island

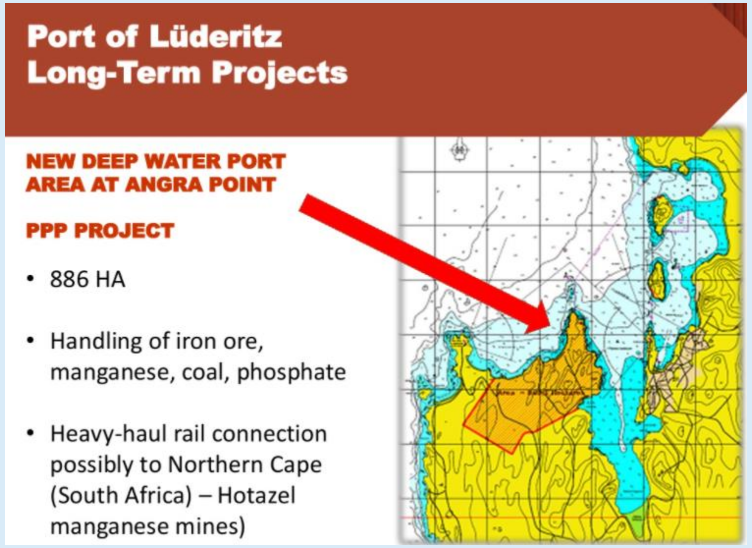
+ Protected from swell waves by the island
+ Sufficient distance from urban areas
- Long trestle needed. Expensive in view of piling in rocks
- Dredging needed in rocky seabed.
- Risk of grounding with large consequences to rocks

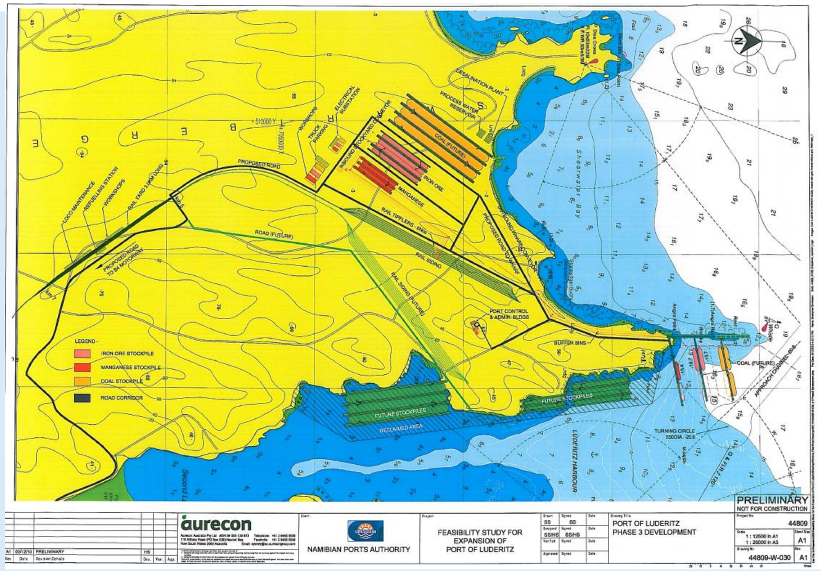
PORT ASSESSMENT

LÜDERITZ – ANGRA POINT

Angra Point Port development

- Planned Manganese export facility
- EIA study led to halt of the project. The area is part of nature park
- Recently government is reconsidering in view of larger economic development ambitions





Project driven by export wish from the world's largest manganese mines in NW South Africa, just across the border as well as Phosphate mining plans south of Lüderitz.

Designs for the terminal were already completed. Export jetties located behind headland with possible small breakwater

Assessment Angra Point

+ Already master planned for mineral export operations
+ Protected from waves through headland. May need small BW
+ Sufficiently far away from urban areas

+& - Minimal dredging required in a kelp coastal area.

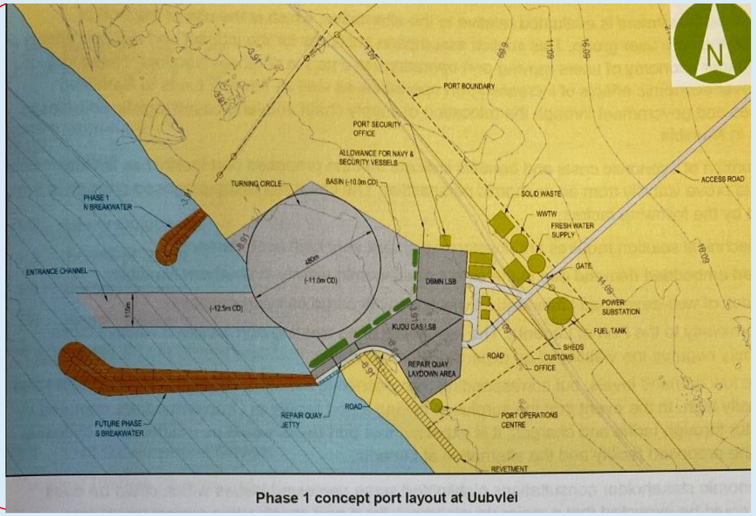
+ & - Port facilities for both minerals as well as H2 will need to developed in an integrated manner

- Investment in marine facilities
- Currently designated nature reserve

PORT ASSESSMENT

ORANJEMUND - UUBVLEI

Oranjemund - Uubvlei
In the past a port plan was already developed in this area close to the SA border.
It would function to support offshore mining activity taking place in the Sperrgebiet – diamond winning area.



Phase 1 concept port layout at Uubvlei

Assessment Oranjemund

+ Existing port design.
- Close to river rmouth on the border with South Africa. Which will result in large coastal flow of sediments
- Inside Sperrgebiet which is a restricted access area and with very little other developments and facilities
- Very exposed to swell. Will require heavy breakwater with a high price tag.

2

PORT ASSESSMENT

RELATED TO PORT OPERATIONS ONLY

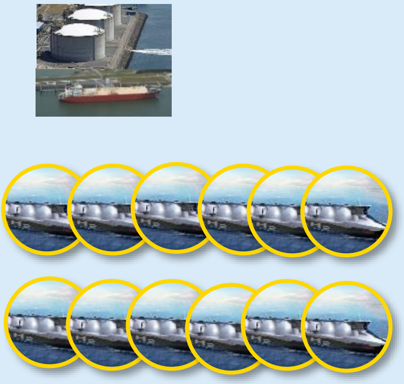
	Walvis Bay – North Port	Lüderitz – Penguin Island	Lüderitz – Angra Point	Oranjemund
Existing Facilities that can be used	++	-	-	--
Sufficient shelter from waves/ need for expensive breakwater structure	++	-	+	-
Environmental impacts & Safety	++	-	-	-
Availability and suitability of land for onshore facilities and future expansions	++	+	++	+
Accessibility	++	++	++	-
OVERALL PORT SCORE	+10	0	+3	-4

Note: this is only scoring the locations for port-related activities. For a new Hydrogen value chain the assessment would need to look broader and include factors such as wind-and solar intensity, logistics, local utilization options, etc.

SHIPPING & PORT REQUIREMENTS

DEPENDS ON THE CARRIER CHOICE FOR STAGE 2: 53 TWH ~ 1MTPA H2

LH2



Mooring	1 jetty
Storage	2 tanks of 52,000 m^3
Ship	12 x 140,000m^3 LH2 tankers
Land area (storage)	Min. 25 Ha

AMMONIA

Mooring	1 jetty
Storage	2 tanks of 80,000 m^3
Ship	12 x very large gas carrier (VLGC), 56K dwt
Land area (storage)	Min. 14 Ha

LOHC (DBT)

Mooring	3 jetties
Storage	10 tanks of 55,000 m^3
Ship	16 product tankers, 100k dwt
Land area (storage)	Min. 60 Ha

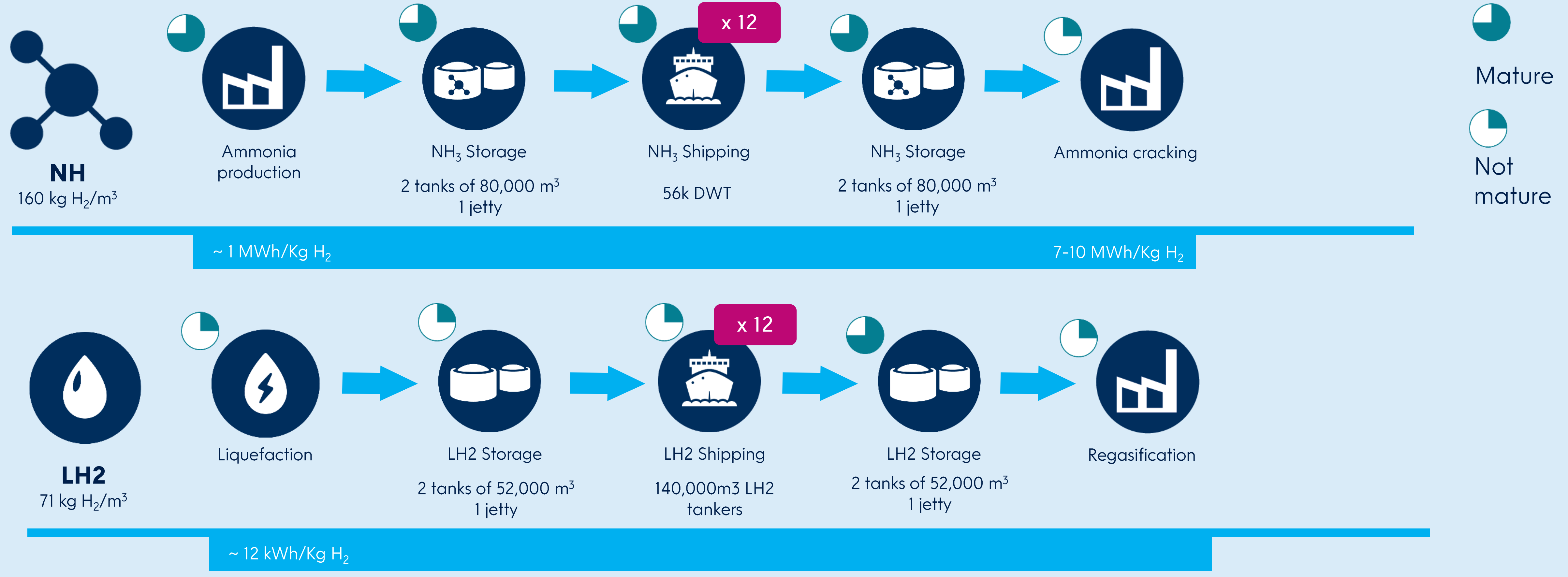
LOHC (MCH)

Mooring	3 jetties
Storage	12 tanks of 55,000 m^3
Ship	18 chemical tankers 100k dwt
Land area (storage)	Min. 80 Ha

34

SHIPPING & PORT REQUIREMENTS

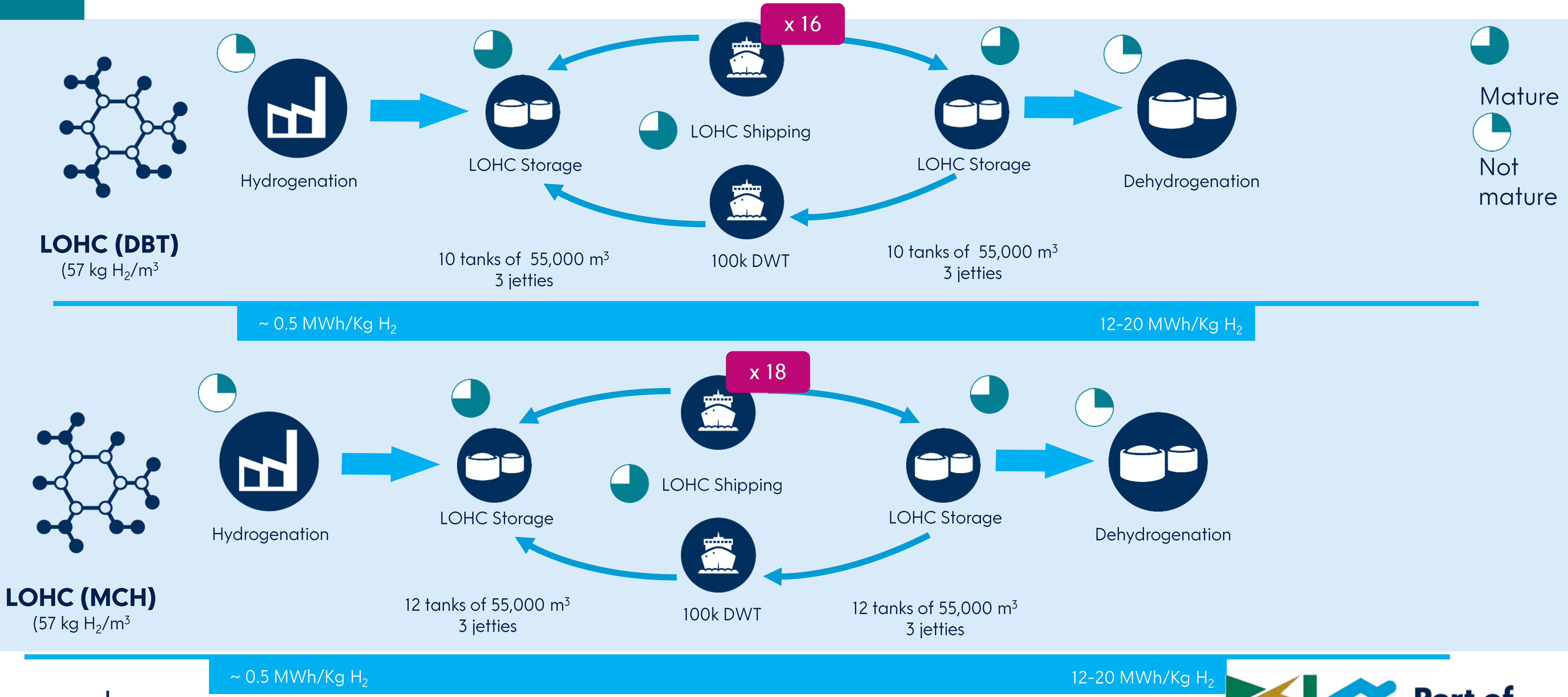
FOR EACH CARRIER THE VARIOUS FACILITIES IN THE SUPPLY CHAIN ARE AT DIFFERENT TECHNICAL MATURITY LEVEL



FOR A STAGE 2 SCENARIO: 20 TWh ~ 420kTPA H2

SHIPPING & PORT REQUIREMENTS

CONT.



FOR A STAGE 2 SCENARIO: 20 TWh ~ 420kTPA H2

NamPower
Powering the Nation and beyond
Port of Rotterdam

HYDROGEN IMPORT FACILITIES

ROTTERDAM WILL BE READY TO RECEIVE, STORE AND PROCESS ALL TYPES OF H2 CARRIERS

- **Green ammonia terminal**
  Existing Europoort terminal operated by OCI.
  New dedicated green ammonia terminals by 2025.
- **Liquid hydrogen terminal**
  Feasibility study started with Kawasaki.
  Expected operational after 2030.
- **LOHC terminals**
  First pilot with DBT at existing Botlek terminal in 2023.
  Other pilots also being planned before 2030.
- **Green methanol terminals**
  Methanol has not been considered as a hydrogen carrier because of high dehydrogenation costs. However green methanol may be one of the future derivatives of hydrogen for which there will also be a market in Europe.

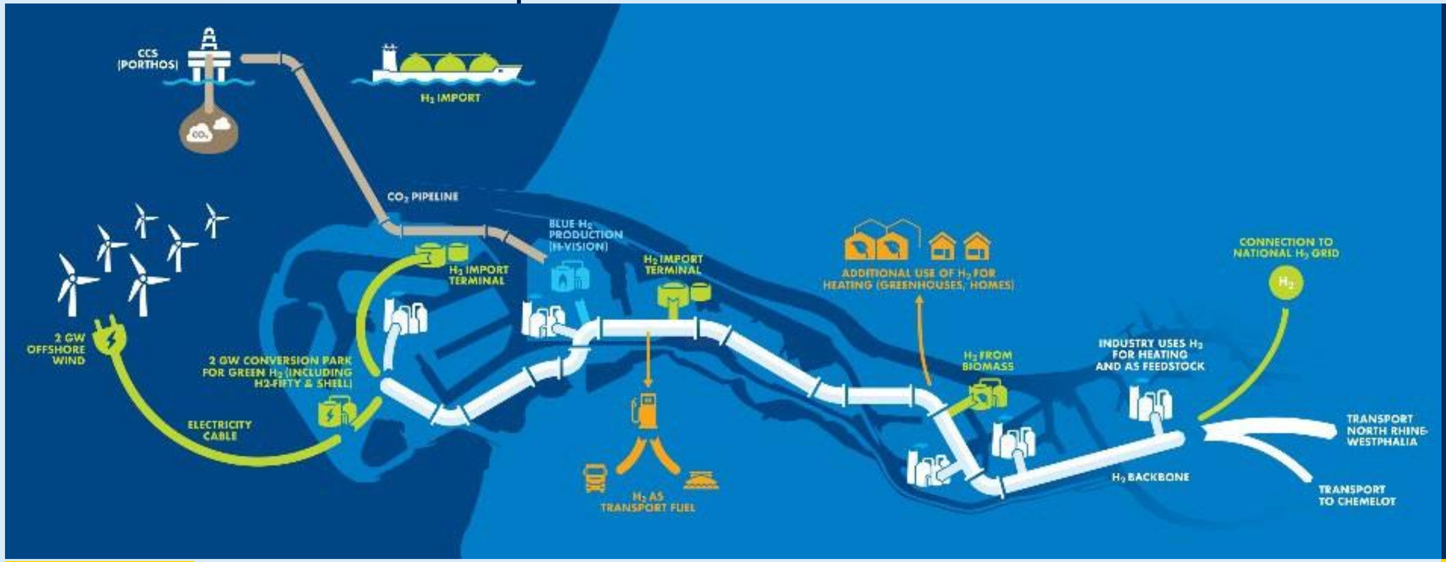
2 DISTRIBUTION

ROTTERDAM HAS EXCELLENT INTERMODAL CONNECTIONS

Hydrogen backbone
Hydrogen infrastructure within the Port of Rotterdam.

Interlink
Connecting the Port of Rotterdam to the rest of the country and neighbouring countries.

European connected hydrogen networks



2025

2030

2035

Source: *Port of Rotterdam Hydrogen Vision, European Hydrogen Backbone (2020)*

HYDROGEN OFFTAKE

MOBILITY AND STEEL FIRST SECTORS TO ADOPT HYDROGEN, OTHER INDUSTRY WILL FOLLOW AFTER 2030

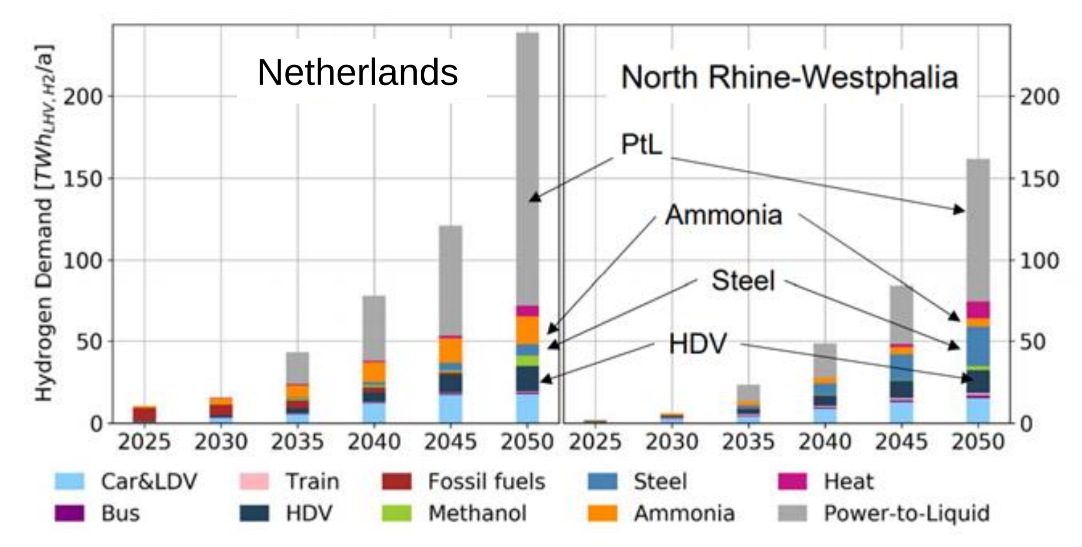
Use of hydrogen stimulated through European and national climate policies.

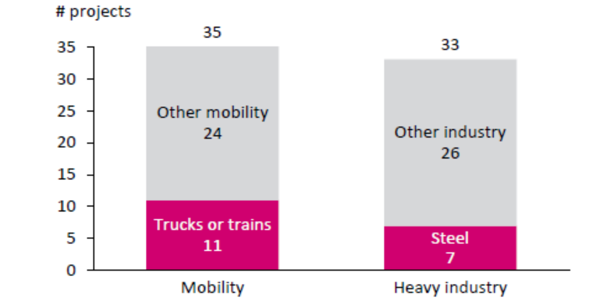
An inflection point in demand is expected in 2030 when Europe embraces the next target.

At this time that European consumption forecast is 60 Mtpa hydrogen in 2050.

Mobility (Car&LDV, HDV, Train, Bus) and Steel could the first sectors to adopt hydrogen (see graph).

The Netherlands and Germany recognize the need for largescale imports because local production capacity will never be able to meet demand.





Source: HY3 - WP1 – Hydrogen demand: scenarios for Netherlands and NRW

HYDROGEN OFFTAKE

WHICH SECTORS LOOK ATTRACTIVE

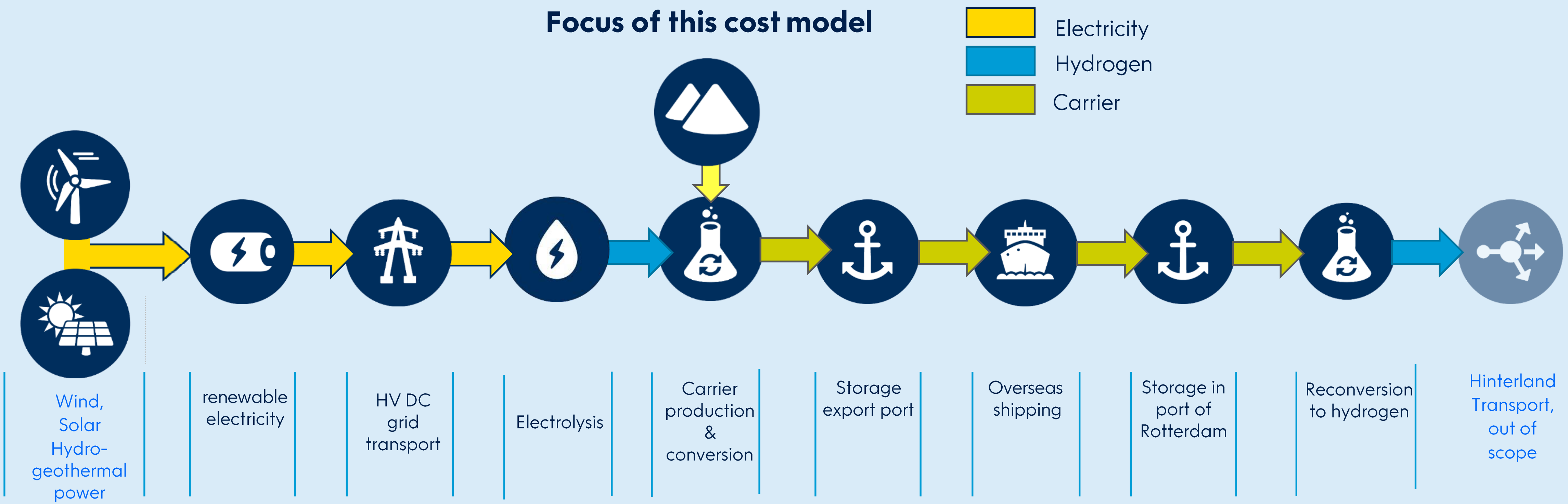
Steel has the best commercial case, HGV's have little competition over long ranges, short haul shipping is less clear but has traction

	Steel	HGV's	(Short haul) shipping
Scale of green hydrogen production required	Up to 1.5 Gwel to replace BF (Blast Furnace) producing around 4.4 Mt steel p.a.	185 Mwel will fuel 1,000 regional trucks, 80000km per truck	46 Mwel would fuel 100 short haul ships, assuming ca. 19000 t/km p.a.
Business case	**Stronger –** Large segments of automotive and construction likely to absorb additional cost required to 'go green' due to low % of total product cost. Higher carbon prices might help.	**Weaker –** Substantial additional incentives required due to high influence of fuel and engine on total cost of freight. Though larger end users may adopt solution at premium	**Weaker –** Substantial additional incentives required due to high influence of fuel and engine on total cost of freight. No expected pressure from EU or IMO, though larger users may adopt.
Technology maturity	**Moderate –** Large scale pilots in development, 2025-2030 targeted. Financing and insurance support to develop.	**Stronger –** Units in operation and several OEMs introducing new models in next 2-3 years (fuel cells, compressed H2)	**Moderate –** Large scale pilots in development, 2025-2030 targeted. Financing and insurance support to develop.
Threat of competing technologies	**Medium –** Only carbon capture likely to compete and is likely to be more expensive	**Medium –** EV batteries more probably for short haul, electricity may compete over longer haul but not everywhere.	**Medium –** Flow batteries appear less expensive for short haul, through H2 in various forms (such as ammonia to be used in fuel cells and engines for long haul).

Source: Baringa

HYDROGEN SUPPLY CHAIN COST MODEL

MODEL SETUP



Disclaimer: The cost model is based on cost parameters which were available at this time. Some of these are guestimates for the future.
The results presented are therefore indicative only and not to be relied upon. The accuracy is in the order of +/-50% (roughly). The purpose of this cost exercise was to get a better feel for relative ratios and relations. A more detailed study will be needed before hard conclusions can be drawn.

HYDROGEN SUPPLY CHAIN COST MODEL

RENEWABLE POWER COST EXPECTED IN 2030

For Stage 2 scenario: 1 Mtpa

Cost price for renewable energy production is expected to decrease due to further technological improvements

		investment (EUR/kW)	
	Full load hours	2020 (by NamPower)	2030 (Irena)
Wind	4730	1.261	800
Solar	3154	797	280

This leads to the following electricity prices:

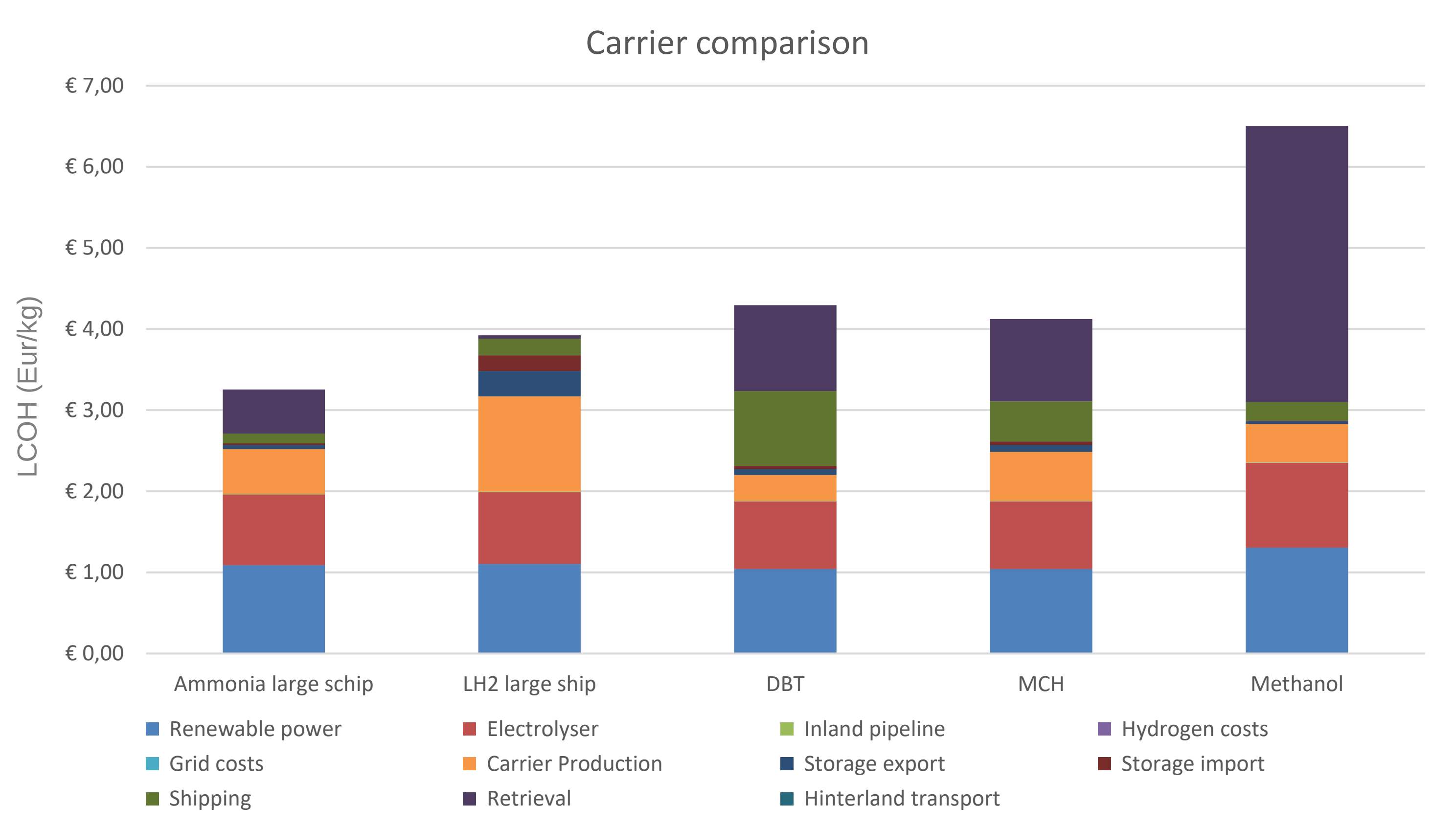
Year	TWh	ktpa H2	Wind	Solar	Energy Price Wind Eur/kWh	Energy Price Solar Eur/kWh
2030	53	1000	70%	30%	0,019	0,013

Disclaimer: The cost model has been set up and is operated by the Port of Rotterdam. Nampower has only provided some input data. The model results have a certain level of accuracy in the order of +/-50% which is related to the input parameters

CARRIER COMPARISON RESULTS

PRELIMINARY CONCLUSIONS

Based on a 1 Mtpa H2 equivalent scenario, Price levels of 2030



Within the margin of error of the model it seems that the cost levels of all 4 carriers, except Methanol, are very close together and are worth keeping in consideration in a next stage study.

Methanol as pure H2 carrier is not so interesting however if green methanol is the end product to sell it could still be of interest to certain industrial customers.

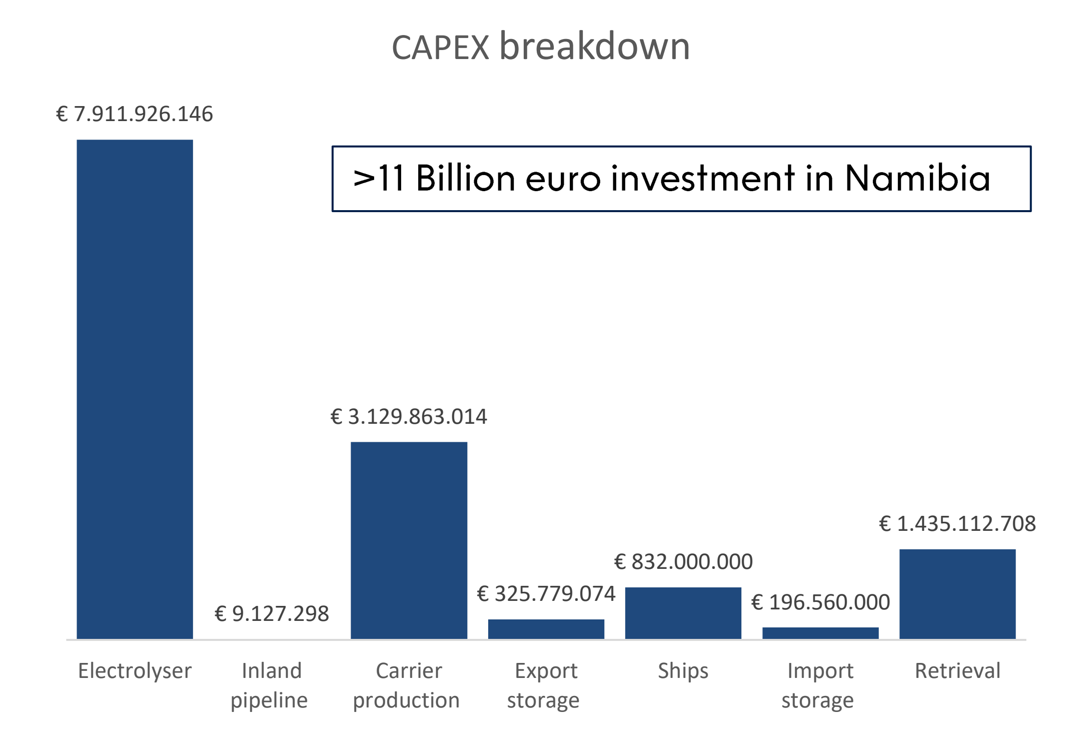
The price for Namibian green hydrogen delivered in Rotterdam can be considered quite competitive.

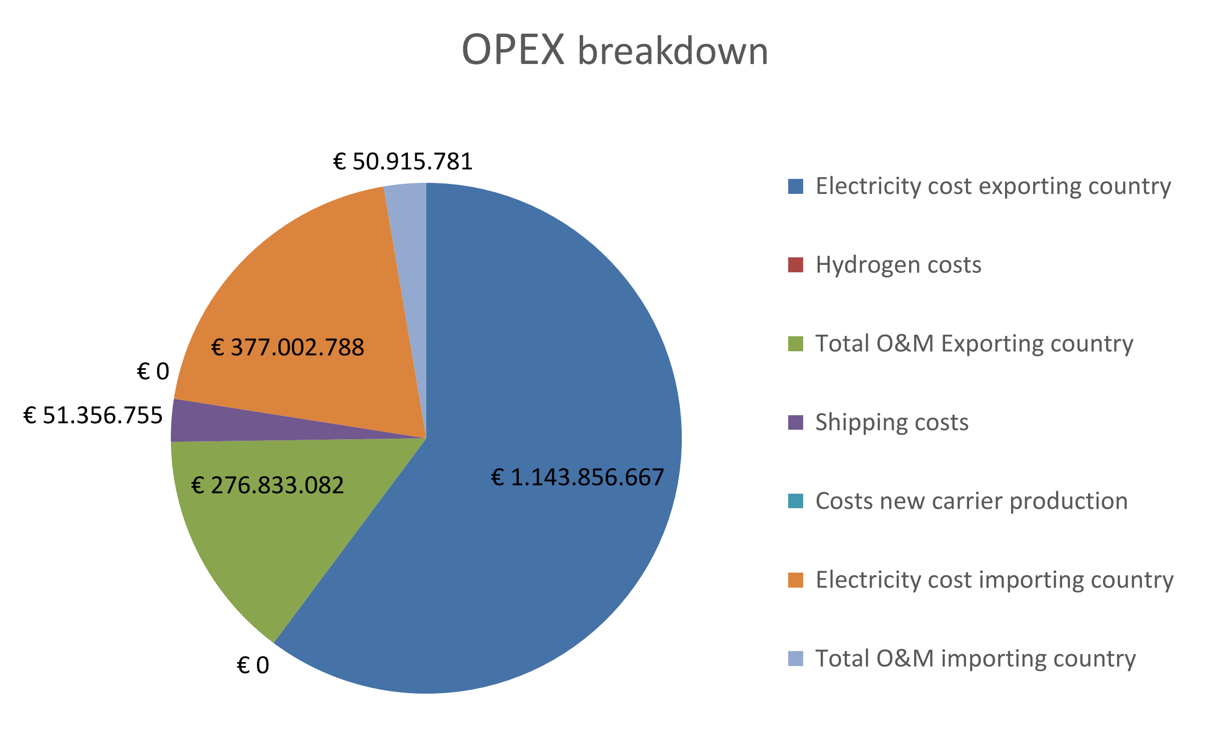
Disclaimer: These figures have an accuracy of +/- 50%. They are indicative and for comparative analysis only and not to be relied upon the exact numbers.

HYDROGEN SUPPLY CHAIN COST MODEL

CAPEX

For a 1 Mtpa H2 scenario, Price levels of 2030, with Ammonia as carrier





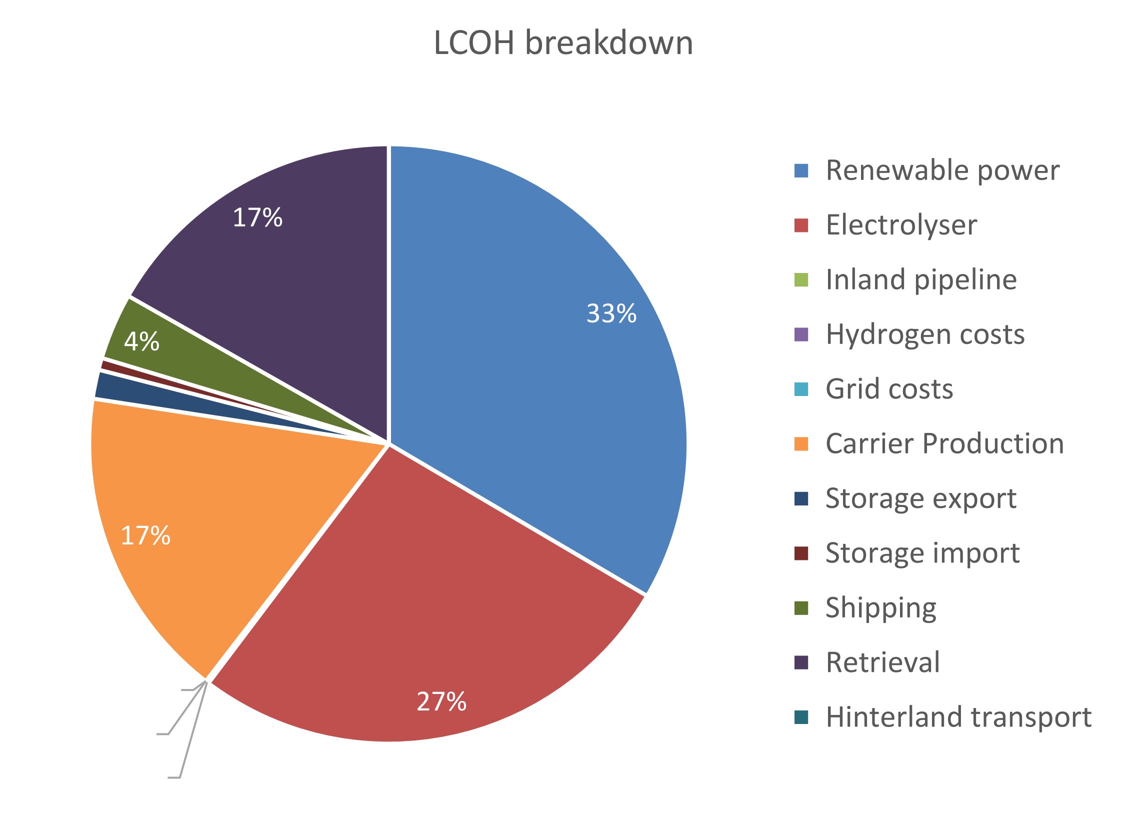
Disclaimer: These figures have an accuracy of +/- 50%. They are indicative and for comparative analysis only and not to be relied upon the exact numbers.

Source: PoR analysis

HYDROGEN SUPPLY CHAIN COST MODEL

TOTAL LEVELIZED COST OF HYDROGEN BREAKDOWN

For a 1 Mtpa H2 scenario, Price levels of 2030, with Ammonia as carrier



Local cost for production of Hydrogen is just over 60% of the final price delivered in Rotterdam.
RE cost, Electrolyser cost and carrier (ammonia) production costs are the 3 main cost parameters.
Shipping-distance-related costs are only 4%.

Note however that the model assumes additional production of hydrogen/ammonia to be used as ships fuel so distance impact is slightly larger but still not major.

Source: PoR analysis

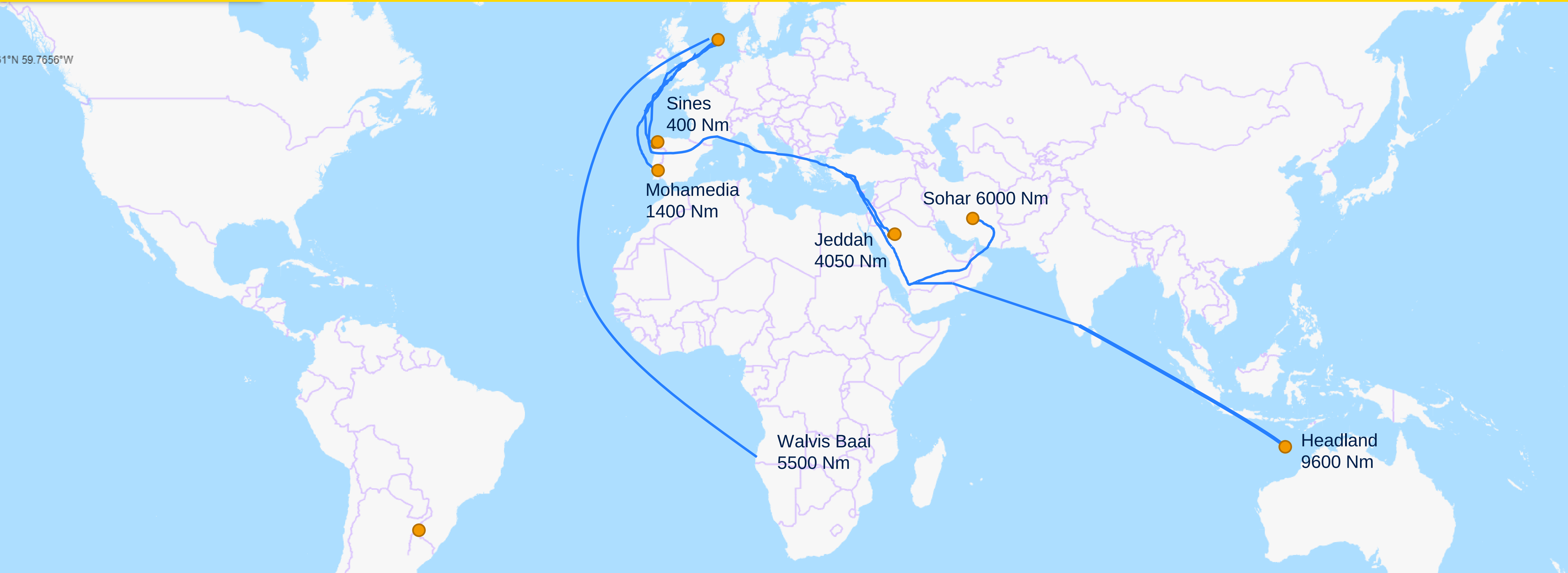
Disclaimer: These figures have an accuracy of +/- 50%. They are indicative and for comparative analysis only and not to be relied upon the exact numbers.

3

SHIPPING DISTANCES

FROM H2 PRODUCING COUNTRIES

COST MODEL

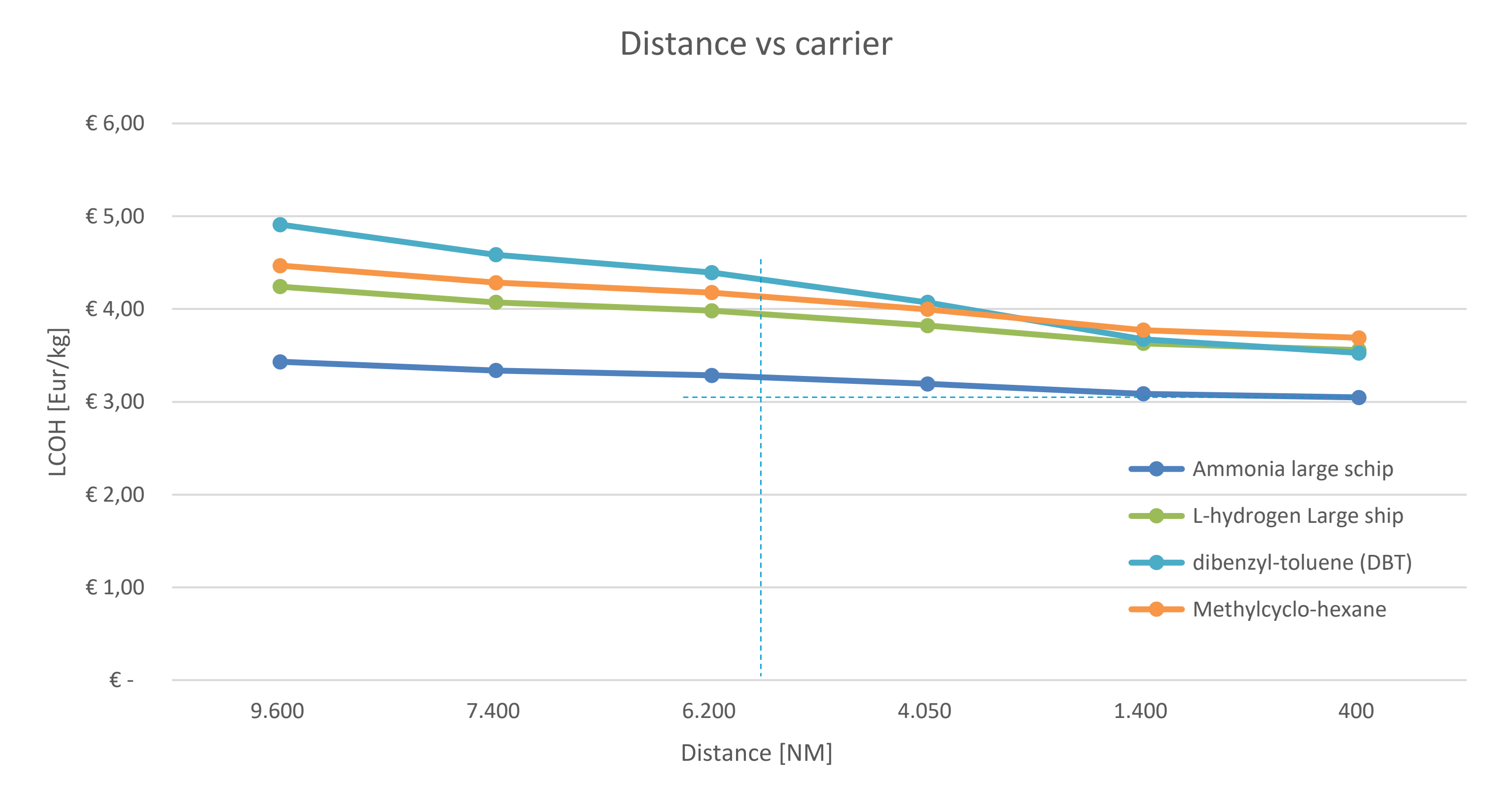


NamPower
Powering the Nation and beyond
Port of Rotterdam

SENSITIVITY ANALYSIS

SHIPPING DISTANCE PER TYPE OF CARRIER

For a 1 Mtpa H2 equivalent scenario, Price levels of 2030



Namibian Hydrogen has only a few % higher cost than Hydrogen from sources closer to or further from Europe.

It can be seen that the larger the shipping distance the less attractive the LOHC's as carrier are.

The unique wind- and solar conditions of Namibia can compensate for this to a certain extent.

Disclaimer: These figures have an accuracy of +/- 50%. They are indicative and for comparative analysis only and not to be relied upon the exact numbers.

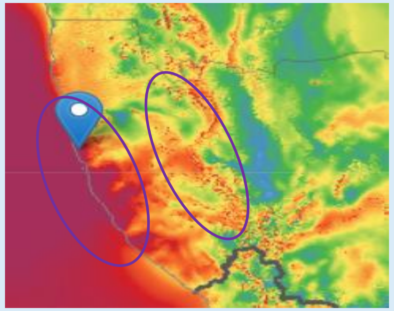
NamPower
Powering the Nation and beyond

Port of Rotterdam

4

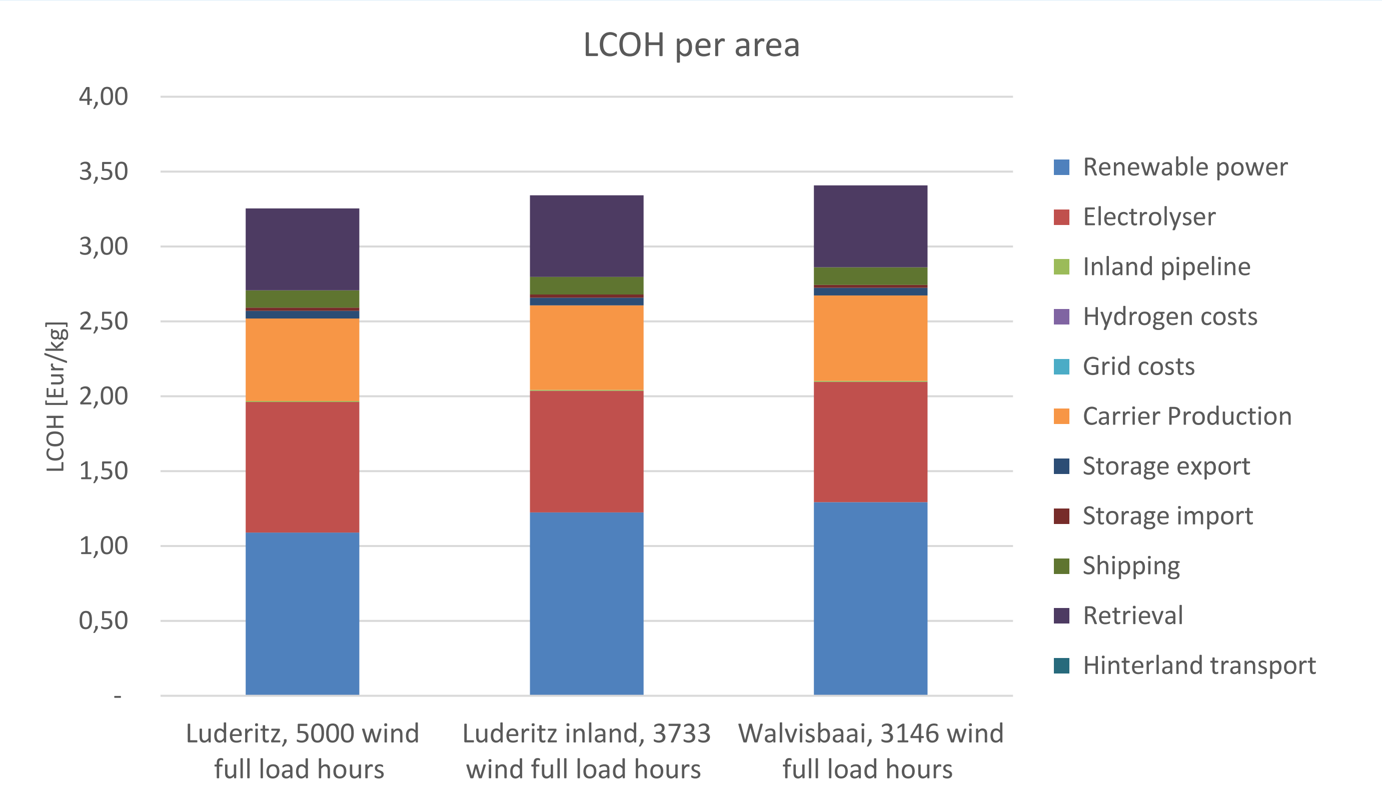
SENSITIVITY ANALYSIS

WIND POWER PRODUCTION LOCATIONS



As could already be seen in earlier wind atlas map, the wind intensity in the Sperrgebiet South of Lüderitz is higher than in the Karas or inland Walvis Bay. This impacts considerably on the price of H2. For Namibia to be competitive it is important that wind power production in this area is made possible at reasonable cost.

For a 1 Mtpa H2 scenario, Price levels of 2030, with Ammonia as carrier



Disclaimer: These figures have an accuracy of +/- 50%. They are indicative and for comparative analysis only and not to be relied upon the exact numbers.

NamPower
Powering the Nation and beyond

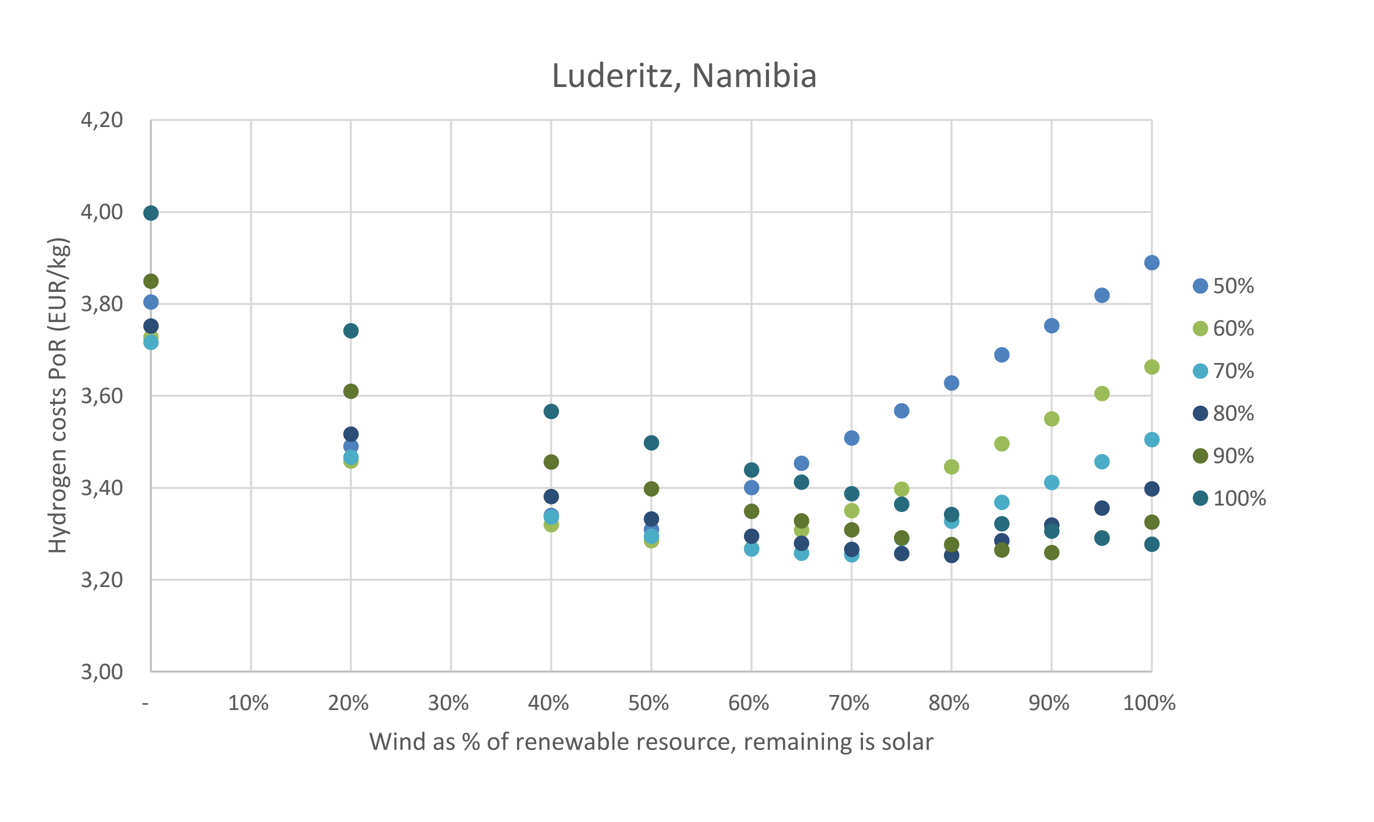
Port of Rotterdam

48

SENSITIVITY ANALYSIS

WIND TO SOLAR TO ELECTROLYSER RATIOS

For a 1 Mtpa H2 scenario, Price levels of 2030, with Ammonia as carrier



For this particular scenario a preliminary optimization exercise was undertaken to show the impact of different wind-to-solar ratios as well as RE power to Electrolyser capacity ratio.

For this case it could be concluded that 70-80% wind and 20- 30% solar is an optimal ratio, with an electrolyser having a capacity of around 80% of the total RE capacity.

Please note that these results and conclusions are preliminary only. In a next engineering stage all parameters and calculations will of course need to be revisited which may lead to different conclusions.

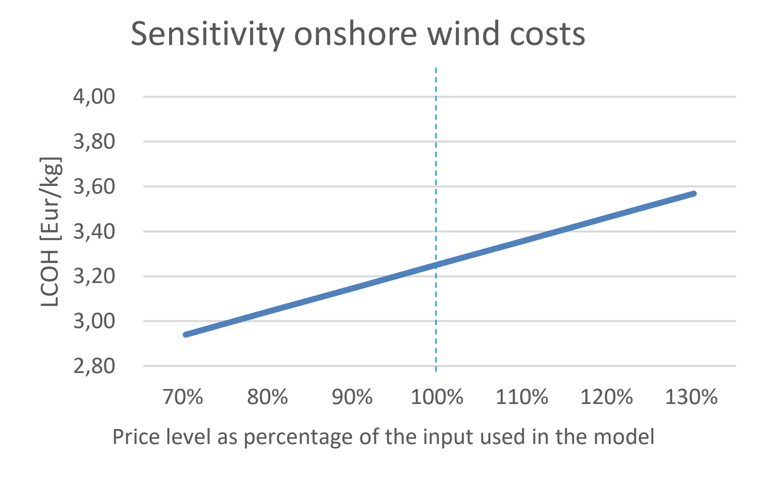
Disclaimer: These figures have an accuracy of +/- 50%. They are indicative and for comparative analysis only and not to be relied upon the exact numbers.

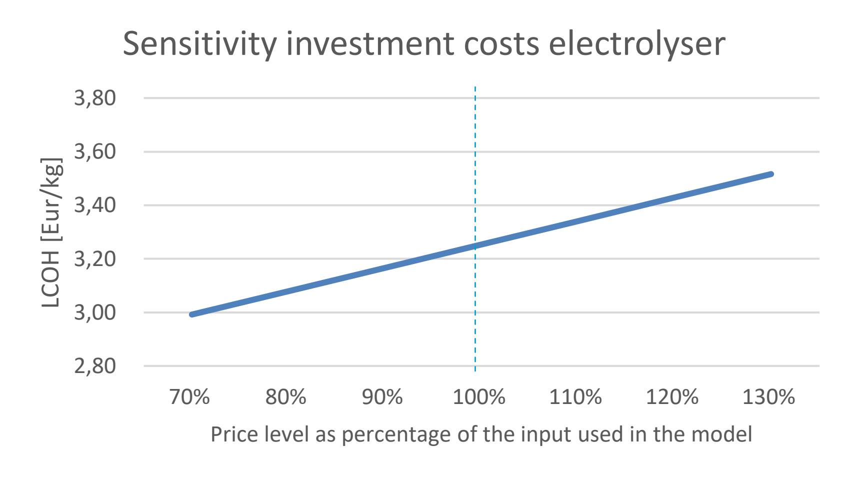
4

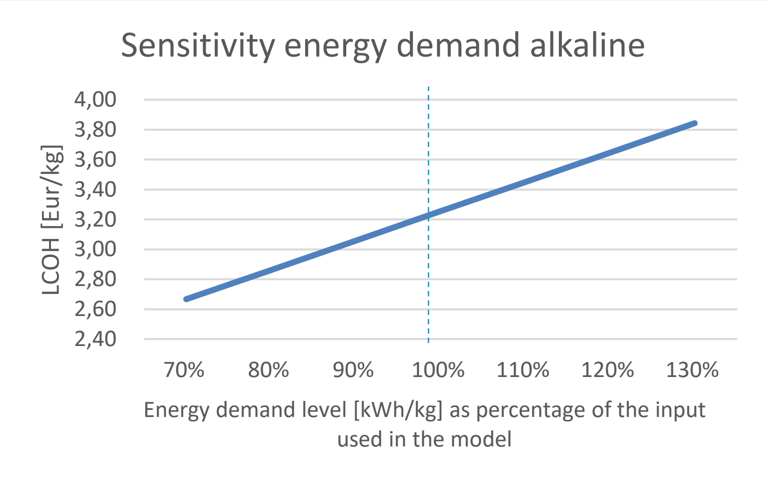
SENSITIVITY ANALYSIS

TECHNOLOGY DEVELOPMENT

For a 1 Mtpa H2 scenario, Price levels of 2030, with Ammonia as carrier







It is anticipated that the cost for Renewable power, especially solar as well as the cost for electrolyser Capex and Opex will come down with the further maturing of the technology. Each would lead to further reduction of the price level delivered in Rotterdam by significant %. Already in the coming decade some of these developments can be expected.

Disclaimer: These figures have an accuracy of +/- 50%. They are indicative and for comparative analysis only and not to be relied upon the exact numbers.

NamPower
Powering the Nation and beyond

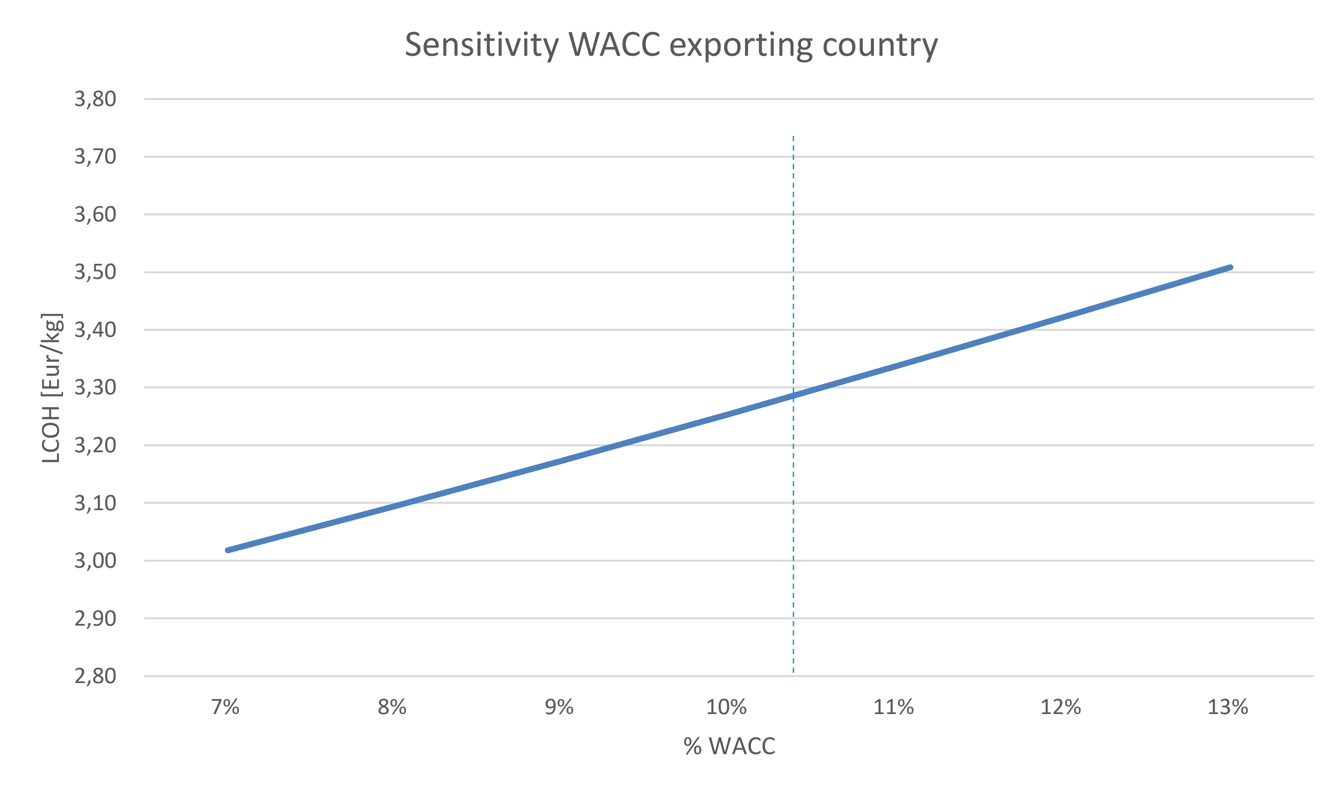
Port of Rotterdam

4

SENSITIVITY ANALYSIS

WACC

For a 1 Mtpa H2 scenario, Price levels of 2030, with Ammonia as carrier



2,5% discount in WACC for Namibia component could lead to a 7% discount in price delivered in Rotterdam backbone.

Disclaimer: These figures have an accuracy of +/- 50%. They are indicative and for comparative analysis only and not to be relied upon the exact numbers.

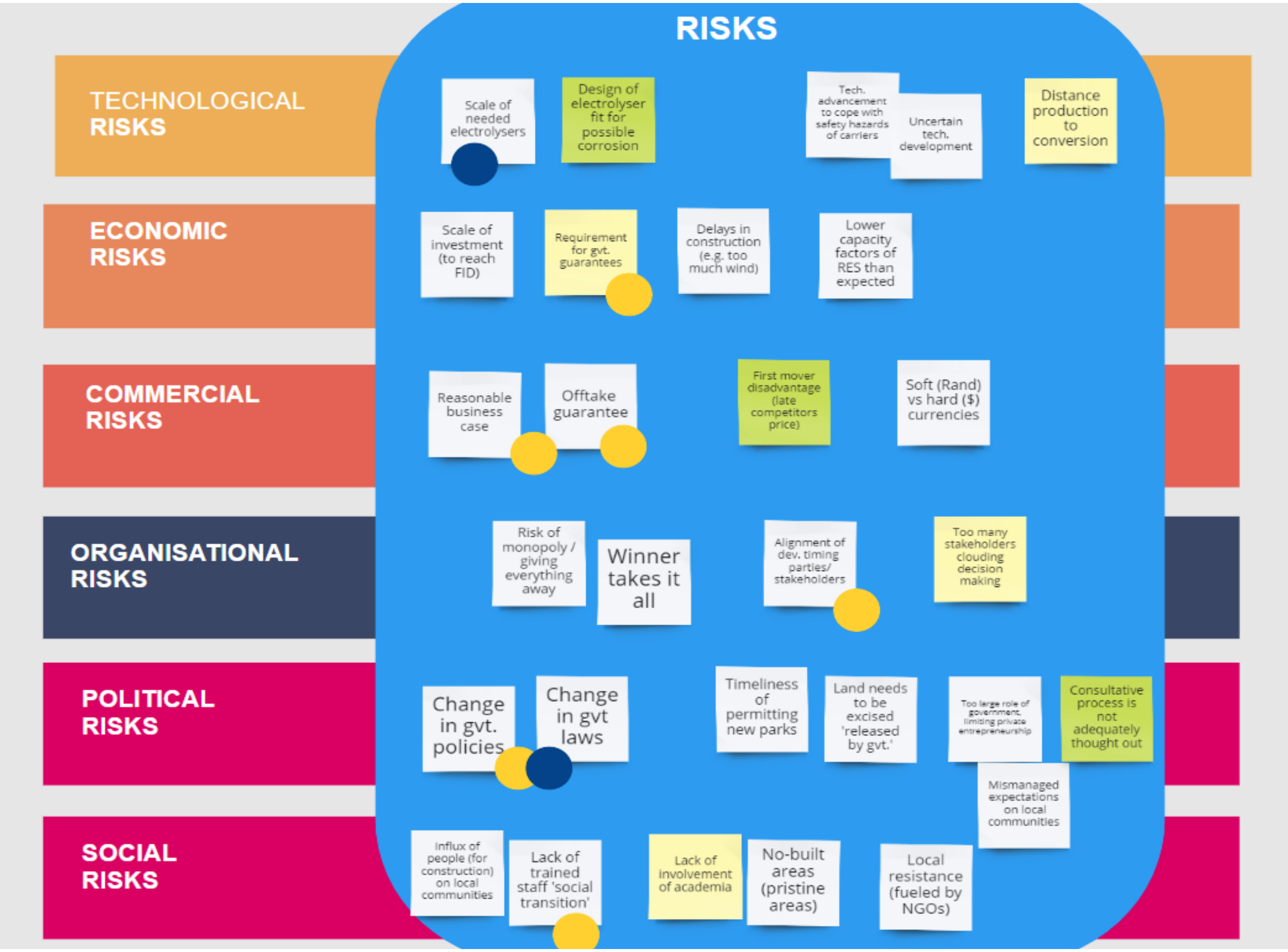
JOINT RISK & BARRIERS WORKSHOP

EXAMPLE OF ONE OF 4 SUPPLY CHAIN COMPONENTS STUDIED

Highest risk

Potential barrier

Renewable Power & H2 production



Collaborative risk analysis workshop on digital whiteboard with relevant NamPower and NamPort's team members.

Example of outcome on 'H2 Production' supply chain component.

5

RISKS AND BARRIERS

SUMMARY OF MAIN RISKS

LARGEST RISKS	MITIGATIONS
New technologies still to be developed (TRL of large-scale electrolysers). Failure at electrolyser. Capex cost overruns and H2 price higher than originally envisaged. High operational costs.	Consider to develop H2 knowledge center and learn by doing with local pilots in Namibia. Collaboration with leading electrolyser developers. Sensitivity studies in model to ensure cost overruns can still be absorbed.
Scale of proposed projects (offtake risk). Currency exposure in case need for Namibian $.	Phased development, start with smaller scale local use. Detailed multi-party roadmap. Intergovernmental or Worldbank financial support solutions. Consider Special Economic Zone with special currency conditions
Access to key land in nature parks. Resistance by NGO's and local population	Careful planning, development and strong stakeholder communication. Consider the use of a citizen council.
Safety risks. And perceived safety risks.	Involve experts. With thorough safety studies and collaborative planning and development risks can be managed
Political risk of future governments, Change in Law, Termination and changing priorities.	Consider a multi-party commitment to climate and energy goals. Or even a set climate law. Any required GRN guarantees to be carefully worded to retain investor confidence and at the same time consider GRN's exposure (contingent liabilities). Follow a country-wide coordinated and structured approach to H2.
Risk of doing nothing. Opportunity passes.	Dream big, plan carefully, execute diligently and safely.

5

ROLES IN THE SUPPLY CHAIN

RISK AND BARRIERS

OPTIONS FOR EACH SUPPLY CHAIN COMPONENT *(results of workshop 30 April)*

1 Renewable power → 2 Local power distribution → 3 H2 Production & Conversion → 4 Local gas distribution → 5 Storage & Export → 6 Local utilization → 7 Shipping → 8 Import & Storage → 9 Local distribution → 10 H2 usage

- By private company
- By public company
- By a PPP (or JV)

H2 MOLECULES

1 Renewable power
- Landlord
- Concession tenderer
- Offtake guarantor/ de-risker
- Investor
- Park developer
- Park operator
- Regulator
- Subsidy Provider
- Royalty collector
- Environment management

NamPower

2 Local power distribution
- Landlord
- Developer
- Investor
- Operator
- Regulator
- Grid integrator
- Trader of surplus
- Royalty collector
- State de risker

NamPower

3 H2 Production & Conversion
- Landlord
- Developer
- Investor
- Operator
- Environment management
- Water management/regulation
- Custodian of Revenues

4 Local gas distribution
- Landlord
- Developer
- Investor
- Transport operator
- Regulator
- Environment management
- State de risker

5 Storage & Export
- Landlord
- Developer terminal
- Investor
- Operator terminal
- Port Authority
- Environment & safety management

NAMPORT Port of Rotterdam

6 Local utilization
- Landlord
- Developer
- Investor
- Plant operator
- Regulator
- Environment & safety management

7 Shipping
- Ship owner
- Ship operator
- International shipping regulator
- Insurer

8 Import & Storage
- Landlord
- Terminal developer & operator
- Safety regulator
- Environmental authority

Port of Rotterdam

9 Local distribution
- Landlord
- Pipeline investor
- Pipeline developer & operator
- Subsidizer / de risker
- Regulator

Port of Rotterdam

10 H2 usage
- Offtaker
- Incentivizer supply guarantee fund
- Early offtakers
- Derisking funds

CONCLUSIONS

1. Great potential identified. Especially the Sperrgebiet area south of Lüderitz is one of the world's top 3 areas for wind production.

2. A staged development.
   - A first stage will require 5.3 TWh (~ 100ktpa H2 or 500ktpa NH3). Land area requirements are 30k Ha for wind and 2k Ha for solar parks. Investment in Namibia will be in the order USD1,1B$.
   - Second stage 53 TWh. (10x stage 1).

3. The price of hydrogen delivered in Rotterdam reasonably competitive: 3,3 EUR/kg.
   - This is based on wind power production in the Sperrgebiet and ammonia as hydrogen carrier.
   - It is noted that further government support may be needed to ensure the 1st stage hydrogen be more competitive.

4. Cost Model results are pre-FS level only. Cost price levels are +/- 50%. A follow-up detailed feasibility study will see a more accurate number.

5. Namibia could produce 2 Mtpa of green hydrogen. This volume could contribute a significant part, approximately 10% - of the hydrogen demand expected in Rotterdam by 2050.

6. Northport in Walvis Bay is most suitable port facilities for fast track development. Minimal investment needed in the port facilities.

7. Lüderitz port has the largest RE potential. Hydrogen industrial complex in conjunction with mining export. 2 challenges that need to be overcome:
   - Accessibility of the Sperrgebiet.
   - Permits to develop in the nature reserve at Angra point.

8. Largest risk: the scale of investment for Namibia and Currency Risk. Close cooperation with international partners and institutions will be key to materialize the potential for Namibia.

9. NamPower and the Port of Rotterdam have had a very productive and pleasant cooperation to date and established a strong working relationship.
   Both are keen to continue working together to make this ambition happen.

RECOMMENDATIONS & NEXT STEPS

Short-term actions:

- Identify potential partners for the stage 1 project (500ktpa NH3) and build a consortium of the willing.
- Define and agree on the roles that Rotterdam and NamPower could play in the Namibian Hydrogen development and supply chain.
- Have one or more detailed Feasibility studies undertaken for one or 2 of the preferred carriers by carrier technology company.
- Identify and lock-in first customers/partners who may be able to offtake this first volumes of H2.
- Consolidate Namibian Governments ambitions and roll-out of H2 exports and local consumption.

Mid-term actions:

- Develop Regulatory framework in Namibia.
- Make final decision on preferred port location and carrier.
- Initiate conceptual designs for one or more green hydrogen port industrial complex.
- Start the Define phase (FEED) for the stage 1 development.

THANK YOU

WITH THE SUPPORT OF

NamPower
- Reiner Jagau
- Grant Muller
- Ernst Krige
- Ernest Dall

Namports
- Nathan Kashweka
- Elzevir Gelderbloem

Port of Rotterdam
- Martijn Coopman
- Douwe van der Stroom
- Marc Aartsen
- Irene Vooijs

President's Office
- James Mnyupe

For more information please contact:

Reiner Jagau
Reiner.Jagau@nampower.com.na

For more information please contact:

Martijn Coopman
m.coopman@portofrotterdam.com

WITH SPECIAL THANKS TO

Servaas van den Bosch (Honorary Consul to The Netherlands)

NamPower
Powering the Nation and beyond
Port of Rotterdam

57

WE ARE MAKING IT HAPPEN

NamPower
Powering the Nation and beyond

Port of Rotterdam

8

APPENDIX

DISCLAIMER

Due to Corona, visits to the port locations were not undertaken yet and site-specific data is not available. All assessments are based on high level desk-top study, publicly available data and information from all the great data received from NamPower and others. In the future the quality of the assessment can be upgraded after real site visits and local interviews.

Following charts and aerial photos are based on Google Earth, Navionics, Seastates maps and proprietary data. More detailed analyses and engineering will need to be undertaken in following design stages.

APPENDIX

ALL CARRIERS REQUIRE SPECIAL HANDLING

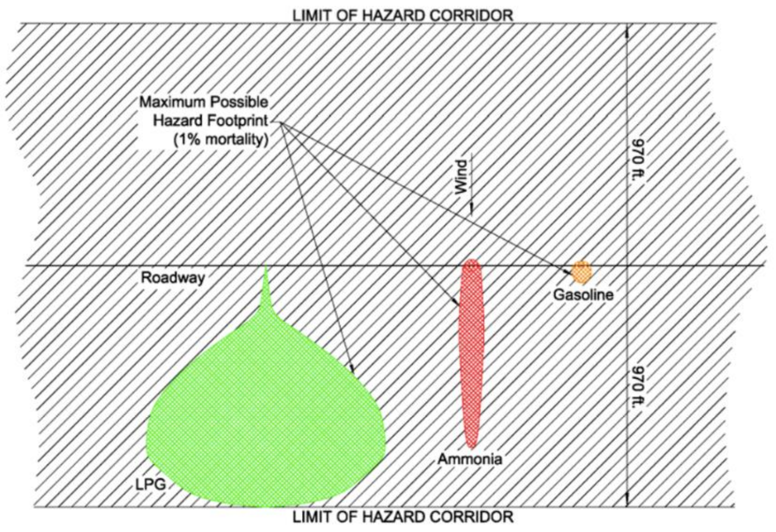


Figure 6-2
Vulnerability Corridors and Zones for the Truck Transport of Gasoline, LPG, and Refrigerated Ammonia

First results from a coarse safety study undertaken by Lloyd's register on impact distances in cases of full bore rupture or part rupture of a 12 inch pipe in a facility.

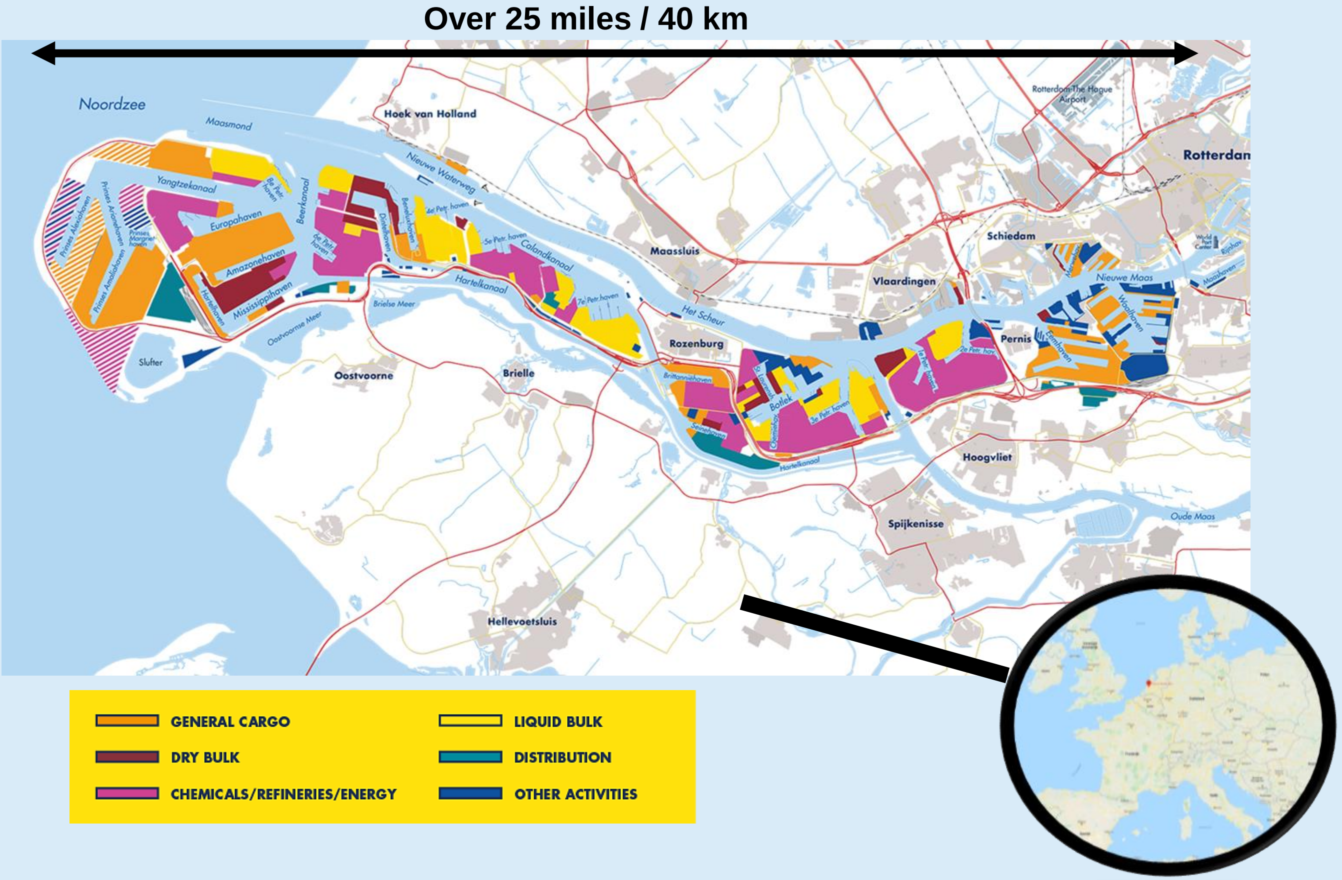
Hazard distance	Fatality potential			Injury potential		
Scenario	Full bore	10%	1%	Full bore	10%	1%
Refrigerated NH_3	25m	25m	10m	280m	250m	220m
Compressed NH_3	~2,000m	270m	30m	>10,000m	~2,000m	200m
Liquid H_2	~300m	25m	N/A	~1,000m	300m	N/A
Compressed H_2	~30-40m	20m	N/A	~300m	200m	50m
LNG	>200m	35m	N/A	>200m	35m	N/A

Source table: Lloyd's Register – Hydrogen and Ammonia Infrastructure (2020)

For each carrier mitigation measures exist to allow for safe storage and handling. The Port of Rotterdam has expertise in shipping, storing and handling of hydrogen, ammonia and LNG for decades and can assist in designing safe facilities and procedures.

8 APPENDIX

ROTTERDAM HAS EXCELLENT INTERMODAL CONNECTIONS

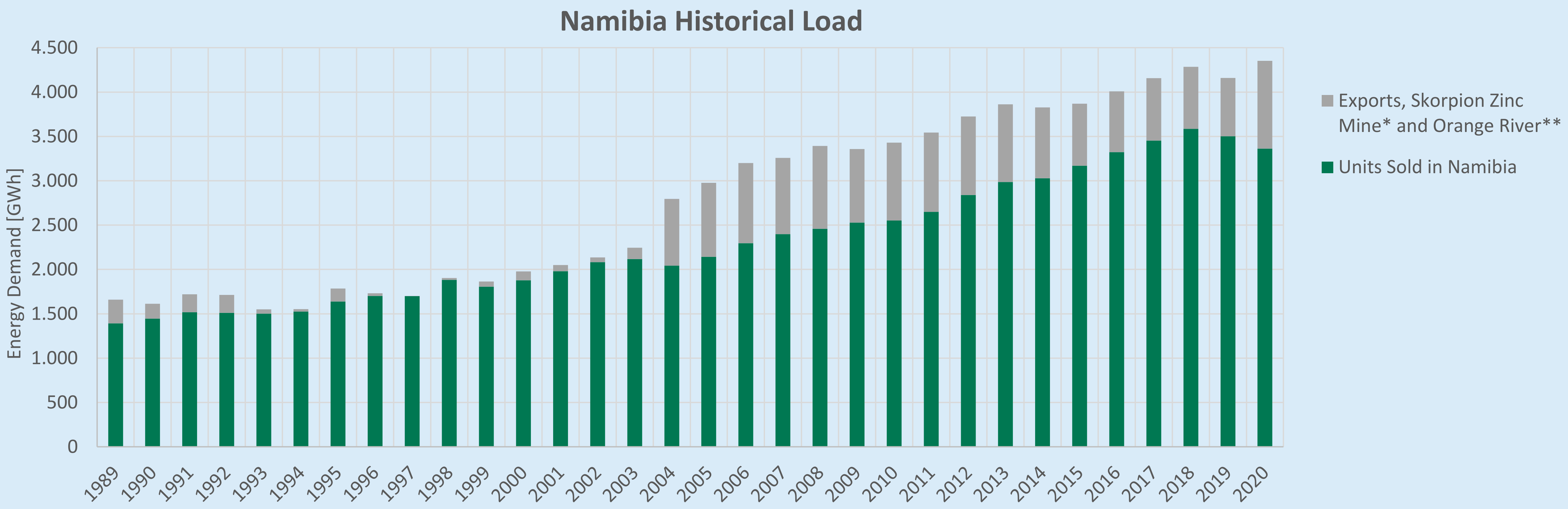


- At this time 13% of the total EU energy-consumption passes through Rotterdam
- Largest port in Europe, 10th port worldwide
- Total employment 385,000 people*
- Total added value € 45,6 billion (6.2% GNP)*
- Visits (2019):
  - 29,491 sea-going vessels
  - 107,000 inland navigation
- 3.000 companies
- Throughput (2019): 469.4 mln tons;14.8 million TEU
  - 45% Liquid bulk
  - 32% containers
  - 17% dry bulk
  - 6% Breakbulk

Source: Port of Rotterdam Hydrogen Vision, European Hydrogen Backbone (2020)

NamPower Powering the Nation and beyond
Port of Rotterdam

8 NAMIBIA'S GROWTH AMBITIONS



*Skorpion Zinc Mine had a back-to-back agreement with Eskom which has now expired. The mine is currently on care and maintenance.
**Orange River Supply Points (Daberas and Oranjemund) are directly connected to the Eskom network

Source: Namibia National Integrated Resource Plan (NIRP) Load Forecast Report (14 April 2021 Draft)