Africa Solar Hydrogen Project (ASHyP) - Solar2Hydrogen system design and contribution to decarbonization for the COP27

Master pack

October 2022

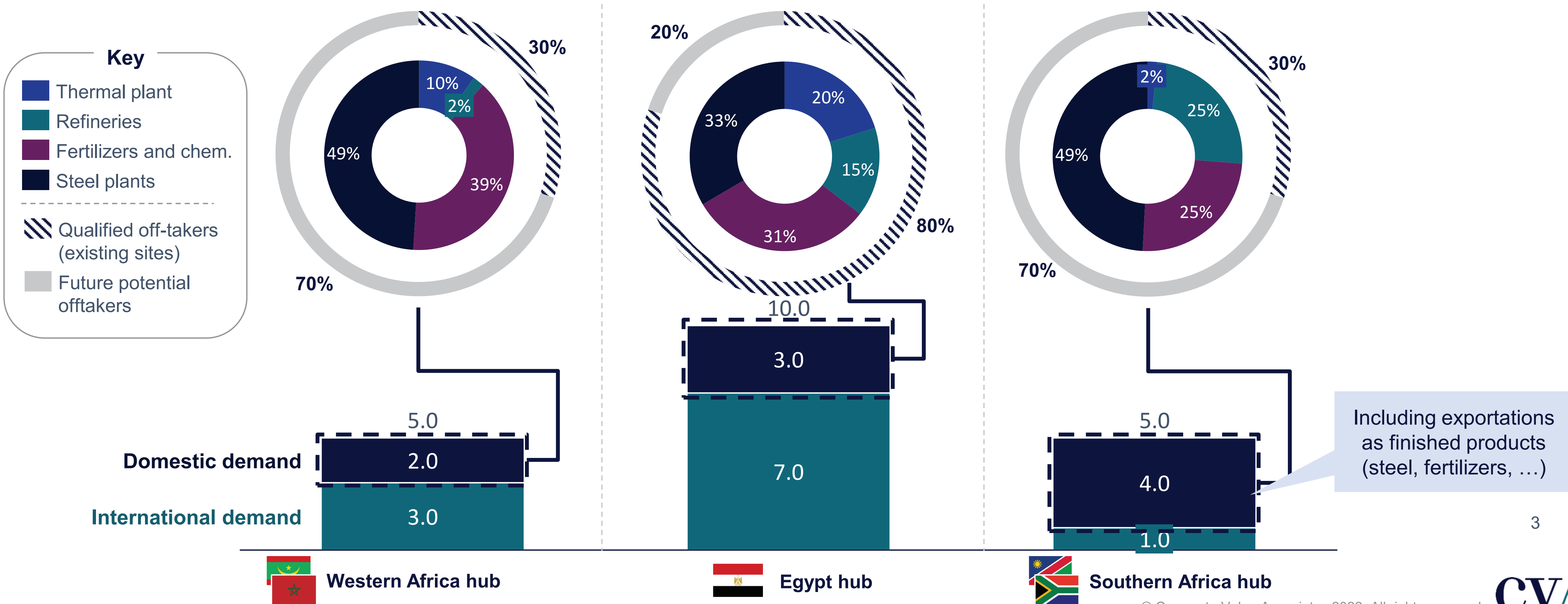
Corporate Value Associates

Agenda

H2 demand equation to address by hub – Vision 2030

A potential H2 demand of ~20Mt/y in 2030 in the 3 areas, shared between domestic demand (~45%) and exportation (55%); the domestic demand will concentrate around green steel materials and commodities (~40%) and green fertilizers and chemicals (~30%)

Estimated potential green H2 demand in 2030 and breakdown by sector (Mt/y)

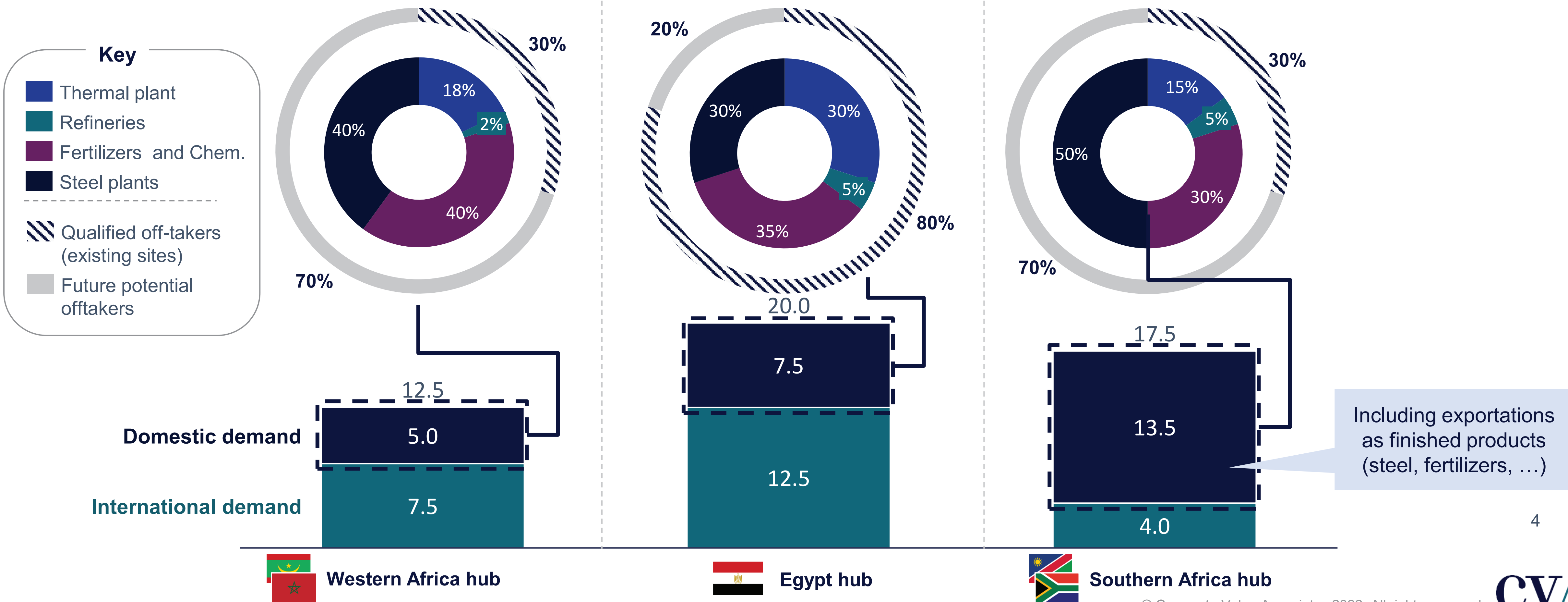


Sources: IEA database, IEA Global Hydrogen Review, CVA analysis

H2 demand equation to address by hub – Vision 2035

H2 demand might increase up to ~50 Mt/y in 2035 in the 3 African hubs, mainly driven by international demand and the emergence of new domestic off-takers / projects related to green gas competitiveness

Estimated potential green H2 demand in 2035 and breakdown by sector (Mt/y)

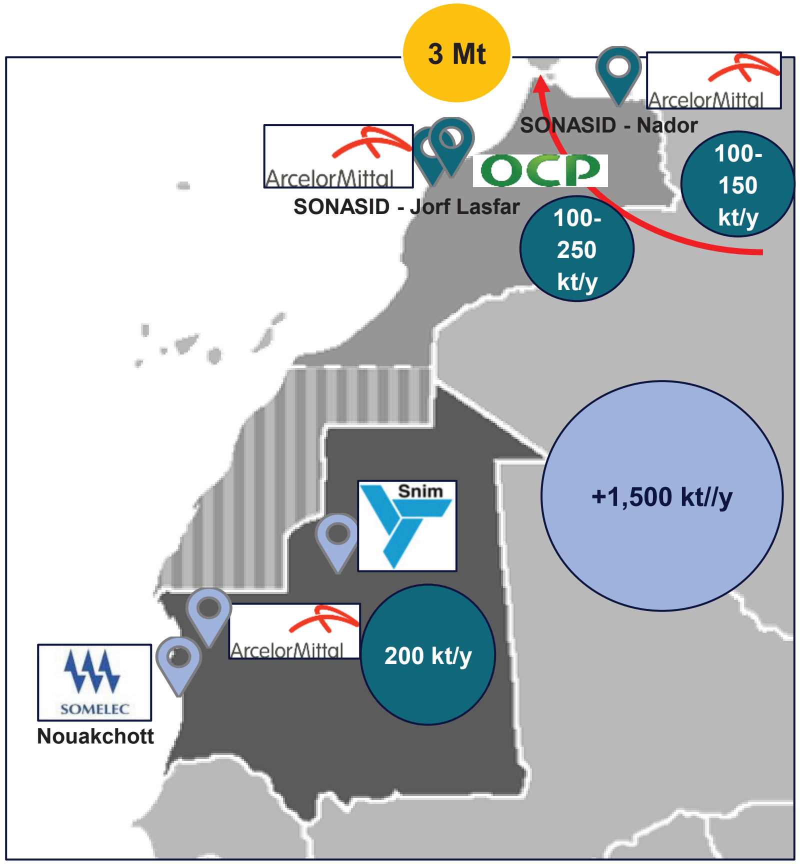


Sources: IEA database, IEA Global Hydrogen Review, CVA analysis

Detailed 2030 vision – H2 potential demand

Details of key sites' H2 demand to address – Western Africa – Vision 2030

In Western Africa there is a significant future potential for domestic H2 off-take estimated up to 2 Mt/y considering existing and potential sites, as well as exportation demand (3 Mt/y)



Existing H2 off-takers	Potential H2 off-takers	
xx 2030 Domestic potential offtake, H2 kt/y	Existing gas pipeline	
+xx Additional potential domestic off-take, H2 kt/y	xx EU exportation potential	

Sources: ONNE, ArcelorMittal, World Steel Association, Moroccan government H2 roadmap, CVA analysis

Focus on domestic demand

	Mauritania	Morocco	*Estimated potential H2 off-take volumes (2030)*
Existing sites with existing or potential H2 offtake (including substitution of fossil fuels)	• *For now, no main H2 off-taker* Thermal plants – assumptions of **50 kt/y in 2030** (e.g SOMELEC)	**600 kt/y primary steel**: **100 - 150 kt/y** of H2 (e.g SONASID) Electricity generation = assumption of **50 kt H2/y** (e.g ONEE) **100 – 250 kt/y H2 for ammonia** (Moroccan government roadmap / e.g OCP) Other: Local demand for **other existing industries** is estimated to **100 kt/y** of H2 by 2030	400-500 kt/y
Future potential H2 off-takers related to new industrial sites (announced green H2 projects and development of new facilies)	**Primary steel production capacity**: **500 kt/y** of H2 (e.g SNIM/AM) Potential development: **1,5 Mt/y of ammonia** which represent **around 300 kt/y of H2** Other: Transport: Assumptions of **50 kt/y in 2030**	Other: Estimated to **50-100 kt/y** (Moroccan government roadmap) Other: Future development of industrial project (e.g chemicals with METHANEX) – **500 kt/y**	~ 1,500 kt/y

Thermal plants | Fertilizers | Steel | Refinery | Chemicals

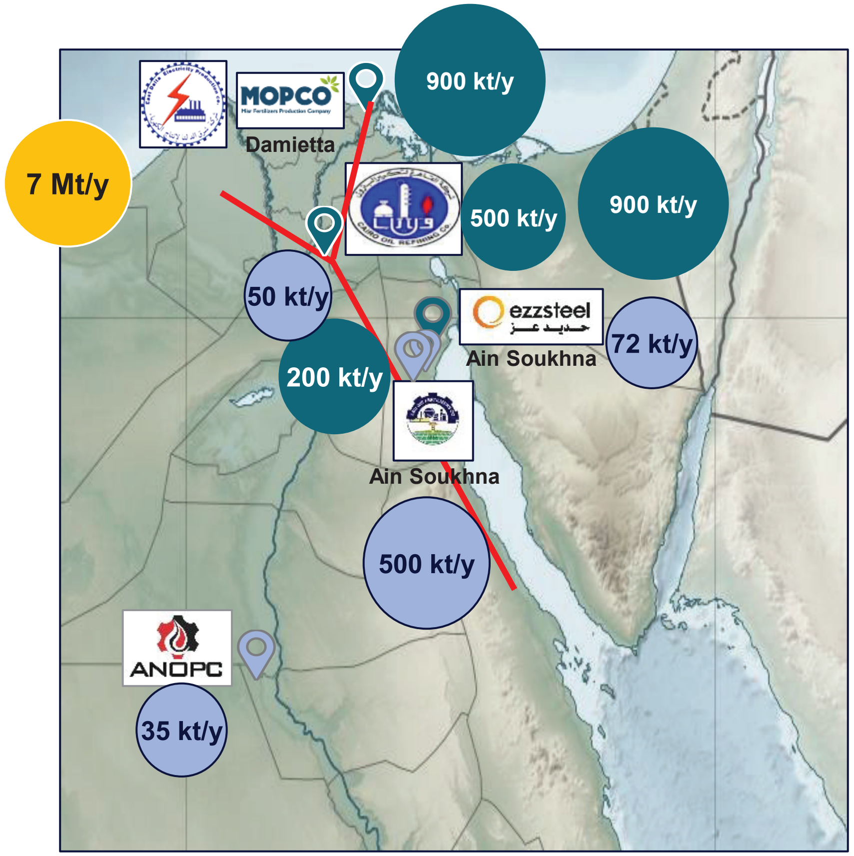
*Yearly production of 0.6 million tones of steel, which represent a consumption 43,140 t of H2 (71.9 kg of H2 is required for each DRI ton produced in steel industry)

African Union | isa INTERNATIONAL SOLAR ALLIANCE | European Investment Bank

Detailed 2030 vision – H2 potential demand

Details of key sites' H2 demand to address – Egypt – Vision 2030

In Egypt, the existing potential for H2 off-take (2.5 Mt/y), combined with a potential domestic development (up to 0.6 Mt/y) is completed by a high potential exportation demand (7 Mt/y)



Existing H2 off-takers | Potential H2 off-takers
xx 2030 Domestic potential offtake, H2 kt/y | Existing gas pipeline
+xx Additional potential domestic off-take, H2 kt/y | xx EU exportation potential

Focus on domestic demand

	Egypt					*Estimated potential H2 off-take volumes (2030)*
	Fertilizers	Steel	Refinery	Chemicals	Other	
Existing sites with existing or potential offtake (including substitution of fossil fuels)	500 kt of H2 in 2021 that could represent **700 kt/y of H2** by 2030 (e.g MOPCO)	**6 Mt primary steel in 2021, representing 800 kt/y of H2** by 2030 **(e.g EZZ STEEL)**	**200 kt refining products in 2021** that could represent **400 kt/y of H2** by 2030 (e.g CORC)	**80 kt of chemical products in 2021** that could represent **200 kt/y of H2** in 2030 (e.gb METHANEX)	Consumption for electricity production I thermal plants: **400 kt/y** (e.g MDEPC)	2,500 kt/y
Future potential H2 off-takers related to new industrial sites (announced green H2 project and development of new usage)	**500 kt/y ammonia** and **900 kt/y of am. nitrate** which represent **250 kt/y H2** (e.g ABU QIR Fertilizers plant project in Ain Sokhna)	Potential for DRI development through development of new steel industry sites: additional **1 Mt/y of primary steel** which represent **72 kt/y of H2**	**3 Mt/y of** petroleum products which represent **35 kt/y of H2** (e.g ANOPC petrol diesel production complex)	**2 Mt/y methanol** which represent **250 kt/y H2** (e.g ABU QIR Fertilizers and HELWAN Fertilizers plant project in Ain Sokhna)	Green H2 to **substitute gas in transports** in the long term – estimated to **50 kt/y**	>650 kt/y

Thermal plants | Fertilizers | Steel | Refinery | Chemicals

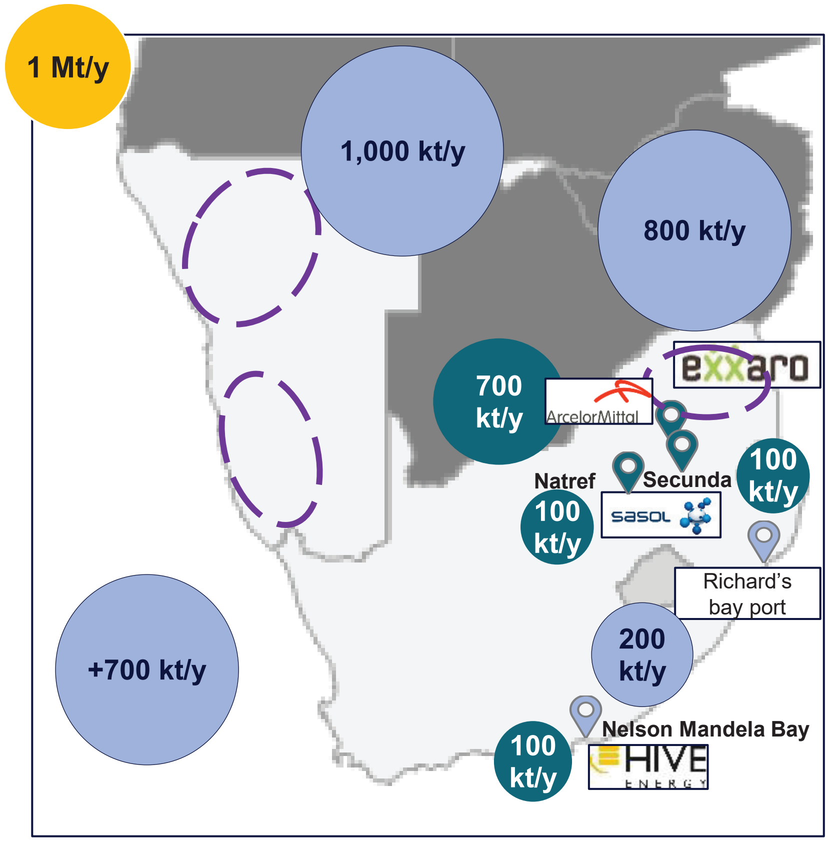
Sources: ONNE, ArcelorMittal, World Steel Association, Moroccan government H2 roadmap, CVA analysis

CVA Corporate Value Associates

Detailed 2030 vision – H2 potential demand

Details of key sites’ H2 demand to address – Southern Africa – Vision 2030

Domestic demand should be driven by a development of new H2 sites with announced projects (~2.5Mt H2/y), adding up to existing refineries and steel production sites (~1.5Mt)



- Existing H2 off-takers
- Future H2 off-takers
- xx 2030 Domestic potential offtake, H2 kt/y
- Mining industry area
- +xx Additional potential domestic off-take, H2 kt/y
- xx EU exportation potential

Focus on domestic demand

	Namibia	South Africa		Estimated potential H2 off-take volumes (2030)
Existing sites with existing or potential offtake	*Currently no main DRI, Ammonia or chemical industries with significant H2 consumption*	Consumption of H2 by refining industry (e.g SASOL **largest refiner** with 2 factories located in the North-East): **500k barrels/day** representing **~140kt H2** Overall industry: **500kt H2**	Consumption of H2 by steel industry: Arcelor Mittal plant: 5 Mt of primary steel in 2021 representing **~350 kt H2** Overall industry by 2030: 10 Mt of steel representing **1,000kt H2**	1,500 kt/y
Future H2 off-takers related t new sites (announced green H2 project)	Mining: fuel for mining trucks (mining industry represents 10% of the national GDP): **1Mt/y of H2** Potential DRI industry development: **2 Mt/y of primary steel** which represent **150 kt/y of H2** Potential Ammonia industry development **100 kt/y of H2**	World’s largest green ammonia plant planned for 2025 (Hive Energy) – Projected volume: **1Mt/y of green ammonia = ~200 kt H2** Mining: fuel for mining trucks – **800 kt H2/y**	Further development of steel industry: **3 Mt/y of primary steel** = **~200 kt/y of H2** Other: Mobility: fuel for heavy and medium duty trucks for freight: **50 kt H2/y**	> 2,500 kt/y

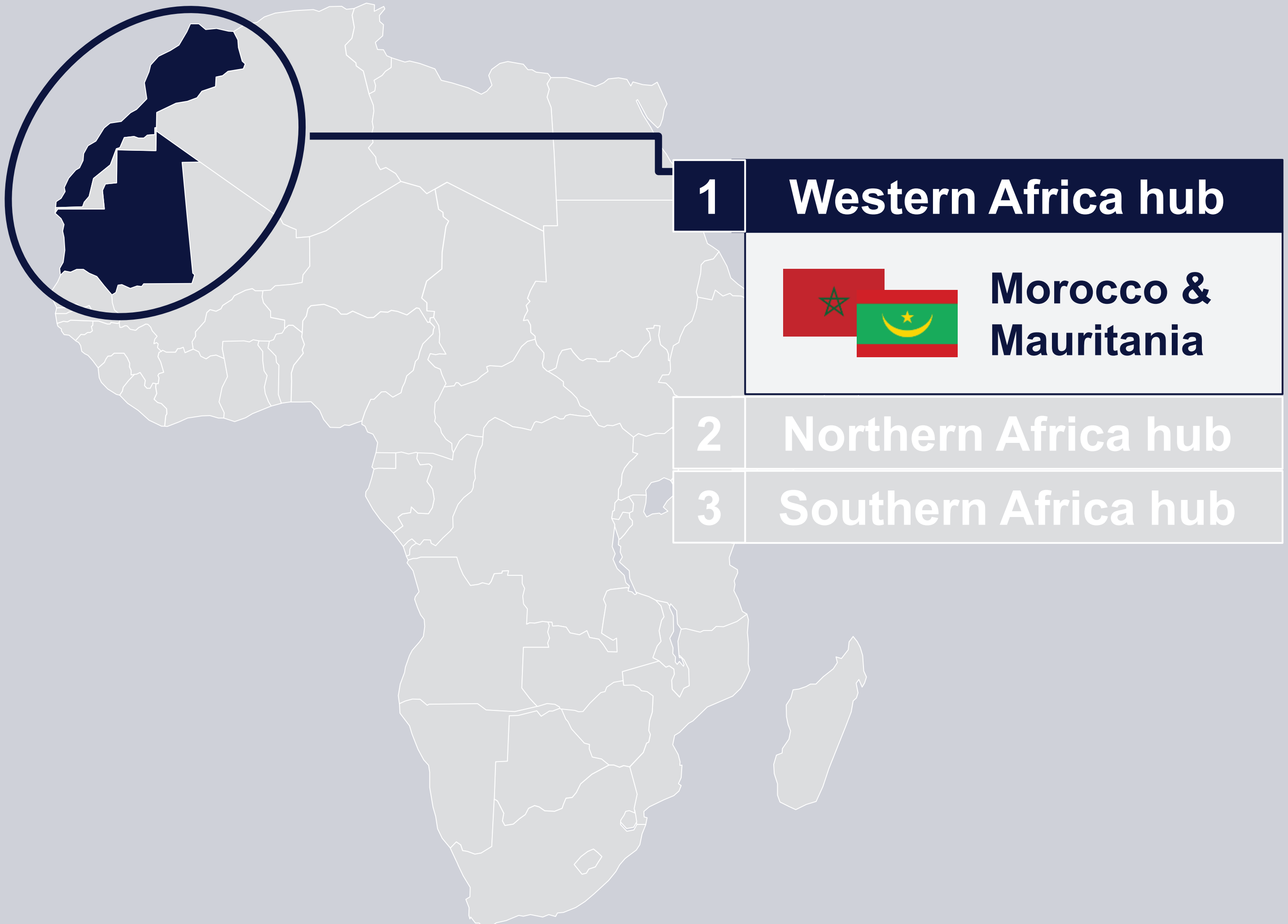
Thermal plants · Fertilizers · Steel · Refinery · Chemicals · Mining

Sources: ONNE, ArcelorMittal, World Steel Association, Moroccan government H2 roadmap, CVA analysis

Agenda

1. African H2 hubs system design – Demand equation to address – 2030 and 2035
2. **African H2 hubs system design – Design and sizing of the 3 hubs**
3. African H2 hubs system design – Resulting costs for the 3 hubs
4. Value creation impact

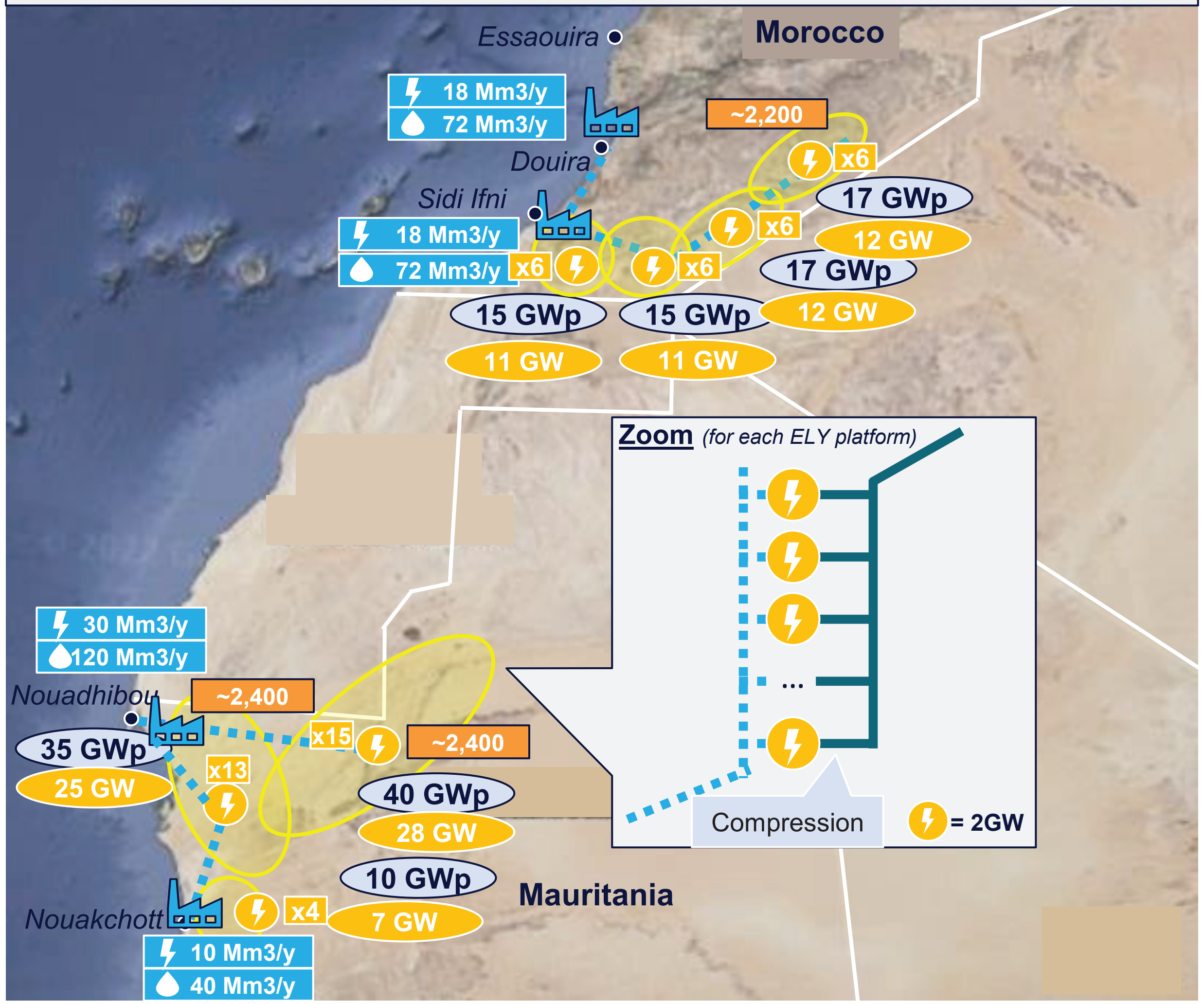
African Union | isa INTERNATIONAL SOLAR ALLIANCE | European Investment Bank



CVA Corporate Value Associates

Focus on Morocco / Mauritanian hubs – Upstream model by **2030**: 150 GWp of solar capacity and 105 GWe of electrolysis capacity to be installed

Link between desalination plants and green H2 plants managed through the **development of a large fresh water supply system**, opening development potentials for a part of the countries



Key

Production

- X — Solar Capacity to be installed by 2030 (GWp)
- Suitable area for solar development
- X — Solar yield (kWh/kWp/y)
- Desalination plant
- X GW — Electrolysis installed capacity
- X Mm3/y — Water volumes required for electrolysis (Mm3/y)
- X Mm3/y — Water volumes available for other usages (agriculture, drinking..)
- xX — Electrolysis platform (number of solar2H2 plants)

T&S

- Potential International H2 backbones
- Water pipe
- Cities

Design & sizing details

Solar generation

- **150 GWp in 7 areas**
- **25 MW** (representing 40 GWh a year) **of additional solar capacities to partially feed desalination plants** for water generation dedicated to electrolysis
- About **170 GWh a year of electricity** used from the **grid** to complement the sourcing (water generation for other usage)

Water desalination

- **76 Mm3/y of water required from desalination** for electrolysis
- **Up to 300 Mm3/y of fresh water available** for agriculture and drinking water: **53%** (160 Mm3) **in Mauritania** (covering **~66% of current Mauritanian needs for agriculture) and 47%** (140 Mm3) **in Morocco**

Water transportation

- **1,600 km of water pipe infrastructures** from desalination facilities to electrolysis platforms

Electrolysis

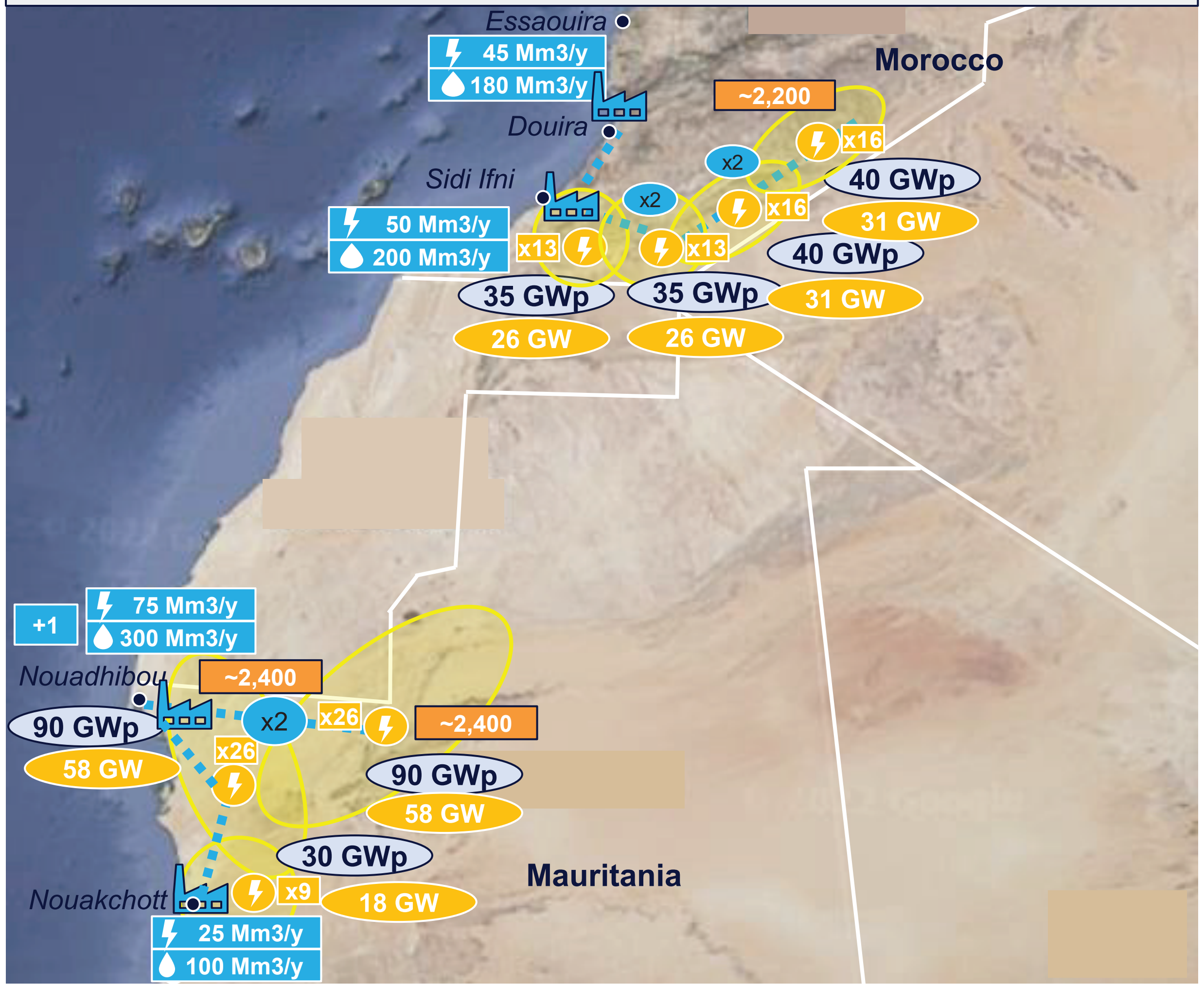
- **7 electrolysis domains** with a **total capacity of 105 GW**

Sources: ONNE, ArcelorMittal, Moroccan government H2 roadmap, Economics of hydrogen, MISO energy, CVA analysis

African Union | ISA International Solar Alliance | European Investment Bank

Focus on Morocco / Mauritanian hubs – Upstream model by **2035**: 360 GWp of solar capacity and 248 GWe of electrolysis capacity to be installed

Solar and electrolysis capacities multiplied by ~2.5 vs. 2030 implying the commissioning of **63 new solar2H2 plants** and **1 new desalination plants**



Key

Production

- X — Solar Capacity to be installed by 2030 (GWp)
- Suitable area for solar development
- X — Solar yield (kWh/kWp/y)
- Desalination plant
- X GW — Electrolysis installed capacity
- X Mm3/y — Water volumes required for electrolysis (Mm3/y)
- X Mm3/y — Water volumes available for other usages (agriculture, drinking..)
- xX — Electrolysis platform (number of solar2H2 plants)

T&S

- Potential International H2 backbones
- Water pipe
- xX — Number of parallel water pipes required
- Cities

Design & sizing details

Solar generation

- **Up to 360 GWp in 7 areas,** representing around **0.5 Mha**
- **100 GWh/year of additional solar capacities to feed desalination plants** for water generation dedicated to ELY

Water desalination

- **Up to 200 Mm3/y of water required from desalination** for electrolysis
- **No additional desalination** plants required in Morocco and 1 additional desalination plant in Mauritania
- **Up to 800 Mm3/y of fresh water available** for agriculture and drinking water: **53%** (420 Mm3) **in Mauritania** (covering **~33% of current Mauritanian needs for agriculture**) **and 47%** (380 Mm3) **in Morocco covering** (covering **~2.5% of current Moroccan needs for agriculture**)

Water transportation

- **Around 2,700 km of water pipe infrastructures** from desalination facilities to electrolysis platforms

Electrolysis

- **7 electrolysis domains** with a **total capacity of 250 GW**

Note (1): Capacity of the largest desalination plants in the world is ~1 Mm3/day

Sources: ONNE, ArcelorMittal, Moroccan government H2 roadmap, Economics of hydrogen, MISO energy, CVA analysis

CVA Corporate Value Associates

African Union | isa INTERNATIONAL SOLAR ALLIANCE | European Investment Bank

Focus on Morocco / Mauritanian hubs – Midstream and downstream model – Vision by 2030

Two networks of dedicated H2 pipelines to be commissioned, one to **supply domestic needs** and volumes, one to extract the molecule **towards large EU consumption** zones

Key

Production

Electrolysis platform

T&S

Domestic H2 pipeline to be built

Potential International H2 backbone

xX (X ") Number of parallel pipelines (diameter of the pipe section, inches)

1 International pipe length:
1. 250 km
2. 1,500 km
3. 600 km
4. 400 km
5. 1,050 km

Off-takers

ArcelorMittal H2 Off-taker

X kt/y Domestic H2 volumes off-take (kt/y)

Storage

Existing or potential salt cavern geological site

Design & sizing details

H2 generation

- **5 Mt H2 produced in 2030** to meet:
  - Domestic demand in 3 main areas (~2Mt)
  - International exportation (~3Mt)

H2 storage

- **2 national storage sites** (salt caverns) **to be sized for H2 dispatch management** with connections to off-take sites:
  - **23 Mm3 storage capacity in Mauritania**
  - **22 Mm3 in Morocco**

H2 transportation

- **1,200 km of H2 simple 48 inches greenfield** pipes for **domestic** use in **Mauritania** and **1,900 km in Morocco,** connected with **2 storage sites.**
- Up to **2,800 km offshore backbone** along Mauritania and Morocco west coast to Gibraltar – sections requiring up to **2 parallel 48 inches** greenfield pipes

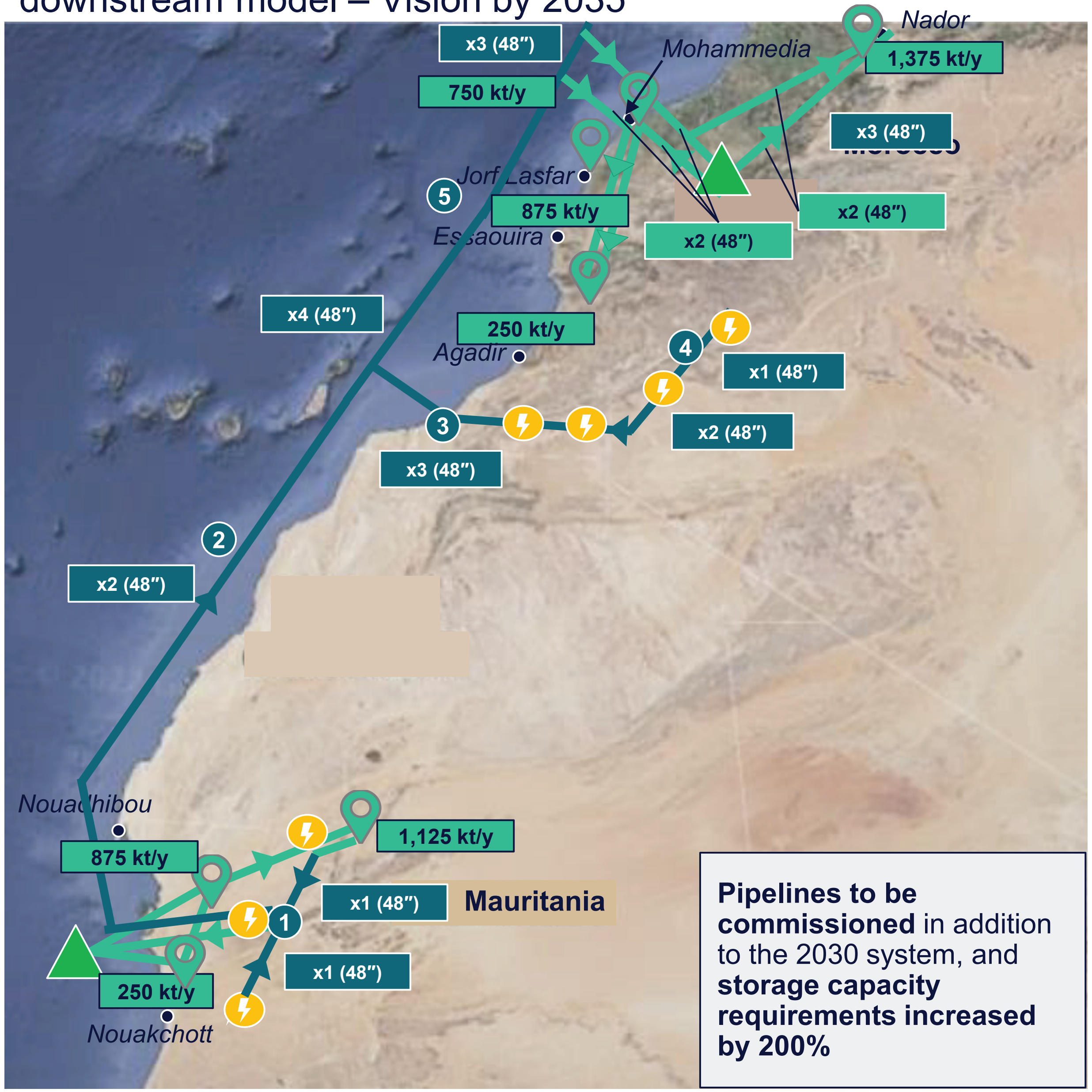
*When not detailed, the pipe is a simple 48″ greenfield pipe

Sources: ONNE, ArcelorMittal, Moroccan government H2 roadmap, Economics of hydrogen, MISO energy, CVA analysis

CVA Corporate Value Associates

African Union | International Solar Alliance | European Investment Bank

Focus on Morocco / Mauritanian hubs – Midstream and downstream model – Vision by 2035



Pipelines to be commissioned in addition to the 2030 system, and **storage capacity requirements increased by 200%**

Key

Production

Electrolysis platform

T&S

Domestic H2 pipeline to be built

xX (X") — Number of additional domestic parallel pipeline and diameter of the pipe section

Potential internat. H2 backbone

xX (X ") — Nb. of additional internat. pipelines vs. 2030 (diameter of the pipe section, inches)

1 — International pipe length:
1. 250 km
2. 1,500 km
3. 600 km
4. 400 km
5. 1,050 km

Off-takers

H2 Off-taker

X kt/y — Domestic H2 volumes off-take (kt/y)

Storage

Existing or potential salt cavern geological site

Design & sizing details

H2 generation

- **12.5 Mt H2 produced in 2035** to meet:
  - Domestic demand in 3 main areas (~5 Mt)
  - International exportation (~7.5 Mt)

H2 storage

- **2 storage sites to be sized for H2 dispatch management** (salt caverns) with connections to off-take sites
  - **52 Mm3 storage capacity in Mauritania**
  - **50 Mm3 storage in Morocco**
- **Total represents ~0.1% of EU's underground Gas storage capacity**

H2 transportation

- **1,200 km of H2 simple 48 inches greenfield** pipes for **domestic** use in **Mauritania** and **1,900 km in Morocco,** connected with **2 storage sites – sections with up to 2 parallel pipes.**
- Up to **2,800 km offshore international backbone** along Mauritania and Morocco west coast to Gibraltar – sections requiring up to **4 parallel 48 inches** greenfield pipes

*Additional greenfield pipeline to the infrastructures built in 2030 – when not detailed, the pipe is a simple 48 inches greenfield pipe

Sources: ONNE, ArcelorMittal, Moroccan government H2 roadmap, Economics of hydrogen, MISO energy, CVA analysis

CVA Corporate Value Associates

The H2 hub systems feature designs implying mass scale sizing while corresponding to managed capacities

The upstream and midstream sizing involves capacities falling into standards of existing industrial designs

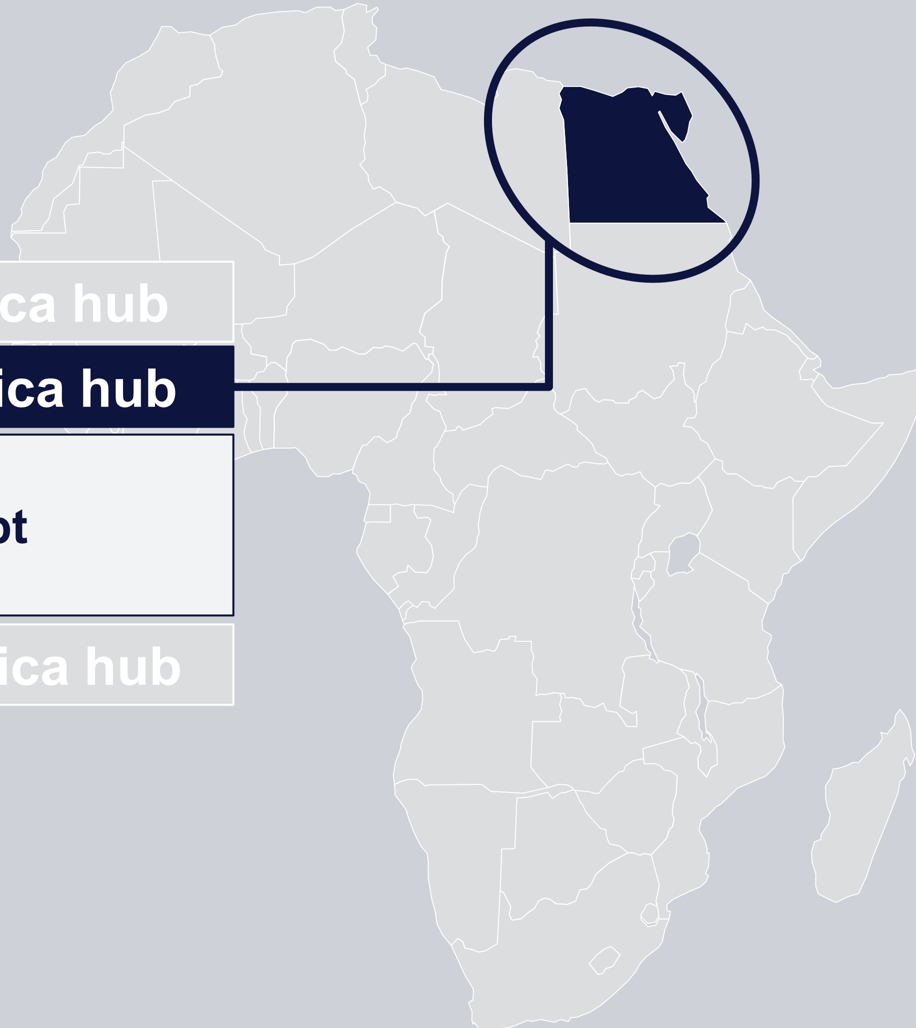
	Capacity required	Check / benchmark	*Capacity management*
PV	• **150 GWp by 2030 to 360 GWp by 2035** of solar capacity to be installed • Surface power capacity density of 1.5 ha / MW	• Total required surface of 225,000 ha by 2030 and 540,000 ha by 2035 : **0.1% to 0.3% of the total countries area**	✓
Desalination	• Desalination capacity required : **376 Mm3 by 2030 and 1,000 Mm3 by 2035** • 4 to 5 desalination facilities with a capacity of 250 Mm3/y	• Desalination plants designed with a capacity of ~250 Mm3/y, **i.e. ~70% of the current largest desalination plants** in the world (e.g. in RAK, Saudi Arabia or in Taweelah, UAE)	✓
Water pipe	• **1,600 to 2,700 km of water transportation pipe** infrastructures, including double pipe sections by 2035 • Water pipe designed with a maximum of **60 inches**	• Total length acceptable, **i.e. 90% of Manmade pipeline** • Water pipe designed with diameter of 60 inches, **i.e. ~75% of the largest water pipeline diameters in the world** (e.g. Oguz-Gabala-Baku Water Pipeline)	✓
Electrolysis	• Units of 2GWp captive solar plants, injecting in electrolysis platforms with a total electrolysis capacity of **105 GWe by 2030 and 248 GWe by 2035**	• **~300 MWe global electrolysis installed capacity** in 2020	*~1000x current global electrolysis capacity* ⚠
H2 pipe	• Total length of greenfield pipes infrastructures is **3,700** • H2 pipes designed with **48 inches diameter**	• **~1% of total global brownfield transport infrastructure** length in 2020 and around **4x Nord Stream gas pipe length**	✓
Storage	• **45 Mm3 by 2030 and 102 Mm3 by 2035** of metric storage volume required • **2 potential salt dome geological storage sites**	• **~0.1% of total EU underground storage capacities** • Typical salt cavern volume capacity is 0.5 to 1 Mm3	✓

1 Western Africa hub

2 Northern Africa hub

Egypt

3 Southern Africa hub



Focus on Egypt hub – Upstream model by **2030**: 240 GWp of solar capacity and 185 GWe of electrolysis capacity to be installed

Key

Production

- X — Solar Capacity to be installed by 2030 (GWp)
- Suitable area for solar development
- X — Solar yield (kWh/kWp/y)
- Desalination plant
- X GW — Electrolysis installed capacity
- X Mm3/y — Water volumes required for electrolysis (Mm3/y)
- X Mm3/y — Water volumes available for other usages (agriculture, drinking..)
- xX — Electrolysis platform (number of solar2H2 plants)

T&S

- Water pipe
- Cities

Design & sizing details

Solar generation

- **240 GWp in 5 areas**
- **53 MW** (representing 84 GWh a year) **of additional solar capacities to partially feed desalination plants** for water generation dedicated to electrolysis
- About **335 GWh a year of electricity** used from the **grid** to complement the sourcing (water generation for other usage)

Water desalination

- **150 Mm3/y of water required from desalination** for electrolysis
- **Up to 600 Mm3/y of fresh water** available representing **1% of current agricultural water needs**

Water transportation

- **720 km of water pipe infrastructures** from desalination facilities to electrolysis platforms

Electrolysis

- **5 electrolysis domains** with a **total capacity of 185 GW**

Sources: Oxford Institute, Economics of hydrogen, NREL, CVA analysis

Focus on Egypt hub – Upstream model by 2035: 451 GWp of solar capacity and 351 GWe of electrolysis capacity to be installed

Note (1): Capacity of the largest desalination plants in the world is ~1 Mm3/day

Sources: Oxford Institute, Economics of hydrogen, NREL, CVA analysis

Key

Production

- X – Solar Capacity to be installed by 2030 (GWp)
- Suitable area for solar development
- X – Solar yield (kWh/kWp/y)
- Desalination plant
- X GW – Electrolysis installed capacity
- X Mm3/y – Water volumes required for electrolysis (Mm3/y)
- X Mm3/y – Water volumes available for other usages (agriculture, drinking..)
- xX – Electrolysis platform (number of solar2H2 plants)

T&S

- Potential International H2 backbones
- Water pipe
- xX – Number of parallel water pipes required
- Cities

Design & sizing details

Solar generation

- **451 GWp in 5 areas**
- **107 MW** (representing 168 GWh a year) **of additional solar capacities to partially feed desalination plants** for water generation dedicated to electrolysis
- About **672 GWh a year of electricity** used from the **grid** to complement the sourcing (water generation for other usage) which represent >0.5% of the national electricity consumption in 2019

Water desalination

- **300 Mm3/y of water required from desalination** for electrolysis
- **Up to 1,200 Mm3/y of fresh water** available representing **3% of current agricultural water needs**

Water transportation

- **1,030 km of water pipe infrastructures** from desalination facilities to electrolysis platforms

Electrolysis

- **5 electrolysis domains** with a **total capacity of 351 GW**

Focus on Egypt hub – Midstream and downstream model – Vision by 2030

*When not detailed, the pipe is a simple 48″ greenfield pipe

Key

Production

Electrolysis platform

T&S

Domestic H2 pipeline to be built

Existing gas pipeline

Potential International H2 backbone

xX (X ") — Number of parallel pipelines (diameter of the pipe section, inches)

1 — International pipe length:
1. 110 km
2. 230 km
3. 220 km
4. 150 km
5. 190 km

Off-takers

ezzsteel — H2 Off-taker

X kt/y — Domestic H2 volumes off-take (kt/y)

Storage

Existing or potential salt cavern geological site

Design & sizing details

H2 generation

- **10 Mt H2 produced in 2030** to meet:
  - Domestic demand in 4 main areas (~3Mt)
  - International exportation (~7Mt)

H2 storage

- **1 national storage site** (salt caverns) **to be sized for H2 dispatch management** with connections to off-take sites:
  - **56 Mm3 storage capacity**

H2 transportation

- **2,310 km of H2 48 inches greenfield** pipes for **domestic** use in Egypt, connected with **1 storage site.**
- Sections requiring up to **3 parallel 48 inches** greenfield pipes …

Sources: Oxford Institute, Economics of hydrogen, NREL, CVA analysis

Focus on Egypt hub – Midstream and downstream model – Vision by 2035

Key

Production

- Electrolysis platform

T&S

- Domestic H2 pipeline to be built
- Existing gas pipeline
- Potential International H2 backbone
- xX (X ") — Number of parallel pipelines (diameter of the pipe section, inches)
- 1 — International pipe length:
  1. 110 km
  2. 230 km
  3. 220 km
  4. 150 km
  5. 190 km

Salt caverns potential capacity to be assessed

Off-takers

- H2 Off-taker
- X kt/y — Domestic H2 volumes off-take (kt/y)

Storage

- Existing or potential salt cavern geological site

Design & sizing details

H2 generation

- **20 Mt H2 produced in 2035** to meet:
  - Domestic demand in 4 main areas (~7.5Mt)
  - International exportation (~12.5Mt)

H2 storage

- **1 national storage site** (salt caverns) **to be sized for H2 dispatch management** with connections to off-take sites:
  - **105 Mm3 storage capacity**
- **Total is <0.1% of Europe's Underground Gas Storage capacity** but restricted to **one area only**

H2 transportation

- **2,310 km of H2 48 inches greenfield** pipes for **domestic** use in Egypt, connected with **1 storage site.**
- Sections requiring up to 5 **parallel 48 inches** greenfield pipes …

*Additional greenfield pipeline to the infrastructures built in 2030 – when not detailed, the pipe is a simple 48 inches greenfield pipe

Sources: Oxford Institute, Economics of hydrogen, NREL, CVA analysis

Corporate Value Associates

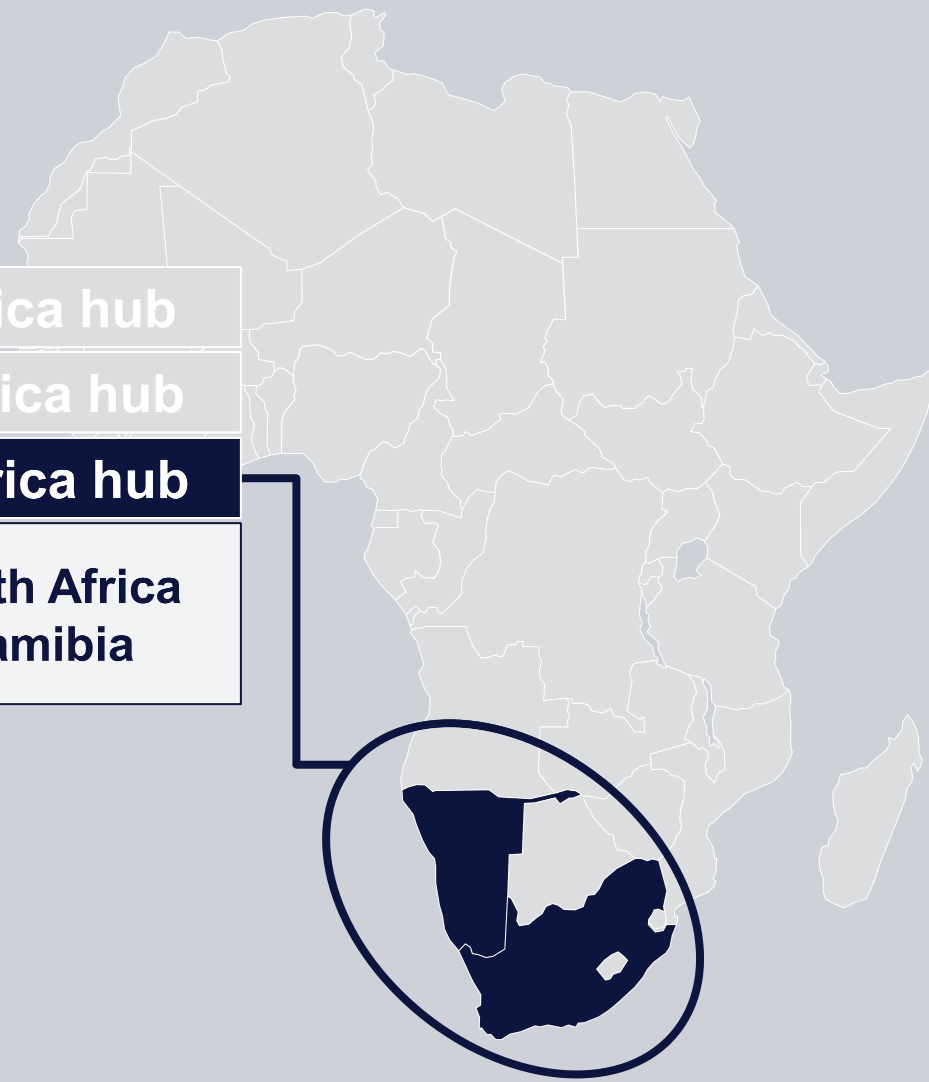
The H2 hub systems feature designs implying mass scale sizing while corresponding to managed capacities

The upstream and midstream sizing involves capacities falling into standards of existing industrial designs

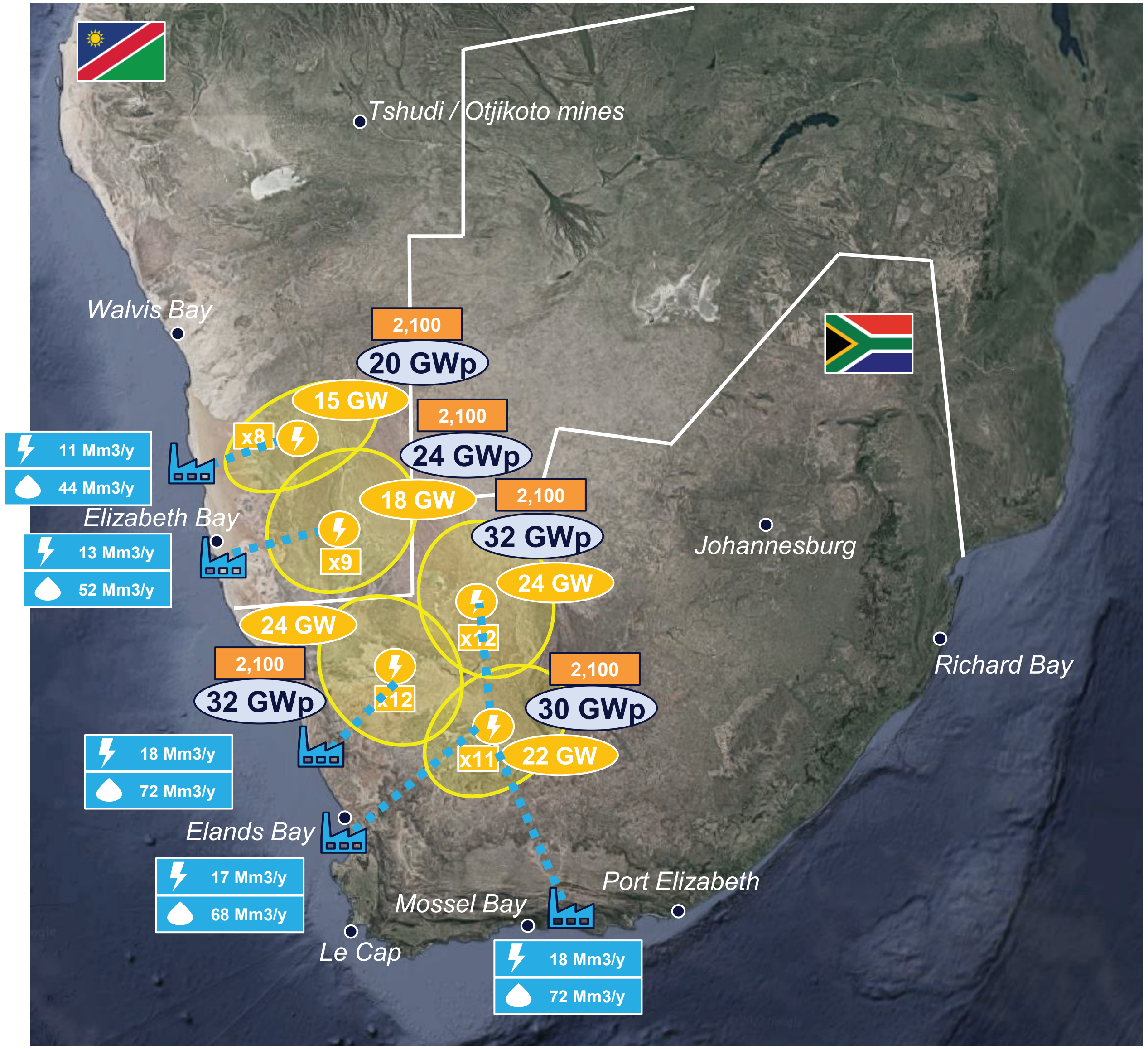
	Capacity required	Check / benchmark	*Capacity management*
PV	• **240 GWp by 2030 to 451 GWp by 2035** of solar capacity to be installed • Surface power capacity density of 1.5 ha / MW	• Total required surface of 360,000 ha by 2030 and 677,000 ha by 2035 < **0.7% of the total countries area**	✓
Desalination	• Desalination capacity required : **750 Mm3 by 2030 and 1,500 Mm3 by 2035** • 6 desalination facilities with a capacity of 250 Mm3/y	• Desalination plants designed with a capacity of ~250 Mm3/y, **i.e. ~70% of the current largest desalination plants** in the world (e.g. in RAK, Saudi Arabia or in Taweelah, UAE)	✓
Water pipe	• **720 to 1,030 km of water transportation pipe** infrastructures, including one double pipe section by 2035 • Water pipe designed with a maximum of **60 inches**	• Realistic length, **~30% of Manmade pipeline** • Water pipe designed with diameter of 60 inches, **i.e. ~75% of the largest water pipeline diameters in the world** (e.g. Oguz-Gabala-Baku Water Pipeline)	✓
Electrolysis	• Units of 2GWp captive solar plants, injecting in electrolysis platforms with a total electrolysis capacity of **185 GWe by 2030 and 351 GWe by 2035**	• **~300 MWe global electrolysis installed capacity** in 2020	⚠ *~1000x current global electrolysis capacity*
H2 pipe	• Total cumulated length of greenfield pipes infrastructures is **2,310 km by 2030 and 4,000 by 2035** • H2 pipes designed with **48 inches diameter** • **Sections with up to 3 parallels pipes**	• **<1% of total global brownfield transport infrastructures** length in 2020 and around **2 to 4 times Nord Stream gas pipe length**	✓
Storage	• **56 Mm3 by 2030 and 105 Mm3 by 2035** of metric storage volume required • **Only 1 potential salt dome geological storage site**	• **~0.1% of total EU underground storage capacities** • Typical salt cavern volume capacity is 0.5 to 1 Mm3	⚠ *Limited geological potential*

1	Western Africa hub
2	Northern Africa hub
3	**Southern Africa hub**

South Africa & Namibia



Focus on South-African hub – Upstream model by **2030**: 138 GWp of solar capacity and 104 GWe of electrolysis capacity to be installed



Key

Production

- X — Solar Capacity to be installed by 2030 (GWp)
- Suitable area for solar development
- X — Solar yield (kWh/kWp/y)
- Desalination plant
- X GW — Electrolysis installed capacity
- X Mm3/y — Water volumes required for electrolysis (Mm3/y)
- X Mm3/y — Water volumes available for other usages (agriculture, drinking..)
- xX — Electrolysis platform (number of solar2H2 plants)

T&S

- Water pipe
- Cities

Design & sizing details

Solar generation

- **138 GWp in 5 areas**
- **9 MW** (representing 14 GWh a year) **in Namibia and 19 MW** (representing 30 GWh) in **SA** of additional solar capacity **to partially feed desalination plants** for water generation dedicated to electrolysis
- About **170 GWh a year of electricity** used from the **grid** to complement the sourcing (water generation for other usage) which represent <1% of SA electricity generation

Water desalination

- **77 Mm3/y of water required from desalination** for electrolysis
- **Up to 308 Mm3/y of fresh water** available: **31%** (96 Mm3) **in Namibia** (covering mostly the overall current Namibian water consumption for agriculture) **and 69%** (212 Mm3) **in South-Africa** (covering around 2% of current SA agricultural water consumption)

Water transportation

- **570 km in Namibia and 1,000 km in SA of water pipe infrastructures** from desalination facilities to electrolysis platforms

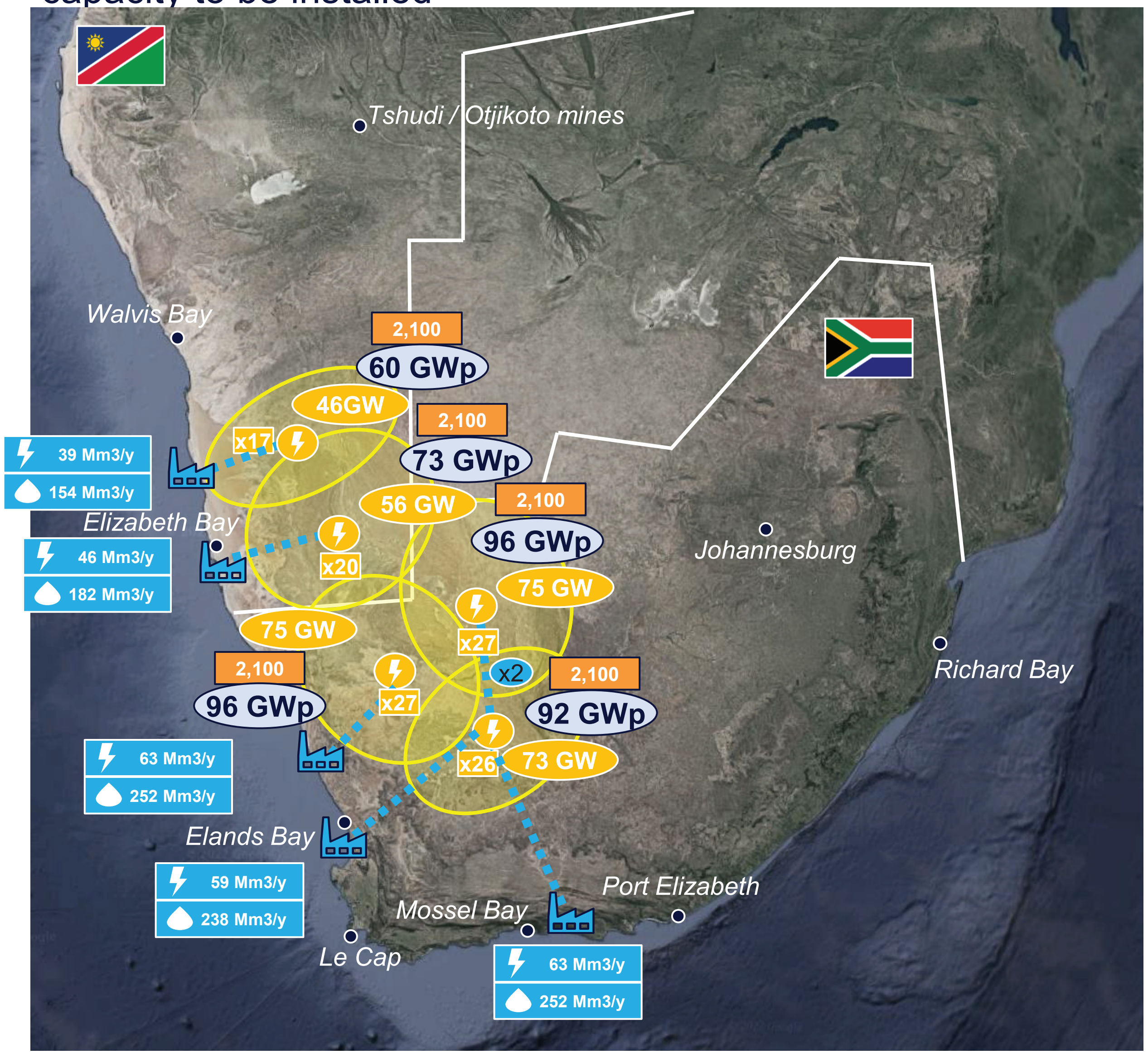
Electrolysis

- **5 electrolysis domains** with a **total capacity of 104 GW**

Sources: FAO Aquastat, CSIS, Department of Science and Innovation of South-Africa, CVA analysis

African Union | isa INTERNATIONAL SOLAR ALLIANCE | European Investment Bank

Focus on South-African hub – Upstream model by **2035**: 420 GWp of solar capacity and 325 GWe of electrolysis capacity to be installed



Key

Production

- X — Solar Capacity to be installed by 2030 (GWp)
- Suitable area for solar development
- X — Solar yield (kWh/kWp/y)
- Desalination plant
- X GW — Electrolysis installed capacity
- X Mm3/y — Water volumes required for electrolysis (Mm3/y)
- X Mm3/y — Water volumes available for other usages (agriculture, drinking..)
- xX — Electrolysis platform (number of solar2H2 plants)

T&S

- Water pipe
- xX — Number of parallel water pipes required
- Cities

Design & sizing details

Solar generation

- **300 GWp in 5 areas**
- **29 MW** (representing 46 GWh a year) **in Namibia and 66 MW** (representing 104 GWh) in **SA** of additional solar capacity **to partially feed desalination plants** for water generation dedicated to electrolysis
- About **467 GWh a year of electricity** used from the **grid** to complement the sourcing (water generation for other usage) which represent <2% of SA electricity generation

Water desalination

- **270 Mm3/y of water required from desalination** for electrolysis
- **Up to 1,080 Mm3/y of fresh water** available: **31%** (335 Mm3) **in Namibia** (covering more that 2 times the overall current Namibian water consumption for agriculture, industry and municipalities) **and 69%** (745 Mm3) **in South-Africa** (covering 7% of current SA agricultural water consumption)

Water transportation

- **570 km in Namibia and 1,240 km in SA of water pipe infrastructures** from desalination facilities to electrolysis platforms

Electrolysis

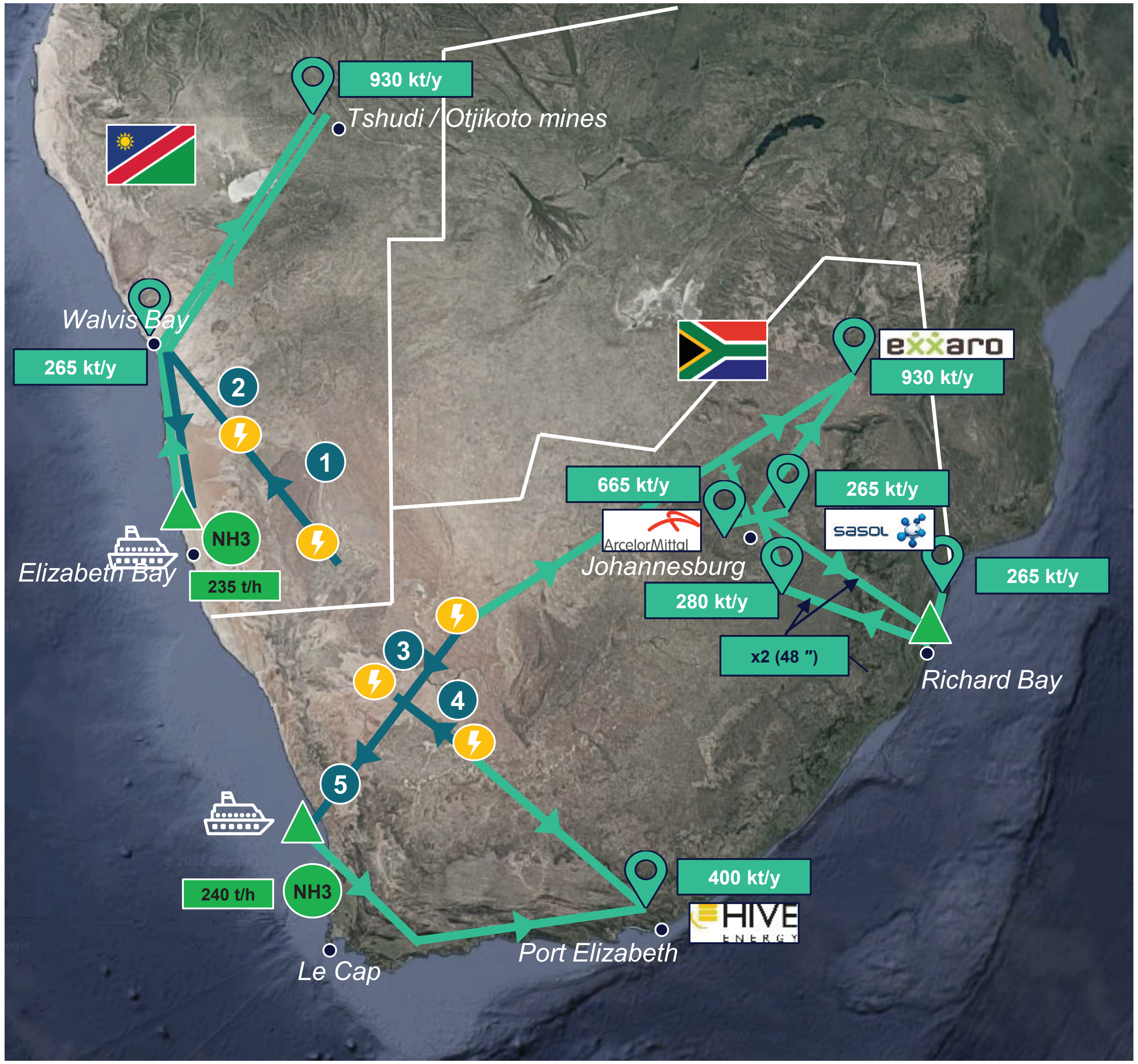
- **5 electrolysis domains** with a **total capacity of 325 GW**

Note (1): Capacity of the largest desalination plants in the world is ~1 Mm3/day

Sources: FAO Aquastat, CSIS, Department of Science and Innovation of South-Africa, CVA analysis

CVA Corporate Value Associates

Focus on South-African hub – Midstream and downstream model – Vision by 2030



*When not detailed, the pipe is a simple 48″ greenfield pipe

Sources: FAO Aquastat, CSIS, Department of Science and Innovation of South-Africa, CVA analysis

Key

Production

Electrolysis platform

T&S

Domestic H2 pipeline to be built

Existing gas pipeline

Potential International H2 backbone

xX (X ") Number of parallel pipelines (diameter of the pipe section, inches)

1 International pipe length:
1. 240 km
2. 170 km
3. 140 km
4. 100 km
5. 240 km

Off-takers

HIVE ENERGY H2 Off-taker

X kt/y Domestic H2 volumes off-take (kt/y)

Port infrastructure for H2 exportation as NH3

Storage

Existing or potential salt cavern geological site

NH3 Ammonia facility for exportation of H2 as NH3

338 t/h Ammonia max. capacity required

Design & sizing details

H2 generation

- **5 Mt H2 produced in 2030** to meet:
  - Domestic demand in 6 main areas (~4Mt)
  - International exportation (~1Mt)

H2 storage

- **2 storage sites in SA and 1 in Namibia to be sized for H2 dispatch management** with connections to off-take sites:
  - **10 and 20 Mm3 storage capacity in SA**
  - **10 Mm3 storage capacity in Namibia**

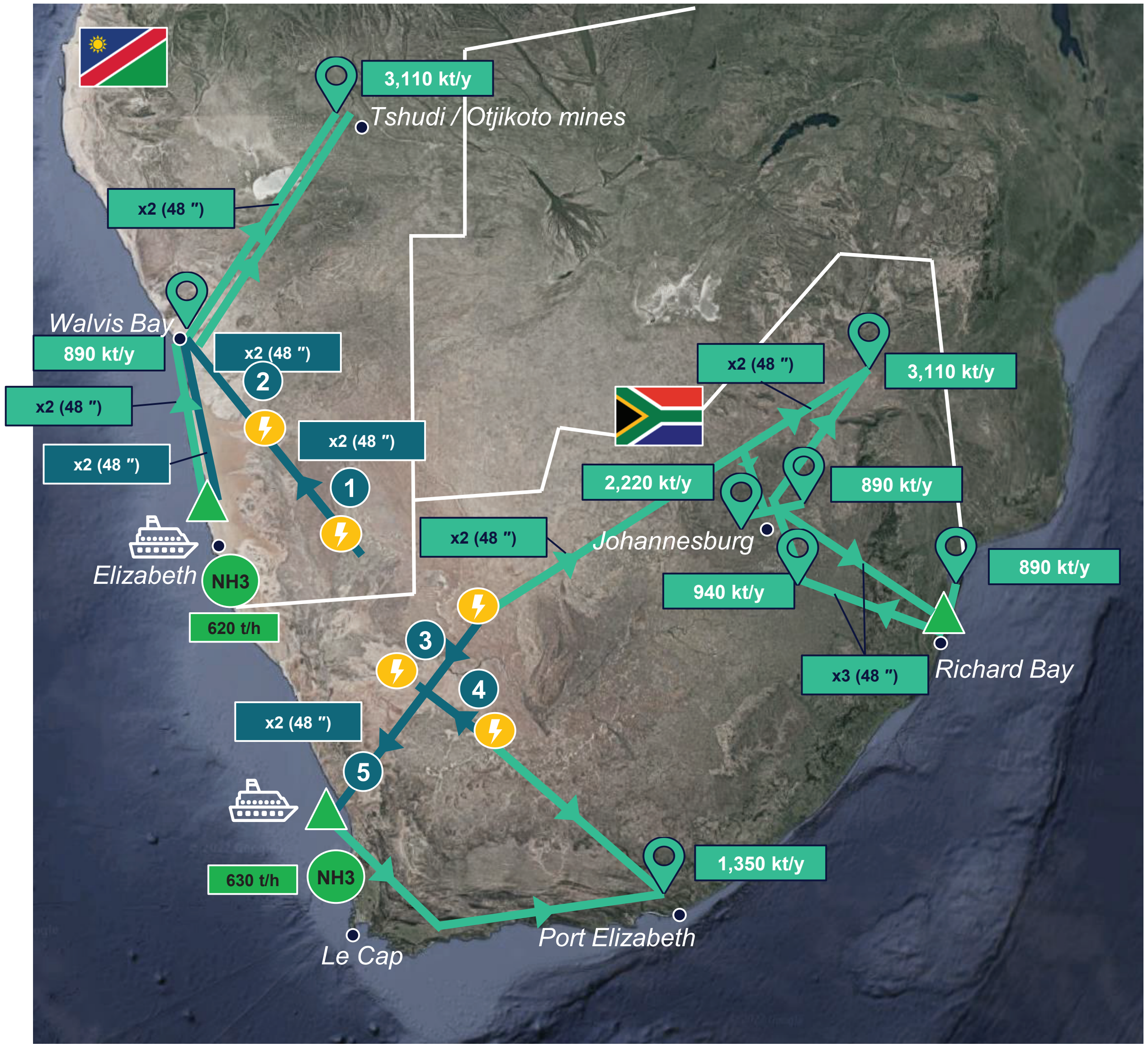
H2 transportation

- **5,500 km of H2 transportation pipes : 48 inches greenfield** connected with **2 storage sites in South-Africa and one in Namibia**
- **Up to 2 parallels pipes**

NH3 exportation

- **1 Mt of H2 to be exported by boat as ammonia**
- **Storage capacity available for line pack process: 3Mt H2 in SA and 1Mt in Namibia**
- **235 t/h ammonia production capacity facility in Namibia and 240 t/h in SA**

Focus on South-African hub – Midstream and downstream model – Vision by 2035



*When not detailed, the pipe is a simple 48″ greenfield pipe

Sources: FAO Aquastat, CSIS, Department of Science and Innovation of South-Africa, CVA analysis

Key

Production

Electrolysis platform

T&S

Domestic H2 pipeline to be built

Existing gas pipeline

Potential International H2 backbone

xX (X ") — Number of parallel pipelines (diameter of the pipe section, inches)

1 — International pipe length:
1. 240 km
2. 170 km
3. 140 km
4. 100 km
5. 240 km

Off-takers

H2 Off-taker

X kt/y — Domestic H2 volumes off-take (kt/y)

Port infrastructure for H2 exportation as NH3

Storage

Existing or potential salt cavern geological site

NH3 — Ammonia facility for exportation of H2 as NH3

338 t/h — Ammonia max. capacity required

Design & sizing details

H2 generation

- **17.5 Mt H2 produced in 2035** to meet:
  - Domestic demand in 6 main areas (~13.5 Mt), incl. H2 for export of finished products (steel & fertilizers)
  - International export. (~4 Mt)

H2 storage

- **2 storage sites in SA & 1 in Namibia to be sized for H2 dispatch mgmt.** with connections to off-take sites:
  - **~70 Mm3 storage capacity in SA**
  - **~30 Mm3 storage capacity in Namibia**
- **Total <0.1% of Europe's Underground Gas Storage capacity**

H2 transportation

- **5,500 km of H2 transportation pipes: 48 inches greenfield** connected with **2 storage sites in South-Africa and one in Namibia**
- **Up to 3 parallels pipes**

NH3 exportation

- **4 Mt to be exported by boat as ammonia**
- **Storage capacity available for line pack process: 4.5 MtH2 in SA and 2.1 Mt in Namibia**
- **620 t/h ammonia prod. capacity facility in Namibia and 630 t/h in SA**

The H2 hub systems feature designs implying mass scale sizing while corresponding to managed capacities

The upstream and midstream sizing involves capacities falling into standards of existing industrial designs

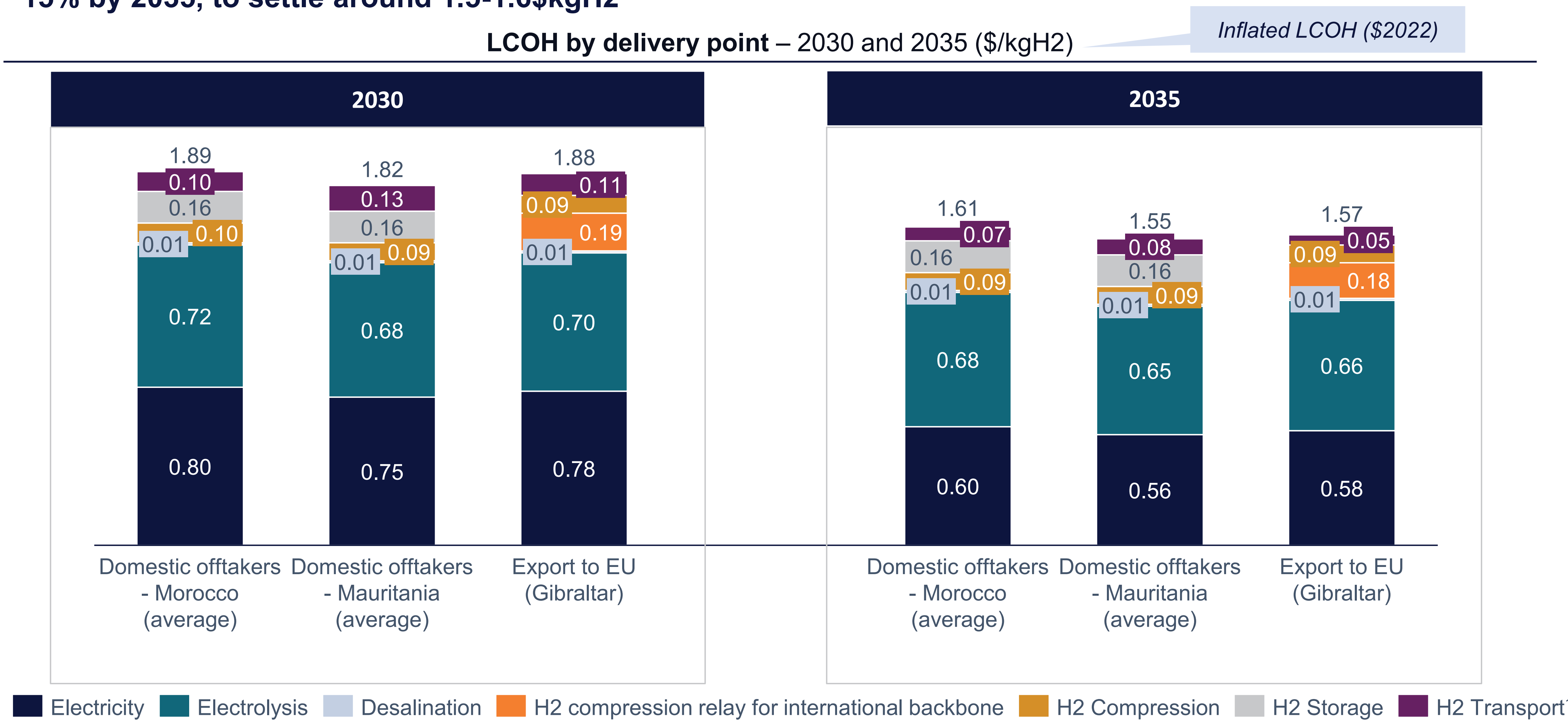
	Capacity required	Check / benchmark	*Capacity management*
PV	• **138 GWp by 2030 to 420 GWp by 2035** of solar capacity to be installed • Surface power capacity density of 1.5 ha / MW	• Total required surface of 207,000 ha by 2030 and 630,000 ha by 2035 < **0.1% of the total countries area**	
Desalination	• Desalination capacity required : **385 Mm3 by 2030 and 1,350 Mm3 by 2035** • 5 desalination facilities with a capacity of 250 Mm3/y	• Desalination plants designed with a capacity of ~250 Mm3/y, **i.e. ~70% of the current largest desalination plants** in the world (e.g. in RAK, Saudi Arabia or in Taweelah, UAE)	
Water pipe	• **1,570 to 1,810 km of water transportation pipe** infrastructures, including one double pipe section by 2035 • Water pipe designed with a maximum of **60 inches**	• Total length acceptable, **i.e. ~60% of Manmade pipeline** • Water pipe designed with diameter of 60”, **i.e. ~75% of the largest water pipeline diameters in the world** (e.g. Oguz-Gabala-Baku)	
Electrolysis	• Units of 2GWp captive solar plants, injecting in electrolysis platforms with a total electrolysis capacity of **104 GWe by 2030 and 325 GWe by 2035**	• **~300 MWe global electrolysis installed capacity** in 2020	*~500 to 1,000x current global electrolysis capacity*
H2 pipe	• Total cumulated length of greenfield pipes infra. is **5,500 km by 2030 and 10,000 by 2035 /** H2 pipes designed with **48 inches diameter, sections with up to 3 parallels pipes**	• **<1% of total global brownfield transport infrastructures** length in 2020 and around **5 to 10 times Nord Stream gas pipe length**	
Storage	• **40 Mm3 by 2030 and ~100 Mm3 by 2035** of metric storage volume required • <u>**3 potential salt dome geological storage site**</u>	• **~0,1% of total EU underground storage capacities** • Typical salt cavern volume capacity is 0.5 to 1 Mm3	
Final product exportation	• **98 Mt of steel production** to be **exported** by 2035 and **42 Mt of fertilizers**	• **5% of global steel production** and **7% of global demand for fertilizers**	

Agenda

1. African H2 hubs system design – Demand equation to address – 2030 and 2035
2. African H2 hubs system design – Design and sizing of the 3 hubs
3. **African H2 hubs system design – Resulting costs for the 3 hubs**
4. Value creation impact

Mauritanian / Morocco systems costing – LCOH per delivery zone

LCOHs around 1.8-1.9$/kgH2 in 2030 both for domestic offtake and EU exports, expected to decrease by ~15% by 2035, to settle around 1.5-1.6$kgH2



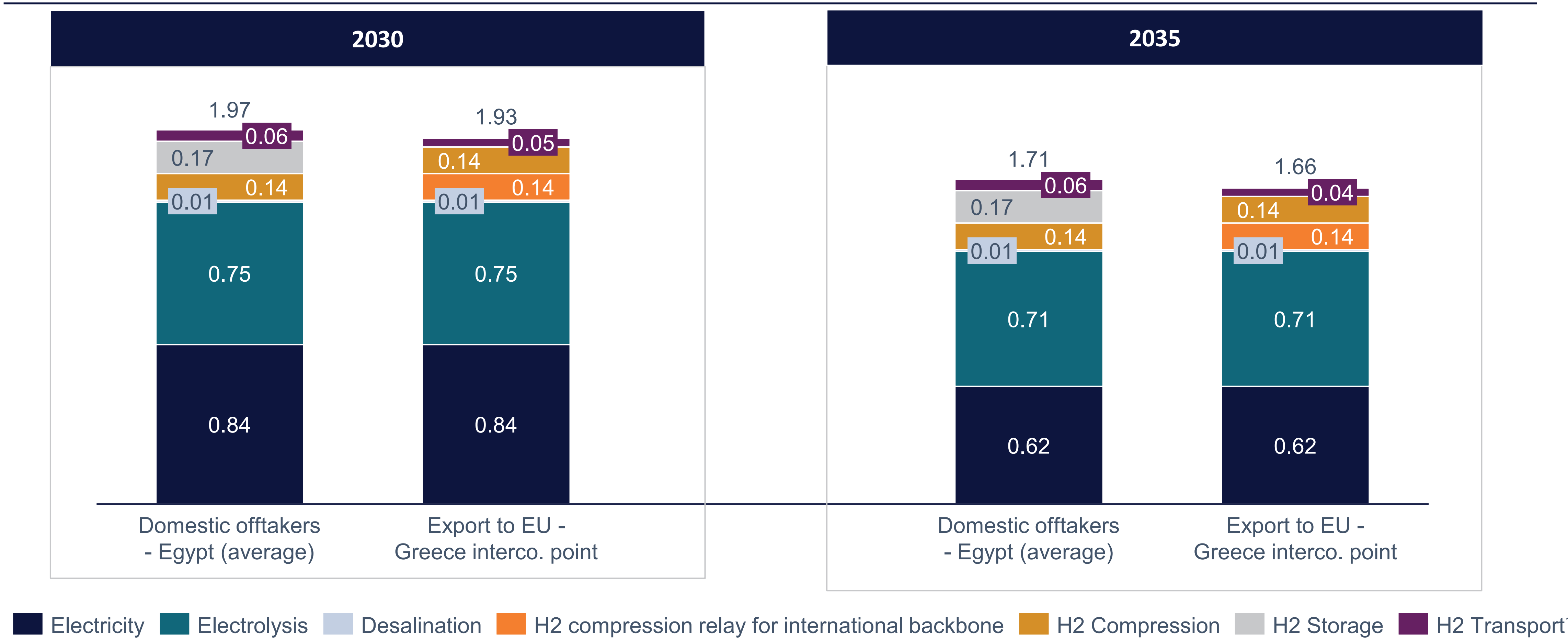
Note (1): Corresponds to transportation through greenfield pipes – domestic costs for transportation include domestic greenfield and international backbone proportionally to the share of total production / EU costs for transportation include only international backbone costs

Egypt system costing – LCOH per delivery zone

LCOHs around 1.9-2.0/kgH2 for both domestic offtake and European exports in 2030, expected to decrease by ~15% by 2035, around 1.6-1.7$/kgH2

LCOH by delivery point – 2030 and 2035 ($/kgH2)

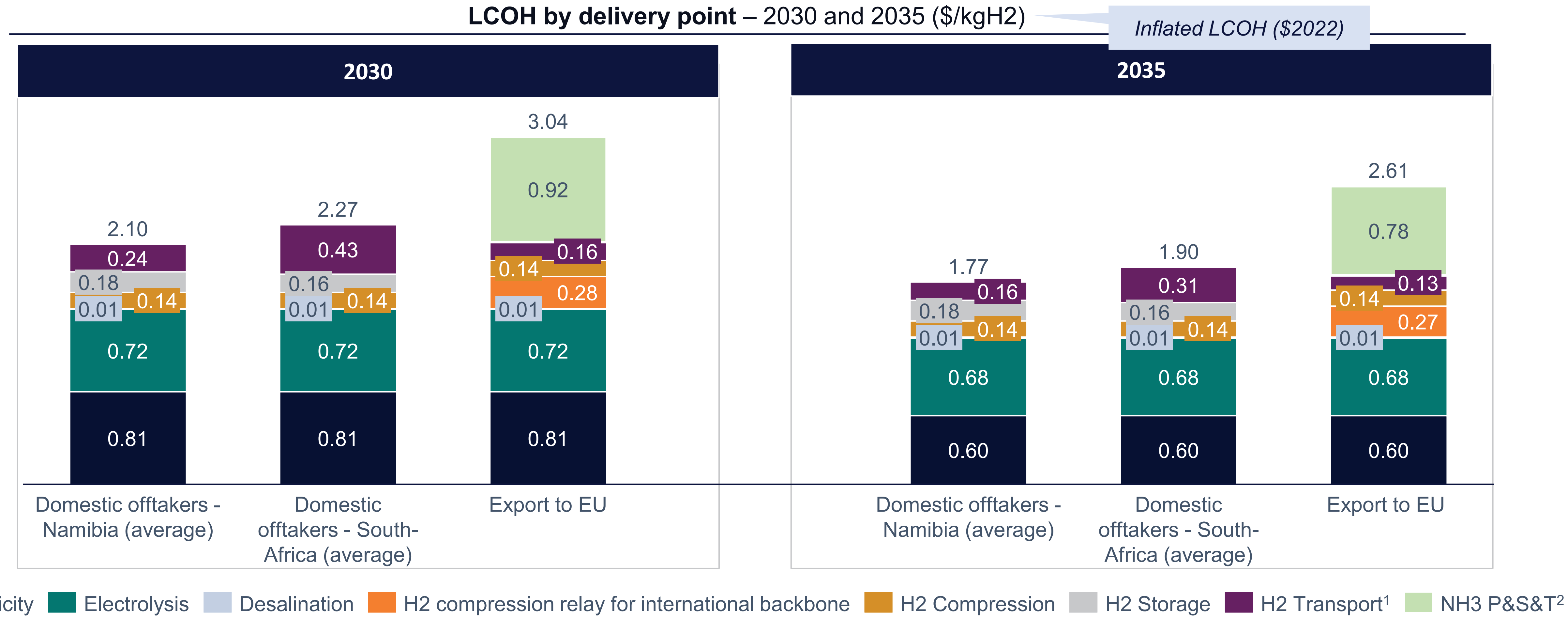
Inflated LCOH ($2022)



Note (1): Corresponds to transportation through greenfield pipes – domestic costs for transportation include domestic greenfield and international backbone / EU costs for transportation include only international backbone costs

Southern Africa systems costing – LCOH per delivery zone

LCOHs around 2-2.3$/kgH2 for domestic offtake and 3$/kgH2 for European exports in 2030, expected to decrease by ~15% by 2035 – NH3 exportation costs represent around 30% of total EU H2 costs



Note (1): Corresponds to transportation through greenfield pipes – domestic costs for transportation include domestic greenfield and international backbone proportionally to the share of total production / EU costs for transportation include only international backbone costs
Note (2): Includes conversion, NH3 storage, loading cost and shipping costs
Sources: BloombergNEF, IEA, NSE, CVA analysis

African Union | isa International Solar Alliance | European Investment Bank

Systems costing – Key hypotheses for 2030 and 2035

Total investments required around 500 Bn$ in 2030 and additional 900 Bn$ in 2035, with solar PV and electrolysis accounting together for >60% of the total CAPEX by 2035

		Item	Unit	Western Africa hub				Egypt hub		Southern Africa hub			
				2030		2035		2030	2035	2030		2035	
				Mor.	Maur.	Mor.	Maur.			S. Afr.	Nam.	S. Afr.	Nam.
Upstream	Solar	CAPEX PV	M$/MWp	0.39		0.30		0.39	0.30	0.39		0.30	
Upstream	Solar	OPEX PV	% CAPEX	2%		2%		2%	2%	2%		2%	
Upstream	Solar	PV degradation[1]	%/year	0.35%		0.35%		0.35%	0.35%	0.35%		0.35%	
Upstream	Solar	Yield	kWh/kWp	2,200	2,400	2,200	2,400	1,990	1,990	2,100	2,100	2,100	2,100
Upstream	Solar	WACC	%	6.5%		6.5%		6.5%	6.5%	6.5%		6.5%	
Upstream	Electrolysis + Compression	CAPEX Electrolyser	$/Wp	0.42		0.35		0.42	0.35	0.42		0.35	
Upstream	Electrolysis + Compression	O&M Electrolyser	% CAPEX	2%		2%		2%	2%	2%		2%	
Upstream	Electrolysis + Compression	Water desalination CAPEX	M$	142	158	376	396	594	828	210	95	524	237
Upstream	Electrolysis + Compression	Water pipe CAPEX	M$	578	603	1,206	1,207	579	1,187	804	458	997	458
Upstream	Electrolysis + Compression	WACC	%	8%		8%		8%	8%	8%		8%	
Upstream	Storage	Storage CAPEX	M$	3,060	2,650	6,770	6,040	10,750	20,885	3,900	2,420	16,620	5,720
Trans-port		CAPEX Pipeline (Green Field)	M$	6,630	7,388	13,144	14,460	18,600	35,908	31,470	9,500	63,560	18,200
Trans-port		OPEX Pipeline (Green Field)	% CAPEX	1%		1%		1%	1%	1%		1%	
Trans-port		WACC	%	6.5%		6.5%		6.5%	6.5%	6.5%		6.5%	
Total CAPEX (PV, ELY, desalination, elec. transmission and storage, greenfield)			Bn$	**~67**	**~58**	**+59**	**+55**	**~219**	**+145**	**~108**	**~46**	**+108**	**+42**

Note (1): Yields are averages of the different developed areas, and technological improvements of the panels are assumed, explaining yield improvements

CVA Corporate Value Associates

Agenda

Multiple value creation impacts both for local production countries and green H2 import countries – Vision at 50 Mt H2 production / year

Cost competitiveness and differentiation

1.55-1.90 € / kg H2 at delivery points (equivalent to 79-96€ per Brent oil barrel, comparable to historical prices plus CO2)

Growth for local economies

An average of 40 Bn€ of direct GDP created / year all along the project lifetime corresponding to ~5% of the current considered countries' GDPs

Strong impact for the communities

Development of an at scale freshwater system: ~3,500 Mm3 production capacity available on the 5 different countries, i.e. more than 5% of the current volumes consumed locally

Direct employment creation

Massive creation of permanent quality jobs along the value chain

Global energy transition

Supply of ~25Mt H2 (equiv. ~70 Mtoe) to overseas countries.
~15% of the current EU gas demand, as an illustration

Dedicated captive energy system

Dedicated production and transmission capacities, to avoid disturbing the existing energy system used for current usages

Contribution to decarbonization

~500 Mt CO2 / y avoided in 2035, either by direct usage of H2 or the supply of green commodities (~40% of African CO2 emissions in 2020)