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

Master pack

October 2022
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
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)

Key
- Thermal plant
- Refineries
- Fertilizers and Chem.
- Steel plants
- Qualified off-takers (existing sites)
- Future potential off-takers

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.

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

Including exportations as finished products (steel, fertilizers, …)
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)

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

### Detailed 2030 vision – H2 potential demand

**Focus on domestic demand**

**Mauritania**
- For now, no main H2 off-taker
- Thermal plants – assumptions of 50 kty in 2030 (e.g. SOMELEC)

**Morocco**
- 600 kty primary steel: 100 - 150 kty of H2 (e.g. SONASID)
- Electricity generation = assumption of 50 kty H2/y (e.g. ONEE)
- 100 – 250 kty H2 for ammonia (Moroccan government roadmap / e.g. OCP)
- Local demand for other existing industries is estimated to 100 kty of H2 by 2030
- Estimated to 50-100 kty (Moroccan government roadmap)
- Future development of industrial project (e.g. chemicals with METHANEX) – 500 kty

**Potential H2 off-takers**
- Primary steel production capacity: 500 kty of H2 (e.g. SNIM/AM)
- Potential development: 1.5 Mt/y of ammonia which represent around 300 kty of H2
- Transport: Assumptions of 50 kty in 2030

**Existing sites with existing or potential H2 off-take (including substitution of fossil fuels)**

**Existing H2 off-takers**
- 2030 Domestic potential off-take, H2 kty
- Additional potential domestic off-take, H2 kty
- Existing gas pipeline
- EU exportation potential

**Future potential H2 off-takers related to new industrial sites**
- (announced green H2 projects and development of new facilities)

### Estimated potential H2 off-take volumes (2030)

400-500 kty

3 Mt

~ 1,500 kty

**Other**
- Local demand for other existing industries is estimated to 100 kty of H2 by 2030
- Estimated to 50-100 kty (Moroccan government roadmap)
- Future development of industrial project (e.g. chemicals with METHANEX) – 500 kty

## 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)
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).

### Focus on domestic demand

#### Existing sites with existing or potential offtake (including substitution of fossil fuels)

- **Ain Soukhna**: 900 kt/y
- **Damietta**: 500 kt/y
- **900 kt/y**

#### Future potential H2 offtakers 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**

### Egypt

- **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 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.g. METHANEX)**
- **Consumption for electricity production I thermal plants: 400 kt/y (e.g. MDEPC)**

### Potential H2 off-takers

- **Existing H2 off-takers**
- **2030 Domestic potential off-take, H2 kt/y**
- **Additional potential domestic offtake, H2 kt/y**

- **Potential H2 off-takers**
- **Existing gas pipeline**
- **EU exportation potential**

### Estimated potential H2 off-take volumes (2030)

- **7 Mt/y**
- **2,500 kt/y**
- **>650 kt/y**

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

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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

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

Mobility: fuel for heavy and medium duty trucks for freight: 50 kt H₂/y

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)

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

Detailed 2030 vision – H₂ potential demand

Estimated potential H₂ off-take volumes (2030)

<table>
<thead>
<tr>
<th>Country</th>
<th>Potential Off-take</th>
</tr>
</thead>
<tbody>
<tr>
<td>Namibia</td>
<td>500kt H₂</td>
</tr>
<tr>
<td>South Africa</td>
<td>500kt H₂</td>
</tr>
<tr>
<td>Total</td>
<td>1,000kt H₂</td>
</tr>
</tbody>
</table>

Detailed 2030 vision – H₂ potential demand

Future H₂ off-takers related to 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

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

Future H₂ off-takers related to 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

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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)
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
Western Africa hub
Morocco & Mauritania
Northern Africa hub
Southern Africa hub
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.

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

**T&S**
- Potential International H2 backbones
- Water pipe
- Cities

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

**Key**

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

**Production**

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

**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

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

**Production**
- Electrolysis platform

**T&S**
- Domestic H2 pipeline to be built
- Potential International H2 backbone

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

**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

**Design & sizing details**

**Key**

**Production**
- Electrolysis platform

**T&S**
- Domestic H2 pipeline to be built
- Potential International H2 backbone

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

**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

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

**Storage**
- Existing or potential salt cavern geological site

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

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

**Production**
- Electrolysis platform

**T&S**
- Domestic H2 pipeline to be built
  - Number of additional domestic parallel pipeline and diameter of the pipe section
  - Potential internat. H2 backbone
  - Nb. of additional internat. pipelines vs. 2030 (diameter of the pipe section, inches)

**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

**Off-takers**
- H2 Off-taker
  - Domestic H2 volumes off-take (kt/y)

**Storage**
- Existing or potential salt cavern geological site

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

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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

<table>
<thead>
<tr>
<th>Capacity required</th>
<th>Check / benchmark</th>
</tr>
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<tbody>
<tr>
<td><strong>PV</strong></td>
<td>• 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</td>
</tr>
<tr>
<td>• 150 GWp by 2030 to 360 GWp by 2035 of solar capacity to be installed</td>
<td>• 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)</td>
</tr>
<tr>
<td>• Surface power capacity density of 1.5 ha / MW</td>
<td>• Total length acceptable, i.e. 90% of Manmade pipeline</td>
</tr>
<tr>
<td><strong>Desalination</strong></td>
<td>• 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)</td>
</tr>
<tr>
<td>• Desalination capacity required: 376 Mm3 by 2030 and 1,000 Mm3 by 2035</td>
<td>• ~300 MWe global electrolysis installed capacity in 2020</td>
</tr>
<tr>
<td>• 4 to 5 desalination facilities with a capacity of 250 Mm3/y</td>
<td>• ~1% of total global brownfield transport infrastructure length in 2020 and around 4x Nord Stream gas pipe length</td>
</tr>
<tr>
<td><strong>Water pipe</strong></td>
<td>• ~0.1% of total EU underground storage capacities</td>
</tr>
<tr>
<td>• 1,600 to 2,700 km of water transportation pipe infrastructures, including double pipe sections by 2035</td>
<td>• Typical salt cavern volume capacity is 0.5 to 1 Mm3</td>
</tr>
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<td>• 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</td>
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<tr>
<td><strong>H2 pipe</strong></td>
<td></td>
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<tr>
<td>• Total length of greenfield pipes infrastructures is 3,700</td>
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<td>• H2 pipes designed with 48 inches diameter</td>
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<td><strong>Storage</strong></td>
<td></td>
</tr>
<tr>
<td>• 45 Mm3 by 2030 and 102 Mm3 by 2035 of metric storage volume required</td>
<td></td>
</tr>
<tr>
<td>• 2 potential salt dome geological storage sites</td>
<td></td>
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<td>• 45 Mm3 by 2030 and 102 Mm3 by 2035 of metric storage volume required</td>
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1. Western Africa hub
2. Northern Africa hub
3. Southern Africa hub

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

**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

- Suitable area for solar development
- Solar yield (kWh/kWp/y)
- Desalination plant
- Electrolysis installed capacity
- Water volumes required for electrolysis (Mm3/y)
- Water volumes available for other usages (agriculture, drinking..)
- Electrolysis platform (number of solar2H2 plants)

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

Note (1): Capacity of the largest desalination plants in the world is ~1 Mm3/day
Sources: Oxford Institute, Economics of hydrogen, NREL, CVA analysis
Focus on Egypt hub – Midstream and downstream model – Vision by 2030

Production

- Electrolysis platform

T&S

- Domestic H2 pipeline to be built
- Existing gas pipeline
- Potential International H2 backbone
- Number of parallel pipelines (diameter of the pipe section, inches)

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

Off-takers

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

Storage

- Existing or potential salt cavern geological site

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

Design & sizing details

H2 generation

- 10 Mt H2 produced in 2030 to meet:
  o Domestic demand in 4 main areas (~3Mt)
  o 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

**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
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.

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<td>• 240 GWp by 2030 to 451 GWp by 2035 of solar capacity to be installed</td>
<td>• Total required surface of 360,000 ha by 2030 and 677,000 ha by 2035 &lt; 0.7% of the total countries area</td>
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<td>• Surface power capacity density of 1.5 ha / MW</td>
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<tr>
<td><strong>Desalination</strong></td>
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<tr>
<td>• Desalination capacity required: 750 Mm3 by 2030 and 1,500 Mm3 by 2035</td>
<td>• 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)</td>
</tr>
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<td>• 6 desalination facilities with a capacity of 250 Mm3/y</td>
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<td><strong>Water pipe</strong></td>
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<tr>
<td>• 720 to 1,030 km of water transportation pipe infrastructures, including one double pipe section by 2035</td>
<td>• Realistic length, ~30% of Manmade pipeline</td>
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<td>• Water pipe designed with a maximum of 60 inches</td>
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<td>• 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</td>
<td>• ~300 MWe global electrolysis installed capacity in 2020</td>
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<td><strong>H2 pipe</strong></td>
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<td>• Total cumulated length of greenfield pipes infrastructures is 2,310 km by 2030 and 4,000 by 2035</td>
<td>• &lt;1% of total global brownfield transport infrastructures length in 2020 and around 2 to 4 times Nord Stream gas pipe length</td>
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<td>• H2 pipes designed with 48 inches diameter</td>
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<td>• Sections with up to 3 parallels pipes</td>
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<td><strong>Storage</strong></td>
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<tr>
<td>• 56 Mm3 by 2030 and 105 Mm3 by 2035 of metric storage volume required</td>
<td>• ~0.1% of total EU underground storage capacities</td>
</tr>
<tr>
<td>• Only 1 potential salt dome geological storage site</td>
<td>• Typical salt cavern volume capacity is 0.5 to 1 Mm3</td>
</tr>
</tbody>
</table>

~1000x current global electrolysis capacity

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

Sources: FAO Aquastat, CSIS, Department of Science and Innovation of South-Africa, CVA analysis
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
- Solar Capacity to be installed by 2030 (GWp)
- Suitable area for solar development
- Solar yield (kWh/kWp/y)
- Desalination plant
- Electrolysis installed capacity
- Water volumes required for electrolysis (Mm3/y)
- Water volumes available for other usages (agriculture, drinking..)
- Electrolysis platform (number of solar2H2 plants)

T&S
- Water pipe
- 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
Focus on South-African hub – Midstream and downstream model – Vision by 2030

**Key**

- **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

**Production**

- Electrolysis platform

**T&S**

- Domestic H2 pipeline to be built
- Existing gas pipeline
- Potential International H2 backbone
- Number of parallel pipelines (diameter of the pipe section, inches)
- International pipe length:
  1. 240 km
  2. 170 km
  3. 140 km
  4. 100 km
  5. 240 km

**Off-takers**

- H2 Off-taker
- Domestic H2 volumes off-take (kt/y)
- Port infrastructure for H2 exportation as NH3

**Storage**

- Existing or potential salt cavern geological site
- Ammonia facility for exportation of H2 as NH3
- Ammonia max. capacity required

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

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

Production
- Electrolysis platform

T&S
- Domestic H2 pipeline to be built
- Existing gas pipeline
- Potential International H2 backbone
  - Number of parallel pipelines (diameter of the pipe section, inches)
  - International pipe length:
    1. 240 km
    2. 170 km
    3. 140 km
    4. 100 km
    5. 240 km

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

*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
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.

<table>
<thead>
<tr>
<th>Capacity required</th>
<th>Check / benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PV</strong></td>
<td></td>
</tr>
<tr>
<td>• 138 GWp by 2030 to 420 GWp by 2035 of solar capacity to be installed</td>
<td>• Total required surface of 207,000 ha by 2030 and 630,000 ha by 2035 &lt; 0.1% of the total countries area</td>
</tr>
<tr>
<td>• Surface power capacity density of 1.5 ha / MW</td>
<td></td>
</tr>
<tr>
<td><strong>Desalination</strong></td>
<td></td>
</tr>
<tr>
<td>• Desalination capacity required : 385 Mm3 by 2030 and 1,350 Mm3 by 2035</td>
<td>• 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)</td>
</tr>
<tr>
<td>• 5 desalination facilities with a capacity of 250 Mm3/y</td>
<td></td>
</tr>
<tr>
<td><strong>Water pipe</strong></td>
<td></td>
</tr>
<tr>
<td>• 1,570 to 1,810 km of water transportation pipe infrastructures, including one double pipe section by 2035</td>
<td>• Total length acceptable, i.e. ~60% of Manmade pipeline</td>
</tr>
<tr>
<td>• Water pipe designed with a maximum of 60 inches</td>
<td>• Water pipe designed with diameter of 60&quot;, i.e. ~75% of the largest water pipeline diameters in the world (e.g. Oguz-Gabala-Baku)</td>
</tr>
<tr>
<td><strong>Electrolysis</strong></td>
<td></td>
</tr>
<tr>
<td>• 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</td>
<td>• ~300 MWe global electrolysis installed capacity in 2020</td>
</tr>
<tr>
<td><strong>H2 pipe</strong></td>
<td></td>
</tr>
<tr>
<td>• 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</td>
<td>• &lt;1% of total global brownfield transport infrastructures length in 2020 and around 5 to 10 times Nord Stream gas pipe length</td>
</tr>
<tr>
<td><strong>Storage</strong></td>
<td></td>
</tr>
<tr>
<td>• 40 Mm3 by 2030 and ~100 Mm3 by 2035 of metric storage volume required</td>
<td>• ~0.1% of total EU underground storage capacities</td>
</tr>
<tr>
<td>• 3 potential salt dome geological storage site</td>
<td>• Typical salt cavern volume capacity is 0.5 to 1 Mm3</td>
</tr>
<tr>
<td><strong>Final product exportation</strong></td>
<td></td>
</tr>
<tr>
<td>• 98 Mt of steel production to be exported by 2035 and 42 Mt of fertilizers</td>
<td>• 5% of global steel production and 7% of global demand for fertilizers</td>
</tr>
</tbody>
</table>

~500 to 1,000x current global electrolysis capacity
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

<table>
<thead>
<tr>
<th>LCOH by delivery point – 2030 and 2035 ($/kgH2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic offtakers - Morocco (average)</td>
</tr>
<tr>
<td>2030</td>
</tr>
<tr>
<td>1.89</td>
</tr>
<tr>
<td>0.10</td>
</tr>
<tr>
<td>0.16</td>
</tr>
<tr>
<td>0.01</td>
</tr>
<tr>
<td>0.72</td>
</tr>
<tr>
<td>0.68</td>
</tr>
<tr>
<td>0.75</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LCOH by delivery point – 2030 and 2035 ($/kgH2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic offtakers - Morocco (average)</td>
</tr>
<tr>
<td>2030</td>
</tr>
<tr>
<td>1.61</td>
</tr>
<tr>
<td>0.70</td>
</tr>
<tr>
<td>0.09</td>
</tr>
<tr>
<td>0.10</td>
</tr>
<tr>
<td>0.68</td>
</tr>
<tr>
<td>0.56</td>
</tr>
</tbody>
</table>

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

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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)

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

<table>
<thead>
<tr>
<th>LCOH by delivery point – 2030 and 2035 ($/kgH2)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2030</strong></td>
</tr>
<tr>
<td>Domestic offtakers - Namibia (average)</td>
</tr>
<tr>
<td><strong>Electricity</strong></td>
</tr>
<tr>
<td>2.10</td>
</tr>
<tr>
<td>0.24</td>
</tr>
<tr>
<td>0.18</td>
</tr>
<tr>
<td>0.01</td>
</tr>
<tr>
<td>0.14</td>
</tr>
<tr>
<td>0.72</td>
</tr>
<tr>
<td>0.72</td>
</tr>
<tr>
<td>0.81</td>
</tr>
<tr>
<td>0.81</td>
</tr>
<tr>
<td>0.81</td>
</tr>
</tbody>
</table>

**Export to EU**

**Electricity**

2.27

0.43

0.27

0.01

0.14

0.14

0.14

0.14

0.72

0.68

0.68

0.60

0.60

0.60

2.61

0.78

0.31

0.13

0.14

0.27

0.01

0.14

0.01

0.14

0.68

0.68

0.68

0.60

0.60

0.60

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
## 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.

### Western Africa hub

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Western Africa hub</th>
<th>Egypt hub</th>
<th>Southern Africa hub</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2030</td>
<td>2035</td>
<td>2030</td>
</tr>
<tr>
<td>CAPEX PV</td>
<td>M$/MWp</td>
<td>0.39</td>
<td>0.30</td>
<td>0.39</td>
</tr>
<tr>
<td>OPEX PV</td>
<td>% CAPEX</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>PV degradation</td>
<td>%/year</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Yield</td>
<td>kWh/kWP</td>
<td>2,200</td>
<td>2,400</td>
<td>2,200</td>
</tr>
<tr>
<td>WACC</td>
<td>%</td>
<td>6.5%</td>
<td>6.5%</td>
<td>6.5%</td>
</tr>
<tr>
<td>CAPEX Electrolyser</td>
<td>$/Wp</td>
<td>0.42</td>
<td>0.35</td>
<td>0.42</td>
</tr>
<tr>
<td>O&amp;M Electrolyser</td>
<td>% CAPEX</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Water desalination CAPEX</td>
<td>M$</td>
<td>142</td>
<td>158</td>
<td>376</td>
</tr>
<tr>
<td>Water pipe CAPEX</td>
<td>M$</td>
<td>578</td>
<td>603</td>
<td>1,206</td>
</tr>
<tr>
<td>WACC</td>
<td>%</td>
<td>8%</td>
<td>8%</td>
<td>8%</td>
</tr>
<tr>
<td>Storage CAPEX</td>
<td>M$</td>
<td>3,060</td>
<td>2,650</td>
<td>6,770</td>
</tr>
<tr>
<td>CAPEX Pipeline (Green Field)</td>
<td>M$</td>
<td>6,630</td>
<td>7,388</td>
<td>13,144</td>
</tr>
<tr>
<td>OPEX Pipeline (Green Field)</td>
<td>% CAPEX</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>WACC</td>
<td>%</td>
<td>6.5%</td>
<td>6.5%</td>
<td>6.5%</td>
</tr>
</tbody>
</table>

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

1. African H2 hubs system design – Demand equation to address – 2030 and 2035
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4. Value creation impact
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)