URUGUAY - PORT OF ROTTERDAM
HYDROGEN SUPPLY CHAIN
THE WORLD IS GEARING UP
GREEN HYDROGEN PROJECTS ALL OVER

**Source:** based on IEEFA, 'Great Expectations' (Aug. 2020)

**Sundance (Canada)**
- Start: 2024
- Capacity: 100-200MW
- CAPEX: 0.2 US$bn
- Production: 22 kt/yr

**Iberdrola (Spain)**
- Start: 2023
- Capacity: 100MW
- CAPEX: 0.2 US$bn
- Production: 7 kt/yr

**NEOM (Saudi Arabia)**
- Start: 2025
- Capacity: 4GW
- CAPEX: 7 US$bn
- Production: 207 kt/yr

**HyGreen (France)**
- Start: 2030
- Capacity: 900 MW
- CAPEX: 1.2 US$bn
- Production: 13 kt/yr

**H2 Fifty (The Netherlands)**
- Start: 2025
- Capacity: 250 MW
- CAPEX: US$bn
- Production: 45 kt/yr

**North H2 (The Netherlands)**
- Start: 2027
- Capacity: 10GW
- CAPEX: 20 US$bn
- Production: 800 kt/yr

**Jingneng (China)**
- Start: 2022
- Capacity: 5GW
- CAPEX: 3.2 US$bn
- Production: 183 kt/yr

**Arrowsmith (Australia)**
- Start: 2022
- Capacity: 200MW
- CAPEX: 0.3 US$bn
- Production: 9 kt/yr

**AREH (Australia)**
- Start: 2027
- Capacity: 11GW
- CAPEX: 15 US$bn
- Production: 562 kt/yr
"THE HOCKEY STICK" DEMAND
HYDROGEN GROWTH TREND

Source: Port of Rotterdam Hydrogen Vision, 2020 & Hydrogen Europe
**H₂ DEVELOPMENT ROADMAP**

**URUGUAY MOVING UP PROGRESSIVELY**

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

**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.

**Uruguay today**

**Steps ahead**

**Largescale Export of H₂**
Due to progressive policy measures, Uruguay has reached 98% renewable power production and thus has become number 2 in % renewable power (from solar and wind) in the world (see graphs below).

Uruguay is one of only two countries outside the OECD in the highest ESG score category.
TARGET VOLUME URUGUAY
PRELIMINARY TARGETS EXPLAINED IN THREE SCENARIOS

**Energy demand for local hydrogen and export**

<table>
<thead>
<tr>
<th>Year</th>
<th>Nominal power demand</th>
<th>Base power demand</th>
<th>Conservative H2 scenario (+0.4 Mtpa H2)</th>
<th>Medium H2 scenario (+0.8 Mtpa H2)</th>
<th>Ambitious H2 scenario (+3 Mtpa H2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2030</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>2040</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>2050</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

**Scenarios for 2050**

- **Conservative** would mean doubling Uruguay's national power production. Local consumption small, most hydrogen produced for export.
- **Medium** Scenario would mean tripling Uruguay's national power production. Large local hydrogen consumption growth and slightly more for export.
- **Ambitious** Scenario signifies Uruguay becomes one of the leading hydrogen economies of South America with large local and regional consumption as well as major exporter to Europe and Asia.
The logistic infrastructure development will await actual trade, yet the trade will not be made if there is no logistic infrastructure. Only with a Joint Vision presented in a national hydrogen masterplan will all supply chain components be developed simultaneously, achieving this new supply chain to take off.
RENEWABLE POWER PRODUCTION
A COMBINATION OF BOTH WIND AND SUN WITH STRONG GROWTH POTENTIAL

<table>
<thead>
<tr>
<th></th>
<th>Onshore wind</th>
<th>Offshore wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed capacity now</td>
<td>1.5 GW</td>
<td>0</td>
</tr>
<tr>
<td>Potential capacity</td>
<td>30 GW</td>
<td>276 GW</td>
</tr>
<tr>
<td>Capacity factor (100m high)</td>
<td>41%</td>
<td>-</td>
</tr>
<tr>
<td>Potential capacity factor (150m+ high)</td>
<td>41% and up</td>
<td>55% and up</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Solar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed capacity now</td>
<td>0.23 GW</td>
</tr>
<tr>
<td>Potential capacity</td>
<td>450 GW</td>
</tr>
<tr>
<td>Capacity factor (fixed tilt)</td>
<td>20%</td>
</tr>
<tr>
<td>Potential capacity factor</td>
<td>t.b.d.</td>
</tr>
</tbody>
</table>

Source: MiEM Solar and wind maps, Port of Rotterdam analysis
RENEWABLE POWER PRODUCTION
WIND AND SUN COMPLEMENT EACH OTHER VERY WELL

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

Sensitivity analysis shows that a 50-50% ratio wind to solar allows for optimal capacity factor of the electrolyser and thus total lower cost of H2.

Source: SIMSEE model based on MIEM solar and wind maps, Port of Rotterdam analysis

SUPPLY CHAIN COMPONENTS
## Local H2 Utilisation

### Existing and New Hydrogen Applications

### Uruguay H2 Transport Project

Pilot project tender in 2021 for:

- Green hydrogen production by electrolyser
- Starting with 10 heavy vehicles: road trucks and buses with a range of ~ 400 km

Potential diesel demand of 670,000 m³/year for heavy duty transport for 2025 (equivalent to 150 kTon of Hydrogen per year)

### Ammonia to Fertiliser

- Uruguay Agricultural sector, produce food for 28 million people (3.4 million inhabitants)
- 100 kton of hydrogen per year as substitution of local fertilizer consumption

### Other Potential Local Uses of H2:

- Ammonia as marine fuel
- Green steel

### In Future:

- Hydrogen train link from pulp plant
- Green Methanol production
- Green diesel (HVO)
- Synthetic fuels
- Marine fuels

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Source: Potential of green steel Dirk Rabenik, Kiko BV
PORT INDUSTRIAL CLUSTER
PRELIMINARY RECOMMENDATION

Pilot phase: ANCAP’s La Teja refinery at Port of Montevideo*:

- Using smaller vessels with suitable draft (max 8m) for existing channel.
- Make use of existing oil and gas operations and its permitting zone.
- Facilities already include 4 LPG spheres & 15 heavy fuel tanks (ammonia and LPG have similar characteristics).
- *this proposed location is subject to detailed study and approval by ANCAP

Next phase: New Deepsea port on the Atlantic Ocean

- Lower social and environmental impact due to remoteness.
- Ample space to develop industrial complex with various hydrogen related industries, among others.
- Secondary and tertiary industrial developments as well as new urban hub.
- Opportunity for a regional deepsea port and green industrial cluster.
LOCAL LOGISTICS AND STORAGE
UTILIZING BOTH EXISTING AND NEW INFRASTRUCTURE

The Pilot project at La Teja Refinery in Montevideo

Two business cases to consider:

a) buy electricity from the grid
b) build a dedicated solar and wind farm in addition to buying surpluses.

The new Deepsea Port on the Atlantic Coast

Two alternatives for logistics:

a) Production of hydrogen in the same place of wind and solar farm. Dedicated hydrogen gas pipeline from solar and wind farms to deepsea port. Production of carrier at the industrial complex in deepsea port.

b) Production of hydrogen and carrier at industrial complex in deepsea port. Connecting renewable power to hydrogen production from a dedicated transmission line and national grid (see image).
## SHIPPING

Comparing carriers

<table>
<thead>
<tr>
<th>Carrier</th>
<th>Density</th>
<th>Type</th>
<th>DWT*</th>
<th>H2 equivalent</th>
<th>LOA**</th>
<th>Draught</th>
</tr>
</thead>
<tbody>
<tr>
<td>LH2</td>
<td>0.071</td>
<td>LNG Tanker</td>
<td>27,600 t</td>
<td>9,000 t</td>
<td>284 m</td>
<td>12 m</td>
</tr>
<tr>
<td>AMMONIA</td>
<td>0.769</td>
<td>LPG Tanker</td>
<td>50,534 t</td>
<td>225 m</td>
<td>12 m</td>
<td></td>
</tr>
<tr>
<td>LOHC (DBT)</td>
<td>0.792</td>
<td>Oil/Chemical</td>
<td>48,933 t</td>
<td>183 m</td>
<td>9.7 m</td>
<td></td>
</tr>
<tr>
<td>LOHC (MCH)</td>
<td>0.792</td>
<td>Chemical</td>
<td>50,000 t</td>
<td>186 m</td>
<td>10.6 m</td>
<td></td>
</tr>
</tbody>
</table>

* DWT = dead weight tonnes
** LOA = length of overall

Source: HyChain - energy carriers and hydrogen supply chain (2018)
• **Green ammonia terminal**
  Existing Europoort terminal operated by OCI.
  New dedicated green ammonia terminals by 2025.

• **LOHC terminals**
  First pilot with DBT at existing Botlek terminal in 2023.
  Other pilots also being planned before 2030.

• **Liquid hydrogen terminal**
  Feasibility study started with Kawasaki.
  Expected operational after 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.
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

Usage 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 be the first sectors to adopt hydrogen (see graph).

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

Source: Jülich Forschungszentrum – Hy3 Project interim Results (2020)
Preliminary estimates for local CAPEX include:
- Renewable power (solar, onshore and offshore wind)
- Electrolyser cost
- Hydrogen pipeline with compression

Investments to be added:
- hydrogen storage
- carrier production & storage
- port facilities.

These investments will depend on carrier choice and port location choice. They may also be significant. To be worked out in next stage.

<table>
<thead>
<tr>
<th></th>
<th>Total Investment per decade (Bill EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conservative</td>
</tr>
<tr>
<td>2020s</td>
<td>1.67</td>
</tr>
<tr>
<td>‘30s</td>
<td>1.49</td>
</tr>
<tr>
<td>‘40s</td>
<td>2.62</td>
</tr>
</tbody>
</table>
**BASE CASE: MID SCENARIO IN 2030**

**COST PARAMETERS AND COST PRICE ADJUSTED FOR 2030**

Focus of this cost model

<table>
<thead>
<tr>
<th></th>
<th>2020</th>
<th>Solar</th>
<th>Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPEX</td>
<td>EUR/kW</td>
<td>675</td>
<td>1012</td>
</tr>
<tr>
<td>EUR/MWh</td>
<td>26.8</td>
<td>30.5</td>
<td></td>
</tr>
</tbody>
</table>

Local renewable power cost basecase

<table>
<thead>
<tr>
<th></th>
<th>2030</th>
<th>Solar</th>
<th>Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUR/MWh</td>
<td>14.7</td>
<td>16.7</td>
<td></td>
</tr>
</tbody>
</table>

*These forecasts are being reviewed*

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 +/-xx%. 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.

Source cost price development: IHS Markit – The role of hydrogen (2020)
Comparing carriers:
Considering the accuracy of the cost parameters used, no final conclusion can be drawn yet on the preferred carrier.

At this time there seems a slight preference to continue to research ammonia and the LOHC methyl-cyclohexane.
### Export Infrastructure Requirements for 2030 ‘Medium’ Scenario (200KTPA Delivered in RDAM)

#### Ammonia

<table>
<thead>
<tr>
<th>Component</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mooring</td>
<td>1 jetty</td>
</tr>
<tr>
<td>Storage</td>
<td>2 tanks of 80,000 m³</td>
</tr>
<tr>
<td>Ship</td>
<td>3 x very large gas carrier (VLGC), 56K dwt</td>
</tr>
<tr>
<td>Land area (storage)</td>
<td>Min. ~ 15 Ha</td>
</tr>
</tbody>
</table>

#### LOHC (MCH)

<table>
<thead>
<tr>
<th>Component</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mooring</td>
<td>1 jetty</td>
</tr>
<tr>
<td>Storage</td>
<td>4 tanks of 55,000 m³</td>
</tr>
<tr>
<td>Ship</td>
<td>4 chemical tankers 50k dwt</td>
</tr>
<tr>
<td>Land area (storage)</td>
<td>Min. ~ 11 Ha</td>
</tr>
</tbody>
</table>
Shipping distance & carrier sensitivity:

As shipping costs are only a small component of the total hydrogen cost, the shipping distance has some but not significant impact on the final H₂ price. Technological developments may further reduce this delta.
JOINT RISK & BARRIERS WORKSHOP
EXAMPLE OF ONE OF 5 SUPPLY CHAIN COMPONENTS STUDIED

2. Local Logistics & Export

Collaborative risk analysis workshop on digital whiteboard with all relevant stakeholders.

Example of outcome on ‘Logistics and Export’ supply chain component.
## Risks and Barriers

### Largest Risks

<table>
<thead>
<tr>
<th>Risk</th>
<th>Mitigations</th>
</tr>
</thead>
<tbody>
<tr>
<td>New technologies still to be developed (TRL of large-scale electrolysers).</td>
<td>Consider to develop H2 knowledge center and learn by doing with local pilots in Uruguay. Collaboration with leading Dutch electrolyser developers.</td>
</tr>
<tr>
<td>Scale of proposed projects (offtake risk).</td>
<td>Phased development, start with smaller scale local use. Detailed multi-party roadmap. Intergovernmental financial support solutions.</td>
</tr>
<tr>
<td>Social and environmental concerns near the export facility.</td>
<td>Careful planning, development and strong stakeholder communication. Consider the use of a citizen council.</td>
</tr>
<tr>
<td>Logistics to and at the export facility.</td>
<td>Careful planning and development. Consider strategic partnerships.</td>
</tr>
<tr>
<td>Political risk of future governments and changing priorities.</td>
<td>Consider a multi-party commitment to climate and energy goals. Or even a set climate law, similar to the Dutch.</td>
</tr>
<tr>
<td>Risk of doing nothing.</td>
<td>Dream big, plan carefully, execute diligently and safely.</td>
</tr>
</tbody>
</table>
CONCLUSIONS

• Uruguay has strong unique selling points for production of competitive green hydrogen (unique combination wind and solar). Sensitivity analysis shows distance to market has a relatively small impact on the H2 price delivered.

• A new greenfield industrial zone and deepsea port on the East Coast are key infrastructure needed to make hydrogen supplychains possible.

• Rotterdam will be the ultimate hub for hydrogen distribution to the rest of Europe and has ample experience with all types of hydrogen carriers (ammonia or in LOHC methyl cyclohexane seem the most attractive options)

• Start with local pilots until European hydrogen demand accelerates further. The price of local hydrogen in Uruguay could by then come down to near €1.3 /kg and the price delivered in Rotterdam near €2.5 /kg.

• Risks foreseen include the scale and social acceptance. The biggest risk for the next generation however is doing nothing

• Uruguay and Rotterdam are a great match to develop key logistics infrastructure that will catalyse the materialization of Uruguay’s potential to become the leading Hydrogen player in South America.
Short-term actions:

• Work towards local hydrogen application pilot projects in sectors such as mobility and small industry.

• Kickstart 2 detailed feasibility studies on both local hydrogen production as well as on an International H2 supply chain with which answers can be found on the remainder of open questions (as stated on the following slide).

• Develop Uruguay hydrogen knowledge centers and learn from the first pilots and accelerate dissemination.

• Develop a ‘National Hydrogen Masterplan’ to align future developments and to warm up all relevant stakeholders.

• Find the right Strategic Development partners, such as but not limited to one or more European governments for pilot subsidies.
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