Offshore Wind Energy and Hydrogen Production

Review of aspects from the perspective of structural engineering.

OWT Offshore Wind Technologie GmbH
Engineering & Consultant
Hafenstr. 6c
26789 Leer – Germany
www.owt.de

Background

Hydrogen is considered as a future technology of energy storage and a new application substituting fossile sources for transport, chemistry and metallurgy. Powered by renewable energies it shall flatten the cyclic energy yield of solar and wind and increase general availability but also support mobility.

From the perspective of structural engineering it is interesting to review some of the current thoughts and expectations, especially in combination with offshore wind. The following presentation does not claim to be complete but is considered to initiate discussions.

Feel free to get in contact with us.

Question

CAN (EXISTING) OFFSHORE SUBSTRUCTURES BE USED FOR PRESSURES BASED STORAGE OF H2?

Background

Offshore steel substructures are characterized by tubulars and large wall thicknesses.

A Monopile of 8 to 9m appears to be an obvious H2 tank which could be used for storage. Jackets also provide a lot of straight tubulars.

Therefore, does it appear feasible to make use of it utilizing pressure based storage?

This following estimate by far may not cover all aspects but it shall provide the general magnitudes which lead to the relevant conclusions.

PRESSURE VS. VOLUME & STORAGE

Key values

Density of hydrogen

» $\rho.h = 0.09 kg/m^3$ at 1bar

Electrolysis production

» $E.h.m \approx 55 kWh/kg$

» $E.h.v \approx 4.9 kWh/m^3$

Turbine

» 8MW, i.e. 3.5t H2/day

» 10MW, i.e. 4.5t H2/day

Structural steel

» f.y = 335MPa*)

Structural steel, high strength

» f.y.h = 480MPa

*) not addressing a tank safety concept but doing so does not impact the conclusions

Scenarios of typical support structures for wind energy

- Monopile, with storage in main column between water level and mud line, 40m water depth.
- Four-leg Jacket with storage in vertical legs from transition piece to mud line, 40m water depth plus 20m above water level.
- External storage by cylindrical tanks of different sizes. They are located on the seabed beside the substructure and is connected by direct piping. In case of submersed, they would require massive ballasting or ground fixation.
- External storage by CFRP small tanks for high pressure in stacks at platform level.

Scenario Monopile

Monopile, storage in main column between water level and mud line, 40m water depth, current turbine sizes 8 to 12MW. Structural parameters:

» Diameter 9m

» Wall thickness 90mm

» Available length 35m

Notes: The structure is already utilized by longitudinal stresses from bending but due to its nature of perpendicular stress directions, the Mises-stress still has nearly full capacity.

Scenario Jacket

Four-leg Jacket with storage in vertical legs from transition piece to mud line, 40m water depth plus 20m above water level.

» Diameter 1.5m

» Wall thickness 40mm

» Available length 60m

» Number 4

Notes: The legs are already utilized by axial stresses from global bending but due to its nature of perpendicular stress directions, the Mises-stress still has nearly full capacity. At joints there is additionally a 3d-stress regime but joints are typical of larger wall thickness and are neglected for the purpose of this general study.

Scenario of external storage, using current fabrication capability

Storage outside by cylindrical section using current offshore structure fabrication capacilities

» Single cylindrical section, 10m diameter, 60m length, wall thickness 90mm as current available maximum monopile-like structure

» Single cylindrical section, 8m diameter, 60m length, wall thickness 90mm as current available typical monopile-like structure

» Single / Stack of cylindrical sections, 1.5m diameter, 60m length, wall thickness 40mm as current available maximum longitudinal welded pipe. Note: While the large diameter are expected to be a single unit at full length, the small diameter may be stacked in batteries and does not require the full length.

» Battery stack of CFRP tanks by current standards with each e.g. 5.6kg capacity, arranged on an outside platform in packets which allow fast pickup and exchange.

Scenario of floating wind turbine

Storage within a floating turbine floater structure

» Equivalent to 10m diameter, 300m total length, wall thickness 90mm as current available maximum monopile-like structure

Note: This scenario has some obvious restrictions. The stability of the floating structure will not allow using the full volume within the floater structure. The tubular equivalent is not conservative for classic ship hull structures, which will have less capacity for the same wall thickness. Therefore, the result represent the upper limit of what is achievable.

	Monopile	Jacket	Floater	Cylinder 10mx60m	Cylinder 8mx60m	Cylinder 1.5mx60	Stack of CFRP tanks
H2 Storage Pressure	65bar	173bar	58.5bar	58.5bar	73.1bar	173bar	700bar
Capacity	12.5t	4x1.5t = 6t	79.7t	23.9t	18.9t	4x1.5t = 6t	10.7t
Time to fill by 8MW	3.6 days	0.4 days	22.8 days	6.8 days	5.4 days	0.4 days	3 days
Weight	existing	existing	existing	1443t	1131t	87.2t	
						17 cylinders with 1482t for 6.8 days	40 packets a 4x4x3 = 1920*5

Summary

The limitation of steel strength (current smaller tanks are made from CFRP or similar) does not allow reaching high pressures which are essential for efficient H2 storage.

From structural perspective the storage of H2 in nowadays structures does not provide much capacity in terms of daily production of a current turbine size, e.g. 8MW, compared to a possible pick up interval offshore.

An external storage by nowadays cylindrical tubular section is basically an additional Monopile per turbine as storage. The capacity in terms of daily production still does not appear sufficient considering a possible pick up interval offshore.

Special summary for Monopiles

- Within Monopiles there is need to adequate cladding to protect against hydrogen brittle fracture which needs to be installed after driving together with pressure resistant caps which are also unlikely to be drivable.

- Lifting complete tanks inside a Monopile after having it driven does not provide any benefit compared to external storage. External tanks may be inspected and replaced. Loss of hydrogen does not affect the support structure and may also not accumulate inside a closed compartment.
  Connecting tanks inside the Monopiles are not easier as they are also underwater. It is not possible to drain a Monopile without any structural efforts, e.g. bottom concrete (grout) plug, which has own structural difficulties.
  Also, there is further reduction on the available storage volume due to the tank infrastructure.

Special summary Floater

A floater would have to pick up intervals less than 20 days. Considering the time for loading, travel time (e.g. 2 days) and unloading let assume that one vessel is required for 2 floating turbines. Weather downtime may cause stop of production as the pick delays after bad weather.

Imagining larger sizes of turbines, e.g. 10MW and two turbines per floater as recently proposed, the daily production may reach up to 9t of H2.

HYDROGEN BRITTLE FRACTURE

Construction steel

Steel that is currently used for fabricating offshore support structures would be subject to hydrogen brittle fracture. The nature of fatigue loading of offshore structure combines with the sensitivity of this kind of steel.

Thus, the offshore support structures may not be used without internal cladding by aluminum, stainless steel, composite or plastic.

The challenge is to provide this cladding completely and without any damages. This is difficult for a monopile which is driven with high accelerations. End caps would need to be installed afterwards which either requires adequate offshore work or the contact areas remain as potential point of failure.

Aluminum and stainless steel can cause contract corrosion if there is any seawater is contact at openings or similar.

External cylindrical tanks

In case of scenario with external tanks, internal cladding should not be a problem. They can fabricated and manufactured by current standards.

However, openings for valves and outlets will require high quality assurance as there are only limited option to revise anything offshore.

PRODUCTION VS. CAPACITY

Storage capacity

The major problem is the need for high pressure to reach adequate capacity. Although the inner volume of the steel structures in question appear large, the limitation by strength lead to relatively small capacities.

Current turbine sizes of 8MW can produce 3.5t of hydrogen per day, which requires a certain amount of storage. Offshore, a frequent pickup is difficult to realize. Vessel travel time, weather downtime and following from that also the number of vessel needed.

It requires turbine individual storage in the magnitude of the substructure itself and a transfer vessel for two or three turbines.

COST ESTIMATES

Steel cylinder, external storage

Monopile, Diameter 8m, 90mm wall thickness and 60m of length, capacity 18.9t, equals 1131t which are estimated by 3€/kg to 3.4m€ without installation.

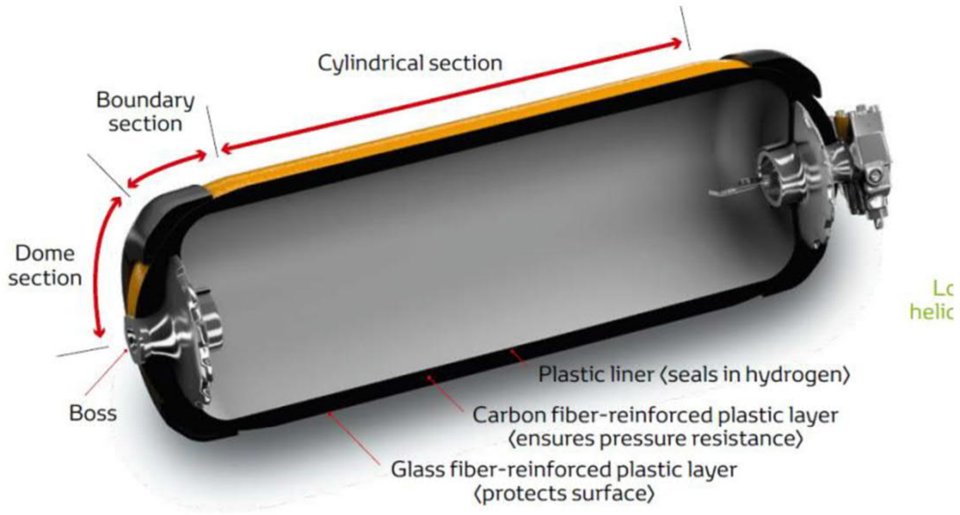
Installation would require transport, lifting in water, connection by diver in worst case. It may be estimated on a serial basis by 0.5m€ basing on 2 day working schedule with approx. 250T€/day fleet total cost.

A rough estimate may be 4m€ installed.

The major disadvantage is that picking up hydrogen would require piping and time by flow restrictions. This is estimated to require much more vessel time than packet based CFRP tanks.

Low weight, high pressure, CFRP tanks

- Tank as described in serial production with approx. 5,6kg approx. $2000 (2016),
- A daily production of 3500kg by a 8MW turbine requires 625 tanks of this type, equals 1.2m$ by this estimate
- A two-story platform around a turbine may accommodate estimated 40 packets, equals 3 days of storage, i.e. 10.5t and 3.8m$
- Advantage of the packet based system: picking up full packets by DP-vessel – fast exchange of full and empty packets.



High-pressure hydrogen tank

Nominal working pressure	70 MPa (700 bar)
Tank storage density	5.7 wt% (world top level *2)
Tank internal volume	122.4 L (front tank: 60.0 L, rear tank: 62.4 L)
Hydrogen storage mass	Approx. 5.0 kg

Figure 3. The Toyota Mirai hydrogen storage unit [14]

source: https://www.osti.gov/servlets/purl/1343975;

SUMMARY

Summary

Pressure based (gas) storage using typically offshore steel structures does not appear adequate from the following reasons:

- The storage capacity is small inside Monopile or Jacket.
- External storage comes with some larger capacity but expensive (basically and additional Monopile) for approx. 5 days capacity, which is still not convincing for adequate pick up frequency.
- Floater with on board storage of hydrogen will lack sufficient capacity, especially when needed due to large distance from shore.
- Offshore structures are fatigue loaded, therefore any damage in cladding will likely result in hydrogen brittle fracture. It requires high quality standards to minimize risk.

Possible solutions

- Direct transfer of produced hydrogen by piping with no local storage.
- Liquefied H2 (cold storage) including adequate infrastructure
- Pressureless, high capacity storage by chemical processes (requires environmental assessment and also space requirements).
- Storage by proven technology, e.g. CFRP stacked in batteries and accepting the cost associated to that.

Question 2

WHAT CAN BE SAID TODAY ABOUT INFRASTRUCTURE FOR H2 PRODUCTION IN REGARD TO STRUCTURAL INFRASTRUCTURE?

Background

H2 Production directly offshore requires structural infrastructure in terms of space and its maintenance. This competes with electrical losses in case of power transportation.

Space is required for

- Water preparation
- Electrolysis
- Preparation for transport / storage – liquification, pressuring, temporary storage, pipeline end point

SIMPLE COST ESTIMATES

Simple cost estimate

Space requirements lead to offshore structures comparable to substations. The prefered substructure up to this date are Jackets but also single and multiple Monopiles are suitable.

The provided estimates are subject to several factors, i.e. weight vs. space of H2 infrastructure and local design conditions.

For example in case of light weight H2 infrastructure, it has currently not been stressed to maximize top side areas. This may lead to lower €/m² than estimated.

Small sized, Monopile based platform

For a Monopile of a small sized platform may be estimated by:

- Monopile substructure 1000t a 3€/kg = 3m€
- Installation approx. 1m€
- Available capacity: 25x25 = 625m² at 3 storages = 1875m²

This equals for approx. 2133€/m² for an installed substructure. The infrastructure for the topside needs to be accounted additionally.

Medium sized, jacket based platform

For a Jacket of a medium sized platform may be estimated by:

» Jacket substructure 1000t a 7€/kg = 7m€

» Installation approx. 3m€

» Available capacity: 30x30 = 900m² at 4 storages = 3600m²

This equals for approx. 2700€/m² for an installed substructure. The infrastructure for the topside needs to be accounted additionally.

Large sized, Jacket based platforms

For a Jacket of a large sized platform may be estimated by:

» Jacket substructure 7000t a 6€/kg = 42m€

» Installation approx. 15m€

» Available capacity: 80x50 = 4000m² at 5 storages = 20000m²

This equals for approx. 2850€/m² for an installed substructure. The infrastructure for the topside needs to be accounted additionally.

Large sized, Monopile based platforms

For multiple Monopiles supporting a large sized platform may be estimated by:

» Monopile substructure 8x1000 = 8000t a 3€/kg = 24m€

» Installation approx. 10m€

» Available capacity: 80x50 = 4000m² at 5 storages = 20000m²

This equals for approx. 1700€/m² for an installed substructure. The infrastructure for the topside needs to be accounted additionally.

Large sized, Monopile based platforms, maximum area

For multiple Monopiles supporting a large sized platform may be estimated by:

» Monopile substructure 8x1000 = 8000t a 3€/kg = 24m€

» Installation approx. 10m€

» Available capacity: 100x80 = 8000m² at 7 storages = 56000m²

This equals for approx. 610€/m² for an installed substructure. The infrastructure for the topside needs to be accounted additionally. In this scenario the topside has an increased impact to the total cost/m².

PERSPECTIVE

Perspective

To provide the growing H2-industry with better estimates it is necessary to conceptually design offshore structures, consisting of substructures and topside. This shall allow to consider adequate infrastructural costs for H2-cost modells.

To achieve this, it is necessary to determine space and weight for electrolyse, pressuring, water preparation, storage (?). This allows to layout the topside and to design suitable substructures with subsequent cost estimate.

It appears favourable to use Monopile-based platforms as they are less expensive and significantly easier in service in maintenance.

Question 2

SUMMARY

Summary

This presentation provides thoughts on two subjects:

- » Pressure based storage in offshore wind substructures does not appear feasible due to several reasons.
- » H2-infrastructure offshore is missing adequate public cost estimates due to missing public conceptual designs. These are necessary to decide for central or distributed H2-production offshore or onshore.

Feel free to get in contact with us.

OWT Offshore Wind Technologie GmbH
Hafenstr. 6c
26789 Leer - Germany
Tel. +49 (0) 491 912 18 0
www.owt.de