Final report

1. Project details

Project title	De-carbonization of Oil & Gas Production by cost effective Floating renewable Technologies
File no.	J.nr. 64019-0833
Name of the funding scheme	EUDP særpulje (Forskning i miljøvenlig og energieffektiv produktion af olie og gas)
Project managing company / institution	Floating Power Plant A/S (FPP)
CVR number (central business register)	28143893
Project partners	Semco maritime A/S Aalborg university Cefront Technology AS (Norway) APL Norway AS (Norway) Lundin Norway AS (Norway – Selffunded)
Submission date	13 December 2020

2. Summary

Describe the objectives of the project, the obtained results and how they will be utilized in the future.

2.1 English version

The objective was “to develop solutions for combining renewable energy with the extraction of oil and gas (O&G), that are cost effective and support the reduction of carbon emissions”

This has been pursued by adapting Floating Power Plant’s (FPP) combined wind and wave platform for use in the offshore O&G sector. This is focused at real client requirements and a different rules set than in the renewable energy market.

The project has been run in 2 phases, a concept phase and a FEED phase. The first phase has developed 3 different conceptual solutions for FPPs technology integration into the O&G sector.

1) Direct Power – supplying an O&G platform with renewable power.

2) Baseload power – Supplying the O&G platform or subsea application with baseload power using local backup on the FPP platform(s).

3) Enhanced Oil Recovery (EOR) – Injecting water into an oil reservoir to increase production. Instead of placing the EoR equipment on the O&G platform far from the injection point, this is placed on FPPs platform and water is injected directly into the reservoir - thus reducing costs.

The “direct power” concept was selected for a Front End Engineering Design (FEED) process. Here the concept was progressed, e.g.

- Updating of platform configuration
- Updating of numerical models
- Detailing rules and certification requirements
- Adapting the O&M concept
- Development of business concept
- Wave basin validation of design

All 3 concepts have both technical and financial merit and are being progressed towards commercialisation. Each concept also has constraints to be overcome. E.g. finding a better backup source than diesel generator, increasing reliability of EoR equipment, reducing CAPEX.

The cost effectiveness is very case dependent. The designs have been targeted at O&G platforms in Norway in Lundins portfolio, but the project results have a broad applicability for O&G sites in other parts of the world, validated by the O&G advisory board associated with the project.

2.2 Danish version

Projektformålet var ”at udvikle løsninger der kombinerede vedvarende energi med udvindingen af kulbrinter, på en kost effektiv måde, for at understøtte deduktionen af CO_2 udledning”

Dette har projektet forfulgt ved at tilpasse Floating Power Plants (FPP) kombinerede vind og bølgeenergi platform til brug i Olie og Gas (O&G) sektoren. Dette fokuseret på reelle kundekrav og et andet regelsæt end i det normale vedvarende energi marked.

Projektet har været opdelt i to faser, en koncept fase og en såkaldt FEED fase. I konceptfasen blev der udviklet tre forskellige koncepter for integrationen ind i O&G markedet.

1) Direkte energi – forsyning af en O&G platform med vedvarende energi
2) Grundlast energi – forsyning af O&G platforme eller subsea udstyr med grundlastenergi ved at bruge lokal backup på FPPs platforme.
3) Forbedret olie udnyttelse (EOR) – Injektion af vand ind i et oliereservoir for at øge produktionen. I stedet for a placere EoR udstyret på O&G platformen langt fra injektionspunktet, er det placeret på FPPs platform og vandet injiceres direkte ind i reservoiret - derved reduceres omkostningerne.

Direkte energi konceptet blev udvalgt til et ”Front End Engineering Design” (FEED). Her blev konceptet udviklet yderligere ved f.eks.:

- Opdatering platform konfiguration
- Opdatering af beregningsmodeller
- Detaljering af love og regler
- Udvikling af koncept for drift og vedligehold
- Udvikling af forretningskoncept

- Validering af designet i et bølgebassin

Alle 3 koncepter har såvel teknisk som finansiel merit og er under yderligere udvikling og kommercialisering. Hvert koncept har udfordringer som skal forbedres, f.eks. at finde en bedre backup teknologi, at øge pålideligheden af EoR systemet, reducere CAPEX.

Forretningscasen er meget site specifik. Designene i dette projekt har været mod O&G platforme i Norge i Lunding portefølje. Men resultaterne har meget bred anvendelighed for O&G sites andre steder i verden, valideret via O&G advisory boardet tilknyttet projektet.

Project objectives

The primary project objective was to develop FPP's floating wind and wave hybrid technology to make it suitable for applications in powering offshore oil and gas assets, helping decarbonise the production of oil and gas in a cost effective way.

The objective were pursued in 2 main phases. First, several potential applications in the O&G industry were assessed, with a generic high level design for FPP's technology developed to meet the requirements and rules of three different use cases, includes business case models

- INTERMITTENT DIRECT POWER
- Enhanced Oil Recovery (EOR) INJECTION
- BASE LOAD POWER

The second phase was a client driven design for a real operational asset provided by Lundin (Norwegian operator). For this phase, Lundin chose the Intermittent direct power use case. A full Front End Engineering Design (FEED) study with development of a suitable technology solution and plan a project for implementation.

In practical terms the objectives were to advance the Technology Readiness Level (TRL) of the combined technology and develop the business case for its use in order to allow a pilot project to be developed while minimising risk to the end users (O&G Operators).

A secondary project objective, was to implement the learnings/design from this O&G application design process into FPP's utility market design.

Figure 1 FPPs P80 platform at an O&G site powering the platform in the background

3. Project implementation

In the project application it was described that three different concepts would be developed in the concept phase of the project:

- Production Support Power
- Enhanced Oil Recovery
- Service/Decom

However, in the beginning of the project based on input form the client (Lundin) and the O&G advisory board (Equinor, Aker BP, DHRTC, Maersk Decon, ECD, Sealand, OGTC) it was decided to change the naming and scope of the concept to:

- INTERMITTENT DIRECT POWER
- Enhanced Oil Recovery (EOR) INJECTION
- BASE LOAD POWER

The scope of the first two are essentially unchanged. The third concept was changed from powering service and decommissioning activities to providing baseload like power, which is a conceptually similar concept but more generic and more relevant to the O&G market in the short term. EUDP approved this change.

The Project has largely progressed according to the project plan. Smaller delays in deliveries have been handled and worked around within the work-packages and have not caused any major problems.

The integration of Lundin as end client in combination with the O&G advisory board has been a significant strength in this project, as the implementation has been very focused on real requirements and needs, with market developments emerging during the project being integrated into the development of the design.

The outbreak of Covid-19 during the project has significantly reduced the foreseen travel activity for internal meetings and conference participation. This situation has largely been delt with by rearranging meetings at virtual meetings and the project was extended (approved by EUDP) till end November.

The project has been implemented by partners:

- Floating power plant
- Semco maritime A/S
- Aalborg university
- Cefront Technology AS (Norway)
- APL Norway AS (Norway)
- Lundin Norway AS (Norway – Selffunded)

The project has been supported by O&G advisory board:

- Equinor
- Aker BP
- OGTC
- DHRTC
- Sealand Project
  Lars bank (Maersk Decom)
  Energy Cluster Denmark (previously EIC)

4. Project results

4.1 Concept phase

4.1.1 Generic design work and requirements

The different use cases in the project have a lot of common components, requirements and other design drivers. These common topics have been addressed in generic design specifications and resulting in generic designs of the FPP platform and generic subsystems:

- Identification of design and operational rules ling to the O&G integration (led by DNV-GL)
- Identification of key client requirements (led by FPP with input from Lundin and the O&G advisory board)
- Generic platform design / geometry
    - Platform geometry
    - Numerical model(s)
    - General arrangement / outfitting
    - Ballast system
    - Safety systems
- Power systems

- Wave energy converters
- Wind turbine
- Electrical power distribution
- Backup systems

- Mooring and cable concept

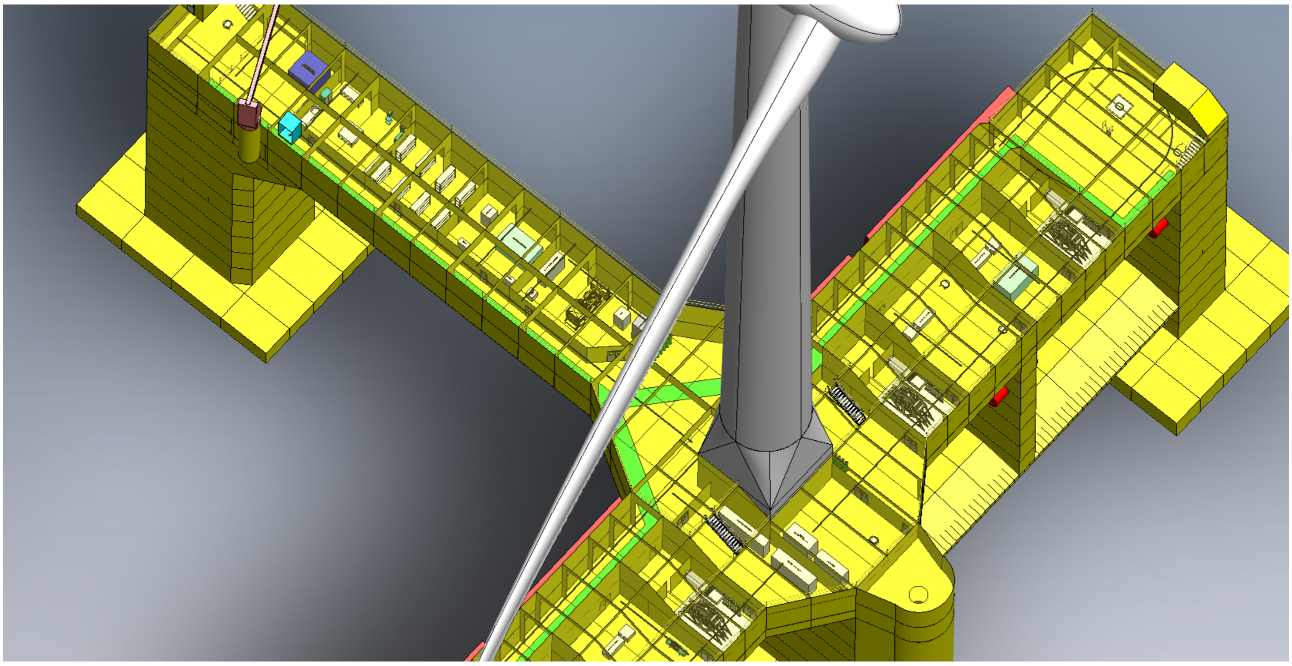


Figure 2 Generic P80 platform design with top deck removed - showing placement of Wave PTO, switch boards, backup generator, spare part storage etc.

4.1.2 Direct intermittent power

The direct intermittent power use case can be defined as "delivering as much power to an O&G platform as possible, when renewable power is available". An FPP platform or an array of FPPs platforms would typically operate in parallel with existing gas turbine generators on the O&G platform. I.e. supplying an O&G platform with a typical demand of 45 MW from an array of 4 P80 Platforms can deliver all of the required power when wind and wave energy is plentiful. In situations where the available wind and wave resource cannot satisfy the demand the existing gas turbine generator will supply the missing energy. This solution can reduce the fossil fuel based energy used by more than 60%.

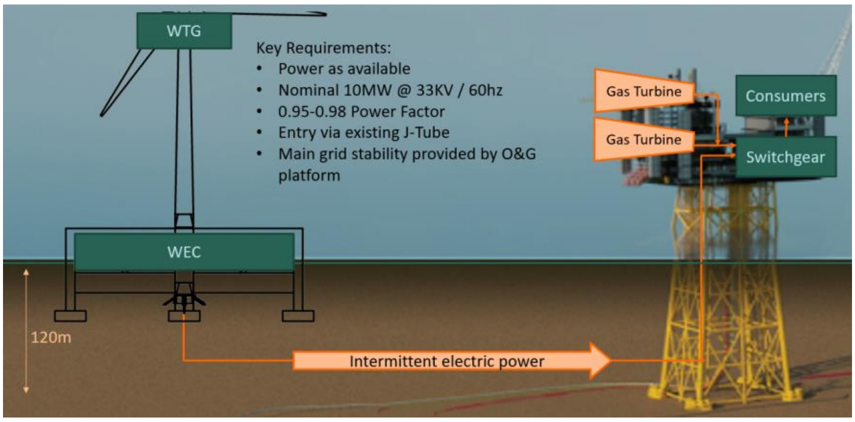


Figure 3 Principle drawing of direct intermittent power and the key requirements – the intermittent renewable energy is backed up by existing gas turbine generators on the O&G platform

The direct intermittent use case requires no changes to the generic design.

The power production distribution over a year is given below in figure 4 and

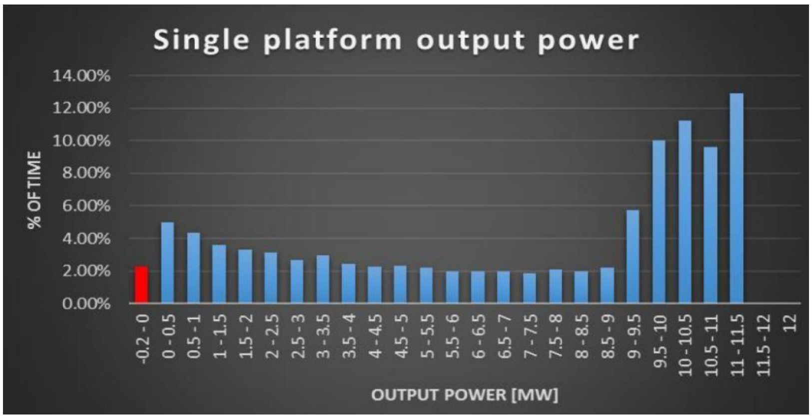


Figure 4: Power distribution over a year

Value	Single unit	Unit
Annual energy delivered to topside	61.0	GWh
Uptime (active power > 0 MW). Excluding down time due to O&M	97.7	%
Max power time (active power >= 10 MW)	33.7	%
Effective capacity factor	60.6	%
Annual energy delivered from topside to P80 (backup)	0.02	GWh

Figure 5: Overview of power production against key requirements. Please note Effective CF only illustrates used power as percentage of total maximum possible generated

4.1.3 EOR

The EOR use case can be summarized as "providing electricity for sea water treatment and injection into an oil reservoir, with a minimum guaranteed "standby power". This EoR system can either be place sub sea or on the P80 platform.

EOR is the process of injecting water into a reservoir as hydrocarbons are extracted to keep up the pressure and hence improve the yield. The injected water is typically sea water that is extensively purified to avoid the water interfering with the chemistry or biology in the reservoir.

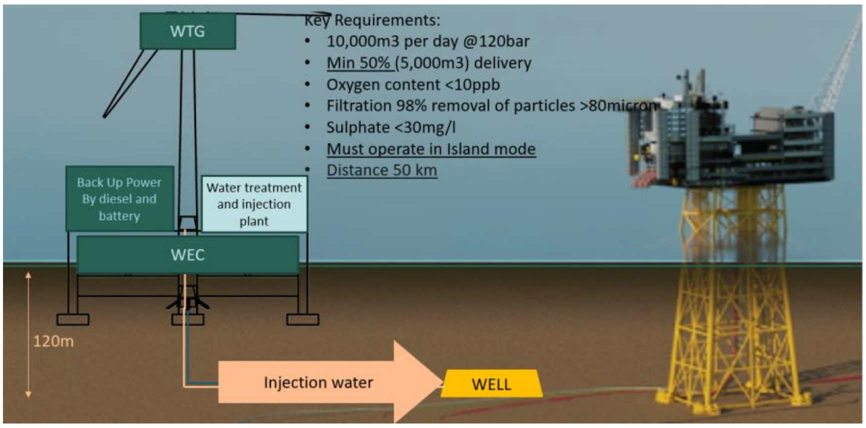


Figure 6 Principle drawing of EOR incl. key requirements - P80 delivering power for water injection backed up by local diesel generators and acting as a host for equipment

It is most often not necessary to uphold a constant injection flowrate, this means that the application is very well suited for intermittent renewable energy, as the injection flowrate can be reduced when less power is available. However, there is typically a significant minimum power requirement specially to keep the water treatment equipment in a standby mode. Here the large indoor volume of the P80 platform can be used for backup power. In this project diesel powered generators were chosen for backup, but another FPP project is looking at using hydrogen produced from excess renewable energy as backup.

Two different concepts were examined

- EOR equipment subsea powered by an umbilical from P80
- EOR equipment on P80, with an additional deck added to P80

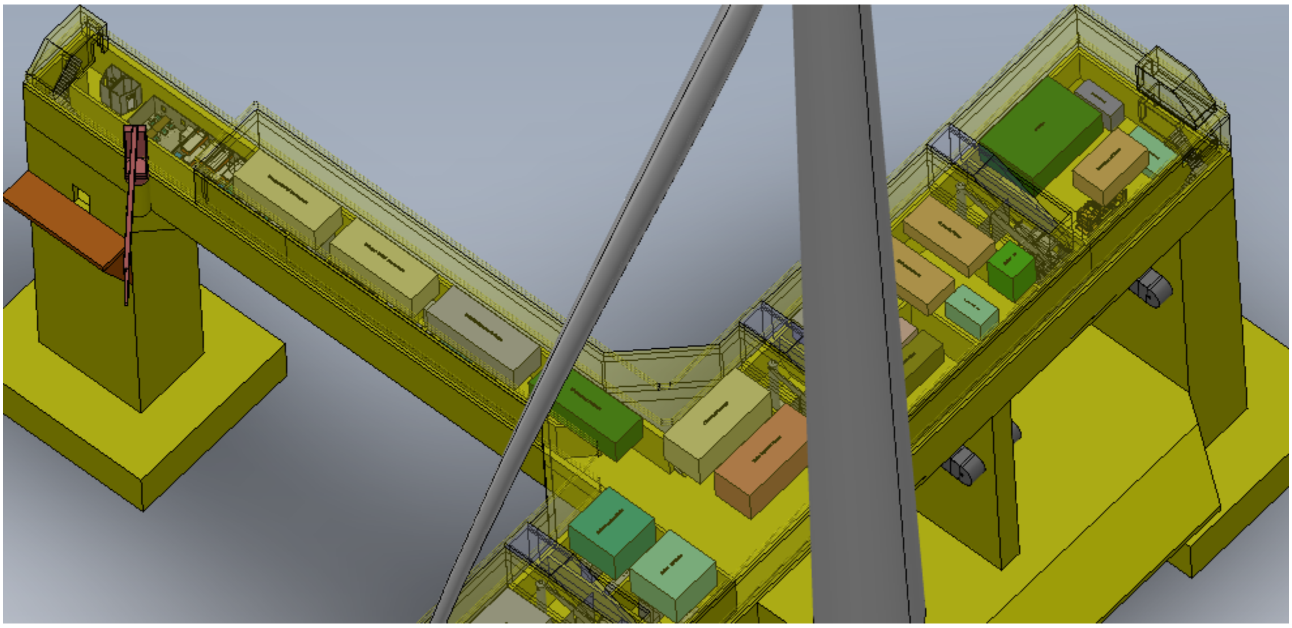


Figure 7 P80 version with an additional deck for process and pump equipment added on top of existing main deck

Through simulation it was found that the concept of powering an EoR solution with renewable and diesel backup is entirely possible. This includes visits to the platform for refuelling and maintenance of diesel generators.

With Support from NOV Fjord and Vulkan Engineering a concept for injecting 10.000 m3 process water per day was established – with a minimum injection of 5000 m3 always provided.

The Power need for the EOR plant housed on board the FPP platform are:

- 3,5 MW Power demand for all systems (10.000 m3/day rate)
- 2,4 MW Power demand for all systems (5.000 m3 /day rate)

This will require the following backup production from diesel gensets on the FPP platform.

Value	Platform equip.	Unit
Annual running hours / generator	953	Hours
Maximum running hours before service	1,247	Hours
Annual diesel consumption (total)	394,606	Litres
Max. consumption between tanking stops (per platform)	529,857	Litres

Figure 8: Overview of backup needed to secure EoR injection requirements

4.1.4 Baseload power

The Purpose of the baseload power use case is to “provide a stable (more stable) power source that can follow the demand from an O&G asset” – top side or subsea. This includes either, storing excess wind and wave energy when the production exceed demand, and deliver the stored energy when it is needed; or backing up the wind and wave energy with a controllable energy source running on an imported fuel.

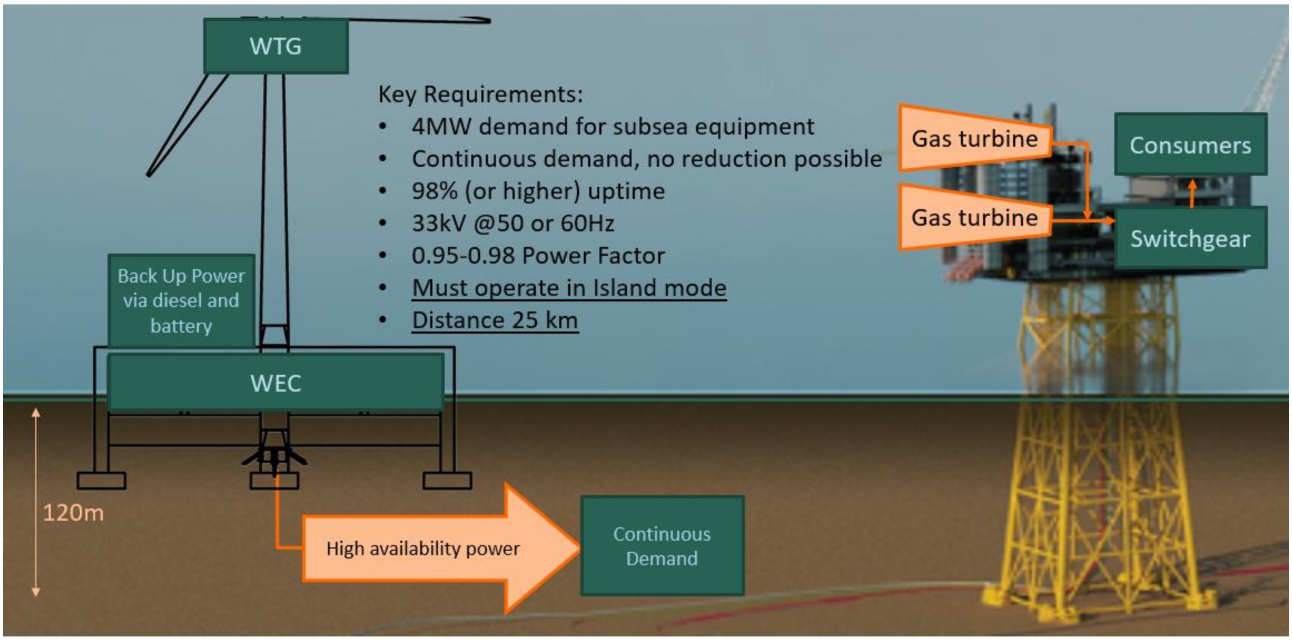


Figure 9: One of the baseload power concepts and key requirements.

In the beginning of the concept phase a screening were conducted to assess the feasibility of using battery energy storage as backup. The screening concluded that a battery solution is not feasible. Providing just 12 hours of backup time would require a battery system the size of the largest grid scale battery backup system in operation and weigh several thousand tons. Therefore, it was selected to use diesel generators onboard the P80 platform for backup in this project. Due to the high energy density of diesel this is highly feasible with a reasonably sized tank capacity (500m^3) and up to 3 annual visits for refuelling and service of diesel generators that must be services every 500-1000 hours of running. In theory the diesel motors could run on a bio or synthetic fuel as these become more available, providing a greener solution.

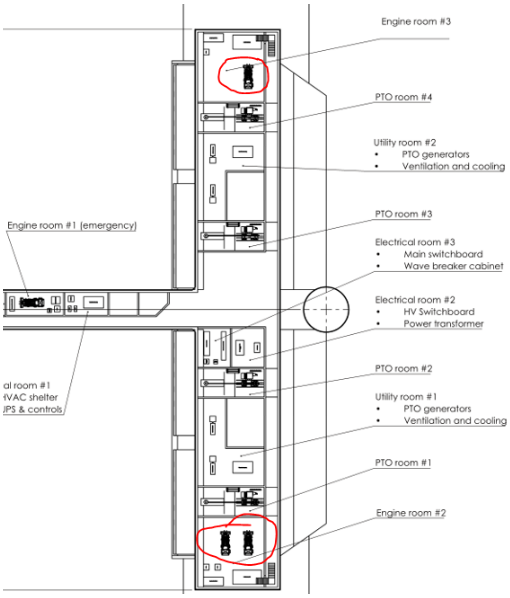


Figure 10 GA drawing of P80 Main deck with room for additional diesel generators for Baseload power

To provide 4 MW baseload power for e.g. an subsea booster pump, the following backup consumption is needed.

Value	1 P80	Unit
Annual running hours / generator	1,598	Hours
Maximum running hours before service	890	Hours
Annual diesel consumption (total)	1,782,026	l
Max. consumption between tanking stops (per platform)	1,001,209	l

Figure 11_ Backup need to secure 4 MW subsea baseload

4.1.5 Concept phase conclusion

The Concept phase work were summarized into two report – a technical and a business report. Based on these two reports Lundin and the O&G advisory board decided to go forward with a Light FEED for the Direct intermittent power concept.

4.2 FEED phase

Below a summary of the FEED work is given.

4.2.1 Platform design optimizations

A number of optimizations were med to the platform

- Platform configuration
- Designed for extreme significant wave height of 14.6m (50 yr return period at site)
- Access to top deck via work-to-work system
- Addition of deck crane and bunkering posts on top deck
- Reduced stress concentrations in main structure
- Simpler box modules for panel line manufacturing
- WTG position changed for yaw stability based on met-ocean pack
- WEC geometry optimized
- “streamlining” of top deck
- Better designed access ways (escape ways)

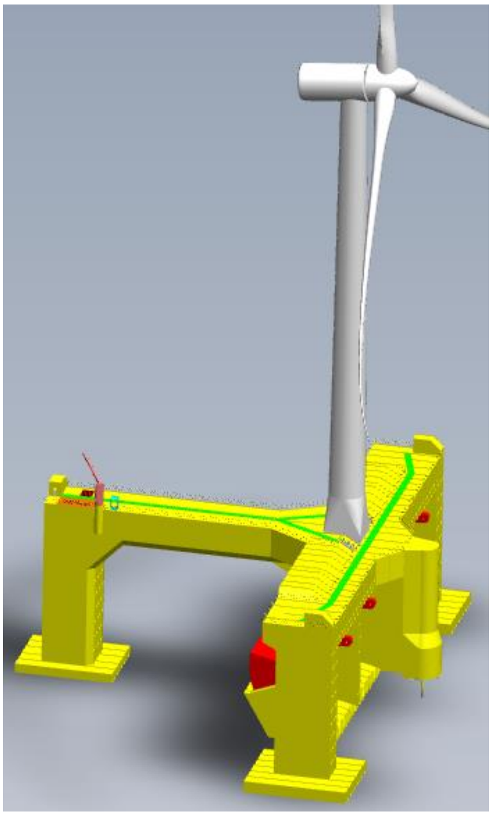


Figure 12 Final design of P80 platform for the direct intermittent power concept

4.2.2 Design validation and demonstration

To validate the finished design of the P80 platform ad to prove the feasibility of the concept towards the industry and potential customers a sophisticated model of the P80 platform were constructed and tested in the wave basin at Aalborg university.

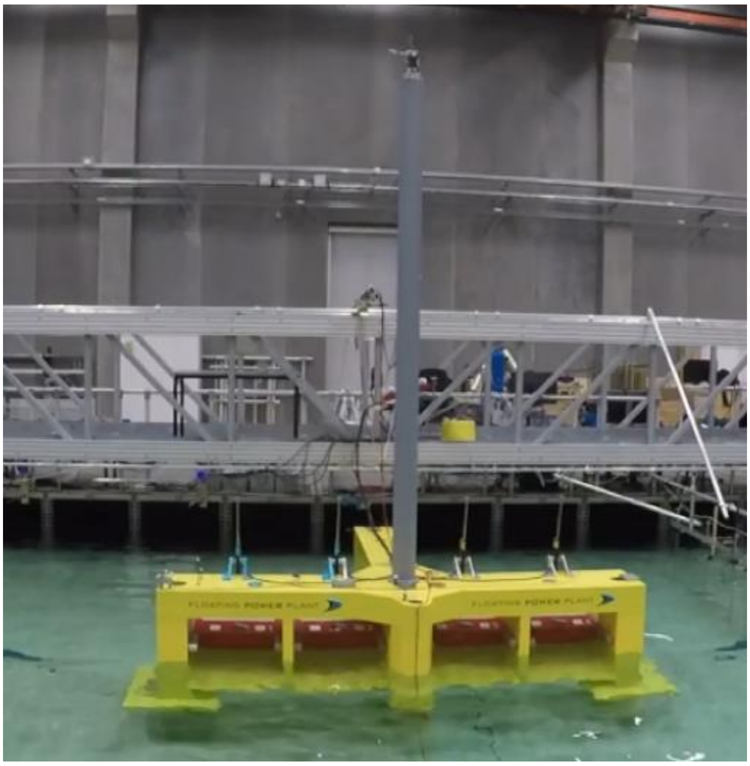


Figure 13 1:30 scale model of the P80 platform in the wave basin at AAU

Compared to previous tests the tests and test model build were very complex and designed to show the behavior of the entire system

- Large model 1:30 for better accuracy
- Complete platform floating model
- Three chain emulated mooring system with springs
- Accurate platform geometry
- Accurate ballasting, mass and inertia properties
- Four working wave absorbers with active PTO system extracting wave power
- Simulated full scale wind turbine, wind trust feedback simulated by Realtime model controlled fan

Apart from the basin testing providing a massive amount of data for numerical model validation, an extensive demonstration program was executed.

Originally it was planned to host physical visits to the basin testing for partners, clients, potential customers and other stakeholders. Due to the outbreak of Covid-19 it became evident that the physical presence would be significantly hindered. It was therefore decided to set up a remote visit concept, where a combination of presentation and web cast of live demonstration could create the sensation of physical presence. This concept worked very well and FPP have had very good feed back from the more than 200 people that visited the tests either virtually or physically - including several O&G operators.

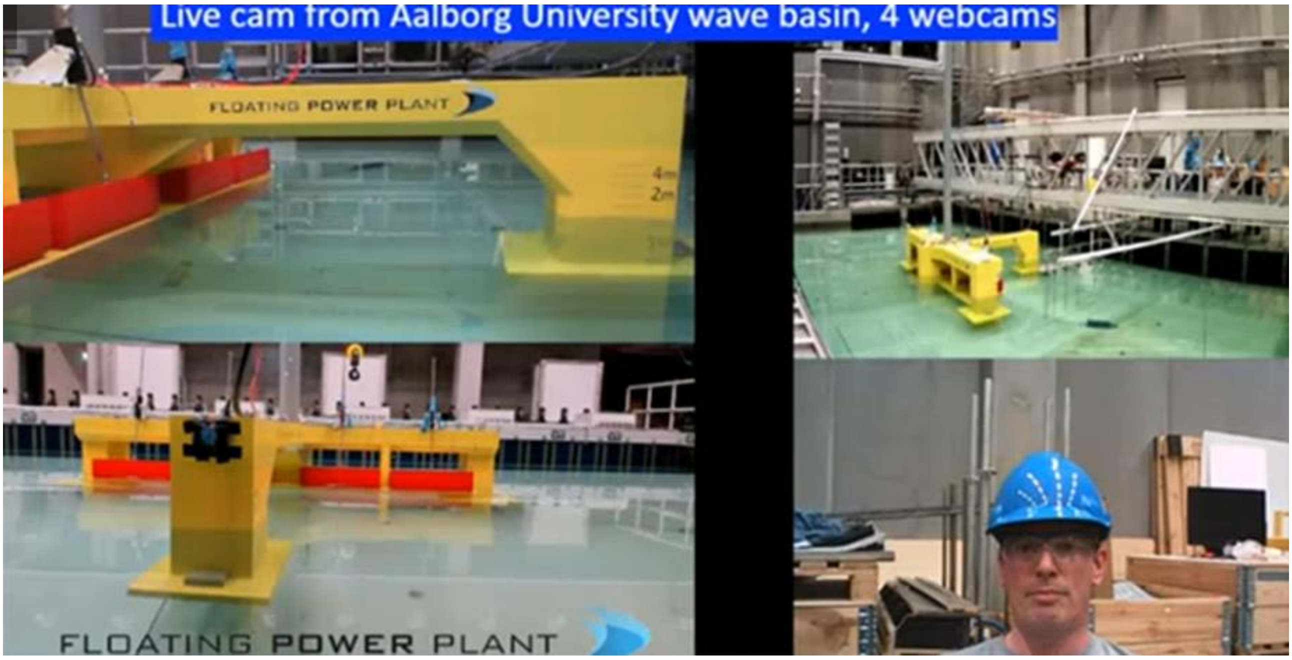


Figure 14 Screen grab of FPPs Morten Kramer demonstrating the P80 testing at one of the webcasts

In the O&G market the integration of other power sources in usually assessed via the CO_2 ”abatemet cost”. This means the cost of reducing the CO_2 emission compared to current the operational setup. This is very dependent on:

- Internal gas price
- CO2 tax
- Capex (10 MW wind and 2 MW wave)

Below a simple illustration is made for a single platform integrated into an O&G platform. The small flags indicate the current level of gas and CO2 tax in respective countries. The calculation is made for the first O&G wind + wave O&G design ever build.

Abatement Cost Single Unit				
		Average CO2 Tax (€/scm gas)		
		Low	Med	High
Average	Low	€ 75	€ 48	€ 20
Gas Price	Med	€ 59	€ 31	€ 4
(€/MBTU)	High	€ 32	€ 4	-€ 23

Figure 15: Abatement cost matrix with sensitivity shown towards CO2 tax and internal gas price for first unit ever build

Just expanding to a small array of 4 platforms significantly improves the business case. When in series production and integrating 12-15 MW turbines and increasing to 3 MW wave, makes all cases positive.

Abatement Cost 4 Units				
		Average CO2 Tax (€/scm gas)		
		Low	Med	High
Average	Low	€ 50	€ 23	-€ 5
Gas Price	Med	€ 34	€ 6	-€ 21
(€/MBTU)	High	€ 7	-€ 21	-€ 48

Figure 16: Abatement cost matrix with sensitivity shown towards CO2 tax and internal gas price for 4 units

5. Utilisation of project results

The project has provided the partners with a very good core design to for the rapidly growing O&G market segment. Based on the findings and models developed in the project FPP and partners are is in dialogue with several O&G operators on different opportunities for using FPPs platforms. During the project e.g. FPP has conducted over 10 site / project assessments or light screenings for potential O&G clients.

The project results have not generated turnover yet.

The project results are being taken forward as concepts as a whole and as individual components. E.g.

- All 3 concepts are being further developed by FPP and partners, see below
- FPP is using the results in its design for renewable energy market targeted large array deployments
- APL NOV is using the learnings towards of floating renewables devices
- Semco is using the learnings towards its O&G and renewable clients
- AAU is using the results in further research
- Lundin is using the results in assessing how electrification of further assets can be done most cost effectively
- Cefront is using the knowledge for designs in other offshore sectors

In parallel with this project FPP have conducted a project with Total Denmark co-funded by EUs regional fund. The Total Denmark project has, to a large extent, drawn on work from this project, building on top of it. The main idea of the Total project is to add hydrogen production and storage to the P80 platform to avoid the need for diesel generator as backup. This solution is a valuable addition to the concepts developed in this project as it adds a greener profile to the concept and shows a way towards a renewable transformation of the O&G industry. In a future where the O&G production is declining, excess capacity on an FPP platform with hydrogen production equipment can be used to produce hydrogen that can be blended into the natural gas network making it greener.

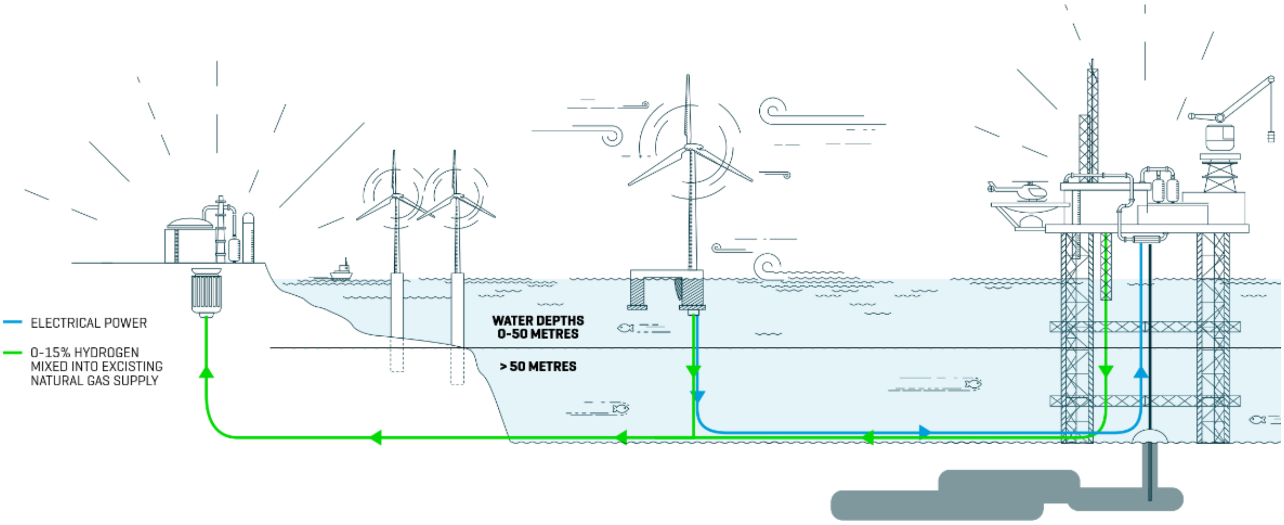


Figure 17 Principle illustration of a P80 with hydrogen backup powering an O&G platform and exporting excess energy as hydrogen

All 3 concepts are being taken forward towards commercialisation as illustrated in the figure 18 below

Concept/ Design	Status	Key Challenge	Next steps	Main opportunities / markets
Intermittent power	Design taken to light FEED	- Get real operational data - Get into volume production - Reduce LCOE - Rules	- Demonstration in Spain - FLW pipeline with clients	- FLW utility scale projects - Simpler O&G electrification projects in energetic areas
EoR	Design iteration ongoing with NOV Fjord	Potentially very good business case, but reliability needs improved significantly to match renewable O&M schedule	FPP in search of Client to progress	- Older assets, e.g .UK - New tie backs
Baseload power	Design being progressed in several contexts - but with hydrogen. **- Key project with Total and Technip FMC**	- "Wrong story" - Lower CO2 reduction - bunkering	- Commercial design contracts - In dialog with several operators globally - Hydrogen integration into FPPs project in spain	Power-2-x for - O&G assets - Remote Island power by diesel - Fish farming - Hydrogen export - Etc.

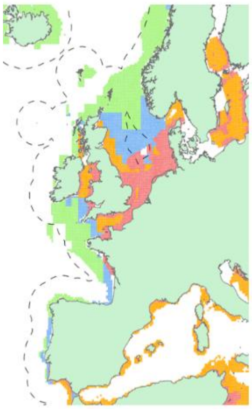
Figure 18 Concept overview and next steps to towards commercialization.

Electrification of O&G operation is a rapidly growing market. This driven by:

- Climate / ESG agenda. CO2 emissions from O&G productions are substantial, e.g. 28% of Norway's CO2 total CO2 Emissions come from the extraction of O&G. This is 2-3% in Denmark.
- Cost. Renewables are coming rapidly down in cost and can reduce the cost of operation, making the O&G cost cheaper. With expected implementation of further C02 taxes, this will only increase.
- Transformation agenda. Most O&G companies are in a transition process towards other energy markets -electrification is a first key step.

The main competitors to the concepts develop in this project are other floating wind technologies. Most O&G assets are in deeper waters. The concepts developed in this project are expected to be very competitive in:

- The energetic market (lots of wind and wave). Indicated by the green and blue colours on the map.
- For assets needing a better power quality which seem the looks to be a significant market pull fore.
- For distributed fields with several tie backs



6. Project conclusion and perspective

The key conclusion from this project is that all 3 project concepts has a commercial future when certain barriers has been overcome. Below is a table form the next steps for each concept:

Concept/ Design	Status	Key Challenge	Next steps	Main opportunities / markets
Intermittent power	Design taken to light FEED	- Get real operational data - Get into volume production - Reduce LCOE - Rules	- Demonstration in Spain - FLW pipeline with clients	- FLW utility scale projects - Simpler O&G electrification projects in energetic areas
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Figure 19 Concept overview and next steps to towards commercialization.

The Results are already playing a key role in both FPPs project in the Floating wind and O&G markets and for each partner individually in FPP projects.

7. Appendices

- The **Confidential** technical and business concept reports from both the concept phase and FEED phase can be provide to the EUDP project if requested
- Homepage http://www.floatingpowerplant.com/publicly-funded-projects/
- Article examples
  - https://www.energy-supply.dk/article/view/752442/dansk_vind_og_bolgekon-cept_bruger_oliegasbranchen_som_traedesten
  - https://www.energy-supply.dk/article/view/706836/flydende_vind_og_bolgeen-ergi_skal_gore_olie_og_gassektoren_gronnere

- Conference presented e.g.
  - Renewable UK / Scottish Renewables Floating Offshore Wind 2020
  - Executive MBA O&G and Renewables Industry Presentation – Fundação Dom Cabral
  - Deepwind Members Presentations – Floating Offshore Wind
  - Lundin Industry Suppliers Day