(source: Synthetex)

FLASC
Renewable Energy Storage

Technology Presentation
Open-Gas Cycle

www.offshoreenergystorage.com
FLASC B.V., Paardenmarkt 1, 2611 PA Delft, The Netherlands

Non-Confidential
November 2024

FLASC: Summary

FLASC is addressing supply–demand mismatch for offshore wind

The **latest Open-Gas-Cycle** technology brings 10-30% of additional revenue to offshore wind farms

Cost-competitive with the cheapest land-based storage

Working with the world's leading wind developers and delivery partners

FLASC solution is prototyped, patented and received a statement of feasibility from DNV

European Innovation Council

- Supported by the EU's most prestigious funding scheme for disruptive high-impact innovation

- **Seeking partners to support upcoming bids for IJmuiden Ver Gamma (Plots A& B)**

The Problem

Supply-Demand mismatch is increasing with more installed offshore wind

- Offshore wind generation is intermittent and can only be used **when** there is immediate energy demand.
- When the onshore grid is constrained, offshore power cannot be delivered **where** it is needed and ends up being wasted.

- **Client-Specific Pain Points**

Offshore Wind Developers

End Client

- **Decreasing offshore wind profitability**
- **Limiting future wind farm deployments**
- **Compromising clean energy transition**

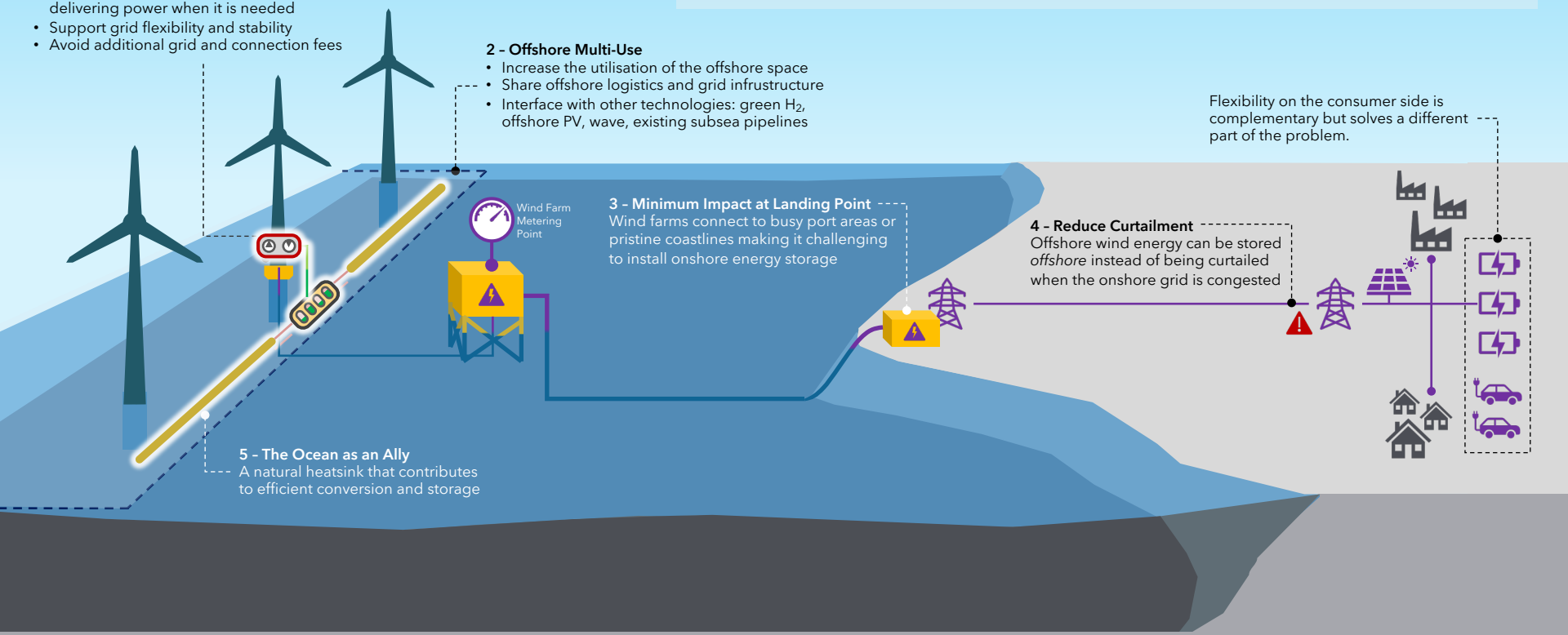
*"The cost of matching UK electricity supply and demand in 2022 **surpassed £4 billion**, tripling since 2019 due to shrinking baseload and rising grid instability" – UK, NIA*

FLASC Delivers an Offshore Energy Storage Solution

▶ Store Energy **where** it is produced ▶ Deliver it **when** needed

1 – Behind-the-Meter Optimisation
- Increase value of the wind farm output by delivering power when it is needed
- Support grid flexibility and stability
- Avoid additional grid and connection fees

2 – Offshore Multi-Use
- Increase the utilisation of the offshore space
- Share offshore logistics and grid infrastructure
- Interface with other technologies: green H_2, offshore PV, wave, existing subsea pipelines



3 – Minimum Impact at Landing Point
Wind farms connect to busy port areas or pristine coastlines making it challenging to install onshore energy storage

4 – Reduce Curtailment
Offshore wind energy can be stored *offshore* instead of being curtailed when the onshore grid is congested

Flexibility on the consumer side is complementary but solves a different part of the problem.

5 – The Ocean as an Ally
A natural heatsink that contributes to efficient conversion and storage

The Technology: Open-Gas Cycle HPES

FLASC is the first utility-scale energy storage solution tailored for co-location in offshore wind farms.

It enables wind developers to store energy **where** it is produced and deliver it **when** needed, improving the wind farm economics.

Pneumatic Pre-Charging:

- Minimises fatigue and increases energy density resulting in a Levelised Cost of Storage **competitive with onshore systems**

The Ocean as a Natural Heatsink:

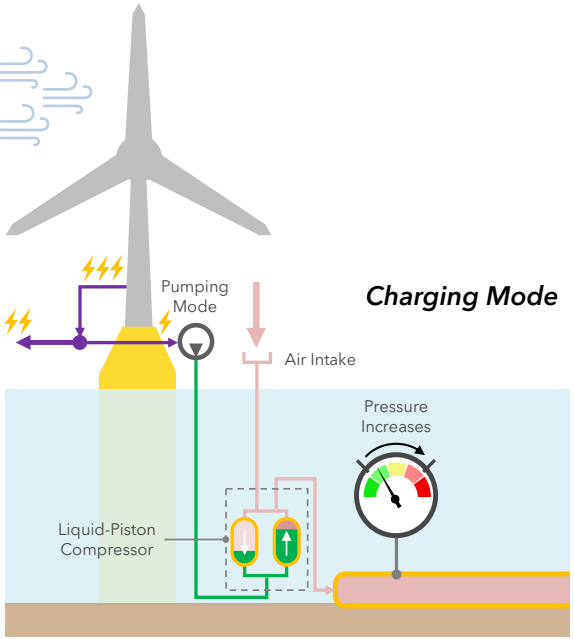
- Enables an isothermal process with **70-75% round-trip efficiency** without complex thermal storage or heat exchangers

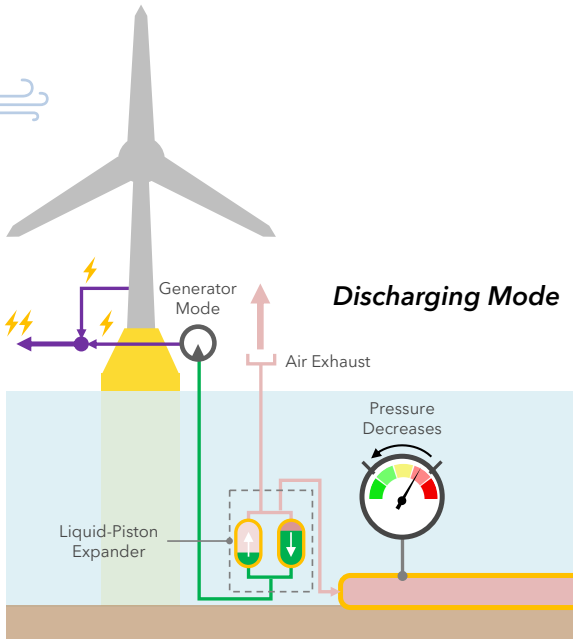
The **Open-Gas Cycle** technology embodies the latest developments in **performance** and **energy density**

- ***Charging Mode***: A motor and hydraulic pump drive a reciprocating liquid piston array to compress air into a pre-charged container
- ***Discharging Mode***: The air expands through the reciprocating liquid pistons which drive the hydraulic system in reverse to produce electricity

Key Technical Advantages:

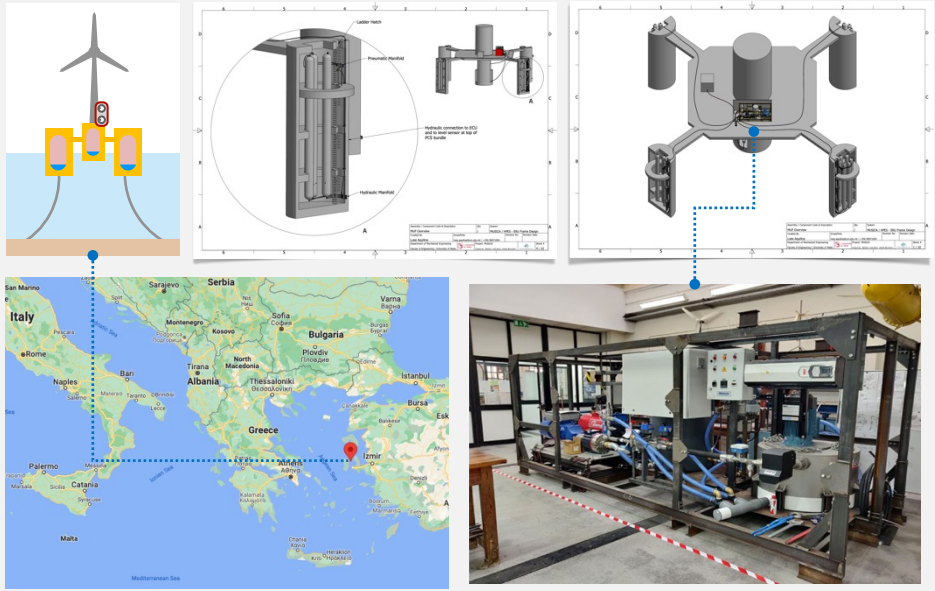
1. No seawater inside the system
2. Significantly increased energy density
3. Use of efficient positive-displacement pumps





Built on Proven Innovation

- Demonstration projects already using the **FLASC Liquid-Piston Technology**



▲ Proof-of-Concept Prototype (2017-19)

Grand Harbour, Malta

- Validating the liquid-piston technology and use of the ocean as a natural heatsink to achieve an isothermal process.
- Isothermal Efficiency of 96% achieved across 15 months of marine testing.[1]

▲ Floating Wind Demo (2020-25)

Oinousses, Greece

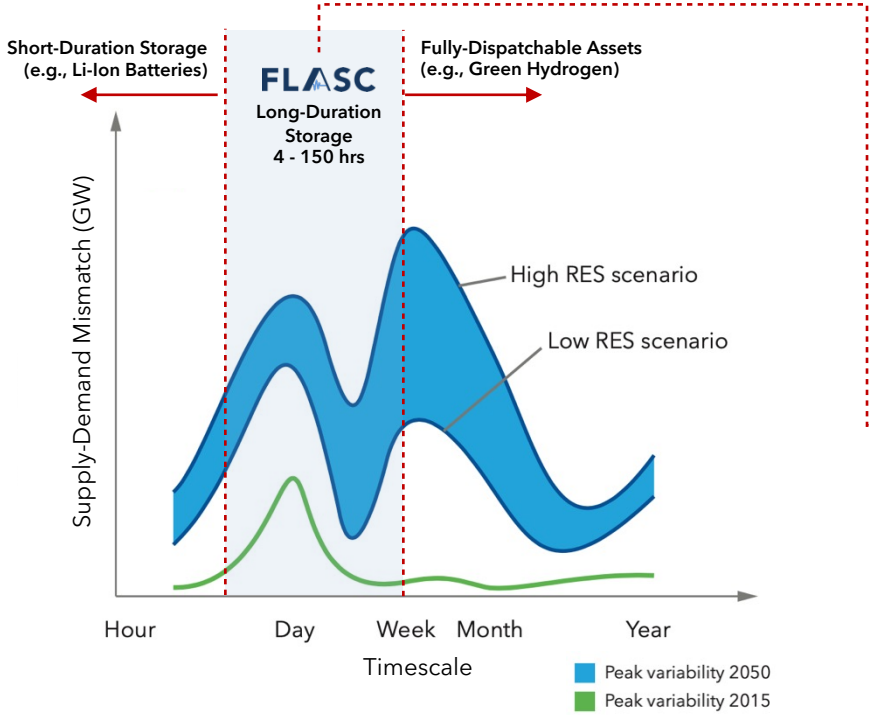
- Liquid-piston integration into a floating wind turbine hull, interface with other technologies on the multi-use platform that will cater for small-island applications.
- Fabrication of the Energy Conversion Unit is complete, including full controls, grid connection and commissioning tests.[2]

[1] Findings published in the *Journal of Energy Storage*: [read more]

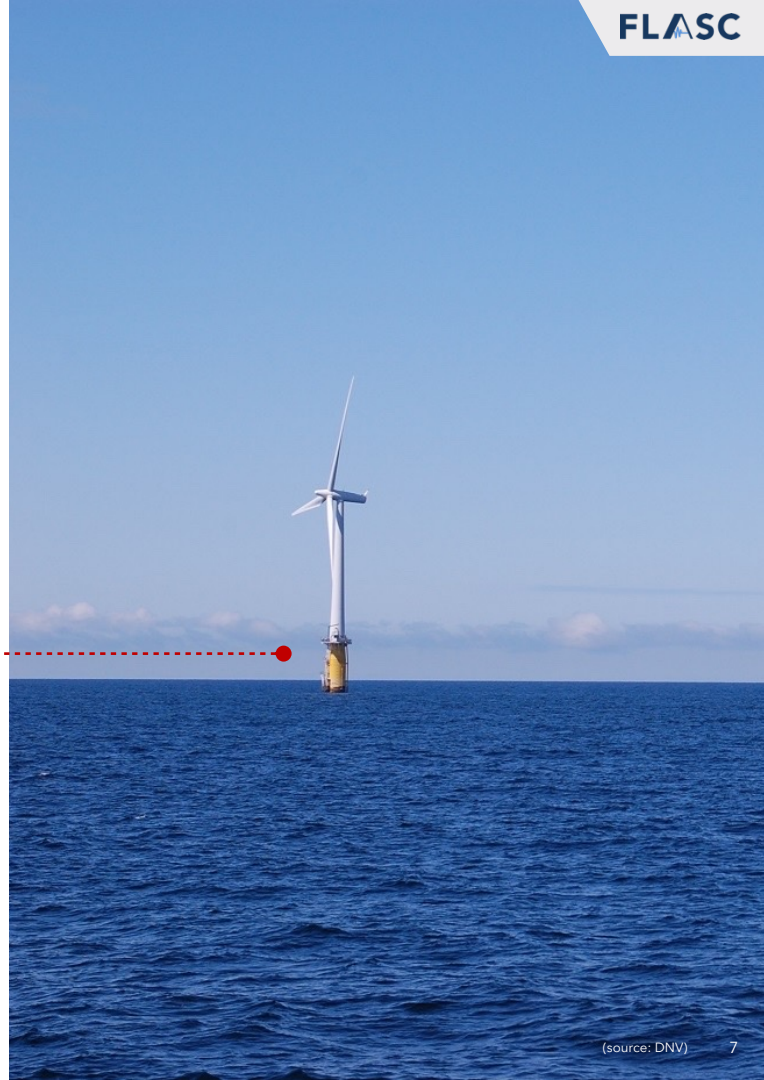
[2] Findings published in the *Energies*: [read more]

Offshore Wind needs Long-Duration Energy Storage

FLASC is in the sweet-spot to provide crucial intra-day storage for supporting offshore wind integration. It also complements short-duration batteries and green hydrogen.

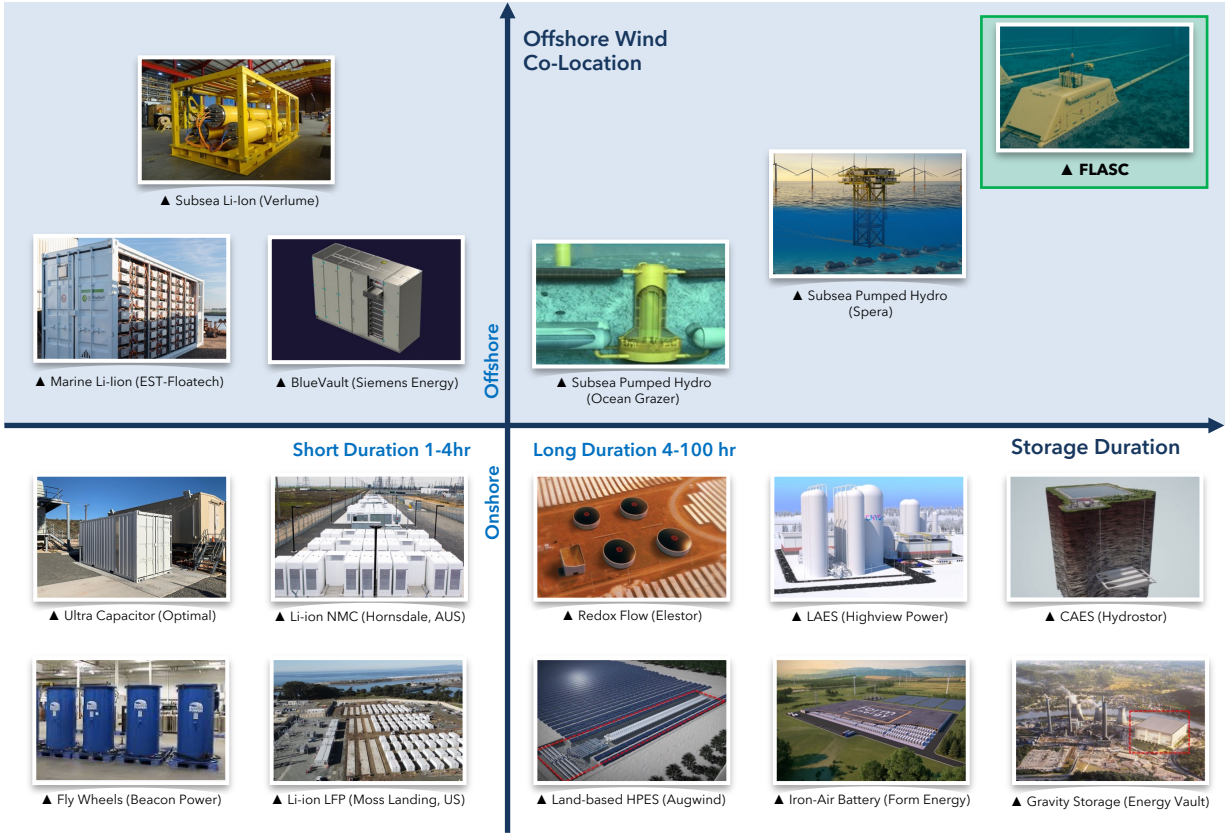


Peak variability of residual load at different time scales
in a European electricity grid in 2015 and expected in 2050
(source: DNV)



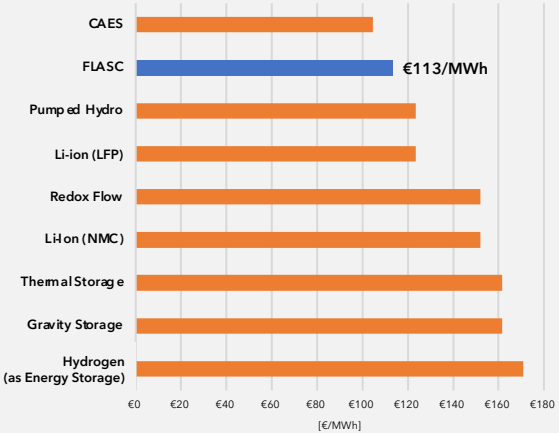
(source: DNV)

The Winning Solution for Offshore Renewables



- FLASC is uniquely positioned to address temporal and spatial mismatch in offshore wind applications
- Energy density up to x100 greater than existing offshore solutions
- **Levelised cost that is competitive with the cheapest land-based storage**

2030 Levelised Cost of Storage (LCOS)[1]



[1] 2022 Grid Energy Storage Technology Cost and Performance Assessment (US Dept of Energy) (+100MW / 10-hr Duration)

The Product: Fully-Integrated Offshore Energy Storage Hardware

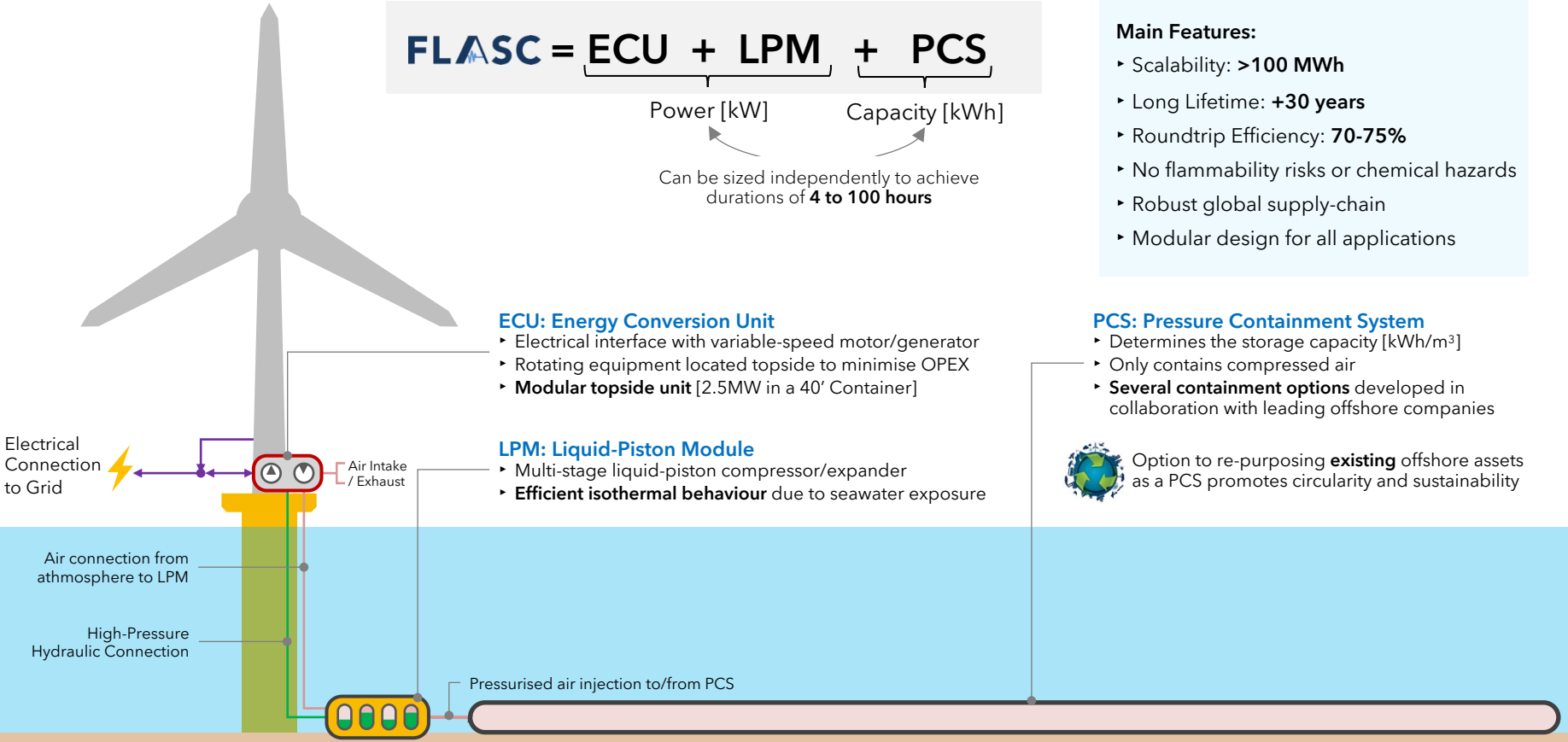
FLASC = ECU + LPM + PCS

Power [kW] — Capacity [kWh]

Can be sized independently to achieve durations of **4 to 100 hours**

Main Features:

- Scalability: **>100 MWh**
- Long Lifetime: **+30 years**
- Roundtrip Efficiency: **70-75%**
- No flammability risks or chemical hazards
- Robust global supply-chain
- Modular design for all applications



ECU: Energy Conversion Unit

- Electrical interface with variable-speed motor/generator
- Rotating equipment located topside to minimise OPEX
- **Modular topside unit** [2.5MW in a 40' Container]

LPM: Liquid-Piston Module

- Multi-stage liquid-piston compressor/expander
- **Efficient isothermal behaviour** due to seawater exposure

PCS: Pressure Containment System

- Determines the storage capacity [kWh/m³]
- Only contains compressed air
- **Several containment options** developed in collaboration with leading offshore companies

Option to re-purposing **existing** offshore assets as a PCS promotes circularity and sustainability

ECU + LPM Configurations

ECU: Energy Conversion Unit
- Electrical to hydraulic power conversion at wind turbine level
- 40-ft container-sized module with 2.5MW of rated power

LPM: Liquid-Piston Module
- Hydraulic to pneumatic power conversion using liquid-pistons
- Subsea modules with up to 40MW of rated power

Equipment can be scaled as needed and optimised for different applications:

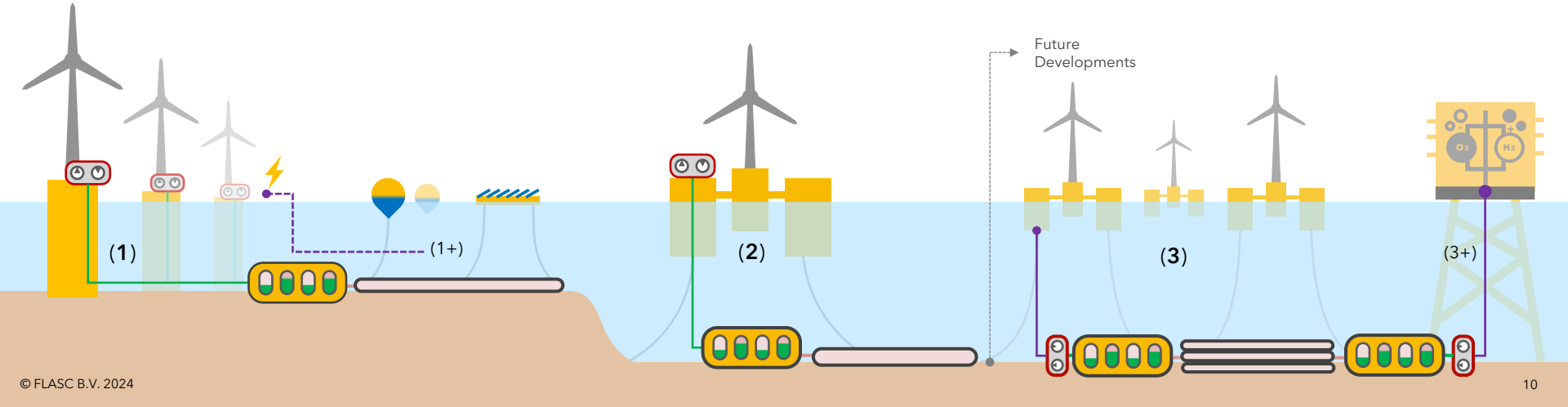
(1) Several turbine-level ECUs hydraulically connected to centralised LPMs on the seabed

(1+) Electrical interface with other generation sources (e.g. wave, solar) also possible for multi-use applications

(2) Floating wind applications currently supported with a topside ECU and hydraulic connection to the subsea LPM

(3) Future developments will include fully-subsea ECU+LPM designs with direct electrical interface to topside

(3+) Specific configurations to support offshore Green Hydrogen production also being developed

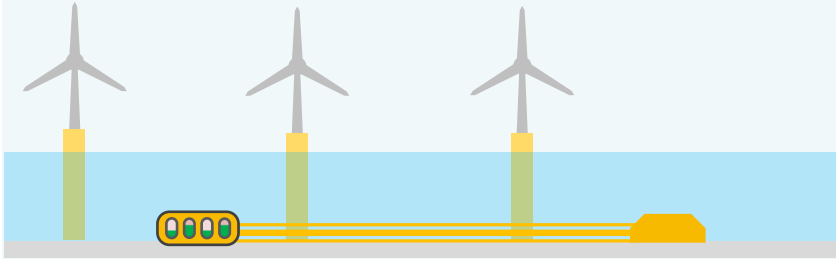


PCS Options

- A range of options developed as part of our long-standing collaboration with subsea 7 a global leader in offshore project delivery across oil & gas and offshore wind development

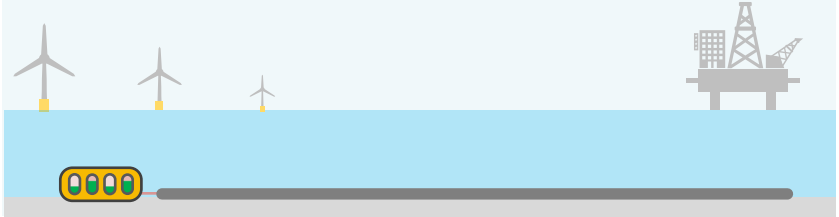
Subsea Bundle

- Fixed length of pipes bundled together to form a rigid towable structure
- Bundles of up to 7km can be fabricated onshore and towed into position
- Maximum OD ø1.5m with a storage capacity of up to 140MWh / bundle



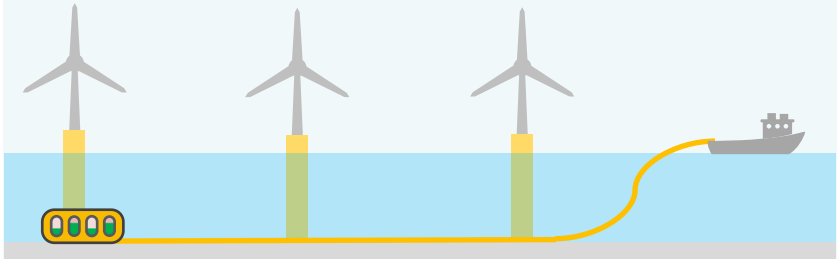
Re-Purpose Existing Pipes

- Offshore pipelines at end-of-life can be re-used for energy storage
- Pressure can be de-rated and optimised in line with pipeline residual life
- Additional cost-benefit by deferring abbandonment cost



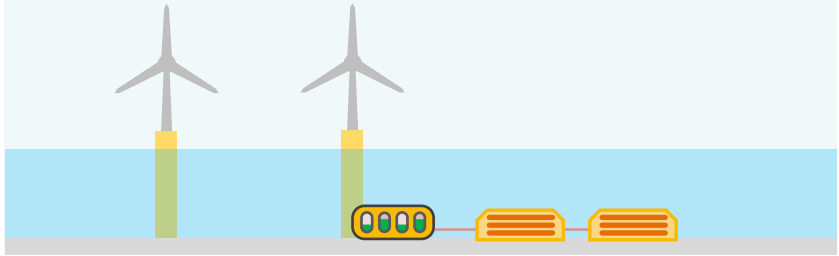
New Pipe

- Install a new length of pipe optimised for the application needs
- Diameter ranges from ø30” to ø42”, reaching up to 14MWh/km
- Scalable to +1GWh of capacity for large wind farm applications



Modular Tanks

- Array of slender tanks suitable for smaller applications
- Standard subsea module designed for towable installation
- Scalable to +10MWh per module and can be combined for larger capacities



Typical FLASC configuration

- Co-located energy storage enables developers to improve business case of existing offshore consents
- Optimum Power/Storage requirements typically correspond to 5-10% of wind farm power with 4-hr duration

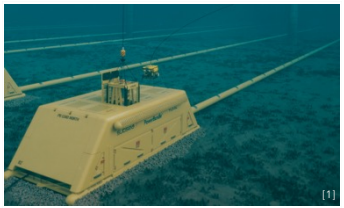
1GW Offshore Wind
(72 x 14MW Turbines)

+ FLASC Energy Storage
[80MW / 320 MWh]

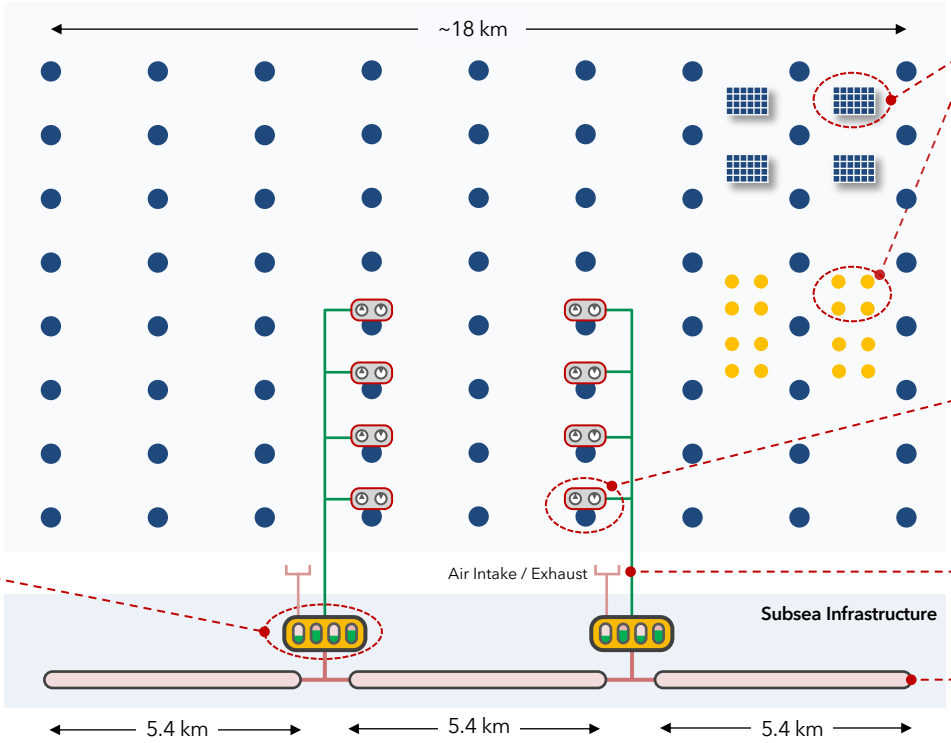
ECU: 8 wind turbines with 10MW installed topside [4x2.5MW modules]

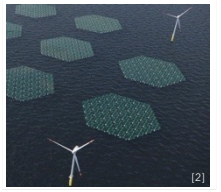
LPM: 2 x 40 MW subsea units interfaced with multiple ECUs

PCS: 3 x 5.4km bundles with ø1.5m storing a total of 320MWh


[1]

▲ Subsea equipment based on established towable designs




[2]


[3]

▲ Can be co-located with other offshore renewables in multi-use applications


[4]

▲ 8 out 72 Turbines fitted with extended deck for topside electrical equipment and hydraulics

High-pressure hydraulic connection between topside ECUs and subsea LPM

PCS storage installed subsea only occupies 1 wind farm row and caters for full energy storage requirements

Images credits: [1] Subsea7/FLASC [2] SolarDuck; [3] CorPower Ocean; [4] RWE/Aquaventus

Applications & Go-To-Market

Stage 1

Offshore Wind & Grid Support

FLASC enables offshore energy storage at scale, making possible the scale-up of offshore clean energy and its integration into the energy system .

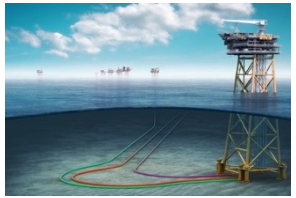
Stage 2

Offshore Hydrogen Production

FLASC enables a stable supply of power to the hydrogen electrolyser, improving efficiencies and prolonging the electrolyser lifetime (patent filed 2021).

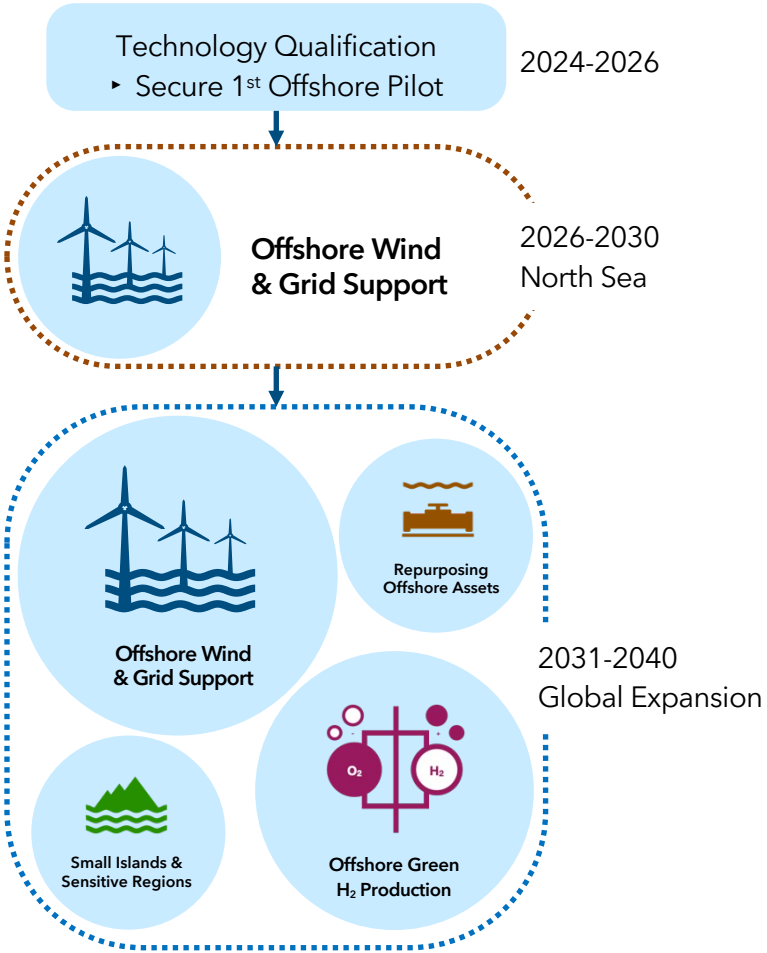
Small-Islands and Sensitive Regions

FLASC storage frees up precious land and provides flexibility as a sustainable and socially-positive solution.



Re-Purposing Offshore Assets

Existing offshore assets such as pipelines and platforms can be repurposed into an offshore energy storage system using the FLASC technology.



FLASC for Offshore Wind & Grid Support

- Evaluation of Offshore Wind Business Cases with Siemens Energy
- Case study on 26 UK offshore wind farms presented at *WindEurope* 2024 [1]

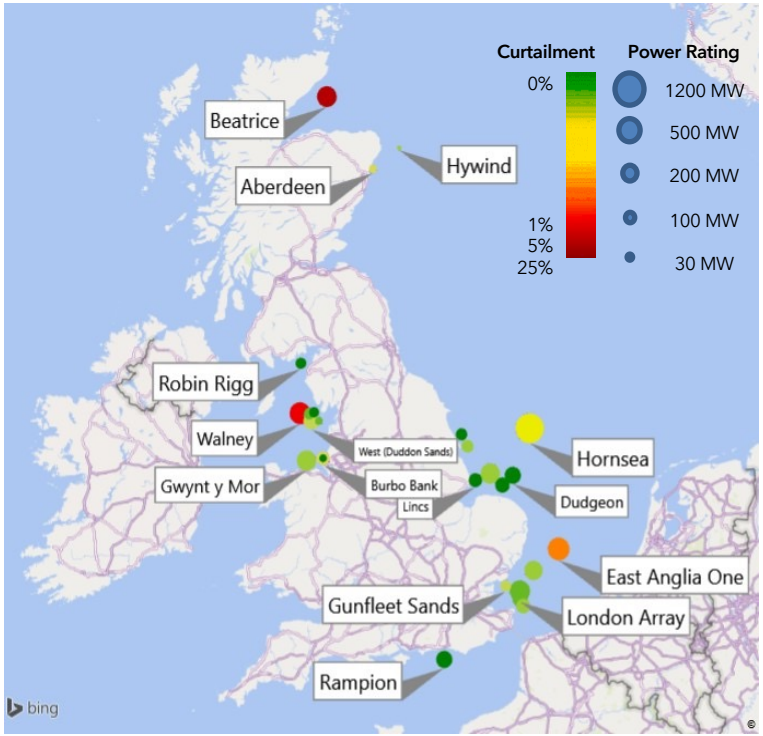
Download the Full Presentation

- Co-locating FLASC with UK offshore wind farms corresponds to an **IRR of 18%**
- Based on 2021-22 markets, FLASC would add **€300m/yr** to UK wind revenues
- Value add increases significantly to 2030 as wind penetration increases.
- Co-located energy storage being incentivised in recent subsidy schemes.

Adds at least 10% more value to existing UK offshore wind farms

Enables participation in balancing markets by hedging against volatility

Offshore wind can become an active provider of grid flexibility



[1] Singuran et al. (FLASC / Siemens Energy) "Clean energy when the wind is not blowing: evaluating business cases for co-located offshore energy storage across 26 UK offshore wind farms". *WindEurope 2024*

(source: Fuel Cell Works)

FLASC for Offshore Green Hydrogen Production

Current Challenges:

- Commercial: green H_2 is expensive, needs cheap green electricity and high utilization rates.
- Technical: electrolyzers need fast response for intermittent power input, lifetime suffers with high on/off cycling, complex infrastructure.

FLASC Value Proposition:

Combined intra-day storage solution for offshore Green H_2 (patent pending):

- Increase H_2 production for same wind farm power rating,
- Reduce in cost of produced H_2 (€/Nm^3) making it **up to 20% cheaper**
- Improve electrolyser lifetime with a **+50% reduction in on/off cycling**

These benefits increase in lower wind climates (e.g. Mediterranean, Western Australia)

FLASC is active in studies and consortia working on Green Hydrogen:

1. Wind4H2[1] was an early feasibility study to evaluate integration of FLASC HPES with offshore green hydrogen production
2. HydroGenEration[2] in 2022 evaluated optimisation of hydrogen production specifically in lower wind climates, such as the Central Mediterranean.

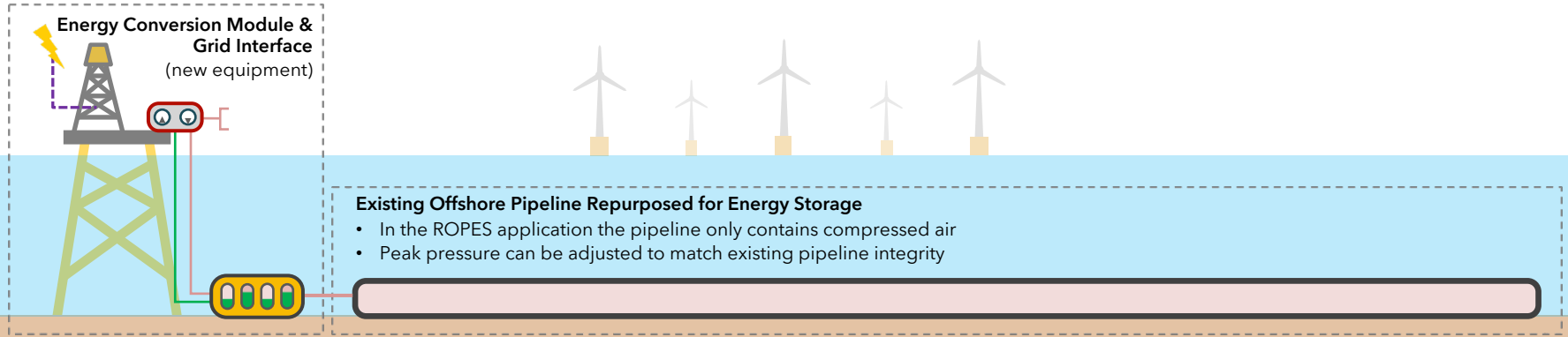
[1] Supported through the Maritime Seed Award (MarSA) 2019
[2] Ref.: EWA 64/22 financed by the Energy and Water Agency under National Strategy for Research and Innovation in Energy and Water (2021-30)

FLASC for ROPES: Re-Purposing Offshore Pipelines for Energy Storage

- There is a significant drive to re-purpose existing offshore assets to support the accelerating energy transition
- Not all pipelines are suitable for hydrogen transmission or carbon capture due to topology, material constraints and structural integrity
- FLASC HPES can be applied to existing pipelines converting them into a utility-scale energy storage system which represents one of the cheapest energy storage systems available
- **In most cases the re-purposing cost is offset by deferring the abandonment cost of the pipeline**

FLASC, Subsea7 and Xodus have evaluated several case studies:

- **UK, the North Sea: 330 MWh**
  - Pipeline Geometry: ø36" x 153km
  - Peak Storage Pressure: 44 bar
  - Application: Grid Integration of Offshore Wind
- **Western Australia: 280 MWh**
  - Pipeline Geometry: ø30" x 55 km
  - Peak Storage Pressure: 160 bar
  - Application: Decarbonization of Oil & Gas



Traction

7
LoIs

- Wind developers with confirmed interest to deploy FLASC systems in their projects.
- Representing an installed capacity of **+1GWh** by 2030

4
MoUs

- FLASC was included in **2 North Sea offshore wind farm tenders** since 2020
- Ongoing discussions for upcoming tender participation

x3

- World-leading delivery partners and suppliers ready to support our growth

+€1m

- Already generated from early revenues

+60

- NDAs established across our value chain including early commercial leads

5
Regions

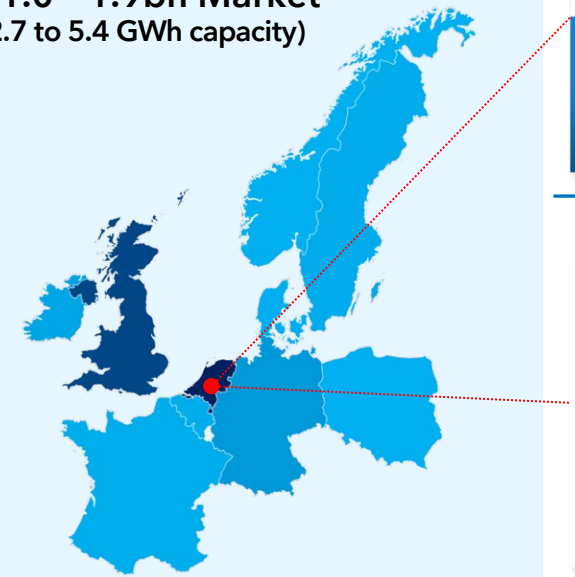
- Technology versatility and established delivery partners enable a global reach

Demo Project Deployment
MoUs / Project Bids
FEED Studies
Feasibility Studies

Incentives for North Sea Offshore Energy Storage by 2030

Offshore Energy Storage

€1.0 – 1.9bn Market
(2.7 to 5.4 GWh capacity)



Gesteld dat deze 100GW 50/50 wordt opgewekt door zon-op-land en wind-op-zee.

- Voor 50GW jaargemiddeld zonvermogen is nodig: 7.140 km². Nederland heeft een oppervlak van 41.000 km². Dit is 17% van het landoppervlak.
- Voor 50GW jaargemiddeld wind-op-zeevermogen is nodig: 22.300 km². De Nederlands Exclusieve Economische Zone heeft een oppervlak van 58.000 km². Dit is 38% van de EEZ.

*"**22,300 km² of offshore space** is needed for the 50GW target"*

Source: Rijksoverheid 07-06-2023 [LINK]

"When looking at the development of offshore wind energy, I take into account the balance between the energy transition, food transition and nature transition in the North Sea. In this context <…> investigating how we can best shape multi-use in offshore wind farms.*

Multi-use of offshore wind farms is permitted in accordance with the North Sea Programme 2022-2027 for: aquaculture, passive fishing, nature restoration and development **and other forms of renewable energy generation and storage (such as offshore solar energy and batteries)"*

Page 5 of the Letter DGKE-DRE / 55305796 to Parliament regarding permit procedure offshore wind energy IJmuiden Ver Gamma and Nederwiek I (4 GW)

Source: Rijksoverheid 06-2024 [LINK]

Development Milestones

2017 — Proof-of-Concept [TRL5]

2018 — International Patents Granted

2019 — DNV Statement of Feasibility

▲ **Patents Granted**: Europe, US, China and Japan

2020-23 — Floating Wind Demo [TRL7]
H2020 BG-05-2019

- Grid-connected ECU system to be deployed offshore on a floating wind turbine.

2024-26 — Technology Qualification [TRL8]

- Onshore qualification and grid-compliance as the only remaining step before market entry

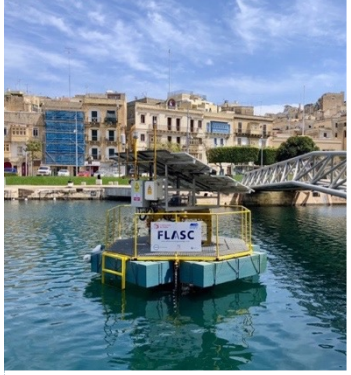
EIC Accelerator

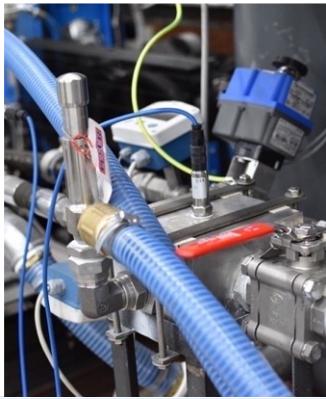
2026 — **Secure 1st Offshore Project**

- **x7 Wind Developers have declared their interest to deploy FLASC in their wind farms after qualification**

2027-30

- Roll-out FLASC systems across North Sea wind farms: 30 units by 2030





European Innovation Council · Interreg Vlaanderen-Nederland · Gefinancierd door de Europese Unie · Horizon2020 European Union Funding for Research & Innovation · Rijksdienst voor Ondernemend Nederland · Department for Energy Security & Net Zero

Winner Offshore Energy Best Innovation Award 2020 · SolarImpulse Efficient Solution · European Inventor Award 2024 Nominee Research Category · PowerUp! by EIT InnoEnergy · Nominated Awards · BLUE INVEST

FLASC – Company profile

- First movers in offshore energy storage since 2015
- **10 FTEs**: technical founders, a team of engineers and a business developer
- Network of seasoned advisers across offshore, energy and finance

L-Università ta' Malta

- **Spin-Off from the University of Malta**
  Established in The Netherlands in 2020, with exclusive access to all related IP and know-how

Buccaneer Delft
accelerating energy & offshore

- **Part of the Buccaneer Delft Accelerator**
  In the heart of the offshore energy sector, with access to an extensive partner network

subsea 7

- **Collaborating with Subsea7 since 2020**
  Jointly developing solutions for offshore energy storage based on FLASC's HPES technology

- **Extensive track-record in securing and managing grant-funded projects across national and EU jurisdictions.**

Opportunities for Collaboration

- **Seeking partners to support bids for IJmuiden Ver Gamma (Plots A & B)**
- Strategic Partnerships / Collaborations
- Concept & Feasibility Studies

FLASC brings:

- ✓ **Experience from multiple wind farm bids on system integration**
- ✓ **Innovative solution built on proven technology**
- ✓ **Credible EPCI partners for project delivery**

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FLASC B.V. is a spin-off from the University of Malta, established in The Netherlands with registration number: 76566404.

The company is part of the Buccaneer Delft energy & offshore accelerator.

"FLASC's solution is an innovative technology with significant potential, offering a competitive and more sustainable alternative to Li-ion battery farms.

The collaboration with FLASC will allow us to leverage Subsea 7's world-class technical expertise in the development of offshore subsea solutions to accelerate the deployment of utility scale, low maintenance, storage solutions."

Thomas Sunde
VP Strategy and Technology, Subsea 7

(photo: Vattenfall)

Peer-Reviewed Literature

Journal of Energy Storage 24 (2019) 100774

Contents lists available at ScienceDirect

Journal of Energy Storage

journal homepage: www.elsevier.com/locate/est

Small-scale Experimental Testing of a Novel Marine Floating Platform with Integrated Hydro-pneumatic Energy Storage

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ARTICLE INFO

Keywords:
Energy storage
Offshore renewable energy
Hydro-pneumatic
Liquid-piston
Compressed air
Experimental testing

ABSTRACT

Co-locating energy storage within the floating platform of offshore renewable energy systems is an effective way of reducing the cost and environmental footprint of marine energy storage devices. However, the development of suitable, non-hazardous technologies, and the influence of the marine environment on their efficiency remains an open problem. Research at the University of Malta has culminated in the Floating Liquid-piston Accumulator using Seawater under Compression (FLASC) concept, a solution involving hydro-pneumatic energy storage tailored for offshore renewables. A small-scale prototype was deployed at a sheltered marine location in the Maltese Islands, in the central Mediterranean Sea. The aim of the experimental campaign was to measure the performance of the energy storage system, and to quantify the effects of different system parameters along with the surrounding meteorological conditions. Results from selected charging-discharging cycles are presented, these include different scheduling schemes and pressure ranges. Overall, results indicate that the experimental system consistently demonstrated a high thermal efficiency (> 93%) across hundreds of charging cycles. Operating pressure range and charging schedule play a limited role on the hydro-pneumatic process, whereas seasonal temperature changes play a more significant role, in that such changes can slightly alter the effective storage capacity of the system. Results from this experimental work provide a practical proof-of-concept for hydro-pneumatic marine energy storage, and can enable key conclusions to be drawn providing a basis to numerous ongoing developments in fluid-based energy storage systems for offshore implementation.

1. Introduction

Offshore renewables have an important role to play, particularly when it comes to coastal and island regions having limited land-resources. The vastness of the offshore environment, and wide range of energy sources such as wind, wave, tidal and floating PV, among others, make this an important pillar of the renewable energy economy [1]. Presently, the most mature technology is offshore wind in shallow waters. It is by-far the most widely used offshore resource and represents the highest capacity factor of all renewable resources operating at commercial scale [2]. Floating wind technology, on the other hand, is still in its infancy, but is rapidly growing, with a number of pre-commercial/serial installations already deployed [3]. This is a particularly important technology, given that 60–80% of the offshore wind resource is located at deep water sites (> 60 m) [4]. Appreciable quantities of power from floating wind are set to reach the grid towards the end of the next decade [5]. Yet, the integration of floating wind farms into electricity supply networks on a wide scale is expected to be more challenging than in the case of present land-based and shallow water wind farms, given that the grid will be more constrained due to the already higher share of renewables. Coupling floating offshore wind turbines to energy storage systems will be crucial in overcoming this barrier. In fact, one of the world's largest technical consultancy and supervisory firms on renewable energy, DNV-GL, has forecast floating wind with storage as part of its vision for the future [6].

While numerous studies in open literature have to-date focussed on numerical modelling [7–9], the present work will analyse the behaviour of a marine-based, hydro-pneumatic, energy storage system through experimental testing, and illustrate effects that have so far been hypothesised or observed only through simulations. Such effects should be duly taken into consideration to ensure efficient and viable designs of offshore energy storage technologies.

The paper is structured as follows: in Section 2, a brief background of energy storage technologies is given, along with a description of the

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https://doi.org/10.1016/j.est.2019.100774
Received 21 March 2019; Received in revised form 10 May 2019; Accepted 10 May 2019
2352-152X/

- Singuran A et al. (FLASC / Siemens Energy). *Clean energy when the wind is not blowing: evaluating business cases for co-located offshore energy storage across 26 UK offshore wind farms*. WindEurope 2024 [LINK].

- Buhagiar D, Sant T, Farrugia RN, *Hydro-Pneumatic Energy Storage*. Book Chapter in Encyclopedia of Energy Storage. Elsevier (in press: 2022). https://doi.org/10.1016/B978-0-12-819723-3.00077-9

- Buhagiar D, Sant T, Farrugia RN, Aquilina L, Farrugia D, Strati FM. *Small-scale Experimental Testing of a Novel Marine Floating Platform with Integrated Hydro-pneumatic Energy Storage*. Journal of Energy Storage. 2019 Aug 1;24:100774 https://doi.org/10.1016/j.est.2019.100774

- Farrugia D, Sant T, Buhagiar D, Farrugia RN. *Analysis of the wind and wave-induced dynamic response of a floating offshore wind turbine integrating a compressed air energy storage system*. Wind Engineering. 2019 May 31:0309524X19849854. https://doi.org/10.1177/0309524X19849854

- Buhagiar D, Sant T, Farrugia RN, Farrugia D. *Increasing the Value of Offshore Wind by Integrating On-Board Energy Storage*. InJournal of Physics: Conference Series 2019 May (Vol. 1222, No. 1, p. 012038). IOP Publishing. doi:10.1088/1742-6596/1222/1/012038

- Sant T, Buhagiar D, Farrugia RN. *Evaluating a new concept to integrate compressed air energy storage in spar-type floating offshore wind turbine structures*. Ocean Engineering. 2018 Oct 15;166:232-41. https://doi.org/10.1016/j.oceaneng.2018.08.017

- Sant T, Buhagiar D, Farrugia RN, Farrugia D, Strati FM. *Cost Evaluation of Two Concepts for the Integration of Hydro-pneumatic Energy Storage in Floating Wind Turbines*. Journal of Physics Conference Series 2018 Jun (Vol. 1037, 4). 10.1088/1742-6596/1037/4/042019

- Buhagiar D, Sant T. *Modelling of a novel hydro-pneumatic accumulator for large-scale offshore energy storage applications*. Journal of Energy Storage. 2017 Dec 1;14:283-94. https://doi.org/10.1016/j.est.2017.05.005

- Sant T, Buhagiar D, Farrugia RN. *Modelling the Dynamic Response and Loads of Floating Offshore Wind Turbine Structures with Integrated Compressed Air Energy Storage*. ASME 2017 36th International Conference on Ocean, Offshore and Arctic Engineering 2017 Sep 25. American Society of Mechanical Engineers Digital Collection. https://doi.org/10.1115/OMAE2017-61587