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COMPRESSED AIR ENERGY STORAGE BARGE (CAES_B) SYSTEM FOR FLOATING ELECTRIC POWER SUBSTATION FOR OFF-SHORE WIND FARM (OSWF)

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Offshore wind farms are being installed worldwide at a rapid pace. Costs have dropped rapidly thanks to innovation and competition. There is growing interest in deep-water wind: the next-generation of offshore wind where floating turbine foundations provides access to better wind quality further from shore, and site selection is not restrained by the maximum water depth practical to build bottom-fixed turbine foundations.

Commercial interest in energy storage systems for wind farms is also building. The initial storage type selections are tending toward electro-chemical, or battery, as lithium-ion (LI) battery technology is advanced and reliable systems can be built today. Norwegian company Equinor teamed with Masdar and have developed Hywind Scotland, a 25MW pilot wind farm of floating spar platforms near Peterhead off the east coast of Scotland, and they are prototyping a battery storage system termed “Batwind.” The shore side battery bank capacity is small at 1MW and 1.3MWh.

Compressed Air Energy Storage Barge (CAES_B) system is a viable alternate to battery storage and may well be preferable over the long term. It is competitive with the Lithium Ion Battery (Table 1). However, the cost analysis does not include that the CAES-B system not only provides electricity but also a high mass flow of chilled air so that there is 1 MW (thermal power) for every 1 MW (electrical power).

A Levelized Cost of Storage Comparison was performed and described in Reference 2 based on the formula:

$$(1)\ LCOS = \frac{(ICC x CRF) + O\&M + COE_{wf}}{AEP_{net}};\ \text{where}$$

LCOS is levelized cost of storage in \$/MWh
ICC is initial capital cost (CAPEX)
CRF is the capital recovery, defined in Equation (2)
O&M is the annual operations and maintenance cost in \$
COEwf is the annual cost of the energy from the wind farm
AEPnet is the net annual energy produced from storage, after losses and availability

For the CAES-B system LCOS = \$453/(MW.HR). It was slightly less for Lithium Battery system LCOS = \$435/MW-HR).

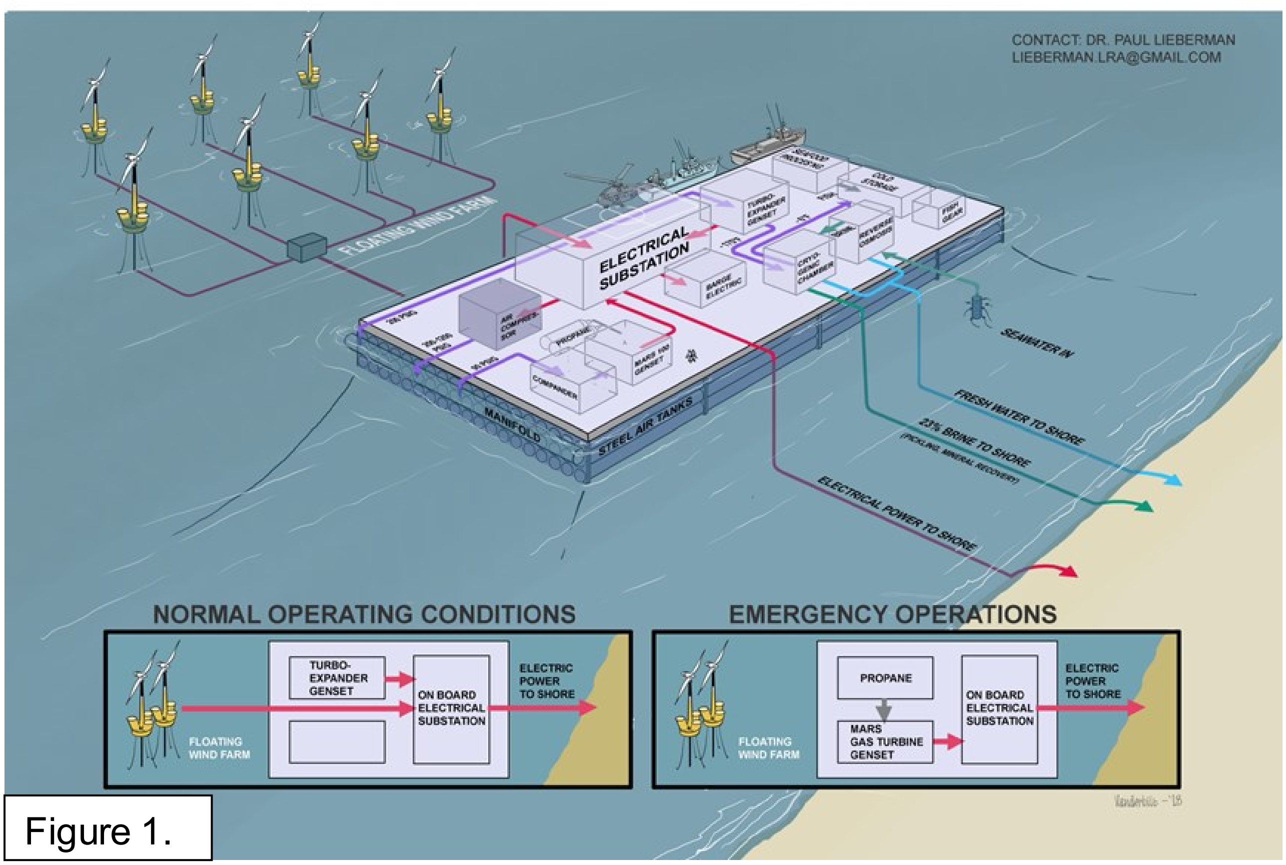


Figure 1.

Batteries supplied only electrical power output; whereas CAES-B supplied both electricity and chilled power. CAES-B, for each1 $MW_{electricity}$ there was also supplied 1 $MW_{thermal}$.

Figure 1 shows a top and an end view of a CAES_B System for an offshore wind farm. Figure 2 shows a specific configuration with horizontal pressure vessels. Figure 3 shows a barge with vertical pressure vessels.

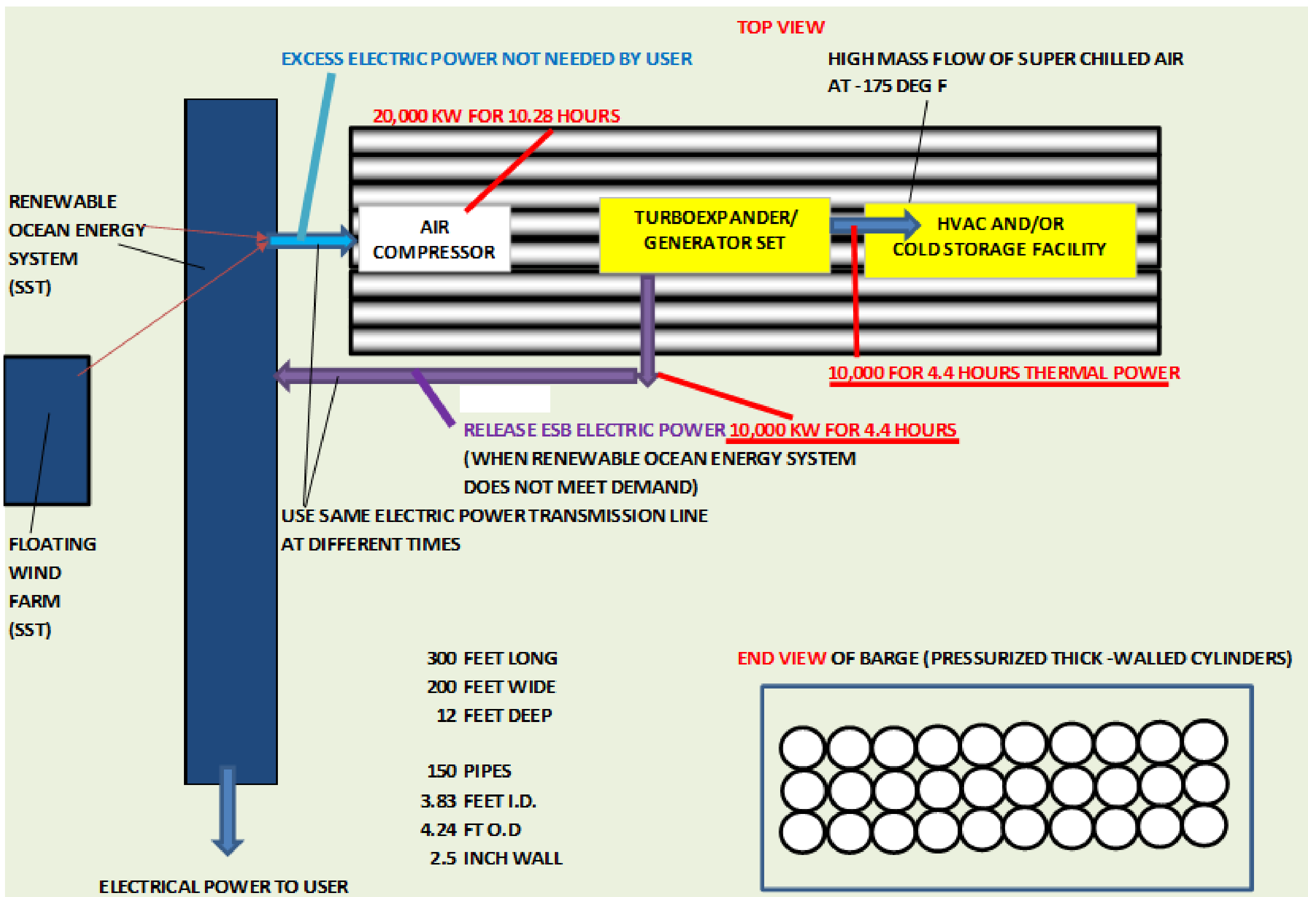
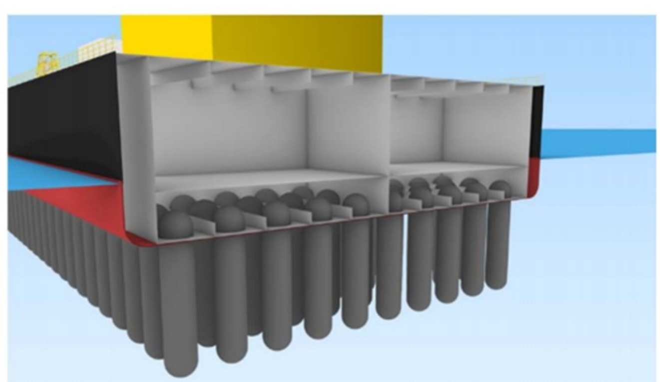


Figure 2

Figure 3



PROPRIETARY TO LIEBERMAN RESEARCH ASSOCIATES

SUMMARY

- THE (CAES_B) SYSTEM RECEIVES THE EXCESS ELECTRICAL ENERGY FROM THE OSWF SYSTEM, STORES IT AND THEN RELEASES THE ENERGY TO ON-SHORE USERS WHEN REQUIRED
- THE CAES_B SYSTEM NOT ONLY PROVIDES ELECTRICITY FROM THE TURBOEXPANDER/GENERATOR (T/G) SET…BUT ALSO SUPPLIES HIGH MASS FLOW OF SUPER-CHILLED AIR FROM THE TURBOEXPANDER EXHAUST AIR
- THE HIGH MASS FLOW OF EXHAUST AIR AT -175^{o}F IS USED FOR HVAC, COLD STORAGE, DESALINATION
- THERE IS EMERGENCY POWER AVAILABLE WITH REDUCED FUEL CONSUMPTION

THE FOLLOWING INNOVATIONS ARE PROVIDED BY THE CAES_B SYSTEM

- COMPRESSED AIR PRESSURE CYLINDERS SUPPLY
- THE SPINE OF THE BARGE STRUCTURE ITSELF
- THE BUOANCY REQUIREMENT FOR THE BARGE
- THE SOURCE OF COMPRESSED AIR FOR THE T/G SET
- HIGH MASS FLOW OF SUPER-CHILLED AIR…HVAC, COLD STORAG
- DESALINATION SYSTEM

PROPOSED WORK

- FULL-SCALE SCALE, SINGLE PRESSURE VESSEL IN WATER-FILLED TRENCH TESTS
    - 1 MW, MULTI-STAGE TURBOCOMPRESSOR (1200 PSIG)
    - ONE 90 FEET LONG, 6 FEET DIAMETER PRESSURE VESSEL (1200 PSIG)
    - 1 MW TURBOEXPANDER GENERATOR SET (-175^{o}F turbine exhaust)
- ENGINEERING/COST STUDY FOR COMPLETE BARGE USING MULTIPLE PRESSURE VESSELS

PROPOSED TEAM OF COMPANIES WITH RELEVANT EXPERTISE

- ATLAS COPCO (TEAM LEADER)
- GLOSTEN, NAVAL ARCHITECTURE & MARINE ENGINEERING
- LIEBERMAN RESEARCH ASSOCIATES (PATENTS, TECHNICAL PAPERS AND PREVIOUS PROJECT AWARD FROM CEC)
- SOUND AND SEA TECHNOLOGY (LIAISON)

- ATLAS COPCO (TURBOEXPANDER/GENERATOR SET, TWO-STAGE TURBOEXPANDER, 200 PSIA INPUT)
- DRESSER-RAND OR G.E. OIL AND GAS* OR INGERSOL-RAND OR ACCURATE AIR ENGINEERING (6, 7 AND 8-STAGE AIR COMPRESSORS, 1200 PSIG OUTPUT)
- CATERPILLAR CORPORATION* (MARS 100 GEN-SET)

REFERENCES

1. PATENT APPLICATION (Lieberman, Sandler and Kurtz)

System and Methodology of an Enhanced Advanced Adiabatic Compressed Air Energy Storage (E-AA-CAES) System with Heat Transfer from Sun and to Soil
US 63072036, August 28, 2020.

2. PATENT (Enis and Lieberman) Method and Apparatus for Integrating On-Shore Green and Other On-Shore Power Sources with a Compressed Air Energy Storage System on a Floating Power Plant.

US 9,903,272, May 7, 2013

The invention relates to a method and apparatus that shares the cost and areal footprint of the barge floatation platform for a floating power platform (FPP) with the cost and aerial footprint of the high pressure vessels of the compressed air energy storage (CAES) system. The integration of these two systems provides cost savings and energy consumption savings with potential for desalination.

3. PATENT (Enis and Lieberman)

Energy Storage Barge
US 16/042,149, July 23, 2018

4. TECHNICAL PRESENTATION (Hurley W.L., Orthmann, A[1]., Lieberman, P[2]., and Enis, B.,)

"Engineering and Cost Study of an Offshore Wind Farm Compressed Air Energy Storage System", Offshore Energy and Storage, Brest, France OSES2019

1. Alan Orthmann (Glosten, Naval Architecture & Marine Engineering Services)
2. Dr. Paul Lieberman (Lieberman Research Associates)

5. FINAL REPORT (Lieberman Research Associates)

"Test and Evaluation of Heat Transfer Parameters for CAES Tank System", Grant No: EISGP 03-24, ENERGY INNOVATIONS SMALL GRANT (EISG) PROGRAM, California Energy Commission