Subsea Buoyancy Energy Storage System (SBESS) and Direct Air Carbon Capture for Deep-Sea Energy Sources

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ABSTRACT

•Power intermittency of many renewable sources of energy and GHG emissions to the atmosphere are two of the biggest challenges faced by the energy industry today.

•Our theoretical design for an offshore energy storage system seeks to provide solutions to both of these challenges into a consolidated system.

•The system involves a motorized cable system built around an offshore energy source (i.e. wind turbine).

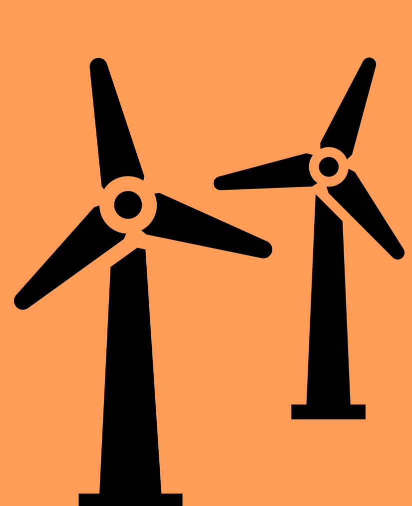
•Balloons filled with air or "gondolas" are connected in series along this cable.

•Energy is stored by powering the motor which drives the gondolas to the ocean floor.

•Energy is recovered by releasing these gondolas and allowing buoyancy to turn a generator.

•As an additional benefit, at maximum depth, hydrostatic pressure is large enough to condense the carbon dioxide content in the air, and the system is designed to separate and store it.

• Storage efficiency was found to be 92.8% and NPV to be \$2.1 million.



INTRODUCTION

Storage systems for offshore sources of energy are not yet very common but are seeing some new innovations. Proposed systems involve the use of water pumps to pressurize air. The efficiencies of these systems, however, have been found to be quite low, nearing 50% [1].

Direct Air Capture (DAC) is currently under widespread research and pilot development. These processes often involve chemical and thermal reactions which can be quite energy intensive, but the technology has the potential to capture large amounts of carbon (large-scale DAC facilities projecting 1Mt CO2/year [2])

Our team is proposing a design to compete with these technologies by utilizing the ocean to separate carbon dioxide and store energy at the same time. By taking advantage of the properties of carbon dioxide, CO2 in the air can be separated by submerging buoyant air-filled containers or "gondolas" underwater. energy source, making it more reliable. We used data from Skagerrak and the Georgia Strait to evaluate system properties.

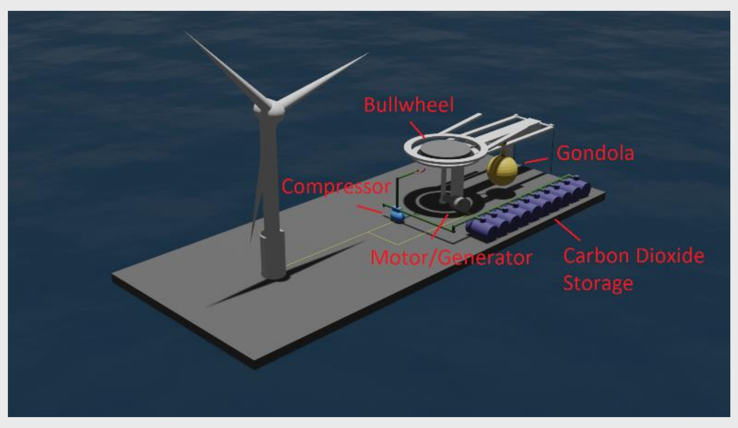


Figure 1. Surface Terminal

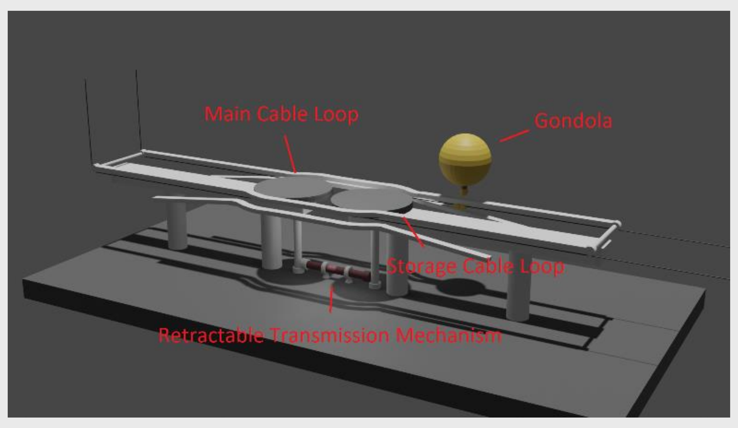


Figure 2. Subsurface Storage Terminal

METHODS AND MATERIALS

Ocean Depth Analysis

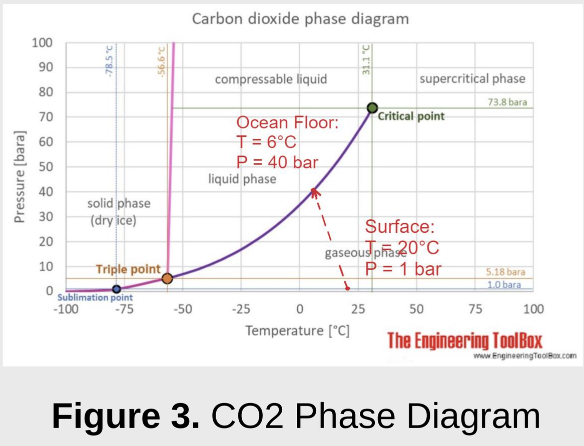


Figure 3. CO2 Phase Diagram

•Thermocline data used in relation to CO2 phase charts to evaluate depth.

Force/Energy Balance

•Buoyancy, gravity, drag and resistive forces (i.e. bearing resistance) taken into consideration.
•Energy losses from compressor station are also considered.
•Analytical MATLAB model used to calculate system forces, energy, efficiency, and carbon dioxide recovery.

Cost Analysis

•Net Present Value is determined using the below formula.

$$NPV = -I + \frac{B - C}{CRF}$$

RESULTS

Cost Analysis

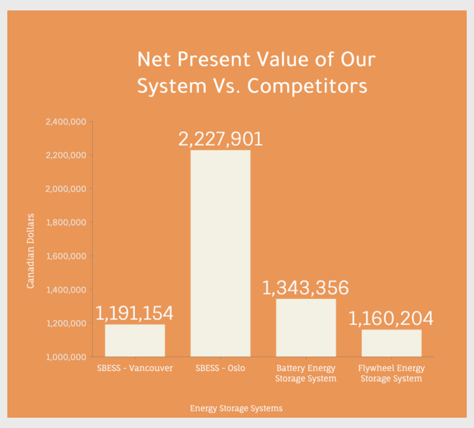


Chart 1. NPV

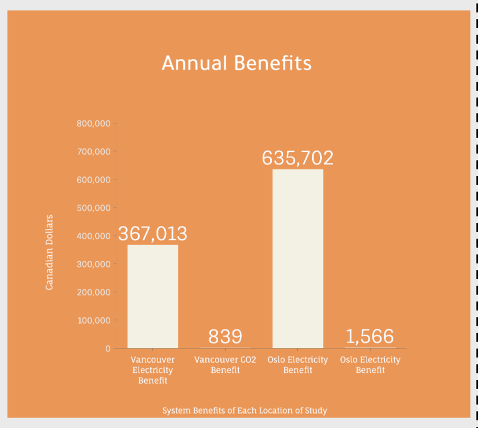


Chart 2. Annual Benefits

- The presented system can be competitive as a business endeavor, with calculated NPV values being in proximity to or exceeding that of conventional energy storage options.

SolidWorks Streamline Analysis

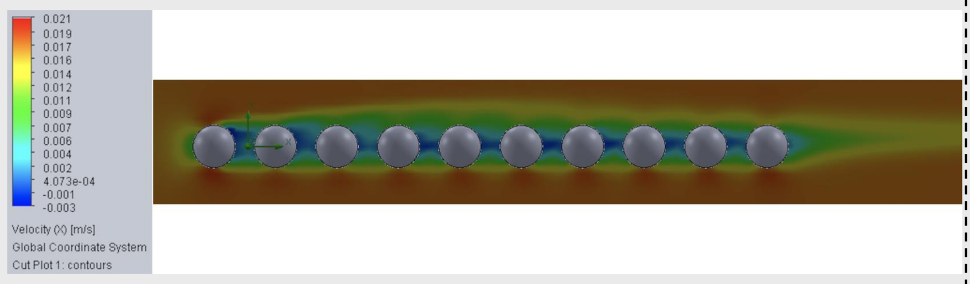


Figure 4. Gondola Streamline Simulation

- Simulation determined a placement of 18.7m (from centroid) between each gondola for lower system drag forces while meeting daily energy targets

MATLAB Analysis

- Figures 5 and 6 showcase the results for efficiency for varying initial volumes for the gondolas.
- Table 1 showcases the input variables for a simulation case where the volume is 1000 cubic meters. Table 2 shows the output variables for these inputs.

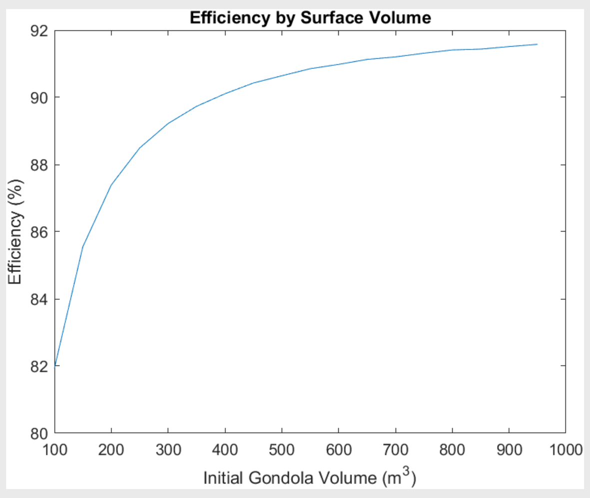


Figure 5. Label in 24pt Arial.

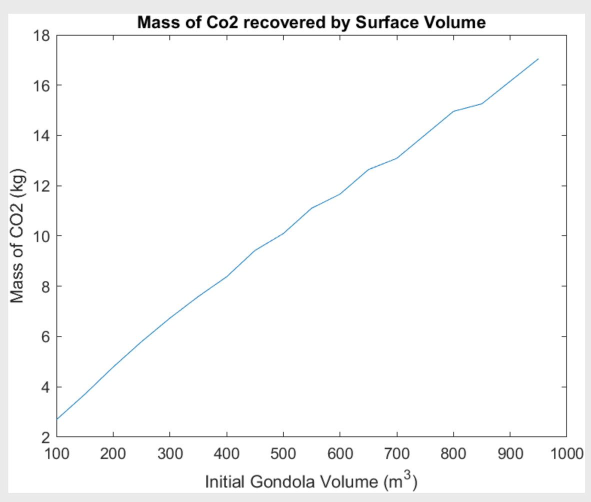


Figure 6. Label in 24pt Arial.

Input Variables	Value
Target Energy Recovery (MWh)	1.0
Target Power Output (MW)	1.0
Initial Pressure (kPa)	101.325
Initial Volume (m^3)	1000
Initial Temperature (ºC)	20
Maximum Velocity (m/s)	1.0
Distance between top two gondolas (m)	6.0

Table 1. Label in 24pt Arial.

Output Variables	Value
Number of Gondolas	24
Distance between gondola centroids (m)	16.57
Energy Recovery (MWh)	2.83
Total Work Input (MWh)	3.05
Efficiency (%)	92.83
Mass CO2 Recovered (kg)	17.95
Time allotted per full cycle (hrs)	5.25

Table 2. Label in 24pt Arial.

DISCUSSION

It can be seen from the plots in figures 3 and 4 that maximizing gondola volume generates better results for efficiency and CO2 recovery and minimizes the number of gondolas required to achieve desired parameters. This means that a system design should seek to make gondolas as large as is physically feasible to maximize performance. Streamlining can be utilized by placing gondolas close in series to reduce counteracting drag forces.

CONCLUSIONS

• Overall calculated efficiency (~93%) proves this technology can be competitive in the energy storage sector
  • NPV results for Vancouver and Oslo indicate positive returns, however not solely as a DAC project (must be energy storage + DAC)
  • Offers passive CO2 capture/storage, and energy storage

•Successful, Innovative design, none other like it in the market, achieving multiple goals within a single project.

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