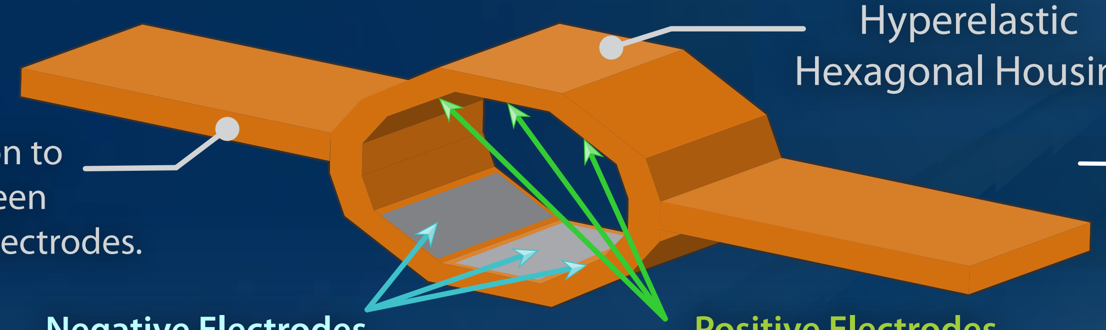
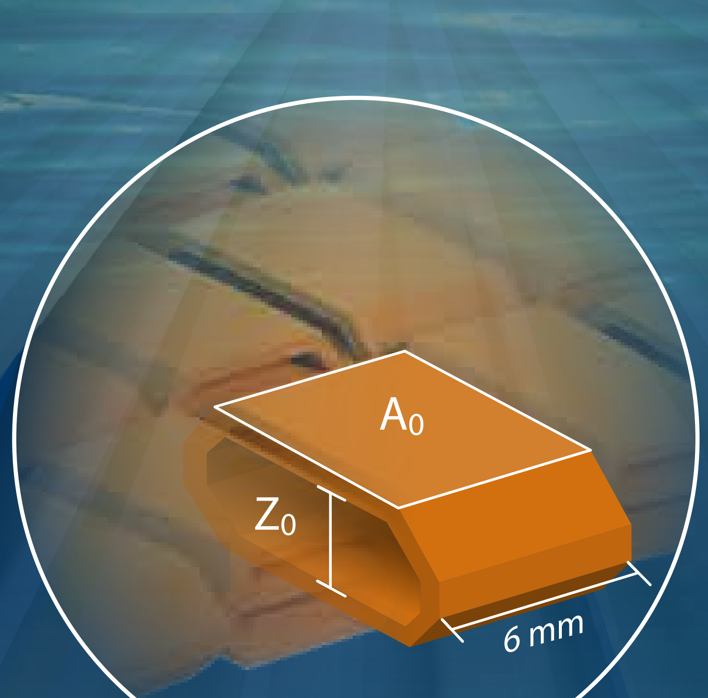
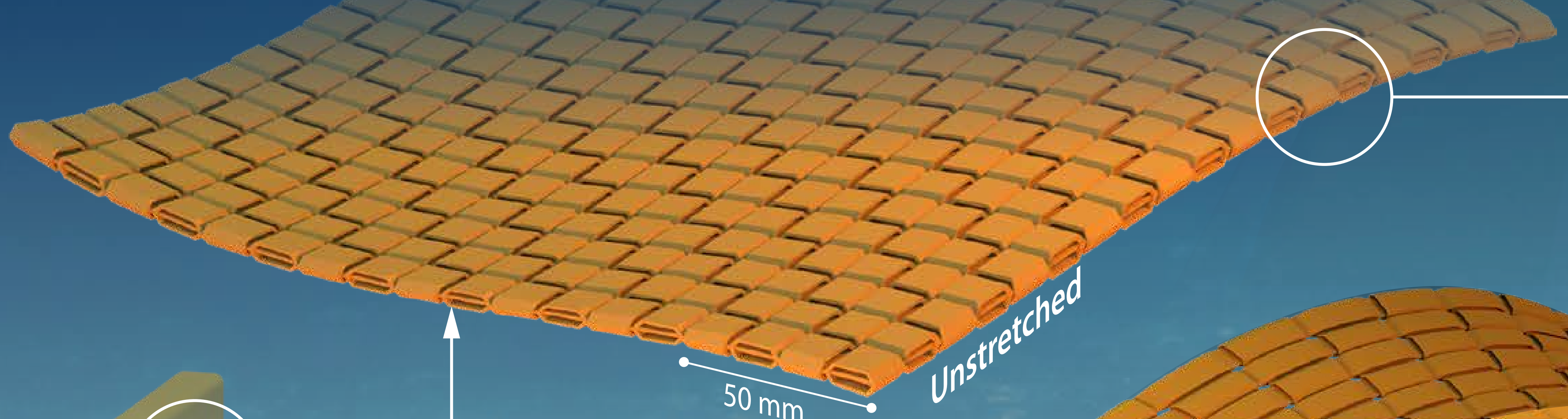
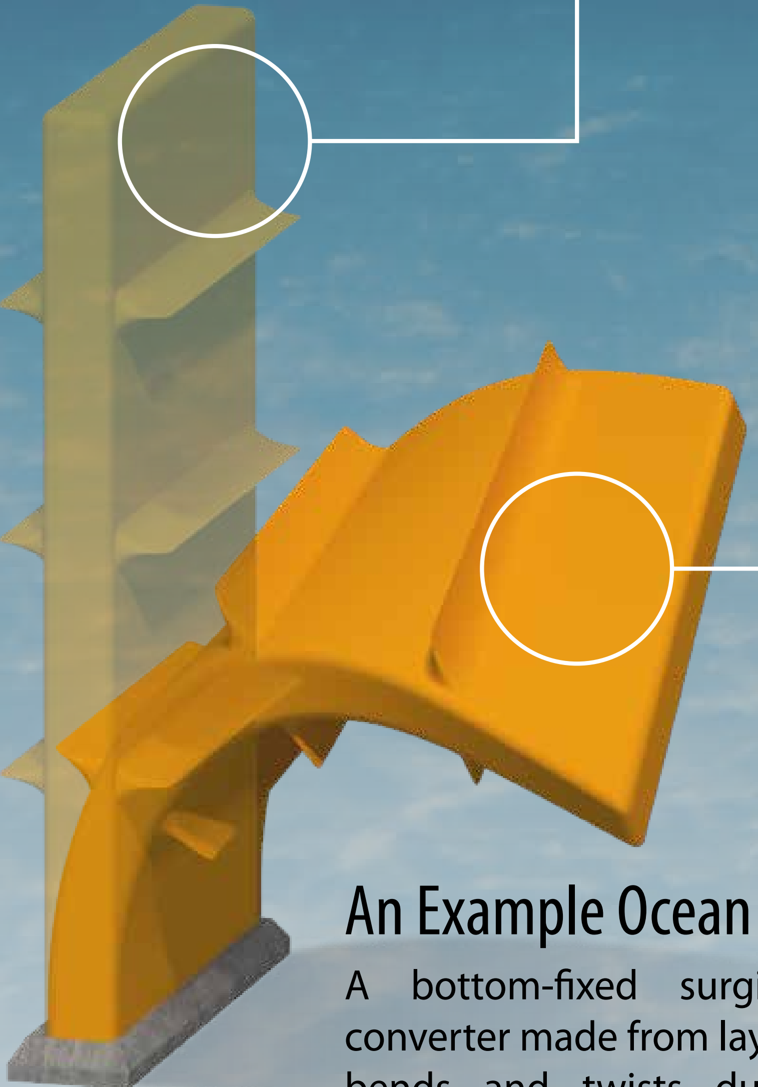
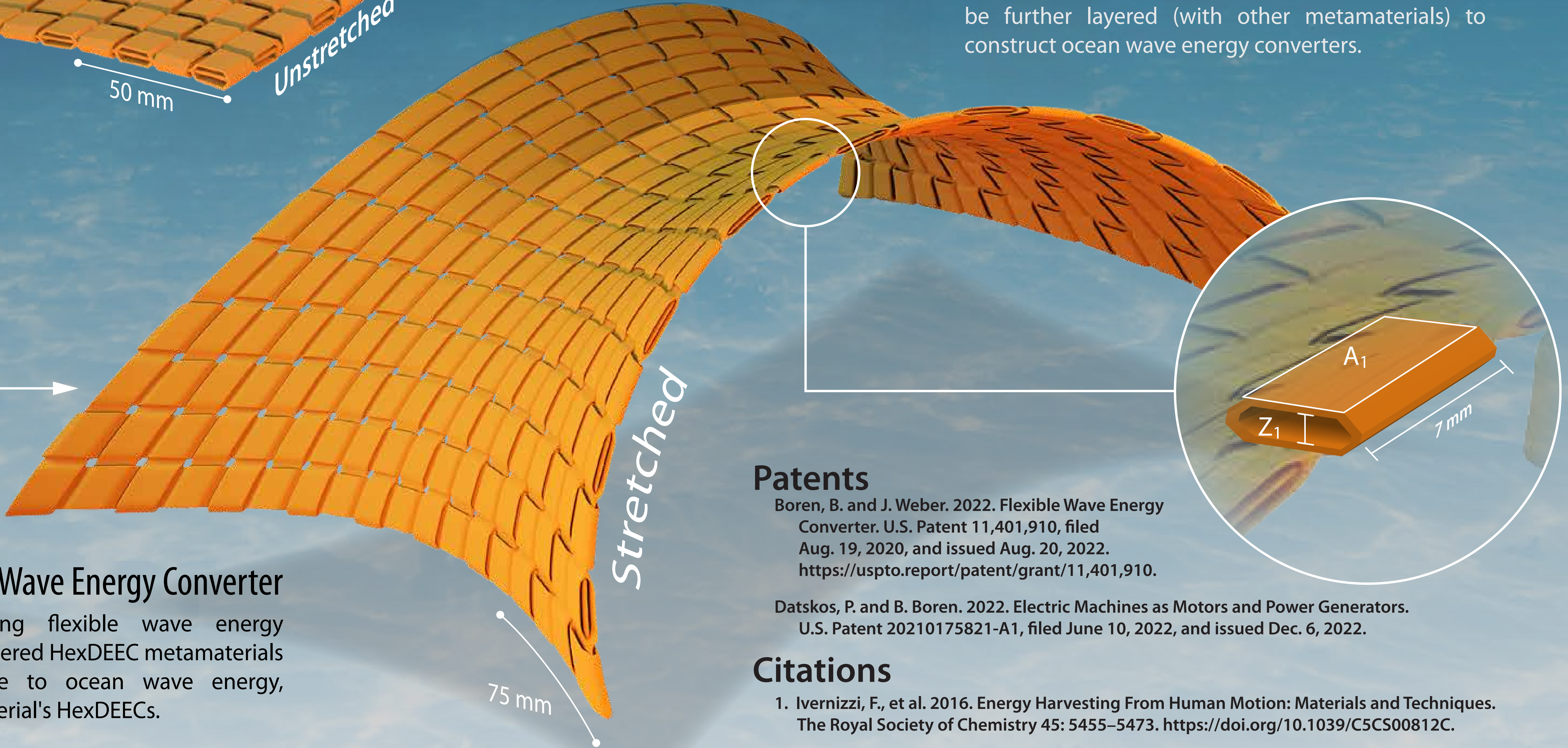
Hexagonal Distributed Embedded Energy Converter HexDEEC











Individual HexDEEC

HexDEECs use variable capacitance to generate electricity from the dynamic deformation of its hyperelastic housing. The capacitance of the electrode plates in the internal hexagonal space change as the housing stretches and alters the gap between those plates, Z_0 vs. Z_1, and their area, A_0 vs. A_1. This change in capacitance causes a charge in electrical potential energy, which is then harvested by the device. When the load is removed, the shape and material properties of the housing enable it to spring back to its original undeformed shape.

HexDEEC Metamaterial

Interweaving strands of HexDEECs together creates a fabric-like metamaterial. The metamaterial can than be further layered (with other metamaterials) to construct ocean wave energy converters.

An Example Ocean Wave Energy Converter

A bottom-fixed surging flexible wave energy converter made from layered HexDEEC metamaterials bends and twists due to ocean wave energy, stretching the metamaterial's HexDEECs.

Patents

Boren, B. and J. Weber. 2022. Flexible Wave Energy Converter. U.S. Patent 11,401,910, filed Aug. 19, 2020, and issued Aug. 20, 2022. https://uspto.report/patent/grant/11,401,910.

Datskos, P. and B. Boren. 2022. Electric Machines as Motors and Power Generators. U.S. Patent 20210175821-A1, filed June 10, 2022, and issued Dec. 6, 2022.

Citations

1. Ivernizzi, F., et al. 2016. Energy Harvesting From Human Motion: Materials and Techniques. The Royal Society of Chemistry 45: 5455–5473. https://doi.org/10.1039/C5CS00812C.

2. Du Toit, V. 2018. Characterizing Material Models for Silicone-Rubber Using an Inverse Finite Element Model Updating Method. Master of Engineering Thesis, Stellenbosch University. https://scholar.sun.ac.za/handle/10019.1/103750

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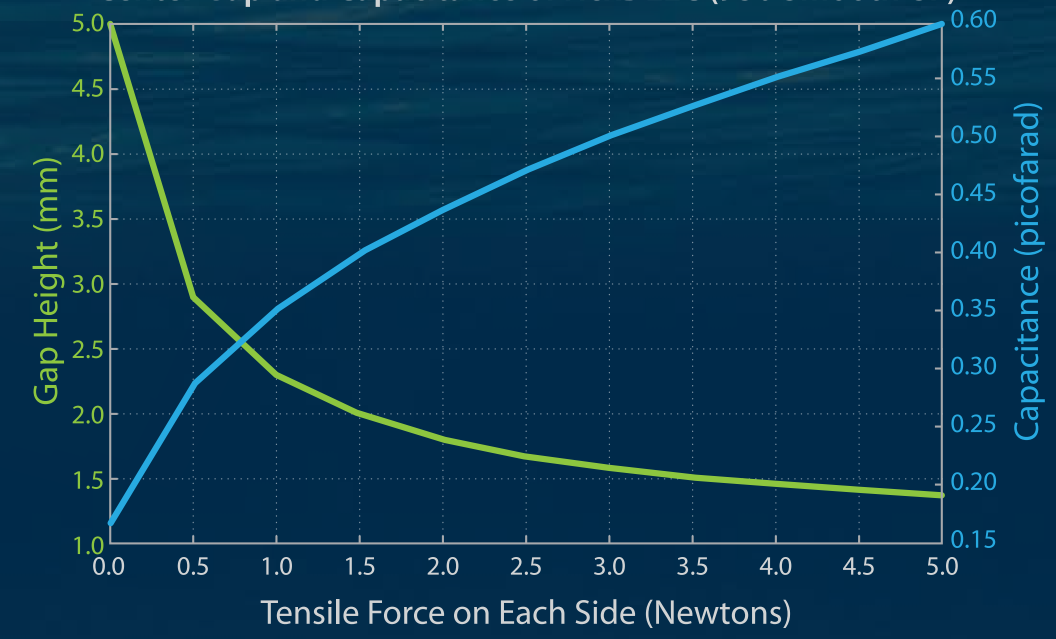
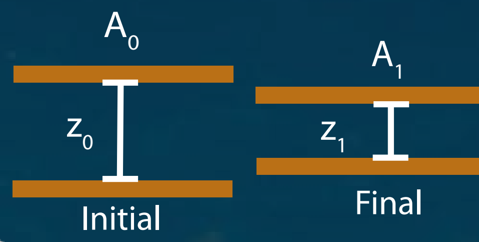
Numerical Modeling



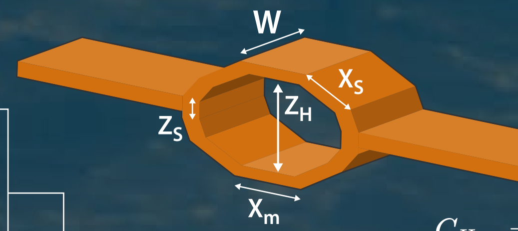
The mechanics of the HexDEEC's hyperelastic housing and its capacitance under tensile loading were assessed via STAR-CCM+. The nonlinear material properties of the silicone housing were modeled using a three-parameter Mooney-Rivlin model with empirically derived material constants from literature[2]. The graph above shows how the gap height (z) shown in green decreases due to the applied loading while the capacitance (C) shown in blue increases.

Based on Variable Capacitance

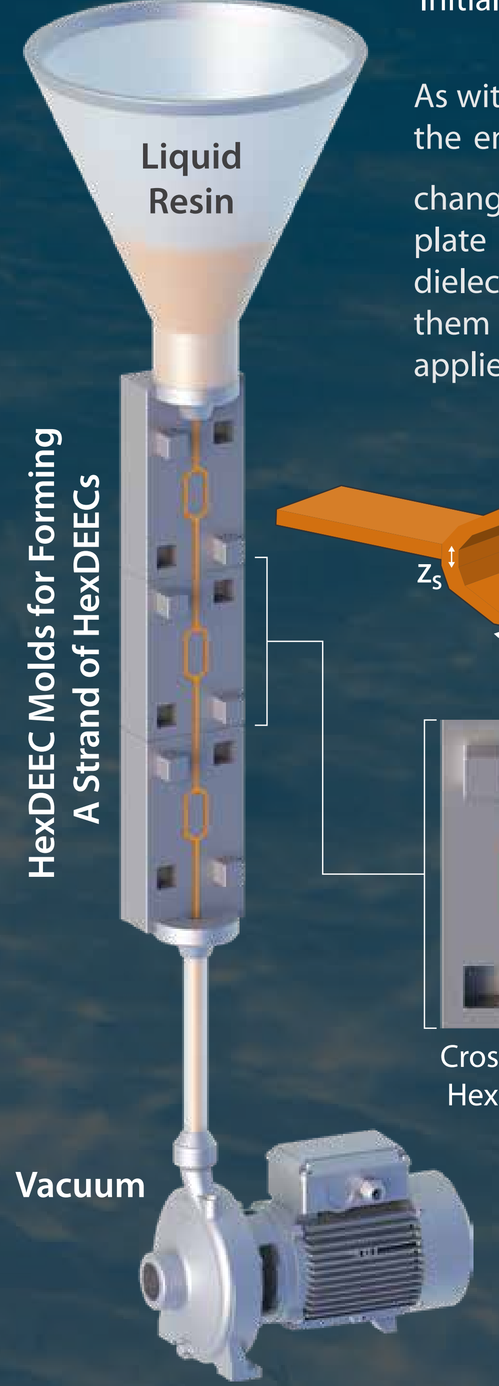


$$C = \frac{\varepsilon A}{z}$$
$$C_O < C_1$$
$$U = \frac{1}{2}CV^2$$
$$\Delta U = U_{final} - U_{initial}$$

As with any variable capacitor with a constant voltage cycle, the energy produced by the HexDEEC is dependent on its change in capacitance[1]. The capacitance (C) of a parallel plate capacitor is determined by the permittivity of the dielectric (ε), area of the plates (A), and distance between them (z). The potential energy (U) depends on C and the applied voltage (V). The HexDEEC's capacitance (C_{Hex}) was derived by approximating the slanted plates as many thin parallel plate capacitors; with their capacitances summed together.



$$C_{Hex} = \varepsilon W \left(\frac{x_m}{z_H} + \frac{2\sqrt{x_S^2 - (\frac{z_H - z_S}{2})^2}}{z_H - z_S} \ln \frac{z_H}{z_S} \right)$$



Fabrication

HexDEECs are made by pouring liquid silicone resin into molds. A vacuum is then used to fill-in those molds with the resin. Sequentially connected HexDEEC molds can be used to cast strands of HexDEECs. These strands of casted HexDEECs can be woven into a HexDEEC metamaterial. Note: electrical components (wires and electrodes) can be placed into the molds to embed them directly within the silicone material.