Enhancing Bio-Electrochemical Carbon Capture & Utilisation (BECCU)

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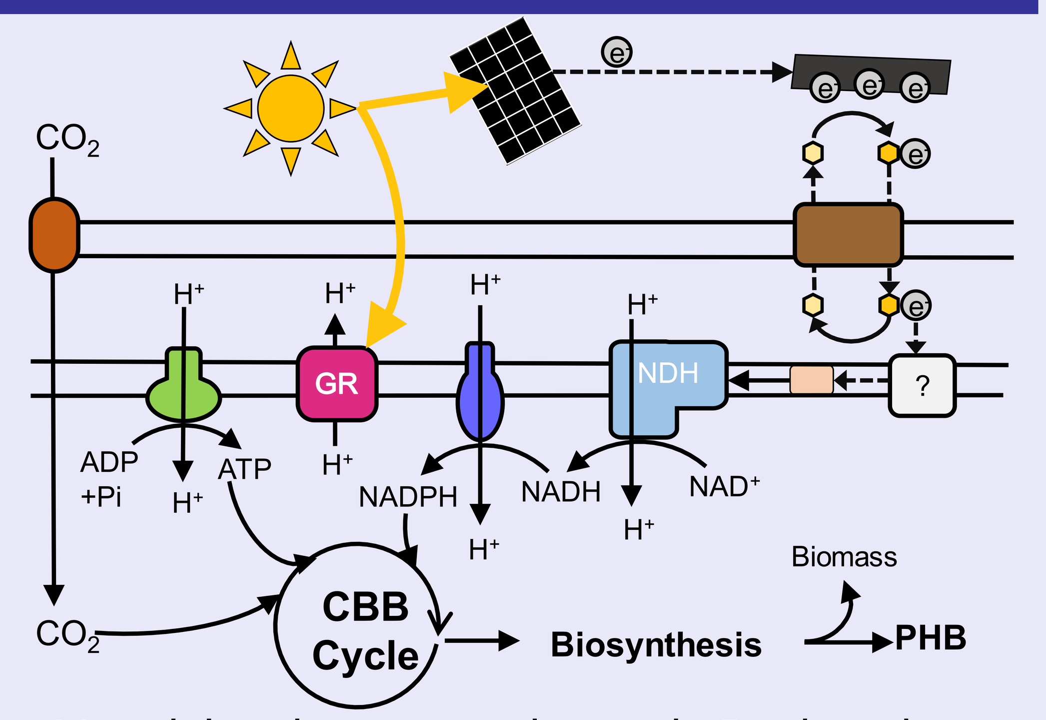
INTRODUCTION

Ensuring a sustainable future for humanity is incumbent on solving the need for efficient (low cost and minimal waste) industrial scale energy and production, while responding to global warming. Bio-Electrochemical Carbon Capture (BECC) has the potential to capture and utilize atmospheric CO_2 to produce Valuable Bioproducts using solely water and renewable energy, and by engineering an artificial light harnessing pathway cell metabolism can be further enhanced.



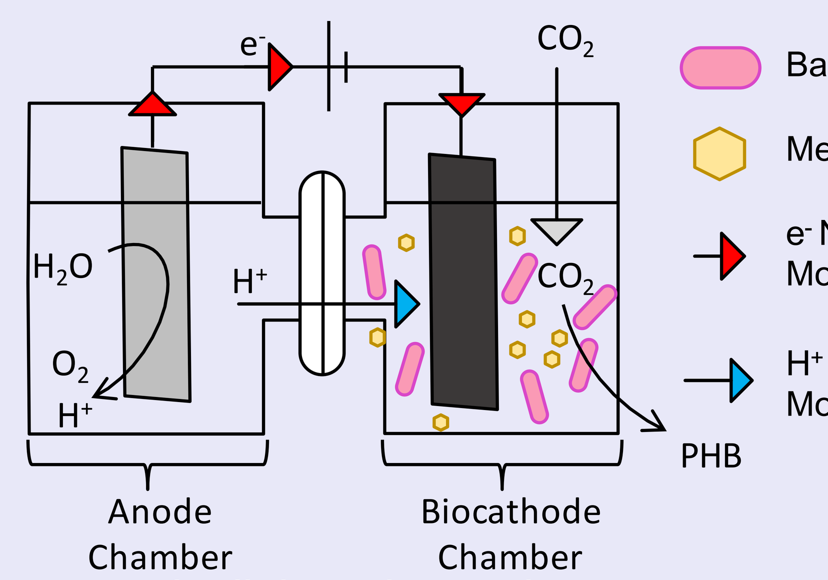
Material and energy pathways in Designed BECC

Going into this project we had three key aims:

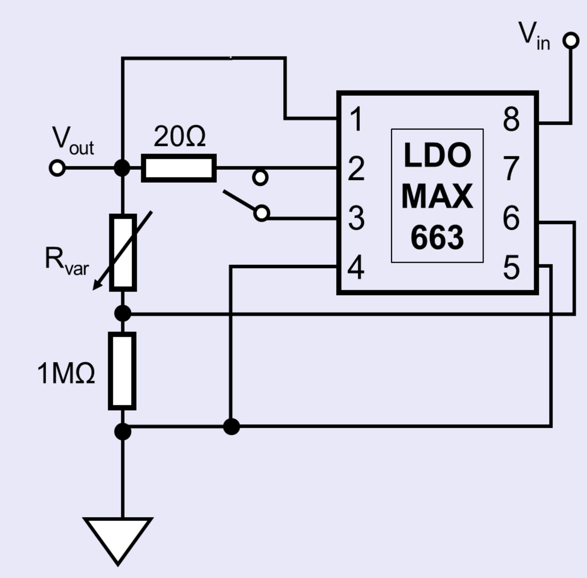
1. **Verify** the ability of an engineered light harnessing pathway to enhance cell metabolism
2. **Model** dynamics to guide optimization, discover bottlenecks and assess performance
3. **Test** solutions to bottlenecks, and iteratively improve performance

METHODS

To assess microbial carbon utilization potential, we used a dual chamber H-Shaped reactor with gaseous CO_2 as the carbon source in minimal media. White light with intensity of that at sunrise, was used to assess the effect of the artificial photosynthetic pathway. To ensure a constant voltage we designed built and tested a voltage regulator. To guide and accelerate electrode design we modelled cathode chamber electrodynamics using a top-down approach, both on the meso and macro-scopically. Thus, allowing simultaneous optimization of both biological and materials aspects within the limited timescale provided.



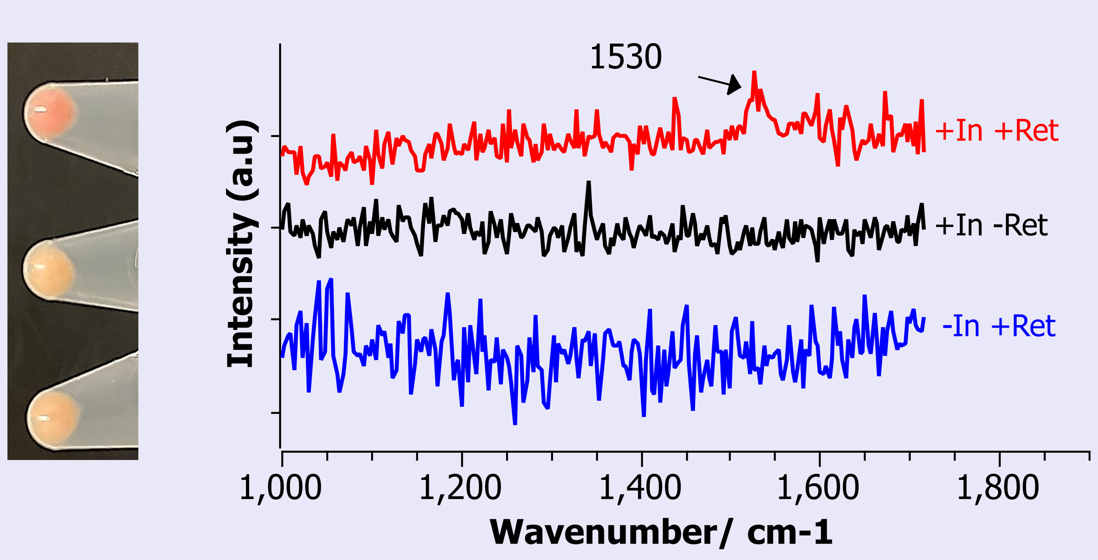
Set up for light Enhanced BECC



Voltage Regulator Designed

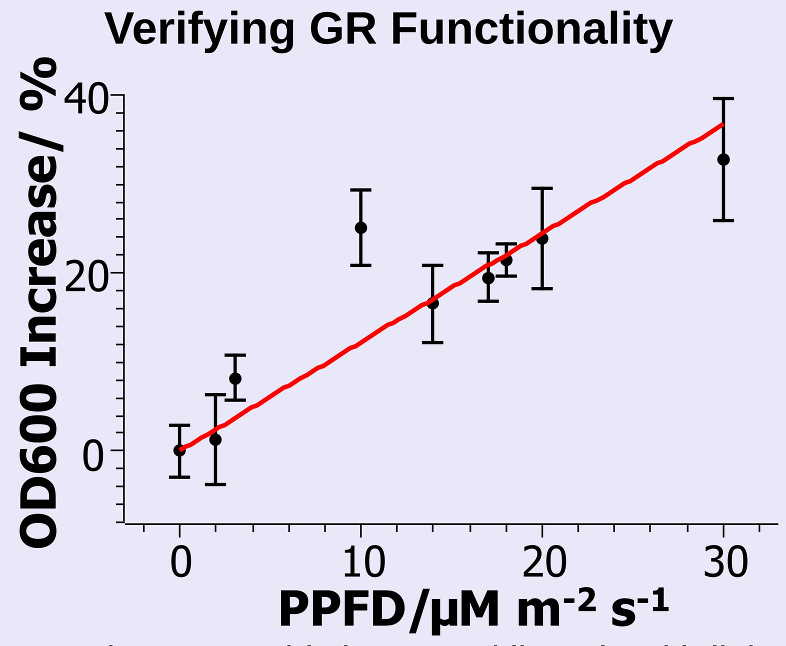
ENGINEERING A LIGHT HARNESSING PATHWAY

Gloeobacter rhodopsin (GR) Expression Verification



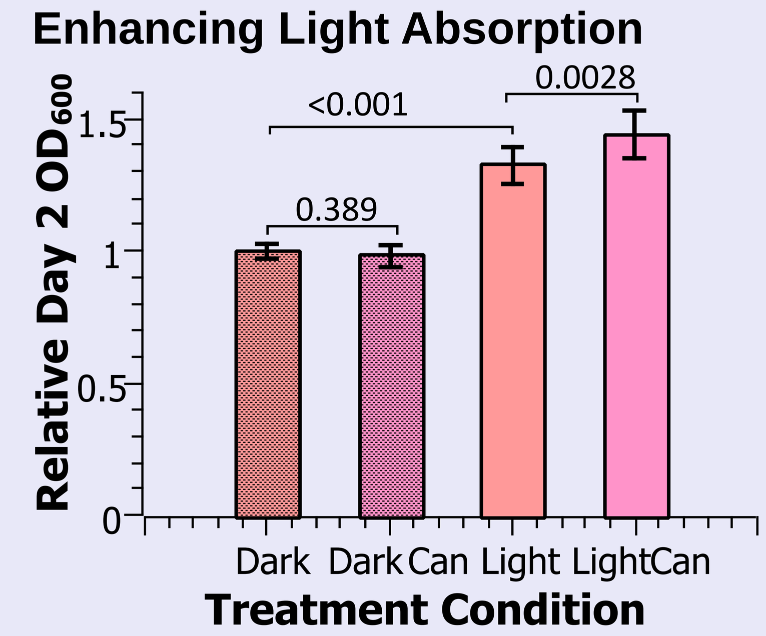
GR expression led to a vibrant pink color & an observed vibrational signature at 1530 cm^{-1} using Single Cell Raman

Verifying GR Functionality



Growth was roughly increased linearly with light demonstrating GR coupling to cell metabolism

Enhancing Light Absorption



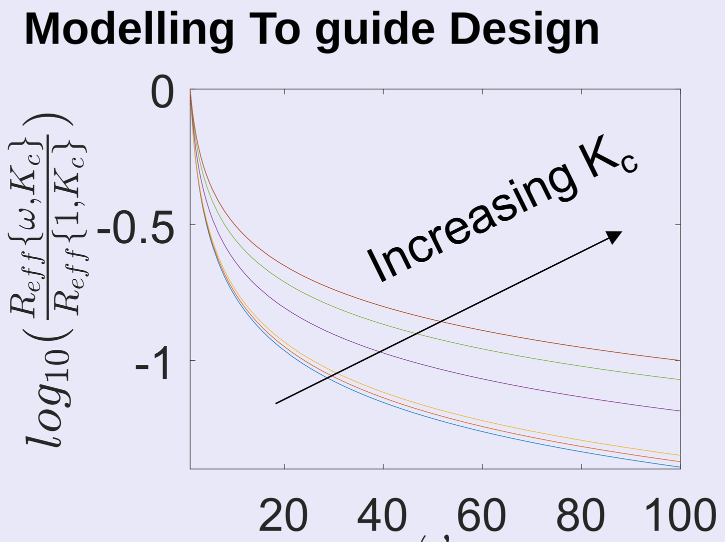
Addition of Canthaxanthin further enhanced growth by 10%

SynBio

1) GR Phenotype Expression was verified by the distinct pink color and Raman shift
2) GR Functionality Was Verified by observing that increasing illumination increased growth rate
3) GR Functionality Was Enhanced by adding a Carotenoid broadening absorption spectra

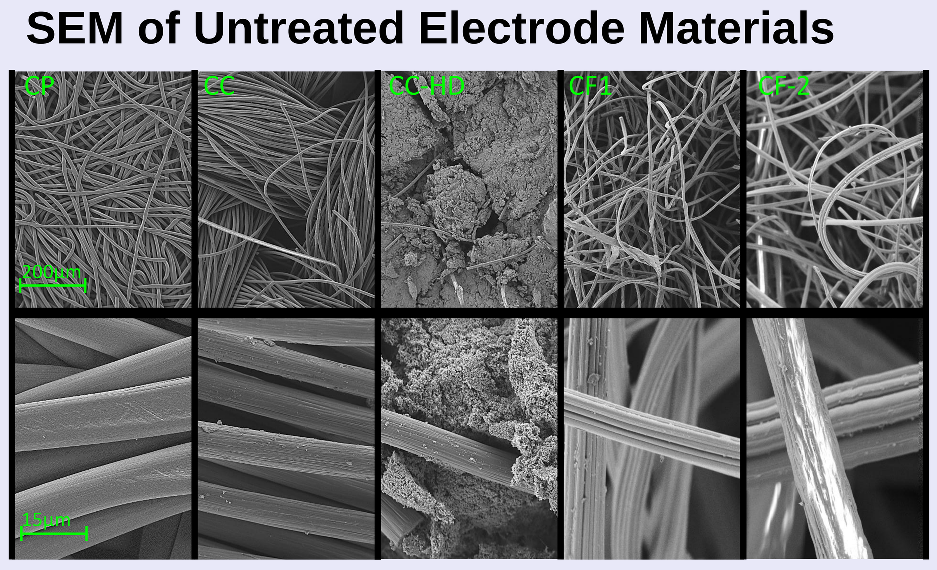
MODELLING TO CHOOSE THE ELECTRODE MATERIAL

Modelling To guide Design



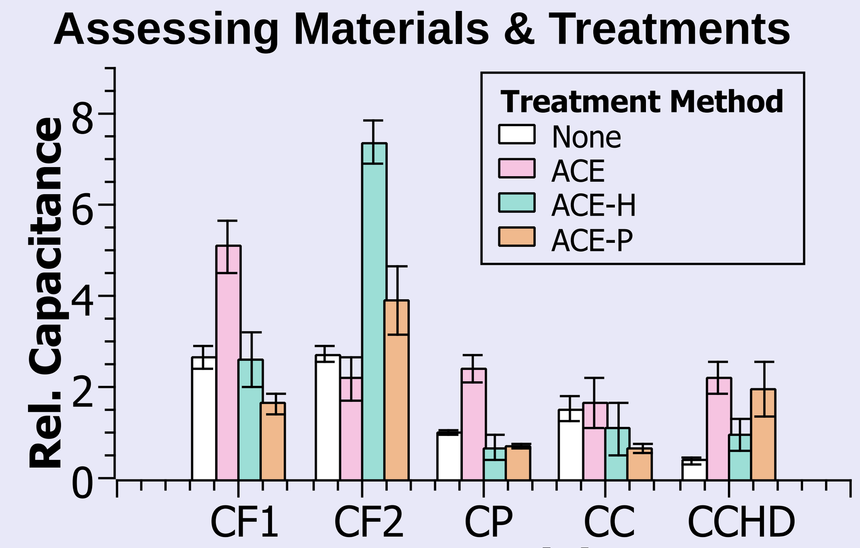
High Specific Surface Area(ω) Reduced Losses in developed Models

SEM of Untreated Electrode Materials



Carbon felt has a high void fraction and high observed surface roughness suggesting it performs well

Assessing Materials & Treatments



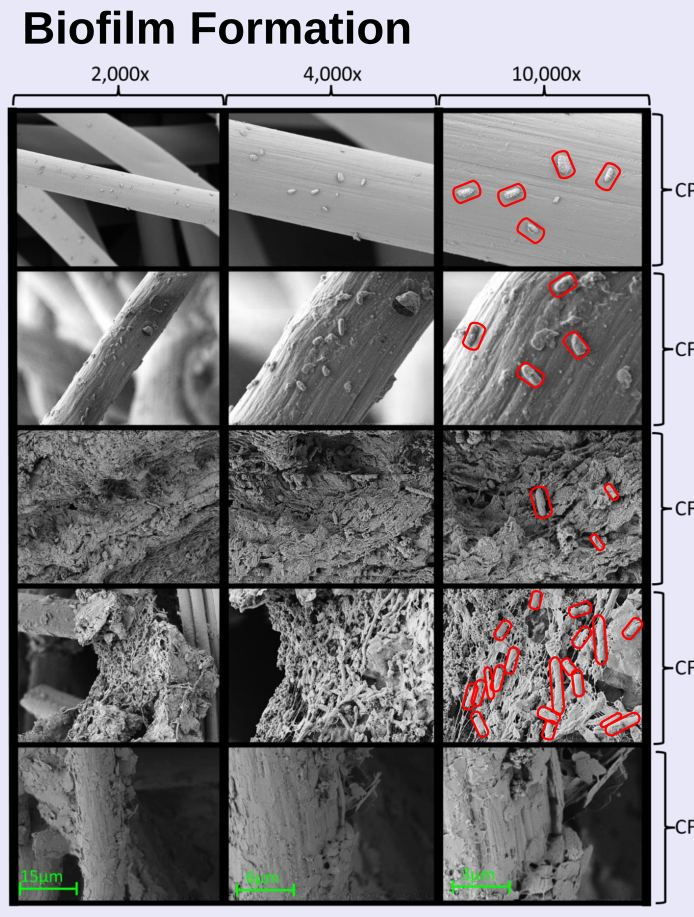
As expected, Carbon felt had the highest capacitance, and hence highest surface area, for all treatments

Model

1) Modelling Predicted that increasing high surface area and porosity reduce losses
2) SEM revealed the highly porous structure of carbon felt
3) Capacitance was used to measure relative surface area of different materials with different treatment methods

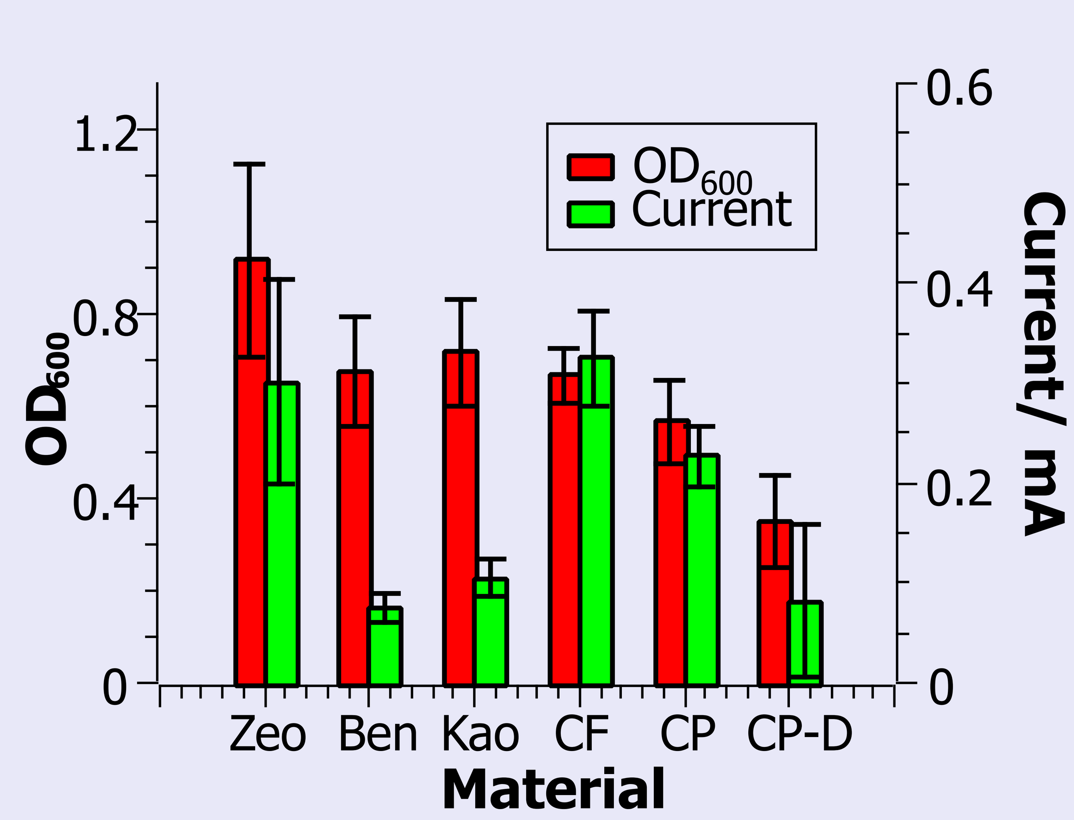
ENHANCING THE ELECTRODE MATERIAL

Biofilm Formation



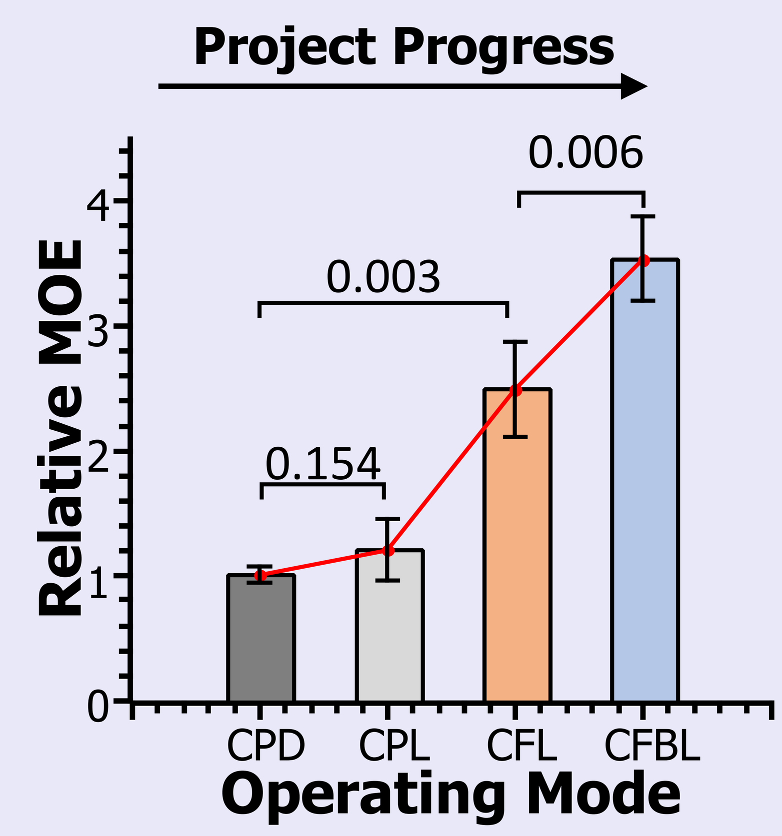
SEMs of Fixated Biofilms showed that Bentonite greatly enhanced biofilm formation

Batch Testing Of Modified Material



Bentonite was seen to significantly reduce current draw while not reducing media bacterial density

Semi Batch System with CO_2 Flow



Through combined Genetic engineering & Materials engineering, Growth per Unit current almost quadrupled

Enhance

1) Coating Carbon felt with Bentonite Was seen to significantly increase biofilm formation
2) Under Batch Experiments Bentonite Modified Electrodes showed the greatest Growth per unit current
3) Bentonite modified Carbon felt Electrodes With a Light Harnessing pathway more than tripled growth per unit current

CONCLUSION

By engineering a light harnessing pathway and using modelling to guide electrode design and enhancement we more than tripled growth per unit current, increasing the Viability of BECCU