CAB Extraction: A Synthetic Biology Approach to Microbial Enhanced Oil Recovery

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Increasing global oil demands require new, innovative technologies for the extraction of unconventional oil sources such as those found in Alberta’s Carbonate Triangle. Carbonate oil deposits account for almost 50% of the world’s oil reserves and approximately 20% of the bitumen found in Alberta. Due to unstable oil prices in Western Canada, these vast reserves have historically been set aside in favor of less time consuming, more economical sites. Microbial enhanced oil recovery (MEOR) has been utilized across the world to increase the productivity of difficult resources including carbonate oil deposits.

Using a synthetic biology approach, we have designed the CAB (CO2, acetic acid, and biosurfactant) extraction method that demonstrates a modified MEOR method for extracting carbonate oil deposits. CAB extraction will utilize the natural carbon fixation machinery in the cyanobacteria Synechococcus elongatus to convert CO2 into sugars to fuel acetic acid and biosurfactant production in Escherichia coli. Acetic acid applied to carbonate rock increases the pore sizes and allows for enhanced oil recovery. The reaction produces gases that will help pressurize the well site to facilitate extraction. The natural biosurfactant rhamnolipid will also be applied to the carbonate rock to further enhance extraction yields.

By coupling carbon capture with acetic acid and biosurfactant production, carbonate oil deposits can be mined with reduced greenhouse gas emissions. The use of carbon fixation to feed downstream systems can be tailored for use as a module in many applications requiring inexpensive methods for fueling biological systems. CAB extraction will be suitable for large-scale bioreactors, providing an alternative, inexpensive, and environmentally sustainable method for MEOR from Alberta’s oil deposits. Furthermore, developing the carbon capture module will be of interest in oil extraction strategies using steam, as it will help with the mitigation of CO2 release caused by steam production using, for example, natural gas.

Glucose Production and Transport: We exploited the carbon fixation pathway that is naturally found in S. elongatus for glucose production by introducing a set of genes encoding for proteins that will produce and transport glucose out of the cell. To do this, we implemented Invertase A (invA) from Zymomonas mobilis that cleaves sucrose into glucose and fructose, as well as GalU that promotes an auxiliary pathway that results in additional sucrose synthesis for enhanced glucose production. For glucose transport, we will employ a GfL (glucose facilitator) protein that also originates from Z. mobilis and exports the intracellular glucose into the surrounding medium.

Acetic Acid Production: An E. coli chassis is integrated with an enhanced glucose dependent acetic acid production and transport system. Typically, extracellular glucose diffuses into the cell and is oxidized into pyruvate and converted to acetyl-CoA through glycolysis. However, the introduced acetic acid module modifies this pathway by utilizing the acetyl-CoA as a substrate for acetic acid production. First, phosphotransacetylase (PTA) catalyzes the chemical reaction of acetyl-CoA into acetyl-phosphate (acyt-P). As a result of the relative abundance of acetyl-P, the kinase (ACK) will convert acetyl-P into acetate. The membrane-bound acetic acid transporter (AacA) then exports the acetate into the extracellular medium.

Figure 1. Growth of S. elongatus monitored by optical density at 750 nm, grown with and without aeration provided by a CO2 bubbler. Data reflects one trial.

Figure 2. 12% SDS-PAGE analysis of overexpression of ACK by E. coli. Lane numbers indicate time in hours after induction with IPTG. L indicates ladder. The expected size of ACK is 43 kDa, indicated by the red box.

Figure 3. Acid concentration present in glucose supplemented LB media inoculated with E. coli. n=3, error bars indicate SD.

Figure 4. Growth curves of E. coli in glucose-supplemented LB media. Data reflects one trial and was fit using a single exponential function.

References:
1. Wyrall, D. W. Emerging Solutions for Heavy Oil Production from Carbonates. (TAMG Oil and Gas Corp., 2008).

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