4th Micro and Nano Flows Conference
UCL, London, UK, 7-10 September 2014

Microfluidics for Energy Applications

David SINTON

* Corresponding author: Tel.: ++1 416 978 1623; Fax: ++1 416 978 7753; Email: sinton@mie.utoronto.ca
1 Department of Mechanical and Industrial Engineering, University of Toronto, 5 King's College Rd,
Toronto, Ontario M5S 3G8, Canada

Abstract Microfluidic methods developed primarily for medical applications have much to offer energy applications. This short paper will provide the motivation and outline my group's recent work in two such areas: (1) microfluidics and optics for bioenergy and (2) microfluidics for carbon management. Full details will be provided in talk. Within the bioenergy theme, we are developing photobioreactor architectures that leverage micro-optics and microfluidics to cater both light and fluids to maximize productivity of microalgae. Within the carbon management theme we are developing a suite of methods to study pore-scale transport and reactivity in carbon sequestration and enhanced oil recovery. Results indicate potential for order of magnitude gains in photobioreactor technology and a 100-fold improvement over current subsurface fluid transport analysis methods.

Keywords: Microfluidics, Optofluidics, Bioenergy, Carbon Management, Porous Media

1. Introduction

As outlined in a recent review by our group, and references therein [1], there are tremendous opportunities for microfluidic (and nanofluidic) technologies in energy applications. In fact, global energy is largely a fluids problem. However, it is also large-scale, which is in stark contrast to microchannels.

In order to provide value, microfluidic energy technologies must offer either massive scalability or direct relevance to energy processes already operating at scale. Areas where microfluidics can have impact in energy applications are outlined schematically in Figure 1. Notably, these applications can be divided into (1) Surface operations making use of solar or electrochemical energy and (2) Sub-surface operations informing carbon sequestration and oil/gas recovery operations with respect to transport and reactivity of fluids underground.

Within these classifications, our group is focused on (1) improving bioenergy operations – specifically biofuel generation from solar energy leveraging photosynthetic microorganisms, or algae; and (2) informing subsurface operations for carbon sequestration in saline aquifers as well as oil recovery operations.

The bioenergy work focuses on improving photobioreactor technology through both catering to photosynthetic organisms light and fluid needs – on the scale of the cell – as well as developing optofluidic systems to screen conditions. The cultivation of photosynthetic bacteria on waveguides has been demonstrated on a prism, flat plate waveguide, fiber and also metallic substrates supporting surface plasmons. The plasmonic approach also enables the combined light-delivery and electron-collection from photosynthetic microorganisms. Such a plasmonic-bio-voltaic cell is a first. We are also pursuing plasmonic approaches analogous to those employed to improve photovoltaics. Specifically, we are incorporating nanoplasmonic particles and films inorder to tune wavelengths and locally deliver light energy to biology. The optofluidic system for screen light and fluid conditions is based on an LCD display, effectively providing 1000s of controllable light sources (pixels). Reactors incorporating nine such pixels in a two-dimensional array enables the assessment of, for instance, light intensity and wavelength (or a mixture of wavelengths, or wavelength and blinking frequency).

The carbon management work, leverages

the control and imaging capabilities offered microfluidics to inform subsurface operations. Notably also, these microfluidic systems are capable of high pressures and temperatures (30 MPa and 300C, for instance) due to the small scale of the channels, which provides an inherent advantage over macroscale testing systems in terms of cost and complexity. It is also possible to mimic the physical pore sizes relevant to reservoirs. We have performed a pore-scale analysis of well-bore dryout during CO_2 injection into a saline aquifer, developed a chip-based approach for the study of carbon dioxide transport and reactivity in reservoirs, quantified nanoparticle-stabilized CO_2 foams for enhanced oil recovery, determined the dew and bubble points in industrially-relevant CO_2 mixtures as well as determined the diffusivity of CO_2 in heavy oils. Collectively this work is motivated by the need to manage carbon emissions while developing and scaling renewable energy technologies – both areas where the microfluidics community can contribute.

[1]* Sinton, D. “Energy: The Microfluidic Frontier” *Lab-on-a*-Chip, 14 (17), 3127-3134 (2014). * [and references therein]

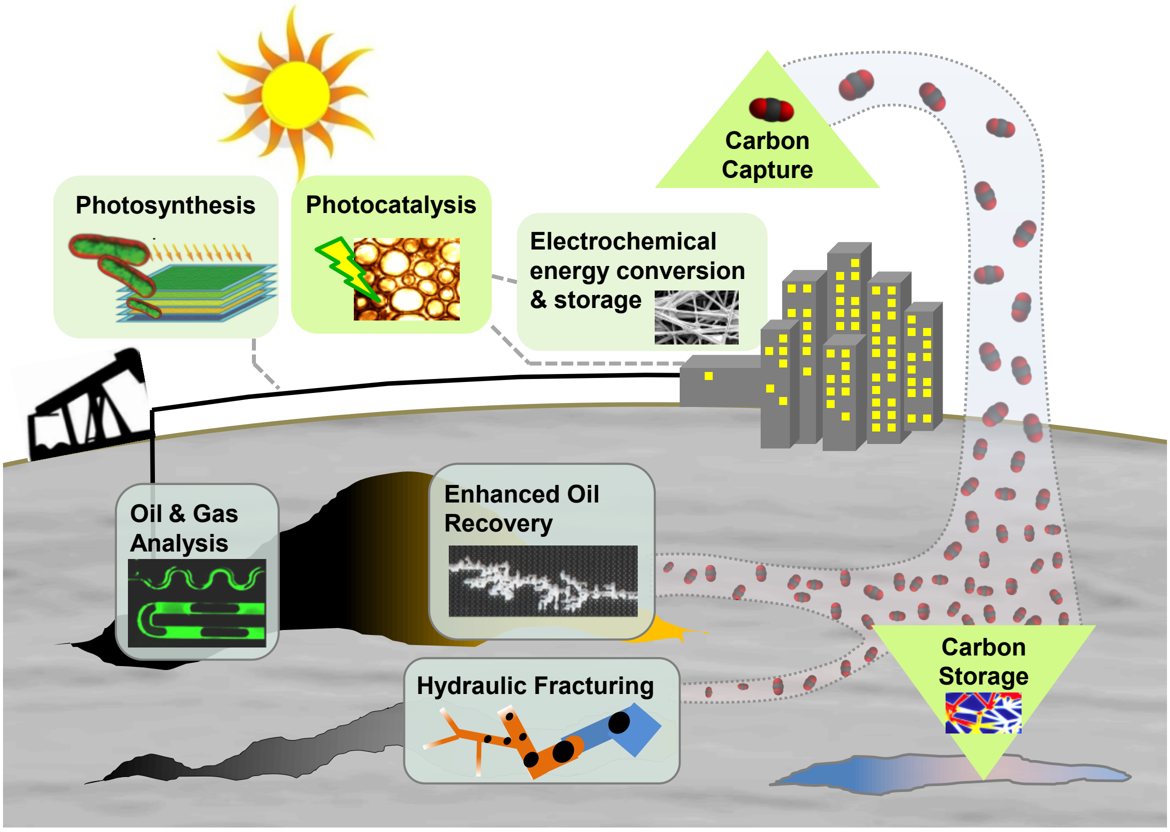

Fig. 1 Overview of current and envisioned energy applications for microfluidics, including both surface and sub-surface operations. [1] Reproduced by permission of The Royal Society of Chemistry.