

Energy Modules for the ChE Curriculum

Jason Keith¹, Tom Edgar²

Gavin Towler³, Scott Fogler⁴, Dan Crowl¹,
David Allen², and Darlene Schuster⁵

¹Michigan Technological University

²University of Texas at Austin

³UOP

⁴University of Michigan

⁵American Institute of Chemical Engineers



Outline

- Project History and Motivation
- Module Content
- Module Location
- Module Detail
- Future Directions
- Conclusions / Acknowledgments

Project History and Motivation

- Project began in 2006 with a focus on fuel cell education
- Involved collaboration between 4 institutions
- Website hosted at Michigan Technological University
- Expansion into other energy areas underway
 - Need to educate ChE's in this area
 - Provide modules to quickly bring energy concepts to ChE curriculum

Module Content

- Most applicable ChE course
- Reference to related sections of ChE texts
- Problem motivation
- Background
- Example problem statement
- Example problem solution
- Home problem statement
- Home problem solution

Module Location

- Energy modules are online and available for use by everyone – see the project website:

<http://www.chem.mtu.edu/~jmkeith/energy>

or

<http://tinyurl.com/energymods>



Module Detail

- Module subject areas:
 - Hydrogen and Fuel Cells
 - General Energy Analysis
 - Wind Energy
 - Water Energy
 - Solar Energy
 - Biomass Energy
 - Coal Energy

Module Detail

- http://www.chem.mtu.edu/~jmkeith/fuel_cell_curriculum

Fuel Cell Curriculum Project: Chemical Engineering - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://www.chem.mtu.edu/~jmkeith/fuel_cell_curriculum/

Most Visited Getting Started Latest Headlines

The Fuel Cell Curriculum Project Website

C A C H E

About This Project	Chemical Engineering Courses	Mechanical Engineering Courses	Electrical Engineering Courses	Project Sponsors
------------------------------------	--	--	--	----------------------------------

Welcome to the Fuel Cell Curriculum Project Website. The goal of this project is to develop modules that bring fuel cell technology into the traditional chemical engineering undergraduate curriculum. The site allows faculty members around the world to have easy access to these modules.

The following table lists chemical engineering courses and the related modules. Each module contains a brief background or motivation, an example problem with a solution, and a homework problem. For access to the homework problem solutions, please contact Jason Keith by email at jmkeith@mtu.edu.

Introductory Material Module 0: Overview of Hydrogen Energy and Fuel Cells
Material and Energy Balances (Stoichiometry) Module 1: Heat of Formation for Fuel Cell Applications Module 2: Material Balances in a Solid Oxide Fuel Cell Module 3: Energy Generation in a Solid Oxide Fuel Cell Module 4: Generation of Electricity Using Recovered Hydrogen
Thermodynamics Module 5: Equation of State for Hydrogen Fuel Module 6: Equilibrium Coefficient and Van't Hoff Equation for Fuel Cell Efficiency Module 7: Fuel Cell Efficiency Module 8: Vapor Pressure / Humidity for Fuel Cell Gases Module 9: Nernst Equation
Fluid Mechanics

Done

start Fuel Cell Curriculum P... DOE merit review ma... Microsoft PowerPoint ... 12:33 PM

Module Detail

- Hydrogen and Fuel Cells
 - Chemical Engineering is “complete” with 38 modules but new content is still being added under DOE project
 - Also includes fuel processing by steam reforming
 - Mechanical Engineering has 17 modules with additional modules under development
 - Electrical Engineering has 6 modules with additional modules under development

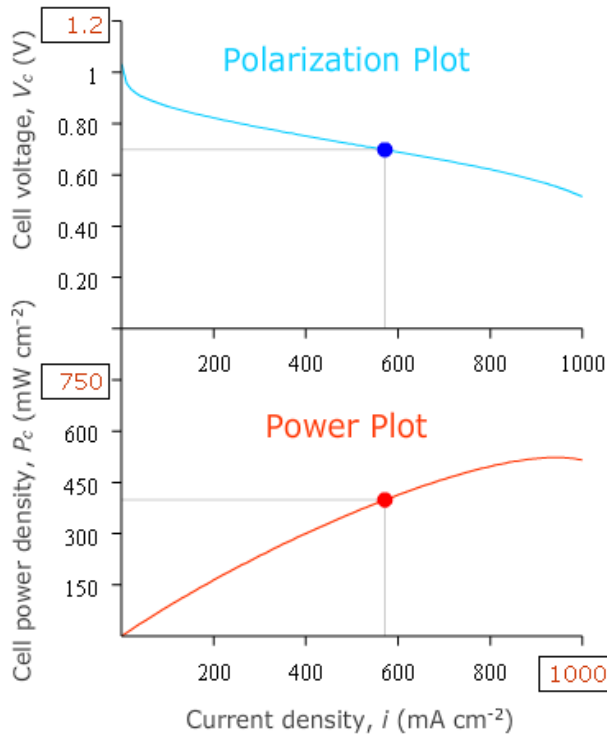
Fuel Cell Calculator

<http://tinyurl.com/FCabacus>

Hydrogen Fuel Cell Power and Voltage Calculator


v 1.0

Current 4.00 A Voltage 0.70 V Power 2.79 W



INPUT

Choose the current, cell area, number of cells, and cell voltage equation constants.



Number of cells, $n =$ $E_{oc} =$ V
Current, $I =$ A $r =$ $\times 10^{-4}$ k Ω cm²
Cell area, $A =$ cm² $A_c =$ $\times 10^{-2}$ V
 $m =$ $\times 10^{-5}$ V
 $n_c =$ $\times 10^{-3}$ cm² mA⁻¹

Current density, $i =$ 5.714e2 mA cm⁻²

Cell power density, $P_c =$ 3.992e2 mW cm⁻²

Cell voltage, $V_c =$ 6.985e-1 V

Stack voltage, $V =$ 6.985e-1 V

Stack power, $P =$ 2.794 W

Hydrogen consumption = 4.146e-5 g H₂ s⁻¹

ENTER

RESET

MichiganTech

Update the graph ranges. Copyright 2009 Dr. Jason Keith, Department of Chemical Engineering, Michigan Technological University.

Input boxes: number of cells, stack current, and fuel cell cross-sectional area
Adjust parameters to move a point along a polarization plot and power density plot
Calculated parameters include voltage, power, and hydrogen consumption rate

Module Detail

- General Energy Analysis (J. Keith, D. Crowl)
 - Stoichiometric Analysis of Fuel Combustion
 - Energy Value of Fuels
 - Hydrogen Production Cost
 - Fuel Energy Cost and Energy Density
 - Hydrogen Flammability
 - Theoretical Fuel Consumption and Power

Module Detail

- General Energy Analysis (J. Keith, D. Crowl)
 - Energy Consumption Analysis
 - Energy Efficiency Analysis
 - Energy Emissions Analysis
 - Battery Energy Analysis
 - Battery / Fuel Cell Vehicle Range

Module Detail

- Testing of modules by J. Keith in CM3977
Fundamentals of Hydrogen as an Energy Carrier
- Energy Knowledge Survey
 - IRB approval
 - Pre-test / Post-test
 - Also used by T. Edgar at UT

Biodiesel Reaction Calculator

v 1.0

RAW MATERIALS

PRODUCTS

Soybean Oil
Triolein

Methanol



Biodiesel
Methyl Oleate

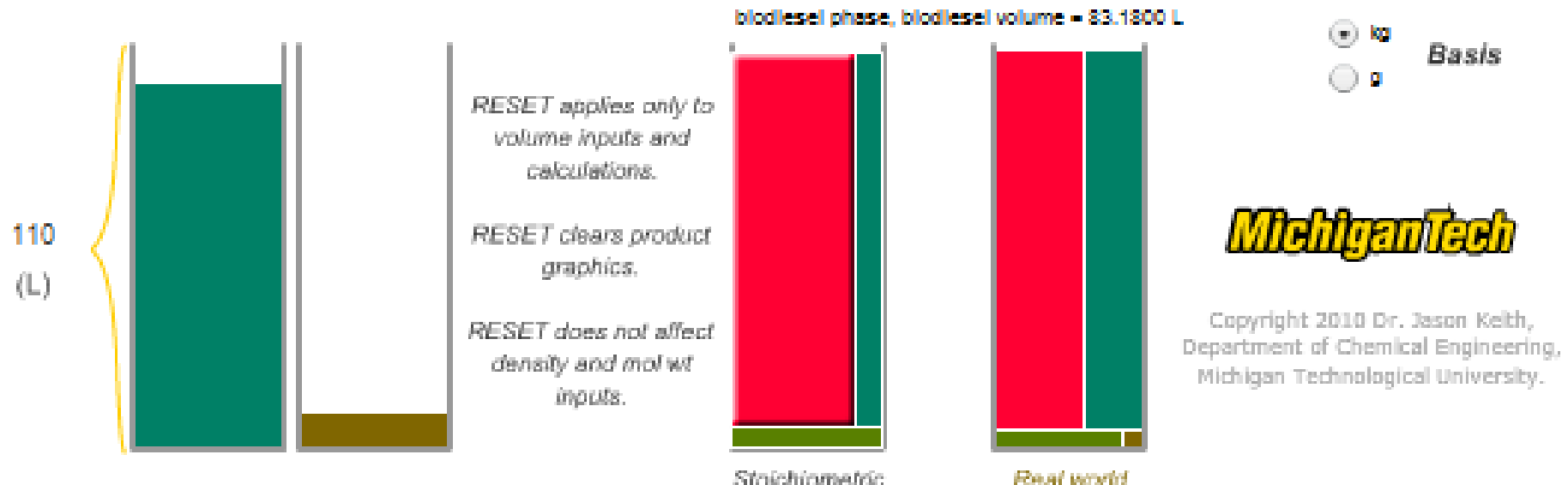
Glycerol

Soybean Oil
Triolein

Methanol

Ratio
Main Product/Byproducts

Volume (L)	<input type="text" value="100"/> <i>Hit ENTER</i>	<input type="text" value="10"/> <i>Hit ENTER</i>	REACT	83.1800	6.01513	19.0378	0	3.32
			RESET	62.3850	4.51135	39.2784	2.50000	1.35
Density (g/cm ³)	<input type="text" value="0.90"/>	<input type="text" value="0.79"/>		<input type="text" value="0.88"/>	<input type="text" value="1.26"/>	0.90	0.79	<i>Stoichiometric values are shown.</i>
Mol Wt (g/mol)	<input type="text" value="885.46"/>	<input type="text" value="32"/>		<input type="text" value="296.50"/>	<input type="text" value="92.10"/>	885.46	32	<input checked="" type="checkbox"/> <i>Display real world values.</i>
Mass (kg)	90	7.90000		73.1984	7.57906	17.1340	0	2.96
				54.8988	5.68430	35.3505	1.97500	1.28
Moles (kg mol)	0.10164	0.24688		0.24688	0.08229	0.01935	0	2.43
				0.18516	0.06172	0.03992	0.06172	1.13



Path Forward

- Development of additional energy modules for CM3977
 - Modeling of coal gasification
 - Modeling of biomass gasification
 - Producing electricity / hydrogen from wind
- Collaboration with other CACHE Trustees
 - Energy Integration (JMK w/ Mahmoud El-Halwagi)
 - Plant design courses
 - Carbon Capture (JMK w/ Chau-Chyun Chen, Aspen)
 - Several modules planned spanning ChE curriculum

Path Forward

- Interaction underway with AIChE on energy modules in traditional and renewable sources, through collaboration with Darlene Schuster of Institute for Sustainability
 - Relationship between conventional and biofuels and thermodynamic efficiency in internal combustion engines , including life cycle assessment
 - Jeff Seay and David Silverstein, University of Kentucky
 - High temperature water splitting for hydrogen production using a sulfur-iodine thermochemical cycle
 - John O'Connell, University of Virginia

Conclusions / Acknowledgments

- Energy Modules are for your use!
- Contact one of the authors to participate
- Acknowledgments of Partial Support:
 - CACHE Corporation
 - JMK: DOE(DE-FG02-04ER63821 and DE-FG36-08GO18108), NSF(DMI-0456537), and the Michigan Space Grant Consortium



U.S. DEPARTMENT OF
ENERGY

<http://tinyurl.com/mtuh2ed>



CENTER FOR ENERGY INITIATIVES
An AIChE Technological Community