



**INSTITUTE OF HEAT ENGINEERING**  
**WARSAW UNIVERSITY OF TECHNOLOGY**



***Molten Carbonate Fuel Cell Fuelled by Biofuels***

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# Introduction



## Introduction

Biofuels

MCFC

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Fuels price inflation

Electricity consumption increase

Efficiency increase

Molten Carbonate Fuel Cell - MCFC

Hybrid Systems: ~250kW



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Currently, the fuel cells are fuelled by:

- hydrogen
- Natural Gas



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## Hydrogen

- not present in the environment in an unconnected form
- difficulties in: production, transportation, and storage

## Natural Gas

- limited resources



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Future?

1. Electricity instead of fuels
2. „Cultivation” of fuels



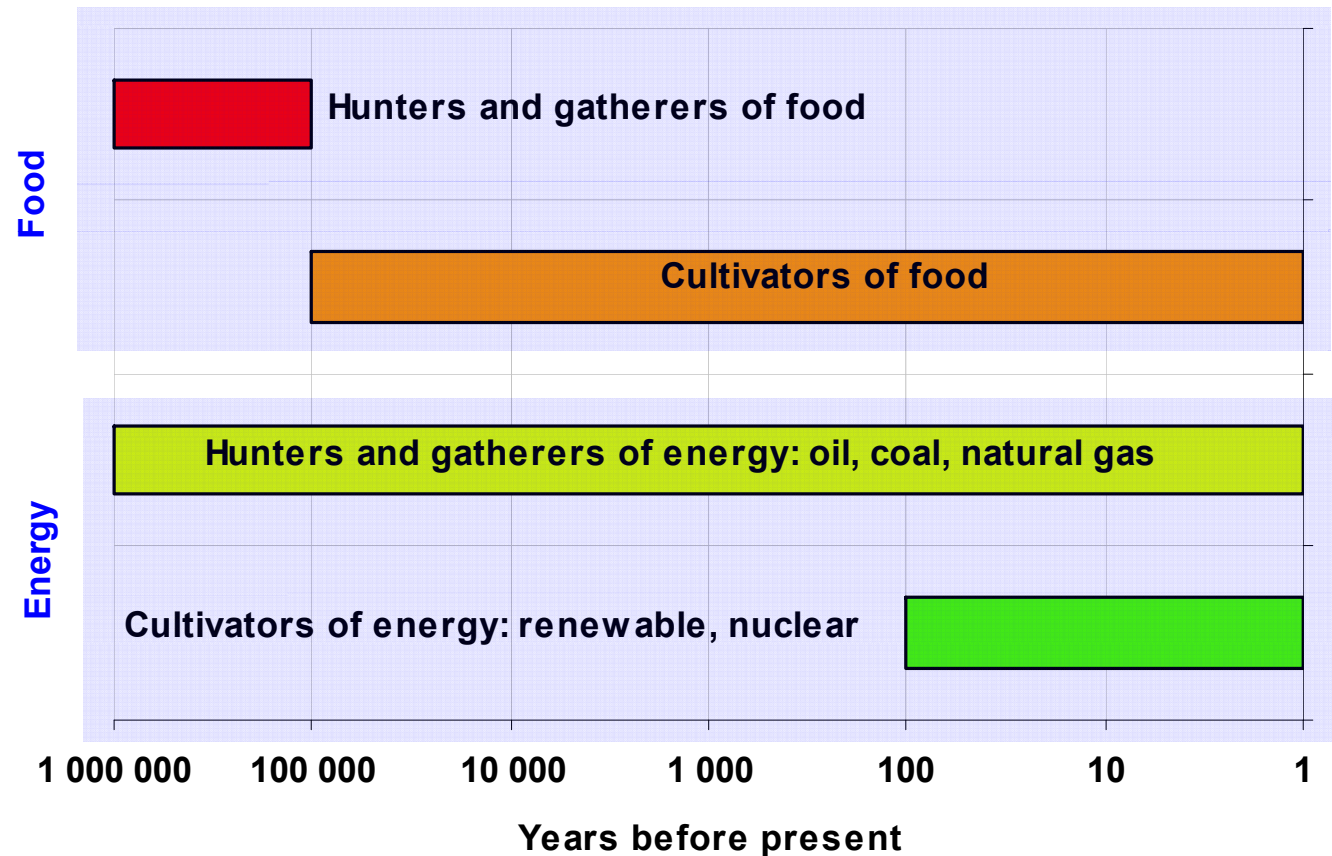
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# Biofuels



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- Gaseous
- Liquid
- Solid
- Others



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## Natural Gas and Hydrogen as reference fuels

- Anaerobic Digester Gas (ADG)
- Landfill Gas (LFG)
- Bio-Methanol
- Bio-Ethanol
- Canola Oil
- Wood



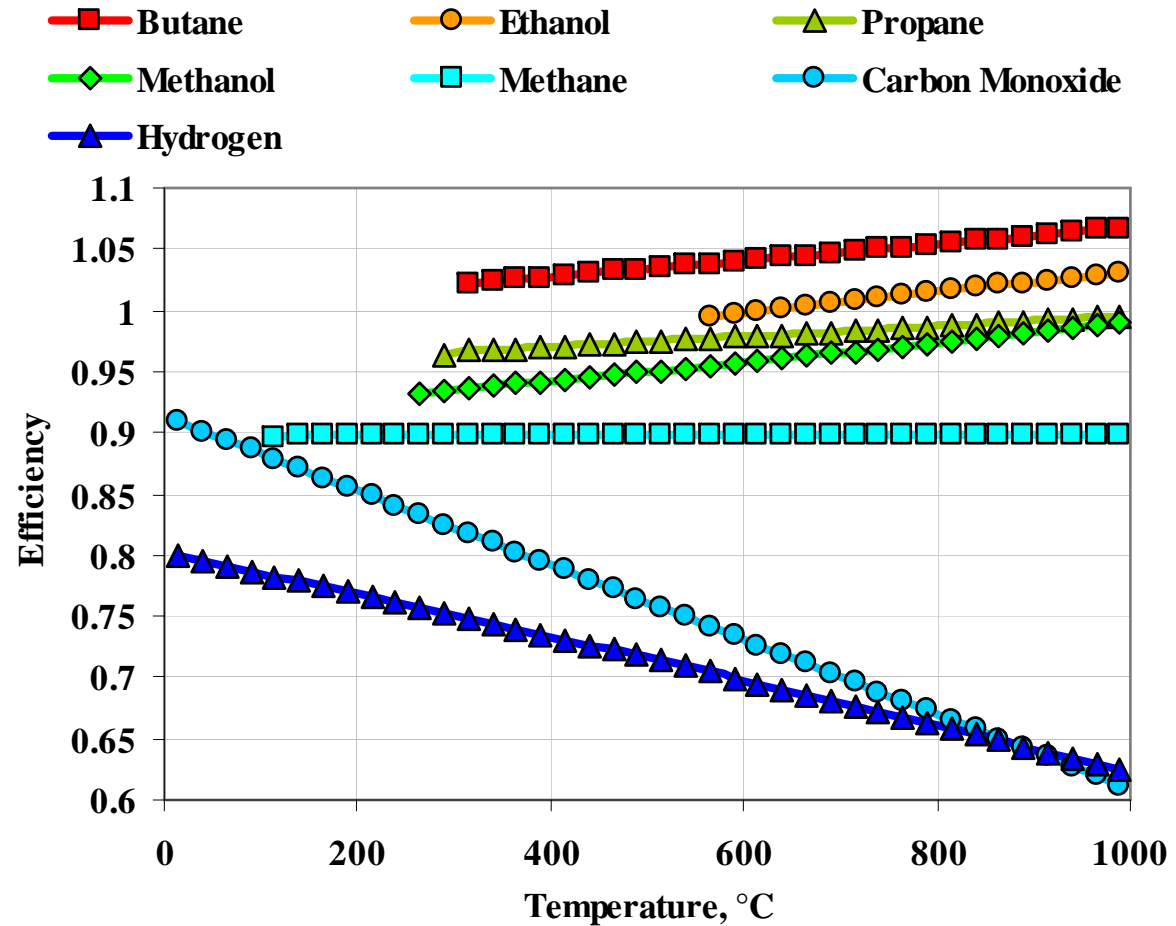
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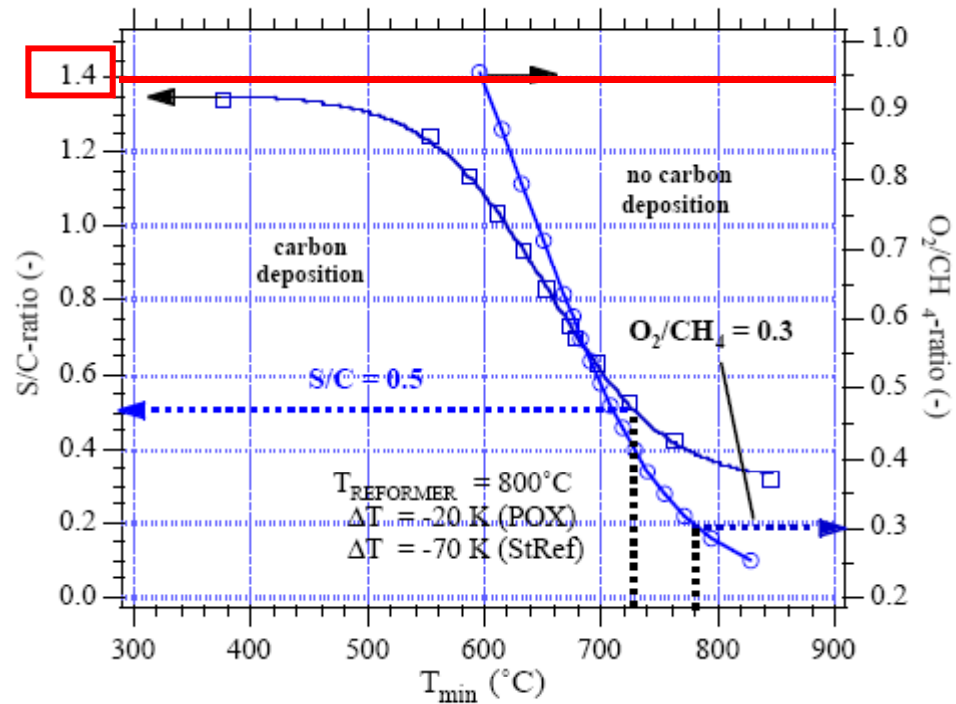
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$$s/c = \frac{n_{H_2O}}{n_{CH_4} + n_{CO}}$$





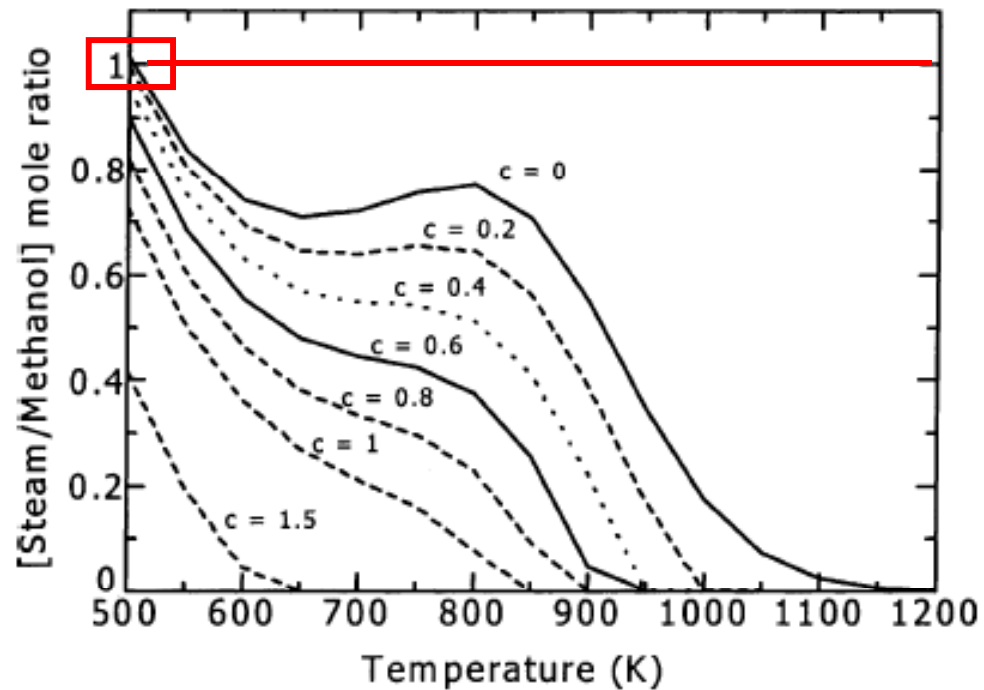
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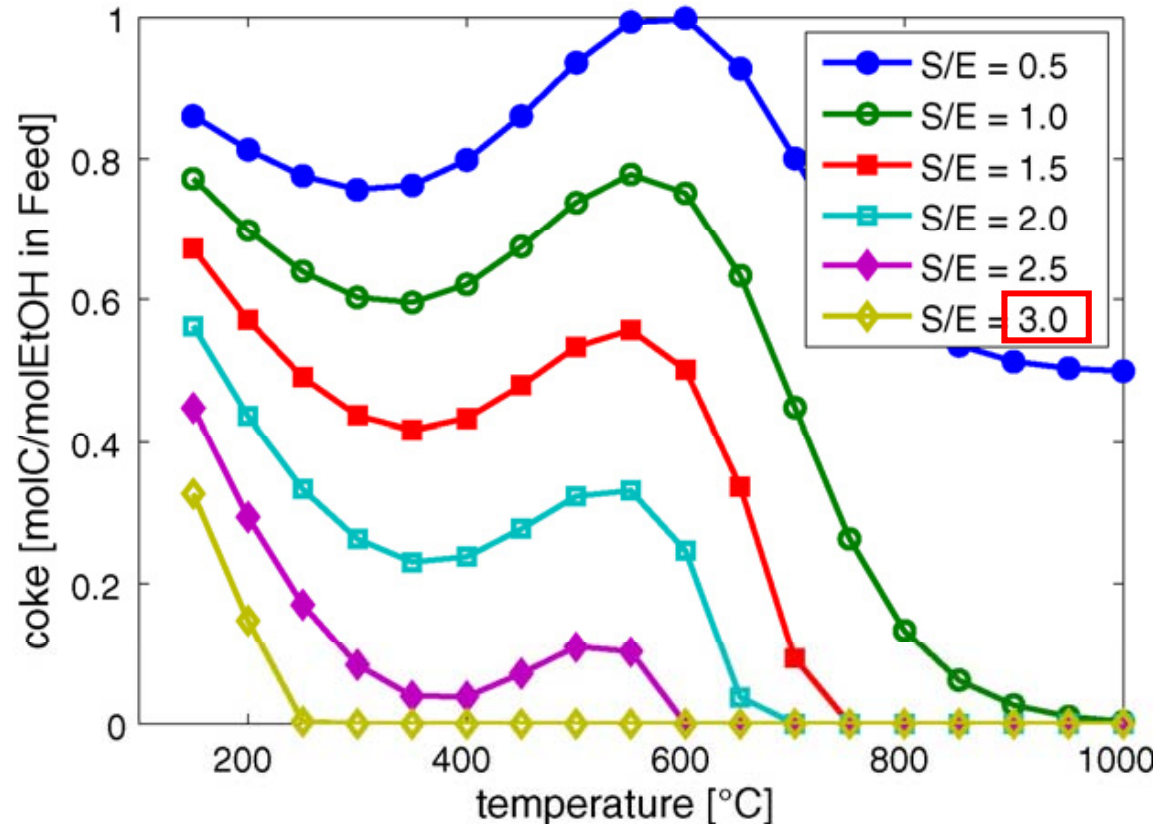
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# Maximum voltage for various chemical reactions



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Chemical reaction	Maximum voltage
	$E_{\max}$ , V
$H_2 + 1/2 O_2 \rightarrow H_2O$	1.23
$CH_4 + 2 O_2 \rightarrow CO_2 + H_2O$	1.06
$CH_3OH + 3/2 O_2 \rightarrow CO_2 + 2 H_2O$	1.22
$C_2H_5OH + 3 O_2 \rightarrow 2 CO_2 + 3 H_2O$	1.25
$C + O_2 \rightarrow CO_2$	1.03
$C + 1/2 O_2 \rightarrow CO$	0.72
$CO + 1/2 O_2 \rightarrow CO_2$	1.34



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	ADG	LFG	NG
	%		
CH <sub>4</sub>	62.8	54.0	69.4
CO <sub>2</sub>	35.2	33.0	-
H <sub>2</sub>	-	-	1.39
H <sub>2</sub> O	2.0	13	-
N <sub>2</sub>	-	-	29.21



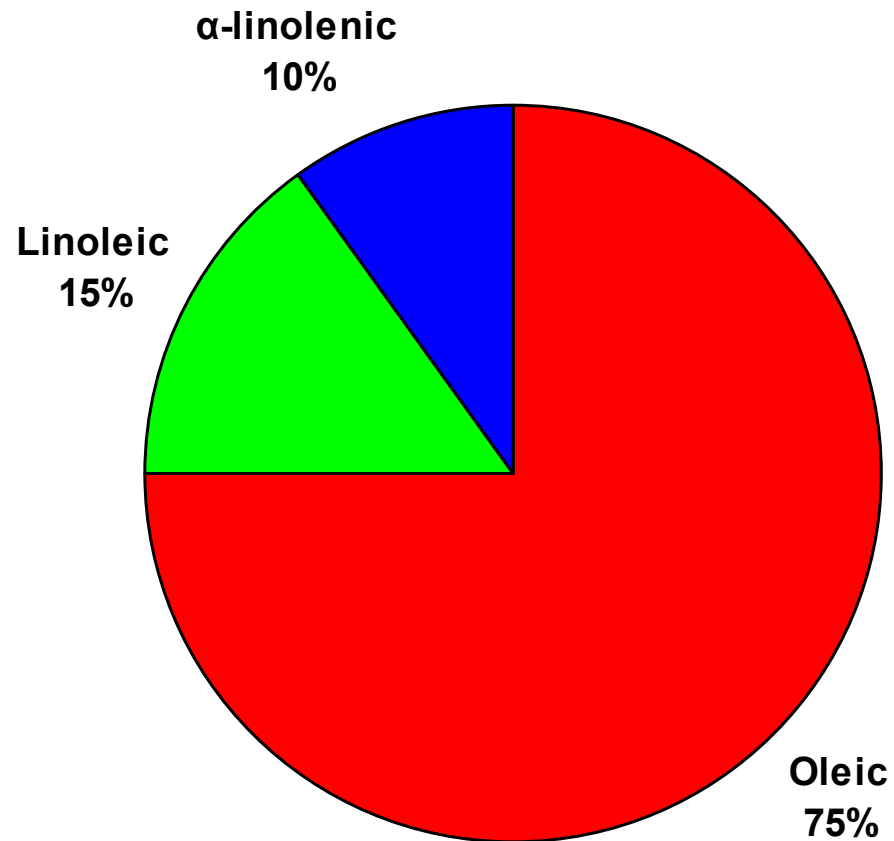
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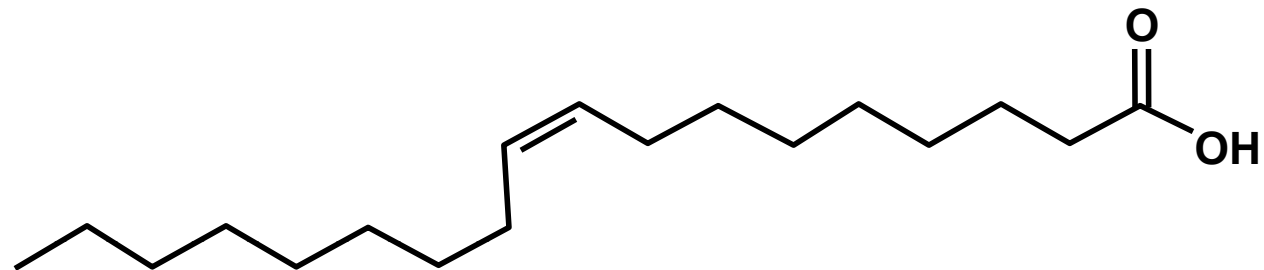
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CH <sub>3</sub> -(CH <sub>2</sub> ) <sub>7</sub> -CH=CH-(CH <sub>2</sub> ) <sub>7</sub> -COOH		
Parameter	Real value	Model
Density, kg/m <sup>3</sup>	895	892
Boiling temperature, K	633	487
Heat capacity, kJ/kg	2.1	1.9



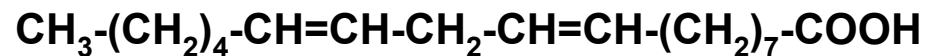
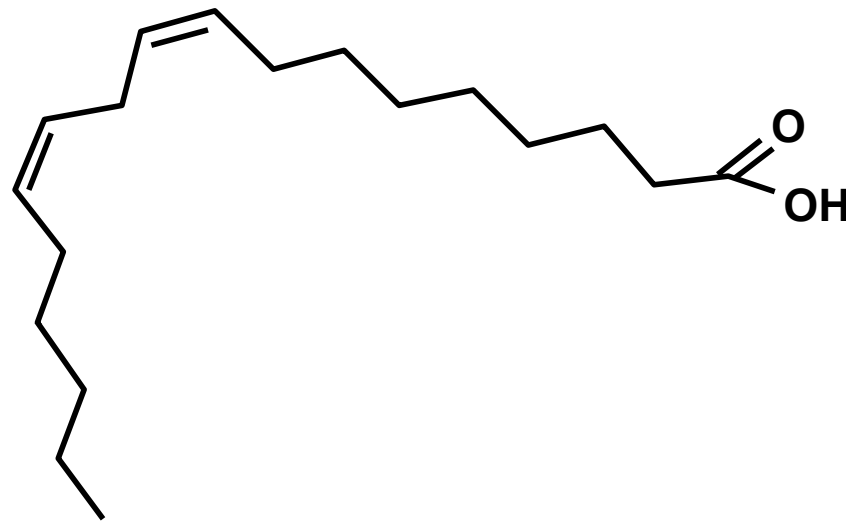
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Parameter	Real value	Model
Density, kg/m <sup>3</sup>	902	931
Boiling temperature, K	502	764
Heat capacity, kJ/kg	-	1.9



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$\text{CH}_3\text{-CH}_2\text{-CH=CH-CH}_2\text{-CH=CH-CH}_2\text{-CH=CH-(CH}_2\text{)}_7\text{-COOH}$		
Parameter	Real value	Model
Boiling temperature, K (4mmHg)	184	281
Heat capacity, kJ/kg	-	1.9
Density, kg/m <sup>3</sup>	916	907



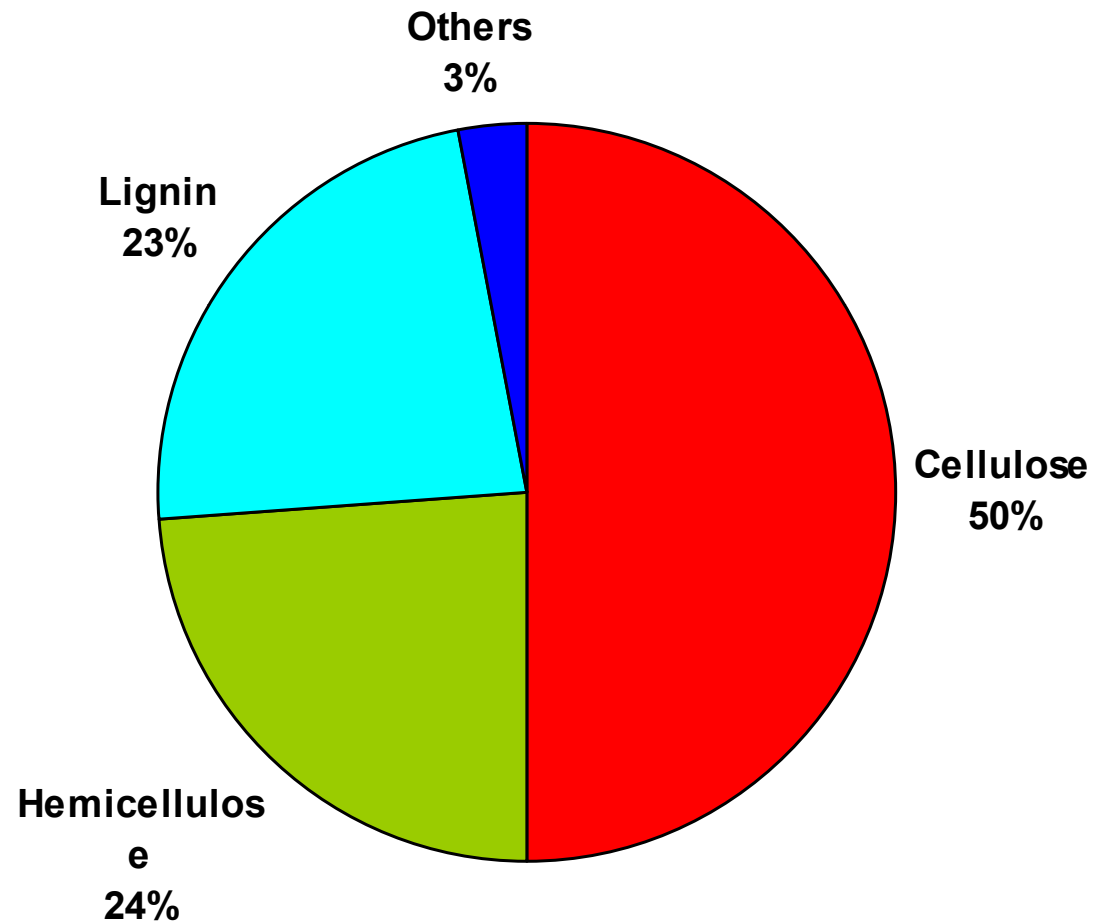
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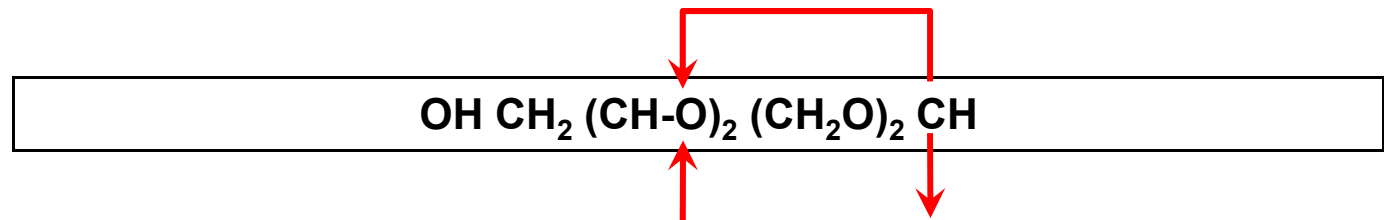
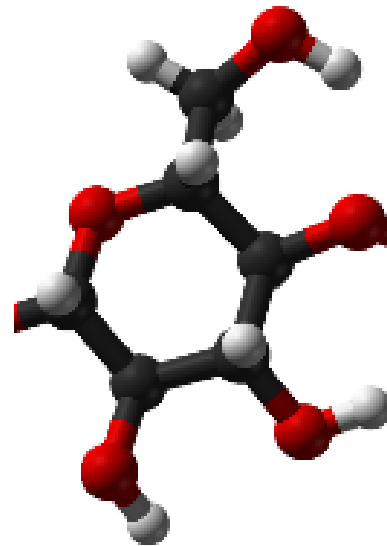
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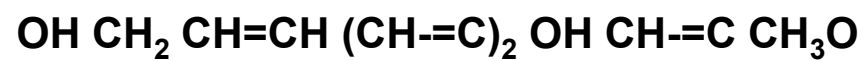
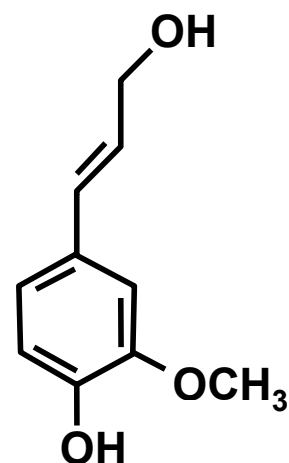
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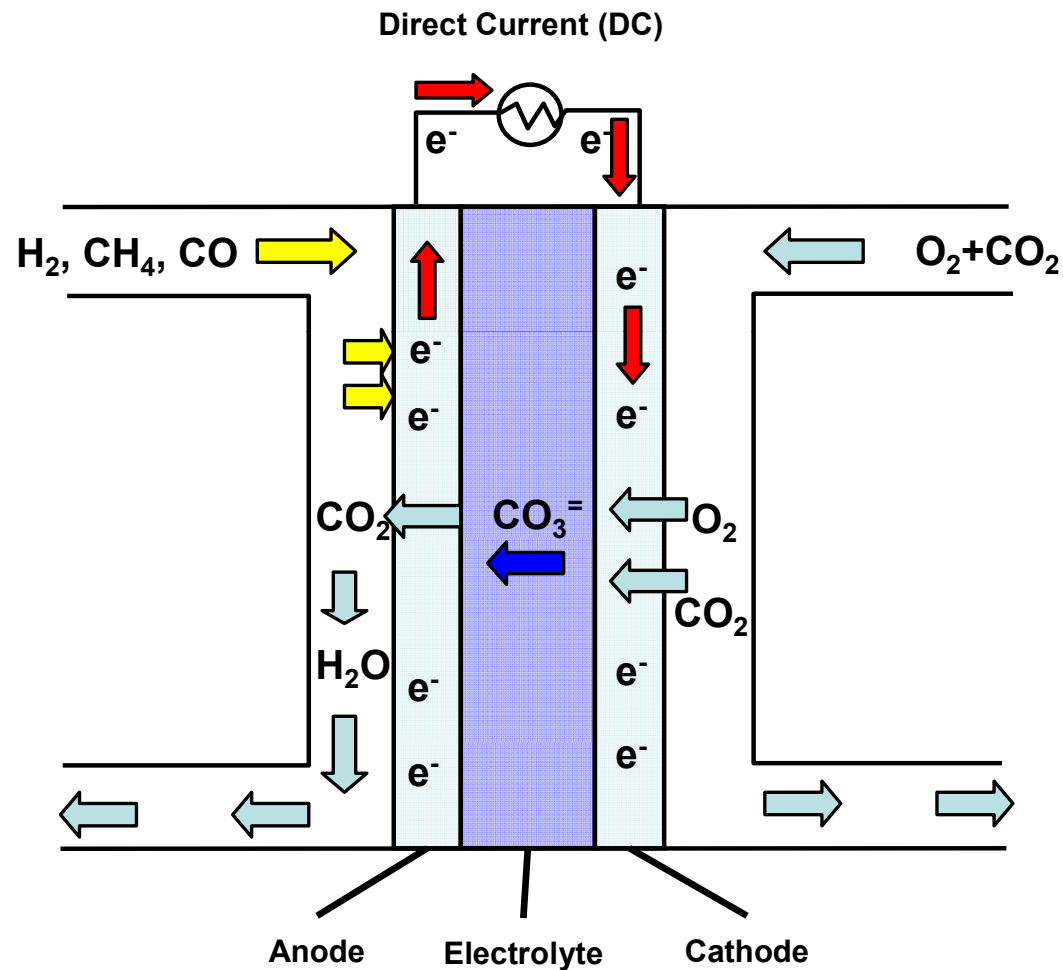
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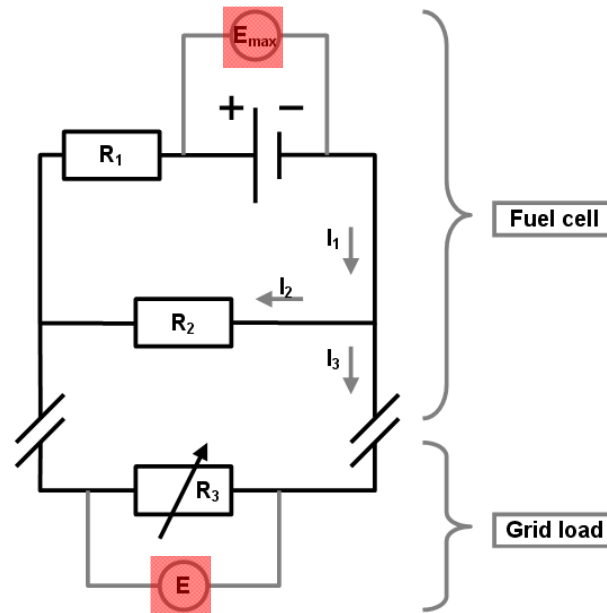
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$$E_{MCFC} = \frac{E_{\max} - \eta_f \cdot i_{\max} \cdot r_1}{\frac{r_1}{r_2} \cdot (1 - \eta_f) + 1}$$

$$E_{\max} = \frac{RT}{4F} \ln \frac{p_{O_2, cathode} \cdot p_{CO_2, cathode}^2}{p_{O_2, anode} \cdot p_{CO_2, anode}^2}$$



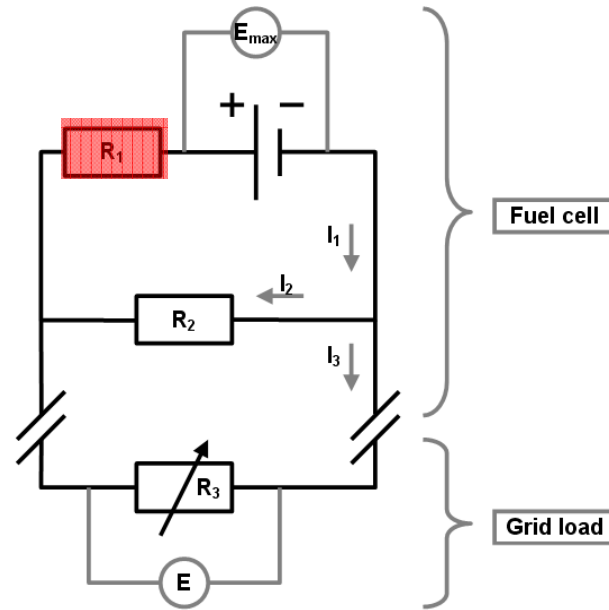
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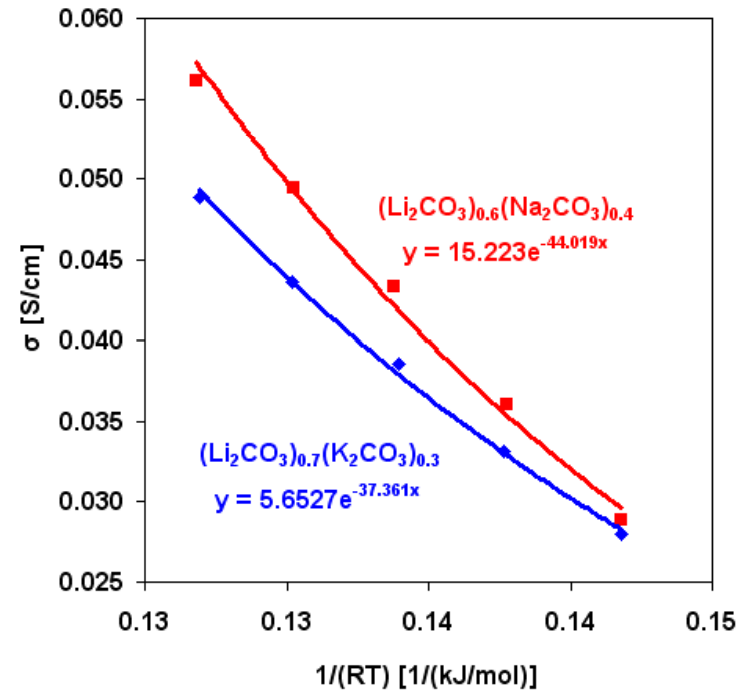
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$$r_1 = \frac{\delta}{\sigma}$$



$$\sigma = \sigma_0 \cdot e^{\frac{-E}{RT}}$$



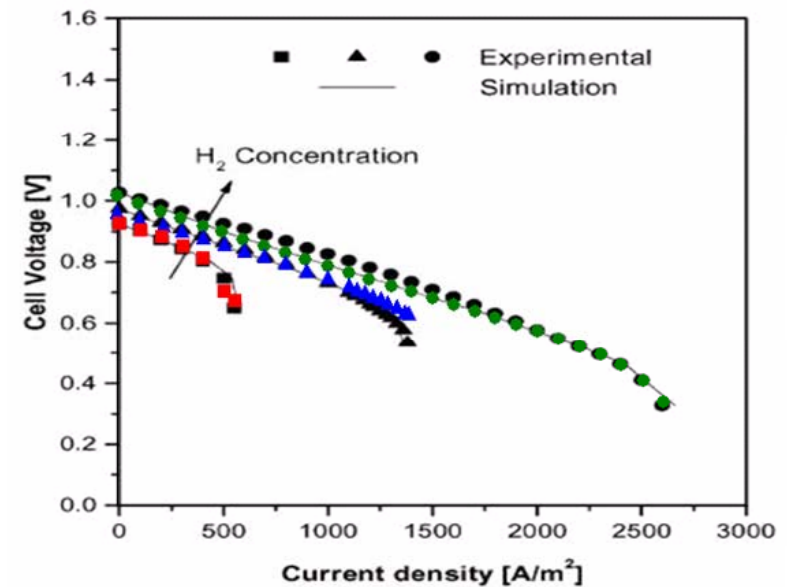
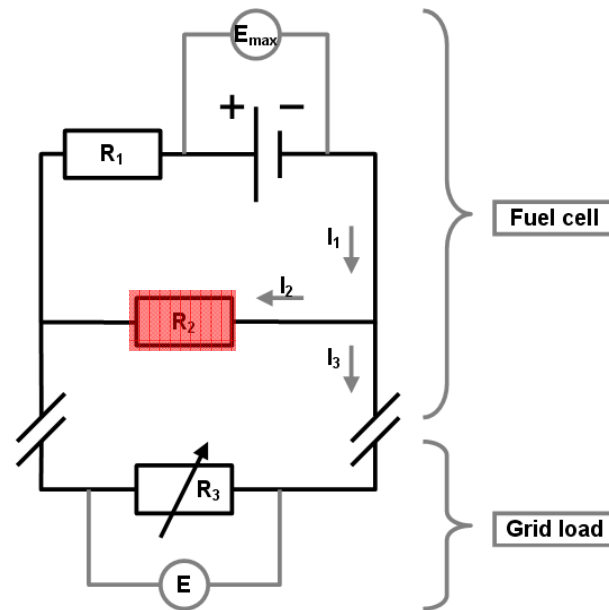
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$$r_2 = 28 \Omega cm^2$$



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- 0D, design point (chemical equilibrium)
- $i_{\max} = \text{constant}$
- pressure: 1bar
- MCFC temperature: 650°C
- electrolyte type: Li/Na
- matrix thickness: 1mm



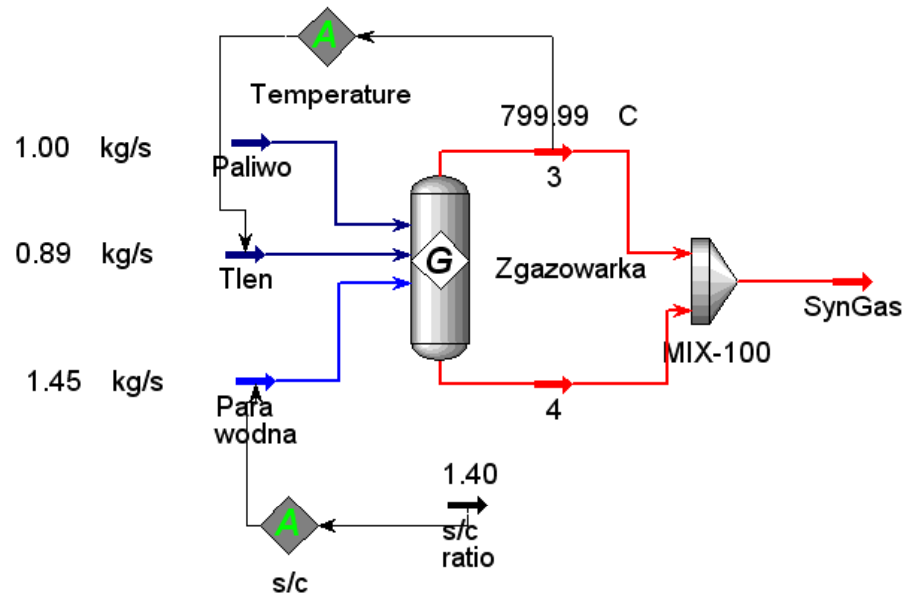
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SynGas		
Temperature	799.99	C
Pressure	1.000	bar
Mass Flow	3.34	kg/s
Hydrogen	0.0520	
H2O	0.2888	
Nitrogen	0.0000	
Oxygen	0.0000	
Methane	0.0004	
CO	0.3201	
CO2	0.1263	
Ethanol	0.0000	
Methanol	0.0000	
Ethane	0.0000	
Propane	0.0000	
Butane	0.0000	
Oleinowy	0.0000	
Linolowy	0.0000	
Linolenowy	0.0000	



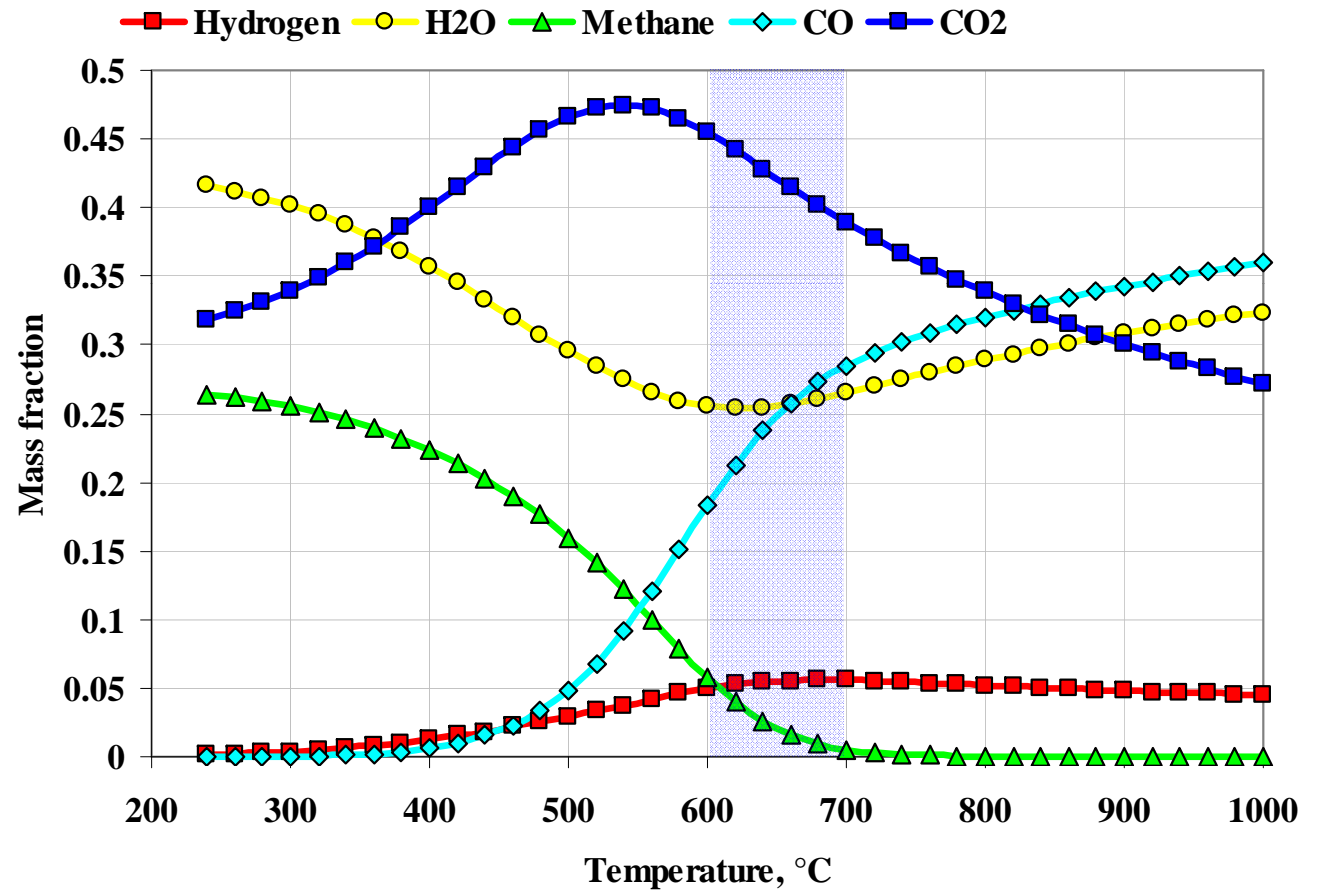
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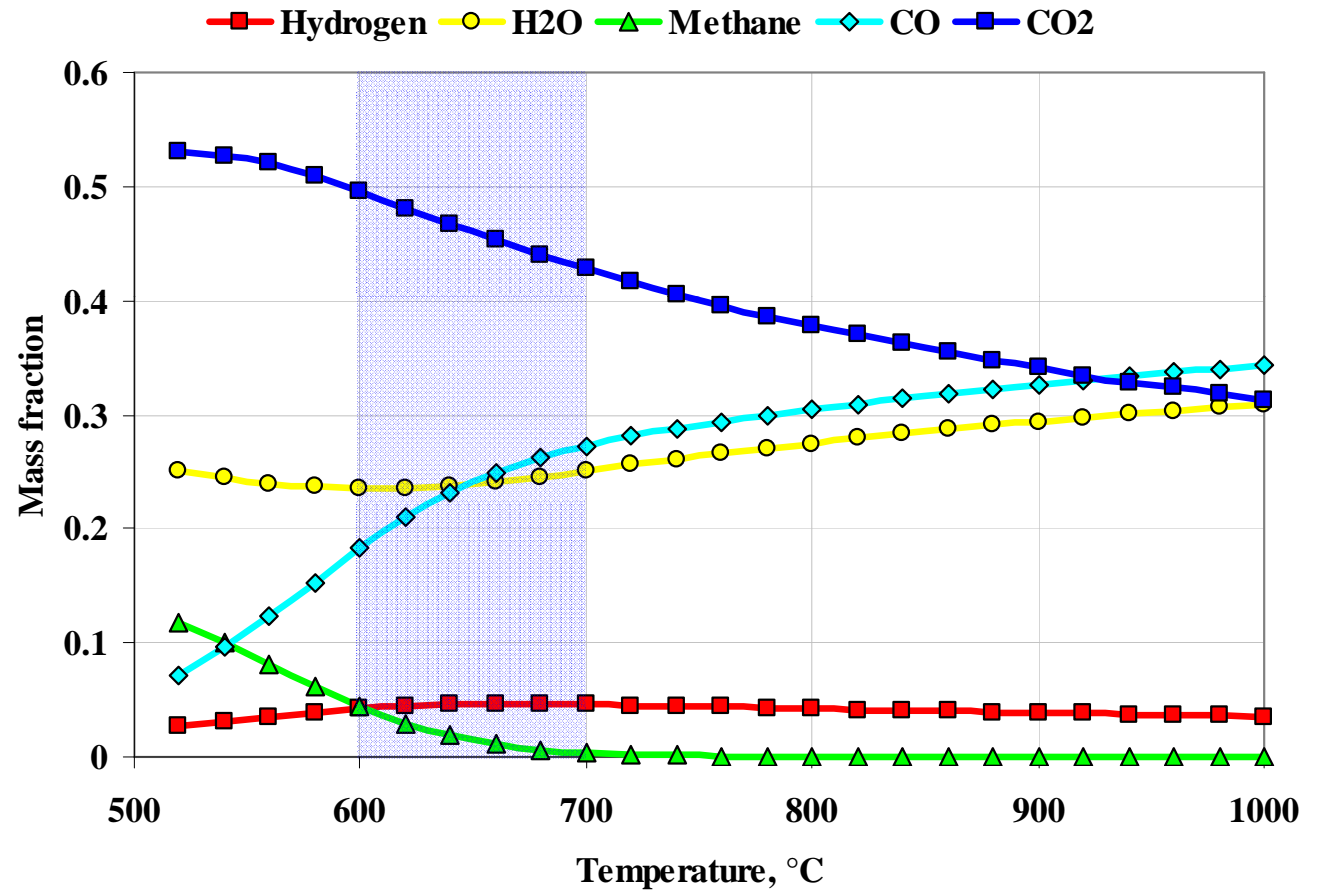
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$$\begin{aligned}
 n_{H_2, \text{equivalent}} &= n_{H_2} + n_{CO} \\
 &+ 3 \cdot n_{CH_3OH} + 4 \cdot n_{CH_4} \\
 &+ 6 \cdot n_{C_2H_5OH} + 7 \cdot n_{C_2H_6} \\
 &+ 10 \cdot n_{C_3H_8} + 13 \cdot n_{C_4H_{10}}
 \end{aligned}$$

$$\eta_f = 1 - \frac{n_{H_2, \text{equivalent}, \text{out}}}{n_{H_2, \text{equivalent}, \text{in}}}$$



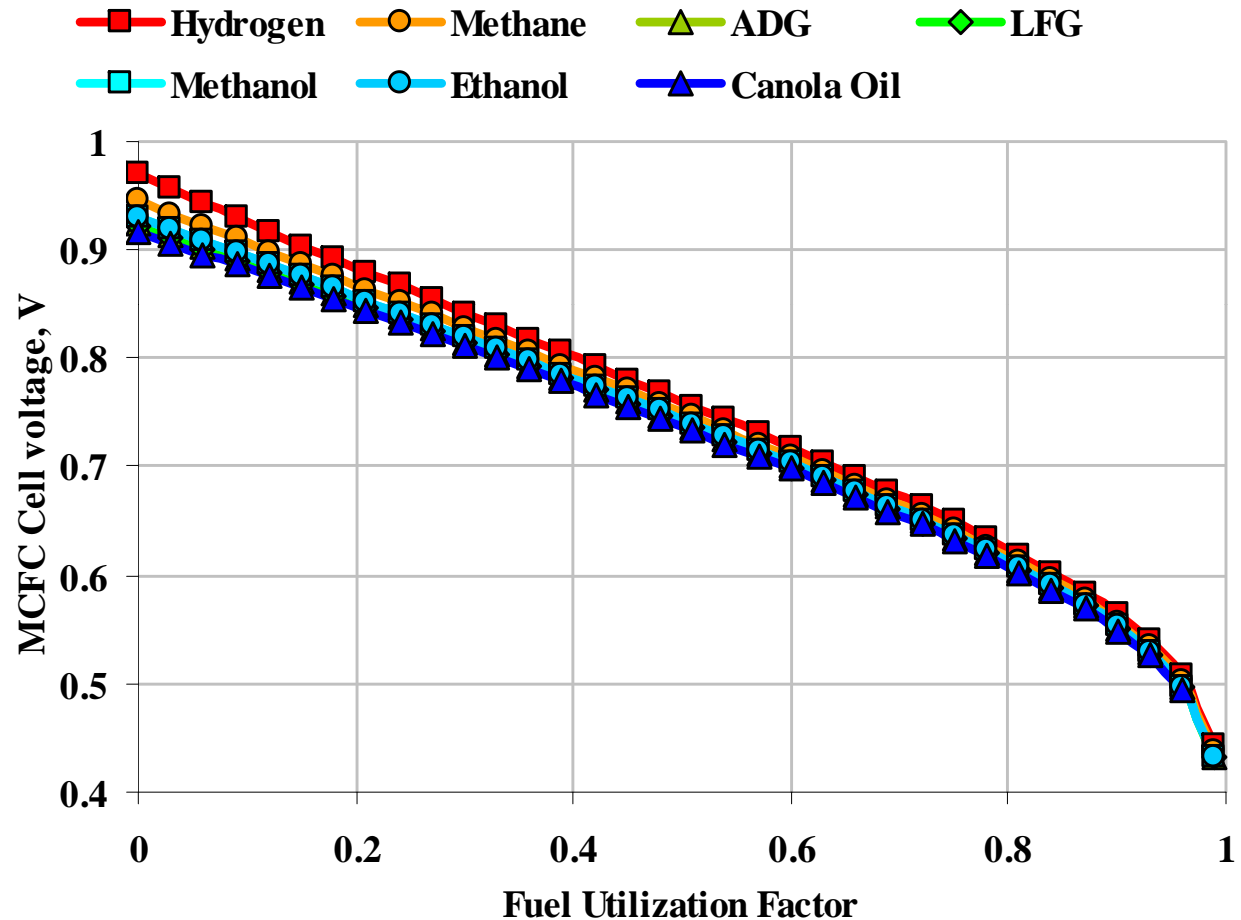
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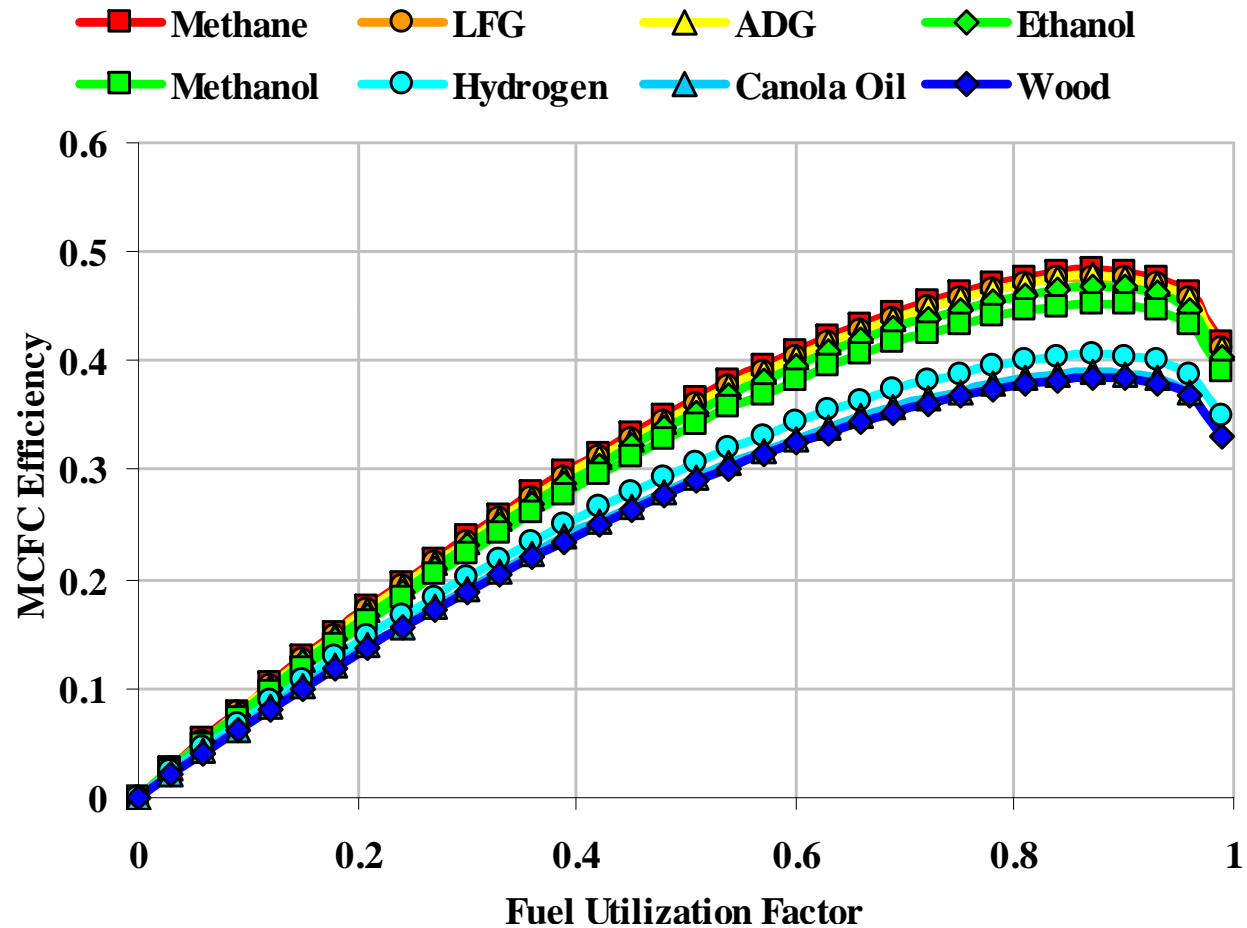
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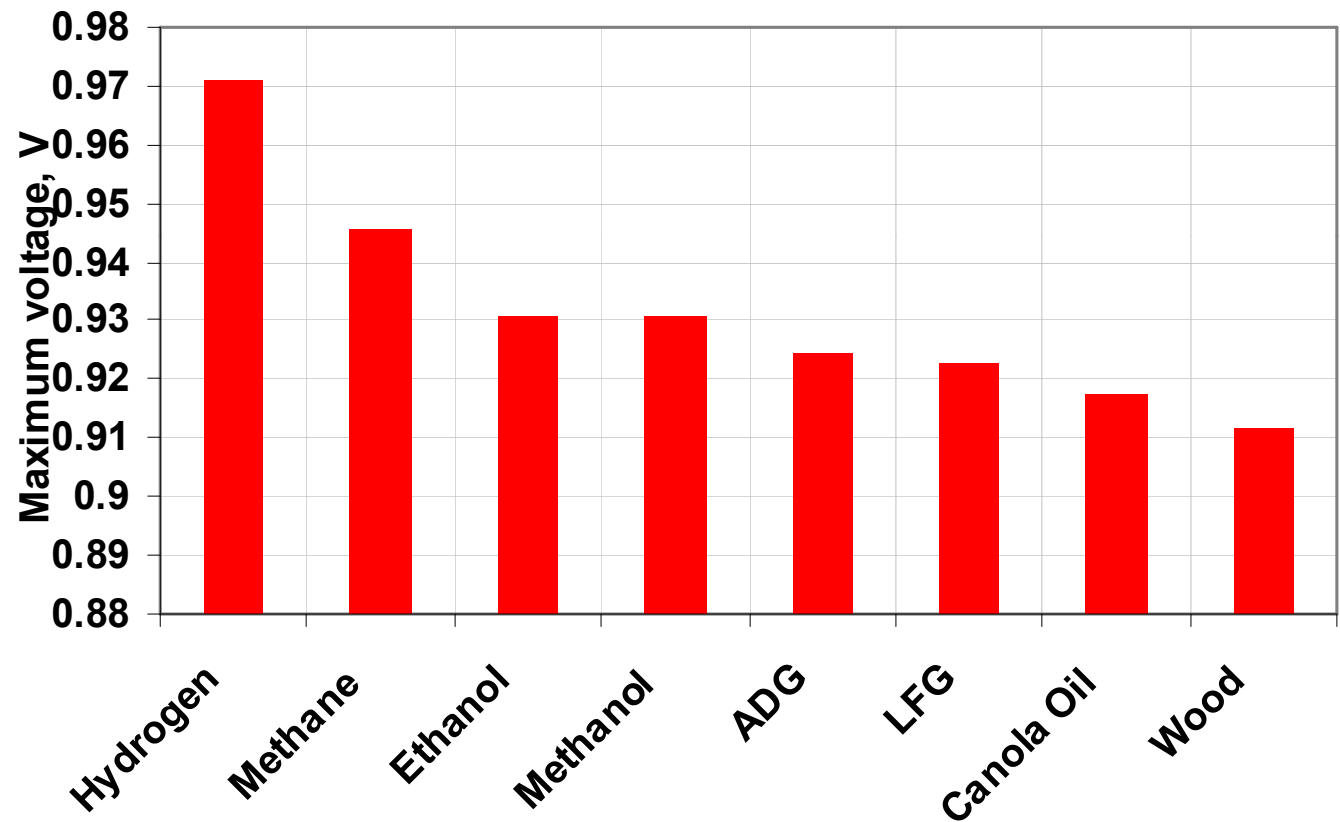
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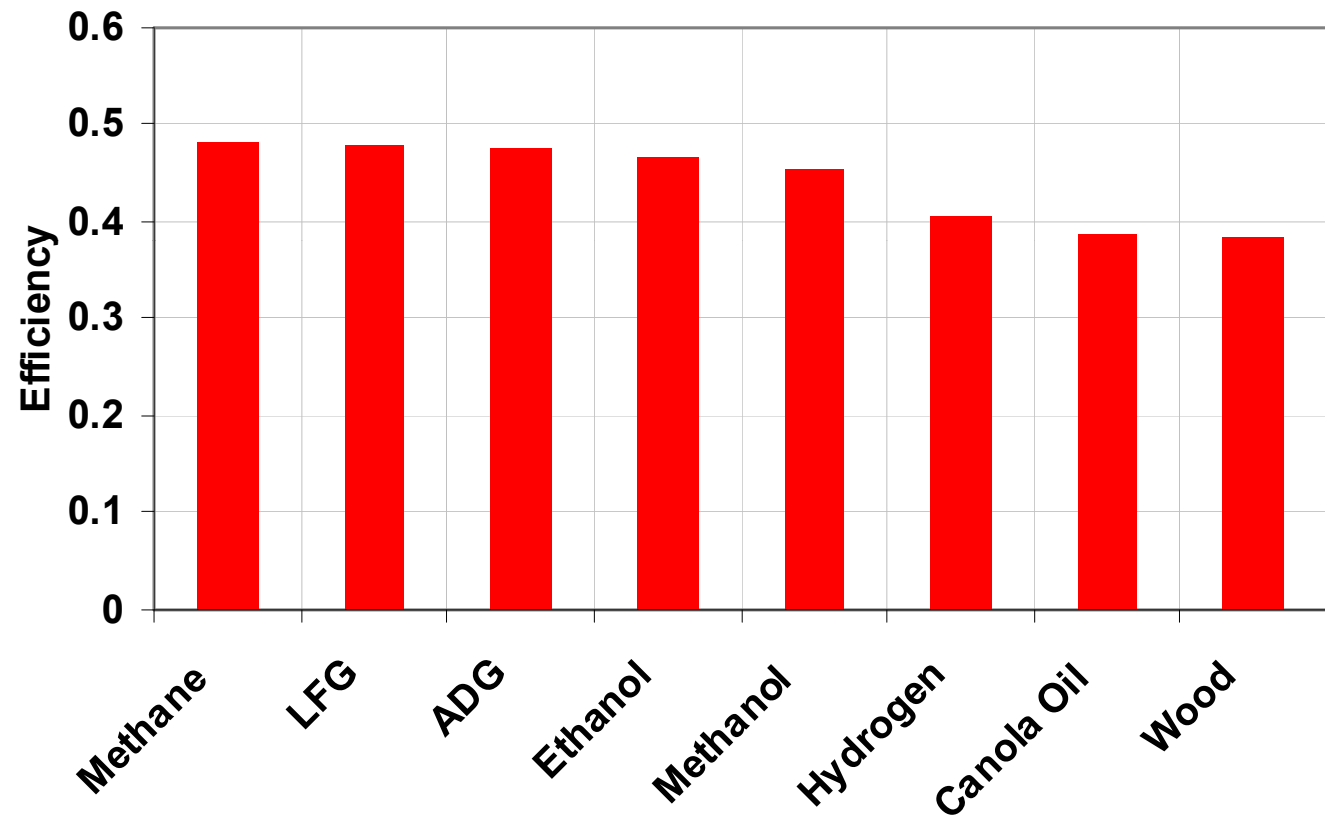
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Biofuels utilization in MCFC means:

- lower efficiency
- lower fuel utilization factor
- pre-mixing with steam
- biogases outperforms other types of biofuels



# Molten Carbonate Fuel Cell Fuelled by Biofuels



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**Thank you.**