Thermochemical Power Group

Sustainable Energy

Mod.1: Fuel Cells & Distributed Generation Systems

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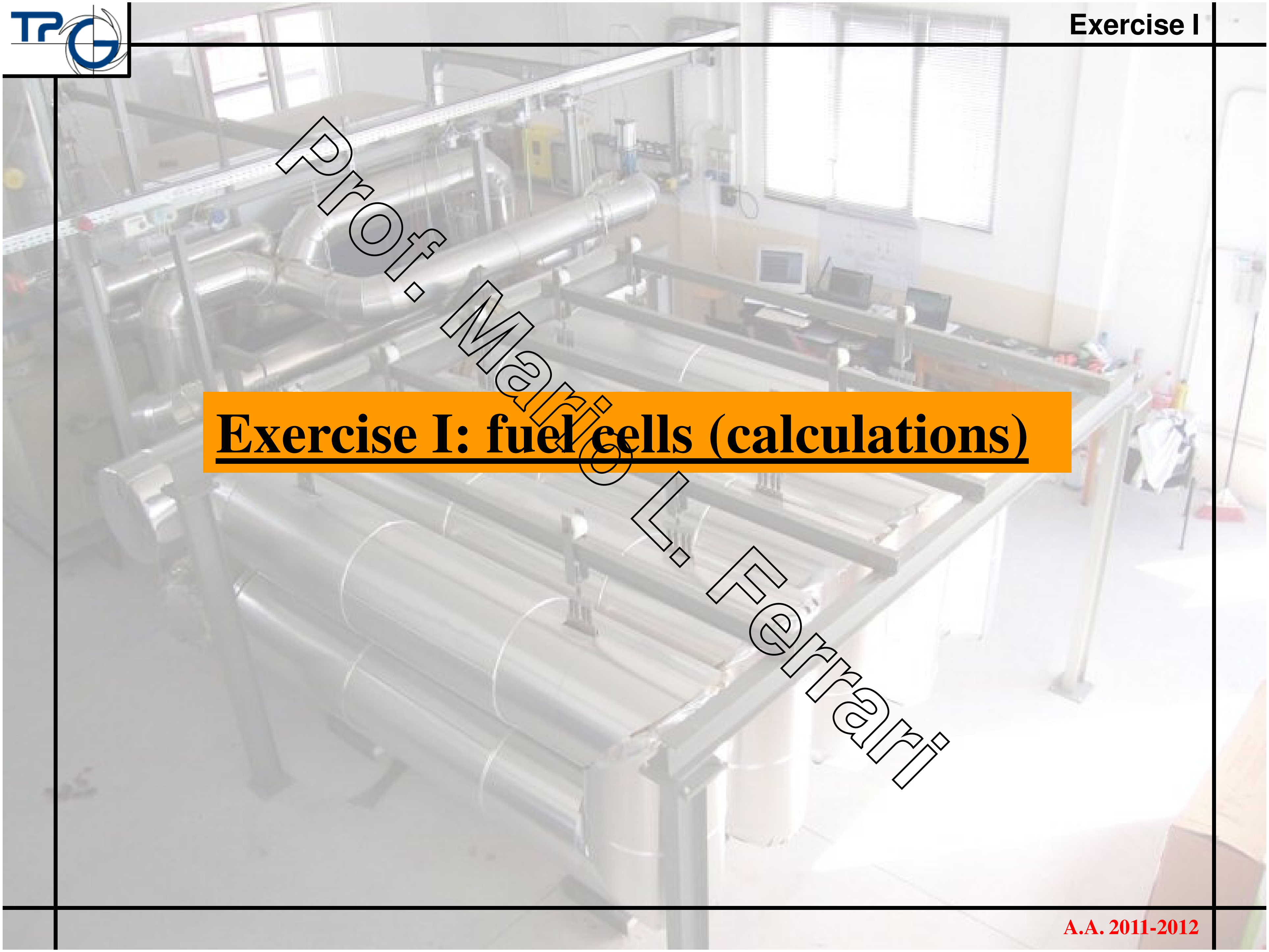

Exercise I: fuel cells (calculations)

Exercise 1: What hydrogen flow rate is required to generate 1.0 ampere of current in a fuel cell ?

Solution:

- For every molecule of hydrogen (H_2) that reacts within a fuel cell, two electrons are liberated at the fuel cell anode: $H_2 \rightarrow 2H^+ + 2e^-$
- One ampere of current is defined as 1 C/sec.
- Moles of electrons per sec.: M_e = (1 [C/s])/(F [C/mol]) = $1.0364 \cdot 10^{-5}$ mol/s
- Moles of hydrogen per sec.: $M_{H2} = M_e/2 = 0.5182 \cdot 10^{-5}$ mol/s
- Moles of hydrogen per hour: $M_{H2/h}$ = 0.01865 mol/h
- Since molar mass of H_2 is: 2.0158 g/mol
- Mass of hydrogen per hour: $M_{H2/h} = 3.759 \cdot 10^{-5}$ kg/h

Exercise 2: A 1.0 MW_{DC} fuel cell stack is operated with a cell voltage of 700 mV on pure hydrogen with a fuel utilization, U_f of 80%. (a) How much hydrogen will be consumed in lb/h? (b) What is the required fuel flow rate? (c) What is the required air flow rate for a 25% oxidant utilization, U_{ox}?

<u>Solution:</u>

- Power (P) is the product of voltage (V) and current (I): $P = I*V$
- So: $I = P/V = 1429$ kA
- Mass of H_2 consumed (kg/h): $M_c = (I\,[A])*(M_{H2/h}\,[kg/(h*A)]) = 53.7$ kg/h
- Mass of H_2 consumed (lb/h): $M_c = 53.7/0.4536 = 118.4$ lb/h
- Fuel flow rate: $H_{2,in} = M_c/U_f = 148.0$ lb/h
- Since molar mass of H_2 is: 2.0158 g/mol
- Mass O_2 consumed (mol/h): $M_{o2} = (M_c*1000)/(2*2.0158) = 13319.8$ mol/h
- O_2 flow rate: $O_{2,in} = M_{o2}/U_{ox} = 53279.2$ mol/h
- Since O_2 concentration is 21% and air molar mass is 28.85 g/mol
- Air mass flow rate: $M_{air} = (O_{2,in}/0.21)*28.85 = 7319547.2$ g/h $=16136.6$ lb/h

Exercise 3: A PAFC, operating on reformed natural gas (900 lb/h) and air, has a fuel and oxidant utilization of 86% and 70%, respectively. With the fuel and oxidant composition and molecular weights (MW) listed below, how much hydrogen will be consumed in mol/h? (b) How much oxygen is consumed in mol/h? (c) What is the required air flow rate in mol/h and lb/h? (d) How much water is generated? (e) What is the composition of the effluent (spent) fuel and air streams in mol percent?

Fuel Data	mol percent
CH_4	4.0
CO	0.4
CO_2	17.6
H_2	75.0
H_2O	3.0
Total	100.0
MW	10.55

Air Data	mol percent, dry	mol percent, wet
H_2O	0.00	1.00
N_2	79.00	78.21
O_2	21.00	20.79
Total	100.00	100.00
MW	28.85	28.74

Solution (1/2):

- Mass of fuel supplied (mol/h): M_{c_s} = (900*453.6)/(10.55)= 38695.7 mol/h
- Mass of H_2 supplied (mol/h): $M_{H2\_s} = M_{c\_s}$ *0.75 = 29021.8 mol/h
- Mass of H_2 consumed (mol/h): $M_{H2\_c} = M_{H2\_s}$ *0.86 = 24958.7 mol/h
- Mass of O_2 consumed (mol/h): $M_{O2\_c} = M_{H2\_c}$ /2 = 12479.4 mol/h
- Mass of O_2 supplied (mol/h): $M_{O2\_s} = M_{O2\_c}$ /0.70 = 17827.7 mol/h
- Mass of air (wet) supplied (mol/h): $M_{air\_s} = M_{O2\_s}$ /0.2079 = 85751.3 mol/h
- Mass of air (wet) supplied (lb/h): M_{air_s}=85751.3*28.74/453.6= 5433.1 lb/h
- Mass of water generated (mol/h): $M_{H2O\_G} = M_{H2\_C}$ = 24958.7 mol/h
- Fuel side:

	mol percent	lb mol/hr			mol percent
Gas	**FC inlet**	**FC inlet**	**FC reaction**	**FC outlet**	**FC outlet**
CH_4	4.0	3.41		3.41	11.27
CO	0.4	0.34		0.34	1.13
CO_2	17.6	15.01		15.01	49.58
H_2	75.0	63.97	-55.01	8.96	29.58
H_2O	3.0	2.56		2.56	8.45
Total	**100.0**	**85.29**	**-55.01**	**30.28**	**100.00**

- In PAFC, only the moles of hydrogen change on the anode side
- These inert gases act to dilute hydrogen lowering cell voltage

Solution (2/2):

• Air side:

	mol percent	lb mol/hr			mol percent
Gas	**FC inlet**	**FC inlet**	**FC reaction**	**FC outlet**	**FC outlet**
H_2O	1.00	1.89	55.01	56.90	26.28
N_2	78.21	147.82		147.82	68.27
O_2	20.79	39.30	-27.51	11.79	5.44
Total	**100.00**	**189.01**	**27.51**	**216.51**	**100.00**

M_{air_s}= 85751.3/453.6=189.04 lb mol/h

Exercise 4: An MCFC operating on 1,000 lb/h of fuel gas and a 70% air/30% CO_2 oxidant has a fuel and oxidant utilization of 75% and 50% respectively. With the fuel and oxidant composition and molecular weights listed below, (a) How much hydrogen will be consumed in mol/h? (b) How much oxygen is consumed in mol/h? (c) What are the required air and oxidant flow rates in mol/h? (d) How much CO_2 is transferred from the cathode to the anode? (e) What is the composition of the effluent (spent) fuel and oxidant streams in mol percent (no water gas shift reaction)?

Fuel Data	Mol percent
CH_4	0.0
CO	0.0
CO_2	20.0
H_2	80.0
H_2O	0.0
Total	100.0
MW	10.42

Oxidant Data	Air	Air + CO_2
	mol percent, wet	Mol percent, wet
CO_2	0.00	30.00
H_2O	1.00	0.70
N_2	78.21	54.75
O_2	20.79	14.55
Total	100.00	100.00
MW	28.74	33.32

Solution (1/2):

- Mass of fuel supplied (mol/h): M_{c_s}=(1000*453.6)/(10.42)= 43531.67 mol/h
- Mass of H_2 supplied (mol/h): M_{H2_s} = M_{c_s} *0.80 = 34825.3 mol/h
- Mass of H_2 consumed (mol/h): M_{H2_c} = M_{H2_s} *0.75 = 26119.0 mol/h
- Mass of O_2 consumed (mol/h): M_{O2_c} = M_{H2_c} /2 = 13059.5 mol/h
- Mass of air (wet) supplied: M_{air_s}=((M_{O2_c} /0.50)/0.2079)=125632.5 mol/h
- Mass of oxidant supplied (mol/h): M_{ox_s}=M_{air_s}/0.70 = 179475.0 mol/h
- Since: $H_{2,\, anode} + \frac{1}{2} O_{2,\, cathode} + CO_{2,\, cathode} \rightarrow H_2O_{,\, anode} + CO_{2,\, anode}$
- Mass of CO_2 transferred=consumed (mol/h): M_{CO2_t}=M_{H2_c}=26119.0 mol/h
- Fuel side:

	mol percent	lb mol/hr			Mol percent
Gas	FC inlet	FC inlet	FC reaction	FC outlet	FC outlet
CH_4	0.0	0.00		0.00	0.00
CO	0.0	0.00		0.00	0.00
CO_2	20.0	19.20	57.61	76.82	50.00
H_2	80.0	76.82	-57.61	19.20	12.50
H_2O	0.0	0.00	57.61	57.61	37.50
Total	**100.0**	**96.02**	**-57.61**	**153.63**	**100.00**

- in the MCFC, both oxygen and carbon dioxide are consumed on the cathode (air) side.

Solution (2/2):

• Air side:

	mol percent	lb mol/hr			Mol percent
Gas	**FC inlet**	**FC inlet**	**FC reaction**	**FC outlet**	**FC outlet**
CO_2	30.00	83.13	-57.61	25.52	13.38
H_2O	0.70	1.94		1.94	1.02
N_2	54.70	151.71		151.71	79.56
O_2	14.6	40.33	-28.81	11.52	6.04
Total	**100.00**	**277.11**	**-86.42**	**190.69**	**100.00**

M_{air_s}= 125632.5/453.6=277 lb mol/h

Exercise 5: Given a desired output of 2.0 MW_{DC} and the desired operating point of 600 mV and 400 mA/cm^2, (a) How much fuel cell area is needed? (b) Assuming a cell area of 1.00 m^2 per cell and 280 cells per stack, how many stacks are needed for this 2.0 MW unit?

<u>Solution:</u>

- Total current: $I = P/V = 2*10^6/0.6 = 3{,}333$ kA = 3.333 MA
- Cell area: $A = I/\text{Current density} = 3.333*10^6/0.4 = 8{,}333{,}333\ cm^2$
- Number of cells: $N_{cell} = A/10000 = 833$ cells
- Number of stacks: $N_{stack} = N_{cell}/280 = 2.98$ stacks ≈ 3 stacks