

Homework 5 Submission – CBE 9413 Intro to Sustainable Energy Systems

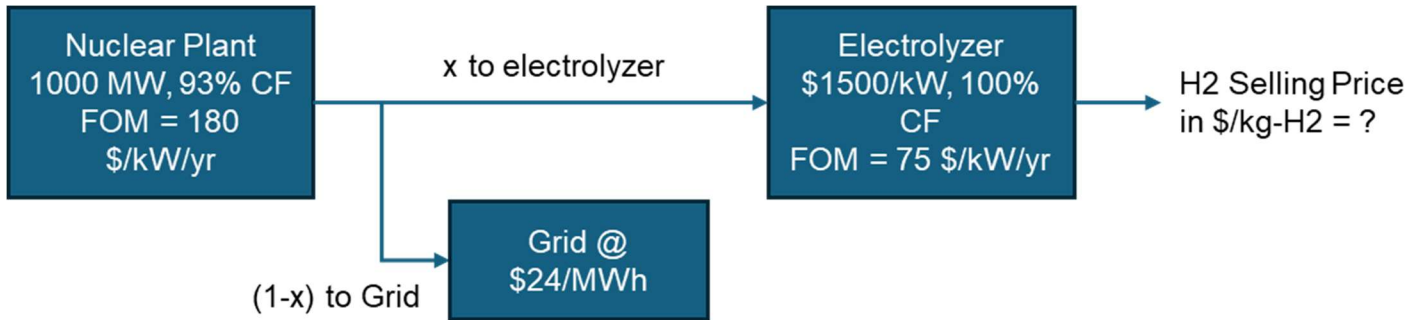
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Disclaimer: I have discussed HW problems with Harsh Gandhi and Anu Deshmukh.

Problem 1

1. The proposed system looks as follows: a share of electricity produced goes to electrolyzer to produce H₂, remaining is sold to grid at average grid price.



2. We need to also know the installed capacity of electrolyzer plant.
- 2.1. Electrolyzer CF should be 100% to ensure that selling price of H₂ at breakeven is minimum (LCOH is inversely proportional to CF).
 - 2.2. Thus, share of electricity to electrolyzer will depend on the installed capacity of electrolyzer. E.g. at 200 MW electrolyzer, 22% electricity goes to electrolyzer to maintain 100% CF.
 - 2.3. Since nuclear plant capacity is fixed at 1000 MW, 93% CF, we can install a maximum of **930 MW of electrolyzer**. (See sensitivity to electrolyzer installed capacity).
3. H₂ production is **~0.14 MMTA in case of LT electrolyzer and 0.22 MMTA in case of HT electrolyzer**.
4. Min. selling price of H₂ (levelized cost) depends on both the average grid electricity price (opportunity cost of making H₂) and installed capacity of electrolyzer.
- 4.1. For 930 MW LT electrolyzer, min. selling price of H₂ must be \$ 3.48/kg to breakeven.
 - 4.2. For 930 MW HT electrolyzer, min. selling price of H₂ must be \$ 3.22/kg to breakeven.
5. Min. selling price of H₂ will increase with increasing grid electricity price (investment in electrolyzer should compensate for **revenue foregone from grid**).
6. Min. selling price of H₂ will increase for any electrolyzer capacity other than 930 MW (< 930 MW: 100% CF but low H₂ production; > 930 MW: high H₂ production but low CF).

Sensitivity of min. selling price of H2 to electrolyzer (HT) capacity and grid electricity price

Electrolyzer (MW)	Grid electricity price (\$/MWh)			Electrolyzer (MW)	Grid electricity price (\$/MWh)		
	24	35	45		24	35	45
50	41.71	48.87	55.38	600	4.43	4.65	4.85
100	21.37	24.75	27.82	700	3.94	4.07	4.20
200	11.20	12.69	14.04	800	3.58	3.64	3.70
300	7.81	8.67	9.45	900	3.30	3.31	3.32
400	6.12	6.66	7.15	930	3.22	3.22	3.22
500	5.10	5.45	5.77	1000	3.37	3.37	3.37

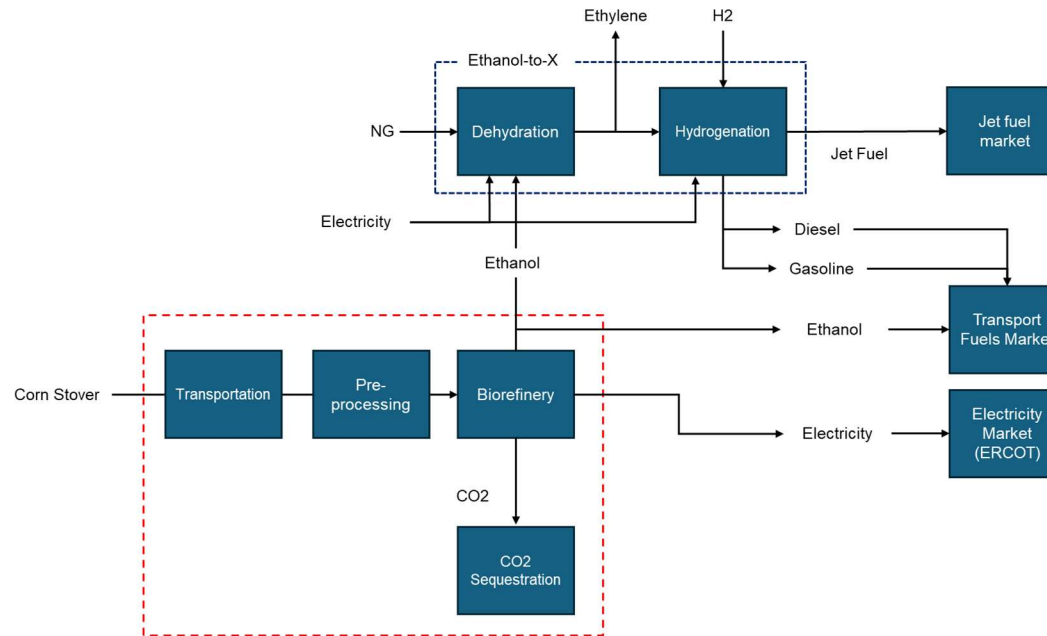
My recommendation to nuclear power plant

1. For the baseline (without electrolyzer), min. selling price of electricity (NPV = 0) from the nuclear plant in the **should be 35 \$/MWh**. (excluding capex of nuclear plant, which is assumed to be fully recovered).
2. H2 produced by nuclear power can qualify as clean H2 which industry can purchase.
 - 2.1. However, clean H2 can also be produced from steam methane reforming with CCS (LCOH as per NREL @ 3 \$/mmbtu: 1.86 \$/kg-H2).
 - 2.2. Therefore, **min. selling price of nuclear power based H2 should be < 2 \$/kg to be cost-competitive** with other technologies.
3. Based on forecast of average grid electricity price (P) in future years, your decision should be as follows:
 - 3.1. If P = \$ 24/MWh – nuclear plant operation is unprofitable; installing electrolyzer will not help because at the current economics. The plant must shut down.
 - 3.2. If P = \$ 35/MWh – nuclear plant operation is at breakeven. You should be indifferent as to install electrolyzer or not at the current economics.
 - 3.3. If P = \$ 45/MWh – nuclear plant operation is profitable. You are better off not investing in electrolyzer at the current economics.

(Please refer to the attached excel file for all supporting calculations).

Problem 2

Part (a) – LCA of ethanol from corn stover used as transport fuel



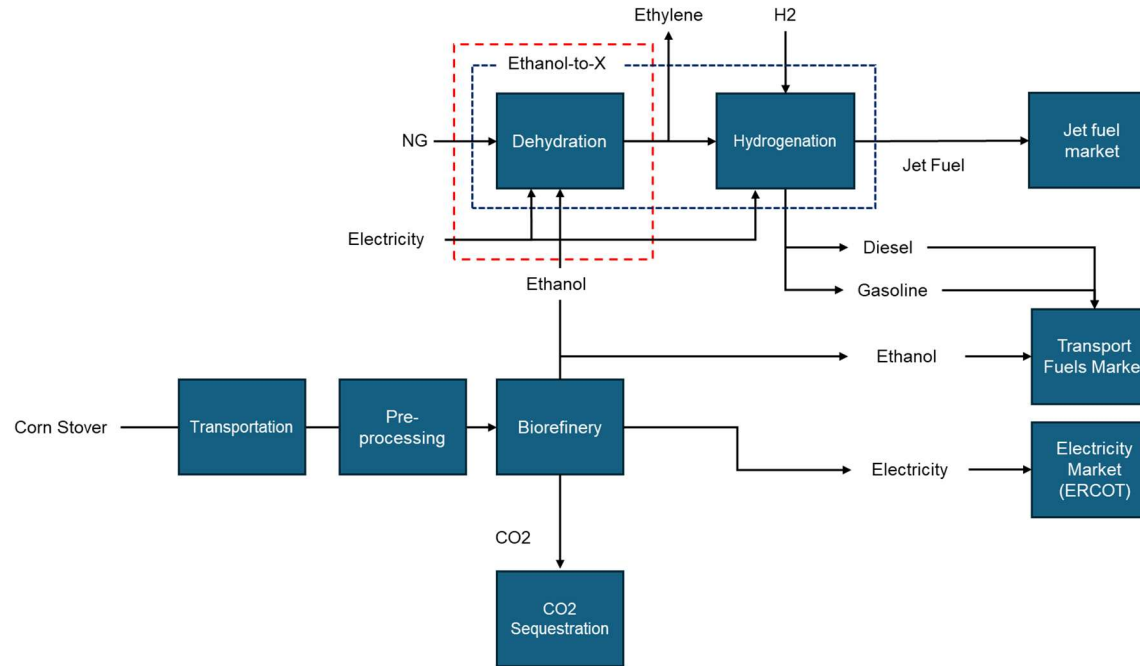
Stage of LCA	UOM	Emission Factor (gCO ₂ e/UOM)	Norm (UOM/MJ ethanol)	Contribution = Emission Factor x Norm (gCO ₂ eq/MJ)
Production of Corn Stover	kg stover (dry)	90	0.13	11.6
Transportation from field to pre-processing	MJ diesel	90	0.01	1.2
Pre-processing	kWh electricity	307.5	0.01	1.7
Transportation from field to Biorefinery	MJ diesel	90	0.01	0.6
Biorefinery: Conversion to Ethanol				
<i>Biogenic CO₂ emissions</i>	kg CO ₂ emissions	0	0.13	0.0
Electricity Export to Regional Grid	kWh electricity	-307.5	0.034	-10.4
Emission Intensity (Well-to-Gate)	MJ ethanol			4.6
Tailpipe emissions from ethanol	kg ethanol	0	0.04	0.0
CO ₂ Sequestration				
<i>CO₂ sequestered</i>	kg CO ₂ captured	-1000	0.04	-35.5
Lifecycle Emission Intensity of Ethanol Use in Transport	MJ ethanol			-30.9

Part (b)

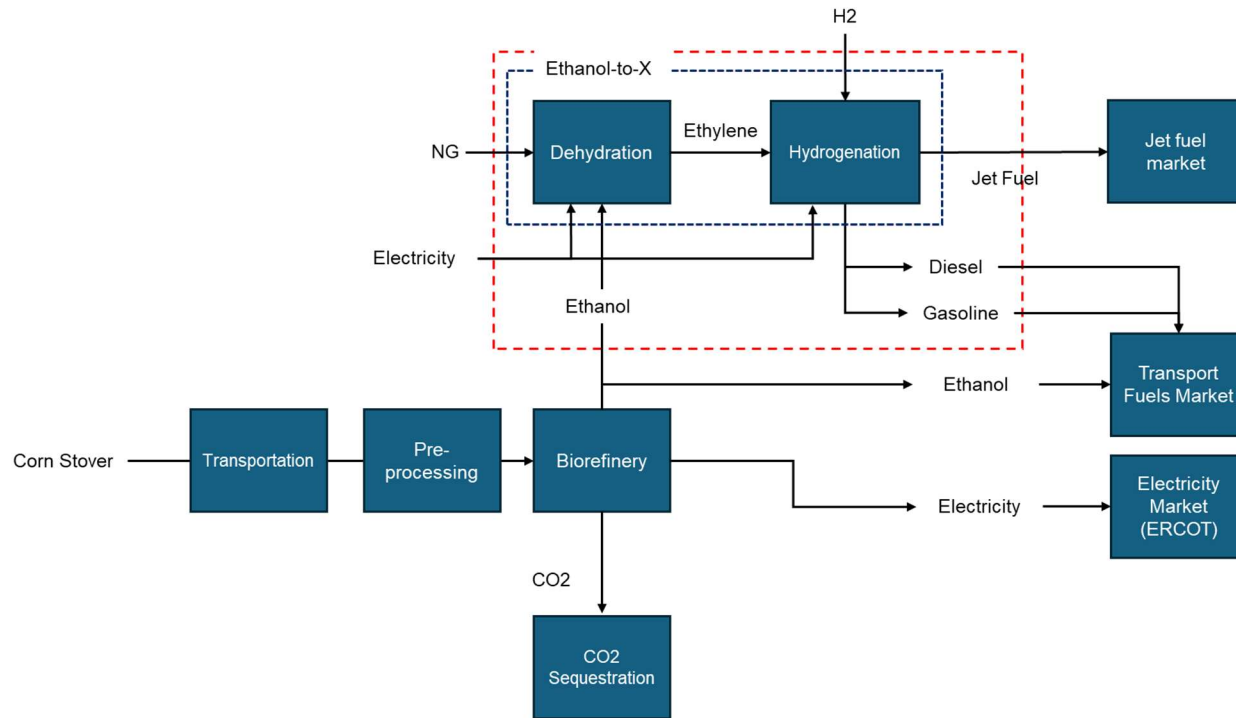
GRID Emission Factor in gCO₂e/kWh	Lifecycle EI of Ethanol Use in Transport	% change over baseline
307.5	-30.9	0%
136.5	-26.0	16%
74.3	-24.3	21%
74.4	-24.3	21%
63.4	-24.0	22%
51.8	-23.7	23%

1. Decrease in grid emission factors leads to increase in Lifecycle EI of ethanol.
2. This implies that the value of credit from export of surplus electricity will decrease, as electricity is increasingly available from low-carbon sources.
3. However, electricity export is not a major contributor to the overall EI of ethanol, thus the impact is less muted compared to extent of decarbonization of grid.

Part (c)



Stage of LCA	UOM	Emission Factor (gCO2e/UOM)	Norm (UOM/kg ethanol feed)	Contribution = Emission Factor x Norm (kgCO2eq/kg ethanol feed)
Production of Ethanol	MJ ethanol	-30.9	26.95	-0.83
Ethylene Production: Dehydration				
<i>Electricity use</i>	kWh	307.5	0.18	0.06
<i>Natural Gas use</i>	MJ	149.04	0.97	0.14
<i>Biogenic CO2 emissions</i>	kg CO2	0	1.50	0.00
<i>Fossil CO2 emissions</i>	kg CO2	1000	0.93	0.93
Incineration	kg C	0	0.86	0.00
Lifecycle Emission Intensity of Ethylene	kg ethanol feed	90	0.65	0.30



Stage of LCA	UOM	Emission Factor (gCO ₂ e/ UOM)	Norm (UOM/ kg ethanol feed)	Contribution = Emission Factor x Norm (kgCO ₂ eq/kg ethanol feed)
Production of Ethanol	MJ ethanol	-30.9	26.95	-0.83
Ethylene Production: Dehydration				
<i>Electricity use</i>	kWh	307.5	0.17	0.05
Oligomerization:				
<i>Hydrogen use</i>	MJ	83.26	1.46	0.12
<i>Biogenic CO₂</i>	kg CO ₂	0	1.05	0.00
<i>Fossil CO₂</i>	kg CO ₂	1000	0.00	0.00
Lifecycle Emission Intensity of Oligomerization	kg ethanol feed			-0.66

<i>Diesel Export Credit</i>	MJ	-90	2.07	-0.19
<i>Gasoline Export Credit</i>	MJ	-90	3.82	-0.34
Tailpipe Emissions from Jet Fuel	MJ	0	18.00	0.00
Lifecycle Emission Intensity of Jet Fuel Use	kg ethanol feed			-1.19

1. Function unit used for comparison is kg of ethanol feed used.
2. Carbon balance for each process accounts for both biogenic and fossil-based C.
 - 2.1. I have assigned 0 emission factor to biogenic carbon (since the carbon cycle is completed with uptake of CO₂ in subsequent crop cycles).
3. For Jet fuel production, I have assumed Jet fuel as the determining product and gasoline, diesel as dependent products.
4. Pathway to make Jet fuel out of ethylene looks more appealing, primarily as it does not involve fossil fuel (NG) use and gets credits for diesel and gasoline export (under system expansion).
 - 4.1. It is also possible to allocate emissions from jet fuel production step as per energy content among all products.
5. The results of LCA for both pathways are tabulated in the tables above.
6. In case of incineration at the end of use of ethylene, there is no change in the LC EI of ethylene because all its carbon content is biogenic.