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Subject: Economic Analysis of Two Construction Alternatives for the Production of Propylene

Background

Propylene serves as a vital building-block material that is used for the production of monomers, polymers, and other intermediates. As a common raw material for industrial processes, approximately ⅔ of propylene is used to make polypropylene, a plastic resin that is used in making clothes, furniture, and many other products. A schematic for the general industrial process of making propylene used in this study is shown in Figure 1 below.

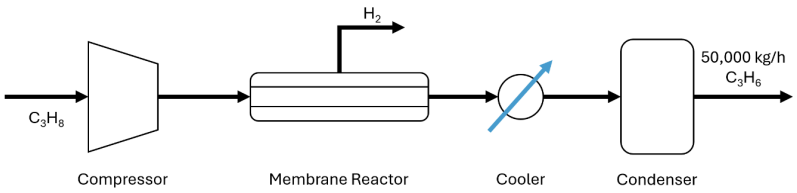


Figure 1. Process diagram for the production of propylene that is used in this study.

The process of propylene production begins with an input of propane, C3H8, that is compressed and passed through a membrane reactor that dehydrogenates the propane. The dehydrogenation reaction can be seen in Equation 1.

$$C_3H_8 \rightarrow C_3H_6 + H_2 \quad (1)$$

During dehydrogenation, the H2 is removed via membrane and burned to sustain the high temperature required for dehydrogenation. The remaining product, C3H6, is cooled, condensed, and ready for storage. The new facility will utilize a novel membrane reactor process that has only been tested at a laboratory scale. At the industrial scale, the unit will be able to produce 50,000 kg/h of propylene. Initially, the propylene that is produced will be stored at one of our chemical storage facilities in the Houston metropolitan area. The stored propylene may be available for other processes within our company or sold to other chemical companies, which is beyond the scope of this project.

Along with the scale up of the novel process, our boss has proposed two new alternative construction methods for building the propylene plant. The first alternative would build the new plant at the same location as the storage facility in Houston. The second alternative would build the plant in Canada where the propylene would be shipped to the storage facility in Houston; this requires extra consideration of tariffs and how it may affect the profitability of propylene. In order to compare the two alternatives, we have conducted an economic analysis involving capital estimates and projection of net operating revenues that allows us to estimate the net present value (NPV) and minimum selling price (MSP). In addition to the two assigned locations, a third alternative construction site in Saudi Arabia was evaluated using cost information from other teams provided in Canvas to determine whether improved economic metrics could be achieved. Additionally, a sensitivity analysis was done using spider plots to visualize and evaluate the effect of changing key parameters on the NPV. This analysis allowed us to compare the profitability of the alternative plant locations and give a recommendation on moving forward with the building process.

Methods for Economic Analysis

Capital Estimate

Capital costs, or upfront costs, are the costs that are incurred one time at the start of a new project. Overall, these costs cover purchasing and installing new units, infrastructure improvements, and labor and company costs. Our method for estimating capital costs began with calculating the inside boundary limit(IBL) costs, or costs directly related to installing new units. Using cost curve data from Table 7.2 found in Towler and Sinnott's "Chemical Engineering Design", we estimated the cost(C) for all units besides the membrane reactor by using Equation 2.

$$C = a + bS^n \quad (2)$$

Values of a, b, and n were found in the table; a and b were divided by a thousand to get cost in units of M$. S is the size of the unit which was given in the problem. To estimate the cost for the membrane reactor, a previous cost of $1.2MM for a 100 kg/h production unit was used in Equation 3 to estimate the new installation cost.

$$C = C_{ref}(\frac{S}{S_{ref}})^{\gamma} \quad (3)$$

C_{ref} is the cost of the reference unit, S_{ref} is the size of the reference unit, S is the size of our unit, and γ is the capacity exponent that was assumed to equal ⅔ since it was not specified. Getting Equation 3 in terms of Equation 2, we set $a = 0,\ b = \frac{C_{ref}}{S_{ref}^{\gamma}}$, and $n = \gamma$.

For each location, the calculated base equipment costs were multiplied directly by a location factor within the IBL calculation to account for regional differences in construction, labor, and material costs. A location factor of 1.00 was used for Houston, 1.15 for Canada to reflect higher construction costs, and 0.80 for Saudi Arabia to reflect lower relative construction expenses. A time correction using the Chemical Engineering Plant Cost Index(CEPCI) was used for the membrane reactor since our reference is from 2024. Finally, a correction factor for 1st pass use was applied to all units. These values were found in the equipment table from Lecture 3, slide 3.

After determining the adjusted IBL values, outside boundary limit (OBL) costs were estimated as 30% of IBL, consistent with a first-pass estimate. The total contractor cost (TCC) was calculated as the sum of IBL and OBL costs. Company costs, including catalyst, refrigerant, and 30% of TCC, were then added to determine the current point estimate (CPE). Time escalation was applied at 3% for one year to adjust costs to the project year. A contingency of 40% of CPE was included due to the implementation of a novel membrane reactor process. Finally, total plant cost (TPC) was calculated by summing CPE, contingency, and escalation costs.

Projection of Net Operating Revenues

With an operational expenditure analysis, or OpEx, we were able to calculate the net operating revenues in $MM/yr for both locations. A capacity factor of 0.95 was assumed for both locations, which falls within the range of capacity factors for chemical plants.

First, we calculated the total revenues from our propylene and hydrogen products. It was given that 50,000 kg/hr of propylene was produced and sold for $0.80/kg at both locations. This results in $332.88 MM/yr. Next the amount of unburned hydrogen that is sold was calculated given molar ratios and that 25% of the produced hydrogen is unburned and sold. This resulted in 598.86 kg/hr of unburned hydrogen being sold at $2/kg for both locations. The revenues from hydrogen equal $9.97 MM/yr, giving us a total revenue of $342.85 MM/yr.

Next, we calculated the total variable costs which typically includes chemicals, utilities, waste management, and other costs related to when the plant is running. The flow rate of our feedstock, propane, was calculated using molar ratios and molar mass. We found that 52396.63 kg/hr of propane is used and costs $0.58/kg in Houston and $0.55/kg in Canada. This costs $252.9 MM/yr in Houston and $239.4 MM/yr in Canada. Next, we know the compressor uses 10000 kW, which costs $.2/kWh for both locations; the cost from the compressor is $166.44 MM/yr. Finally, the cooling water runs 1000 kL/hr and costs $.02/kg for both locations. This results in a cost of $.166 MM/yr. Adding all the variable costs up, the total variable costs are equal to $269.72 MM/yr in Houston and $258.34 MM/yr in Canada.

Finally, we must calculate the fixed costs. It was given that the facility requires two principal engineers($100/hr), one supervisor ($60/hr), and four operators ($35/hr). This adds up to $0.4 M/hr or $3.328 MM/yr in Houston. In Canada, the labor costs are 103% of US labor, therefore the total is $3.428 MM/yr in Canada. Overhead costs are 6 times the labor costs which results in $19.97 MM/yr in Houston and $20.571 MM/yr in Canada. Maintenance is $1000 M/yr and facility costs are $500 M/yr. Adding up the fixed costs, the total fixed costs are $24.8 MM/yr in Houston and $29.66 MM/yr in Canada.

Total costs were calculated by adding together the total variable costs and fixed costs. Net revenue was calculated by subtracting the total costs from the total revenue.

Considering Tariffs

In order to calculate the amount of tariffs that will be paid each year if the site is in Canada, we first began by calculating the “breakeven price”. This is the selling price of propylene, before considering tariffs, that makes the net annual revenue equal to zero. In order to find the total amount in tariffs paid, we multiplied the breakeven price x annual amount of propylene produced x 30%. The 30% is the associated tariff rate for Canada, but varies based on the international location.

Determining NPV and MSP

The NPV and MSP were calculated using a simple cash flow model in Excel. Assuming a 1 year build with all capital spend in year 0, the NPV was found in row 31 of the cash flow analysis. Row 31 corresponds to year 30, which is the given plant operating lifetime following completion of construction.

When determining MSP, a discount rate of 15% was assumed for both locations; this value falls within the range for chemical operations. The payback period was found by identifying the year where the NPV went from negative to positive. Using goal seek analysis in Excel, we were able to find the internal rate of return and MSP. Internal rate of return was found by setting the NPV at year 31 equal to 0, by changing the discount rate. MSP was found by setting the NPV at year 31 equal to 0, subtracting the revenue from hydrogen, and dividing the remainder by the total produced kg of propylene to get the minimum selling price of propylene.

Sensitivity analysis

Spider plots were used to visualize and evaluate the effect of changing key parameters such as feed costs, product selling price, utility costs, etc., on the NPV. Each key parameter was changed by $\pm$10% from the original value and the resulting NPV was recorded. The NPV has the greatest sensitivity to the parameter represented by the line with the steepest slope. Plots were made for both the Houston and Canada plant locations assuming a 1 year build for both locations and results are shown in figures 4 and 5.

Proposed third location in Saudi Arabia

As part of the additional tasks, a third construction alternative in Saudi Arabia was evaluated using the same capital estimation procedures, operational expenditure analysis and 30-year cash flow model applied to the Houston and Canada sites. The difference with Saudi Arabia included a tariff rate of 10%, shipping cost of $.03/kg, labor cost equal to 46% of U.S. labor costs, feedstock cost of $0.4/kg, and a location factor of 0.8.

Results

The full capital estimates for both locations can be seen below in Figures 2 and 3.

CAPITAL ESTIMATE HOUSTON										
IBL Costs			Note - all parameters converted to [M$]							
Unit	*S*		a	b	n	Ftime	Floc		Fp	Cost (M$)
Reciprocating Compressor	*10,000*	*kW*	260	2.7	0.75	1.490909091	1		2.5	11032.73
Membrane Reactor	*50,000*	*kg/hr*	0	55.699066	0.6666667	1.03797	0.869565217		1	68230.97
Cooler (double pipe heat exchanger)	*45*	*m^2*	1.9	2.5	1	1.490909091	1		3.5	596.96
Condenser (carbon steel vertical pressure tanl	*100,000*	*kg*	11.6	0.034	0.85	1.490909091	1		4	3674.88
Floating Head shell and tub heat exchanger	*200*	*m^2*	32	0.07	1.2	1.490909091	1		3.5	377.77
Mechanical Refrigerator Evaporator	1000	kW	24	3.5	0.9	1.490909091	1		2.5	6627.66982
Total IBL										90540.98
OBL costs	30%		of IBL							27162.29
TCC										117703.28
Company costs										
Refrigerant	100	kg	0.2	M$/kg						20.00
Catalysts	25	kg	0.25	M$/lb						6.25
Other	30%		of TCC							35310.98
Total Company										35337.23
CPE										153040.51
Escalation	3%		per year	1	year	0.03	of CPE			4591.22
Contingency	40%		of CPE							61216.20
TPC										**218847.93**

Figure 2. Screenshot of the Excel used for calculating the capital estimate for the Houston plant site. Estimated total plant cost equals $218.85 MM/yr.

CAPITAL ESTIMATE HOUSTON										**BASE CASE**	
IBL Costs			Note - convert all parameters to [M$]								
Unit	*S*	*[units for S]*	a	b	n	Ftime	Floc	Floc-ref	Fp	Cost (MM$)	
Compressor 1-reciproc	*10000*	*kW*	260	2.7	0.75	1.49090909	1.15	1	2.5	12.69	
Membrane RXR	*50000*	*kg/hr*	0	55.699066	0.66666667	1.03797468	1.15	1.15	1	78.47	
Cooler (2xpipe)	*45*	*m^2*	1.9	2.5	1	1.49090909	1.15	1	3.5	0.69	
Conden-vertival press	*100000*	*kg*	11.6	0.034	0.85	1.49090909	1.15	1	4	4.23	
Evaporator	*1000*	*kW*	24	3.5	0.9	1.49090909	1.15	1	2.5	7.62	
Conden-head shell and	*200*	*m^2*	32	0.07	1.2	1.49090909	1.15	1	3.5	0.43	
Total IBL										**104.12**	
OBL costs	30%		of IBL							31.24	
TCC										**135.36**	
Company costs											
Catalysts	0.00025	M$/kg	25	kg						0.00625	
Refrigerant (chemical	0.0002	M$/kg	100	kg						0.02000	
Other	30%	of TCC								40.6077687	
Total Company										**40.63**	
CPE										175.99	
Escalation	3%		per year	1	year	0.03	of CPE			5.28	
Contingency	40%		of CPE							70.40	
TPC										**251.67**	

Figure 3. Screenshot of the Excel used for calculating the capital estimate for the Canada plant site. Estimated total plant cost equals $251.67 MM/yr.

To summarize the results from Figures 2 and 3, Table 1 presents an overall comparison between some of the notable capital costs that were calculated for both construction sites.

Table 1. Comparison of capital costs between Houston and Canada site.

Type of Capital Cost[$MM]	Houston Site	Canada Site
IBLs	90.540	104.12

OBLs	27.162	36.44
TCC	117.7	135.36
CPE	153.04	175.99
TPC	218.85	251.67

Next, Table 2 compares the net revenue in $MM/yr for both locations that was found using OpEx analysis.

Table 2. Projection of net operating revenue(opex) for both locations.

	Houston Site	**Canada Site**
Net Revenue [$MM/yr]	46.6	-45.9

Our results from using a cash flow analysis to find the NPV, payback period, internal rate of return, and MSP are summarized in Table 3 below.

Table 3. Estimate of Net Present Value(NPV), Payback Period, Internal Rate of Return, and Minimum Selling Price(MSP) for both locations.

	Houston Site - 1 yr build	**Canada Site - 1 yr build**
Net Present Value [$MM]	87.74	-553.98
Payback Period [yrs]	9	N/A
Internal Rate of Return [%]	21	N/A
Minimum Selling Price [$/kg]	0.05	0.06

We will now look at the results of our additional tasks which includes a sensitivity analysis using a spider plot and a proposed third location in Saudi Arabia.

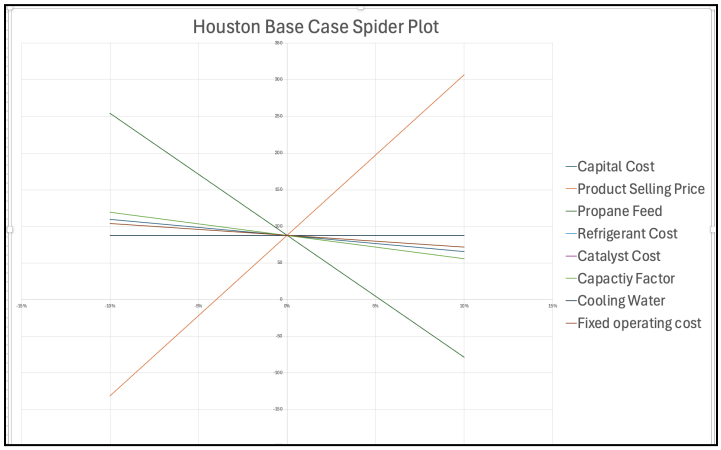


Figure 4. Results from our sensitivity analysis using spider plots for Houston.

CAPITAL ESTIMATE Saudi										
IBL Costs			Note - all parameters converted to [M$]							
Unit	*S*		a	b	n	Ftime	Fhere	Fthere	Fp	Cost (M$)
Reciprocating	*10,000*	*kW*	260	2.7	0.75	1.49090909	0.8	1	2.5	8826.18
Membrane Re	*50,000*	*kg/hr*	0	55.699066	0.66666667	1.03797	0.8	1.15	1	54584.78
Cooler (doub	*45*	*m^2*	1.9	2.5	1	1.49090909	0.8	1	3.5	477.57
Condenser (c	*100,000*	*kg*	11.6	0.034	0.85	1.49090909	0.8	1	4	2939.91
Floating Head	*200*	*m^2*	32	0.07	1.2	1.49090909	0.8	1	3.5	302.22
Mechanical R	1000	kW	24	3.5	0.9	1.49090909	0.8	1	2.5	5302.14
Total IBL										72432.79
OBL costs	30%		of IBL							21729.84
TCC										94162.62
Company costs										
Refrigerant	100	kg	0.2	M$/kg						20.00
Catalysts	25	kg	0.25	M$/lb						6.25
Other	30%		of TCC							28248.79
Total Company										28275.04
CPE										122437.66
Escalation	3%		per year	1	year	0.03	of CPE			3673.13
Contingency	40%		of CPE							48975.06
TPC										**175085.85**

Figure 5. Screenshot of the Excel used for calculating the capital estimate for the third location (Saudi Arabia) plant site. Estimated total plant cost roughly equals $175.09 MM/yr.

The total plant cost (TPC) for the Saudi Arabia location was estimated to be $175.09 MM/yr, which is substantially lower than both previously analyzed alternatives due to favorable construction, labor and location cost factors. Annual revenues remain consistent at $342.85 MM/yr, based on propylene and hydrogen sales. However, the reduced propane feedstock cost of $0.40/kg significantly decreases total variable costs to $192.93 MM/yr, resulting in total annual costs of $217.63 MM/yr. This yields a net operating revenue of $125.21 MM/yr before tariffs. After incorporating a 10% export tariff on propylene, the adjusted net revenue remains strong at $103.45 MM/yr.

Conclusions

Looking at our results when considering the two alternatives, we recommend moving forward with building the plant in Houston instead of Canada. From Tables 1 and 2, we can see that the TPC is lower in Houston and the net revenue is roughly 8 times larger than the net revenue from the Canada site. Additionally, the NPV calculated is much worse for Canada with a value of -$553.98 MM. Combining all of these results, it is a clear answer that the plant should be located in Houston rather than Canada.

From our additional sensitivity analysis, we can conclude that the NPV is the most sensitive to the product selling price and propane feedstock cost for both locations. This is typically the case and makes sense because the selling price is a large contributor to the revenue of a company or facility, and the feedstock price is a deterministic factor in revenue turnover. Furthermore, if feasible, we recommend looking into building the plant in a third alternative location, such as Saudi Arabia. The latter location presents the lowest capital costs out of the three locations and relatively high profitability metrics, most likely due to the low labor and feedstock costs. If similar analysis could be done on other international sites, there may be a stand-out option with much better outcomes compared to both Houston and Canada.