Title

A senior design report submitted to

the Faculty of

The Department of Chemical and Biological Engineering



by

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in partial fulfillment of the requirements for CBE 451

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# Executive Summary

﻿This is a brief description of the design report, focusing on its key conclusions, special features, and assumptions in one or two paragraphs. These include projections of any applicable economic measures of goodness (e.g., the return on investment and the net present value) and recommendations to management. Care should be taken to report only significant figures.

# Chapter 1. Project scope and timeline

﻿This presents the origin of the design project and focuses on the objective-time chart of the tasks needed to be accomplished over the project duration. Included are the specific goals, a project scope, and the deliverables and time line followed.

## Origin and motivation

This section presents background and context for the project. It should include background on prior work, including (especially) prior and ongoing CSU teams and researchers. Indicate potential motivations of stakeholders with an interest in developing or using the product or service.

## Product or service delivered (Problem definition)

Description of the product to be manufactured or the service delivered, including chemical formula, discussion of the role of the product in the industry and its economic significant. It’s not typical in chemical engineering to talk about service. But, especially in the case of a project involved with mitigating environmental problems, like food waste and carbon sequestration, this is a concept that makes more sense. Even for conventional products, it is possible to discuss the service it actually delivers and the alternatives available.

## Project goals

List key technical goals (e.g. goals of lab work, and engineering analysis).

## Project timeline

The team will develop a Gantt chart describing key tasks and activities in support of the project;s technical goals.. An example of a Gantt chart is shown in Figure 1.



Figure 1. Project goals, objectives and timeline

The Gantt chart and associated text should address:

* Relation of activities. Gantt charts are particularly effective for addressing the following kinds of questions:
* What activities are required to be completed as predecessors to other activities?
* What activities can be done partially or completely in parallel?
* Key milestones and deliverables
* Team member assignments/responsibilities
* Start and stop dates and durations

## Design constraints

Briefly describe the design constraints to be considered, highlighting any key aspects specific to the proposed product or service. These may include:

* Economic
* Environmental
* Social
* Health and safety

## Methods and tools

This presents brief descriptions of the methods and tools used: More details will be provided in subsequent sections

### Laboratory experiments (if appropriate)

### Process analysis

Options include spreadsheets like Excel, process simulators (Aspen Plus or SimaPro), R, MatLab, Python etc. or some combination.

### Economic analysis

Options include spreadsheets like Excel, process simulators (Aspen Plus or SimaPro), R, MatLab, Python etc. or some combination.

### Life cycle analysis (if appropriate)

Options include spreadsheets like Excel, process simulators (Aspen Plus or SimaPro), R, MatLab, Python etc. or some combination.

### Other

# Chapter 2. Market and competitive analysis

These describe the market(s) for the new product and identify the principal competitors. When available, the production levels and annual sales of existing products are provided. Also, sales projections for the new product are included.

# Chapter 3. Preliminary process synthesis

﻿The alternative process flowsheets should be presented and possibly the synthesis tree (see Figure 2.7) with a discussion of the most promising flowsheets.

## Summary of data-gathering for process synthesis

### Review of relevant published literature, patents and reports

### Summary of laboratory data collected as part of the project (if applicable)

## Summary of design options considered

Summarize the methods you have identified for manufacture the product, including the final choice of process selected for your design. Provide raw materials, principal reactions, byproducts, and intermediates.

This should also include basic process flow diagrams for the options considered. Process options may involve:

* Different chemical routes
* Options for reactor design
* Options for downstream processing (recovery and purification of products)

## Process flowsheet options

The alternative process flowsheets should be presented and possibly the synthesis tree (see Figure 1) with a discussion of the most promising flowsheets.

A picture containing scale, device, boat, outdoor

Description automatically generated

Figure 2. Synthesis tree for vinyl chloride design options as presented in Seider et al

Whether you explicitly use the synthesis tree or represent your process synthesis in some other format, the goal of this synthesis activity is to walk through each of the key synthesis steps shown in Figure 1 to show how you paired down your choices resulting in a preliminary process flow diagram representing a fully integrated set of unit operations. Note that you may, in many cases there may be one or more paths at a given level.

## Effect of design constraints on process synthesis choices

Discuss how, if at all, these design constraints may have influenced your choice of final design among the survey of process options you considered.

### Environmental considerations

For some designs, environmental factors may be one of the major drivers for the design concept, and you may wish to emphasize that these considerations are not so much constraints but represent major design objectives for which economics may be viewed more as a constraint to be minimized.

For others, these may be viewed more as constraints, for which the goal is to minimize the impacts to the environment while maximizing market value and profitability. In either case, discuss what you have been able to find out with respect to know environmental impacts that should be considered.

If you are planning to include a preliminary life cycle assessment as part of your design, this should be mentioned here, with some indication of why an LCA is important for this design.

### Safety and health considerations

Identify potential hazards and risks associated with the process, and what, if any specific approaches might be needed to minimize these risks. Obvious considerations include:

* Temperature and pressures in the system
* Hazardous or toxic chemicals involved in the process. Include a review of Material and Safety Data Sheets (MSDS’s) for raw materials and chemical intermediates and products.
* Optional preliminary HAZOP analysis, or discussion of need to conduct preliminary HAZOP analysis as part of the design.

### Broader societal considerations

Here you have the opportunity to identify important societal goals that might be supported by your proposed product/service and process design. These can include broad goals not necessarily explicitly acknowledged or goals that are explicit in government policies.(Fisher Scientific, 2013)

## Chemical data

﻿The principal thermophysical and transport property data should be presented with chemical kinetics data and toxicity data and prices for the principal chemicals.

# Chapter 4. Process Description

In this section, you should provide an explanation of the process based on the detailed process flow diagram shown previously.

## Process overview

Your explanation of the process should start with a simple block flow diagram of the process such as shown here from Seider et al. Here you should focus on key process steps that involve chemical reactions and separations.

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Description automatically generated

Figure 4. Simple block flow diagram used to provide overview of major steps in the process

## Detailed process description

This section should culminate in a detailed process flow diagram (see example in Figure 3). All of the streams are numbered clearly and all of the process units are labeled. At some point on the arc for each stream, the temperature and pressure should appear or the information should be tabulated. While it is possible to use a process simulator to create a PFD, you are encouraged to use LucidChart or some other chart software to create a higher quality diagram.

A picture containing text, map

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Figure 3. Example of detailed process flow diagram for vinyl chloride

The following should be included:

* All streams are numbered, and all process units are labeled
* Temperature and pressure should be shown on the diagram or provided in tabular form
* Material and energy balance table summarizing: Total flow rate’ Flow rate of each chemical species and Temperature and pressure. This is data that should be readily extracted from a process simulator.

### Detailed functional description of major equipment

Based on the process flow diagram, present details on:

* The function of each major piece of equipment
* An explanation/justification for the choice of each piece of equipment
* A table listing key specifications for each piece of equipment (e,g, size, capacity, materials of construction, operating conditions).

## Summary of utility requirements

In describing most chemical processes, it is desirable to have a section that discusses the energy requirements of the process. In this report item, all of the heating, cooling, power, and other utility demands should be identified (with numerical values provided), and the methods of satisfying these demands shown.

## Important design assumptions and calculations

Here, describe what models and calculations you used to arrive at your equipment and process flow configurations. This does not mean just stating “we used Aspen Plus” or “SImaPro.” Include any known limitations or caveats about the design methodology and assumptions used. For example, if you used a simple yield or stoichiometric conversion approach, you should indicate this, and suggest any options for further refinement of the design methodology that future teams might take. For any major assumptions, indicate the basis for these assumptions (experimental, educated guesses or other bases taken from your own or other published literature).

When using a process simulator, indicate the nature of the model blocks used, and your choices of input values for them.

This is where you would also provide any code used to develop your design from other tools such as MatLab.

# Chapter 5: Techno-economic analysis

Includes a table with estimated purchase price of all equipment in the process flow diagram, linked to the ID in the process flow sheet and in the equipment list. Provide sources (graphical, tabular, quotation).

## Fixed capital investment summary

The fixed capital investment is related to the estimated purchase cost of the equipment items. The methods for estimating the fixed capital investment, beginning with the purchase costs, should be clearly stated. If desired, the equipment list and the list of equipment purchase costs can be combined. If a factored cost estimate is used, the overall factor or individual equipment factors should be noted.

## Operating cost summary

Report annual operating cost (excluding cost of capital). You should report costs as total plant costs ($2019 per year) and as normalized cost relative to product ($2019 per unit of product). See table for example: It is very likely you will NOT have this much detail. For example, you may have aggregate numbers for process heat and cooling. Likewise, most of the operating costs listed here (beyond specific raw materials used in your process) will be based on simple factored analyses (see Seider et al).

Table 1. Example cost summary from Seider et al

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## Profitability analysis

﻿For a profitability analysis, begin by adding the working capital to the total permanent investment to give the total capital investment. Then, present estimates of one or more of the approximate profitability measures, such as the return on investment (ROI) and the venture profit (VP), and one or more of the rigorous methods that involve cash flows, such as the net present value (NPV) and the investor’s rate of return (IRR). The latter is also referred to as the discounted cash flow rate of return (DCFRR). In all cases, it is important to indicate clearly the depreciation schedule and, for the rigorous methods, to provide a table that shows the calculation of the annual cash. Finally, the design team should present its judgment of the profitability of the proposed investment. Where possible, the results of sensitivity analyses and optimization should be presented. For new product designs, it is common to include the profitability analysis within a business case study (see Section 19.2).

# Chapter 6. Sustainability and other considerations

If you have conducted a life cycle analysis, this is where the results should be included. To the extent that the life cycle analysis may have influenced specific design decisions, these should be discussed.

## Environmental impacts

## Societal impacts

## Workplace and community health and safety impacts

# Chapter 7. Conclusions and recommendations

This section should include a clear statement of the recommendations accompanied by justifications for management. **Focus on next steps for future design teams: 1) improved design methodologies, 2) other process schemes, etc.**

# Appendices

﻿All process simulation computer files should be uplinked to Teams.