LETTER OF TRANSMITTAL

Memorandum

To: AIChE 2019 Student Design Composition Judges

From: Process Design Group # ___

Process Engineering

Date: March 14th, 2018

Subject: Completion of the Manufacturing Facility for a Biopharmaceutical: Monoclonal Antibody

On February 12th, 2019 our team was tasked with developing a preliminary design and economic analysis for a new biopharmaceutical manufacturing facility to produce a new Monoclonal Antibody. The facility needed to be designed to process CHO cells to produce a minimum of 1,000 kg of product a year. We were able to meet this specification by designing a facility that can run 21 batches in a year to produce 1307 kg of MAb. The plant was also designed on a fed-batch system to run at current titers of 1 to 2 g/L and has the ability to run at future titers of 5 to 10 g/L. A detailed economic analysis revealed that this endeavor is very economically favorable and we recommend moving forward with the project.

Overall, our group was able to successfully complete all requests from AIChE for the preliminary design and economic analysis of the new facility. Please find enclosed a copy of our completed report detailing the preliminary design and economic evaluation of the Manufacturing Facility for Monoclonal Antibodies.

Sincerely,

Project Group # _

AIChE
The Global Home of Chemical Engineers

2019 Student Design Composition

Manufacturing Facility for a Biopharmaceutical: Monoclonal Antibody

Group #___

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ABSTRACT

The biopharmaceutical facility for the production of monoclonal antibodies (MAbs) in this document was prompted by the 2019 AIChE Student Design Competition and follows all guidelines and rules contained within it. This design was created using SuperPro software and was frequently checked with simple mass balances to ensure the validity of the process. The proposed design to produce monoclonal antibodies involves the replication of Chinese Hamster Ovary (CHO) cells that are a "host" cell to the desired MAb. It is a "flexible" facility that is able to produce a wide range of MAbs that vary in concentration from 1-2 g/L titers to 5-10 g/L titers. All risks associated with this process have been carefully identified and mitigated through inherently safer design as well as active and passive safety measures. Our final design is able to run 21 batches in a year to produce 1307 kg per year.

The maximum temperature and pressure of the process are 37°C and 10 bar, respectively, though most of the process operates under ambient temperatures and pressures. The material of construction for the process equipment is stainless steel because of its resistance to corrosion and sterile. Inherently safer conditions were considered such simplification of the equipment and chemicals used in the process.

The total capital expenditures will cost $85.7 million and includes all process equipment and a building to house the equipment on the prepared existing site. Starting in the first full year of production, operating costs will be $8.7 million per year, and the project life span was set to be 25 years. The process's capital and operating costs will be offset by the revenue which was calculated to be $16.0 billion per year.

The economic evaluation of our design resulted in a net present value of $65.7 billion, discounted cash flow rate of return of 5956%, and a payback period of 54 days. Our process is most sensitive to the selling price of our product, but given the fact that the process has a positive NPV of $52.5 billion with a 20% decrease in selling price and the historical consistency of the selling prices from major pharmaceutical companies, we are confident with the economic attractiveness of our project. Based upon these economic analyses, it has been concluded that this is a desirable and economically attractive project that we recommend moving into the detailed design stage and eventual construction.

INTRODUCTION

Monoclonal antibodies have become a key component in recent medical research, treatment schemes, and biopharmaceutical production as they have been identified as a powerfully effective and safe treatment. In fact, "Recombinant protein manufacturing with Chinese hamster ovary (CHO) cells represents over 70% of the entire biopharmaceutical industry" [1]. The first monoclonal antibody was produced in 1975 and the first fully licensed antibody was produced in 1986 [2]. Advancements in medical science and genetic sequencing have advanced monoclonal antibodies to become the fastest-growing group of biotechnical derived molecules [3]. MAbs have the ability to treat many autoimmune diseases, inflammatory diseases, infectious diseases, and some types of cancer, as seen in Figure 1. In fact, our company has clinical studies in colon cancer, breast cancer, endovascular cancer, and macular degeneration for our MAb.

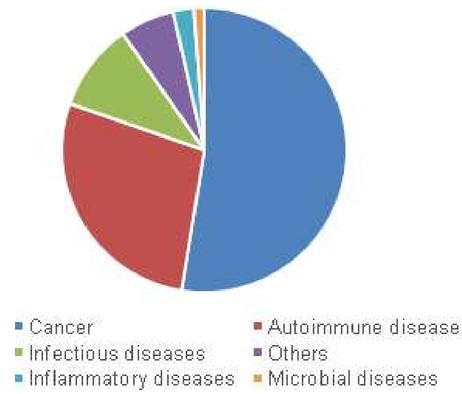


Figure 1 Applications of Monoclonal Antibodies

Antibodies are proteins naturally produced in the body that binds to a protein called an antigen. Antigens are foreign substances in the human body that elicit an immune response. When an antibody attaches to an antigen, it recruits the immune system to attack and destroy the antigen, as seen in Figure 2. MAbs are produced in such a way that they will bind only to a specific antigen. Monoclonal antibodies are praised for their "exquisite precision" as they "bind in very predictable ways to very specific antibodies" [4]. This is an effective way to help the body fight off diseases with its natural immune functions. MAbs typically have very few negative side effects compared with other treatment options. As a result, they are much less risky compared with other treatments, such as chemotherapy [5].

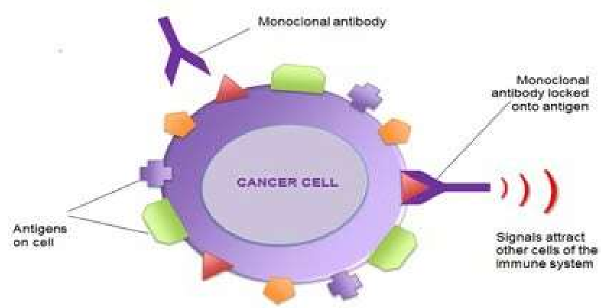


Figure 2 Antibody-Antigen diagram

Monoclonal antibodies can be produced either by cell lines or by hybridomas. The first MAbs originated from a hybridoma, which is a hybrid cell created by injecting an animal, typically a mouse, with an antigen, collecting the resulting antibody-producing B-Lymphocyte, and fusing it with a tumor cell [6]. This fusion is conducted because tumor cells are easily able to replicate indefinitely at a much faster rate than normal cells. On the other hand, for the cell line production platform, a mouse is injected with an antigen that produces the desired antibody for production. The antibody is recovered and then transfected into the cells that will replicate to produce the MAb. Cell lines are chosen based on the requirements that the cells must be stable and produce the desired protein with the conformation at high levels [7]. For MAb production, the mammalian cell is the most commonly used [7]. For our process, the Chinese Hamster Ovary Cell platform was selected as this is the most commonly used cell line for monoclonal antibody production. CHO cells were specifically chosen because they are a part of an immortal cell line. This means that the cells continue to grow in the lab similar to how tumor cells grow. CHO cell also produces high yields of monoclonal antibodies which makes them ideal for our production process. Our CHO cells will be transfected with Global Manufacturing's lab-produced murine antibody proteins. This design project focuses on mass production of MAbs upon obtaining the CHO cells containing the selected antibody.

According to Grand View Research, the MAb global market was worth $85.4 billion in 2015 and is anticipated to be worth $138.6 billion by 2024 as seen in Figure 3. There are already more than 50 MAbs that have been approved for sale in the U.S. and this will continue to grow as the demand for personalized medicine is growing exponentially since research found that individuals respond to treatments differently. This and the presence of fewer adverse side effects has resulted in substantial market growth of MAb production in recent years. Furthermore, the U.S. National Institute of Standards and Technology Bio-manufacturing Initiative strives to help the industry produce high-quality drugs at a much lower cost than in the past, as protein drugs are the fastest growing category of health care costs [8]. Science, industry standards, state of the art tools, and reference data provided by NIST since 2013 have contributed to growth in the MAb industry [8]. MAb production is backed by proven science and manufacturing methods and has immeasurable potential to improve and save human life.

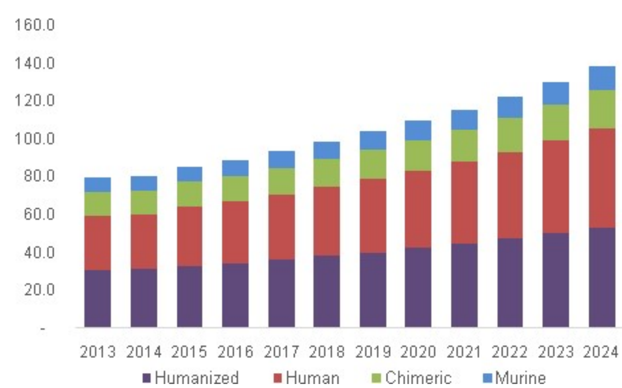
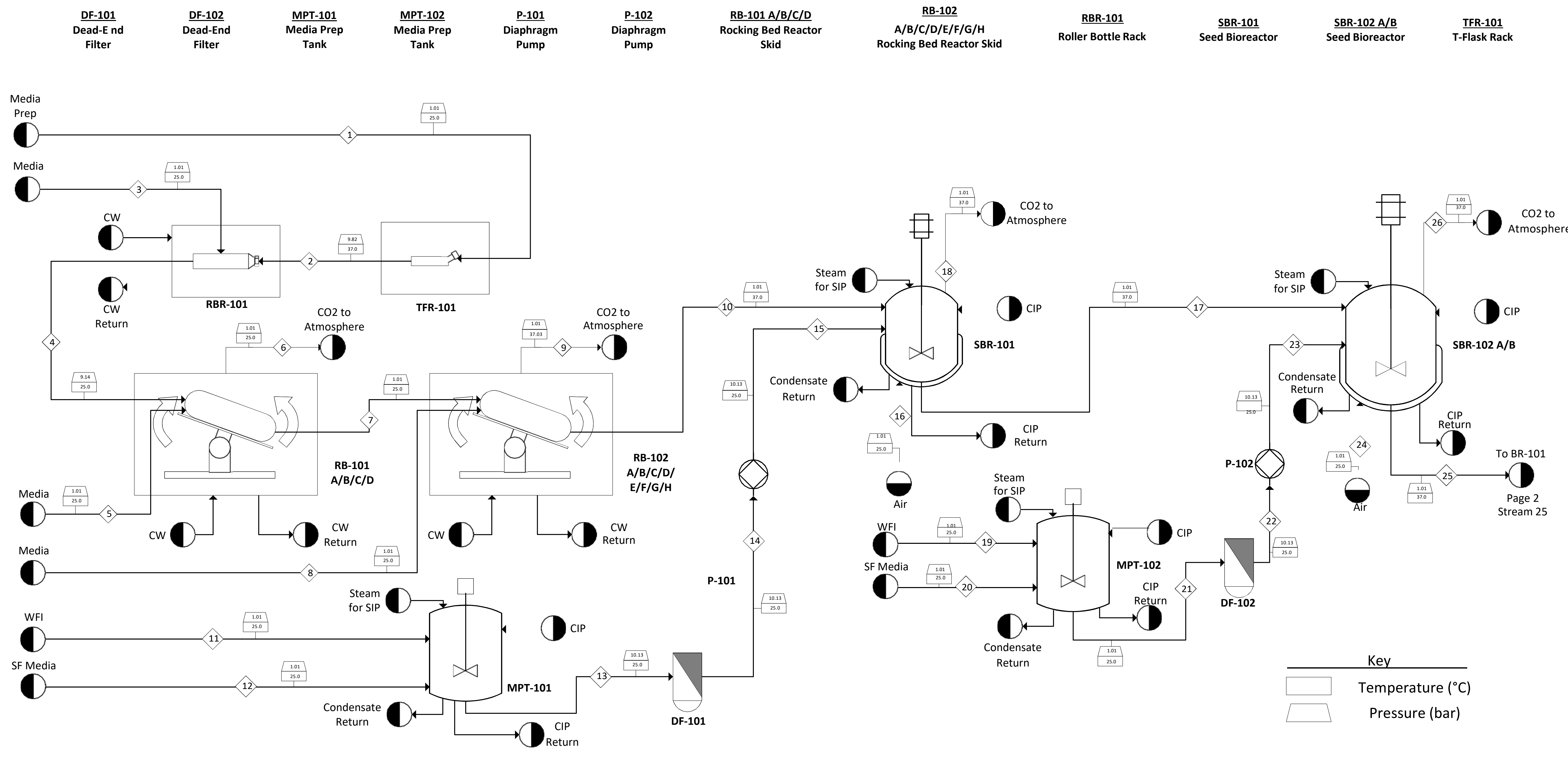


Figure 3 Monoclonal Antibodies Market, By Source Type, 2013-2014 (USD Billion)



			REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED			
	0	Process Flow Diagram Created	3/14/18				

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Monoclonal Antibody Production Plant

Process Flow Diagram of Monoclonal Antibody Production Process

SIZE	FSCM NO	DWG NO	REV
SCALE 1 : 1		SHEET 1 OF 6	

BR-101 A/B Bioreactor

C-101 Protein-A Chromatography Column

DSC-101 A/B/C Disk Stack Centrifuge

DF-103 Dead-End Filter

DF-104 Dead-End Filter

DF-105 Dead-End Filter

DF-106 Dead-End Filter

F-101 A/B Diafilter Membrane

MPT-103 Media Prep Tank

MPT-104 Media Prep Tank

P-103 Diaphragm Pump

P-104 Diaphragm Pump

P-105 Diaphragm Pump

P-106 Diaphragm Pump

P-107 Diaphragm Pump

P-108 Diaphragm Pump

P-109 Diaphragm Pump

P-110 Diaphragm Pump

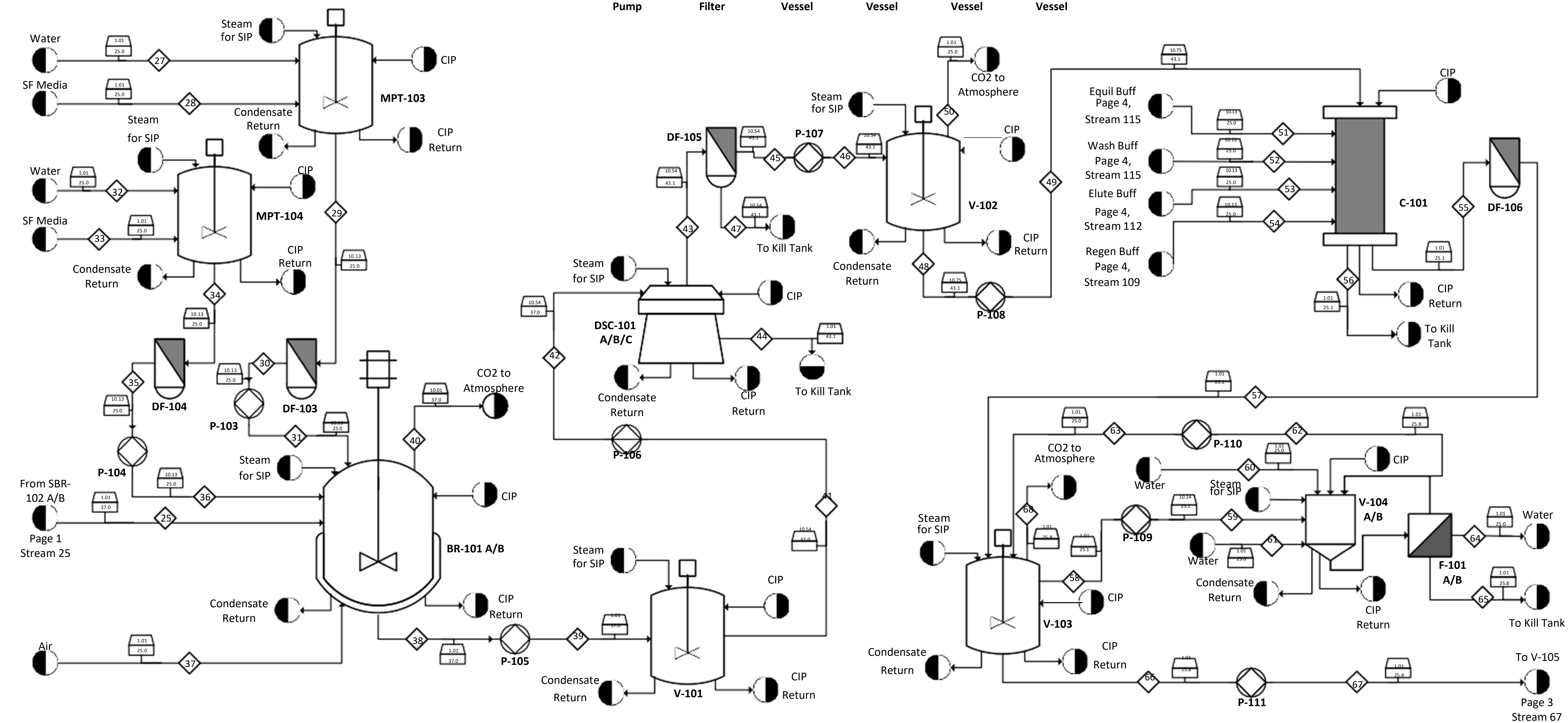
P-111 Diaphragm Filter

V-101 Storage Vessel

V-102 Storage Vessel

V-103 Storage Vessel

V-104 A/B Diafilter Vessel



				REVISIONS			
				ZONE	REV	DESCRIPTION	DATE	APPROVED
					0	Process Flow Diagram Created	3/14/18	

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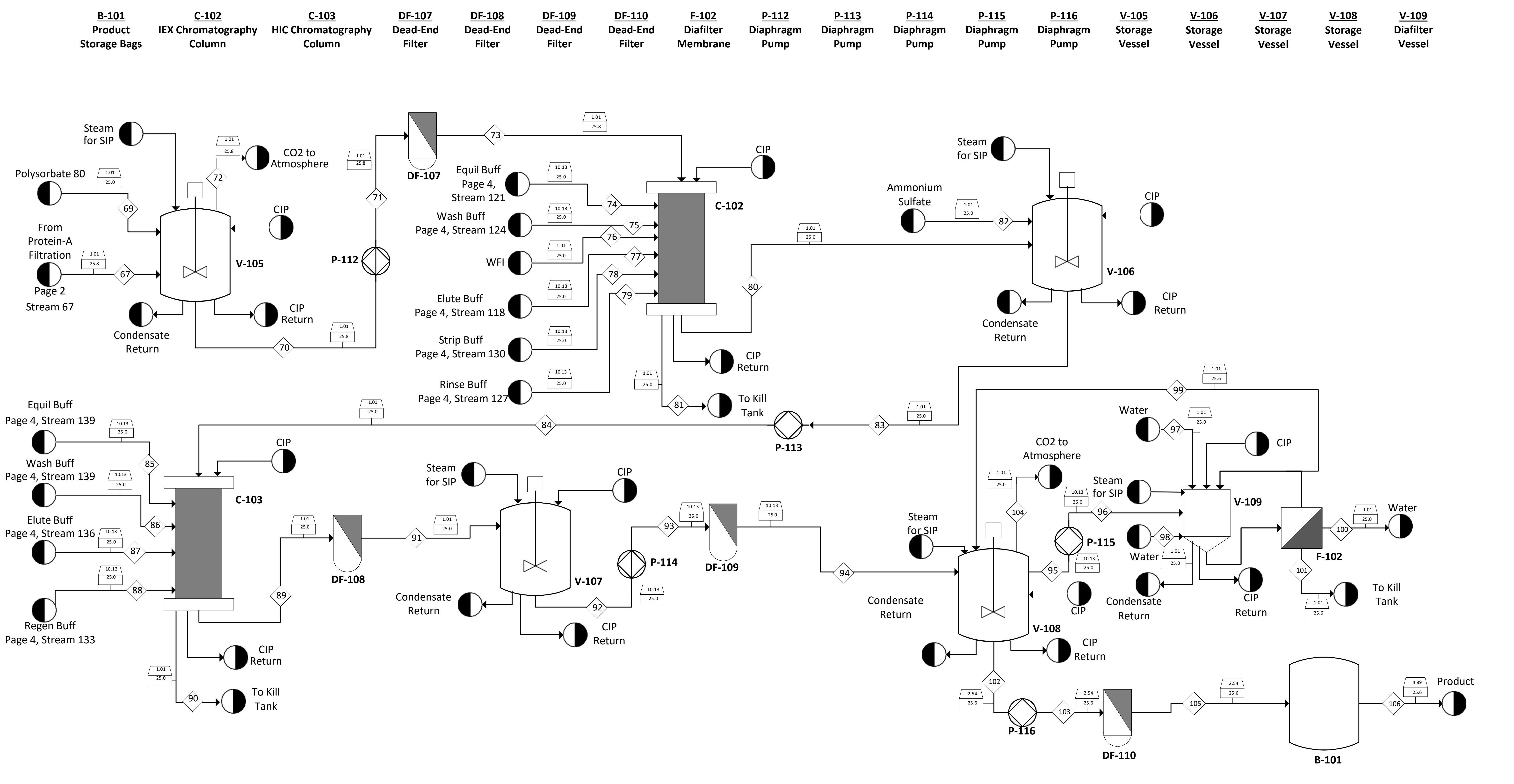
Monoclonal Antibody Production Plant

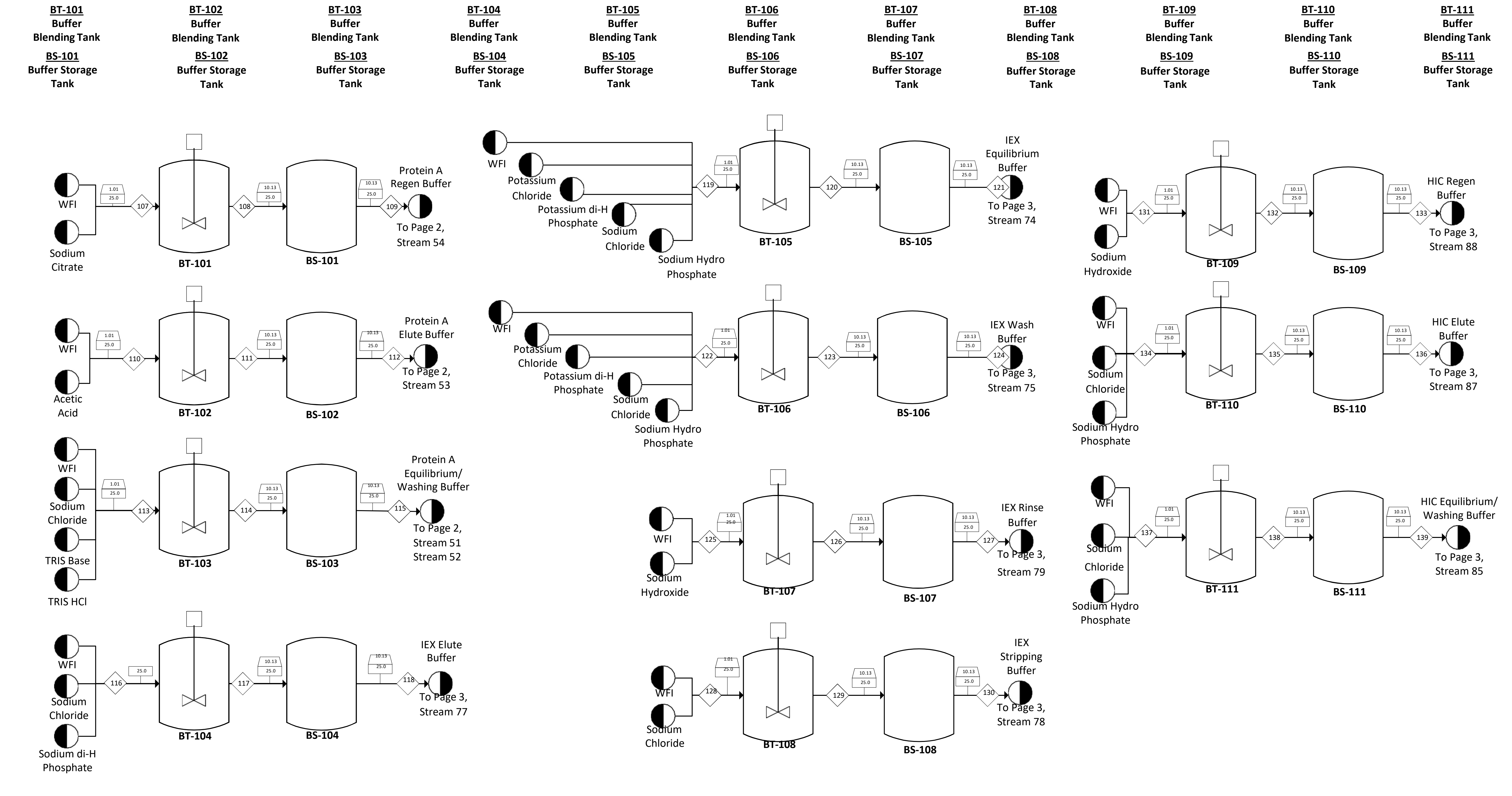
Process Flow Diagram of Monoclonal Antibody Production Process

SIZE	FSCM NO	DWG NO	REV
SCALE 1 : 1		SHEET 2 OF 6	



		REVISIONS				NOTE: THIS PRINT IS CONFIDENTIAL AND SHOULD NOT BE TRACED, PHOTOGRAPHED, COPIED, OR REPRODUCED IN ANY MANNERWITHOUT EXPLICIT PERMISSION.	Monoclonal Antibody Production Plant
	ZONE	REV	DESCRIPTION	DATE	APPROVED		Process Flow Diagram of Monoclonal Antibody Production Process
		0	Process Flow Diagram Created	3/14/18			

SIZE	FSCM NO	DWG NO	REV
SCALE	1 : 1	SHEET	3 OF 6



			REVISIONS				
			ZONE	REV	DESCRIPTION	DATE	APPROVED
				0	Process Flow Diagram Created	3/14/18	

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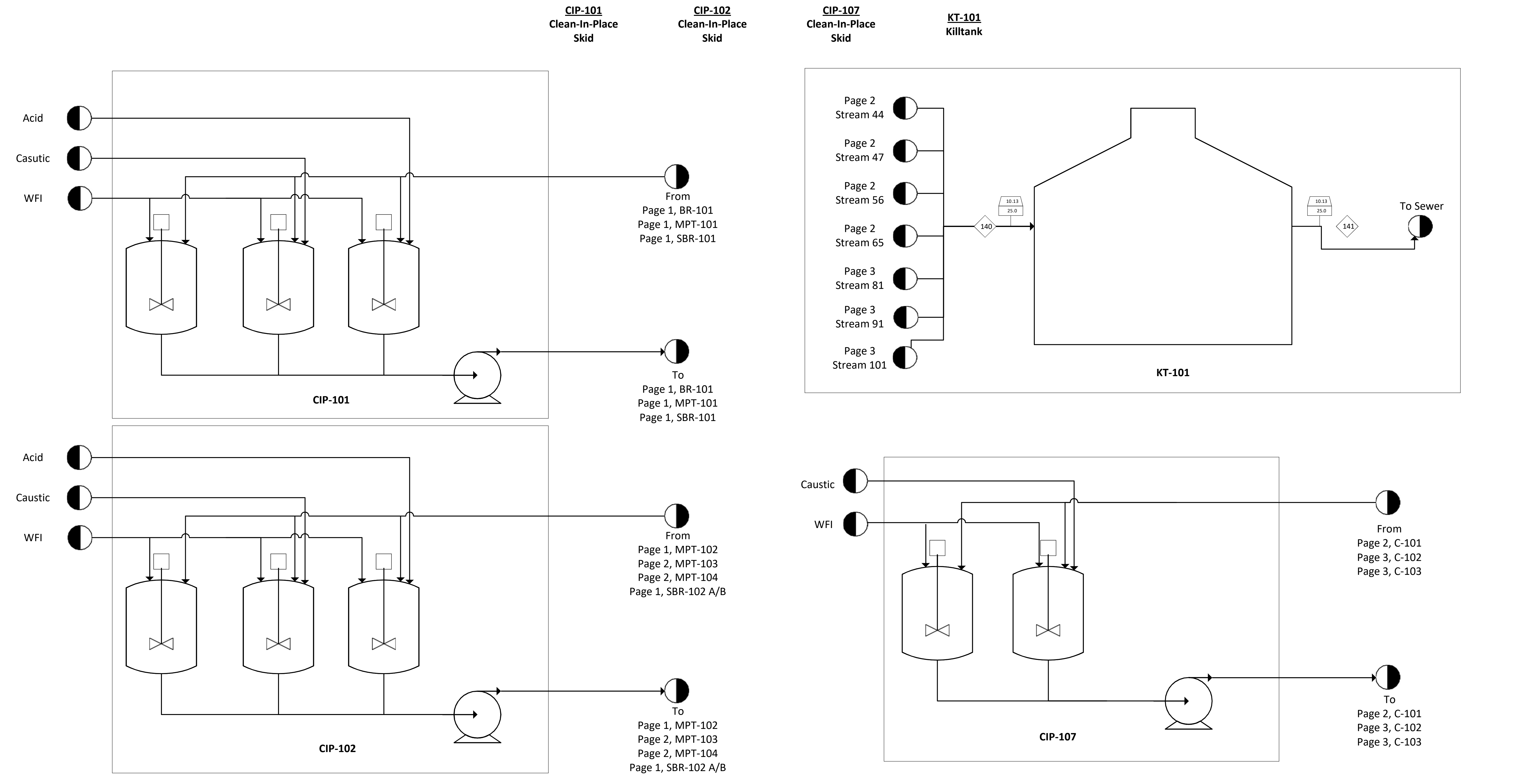
Monoclonal Antibody Production Plant

Process Flow Diagram of Monoclonal Antibody Production Process

SIZE	FSCM NO	DWG NO	REV
SCALE	1 : 1	SHEET	4 OF 6



REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED
	0	Process Flow Diagram Created	3/14/18	

Monoclonal Antibody Production Plant

Process Flow Diagram of Monoclonal Antibody Production Process

SIZE	FSCM NO	DWG NO	REV

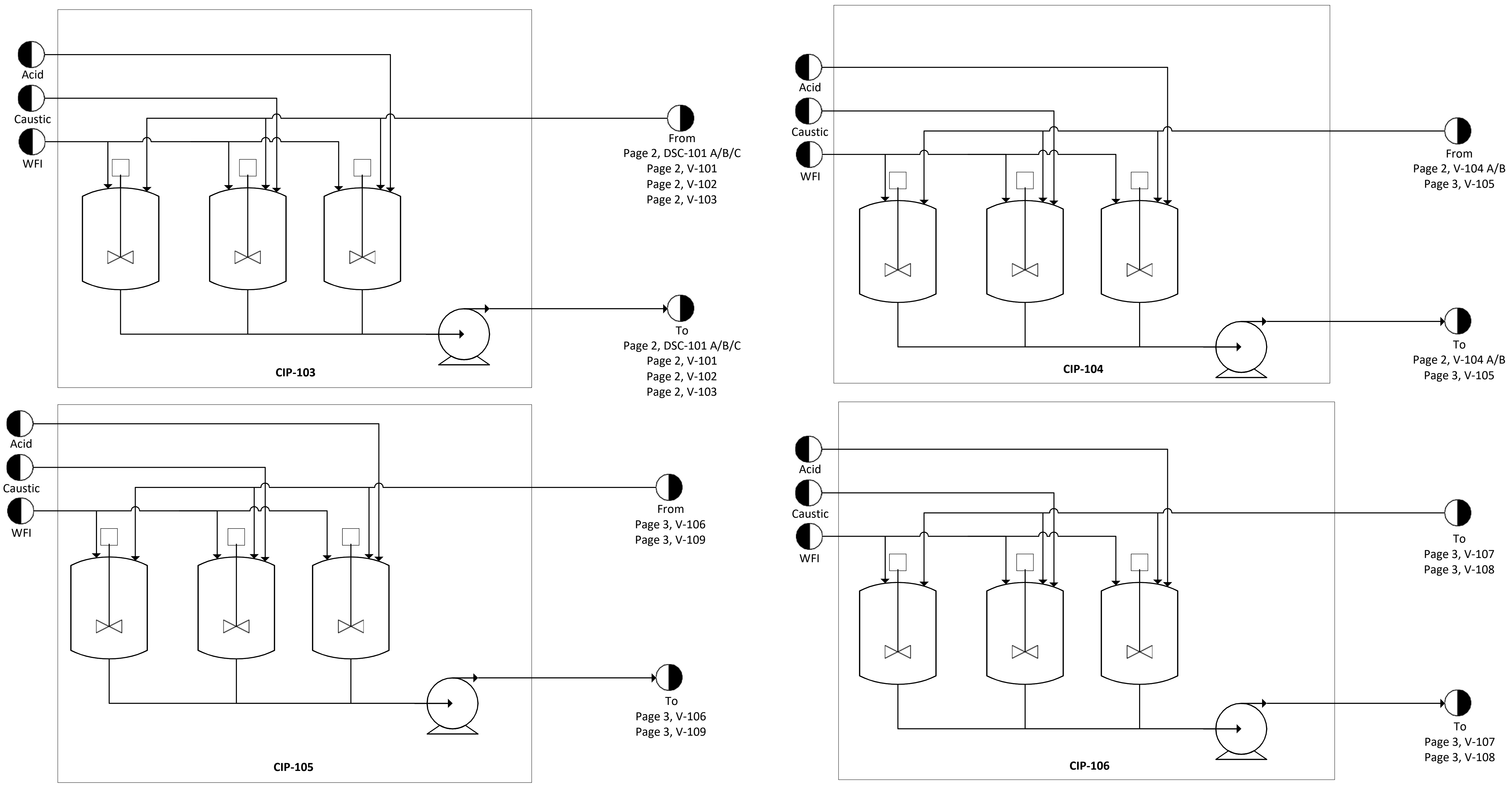
SCALE	1 : 1		SHEET	5 OF 6

CIP-103
Clean-In-Place
Skid

CIP-104
Clean-In-Place
Skid

CIP-105
Clean-In-Place
Skid

CIP-106
Clean-In-Place
Skid



REVISIONS

ZONE	REV	DESCRIPTION	DATE	APPROVED
	0	Process Flow Diagram Created	3/14/18	

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Monoclonal Antibody Production Plant

Process Flow Diagram of Monoclonal Antibody Production Process

SIZE	FSCM NO	DWG NO	REV
SCALE 1 : 1		SHEET 6 OF 6	

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Temperature (°C)	25.00	37.00	25.00	25.00	25.00	25.00	25.00	25.00	37.03	37.00	25.00	25.00	25.00	25.00	25.00	25.00	37.00	37.00	25.00	25.00	25.00
Pressure (bar)	1.01	9.82	1.01	9.14	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	10.13	10.13	10.13	1.01	1.01	1.01	1.01	1.01	1.01
Actual Volumetric Flow Rate (m^3/batch)	0.01	0.01	0.03	0.04	0.13	0.12	0.18	0.53	0.56	0.70	2.06	0.47	2.11	2.11	2.11	1308.51	2.82	1366.29	8.24	0.19	8.45
Density (kg/m^3)	994.70	990.50	994.70	994.85	994.70	1.32	994.81	994.70	1.27	990.43	994.70	994.70	994.70	994.70	994.70	1.18	990.47	1.13	994.70	994.70	994.70
Total Mass Flow (kg/batch)	10.74	10.74	34.02	44.76	130.11	0.16	174.66	523.41	0.71	697.21	2050.09	46.56	2096.65	2096.65	2096.65	1543.02	2790.13	1550.10	8220.63	186.71	8407.34
Total Mole Flow (kmol/batch)	0.60	0.60	1.89	2.48	7.23	0.00	9.69	29.06	0.02	38.68	113.80	2.59	116.39	116.39	116.39	53.48	154.78	53.69	456.32	10.36	466.69
Component Flowrates (kmol/batch)																					
Acetic Acid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amnonium Sulfate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	0.00	1.32E-03	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	1.11E-03	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00
Di-Sodium Hydro Phosphate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EDTA Sodium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Impurities	0.00	0.00	0.00	6.30E-04	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00
MAB	0.00	9.00E-05	0.00	4.00E-04	0.00	0.00	1.59E-03	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
Media: CD Fed-Batch Media	0.01	3.87E-03	0.04	0.01	0.16	0.00	0.05	0.63	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00
Nitrogen	0.00	0.00	0.00	0.00	0.00	2.96E-03	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	42.25	0.00	42.35	0.00	0.00	0.00
Oxygen	0.00	0.00	0.00	0.00	0.00	7.90E-04	0.00	0.00	3.56E-03	0.00	0.00	0.00	0.00	0.00	0.00	11.23	0.00	11.25	0.00	0.00	0.00
Polysorbate 80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potassium Chloride	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potassium di-Hydrogen Phosphate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Serum Free Media: CD Feed 1 with Glucose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.59	2.59	2.59	2.59	0.00	0.52	0.00	0.00	10.36	10.36
Sodium Chloride	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium Citrate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium di-Hydrogen Phosphate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium Hydroxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TRIS Base	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TRIS Hydrochloric Acid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	0.00	0.01	0.00	0.03	0.00	0.00	0.12	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00	1.92	0.00	0.00	0.00	0.00
WFI	0.59	0.58	1.85	2.43	7.07	0.00	9.50	28.43	0.00	37.92	113.80	0.00	113.80	113.80	113.80	0.00	151.72	0.00	456.32	0.00	456.32

Stream Number	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Temperature (°C)	25.00	25.00	25.00	37.00	37.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	37.00	37.00	37.00	37.00	37.00
Pressure (bar)	10.13	10.13	1.01	1.01	1.01	1.01	1.01	10.13	10.13	10.13	1.01	1.01	10.13	10.13	10.13	1.01	1.01	1.01	10.01	10.54	10.54
Actual Volumetric Flow Rate (m^3/batch)	8.45	8.45	5244.31	11.34	5415.12	30.00	2.07	32.07	32.07	32.07	4.12	0.28	3.25	3.25	3.25	40395.96	47.01	47.01	41703.36	47.01	47.01
Density (kg/m^3)	994.70	994.70	1.18	990.60	1.14	994.70	994.70	994.70	994.70	994.70	994.70	994.70	994.70	994.70	994.70	1.18	990.91	990.91	1.14	990.97	990.99
Total Mass Flow (kg/batch)	8407.34	8407.34	6184.21	11228.84	6166.33	29841.13	2055.46	31896.59	31896.59	31896.59	4100.00	282.00	3231.80	3231.80	3231.80	47635.79	46585.43	46585.43	47463.51	46585.43	46586.43
Total Mole Flow (kmol/batch)	466.69	466.69	214.36	622.50	212.78	1656.46	114.10	1770.56	1770.56	1770.56	227.59	15.65	179.39	179.39	179.39	1651.16	2578.80	2578.80	1619.14	2578.80	2578.80
Component Flowrates (kmol/batch)																					
Acetic Acid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amnonium Sulfate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	0.00	0.00	0.00	2.19	2.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.39	19.39	0.00	19.39	19.39
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Di-Sodium Hydro Phosphate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EDTA Sodium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Impurities	0.00	0.00	0.00	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.04	3.04	0.00	3.04	3.04
MAB	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.20	5.20	0.00	5.20	5.20
Media: CD Fed-Batch Media	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.20	0.20
Nitrogen	0.00	0.00	169.35	0.00	169.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1304.48	0.00	0.00	1306.01	0.00	0.00
Oxygen	0.00	0.00	45.01	0.00	40.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	346.68	0.00	0.00	313.14	0.00	0.00
Polysorbate 80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potassium Chloride	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potassium di-Hydrogen Phosphate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Serum Free Media: CD Feed 1 with Glucose	10.36	10.36	0.00	2.18	0.00	0.00	114.10	114.10	114.10	114.10	0.00	15.65	11.54	11.54	11.54	0.00	67.50	67.50	0.00	67.50	67.50
Sodium Chloride	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium Citrate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium di-Hydrogen Phosphate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium Hydroxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TRIS Base	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TRIS Hydrochloric Acid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	0.00	0.00	0.00	8.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	51.11	51.11	0.00	51.11	51.11
WFI	456.32	456.32	0.00	608.04	0.00	1656.46		1656.46	1656.46	1656.46	227.59	0.00	167.85	167.85	167.85	0.00	2432.35	2432.35	0.00	2432.35	2432.35

Stream Number	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
Temperature (°C)	43.10	43.10	43.10	43.10	43.10	43.10	43.10	25.00	25.00	25.00	25.00	25.00	25.10	25.10	25.10	25.10	25.10	25.00	25.00	25.80	25.80
Pressure (bar)	10.54	1.01	10.54	10.54	10.54	10.75	10.75	1.01	10.13	10.13	10.13	10.13	1.01	1.01	1.01	10.14	10.14	1.01	1.01	1.01	1.01
Actual Volumetric Flow Rate (m^3/batch)	44.77	2.34	44.75	44.75	0.02	44.75	44.75	0.00	29.95	35.95	29.95	17.97	12.25	12.25	12.25	12.25	12.25	2.45	1.00	2.45	2.45
Density (kg/m^3)	988.18	1001.89	988.21	988.23	1019.07	988.11	988.13	0.00	1030.00	1005.00	1010.00	1005.00	994.93	995.01	994.93	994.93	995.01	994.70	994.70	994.50	994.91
Total Mass Flow (kg/batch)	44241.00	2344.42	44222.46	44223.46	18.54	44222.46	44223.46	0.00	30853.39	36125.43	30254.28	18062.71	12185.75	12186.75	12185.75	12185.75	12186.75	2436.60	994.70	2436.80	2437.80
Total Mole Flow (kmol/batch)	2455.64	123.16	2454.76	2454.76	0.89	2454.76	2454.76	0.00	1702.16	1995.99	1672.34	1000.97	673.60	673.60	673.60	673.60	673.60	135.25	55.22	135.06	135.06
Component Flowrates (kmol/batch)																					
Acetic Acid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.02	0.00	1.21	1.21	1.21	1.21	1.21	0.00	0.00	0.09	0.09
Amnonium Sulfate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	0.39	19.00	0.00	0.00	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Di-Sodium Hydro Phosphate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EDTA Sodium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Impurities	2.92	0.12	2.92	2.92	5.90E-04	2.92	2.92	0.00	0.00	0.00	0.00	0.00	0.18	0.18	0.18	0.18	0.18	0.00	0.00	0.01	0.01
MAB	4.99	0.21	4.99	4.99	0.00	4.99	4.99	0.00	0.00	0.00	0.00	0.00	4.49	4.49	4.49	4.49	4.49	0.00	0.00	4.49	4.49
Media: CD Fed-Batch Media	0.20	0.01	0.20	0.20	4.00E-05	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polysorbate 80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potassium Chloride	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00E-04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potassium di-Hydrogen Phosphate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00E-04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Serum Free Media: CD Feed 1 with Glucose	64.75	2.75	64.74	64.74	0.01	64.74	64.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium Chloride	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	2.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium Citrate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium di-Hydrogen Phosphate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium Hydroxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TRIS Base	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TRIS Hydrochloric Acid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	49.03	2.08	49.02	49.02	0.01	49.02	49.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WFI	2333.37	98.98	2332.90	2332.90	0.47	2332.90	2332.90	0.00	1700.66	1992.76	1669.32	1000.84	667.73	667.73	667.73	667.73	667.73	135.25	55.22	130.47	130.47

Stream Number	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84
Temperature (°C)	25.00	25.80	25.80	25.80	25.80	25.00	25.80	25.80	25.80	25.80	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Pressure (bar)	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	10.13	10.13	1.01	10.13	10.13	10.13	1.01	1.01	1.01	1.01	1.01
Actual Volumetric Flow Rate (m^3/batch)	1.00	12.25	2.45	2.45	2.49	5.60E-04	2.45	2.45	2.46	2.45	20.22	101.10	95.54	5.55	60.66	60.66	40.52	307.33	2.40	42.93	42.93
Density (kg/m^3)	994.70	994.65	994.50	994.91	1.18	869.64	994.47	994.88	1.18	994.47	1004.00	1005.00	994.70	1030.00	1030.00	1021.00	996.40	1005.90	1769.00	1039.69	1039.71
Total Mass Flow (kg/batch)	994.70	12185.56	2436.80	2437.80	2.93	0.49	2437.28	2438.28	2.89	2437.28	20300.70	101604.62	95038.76	5721.04	62479.26	61933.32	40376.72	309138.26	4254.11	44630.83	44631.83
Total Mole Flow (kmol/batch)	55.22	673.79	135.06	135.06	0.10	0.01	135.08	135.08	0.10	135.08	1118.78	5564.33	5275.54	303.58	3332.15	3400.84	2235.69	16894.61	32.20	2267.88	2267.88
Component Flowrates (kmol/batch)																					
Acetic Acid	0.00	1.12	0.09	0.09	0.00	0.00	0.09	0.09	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00
Amnonium Sulfate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	32.20	32.20	32.20
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Di-Sodium Hydro Phosphate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.79	0.00	0.00	0.00	0.00	0.00	0.94	0.00	0.00	0.00
EDTA Sodium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Impurities	0.00	0.16	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	3.36E-04	0.01	0.00	7.50E-04	7.50E-04
MAB	0.00	0.00	4.49	4.49	0.00	0.00	4.49	4.49	0.00	4.49	0.00	0.00	0.00	0.00	0.00	0.00	4.04	0.45	0.00	4.04	4.04
Media: CD Fed-Batch Media	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrogen	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polysorbate 80	0.00	0.00	0.00	0.00	0.00	1.90E-04	1.90E-04	1.90E-04	0.00	1.90E-04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.90E-04	0.00	0.00	0.00
Potassium Chloride	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00E-04	2.70E-03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potassium di-Hydrogen Phosphate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00E-04	1.50E-03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Serum Free Media: CD Feed 1 with Glucose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium Chloride	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.13	31.28	0.00	5.06	60.62	0.00	2.02	98.07	0.00	2.02	2.02
Sodium Citrate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium di-Hydrogen Phosphate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.00	0.00	0.19	0.28	0.00	0.19	0.19
Sodium Hydroxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.35	0.00	30.35	0.00	0.00	0.00
TRIS Base	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TRIS Hydrochloric Acid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6642.03	0.00	0.00	0.00
WFI	55.22	672.51	130.47	130.47	0.00	0.01	130.49	130.49	0.00	130.49	1115.49	5532.25	5275.54	298.06	3271.53	3370.49	2229.44	10122.39	0.00	2229.44	2229.44

Stream Number	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
Temperature (°C)	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.60	25.00	25.60	25.60	25.60	25.00	25.60
Pressure (bar)	10.13	10.13	10.13	10.13	1.01	1.01	1.01	10.13	10.13	10.13	10.13	10.13	1.01	1.01	1.01	1.01	1.01	2.54	2.54	1.01	2.54
Actual Volumetric Flow Rate (m^3/batch)	3.64	9.10	9.10	9.10	3.74	70.34	3.74	3.74	3.74	3.74	3.74	3.74	4.99	0.50	2.50	0.50	6.24	2.50	2.50	0.00	2.50
Density (kg/m^3)	1060.00	1060.00	1025.00	1021.00	1014.85	1037.12	1014.85	1014.85	1015.12	1014.85	1014.85	1015.12	1000.00	994.70	1000.83	994.70	1007.49	1000.83	1001.23	0.00	1000.83
Total Mass Flow (kg/batch)	3857.94	9644.86	9326.39	9290.00	3796.07	72953.95	3796.07	3796.07	3797.07	3796.07	3796.07	3797.07	4987.37	497.35	2498.35	497.35	6285.09	2498.35	2499.35	0.00	2498.35
Total Mole Flow (kmol/batch)	184.54	496.98	502.38	510.13	204.59	3757.32	204.59	204.59	204.59	204.59	204.59	204.59	275.05	27.61	137.37	27.61	342.26	3.48	3.48	0.00	137.37
Component Flowrates (kmol/batch)																					
Acetic Acid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amnonium Sulfate	0.00	0.00	0.00	0.00	0.00	32.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Di-Sodium Hydro Phosphate	0.08	0.22	0.19	0.00	0.08	0.41	0.08	0.08	0.08	0.08	0.08	0.08	0.04	0.00	0.02	0.00	0.09	0.02	0.02	0.00	0.02
EDTA Sodium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Impurities	0.00	0.00	0.00	0.00	0.00	7.50E-04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAB	0.00	0.00	0.00	0.00	3.64	0.40	3.64	3.64	3.64	3.64	3.64	3.64	0.00	0.00	3.45	0.00	0.00	3.45	3.45	0.00	3.45
Media: CD Fed-Batch Media	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polysorbate 80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potassium Chloride	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00E-04	0.00	6.00E-05	0.00	8.00E-04	6.00E-05	6.00E-05	0.00	6.00E-05
Potassium di-Hydrogen Phosphate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00E-04	0.00	3.00E-05	0.00	4.00E-05	3.00E-05	3.00E-05	0.00	3.00E-05
Serum Free Media: CD Feed 1 with Glucose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium Chloride	12.94	16.45	6.25	0.00	2.50	35.16	2.50	2.50	2.50	2.50	2.50	2.50	0.68	0.00	0.51	0.00	2.67		0.00	0.00	0.51
Sodium Citrate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium di-Hydrogen Phosphate	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium Hydroxide	0.00	0.00	0.00	4.55	0.00	4.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TRIS Base	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TRIS Hydrochloric Acid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	0.00	0.00	0.00	0.00	0.00	505.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WFI	171.51	480.32	495.94	505.57	198.38	3178.83	198.38	198.38	198.38	198.38	198.38	198.38	274.32	27.61	133.39	27.61	339.50	0.00	0.00	0.00	133.39

Stream Number	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126
Temperature (°C)	25.60	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Pressure (bar)	4.89	1.01	10.13	10.13	1.01	10.13	10.13	1.01	10.13	10.13	1.01	10.13	10.13	1.01	10.13	10.13	1.01	10.13	10.13	1.01	10.13
Actual Volumetric Flow Rate (m^3/batch)	2.50	17.97	17.97	17.97	29.95	29.95	29.95	29.95	29.95	29.95	5.55	5.55	5.55	20.22	20.22	20.22	101.10	101.10	101.10	60.66	60.66
Density (kg/m^3)	1000.83	1005.00	1005.00	1005.00	1010.00	1010.00	1010.00	1030.00	1030.00	1030.00	1030.00	1030.00	1030.00	1004.00	1004.00	1004.00	1005.00	1005.00	1005.00	1021.00	1021.00
Total Mass Flow (kg/batch)	2498.35	18062.71	18062.71	18062.71	30254.28	30254.28	30254.28	30853.39	30853.39	30853.39	5721.04	5721.04	5721.04	20300.70	20300.70	20300.70	101604.62	101604.62	101604.62	61933.32	61933.32
Total Mole Flow (kmol/batch)	137.37	1010.97	1000.97	1000.97	1672.34	1672.34	1672.34	1702.16	1702.16	1702.16	303.58	303.58	303.58	1118.78	1118.78	1118.78	5564.33	5564.33	5564.33	3400.84	3400.84
Component Flowrates (kmol/batch)																					
Acetic Acid	0.00	0.00	0.00	0.00	3.02	3.02	3.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amnonium Sulfate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Di-Sodium Hydro Phosphate	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.16	0.16	0.79	0.79	0.79	0.00	0.00
EDTA Sodium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.18	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Impurities	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAB	3.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Media: CD Fed-Batch Media	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polysorbate 80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potassium Chloride	6.00E-05	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00E-04	5.00E-04	5.00E-04	2.70E-03	2.70E-03	2.70E-03	0.00	0.00
Potassium di-Hydrogen Phosphate	3.00E-05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00E-04	3.00E-04	3.00E-04	1.50E-03	1.50E-03	1.50E-03	0.00	0.00
Serum Free Media: CD Feed 1 with Glucose	0.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium Chloride	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.53	0.53	5.06	5.06	5.06	3.13	3.13	3.13	31.28	31.28	31.28	0.00	0.00
Sodium Citrate	0.00	0.13	0.13	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium di-Hydrogen Phosphate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.47	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium Hydroxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.35	30.35
TRIS Base	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TRIS Hydrochloric Acid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59	0.59	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WFI	133.39	1000.84	1000.84	1000.84	1669.32	1669.32	1669.32	1700.66	1700.66	1700.66	298.06	298.06	298.06	1115.49	1115.49	1115.49	5532.25	5532.25	5532.25	3370.49	3370.49

Stream Number	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141
Temperature (°C)	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Pressure (bar)	10.13	1.01	10.13	10.13	1.01	10.13	10.13	1.01	10.13	10.13	1.01	10.13	10.13	1.01	1.01
Actual Volumetric Flow Rate (m^3/batch)	60.66	60.66	60.66	60.66	9.10	9.10	9.10	9.10	9.10	9.10	9.10	9.10	9.10	344.16	112.84
Density (kg/m^3)	1021.00	1030.00	1030.00	1030.00	1021.00	1021.00	1021.00	1025.00	1025.00	1025.00	1060.00	1060.00	1060.00	1005.21	1006.84
Total Mass Flow (kg/batch)	61933.32	62479.26	62479.26	62479.26	9290.00	9290.00	9290.00	9326.39	9326.39	9326.39	9644.86	9644.86	9644.86	345953.68	113616.00
Total Mole Flow (kmol/batch)	3400.84	3332.15	3332.15	3332.15	510.13	510.13	510.13	502.38	502.38	502.38	496.98	496.98	496.98	18912.90	18912.90
Component Flowrates (kmol/batch)															
Acetic Acid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.42	2.42
Amnonium Sulfate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.39	19.39
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Di-Sodium Hydro Phosphate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.19	0.19	0.22	0.22	0.22	1.11	1.11
EDTA Sodium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Impurities	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.47
MAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.79	8.79
Media: CD Fed-Batch Media	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Nitrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polysorbate 80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potassium Chloride	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potassium di-Hydrogen Phosphate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Serum Free Media: CD Feed 1 with Glucose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.76	2.76
Sodium Chloride	0.00	60.62	60.62	60.62	0.00	0.00	0.00	6.25	6.25	6.25	16.45	16.45	16.45	103.24	103.24
Sodium Citrate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium di-Hydrogen Phosphate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.28
Sodium Hydroxide	30.35	0.00	0.00	0.00	4.55	4.55	4.55	0.00	0.00	0.00	0.00	0.00	0.00	30.35	30.35
TRIS Base	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TRIS Hydrochloric Acid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6644.12	6644.12
WFI	3370.49	3271.53	3271.53	3271.53	505.57	505.57	505.57	495.94	495.94	495.94	480.32	480.32	480.32	12099.96	12099.96

PROCESS DESCRIPTION

Design Philosophy

Monoclonal antibody production, while having many variations, always follows the same general process flow: media preparation, upstream scale up, and downstream purification. Besides the general monoclonal antibody production process, there are necessary support processes such as the creation of water for injection, clean steam for steam-in-place (SIP), and a refrigeration system for the final product. To begin the upstream process, the media to support cell growth and buffers selected for purification steps must be carefully selected and prepared. The specific media preparation step varies on the exact media chosen and is detailed in subsequent sections. In the downstream process, the purification and polishing steps are strategically chosen with sufficient redundancy to maximize MAb recovery and purity. There are several industry-recognized viral inactivation steps, and we selected our methods with both product and manufacturing safety in mind.

The monoclonal antibody manufacturing facility was designed with the student version of SuperPro Designer software provided by Intelligen, Inc. This software is an industry standard for designing pharmaceutical processes, modeling, and debottlenecking. The efficiency, feasibility, and overall safety of the manufacturing process were the basis for our design. We designed two separate MAb production systems on SuperPro to explore design options. The idea for the first system was to use multiple smaller units and run more batches and for the second system to use larger units and run fewer batches. A broad overview of the findings for each system is listed in Table 1.

Table 2 Comparison of Design Options 1 and 2

Design 1	Design 2
21 batches/year	7 batches/year
~1,300 kg of Mab produced	~4,000 kg of Mab produced
2 smaller production bioreactors	1 large production bioreactor
Multiple smaller units	Fewer larger units
Benefits: • Lower capital costs • Lower operating costs • Lower facility costs • Easily feasible • Inherently safer	Benefits: • Larger production volume
Drawbacks: • Smaller production volume	Drawbacks: • Questionable feasibility • Less safe • Significantly higher capital and operating costs

We selected Design 1 because of its feasibility, economic advantages, and because of its inherently safer design. We felt it was more technically feasible to have multiple smaller units because that would allow us to buy equipment in standard sizes. The economic and safety aspects of this design are explained in detail in subsequent sections.

Design Basis

This process is required to produce a minimum of 1,000 kg of MAb product every year and must be able to produce product at current titers of 1 to 2 g/L and future titers of 5 to 10 g/L. As the titers of product increases, fewer batches will be needed per year. It is assumed that our company is a well-established biopharmaceutical company that must meet a minimum rate of return of 16.5% for this project to be considered a favorable investment. A tax rate of 21% has been applied, in accordance with the Tax Cuts and Jobs Act of December 2017 [9]. The project will be evaluated with a 25-year project life.

The largest single component of MAb production is water for injection, or WFI. WFI is added in many steps of the production process. WFI is water of ultra-high quality without contamination. It can be produced through reverse osmosis, distillation, or vapor compression. For the product to meet European regulations, distillation must be used to make this water [10].

We opted to purchase a distillation WFI skid to make our own WFI from city water instead of purchasing WFI from elsewhere because of the economic benefit from producing it ourselves.

The MAbs must be produced using one 1 mL vial of CHO cells for each batch of MAb produced. The vials contain 1 X 10^6 viable cells/mL and the cells have a doubling time of 36 hours. It was assumed that our cells produce product at a rate of 25 pg/(cell*day). These cells must be expanded by passage into larger and larger volumes in a batch system Seed Train before entering the production reactor. The facility will have the capability to run both batch and fed-batch processes. However, for our design purposes, our design will run on a fed-batch platform and the glucose level in our bioreactors should not fall below 2 g/L.

For the downstream process, it was specified that Protein-A Chromatography must be used for the first purification step because it has the capability to remove 99.5% impurities which allows for there to be fewer purification steps in the rest of the process. Storage for the buffers must be designed in order to accommodate the chemicals that will be used in the purification processes. Virus inactivation and polishing steps must also be accounted for in our downstream design. Other design specifications include a method to store the Mab product for a minimum of one year and pretreating waste in "kill tanks" for disposal in the sewer. A Block Flow Diagram of our overall process can be seen in Figure 5.

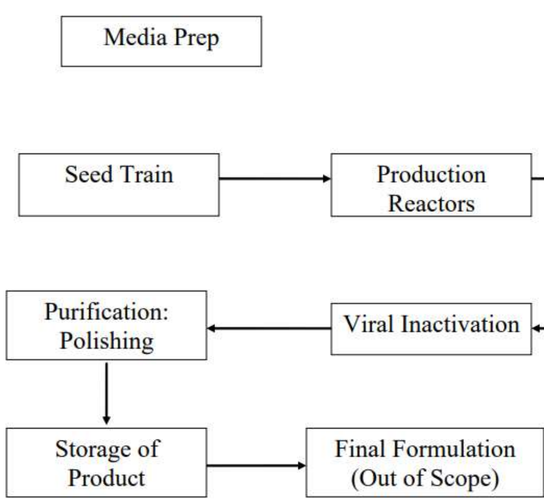

Figure 5 Block Flow Diagram of Biopharmaceutical Facility for Mab Production

Furthermore, our design basis is built upon safety and purity specifications for the final MAb product set by the United States Food and Drug Administration (FDA) and the European Medicines Agency (EMA). Both agencies outline Good Manufacturing Practices (GMP) that must be adhered to in our facility. This design was created while keeping all regulations, safety measures, and inherently safer design at the forefront.

The production quantities and revenues were provided for other MAbs on the market. A table that summarizes the selling prices in millions of dollars per kilogram of MAb can be seen in Table 3. These prices were taken from 2007 records and brought to today's prices using the PPI index [11]. The average selling price based on the quotes provided was 15.4 million dollars per kilogram. However, it was stated that Enbrel's dose requirements, treatment cost, and production process are very similar to our MAbs and about half of the products listed were producing product below our production rate 1,000 kg. As a result, we decided to use Enbrel as the basis for establishing our selling price. Our product will be sold for $12 million per kilogram, which represents a 3.2% premium over Enbrel. This slight premium is justified because our product will be produced in a newer and more technologically advanced facility, which we believe will lead to a superior product.

Table 3 Production Prices of MAbs

Product	Selling Price (MIL$/kg) 2007	Today's Selling Price (MIL$/kg)
Enbrel	5.17	11.63
Remicade	4.53	10.19
Rituxan/MabTherma	3.91	8.81
Herceptin	3.99	8.97
Avastin	3.92	8.82
Humira	24.79	55.77
Xolair	2.49	5.61
Tysabri	6.73	15.13
Vectibix	6.07	13.66

Since this is a preliminary design, a design scheme for utilities, such as electricity, sewer, and, water is not required. However, these utilities are considered from an economic standpoint. The process design utilizes large amounts of water for injection (WFI). Due to the high cost associated with purchasing WFI, we have decided to purchase a WFI production system to convert city water into WFI. This system and its costs will be explained in greater detail in subsequent sections. Table 4 contains the anticipated utility prices which will be used to estimate operating costs.

Table 4 Utilities Summary

Utility Costs	
Electricity ($/kWhr)	0.05
Sewer ($/1000 gallons)	5
Water ($/1000 L)	0.543
WFI ($/L)	1

Production Facility

The site on which the process will be constructed is already prepared with utilities but lacks a physical structure to house the process. The basis of size and location for the structure is based on the production facility used by Amgen to produce Enbrel. The production facility will be 500,000 square feet and located in West Greenwich, Rhode Island [12]. Based on this facility size and location the various costs associated with building a new facility were calculated. The cost of materials and construction were selected from a range of average warehouse construction costs. The range of costs spanned $50-$80/square foot of space. The value of $80/square foot was selected since the building will house a pharmaceutical process and will likely need more specialized construction compared to a typical warehouse [13]. The total cost of the facility was calculated based on the physical construction cost, cost of a building permit in West Greenwich, a lighting system to provide adequate lighting for the process, an HVAC system to provide adequate cooling and heating for the building, and a high deluge water and foam fire suppression system. The following Table 5 contains a summary of the process facility capital costs:

Table 5 Process Facility Capital Cost Summary

Cost of Building Process Facility			
Item	**Size**	**Total Cost**	
Building Permit	-	$	280,470
Building	500,000 square feet	$	40,000,000
Lighting	2000 Industrial Lights	$	518,000
HVAC System	1620 Tons of Cooling	$	2,216,297
Fire Suppression System	500,000 sqaure feet of coverage	$	5,000,000
Contingencies	-	$	7,160,145
Other Fees	-	$	1,432,029
Grand Total		$	56,606,941

The cost of the building permit in West Greenwich, RI is $470 + $7 per $1000 of project value over $50,000 [14]. The HVAC system tonnage was calculated based on the square footage of the facility, heat released by the processes, and the projected number of occupants on a normal day of operation. The system will need to be able to provide 1,620 tons of cooling to the building which will be delivered by 10 Trane IntelliPak II Rooftop units [15]. The lighting for the processing facility will be provided by 2,000 round, LED high bay industrial lights. This amount of lighting was calculated to provide 100 lumens per square foot of workspace which is adequate for any detailed work that will take place within the processing facility [16]. The fire suppression system is costed at $10/square foot of building space [17].

Upstream Process

<u>Media Prep</u>

The upstream process begins in the media preparation area. This is where the media is made and combined with CHO cells that have been transfected with Global Manufacturing's Monoclonal Antibody. Media is very important to the overall success of this manufacturing process as it is what helps the cells grow and produce the MAb. As a result, the first step in designing this subsystem was the selection of a suitable media. The media must meet the requirements of being a Chemically Defined Medium and it must be free of any animal product in order to meet the FDA and European regulations of being an animal-free facility. A Chemically Defined Medium is an artificial media that contains "contamination-free ultra-pure inorganic and organic ingredients" and does not contain animal components [18]. It was also specified that the media must be bought and stored in the form of powders because powdered media is the least expensive [18]. In order to meet these media specifications, we decided to use an off the shelf media from Sigma Aldrich. We choose Ex-Cell Advanced CHO Fed-batch medium and Ex-Cell Advanced CHO Feed 1 with glucose because these media were advertised to be used in a "fed-batch platform across a diverse set of Chinese Hamster Ovary Cells" which matched our cell line and cell culture platform [19,20]. These media are intended to be used together with the Fed-batch medium added in the Seed Train and the Feed 1 medium added into the bioreactors that immediately follow the Seed Train.

To fully design the media prep area, Ex-Cell's media prep guidelines were consulted in order to determine what equipment would be required in order to prepare the necessary media.

Based on these guidelines it was clear that the media would need special storage as it requires storage in the dark and between 2 - 8 °C [21,22]. In order to meet this requirement, a laboratory grade refrigerator with solid light shielding doors is necessary for the storage of the media. It was also determined that general lab equipment would need to be provided such as micropipettes, spatulas, digital thermometers, hot plate magnetic stirrers, scales, pH meters, glass beakers, an Osmometer, hot water baths, shake flasks, an orbital shaker platform, and an automated cell counter. It was also decided that it would be best to use disposables in the media prep area in order to meet FDA and European regulations. We chose this method of cleaning for this area because it is the most cost effective and environmentally friendly for this subsystem [23]. A more detailed discussion of disposable technology and the environment will be discussed in later sections.

Seed Train

For the Seed Train, we had the choice of three different platforms to use, batch, fed-batch, or perfusion cell culture platform. "In the batch method, all nutrients are supplied in an initial base medium while the fed-batch method adds nutrients once they are depleted, and the perfusion method circulates medium through a growing culture, allowing simultaneous removal of waste, the supply of nutrients, and harvesting of product" [24]. We decided to model our process as a fed-batch cell culture platform. This results in the production of higher cell densities than the batch system which equates to higher product yield. "Fed-batch and perfusion culture techniques also optimize nutrient delivery while minimizing accumulation of unwanted waste products" [25]. Although perfusion has been experimentally proven to result in the highest cell densities out of all three platforms, it is also the most expensive as it requires larger volumes of media, more space, and is significantly more complex than the fed-batch platform [24]. As a result, we decided that a fed-batch cell culture system was the optimal platform to use in our process.

The purpose of the Seed Train is to help "generate an adequate number of cells for the inoculation of the production bioreactor" or, in other words, to scale up the volume of cells for addition into the bioreactor [26]. In general, this process typically begins with a single vial of cells that are added to medium and then distributed among T-flasks to culture. For mammalian cells, like our CHO cells, the cells expand faster in a rocking bag apparatus as compared to other options for the next steps in the Seed Train [27]. For this reason, the CHO cells are generally moved up to rocking bag reactors after culturing in T-flasks and roller bottles. The cells are then moved from rocking bag bioreactors to small scale seed bioreactors until the cell volume meets the required volume to go into the main production bioreactor. The image below in Figure 6 illustrates the general model for cell culture scale up.

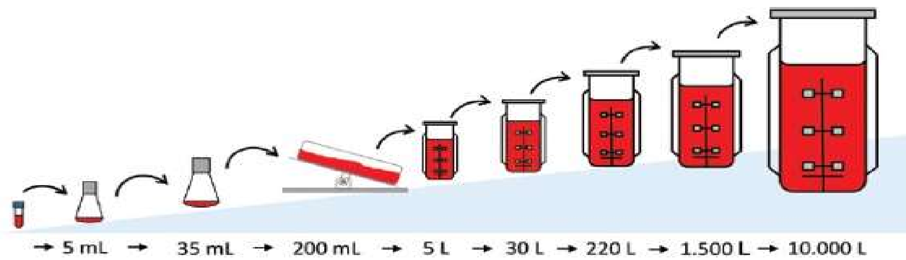

Figure 6 Seed Train Expansion of Cells [28]

For our process, the Seed Train begins with the inoculum medium. This medium, mixed with cells, is diluted by hand with water for injection and divided among fifty-four 225 mL T-flasks where the cells will culture for 98 hours. From the T-flasks the cell broth is mixed with more inoculum medium and transferred to twenty-three 2.2 L roller bottles. The cells will culture in the roller bottles for 146.5 hours before moving to the first set of bioreactor skids. The first bioreactor skid consists of four 100 L rocking bag bioreactors. In these skids, the cell broth will be mixed with more inoculum medium and will culture for 147.5 hours before being transferred to the next bioreactor skid and mixed with more inoculum medium. The second bioreactor skid consists of eight 200 L rocking bag bioreactors. After the cell broth has cultured in the second bioreactor skid for 147 hours it will move on to a set of seed bioreactors in the Seed Train. The purpose of having two bioreactor skids is to help increase the volume of the cells before they go into the seed reactors for further expansion. Due to the large volume of media that must be fed into the first seed reactor, the Feed 1 powder is added to a 10,000 L blending tank with the appropriate amount of water for injection as specified by the Ex-Cell media protocol. The medium is then sent through a dead-end filter to remove unwanted proteins and impurities before being sent to the seed reactor [29]. The first seed reactor is 10,000 L and the cells cultured in this seed reactor for 175.65 hours. The cell culture is then divided between two 10,000 L seed bioreactors where they will culture for 177.98 hours. The Feed 1 medium is added with water to a 12,000 L blending tank and filtered before being added to these two seed bioreactors will the cells. The cells will then move on to the final subsystem of the upstream process. These seed reactors are batch reactors which were chosen to culture our CHO cells as that is what is commonly used in a fed-batch platform for the Seed Train [7].

Similar to Media Prep, the beginning portion of the Seed Train was also designed using disposable technology in order to maintain the level of cleanliness and sterility that the FDA and European regulations require. The T-flasks, roller bottles, and bags in the rocking bag bioreactors are all disposable. However, the seed reactors were designed with clean-in-place and steam-in-place technology because their scale is too large to realistically use disposables for each batch. Furthermore, "disposables are only applicable for Good Manufacturing Practice if they are 2000 L or less in scale" [32].

Production Bioreactors

From the Seed Train, the cell culture is divided among two production scale, 40,000 L fed-batch bioreactors. Two sets of Feed 1 media are mixed with water for injection in blending units and then filtered in dead-end filters before feeding into the two bioreactors. The scale of both blending tanks is 45,000 L. The cells culture for 318.33 hours in the bioreactors before they reach optimum cell density to produce the desired amounts of MAb. From the bioreactors, the cell broth will move on to the downstream portion of our process. The production bioreactor system was designed with CIP and SIP technology as the scale is too large to effectively use disposable cleaning technology [23].

Buffer Preparation

The buffers fed into each chromatography column are of high importance to achieve the desired separation. Each buffer has a specific composition and properties. Thus they must be carefully created. To avoid cross-contamination, we have designated two tanks for each of the 11 process buffers. Each buffer starts with water and chemicals added in correct proportions to the mixing tank. The mixing time required for each buffer will vary depending on its composition. The buffer will then be sent to a holding tank where it will wait to be used in the columns.

Downstream Process

Downstream processing begins at the outlet of the production reactor and is of the utmost importance in order to separate our desired MAbs from the rest of the cell and the cell culture and to ensure product purity and safety. Before each unit of the downstream process, we incorporated dead-end filtration to ensure sterility and capture of impurities [29]. The downstream process can be broken into the primary recovery, purification, virus inactivation, and polishing steps.

Primary Recovery

To begin the primary product recovery, the cells will be fed into a set of 3 Disc-Stack centrifuges. The centrifuges were chosen because they are an industry standard and can easily be scaled for large volumes [30]. The solid biomass and cell wastes are sent to a waste stream. After centrifugation and in between each consecutive unit of the downstream purification process, 0.2 μm dead-end filters will be used to ensure that the system is sterile, and contaminants are captured [29]. Additionally, after the dead-end filters, the liquid will feed into blending storage tanks following each consecutive downstream unit. These blending storage tanks ensure that there is homogeneity in the liquid that is being fed into the following unit and allows for the adequate lag in case there are any disruptions in the downstream or with buffer preparation.

Purification

Between the purification and polishing processes, there are three chromatography columns, Protein-A affinity, cation exchange, and hydrophobic interaction columns. Each of these processes utilizes different chemical or physical properties to purify the proteins into the final product. However, all three processes consist of five basic steps for each batch. It begins first with buffer preparation. Buffer pH, ionic strength, and composition are crucial for all chromatography, as detailed above. Secondly, the column goes through equilibration by washing the column with 3 to 5 column volumes of buffer. This step sets the column back to the appropriate pH and conductivity. Third, the sample is loaded into the column and interacts with the resin. In the fourth step, the column is washed with another buffer until no more protein is detected flowing through. Finally, the column goes through an elution step, where the protein of interest is flushed from the resin with an elution buffer or change in conditions [31].

From the post-centrifugation tank, the cells and liquid are fed into a Protein-A affinity chromatography column, which is responsible for removing most of the contaminants. The Protein-A chromatography process is highly selective to MAb as it utilizes the interactions between the Fc region of MAbs and immobilized Protein-A, often resulting in >99% purity from the cell culture supernatant [30]. The liquid is fed into the column at a neutral pH. The MAb proteins Fc regions bind to Protein-A, while other contaminants and the host cell are flushed in a wash step at intermediate pH as shown in Figure 7. Finally, an elution buffer, an acetic acid solution with a pH of about 2, is used to strip away the MAbs.

The Protein-A chromatography column contains a solid resin that serves as a platform for Protein-A. We have selected MabSelect SuRe LX resin for the Protein-A chromatography column because it is shown to have particularly high capacity and reusability for more than 100 cycles, which reduces overall costs [33]. This resin must be regenerated after each elution in the column by using a regeneration buffer of sodium citrate solution [34]. However, Protein-A chromatography can result in leached Protein-A ligands because of the proteases found in the supernatant. To combat the leached ligands, after dead end filtration and the storage tank, the liquid is fed into the diafiltration unit. Diafiltration retains the desired cells and allows water and other small soluble substances to flow through the filter [35]. The retained cells are now transferred to the virus inactivation step.

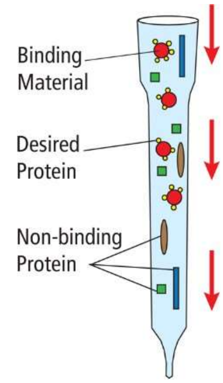

Figure 7 Protein-A Chromatography [32]

Virus Inactivation

There are several methods that may be utilized for the virus inactivation step. In this design, we have opted for a combination of low pH treatment and solvent/detergent (SD) viral inactivation. Since the elution coming out of the Protein-A chromatography column is at a low pH and MAbs are stable at low pH, this is a logical and simple viral inactivation step. Additionally, low pH treatment is proven to successfully inactivate viruses in a variety of processes, including MAb production [30]. The elution and cells are incubated in a holding tank for 3 hours to ensure retroviruses have been inactivated. Next, the cells are fed into a holding tank where they are chemically treated with Polysorbate 80, a powerful natural solvent, for 90 minutes. SD is a renowned viral inactivation treatment because of its incredible safety record; there has not been a single account of enveloped viruses transmitted by SD treated products [36]. SD treatment is growing in popularity in MAb production and helps our process meet its stringent safety standards.

Polishing

Finally, the cells enter the polishing stage, which involves two additional chromatography steps. These additional chromatography steps allow for a sufficient level of redundancy to ensure product purity [30]. First, the cells enter cation exchange chromatography. This process works similarly to Protein-A chromatography, but instead of the MAbs being attracted to Protein-A on the resin, the positively charged proteins are separated by their attraction to the negatively charged resin beads. The charge of the protein is dictated by the protein's isoelectric point (pI). At a pH below the pI, the protein carries a net positive charge. The isoelectric point will vary depending on the specific MAb we are producing at a specific point in time in our flexible manufacturing facility. However, most monoclonal antibodies have an isoelectric point of 7.5-9.5 [38]. Cation exchange chromatography traditionally could not cope with increasing titers, but optimizations in resin have resulted in a significant increase in capacity, high flow rates, and purity [38]. We selected Eshmuno S Resin because of its ability to achieve separation under small elution volumes and lower duration times [39]. The positively charged particles are purged from the solution in the wash step. An elution washes out the desired Protein-And it continues on to a holding tank.

In the holding tank, ammonium sulfate is added to increase the solution's ionic strength to "salt out" our immunoglobulin proteins during hydrophobic interaction chromatography (HIC). Addition of the ammonium sulfate salt reduces the number of hydrogen bonds in the solution and increases the strength of protein-protein intermolecular interaction. This process also stabilizes the proteins in solution due to the interaction of salt and water, which raises the temperature necessary to denature the protein [40]. The MAb protein molecules associate together due to their hydrophobic nature. Instead of simply using the "salting out" method, we have opted to run the salted solution through HIC because of its higher throughput and recovery of enzymatic activity [41]. The proteins cling to the hydrophobic ligands of HIC resin in the column while impurities are washed out. We have selected TOYOPEARL Hexyl-650C resin because of its high hydrophobicity, which allows lower salt concentrations to be used in the solution [42]. Lower salt concentrations correlate to saved raw material and waste treatment costs. The desired proteins are eluted out of the column by decreasing the salt concentration. From here the MAbs and liquid are sent through two more dead-end filters and through a final diafiltration step, where the liquid is adjusted to the proper concentration for storage. From there the liquid is dead end filtered a final time and is sent to a storage tank to await freezing and long term storage.

<u>Storage</u>

To store our final product, we will freeze it to -20℃ and store it in a modular cold storage room [43]. We would purchase a freezing storage system with a 1,100 50-liter storage bag capacity, which is enough space to store one year's worth of product, from Cincinnati SubZero. The MAb product is shelf stable for one year under these conditions.

Pumps

This process contains many units, so pumps are necessary to efficiently transport fluid between many of them. Special consideration must be taken when pumping biologic material because mammalian cells are easily susceptible to shear force, which can tear or severely damage the cells. Pumps can easily damage cells through shearing or physically grinding cells trapped in moving pump parts. The cells are delicate, and their integrity must be maintained in order to produce the desired MAb yield. For these reasons, we have identified positive displacement diaphragm pumps as the most appropriate method for transferring cells and liquid to each unit [44]. These pumps achieve high purity by avoiding cell damage, maintain sterility and constant flow, and avoid heat addition and pulsation [45]. The diaphragm pumps were designed by evaluating the flow rate of each stream in SuperPro and comparing it to the power required according to Quattroflow Pumps [46]. From there the pumps were costed and are accounted for in the economic analysis.

Clean in Place and Steam in Place

Our facility utilizes clean in place (CIP) and steam in place (SIP) technology. This is a regulation required and industry standard cleaning practice for pharmaceutical production [47]. CIP cleans the interior surfaces of production vessels without disassembly of the unit, which saves time, is inherently safer than taking apart and reassembling each unit after every batch, and has excellent cleanliness results. First, we utilize a WFI rinse cycle. Next, the vessel is washed with a 0.5 molar caustic solution, which in our case is sodium hydroxide. Now the vessel is rinsed with an acidic solution, which we have chosen to be phosphoric acid. This acid rinse removes any residual mineral precipitates and proteins. Finally, another WFI rinse is utilized. During each step of CIP, a series of controls monitor temperature, conductivity, and flow rate to indicate any residue [48]. Steam in place is used before the initiation of each batch in the vessel, which is after the CIP procedure from the previous batch. SIP ensures sterile conditions in the vessel. Clean steam, which meets the same composition requirements as WFI, is vented into the processing unit and sterilizes it. The condensate is collected and sent to the waste stream [49]. It was assumed for costing purposes that a clean steam system already exists at the company's adjacent research and development facility that can supply all of our clean steam needs.

Waste Treatment

Several process units including the centrifuges, chromatography columns, and diafiltration skids have a waste stream leading to the waste treatment "kill tank". The largest single component of the kill tank is water. The second largest component besides water will be the sodium hydroxide from the caustic step of clean in place, then phosphoric acid from buffers, and then the ammonium sulfate added before hydrophobic interaction chromatography. This kill tank will also contain biomass and other various chemicals from the buffers, including both acids and bases. Several of the acids and bases will neutralize each other. Additionally, all chemicals in the tank are of very dilute proportions because of the massive volume of wastewater. However, the pH of the kill tank will be basic without treatment and must be neutralized before sent to the city sewer system. Sodium hydroxide is a strong base that can easily be neutralized with hydrochloric acid. Ammonium sulfate can also be neutralized with dilute hydrochloric acid [50]. The hydrochloric acid will also denature other proteins and biomass found in the solution. To optimize the amount of hydrochloric acid added to the kill tank, our design adds a pH transmitter onto the tank. The transmitter will send a signal to a controller that will automatically add the exact amount of hydrochloric acid added. This is an inherently safer chemical dilution process because it eliminates the need for an operator to physically add this dangerous chemical to the kill tank. It is also a more accurate way to measure and add the exact amount of acid needed. When the basic solution has been neutralized, the kill tank can be emptied into the city sewer.

ENERGY BALANCE AND UTILITY REQUIREMENTS

The following tables include a summary of the energy and utility requirements for the design of the new facility.

Table 6 Energy Consumption/ Energy Balance

Stream	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Enthalpy (kW-hr/batch)	0.31	0.46	0.99	1.31	3.80	0.00	5.10	15.27	0.02
Stream	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Enthalpy (kW-hr/batch)	30.06	59.83	1.36	61.19	61.19	61.19	10.85	120.30	16.36
Stream	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Enthalpy (kW-hr/batch)	239.90	5.45	245.34	245.34	245.34	43.48	484.14	72.03	870.83
Stream	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
Enthalpy (kW-hr/batch)	59.98	930.81	930.81	930.81	119.65	8.23	94.31	94.31	94.31
Stream	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**
Enthalpy (kW-hr/batch)	334.93	2008.54	2008.54	547.72	2008.45	2008.45	2220.71	117.62	2219.78
Stream	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**
Enthalpy (kW-hr/batch)	2219.84	0.93	2219.39	2219.39	0.00	895.13	1050.91	880.17	526.23
Stream	**55**	**56**	**57**	**58**	**59**	**60**	**61**	**62**	**63**
Enthalpy (kW-hr/batch)	356.28	5215.54	356.25	356.27	356.27	71.105	29.03	73.37	73.37
Stream	**64**	**65**	**66**	**67**	**68**	**69**	**70**	**71**	**72**
Enthalpy (kW-hr/batch)	29.03	366.25	73.36	73.36	0.02	0.01	73.37	73.37	0.02
Stream	**73**	**74**	**75**	**76**	**77**	**78**	**79**	**80**	**81**
Enthalpy (kW-hr/batch)	73.37	589.83	2942.01	2773.43	162.30	1784.22	1790.30	1176.49	8938.91
Stream	**82**	**83**	**84**	**85**	**86**	**87**	**88**	**89**	**90**
Enthalpy (kW-hr/batch)	42.00	1218.46	1218.46	103.94	270.08	267.46	268.54	108.89	2019.58
Stream	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**
Enthalpy (kW-hr/batch)	108.90	108.89	108.89	108.89	108.89	108.89	144.96	14.51	74.28
Stream	**100**	**101**	**102**	**103**	**104**	**105**	**106**	**107**	**108**
Enthalpy (kW-hr/batch)	14.51	185.82	74.28	74.28	0.00	74.28	74.28	526.23	526.23
Stream	**109**	**110**	**111**	**112**	**113**	**114**	**115**	**116**	**117**
Enthalpy (kW-hr/batch)	526.23	880.17	880.17	880.17	895.13	895.13	895.13	162.30	162.30
Stream	**118**	**119**	**120**	**121**	**122**	**123**	**124**	**125**	**126**
Enthalpy (kW-hr/batch)	162.30	589.83	589.83	589.83	2942.01	2942.01	2942.01	1790.30	1790.30
Stream	**127**	**128**	**129**	**130**	**131**	**132**	**133**	**134**	**135**
Enthalpy (kW-hr/batch)	1790.30	1784.22	1784.22	1784.22	268.54	268.54	268.54	267.46	267.46
Stream	**136**	**137**	**138**	**139**					
Enthalpy (kW-hr/batch)	267.46	270.08	270.08	270.08					

Table 7 Utilities Summary

Steam				
Vessel	Number of Vessels	Heat Transfer per Unit (kcal/hr)	Hours in Operation (hr)	Total Heat Transfer (kcal)
RB-102	8	40.95	144	47174.4
TFR-101	54	0.88	96	4561.92
Cooling Water				
Vessel	Number of Vessels	Heat Transfer per Unit (kcal/hr)	Hours in Operation (hr)	Total Heat Transfer (kcal)
RB-101	4	4.75	144	2736
SBR-101	1	521.46	144	75090.24
SBR-102	2	1359.43	144	391515.84
BR-101	2	20884.33	720	30073435.2
RBR-101	23	2.83	144	9372.96
Electricity				
Vessel	Number of Vessels	Power per Unit (kW)	Hours in Operation (hr)	Total Power (kW-hr)
BR-101	2	10.3071	720	14842.224
DSC-101	3	79.1852	8.33	1978.838148
F-101	2	30.6195	4	244.956
SBR-101	1	0.8443	144	121.5792
SBR-102	2	2.5455	144	733.104
RB-101	4	0.0055	144	3.168
RB-102	8	0.0198	144	22.8096
P-101	1	2.2	1	2.2
P-102	1	4	1	4
P-103	1	7	1	7
P-104	1	0.05	288	14.4
P-105	1	5	1	5
P-106	1	4	8.33	33.32
P-107	1	0.05	8.33	0.4165
P-108	1	0.37	86.985	32.18445
P-109	1	2.2	0.25	0.55
P-110	1	0.37	4	1.48
P-111	1	0.37	0.25	0.0925
P-112	1	0.37	4.06	1.5022
P-113	1	5	2	10
P-114	1	2.2	2.3	5.06
P-115	1	0.37	4	1.48
P-116	1	2.2	1	2.2

EQUIPMENT LIST AND UNIT DESCRIPTIONS

Each piece of equipment in this process, not counting duplicate lines, serves a unique purpose as described in the Equipment Specification Sheets. Each piece of equipment's material of constriction is stainless steel for sterility and durability reasons. Stainless steel is easily cleaned and is resistant to corrosion.

The team selected diaphragm pumps for every pump located within the process. Mammalian cells are very sensitive to shear forces that can be applied by pumps. Diaphragm pumps apply less shear force to the mammalian cells than other pumps such as centrifugal and positive displacement because it pulses the process stream through the pipe as opposed to applying a centrifugal force to the process stream. The result is a lower mortality rate of live cells as they travel through the pipe.

Process vessels, including the media prep tanks, production bioreactors, seed bioreactors, chromatography columns, and storage vessels, were sized based on the predicted volume of process materials in the vessel and oriented based Heuristics for Process Vessels and Storage Tanks found in Chapter 11 of the Turton design book [51]. Storage vessels sized smaller than 3.8 cubic meters and larger than XX cubic meters were oriented vertically. Storage vessels sized between 3.8 and XX cubic meters were oriented horizontally. All reactors were oriented vertically and modeled as jacketed-agitated bioreactors. The team selected a pitched-blade impeller for the seed bioreactors and production bioreactors because of its cost-effectiveness and high mixing ability [52]. The impellers were individually costed through the power number equation (Equation 1) and using the fluid density found in the SuperPro simulation while assuming a low impeller speed of 1.5 revolutions per second.

$$PP_{NN} = \frac{PP}{nn^3 DD_{aa}^5 \rho\rho} \quad \text{(Equation 1)}$$

The team modeled the dead-end filters as plate-and-frame filters for costing purposes because of their similar behaviors and uses in industries. They were sized and costed based required membrane surface area modeled in the SuperPro simulation.

The team modeled Clean in Place skids as multiple process vessels and a centrifuge pump packaged together. They created a process vessel for each solution needed in the cleaning process and were sized based on the maximum volume required by a single step in the cleaning process. For bioreactors, seed bioreactors, media prep tanks, and storage vessels, three tanks were determined necessary for the cleaning process. For the Protein-A, IEX, and HIC chromatography columns, two tanks were determined necessary for the cleaning process. The team selected centrifugal pumps for the CIP skids because of the maximum shaft power and flow rate that the pumps experience.

Table 8 Equipment List and Unit Descriptions

Process Equipment	Description
RB-101 A-D	Grow cells in agitated environment.
RB-102 A-H	Grow cells in agitated environment.
MPT-101	Mixes serum free media and WFI to feed into seed bioreactor.
DF-101	Filters the WFI and media mixutre before feeding to the seed bioreactor to ensure sterility.
SBR-101	Promote cell growth by fermentation.
SBR-101 Impeller	Agitate cell broth to promote ideal cell division conditions.
MPT-102	Mixes serum free media and WFI to feed into seed bioreactor.
DF-102	Filters the WFI and media mixutre before feeding to the seed bioreactor to ensure sterility.
SBR-102 A/B	Promote cell growth by fermentation.
SBR-102 A/B Impellers	Agitate cell broth to promote ideal cell division conditions.
MPT-103	Mixes serum free media and WFI to feed into production bioreactor.
DF-103	Filters the WFI and media mixutre before feeding to the production bioreactor to ensure sterility.
MPT-104	Mixes serum free media and WFI to feed into production bioreactor.
DF-104	Filters the WFI and media mixutre before feeding to the production bioreactor to ensure purity.
BR-101 A/B	Promote exponential cell growth by fermentation.
BR-101 A/B Impellers	Agitate cell broth to promote ideal cell division conditions.

V-101	Store liquid before centrufugation.
DSC-101 A-C	Centrifuge for the primary recovery of MAb.
DF-105	Filters liquid to ensure sterility.
V-102	Holds feed for Protein A Chromatography column.
C-101	Purifies the product through Protein A affinity
DF-106	Filters liquid to ensure sterility.
V-103	Holds feed for Protein A Chromatography column.
F-101	Diafilter membrane to filter impurities from liquid from storage tank.
V-105	Stores Protein A purified product.
DF-107	Filters liquid to ensure sterility.
C-102	Purifies the product through cation exchange chromatography.
V-106	Stores IEX filtration product.
C-103	Purifies the product through hydrophobic interaction chromatography.
DF-108	Filters liquid to ensure sterility.
V-107	Stores HIC purified product.
DF-109	Filters liquid to ensure sterility.
V-108	Holds liquid for diafiltration.
F-102	Diafilter membrane to filter impurities from liquid from storage tank.
V-109	Holds feed for diafiltration.
DF-110	Filters liquid to ensure sterility.
CIP-101	Clean in place skid.
CIP-102	Clean in place skid.
CIP-103	Clean in place skid.
CIP-104	Clean in place skid.
CIP-105	Clean in place skid.
CIP-106	Clean in place skid.
CIP-107	Clean in place skid.
Kill Tank	Waste collection and treatment tank.

EQUIPMENT SPECIFICATION SHEETS

Bioreactors

Equipme nt Name:	Seed Bioreactor			
Item No:	SBR-101			
No. Re quire d:	1			
Function:	Promote cell growth by fermentation			
Ope ration:	Batch			
Materials handle d (kg/batch):	Stream 10:	Stream 15:	Stream 17:	Stream 18:
Total:	697.21	2,096.65	2,790.13	1,550.10
Biomass:	1.20	0.00	6.79	0.00
Carbon Dioxide:	0.00	0.00	0.00	3.72
Impurities:	0.44	0.00	1.93	0.00
MAb:	0.11	0.00	0.49	0.00
Media:	3.67	0.00	3.67	0.00
Nitrogen:	0.00	0.00	0.00	1,186.26
Oxygen:	0.00	0.00	0.00	360.12
Serum Free Media:	0.00	46.56	9.31	0.00
Water:	8.60	0.00	34.68	0.00
WFI:	683.19	2,050.09	2,733.28	0.00
Design Data:				
Temperature (°C):	37.00	25.00	37.00	37.00
Pressure (bar):	1.01	10.13	1.01	1.01
Density (g/L):	990.43	994.70	990.47	1.13
Total Enthalpy (kW-h):	30.06	61.18	120.30	16.36
Specific Enthalpy(kcal/kg):	37.10	25.11	37.10	9.08
Heat Capacity (kcal/kg*°C):	1.00	1.00	1.00	0.24
Utilitie s:	Chilled water at inlet T 5°C and 103.83 kg/h			
Comme nts:	MOC is SS			

Equipme nt Name:	Seed Bioreactor				
Item No:	SBR-102				
No. Re quire d:	2				
Function:	Promote cell growth by fermentation				
Ope ration:	Batch				
Materials handle d (kg/batch):	Stream 17:	Stream 23:	Stream 24:	Stream 25:	Stream 26:
Total:	2,790.13	2,096.65	2,790.13	1,550.10	6,166.33
Biomass:	6.79	0.00	6.79	0.00	0.00
Carbon Dioxide:	0.00	0.00	0.00	3.72	125.39
Impurities:	1.93	0.00	1.93	0.00	0.00
MAb:	0.49	0.00	0.49	0.00	0.00
Media:	3.67	0.00	3.67	0.00	
Nitrogen:	0.00	0.00	0.00	1,186.26	4,754.35
Oxygen:	0.00	0.00	0.00	360.12	1,286.59
Serum Free Media:	9.31	46.56	9.31	0.00	0.00
Water:	34.68	0.00	34.68	0.00	0.00
WFI:	2,733.28	2,050.09	2,733.28	0.00	0.00
Design Data:					
Temperature (°C):	37.00	25.00	37.00	37.00	37.00
Pressure (bar):	1.01	10.13	1.01	1.01	1.01
Density (g/L):	990.47	994.70	990.47	1.13	1.14
Total Enthalpy (kW-h):	120.30	61.18	120.30	16.36	72.03
Specific Enthalpy(kcal/kg):	37.10	25.11	37.10	9.08	10.05
Heat Capacity (kcal/kg*°C):	1.00	1.00	1.00	0.24	0.24
Utilitie s:	Chilled water at inlet T 5°C and 270.68 kg/h				
Comme nts:	MOC is SS				

Equipment Name:B58:H83	Bioreactor					
Item No:	BR-101					
No. Required:	2					
Function:	Promote exponential cell growth by fermentation					
Operation:	Batch					
Materials handled (kg/batch):	Stream 25:	Stream 31:	Stream 36:	Stream 37:	Stream 38:	Stream 40:
Total:	1,550.10	31,896.59	3,231.80	47,635.79	46,585.43	47,463.51
Biomass:	0.00	0.00	0.00	0.00	477.64	0.00
Carbon Dioxide:	3.72	0.00	0.00	858.25	0.00	858.25
Impurities:	0.00	0.00	0.00	0.00	54.81	0.00
MAb:	0.00	0.00	0.00	0.00	93.70	0.00
Media:	0.00	0.00	0.00	0.00	3,67	0.00
Nitrogen:	1,186.26	0.00	0.00	36,585.12	0.00	36,585.12
Oxygen:	360.12	0.00	0.00	10,020.14	0.00	10,020.14
Serum Free Media:	0.00	2,055.46	207.98	0.00	1,215.94	0.00
Water:	0.00	0.00	0.00	0.00	920.82	0.00
WFI:	0.00	29,841.13	3,023.82	0.00	43,818.86	0.00
Design Data:						
Temperature (°C):	37.00	25.00	25.00	25.00	37.00	37.00
Pressure (bar):	1.01	10.13	10.13	1.01	1.01	1.01
Density (g/L):	1.13	994.70	994.70	1.18	990.91	1.14
Total Enthalpy (kW-h):	16.36	930.81	94.31	334.93	2,008.54	547.72
Specific Enthalpy(kcal/kg):	9.08	25.11	25.11	6.05	37.10	9.93
Heat Capacity (kcal/kg*°C):	0.24	1.00	1.00	0.24	1.00	0.24
Utilities:	Chilled water at inlet T 5°C and 4158.39 kg/h					
Comments:	MOC is SS					

Buffer Prep Tanks

Equipme nt Name:	Protein A Regeneration Buffer Blending Tank	
Item No:	BT-101	
No. Re quire d:	1.00	
Function:	Mix Sodium Cirate and WFI to feed into Protein A Chromatography Column	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 107:	Stream 108:
Total:	17,892.62	17,892.62
Sodium Citrate:	32.21	32.21
WFI:	17,860.42	17,860.42
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	1.01	10.13
Density (g/L):	995.54	995.54
Total Enthalpy (kW-h):	521.27	521.27
Specific Enthalpy(kcal/kg):	25.07	25.07
Heat Capacity (kcal/kg*°C):	1.00	1.00
Utilitie s:	76.7 kW-h delivered per batch	
Comme nts:	MOC is SS	

Equipme nt Name:	Protein A Regeneration Buffer StorageTank	
Item No:	BS-101	
No. Re quire d:	1.00	
Function:	Store Protein A	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 108:	Stream 109:
Total:	17,892.62	17,892.62
Sodium Citrate:	32.21	32.21
WFI:	17,860.42	17,860.42
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	10.13	10.13
Density (g/L):	995.54	995.54
Total Enthalpy (kW-h):	521.27	521.27
Specific Enthalpy(kcal/kg):	25.07	25.07
Heat Capacity (kcal/kg*°C):	1.00	1.00
Utilitie s:	None	
Comme nts:	MOC is SS	

Equipme nt Name:	Protein A Elution Buffer Blending Tank	
Item No:	BT-102	
No. Re quire d:	1.00	
Function:	Mix Acetic Acid and WFI to feed into Protein A Chromatography Column	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 110:	Stream 111:
Total:	29,804.24	29,804.24
Acetic Acid:	178.83	178.83
WFI:	29,625.41	29,625.41
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	1.01	10.13
Density (g/L):	994.98	994.98
Total Enthalpy (kW-h):	867.08	867.08
Specific Enthalpy(kcal/kg):	25.03	25.03
Heat Capacity (kcal/kg*°C):	1.00	1.00
Utilitie s:	127.9 kW-h delivered per batch	
Comme nts:	MOC is SS	

Equipme nt Name:	Protein A Elution Buffer StorageTank	
Item No:	BS-102	
No. Re quire d:	1.00	
Function:	Store Protein A Elution	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 111:	Stream 112:
Total:	29,804.24	29,804.24
Acetic Acid:	178.83	178.83
WFI:	29,625.41	29,625.41
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	10.13	10.13
Density (g/L):	994.98	994.98
Total Enthalpy (kW-h):	867.08	867.08
Specific Enthalpy(kcal/kg):	25.03	25.03
Heat Capacity (kcal/kg*°C):	1.00	1.00
Utilitie s:	None	
Comme nts:	MOC is SS	

Equipme nt Name:	Protein A Equilibrium/Wash Buffer Blending Tank	
Item No:	BT-103	
No. Re quire d:	1.00	
Function:	Mix Sodium Chloride, TRIS Base, TRIS HCl and WFI to feed into Protein A Chromatography Column	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 113:	Stream 114:
Total:	65,725.45	65,725.45
Sodium Chloride:	65.73	65.73
TRIS Base:	65.73	65.73
TRIS HCl:	197.18	197.18
WFI:	65,396.82	65,396.82
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	1.01	10.13
Density (g/L):	997.34	997.34
Total Enthalpy (kW-h):	1,910.48	1,910.48
Specific Enthalpy(kcal/kg):	25.01	25.01
Heat Capacity (kcal/kg*°C):	1.00	1.00
Utilitie s:	281.33 kW-h delivered per batch	
Comme nts:	MOC is SS	

Equipme nt Name:	Protein A Equilibrium/Wash Buffer StorageTank	
Item No:	BS-103	
No. Re quire d:	1.00	
Function:	Store Protein A	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 114:	Stream 115:
Total:	65,725.45	65,725.45
Sodium Chloride:	65.73	65.73
TRIS Base:	65.73	65.73
TRIS HCl:	197.18	197.18
WFI:	65,396.82	65,396.82
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	10.13	10.13
Density (g/L):	997.34	997.34
Total Enthalpy (kW-h):	1,910.48	1,910.48
Specific Enthalpy(kcal/kg):	25.01	25.01
Heat Capacity (kcal/kg*°C):	1.00	1.00
Utilitie s:	None	
Comme nts:	MOC is SS	

Equipme nt Name:	IEX Elution Buffer Blending Tank	
Item No:	BT-104	
No. Re quire d:	1.00	
Function:	Mix Sodium Chloride, Sodium di-H Phosphate and WFI to feed into IEX Chromatography Column	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 116:	Stream 117:
Total:	5,696.55	5,696.55
Sodium Chloride:	294.20	294.20
Sodium di-H Phosphate:	55.83	55.83
WFI:	5,346.52	5,346.52
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	1.01	10.13
Density (g/L):	1,025.59	1,025.59
Total Enthalpy (kW-h):	161.61	161.61
Specific Enthalpy(kcal/kg):	24.41	24.41
Heat Capacity (kcal/kg*°C):	0.97	0.97
Utilitie s:	23.7 kW-h delivered per batch	
Comme nts:	MOC is SS	

Equipme nt Name:	IEX Elution Buffer Storage Tank	
Item No:	BS-104	
No. Re quire d:	1.00	
Function:	Store IEX Elution	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 117:	Stream 118:
Total:	5,696.55	5,696.55
Sodium Chloride:	294.20	294.20
Sodium di-H Phosphate:	55.83	55.83
WFI:	5,346.52	5,346.52
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	10.13	10.13
Density (g/L):	1,025.59	1,025.59
Total Enthalpy (kW-h):	161.61	161.61
Specific Enthalpy(kcal/kg):	24.41	24.41
Heat Capacity (kcal/kg*°C):	0.97	0.97
Utilitie s:	None	
Comme nts:	MOC is SS	

Equipme nt Name:	IEX Equilibrium Buffer Blending Tank	
Item No:	BT-105	
No. Re quire d:	1.00	
Function:	Mix WFI, Potassium Chloride, Potassium di-H Phosphate, Sodium Chloride, and Sodium Hydro Phosphate for use in IEX Chromatography Column	
Ope ration:	Batch	
Materials handled (kg/batch):	Stream 119:	Stream 120:
Total:	20,210.24	20,210.24
Potassium Chloride:	0.04	0.04
Potassium di-H Phosphate:	0.04	0.04
Sodium Chloride:	181.89	181.89
Sodium Hydro Phosphate:	22.23	22.23
WFI:	20,006.03	20,006.03
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	1.01	10.13
Density (g/L):	999.53	999.53
Total Enthalpy (kW-h):	587.20	587.20
Specific Enthalpy(kcal/kg):	25.00	25.00
Heat Capacity (kcal/kg*°C):	1.00	1.00
Utilitie s:	86.3 kW-h delivered per batch	
Comme nts:	MOC is SS	

Equipment Name:	IEX Equilibrium Buffer StorageTank	
Item No:	BS-105	
No. Required:	1.00	
Function:	Store IEX Equilibrium	
Operation:	Batch	
Materials handle d (kg/batch):	Stream 120:	Stream 121:
Total:	20,210.24	20,210.24
Potassium Chloride:	0.04	0.04
Potassium di-H Phosphate:	0.04	0.04
Sodium Chloride:	181.89	181.89
Sodium Hydro Phosphate:	22.23	22.23
WFI:	20,006.03	20,006.03
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	10.13	10.13
Density (g/L):	999.53	999.53
Total Enthalpy (kW-h):	587.20	587.20
Specific Enthalpy(kcal/kg):	25.00	25.00
Heat Capacity (kcal/kg*°C):	1.00	1.00
Utilities:	None	
Comments:	MOC is SS	

Equipment Name:	IEX Wash Buffer Blending Tank	
Item No:	BT-106	
No. Required:	1.00	
Function:	Mix WFI, Potassium Chloride, Potassium di-H Phosphate, Sodium Chloride, and Sodium Hydro Phosphate for use in IEX Chromatography Column	
Operation:	Batch	
Materials handle d (kg/batch):	Stream 122:	Stream 123:
Total:	101,497.24	101,497.24
Potassium Chloride:	0.20	0.20
Potassium di-H Phosphate:	0.20	0.20
Sodium Chloride:	1,826.95	1,826.95
Sodium Hydro Phosphate:	111.65	111.65
WFI:	99,558.24	99,558.24
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	1.01	10.13
Density (g/L):	1,003.94	1,003.94
Total Enthalpy (kW-h):	2,938.90	2,938.90
Specific Enthalpy(kcal/kg):	24.91	24.91
Heat Capacity (kcal/kg*°C):	0.99	0.99
Utilities:	431.6 kW-h delivered per batch	
Comments:	MOC is SS	

Equipme nt Name:	IEX Wash Buffer Storage Tank	
Item No:	BS-106	
No. Re quire d:	1.00	
Function:	Store IEX Wash	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 123:	Stream 124:
Total:	101,497.24	101,497.24
Potassium Chloride:	0.20	0.20
Potassium di-H Phosphate:	0.20	0.20
Sodium Chloride:	1,826.95	1,826.95
Sodium Hydro Phosphate:	111.65	111.65
WFI:	99,558.24	99,558.24
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	10.13	10.13
Density (g/L):	1,003.94	1,003.94
Total Enthalpy (kW-h):	2,938.90	2,938.90
Specific Enthalpy(kcal/kg):	24.91	24.91
Heat Capacity (kcal/kg*°C):	0.99	0.99
Utilitie s:	None	
Comme nts:	MOC is SS	

Equipme nt Name:	IEX Rinse Buffer Blending Tank	
Item No:	BT-107	
No. Re quire d:	1.00	
Function:	Mix Sodium Hydroxide and WFI for use in IEX Chromatography Column	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 125:	Stream 126:
Total:	60,911.44	60,911.44
Sodium Hydroxide:	1,193.86	1,193.86
WFI:	59,717.58	59,717.58
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	1.01	10.13
Density (g/L):	1,004.15	1,004.15
Total Enthalpy (kW-h):	1,760.76	1,760.76
Specific Enthalpy(kcal/kg):	24.87	24.87
Heat Capacity (kcal/kg*°C):	0.99	0.99
Utilitie s:	259.0 kW-h delivered per batch	
Comme nts:	MOC is SS	

Equipme nt Name:	IEX Rinse Buffer Storage Tank	
Item No:	BS-107	
No. Re quire d:	1.00	
Function:	Store IEX Rinse	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 126:	Stream 127:
Total:	60,911.44	60,911.44
Sodium Hydroxide:	1,193.86	1,193.86
WFI:	59,717.58	59,717.58
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	10.13	10.13
Density (g/L):	1,004.15	1,004.15
Total Enthalpy (kW-h):	1,760.76	1,760.76
Specific Enthalpy(kcal/kg):	24.87	24.87
Heat Capacity (kcal/kg*°C):	0.99	0.99
Utilitie s:	None	
Comme nts:	MOC is SS	

Equipme nt Name:	IEX Stripping Buffer Blending Tank	
Item No:	BT-108	
No. Re quire d:	1.00	
Function:	Mix Sodium Chloride and WFI for use in IEX Chromatography Cloumn	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 128:	Stream 129:
Total:	62,047.90	62,047.90
Sodium Chloride:	3,518.12	3,518.12
WFI:	58,529.78	58,529.78
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	1.01	10.13
Density (g/L):	1,022.89	1,022.89
Total Enthalpy (kW-h):	1,771.90	1,771.90
Specific Enthalpy(kcal/kg):	24.57	24.57
Heat Capacity (kcal/kg*°C):	0.98	0.98
Utilitie s:	259.0 kW-h delivered per batch	
Comme nts:	MOC is SS	

Equipme nt Name:	IEX Stripping Buffer Storage Tank	
Item No:	BS-108	
No. Re quire d:	1.00	
Function:	Store IEX Stripping	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 129:	Stream 130:
Total:	62,047.90	62,047.90
Sodium Chloride:	3,518.12	3,518.12
WFI:	58,529.78	58,529.78
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	10.13	10.13
Density (g/L):	1,022.89	1,022.89
Total Enthalpy (kW-h):	1,771.90	1,771.90
Specific Enthalpy(kcal/kg):	24.57	24.57
Heat Capacity (kcal/kg*°C):	0.98	0.98
Utilitie s:	None	
Comme nts:	MOC is SS	

Equipme nt Name:	HIC Regeneration Buffer Blending Tank	
Item No:	BT-109	
No. Re quire d:	1.00	
Function:	Mix Sodium Hydroxide and WFI for use in HIC Chromatography Cloumn	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 131:	Stream 132:
Total:	9,136.72	9,136.72
Sodium Hydroxide:	179.08	179.08
WFI:	8,957.64	8,957.64
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	1.01	10.13
Density (g/L):	1,004.15	1,004.15
Total Enthalpy (kW-h):	264.11	264.11
Specific Enthalpy(kcal/kg):	24.87	24.87
Heat Capacity (kcal/kg*°C):	0.99	0.99
Utilitie s:	38.9 kW-h delivered per batch	
Comme nts:	MOC is SS	

Equipme nt Name:	HIC Regeneration Buffer Storage Tank	
Item No:	BS-109	
No. Re quire d:	1.00	
Function:	Store HIC	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 132:	Stream 133:
Total:	9,136.72	9,136.72
Sodium Hydroxide:	179.08	179.08
WFI:	8,957.64	8,957.64
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	10.13	10.13
Density (g/L):	1,004.15	1,004.15
Total Enthalpy (kW-h):	264.11	264.11
Specific Enthalpy(kcal/kg):	24.87	24.87
Heat Capacity (kcal/kg*°C):	0.99	0.99
Utilitie s:	None	
Comme nts:	MOC is SS	

Equipme nt Name:	HIC Elution Buffer Blending Tank	
Item No:	BT-110	
No. Re quire d:	1.00	
Function:	Mix Sodium Chloride, Sodium Hydro Phosphate, and WFI for use in HIC Chromatography Cloumn	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 134:	Stream 135:
Total:	9,237.32	9,237.32
Sodium Hydro Phosphate:	26.50	26.50
Sodium Chloride:	361.72	361.72
WFI:	8,849.09	8,849.09
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	1.01	10.13
Density (g/L):	1,015.21	1,015.21
Total Enthalpy (kW-h):	264.90	264.90
Specific Enthalpy(kcal/kg):	24.67	24.67
Heat Capacity (kcal/kg*°C):	0.98	0.98
Utilitie s:	38.9 kW-h delivered per batch	
Comme nts:	MOC is SS	

Equipme nt Name:	HIC Elution Buffer Storage Tank	
Item No:	BS-110	
No. Re quire d:	1.00	
Function:	Store HIC Elution	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 135:	Stream 136:
Total:	9,237.32	9,237.32
Sodium Hydro Phosphate:	26.50	26.50
Sodium Chloride:	361.72	361.72
WFI:	8,849.09	8,849.09
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	10.13	10.13
Density (g/L):	1,015.21	1,015.21
Total Enthalpy (kW-h):	264.90	264.90
Specific Enthalpy(kcal/kg):	24.67	24.67
Heat Capacity (kcal/kg*°C):	0.98	0.98
Utilitie s:	None	
Comme nts:	MOC is SS	

Equipme nt Name:	HIC Equilibrium/Wash Buffer Blending Tank	
Item No:	BT-111	
No. Re quire d:	1.00	
Function:	Mix Sodium Chloride, Sodium Hydro Phosphate, and WFI for use in HIC Chromatography Cloumn	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 137:	Stream 138:
Total:	13,334.12	13,334.12
Sodium Hydro Phosphate:	42.42	42.42
Sodium Chloride:	1,328.93	1,328.93
WFI:	11,962.78	11,962.78
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	1.01	10.13
Density (g/L):	1,046.76	1,046.76
Total Enthalpy (kW-h):	373.38	373.38
Specific Enthalpy(kcal/kg):	24.09	24.09
Heat Capacity (kcal/kg*°C):	0.96	0.96
Utilitie s:	54.4 kW-h delivered per batch	
Comme nts:	MOC is SS	

Equipme nt Name:	HIC Equilibrium/Wash Buffer Storage Tank	
Item No:	BS-111	
No. Re quire d:	1.00	
Function:	Store HIC	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 138:	Stream 139:
Total:	13,334.12	13,334.12
Sodium Hydro Phosphate:	42.42	42.42
Sodium Chloride:	1,328.93	1,328.93
WFI:	11,962.78	11,962.78
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	10.13	10.13
Density (g/L):	1,046.76	1,046.76
Total Enthalpy (kW-h):	373.38	373.38
Specific Enthalpy(kcal/kg):	24.09	24.09
Heat Capacity (kcal/kg*°C):	0.96	0.96
Utilitie s:	None	
Comme nts:	MOC is SS	

Centrifuges

Equipme nt Name:	Disk Stack Centrifuge		
Item No:	DSC-101		
No. Re quire d:	3		
Function:	Primary recovery of cells		
Ope ration:	Batch		
Materials handle d (kg/batch	Stream 42:	Stream 43:	Stream 44:
Total:	46,585.43	44,241.00	2,344.42
Biomass:	477.64	9.55	468.09
Impurities:	54.81	52.58	2.23
MAb:	93.70	89.88	3.81
Media:	3,67	3.52	0.15
Serum Free Media:	1,215.94	1,166.46	49.48
Water:	920.82	883.35	37.47
WFI:	43,818.86	42,035.67	1,783.19
Design Data:			
Temperature (°C):	37.00	43.10	43.10
Pressure (bar):	10.54	10.54	1.01
Density (g/L):	990.91	988.12	999.87
Total Enthalpy (kW-h):	2,008.54	2,220.71	117.62
Specific Enthalpy(kcal/kg):	37.10	43.19	43.17
Heat Capacity (kcal/kg*°C):	1.00	1.00	1.00
Utilitie s:	Chilled water at inlet T 5°C, 79.2 kW power		
Comme nts:	MOC is SS		

Chromatography Columns

Equipme nt Name:	Protein A Chromatography Column						
Item No:	C-101						
No. Re quire d:	1						
Function:	Purifies the product through Protein A affinity						
Ope ration:	Batch						
Materials handle d (kg/batch):	Stream 49:	Stream 51:	Stream 52:	Stream 53:	Stream 54:	Stream 55:	Stream 56:
Total:	4,422.46	30,853.39	36,125.42	30,254.29	18,062.71	12,185.75	147,332.53
EDTA Sodium	0.00	61.71	0.00	0.00	0.00	0.00	61.71
Acetic Acid	0.00	0.00	0.00	181.53	0.00	72.61	108.92
Impurities	52.57	0.00	0.00	0.00	0.00	3.15	49.41
KCl	0.00	0.00	0.04	0.00	0.00	0.00	0.04
KH2PO4	0.00	0.00	0.04	0.00	0.00	0.00	0.04
Na2HPO4	0.00	0.00	19.87	0.00	0.00	0.00	19.87
MAB	89.86	0.00	0.00	0.00	0.00	80.88	8.99
Media	3.52	0.00	0.00	0.00	0.00	0.00	3.52
Serum Free Media	1,166.22	0.00	0.00	0.00	0.00	0.00	1,166.22
Sodium Chloride	0.00	30.85	173.40	0.00	0.00	0.00	204.26
Sodium Citrate	0.00	0.00	32.51	0.00	32.51	0.00	65.03
TRIS Base	0.00	30.85	0.00	0.00	0.00	0.00	30.85
TRIS HCl	0.00	92.56	0.00	0.00	0.00	0.00	92.56
Water	883.17	0.00	0.00	0.00	0.00	0.00	883.17
WFI:	42,027.13	30,637.42	35,899.57	30,072.77	18,030.20	12,029.11	144,637.97
Design Data:							
Temperature (°C):	43.09	25.00	25.00	25.00	25.00	25.12	30.43
Pressure (bar):	10.75	1.01	1.01	1.01	1.01	1.01	1.01
Density (g/L):	988.11	1,030.00	1,005.00	1,010.00	1,005.00	994.93	994.35
Total Enthalpy (kW-h):	2,219.39	895.13	1,050.91	880.17	526.23	356.28	5,215.54
Specific Enthalpy(kcal/kg):	43.18	24.96	25.03	25.03	25.07	25.16	30.46
Heat Capacity (kcal/kg*°C):	1.00	0.99	1.00	1.00	1.00	1.00	1.00
Utilitie s:	None						
Comme nts:	None						

Equipme nt Name:	IEX Chromatography Column								
Item No:	C-102								
No. Re quire d:	1								
Function:	Purifies the product through cation exchange								
Ope ration:	Batch								
Materials handle d (kg/batch):	Stream 73:	Stream 74:	Stream 75:	Stream 76:	Stream 77:	Stream 78:	Stream 79:	Stream 81:	Stream 80:
Total:	2,437.28	20,300.70	101,604.62	95,038.76	5,721.02	62,479.26	61,933.32	309,138.26	40,376.72
Acetic Acid	5.20	0.00	0.00	0.00	0.00	0.00	0.00	5.20	0.00
Ammonium Sulfate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Impurities	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.01
KCl	0.00	0.04	0.20	0.00	0.00	0.00	0.00	0.24	0.00
KH2PO4	0.00	0.04	0.20	0.00	0.00	0.00	0.00	0.24	0.00
MAB	80.88	0.00	0.00	0.00	0.00	0.00	0.00	8.09	72.79
Na2HPO4	0.00	22.33	111.77	0.00	0.00	0.00	0.00	134.10	118.18
NaH2PO4	0.00	0.00	0.00	0.00	56.07	0.00	0.00	33.64	22.43
Polysorbate 80	0.24								
Sodium Chloride	0.00	182.71	1,828.88	0.00	295.07	3,542.57	0.00	5,731.44	0.00
Sodium Hydroxide	0.00	0.00	0.00	0.00	0.00	0.00	1,213.89	1,213.89	0.00
Water	0.00	0.00	0.00	0.00	0.00	58,936.68	60,719.43	119,656.11	0.00
WFI:	2,350.74	20,095.59	99,663.56	95,038.76	5,369.49	0.00	0.00	182,354.85	40,163.30
Design Data:									
Temperature (°C):	25.82	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Pressure (bar):	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01
Density (g/L):	994.47	1,004.00	1,005.00	994.70	1,030.00	1,030.00	1,021.00	1,005.90	996.40
Total Enthalpy (kW-h):	73.37	589.83	2,942.01	2,773.43	162.30	1,784.22	1,790.00	8,938.91	1,176.49
Specific Enthalpy(kcal/kg):	25.90	25.00	24.91	25.11	24.41	24.57	24.87	24.88	25.07
Heat Capacity (kcal/kg*°C):	1.00	1.00	0.99	1.00	0.97	0.98	0.99	0.99	1.00
Utilitie s:	None								
Comme nts:	None								

Equipme nt Name:	HIC Chromatography Column						
Item No:	C-103						
No. Re quire d:	1						
Function:	Purifies the product through hydrophobic interaction						
Ope ration:	Batch						
Materials handle d (kg/batch):	Stream 84:	Stream 85:	Stream 86:	Stream 87:	Stream 88:	Stream 89:	Stream 90:
Total:	44,630.83	3,857.94	9,644.86	9,326.39	9,290.00	3,796.07	72,953.95
Ammonium Sulfate	4,254.11	0.00	0.00	0.00	0.00	0.00	4,254.11
Impurities	0.01	0.00	0.00	0.00	0.00	0.00	0.01
MAB	72.79	0.00	0.00	0.00	0.00	65.51	7.28
Na2HPO4	0.00	11.96	30.68	26.76	0.00	10.70	58.69
NaH2PO4	22.43	0.00	0.00	0.00	0.00	0.00	22.43
Sodium Chloride	118.18	756.16	961.24	365.21	0.00	146.08	2,054.71
Sodium Hydroxide	0.00	0.00	0.00	0.00	182.08	0.00	182.08
Water	0.00	0.00	0.00	0.00	9,107.91	0.00	9,107.91
WFI:	40,163.30	3,089.83	8,652.93	8,934.42	0.00	3,573.77	57,266.71
Design Data:							
Temperature (°C):	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Pressure (bar):	10.13	1.01	1.01	1.01	1.01	1.01	1.01
Density (g/L):	1,039.69	1,060.00	1,060.00	1,025.00	1,021.00	1,014.85	1,037.12
Total Enthalpy (kW-h):	1,218.46	103.94	270.08	267.45	268.54	108.89	2,019.58
Specific Enthalpy(kcal/kg):	23.49	23.18	24.09	24.67	24.87	24.68	23.82
Heat Capacity (kcal/kg*°C):	0.94	0.92	0.96	0.98	0.99	0.98	0.95
Utilitie s:	None						
Comme nts:	None						

Diafilter Membranes

Equipment Name:	Diafilter Membrane		
Item No:	F-101		
No. Required:	2		
Function:	Filters product from V-103		
Operation:	Batch		
Materials handled (kg/batch):	Stream 62:	Stream 64:	Stream 65:
Total:	2,436.79	994.70	12,185.56
Acetic Acid	5.20	0.00	67.41
Impurities	0.23	0.00	2.93
MAB	80.88	0.00	0.00
WFI:	2,350.49	994.70	12,115.22
Design Data:			
Temperature (°C):	25.83	25.00	25.83
Pressure (bar):	1.01	1.01	1.01
Density (g/L):	994.50	994.50	994.65
Total Enthalpy (kW-h):	73.37	73.37	366.25
Specific Enthalpy(kcal/kg):	25.94	25.94	25.86
Heat Capacity (kcal/kg*°C):	1.00	1.00	1.00
Utilities:	None		
Comments:	None		

Equipme nt Name:	Diafilter Membrane		
Item No:	F-102		
No. Re quire d:	1		
Function:	Filters product from V-109		
Ope ration:	Batch		
Materials handle d (kg/batch):	Stream 100:	Stream 101:	Stream 99:
Total:	497.35	6,285.09	2,498.35
KCl	0.00	0.01	0.00
KH2PO4	0.00	0.01	0.00
MAB	0.00	0.00	62.24
Na2HPO4	0.00	12.92	3.27
Sodium Chloride	0.00	156.10	29.88
WFI:	497.35	6,116.06	2,402.95
Design Data:			
Temperature (°C):	25.00	25.62	25.62
Pressure (bar):	1.01	1.01	1.01
Density (g/L):	994.70	1,007.49	1,000.83
Total Enthalpy (kW-h):	14.51	185.82	74.27
Specific Enthalpy(kcal/kg):	25.11	25.44	25.58
Heat Capacity (kcal/kg*°C):	1.00	0.99	0.99
Utilitie s:	None		
Comme nts:	None		

Filters

Equipme nt Name:	Dead-End Filter	
Item No:	DF-101	
No. Re quire d:	1	
Function:	Filters out impurities	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 13:	Stream 14:
Total:	2,096.65	2,096.65
Serum Free Media:	46.56	46.56
WFI:	2,050.09	2,050.09
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	10.13	10.13
Density (g/L):	994.70	994.70
Total Enthalpy (kW-h):	61.18	61.18
Specific Enthalpy(kcal/kg):	25.11	25.11
Heat Capacity (kcal/kg*°C):	1.00	1.00
Utilitie s:	None	
Comme nts:	None	

Equipme nt Name:	Dead-End Filter	
Item No:	DF-102	
No. Re quire d:	1	
Function:	Filters out impurities	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 21:	Stream 22:
Total:	8,407.34	8,407.34
Serum Free Media:	186.71	186.71
WFI:	8,220.63	8,220.63
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	1.01	10.13
Density (g/L):	994.70	994.70
Total Enthalpy (kW-h):	239.90	245.34
Specific Enthalpy(kcal/kg):	25.11	25.11
Heat Capacity (kcal/kg*°C):	1.00	1.00
Utilitie s:	None	
Comme nts:	None	

Equipme nt Name:	Dead-End Filter	
Item No:	DF-104	
No. Re quire d:	1	
Function:	Filters out impurities	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 34:	Stream 35:
Total:	3,231.80	3,231.80
Serum Free Media:	207.98	207.98
WFI:	3,023.82	3,023.82
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	10.13	10.13
Density (g/L):	994.70	994.70
Total Enthalpy (kW-h):	94.31	94.31
Specific Enthalpy(kcal/kg):	25.11	25.11
Heat Capacity (kcal/kg*°C):	1.00	1.00
Utilitie s:	None	
Comme nts:	None	

Equipme nt Name:	Dead-End Filter	
Item No:	DF-103	
No. Re quire d:	1	
Function:	Filters out impurities	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 29:	Stream 30:
Total:	31,896.59	31,896.59
Serum Free Media:	2,055.46	2,055.46
WFI:	29,841.13	29,841.13
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	10.13	10.13
Density (g/L):	994.70	994.70
Total Enthalpy (kW-h):	930.81	930.81
Specific Enthalpy(kcal/kg):	25.11	25.11
Heat Capacity (kcal/kg*°C):	1.00	1.00
Utilitie s:	None	
Comme nts:	None	

Equipme nt Name:	Dead-End Filter		
Item No:	DF-105		
No. Re quire d:	1		
Function:	Filters out impurities		
Ope ration:	Batch		
Materials handle d (kg/batch):	Stream 43:	Stream 45:	Stream 47:
Total:	44,241.00	44,222.46	18.54
Biomass:	9.55	0.00	9.55
Impurities:	52.58	52.57	0.00
MAb:	89.88	89.86	0.00
Media:	3.52	3.52	0.00
Serum Free Media:	1,166.46	1,166.22	0.24
Water:	883.35	883.17	0.00
WFI:	42,035.67	42,027.13	8.54
Design Data:			
Temperature (°C):	43.10	43.10	43.10
Pressure (bar):	10.54	10.54	10.54
Density (g/L):	988.12	988.11	1,019.05
Total Enthalpy (kW-h):	2,220.71	2,219.78	0.93
Specific Enthalpy(kcal/kg):	43.19	43.19	43.13
Heat Capacity (kcal/kg*°C):	1.00	1.00	1.00
Utilitie s:	Chilled water at inlet T 5°C, 79.2 kW power		
Comme nts:	MOC is SS		

Equipment Name:	Dead-End Filter	
Item No:	DF-106	
No. Required:	1	
Function:	Filters out impurities	
Operation:	Batch	
Materials handled (kg/batch):	Stream 55:	Stream 57:
Total:	12185.75	
Acetic Acid	72.61	72.61
Impurities	3.15	3.15
MAB	80.88	80.88
WFI:	12029.11	12029.11
Design Data:		
Temperature (°C):	25.12	25.12
Pressure (bar):	1.01	1.01
Density (g/L):	994.93	994.93
Total Enthalpy (kW-h):	356.28	356.25
Specific Enthalpy(kcal/kg):	25.16	25.15
Heat Capacity (kcal/kg*°C):	1	1
Utilities:	None	
Comments:	None	

Equipme nt Name:	Dead-End Filter	
Item No:	DF-107	
No. Re quire d:	1	
Function:	Filters out impurities	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 71:	Stream 73:
Total:	2437.28	2437.28
Acetic Acid	5.2	5.2
Impurities	0.23	0.23
MAB	80.88	80.88
Polysorbate 80	0.24	0.24
WFI:	2350.74	2350.74
Design Data:		
Temperature (°C):	25.82	25.82
Pressure (bar):	1.01	1.01
Density (g/L):	994.47	994.47
Total Enthalpy (kW-h):	73.37	73.37
Specific Enthalpy(kcal/kg):	25.9	25.9
Heat Capacity (kcal/kg*°C):	1	1
Utilitie s:	None	
Comme nts:	None	

Equipme nt Name:	Dead-End Filter	
Item No:	DF-108	
No. Re quire d:	1	
Function:	Filters out impurities	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 89:	Stream 91:
Total:	3796.07	3796.07
MAB	65.51	65.51
Na2HPO4	10.7	10.7
Sodium Chloride	146.08	146.08
WFI:	3573.77	3573.77
Design Data:		
Temperature (°C):	25	25
Pressure (bar):	1.01	1.01
Density (g/L):	1014.85	1014.85
Total Enthalpy (kW-h):	108.89	108.89
Specific Enthalpy(kcal/kg):	24.68	24.68
Heat Capacity (kcal/kg*°C):	0.98	0.98
Utilitie s:	None	
Comme nts:	None	

Equipme nt Name:	Dead-End Filter	
Item No:	DF-109	
No. Re quire d:	1	
Function:	Filters out impurities	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 93:	Stream 94:
Total:	3796.07	3796.07
MAB	65.51	65.51
Na2HPO4	10.7	10.7
Sodium Chloride	146.08	146.08
WFI:	3573.77	3573.77
Design Data:		
Temperature (°C):	25	25
Pressure (bar):	10.13	10.13
Density (g/L):	1014.85	1014.85
Total Enthalpy (kW-h):	108.89	108.89
Specific Enthalpy(kcal/kg):	24.68	24.68
Heat Capacity (kcal/kg*°C):	0.98	0.98
Utilitie s:	None	
Comme nts:	None	

Equipment Name:	Dead-End Filter	
Item No:	DF-110	
No. Required:	1	
Function:	Filters out impurities	
Operation:	Batch	
Materials handled (kg/batch):	Stream 103:	Stream 105:
Total:	2498.35	2498.35
MAB	62.24	3.27
Na2HPO4	3.27	62.24
Sodium Chloride	29.88	29.88
WFI:	2402.95	2402.95
Design Data:		
Temperature (°C):	25	25.62
Pressure (bar):	10.13	2.54
Density (g/L):	994.7	1000.83
Total Enthalpy (kW-h):	61.18	74.27
Specific Enthalpy(kcal/kg):	25.11	25.58
Heat Capacity (kcal/kg*°C):	1	0.99
Utilities:	None	
Comments:	None	

Kill Tank

Equipme nt Name:	Kill Tank	
Item No:	KT-101	
No. Re quire d:	1	
Function:	Store and neutralize biological and chemical waste	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 140:	Stream 141:
Total:	481,022.38	481,022.38
Acetic acid	181.53	181.53
EDTA Sodium	61.71	61.71
Biomass:	477.64	477.64
Impurities:	54.79	54.79
Dilute HCl	0.00	amount determined by pH controller
KCl	0.29	0.29
KH2PO4	0.29	0.29
MAb:	86.42	86.42
Media:	3.67	3.67
Na2HPO4	166.89	166.89
Serum Free Media:	1,249.58	1,249.58
Polysorbate 80	0.24	0.24
Sodium Chloride	6,237.88	6,237.88
Sodium Citrate	65.03	65.03
Sodium Hydroxide	1,213.89	1,213.89
TRIS Base	30.85	30.85
TRIS HCl	92.56	92.56
Water:	120,576.93	120,576.93
WFI:	350,589.60	350,589.60
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	1.01	1.01
Density (g/L):	~1000	~1000
Total Enthalpy (kW-h):	108.89	108.89
Specific Enthalpy(kcal/kg):	24.68	24.68
Heat Capacity (kcal/kg*°C):	1.00	1.00
Utilitie s:	None	
Comme nts:	MOC is SS	

Media Prep Tanks

Equipme nt Name:	Media Prep Tank		
Item No:	MPT-101		
No. Re quire d:	1		
Function:	Mix media and WFI to feed into seed bioreactors		
Ope ration:	Batch		
Materials handle d (kg/batch):	Stream 11:	Stream 12:	Stream 13:
Total:	2,050.09	46.56	2,096.65
Serum Free Media:	0.00	46.56	46.56
WFI:	2,050.09	0.00	2,050.09
Design Data:			
Temperature (°C):	25.00	25.00	25.00
Pressure (bar):	1.01	1.01	10.13
Density (g/L):	994.70	994.70	994.70
Total Enthalpy (kW-h):	59.83	1.36	61.18
Specific Enthalpy(kcal/kg):	25.11	25.11	25.11
Heat Capacity (kcal/kg*°C):	1.00	1.00	1.00
Utilitie s:	None		
Comme nts:	MOC is SS		

Equipme nt Name:	Media Prep Tank		
Item No:	MPT-102		
No. Re quire d:	1		
Function:	Mix media and WFI to feed into seed bioreactors		
Ope ration:	Batch		
Materials handle d (kg/batch):	Stream 19:	Stream 20:	Stream 21:
Total:	8,220.63	186.71	8,407.34
Serum Free Media:	0.00	186.71	186.71
WFI:	8,220.63	0.00	8,220.63
Design Data:			
Temperature (°C):	25.00	25.00	25.00
Pressure (bar):	1.01	1.01	10.13
Density (g/L):	994.70	994.70	994.70
Total Enthalpy (kW-h):	239.90	5.45	245.34
Specific Enthalpy(kcal/kg):	25.11	25.11	25.11
Heat Capacity (kcal/kg*°C):	1.00	1.00	1.00
Utilitie s:	None		
Comme nts:	MOC is SS		

Equipme nt Name:	Media Prep Tank		
Item No:	MPT-3		
No. Re quire d:	1		
Function:	Mix media and WFI to feed into bioreactor		
Ope ration:	Batch		
Materials handle d (kg/batch):	Stream 27:	Stream 28:	Stream 29:
Total:	29,841.13	2,055.46	31,896.59
Serum Free Media:	0.00	2,055.46	2,055.46
WFI:	29,841.13	0.00	29,841.13
Design Data:			
Temperature (°C):	25.00	25.00	25.00
Pressure (bar):	1.01	1.01	10.13
Density (g/L):	994.70	994.70	994.70
Total Enthalpy (kW-h):	870.83	59.98	930.81
Specific Enthalpy(kcal/kg):	25.11	25.11	25.11
Heat Capacity (kcal/kg*°C):	1.00	1.00	1.00
Utilitie s:	None		
Comme nts:	MOC is SS		

Equipme nt Name:	Media Prep Tank		
Item No:	MPT-4		
No. Re quire d:	1		
Function:	Mix media and WFI to feed into bioreactor		
Ope ration:	Batch		
Materials handle d (kg/batch):	Stream 32:	Stream 33:	Stream 34:
Total:	4,100.00	282.00	3,023.82
Serum Free Media:	0.00	282.00	207.98
WFI:	4,100.00		
Design Data:			
Temperature (°C):	25.00	25.00	25.00
Pressure (bar):	1.01	1.01	10.13
Density (g/L):	994.70	994.70	994.70
Total Enthalpy (kW-h):	119.65	8.23	94.31
Specific Enthalpy(kcal/kg):	25.11	25.11	25.11
Heat Capacity (kcal/kg*°C):	1.00	1.00	1.00
Utilitie s:	None		
Comme nts:	MOC is SS		

Pumps

Equipme nt Name:	Diaphragm Pump	
Item No:	P-101	
No. Re quire d:	1	
Function:	Pump cell broth to seed bioreactor	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 14:	Stream 15:
Total:	2096.65	2096.65
Serum Free Media:	46.56	46.56
WFI:	2050.09	2050.09
Design Data:		
Temperature (°C):	25	25
Pressure (bar):	10.13	10.13
Density (g/L):	994.7	994.7
Total Enthalpy (kW-h):	61.18	61.18
Specific Enthalpy(kcal/kg):	25.11	25.11
Heat Capacity (kcal/kg*°C):	1	1
Utilitie s:	2.2 kW of electricity delivered	
Comme nts:	MOC is SS	

Equipme nt Name:	Diaphragm Pump	
Item No:	P-102	
No. Re quire d:		
Function:	Pump cell broth to seed bioreactor	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 22:	Stream 23:
Total:	8,407.34	8,407.34
Serum Free Media:	186.71	186.71
WFI:	8,220.63	8,220.63
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	10.13	10.13
Density (g/L):	994.70	994.70
Total Enthalpy (kW-h):	245.34	245.34
Specific Enthalpy(kcal/kg):	25.11	25.11
Heat Capacity (kcal/kg*°C):	1.00	1.00
Utilitie s:	4 kW of electricity delivered	
Comme nts:	MOC is SS	

Equipme nt Name:	Diaphragm Pump	
Item No:	P-103	
No. Re quire d:	1	
Function:	Pump cell broth to bioreactor	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 30:	Stream 31:
Total:	31,896.59	31,896.59
Serum Free Media:	2,055.46	2,055.46
WFI:	29,841.13	29,841.13
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	10.13	10.13
Density (g/L):	994.70	994.70
Total Enthalpy (kW-h):	930.81	930.81
Specific Enthalpy(kcal/kg):	25.11	25.11
Heat Capacity (kcal/kg*°C):	1.00	1.00
Utilitie s:	7 kW of electricity delivered	
Comme nts:	MOC is SS	

Equipme nt Name:	Diaphragm Pump	
Item No:	P-104	
No. Re quire d:	1	
Function:	Pump cell broth to bioreactor	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 35:	Stream 36:
Total:	3,231.80	3,231.80
Serum Free Media:	207.98	207.98
WFI:	3,023.82	3,023.82
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	10.13	10.13
Density (g/L):	994.70	994.70
Total Enthalpy (kW-h):	94.31	94.31
Specific Enthalpy(kcal/kg):	25.11	25.11
Heat Capacity (kcal/kg*°C):	1.00	1.00
Utilitie s:	0.05 kW of electricity delivered	
Comme nts:	MOC is SS	

Equipme nt Name:	Diaphragm Pump	
Item No:	P-105	
No. Re quire d:	1	
Function:	Pump cell broth to tank	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 38:	Stream 39:
Total:	46,585.43	46,585.43
Biomass:	477.64	477.64
Impurities:	54.81	54.81
MAb:	93.70	93.70
Media:	3,67	3,67
Serum Free Media:	1,215.94	1,215.94
Water:	920.82	920.82
WFI:	43,818.86	43,818.86
Design Data:		
Temperature (°C):	37.00	37.00
Pressure (bar):	1.01	1.01
Density (g/L):	990.91	990.91
Total Enthalpy (kW-h):	2,008.54	2,008.54
Specific Enthalpy(kcal/kg):	37.10	37.10
Heat Capacity (kcal/kg*°C):	1.00	1.00
Utilitie s:	5 kW of electricity delivered	
Comme nts:	MOC is SS	

Equipme nt Name:	Diaphragm Pump	
Item No:	P-106	
No. Re quire d:	1	
Function:	Pump cell broth to centrifuge	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 41:	Stream 42:
Total:	46,585.43	46,585.43
Biomass:	477.64	477.64
Impurities:	54.81	54.81
MAb:	93.70	93.70
Media:	3,67	3,67
Serum Free Media:	1,215.94	1,215.94
Water:	920.82	920.82
WFI:	43,818.86	43,818.86
Design Data:		
Temperature (°C):	37.00	37.00
Pressure (bar):	10.54	10.54
Density (g/L):	990.91	990.91
Total Enthalpy (kW-h):	2,008.54	2,008.54
Specific Enthalpy(kcal/kg):	37.10	37.10
Heat Capacity (kcal/kg*°C):	1.00	1.00
Utilitie s:	5 kW of electricity delivered	
Comme nts:	MOC is SS	

Equipme nt Name:	Diaphragm Pump	
Item No:	P-107	
No. Re quire d:	1	
Function:	Pump product from DF-105 to V-102	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 45:	Stream 46:
Total:	4422.46	4422.46
Impurities	52.57	52.57
MAB	89.86	89.86
Media	3.52	3.52
Serum Free Media	1166.22	1166.22
Water	883.17	883.17
WFI:	42027.13	42027.13
Design Data:		
Temperature (°C):	43.1	43.1
Pressure (bar):	10.54	10.54
Density (g/L):	988.11	988.11
Total Enthalpy (kW-h):	2219.78	2219.78
Specific Enthalpy(kcal/kg):	43.19	43.19
Heat Capacity (kcal/kg*°C):	1	1
Utilitie s:	None	
Comme nts:	None	

Equipme nt Name:	Diaphragm Pump	
Item No:	P-108	
No. Re quire d:	1	
Function:	Pump product from V-102 to C-101	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 48:	Stream 49:
Total:	44222.46	44222.46
Impurities	52.57	52.57
MAB	89.86	89.86
Media	3.52	3.52
Serum Free Media	1166.22	1166.22
Water	883.17	883.17
WFI:	42027.13	42027.13
Design Data:		
Temperature (°C):	43.09	43.09
Pressure (bar):	10.75	10.75
Density (g/L):	988.11	988.11
Total Enthalpy (kW-h):	2219.39	2219.39
Specific Enthalpy(kcal/kg):	43.18	43.18
Heat Capacity (kcal/kg*°C):	1	1
Utilitie s:	None	
Comme nts:	None	

Equipme nt Name:	Diaphragm Pump	
Item No:	P-109	
No. Re quire d:	1	
Function:	Pump product from V-103 to V-104	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 58:	Stream 59:
Total:	12185.75	12185.75
Acetic Acid	72.61	72.61
Impurities	3.15	3.15
MAB	80.88	80.88
WFI:	12029.11	12029.11
Design Data:		
Temperature (°C):	25.12	25.12
Pressure (bar):	10.14	10.14
Density (g/L):	994.93	994.93
Total Enthalpy (kW-h):	356.27	356.27
Specific Enthalpy(kcal/kg):	25.16	25.16
Heat Capacity (kcal/kg*°C):	1	1
Utilitie s:	None	
Comme nts:	None	

Equipme nt Name:	Diaphragm Pump	
Item No:	P-110	
No. Re quire d:	1	
Function:	Pump product from F-101 to V-103	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 62:	Stream 63:
Total:	2436.79	2436.79
Acetic Acid	5.2	5.2
Impurities	0.23	0.23
MAB	80.88	80.88
WFI:	2350.49	2350.49
Design Data:		
Temperature (°C):	25.83	25.83
Pressure (bar):	1.01	1.01
Density (g/L):	994.5	994.5
Total Enthalpy (kW-h):	73.37	73.37
Specific Enthalpy(kcal/kg):	25.91	25.91
Heat Capacity (kcal/kg*°C):	1	1
Utilitie s:	None	
Comme nts:	None	

Equipme nt Name:	Diaphragm Pump	
Item No:	P-111	
No. Re quire d:	1	
Function:	Pump product from V-103 to V-105	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 66:	Stream 67:
Total:	2436.79	2436.79
Acetic Acid	5.2	5.2
Impurities	0.23	0.23
MAB	80.88	80.88
Polysorbate 80	0.24	0.24
WFI:	2350.49	2350.49
Design Data:		
Temperature (°C):	25.82	25.82
Pressure (bar):	1.01	1.01
Density (g/L):	994.5	994.5
Total Enthalpy (kW-h):	73.36	73.36
Specific Enthalpy(kcal/kg):	25.9	25.9
Heat Capacity (kcal/kg*°C):	1	1
Utilitie s:	None	
Comme nts:	None	

Equipme nt Name:	Diaphragm Pump	
Item No:	P-112	
No. Re quire d:	1	
Function:	Pump product from V-105 to DF-107	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 70:	Stream 71:
Total:	2437.28	2437.28
Acetic Acid	5.2	5.2
Impurities	0.23	0.23
MAB	80.88	80.88
Polysorbate 80	0.24	0.24
WFI:	2350.74	2350.74
Design Data:		
Temperature (°C):	25.82	25.82
Pressure (bar):	1.01	1.01
Density (g/L):	994.47	994.47
Total Enthalpy (kW-h):	73.37	73.37
Specific Enthalpy(kcal/kg):	25.9	25.9
Heat Capacity (kcal/kg*°C):	1	1
Utilitie s:	None	
Comme nts:	None	

Equipme nt Name:	Diaphragm Pump	
Item No:	P-113	
No. Re quire d:	1	
Function:	Pump product from V-106 to C-103	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 83:	Stream 84:
Total:	44630.83	44630.83
Ammonium Sulfate	4254.11	4254.11
Impurities	0.01	0.01
MAB	72.79	72.79
NaH2PO4	22.43	22.43
Sodium Chloride	118.18	118.18
WFI:	40163.3	40163.3
Design Data:		
Temperature (°C):	25	25
Pressure (bar):	10.13	10.13
Density (g/L):	1039.69	1039.69
Total Enthalpy (kW-h):	1218.46	1218.46
Specific Enthalpy(kcal/kg):	23.49	23.49
Heat Capacity (kcal/kg*°C):	0.94	0.94
Utilitie s:	None	
Comme nts:	None	

Equipme nt Name:	Diaphragm Pump	
Item No:	P-114	
No. Re quire d:	1	
Function:	Pump product from V-107 to DF-109	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 92:	Stream 93:
Total:	3796.07	3796.07
MAB	65.51	65.51
Na2HPO4	10.7	10.7
Sodium Chloride	146.08	146.08
WFI:	3573.77	3573.77
Design Data:		
Temperature (°C):	25	25
Pressure (bar):	10.13	10.13
Density (g/L):	1014.85	1014.85
Total Enthalpy (kW-h):	108.89	108.89
Specific Enthalpy(kcal/kg):	24.68	24.68
Heat Capacity (kcal/kg*°C):	0.98	0.98
Utilitie s:	None	
Comme nts:	None	

Equipme nt Name:	Diaphragm Pump	
Item No:	P-115	
No. Re quire d:	1	
Function:	Pump product from V-108 to V-109	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 95:	Stream 96:
Total:	3796.07	3796.07
MAB	65.51	65.51
Na2HPO4	10.7	10.7
Sodium Chloride	146.08	146.08
WFI:	3573.77	3573.77
Design Data:		
Temperature (°C):	25	25
Pressure (bar):	10.13	10.13
Density (g/L):	1014.85	1014.85
Total Enthalpy (kW-h):	108.89	108.89
Specific Enthalpy(kcal/kg):	24.68	24.68
Heat Capacity (kcal/kg*°C):	0.98	0.98
Utilitie s:	None	
Comme nts:	None	

Equipme nt Name:	Diaphragm Pump	
Item No:	P-116	
No. Re quire d:	1	
Function:	Pump product from V-108 to DF-110	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 102:	Stream 103:
Total:	2498.35	2498.35
KCl	0	0
KH2PO4	0	0
MAB	62.24	62.24
Na2HPO4	3.27	3.27
Sodium Chloride	29.88	29.88
WFI:	2402.95	2402.95
Design Data:		
Temperature (°C):	25	25
Pressure (bar):	10.13	10.13
Density (g/L):	994.7	994.7
Total Enthalpy (kW-h):	61.18	61.18
Specific Enthalpy(kcal/kg):	25.11	25.11
Heat Capacity (kcal/kg*°C):	1	1
Utilitie s:	None	
Comme nts:	None	

Rocking Bioreactors

Equipme nt Name:	Rocking bioreactor			
Item No:	RB-101			
No. Re quire d:	4			
Function:	Rock media and cell culture to promote cell division			
Ope ration:	Batch			
Materials handle d (kg/batch):	Stream 4:	Stream 5:	Stream 6:	Stream 7:
Total:	44.76	130.11	0.16	523.41
Biomass:	0.13	0	0	0.34
Impurities:	0.01	0	0	0
MAb:	0.01	0	0	0
Media:	0.24	2.81	0	11.31
Water:	0.58	0	0	0
WFI:	43.79	127.3	0	512.1
Carbon Dioxide:	0	0	0.05	0
Oxygen	0	0	0.03	0
Nitrogen:	0	0	0.08	0
Design Data:				
Temperature (°C):	25	25	25	25
Pressure (bar):	9.14	1.01	1.01	1.01
Density (g/L):	994.85	994.7	1.32	994.81
Total Enthalpy (kW-h):	1.31	3.8	0	5.1
Specific Enthalpy(kcal/kg):	25.11	25.11	22.66	25.11
Heat Capacity (kcal/kg*°C):	1	1	0.23	1
Utilitie s:	Cooling water at inlet T 5°C and 0.95 kg/h			
Comme nts:	MOC is SS			

Equipme nt Name:	Rocking bioreactor			
Item No:	RB-102			
No. Re quire d:	8			
Function:	Rock media and cell culture to promote cell division			
Ope ration:	Batch			
Materials handle d (kg/batch):	Stream 7:	Stream 8:	Stream 9:	Stream 10:
Total:	523.41	523.41	0.71	697.21
Biomass:	0.34	0	0	1.2
Carbon Dioxide:	0	0	0.22	0
Impurities:	0.1	0	0	0.44
MAb:	0.03	0	0	0.11
Media:	0.92	11.31	0	3.67
Nitrogen:	0	0	0.37	0
Oxygen:	0	0	0.11	0
Water:	2.18	0	0	8.6
WFI:	171.09	512.1	0	683.19
Design Data:				
Temperature (°C):	25	25	37.03	37
Pressure (bar):	1.01	1.01	1.01	1.01
Density (g/L):	994.81	994.7	1.27	990.43
Total Enthalpy (kW-h):	5.1	15.27	0.02	30.06
Specific Enthalpy(kcal/kg):	25.11	25.11	25.43	37.1
Heat Capacity (kcal/kg*°C):	1	1	0.23	1
Utilitie s:	Steam at inlet T 152 °C and 0.08 kg/h			
Comme nts:	MOC is SS			

Storage Bags

Equipme nt Name:	Product Storage Bags	
Item No:	B-101	
No. Re quire d:	1	
Function:	Prepares product for storage of up to 1 year	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 105:	Stream 106:
Total:	2,498.35	2,498.35
Na2HPO4	3.27	3.27
MAb:	62.24	62.24
Sodium Chloride	29.88	29.88
WFI:	2,402.95	2,402.95
Design Data:		
Temperature (°C):	25.62	25.62
Pressure (bar):	2.54	4.89
Density (g/L):	1,000.83	1,000.83
Total Enthalpy (kW-h):	74.27	74.27
Specific Enthalpy(kcal/kg):	25.58	25.58
Heat Capacity (kcal/kg*°C):	0.99	0.99
Utilitie s:	None	
Comme nts:	None	

Storage Vessels

Equipme nt Name:	Storage Vessel	
Item No:	V-101	
No. Re quire d:	1	
Function:	Store cell broth before centrufugation	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 39:	Stream 41:
Total:	46,585.43	46,585.43
Biomass:	477.64	477.64
Impurities:	54.81	54.81
MAb:	93.70	93.70
Media:	3,67	3,67
Serum Free Media:	1,215.94	1,215.94
Water:	920.82	920.82
WFI:	43,818.86	43,818.86
Design Data:		
Temperature (°C):	37.00	37.00
Pressure (bar):	1.01	10.54
Density (g/L):	990.91	990.91
Total Enthalpy (kW-h):	2,008.54	2,008.54
Specific Enthalpy(kcal/kg):	37.10	37.10
Heat Capacity (kcal/kg*°C):	1.00	1.00
Utilitie s:	None	
Comme nts:	MOC is SS	

Equipme nt Name:	Storage Vessel		
Item No:	V-102		
No. Re quire d:	1		
Function:	Holds feed for C-101		
Ope ration:	Batch		
Materials handle d (kg/batch):	Stream 46:	Stream 48:	Stream 50:
Total:	4,422.46	44,222.46	0.00
Impurities	52.57	52.57	0.00
MAB	89.86	89.86	0.00
Media	3.52	3.52	0.00
Serum Free Media	1,166.22	1,166.22	0.00
Water	883.17	883.17	0.00
WFI:	42,027.13	42,027.13	0.00
Design Data:			0.00
Temperature (°C):	43.10	43.09	0.00
Pressure (bar):	10.54	10.75	0.00
Density (g/L):	988.11	988.11	0.00
Total Enthalpy (kW-h):	2,219.78	2,219.39	0.00
Specific Enthalpy(kcal/kg):	43.19	43.18	0.00
Heat Capacity (kcal/kg*°C):	1.00	1.00	0.00
Utilitie s:	None		
Comme nts:	None		

Equipme nt Name:	Storage Vessel				
Item No:	V-103				
No. Re quire d:	1				
Function:	Stores Protein A filtration product				
Ope ration:	Batch				
Materials handle d (kg/batch):	Stream 57:	Stream 58:	Stream 63:	Stream 66:	Stream 67:
Total:	12,185.75	12,185.75	2,436.79	2,436.79	0.00
Acetic Acid	72.61	72.61	5.20	5.20	0.00
Impurities	3.15	3.15	0.23	0.23	0.00
MAB	80.88	80.88	80.88	80.88	0.00
WFI:	12,029.11	12,029.11	2,350.49	2,350.49	0.00
Design Data:					0.00
Temperature (°C):	25.12	25.12	25.83	25.83	0.00
Pressure (bar):	1.01	10.14	1.01	1.01	0.00
Density (g/L):	994.93	994.93	994.50	994.50	0.00
Total Enthalpy (kW-h):	536.25	356.27	73.37	73.37	0.00
Specific Enthalpy(kcal/kg):	25.15	25.16	25.91	25.91	0.00
Heat Capacity (kcal/kg*°C):	1.00	1.00	1.00	1.00	0.00
Utilitie s:	None				
Comme nts:	None				

Equipme nt Name:	Diafilter Vessel			
Item No:	V-104			
No. Re quire d:	2			
Function:	Holds diafilter membrane feed			
Ope ration:	Batch			
Materials handle d (kg/batch):	Stream 59:	Stream 60:	Stream 61:	Stream 62:
Total:	12,185.75	2,436.60	994.70	2,436.79
Acetic Acid	72.61	0.00	0.00	5.20
Impurities	3.15	0.00	0.00	0.00
MAB	80.88	0.00	0.00	80.88
Na2HPO4	0.00	0.00	0.00	0.00
Sodium Chloride	0.00	0.00	0.00	0.00
WFI:	12,029.11	2,436.60	994.70	2,350.49
Design Data:				
Temperature (°C):	25.12	25.00	25.00	25.83
Pressure (bar):	10.14	1.01	1.01	1.01
Density (g/L):	994.93	994.70	994.70	994.50
Total Enthalpy (kW-h):	356.27	71.11	29.03	73.37
Specific Enthalpy(kcal/kg):	25.16	25.11	25.11	25.91
Heat Capacity (kcal/kg*°C):	1.00	1.00	1.00	1.00
Utilitie s:	None			
Comme nts:	None			

Equipme nt Name:	Storage Vessel			
Item No:	V-105			
No. Re quire d:	1			
Function:	Stores Protein A filtration product			
Ope ration:	Batch			
Materials handle d (kg/batch):	Stream 67:	Stream 69:	Stream 70:	Stream 72:
Total:	2,436.79	0.49	2,437.28	2.89
Acetic Acid	5.20	0.00	5.20	0.00
Impurities	0.23	0.00	0.23	0.00
MAB	80.88	0.00	80.88	0.00
Nitrogen	0.00	0.00	0.00	2.22
Oxygen	0.00	0.00	0.00	0.67
Polysorbate 80	0.00	0.24	0.24	0.00
WFI:	2,350.49	0.24	2,350.74	0.00
Design Data:				
Temperature (°C):	25.82	25.82	25.82	25.62
Pressure (bar):	1.01	1.01	1.01	1.01
Density (g/L):	994.50	1.18	994.47	1,000.83
Total Enthalpy (kW-h):	73.36	0.02	73.37	74.27
Specific Enthalpy(kcal/kg):	25.90	6.25	25.90	25.58
Heat Capacity (kcal/kg*°C):	1.00	0.24	1.00	0.99
Utilitie s:	None			
Comme nts:	None			

Equipme nt Name:	Storage Vessel		
Item No:	V-106		
No. Re quire d:	1		
Function:	Holds feed for C-103		
Ope ration:	Batch		
Materials handle d (kg/batch):	Stream 80:	Stream 82:	Stream 83:
Total:	40,163.30	4,254.11	44,630.83
Ammonium Sulfate	0.00	4,254.11	4,254.11
MAB	72.79	0.00	72.79
NaH2PO4	118.18	0.00	22.43
Sodium Chloride	0.00	0.00	118.18
WFI:	40,163.30	0.00	40,163.30
Design Data:			
Temperature (°C):	25.00	25.00	25.00
Pressure (bar):	1.01	1.01	10.13
Density (g/L):	996.40	1,769.00	1,039.69
Total Enthalpy (kW-h):	1,176.49	42.00	1,218.46
Specific Enthalpy(kcal/kg):	25.07	8.50	23.49
Heat Capacity (kcal/kg*°C):	1.00	0.34	0.94
Utilitie s:	None		
Comme nts:	None		

Equipme nt Name:	Storage Vessel	
Item No:	V-107	
No. Re quire d:	1	
Function:	Holds diafilter membrane feed for DF-109	
Ope ration:	Batch	
Materials handle d (kg/batch):	Stream 91:	Stream 92:
Total:	3,796.07	3,796.07
MAB	65.51	65.51
Na2HPO4	10.70	10.70
Sodium Chloride	146.08	146.08
WFI:	3,573.77	3,573.77
Design Data:		
Temperature (°C):	25.00	25.00
Pressure (bar):	1.01	10.13
Density (g/L):	1,014.85	1,014.85
Total Enthalpy (kW-h):	108.89	108.89
Specific Enthalpy(kcal/kg):	24.68	24.68
Heat Capacity (kcal/kg*°C):	0.98	0.98
Utilitie s:	None	
Comme nts:	None	

Equipme nt Name:	Storage Vessel				
Item No:	V-108				
No. Re quire d:	1				
Function:	Stores viral exclusion filter product				
Ope ration:	Batch				
Materials handle d (kg/batch):	Stream 94:	Stream 95:	Stream 99:	Stream 102:	Stream 104:
Total:	3,796.07	3,796.07	2,496.27	2,498.35	0.00
MAB	65.51	65.51	62.24	62.24	0.00
Na2HPO4	10.70	10.70	3.27	3.27	0.00
Sodium Chloride	146.08	146.08	29.88	29.88	0.00
WFI:	3,573.77	3,573.77	2,402.95	2,402.95	0.00
Design Data:					0.00
Temperature (°C):	25.00	25.00	25.62	25.62	0.00
Pressure (bar):	10.13	10.13	1.01	2.54	0.00
Density (g/L):	1,014.85	1,014.85	1,000.83	1,000.83	0.00
Total Enthalpy (kW-h):	108.89	108.89	74.27	74.27	0.00
Specific Enthalpy(kcal/kg):	24.68	24.68	25.58	25.58	0.00
Heat Capacity (kcal/kg*°C):	0.98	0.98	0.99	0.99	0.00
Utilitie s:	None				
Comme nts:	None				

Equipme nt Name:	Diafilter Vessel			
Item No:	V-109			
No. Re quire d:	1			
Function:	Holds diafilter membrane feed			
Ope ration:	Batch			
Materials handle d (kg/batch):	Stream 96:	Stream 97:	Stream 98:	Stream 99:
Total:	3,796.07	4,987.37	497.35	2,496.27
KCl	0.00	0.01	0.00	0.00
KH2PO4	0.00	0.01	0.00	0.00
MAB	65.51	0.00	0.00	62.24
Na2HPO4	10.70	5.49	0.00	3.27
Sodium Chloride	146.08	39.90	0.00	29.88
WFI:	3,573.77	4,941.96	497.35	2,402.95
Design Data:				
Temperature (°C):	25.00	25.00	25.00	25.62
Pressure (bar):	10.13	1.01	1.01	1.01
Density (g/L):	1,014.85	1,000.00	994.70	1,000.83
Total Enthalpy (kW-h):	108.89	144.96	14.51	74.27
Specific Enthalpy(kcal/kg):	24.68	25.01	25.11	25.58
Heat Capacity (kcal/kg*°C):	0.98	1.00	1.00	0.99
Utilitie s:	None			
Comme nts:	None			

EQUIPMENT COST SUMMARY

To cost our equipment we utilized parameters found in SuperPro Designer and the method found in *Analysis, Synthesis, and Design of Chemical Processes* by Turton et al. We utilized the Chemical Engineering Plant Cost Index (CEPCI) to escalate our costs to the current year's dollars [53]. The equations used for costing equipment can be found in Appendix A. Each piece of equipment is costed for in the appropriate material of construction (MOC). A summary of the cost of each piece of equipment can be found in Table 8.

Table 9 Equipment Cost Summary

Capital Cost Summary		
Equipment Name	**Description**	**Capital Cost**
Process Facility	Completed Cost of Facility	$ 40,000,000.00
Air Conditioning	Cost of Air-Conditioning System	$ 2,216,297.10
Fire Suppression	Foam and Water Fire Suppression System	$ 5,000,000.00
Media Prep Equipment	Media Preparation Lab Equipment	$ 50,839.53
Buffer Prep Equipment	Buffer Prep Blending and Storage Tanks	$ 10,848,355.36
Process Pumps	Diaphragm pumps to move broth	$ 208,812.00
WFI System	Water for Injection Production System	$ 500,000.00
Product Storage	Cold Room Product Storage	$ 126,000.00
RB-101 A-D	Four 100-L Rocking Bag Reactors	$ 70,179.78
RB-102 A-H	Eight 200-L Rocking Bag Reactors	$ 189,374.72
MPT-101	SBR-101 Media Prep Tank	$ 43,017.58
DF-101	SBR-101 Media Filter	$ 160,759.24
SBR-101	Seed Bioreactor 1	$ 337,638.53
SBR-101 Impeller	Seed Bioreactor 1 Impeller	$ 26,048.02
MPT-102	SBR-102 Media Prep Tank	$ 94,986.15
DF-102	SBR-102 Media Filter	$ 338,809.86
SBR-102 A/B	Seed Bioreactor 2	$ 675,277.06
SBR-102 A/B Impellers	Seed Bioreactor 2 A/B Impellers	$ 72,658.08
MPT-103	Production Bioreactor Media Prep Tank 1	$ 224,662.75
DF-103	Production Bioreactor Media Filter 1	$ 701,379.76
MPT-104	Production Bioreactor Media Prep Tank 2	$ 64,209.11
DF-104	Production Bioreactor Media Filter 2	$ 160,759.24
BR-101 A/B	Production Bioreactor	$ 1,409,271.32
BR-101 A/B Impellers	Production Bioreactor A/B Impellers	$ 44,252.97
V-101	Centrifuge Holding Tank	$ 276,501.93
DSC-101 A-C	Three Disk Stack Centrifuges	$ 175,361.61
DF-105	Polishing Filter	$ 287,414.97
V-102	Centrifuge Product Tank	$ 259,472.71
C-101	Protein A Chromatography Column	$ 476,347.10
DF-106	Protein A Product Polishing Filter	$ 160,759.24
V-103	Diafilter Holding Tank	$ 130,125.02
F-101	Diafilter	$ 1,386,174.68
V-105	Virus Inactivation Process Vessel	$ 46,985.07
DF-107	Polishing Filter	$ 160,759.24
C-102	IEX Chromatography Column	$ 1,179,236.52
V-106	IEX Chromatography Product Tank	$ 242,209.58
C-103	HIC Chromatography Column	$ 278,063.80
DF-108	HIC Chromatography Product Filter	$ 160,759.24
V-107	HIC Chromatography Product Holding Tank	$ 58,314.93
DF-109	Viral Exclusion Filtration	$ 160,759.24
V-108	Viral Exclusion Product Storage	$ 58,314.93
F-102	Diafilter	$ 601,224.01
DF-110	Final Polishing	$ 160,759.24
CIP-101	Clean-in-place skid 1	$ 151,482.35
CIP-102	Clean-in-place skid 2	$ 150,928.18
CIP-103	Clean-in-place skid 3	$ 164,304.73
CIP-104	Clean-in-place skid 4	$ 118,589.85
CIP-105	Clean-in-place skid 5	$ 151,696.70
CIP-106	Clean-in-place skid 6	$ 118,788.13
CIP-107	Clean-in-place skid 7	$ 73,287.76
Kill Tank	Waste Treatment Tank	$ 1,082,000.00
Total Cost		$ 24,617,911.82

FIXED CAPITAL INVESTMENT SUMMARY

The total fixed capital investment of this project equates to $85.7 million after accounting for all equipment costs, building permits, contingencies and fees. A summary of the total fixed capital investment is shown in Figure 8.

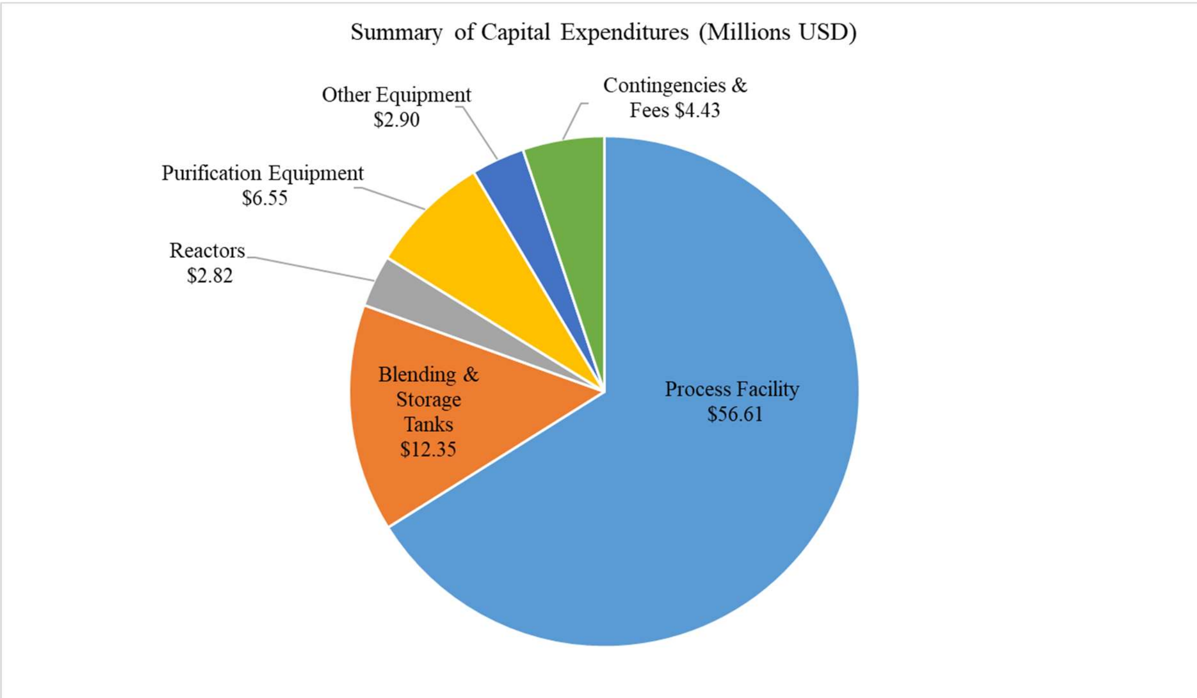

Figure 8 Capital Investment Summary

SAFETY, HEALTH, AND ENVIRONMENTAL CONSIDERATIONS

One major safety consideration is that safety goggles/appropriate eye protection, gloves, and lab coats must be worn in the media prep area at all times because the Fed-batch medium, as well as the other chemicals used in this area, are an eye, skin, and respiratory irritants. There are various other chemicals throughout the facility that are also the eye, skin, and respiratory irritants and pose other health and safety hazards that will be discussed in the Process Safety Considerations section. As a result, protective eyewear, clothing, and gloves should be worn throughout the entire facility. Steam is used throughout this facility which can cause burns if not handled carefully. Operators should also wear steel-toed boots in the manufacturing facility due to the amount of large-scale equipment that is present, and this facility contains mechanical hazards that would require long hair to be pulled back. Operators should follow proper protocol when handling the steam and steam lines to avoid getting burned. OSHA confined space procedures will also need to be followed anytime someone would need to enter one of the process vessels. This would only be necessary if the vessels needed to be repaired. Development of these procedures will need to be finalized in the detailed design stage.

Since the MAb is being produced from CHO cells, which are of animal origin, the cell cultures and product should be handled as potential biohazards [54]. This means that appropriate protective clothing should always be worn in the facility and direct handling of the cells products and cultures should be reduced to a minimum [54]. Our process was designed with the minimum amount of handling of the cells and product as possible. Once the cell culture enters the first seed bioreactor, the biohazards are no longer being directly handled by people. Moreover, the only places that the CHO and transfected cells are being handled are in the media prep area and the early stages of the Seed Train.

In order to meet FDA and EMA regulations, all hair should be covered with hair nets in order to prevent any contaminants from infiltrating the final product. For selling our product in Europe, EMA guidelines state that RO cannot be used for our WFI [55]. As a result, we had to implement a distillation system to purify the WFI for our process. FDA and EMA regulations were considered throughout our design to ensure that the final product is safe for customer consumption. An example of this is the need to clean all equipment thoroughly between batches. In order to meet this regulation and GMP, we utilized CIP and SIP technology in our facility as well as disposable technology in the smaller scale processes. Filters are implemented throughout our process to guarantee sterility and ensure that no impurities affect our product. Virus inactivation is one of the most important safety steps of our process that also helps our facility meet regulations, as it is what safeguards our final product against any viruses that could be transferred from the mammalian cells to humans.

Several environment factors were considered when designing our facility. The first factor was that most of the waste from our process cannot go down the drain as is. If it did, it would violate EPA regulations. As a result, we had to design kill tanks that would neutralize any waste that would need to enter the sewer. The Fed-Batch Medium also cannot go down drains that expose it to the environment as specified by its SDS [21]. Thus, in the case that the medium is spilled and needs to be cleaned up it will need to be stored until it can be transported to a waste management facility. Another environmental factor we considered was the use of disposables. Disposable technology is not only more cost effective but is also more environmentally friendly compared with the SIP and CIP methods. This is so because SIP and CIP result in very high utility costs that negatively affect the environment [56]. Some of the benefits of using cleaning technology that is entirely based on disposables include "significant reductions in water usage (87%), space (38%), and energy (30%) to operate such a facility and results in a substantial decrease in carbon footprint" [57]. As a result, we chose to use disposables as much as possible in our design. However, due to how large the vessels become in the late stages of the Seed Train and beyond it is not feasible to use disposables for those parts of the process especially because using disposables for anything larger than 2,000 L is not GMP [23]. Moreover, it might be beneficial to explore if there are new large-scale disposable technologies that follow GMP because they are so cost effective and better for the environment.

PROCESS SAFETY CONSIDERATIONS

The safety of people, the environment, and the process equipment is imperative in this process design. The health and safety of the employees in the biopharmaceutical facility are held paramount. Compliance with the Occupational Safety and Health Administration's (OSHA) Process Safety Management (PSM) is mandatory for this processing facility. According to the OSHA Process Safety Management Guidelines, PSM is "the proactive identification, evaluation and mitigation or prevention of chemical releases that could occur as a result of failures in processes, procedures, or equipment." [58]. In order to maintain compliance with PSM, the company must identify, control, and mitigate hazards, train employees how to safely operate equipment, be mindful of abnormalities, and handle emergencies. A Process Hazard Analysis (PHA), which is the heart of PSM, has been completed to identify and mitigate all hazards associated with the production of monoclonal antibodies. The main hazards that have been identified are biohazards and chemical hazards.

Inherently Safer Design

An inherently safer design is one that follows the philosophy of avoiding, eliminating, or reducing hazards instead of focusing on controlling the hazards. For our design, we utilized the inherent safety concept of simplification which is intended to minimize unnecessary complexity to reduce the opportunity for error or incorrect usage. We used this concept to address five inherent hazards in our process which is summarized in the table below (Table 9).

Table 10 Inherently Safer Design Considerations Summary

Hazard	Inherent Safety Concept	Incorporated into Design
Cleaning buffer storage tanks	Simplification	Each buffer needed in the process has its own mixing and storage tanks. This keeps operators from being exposed to the risky activity of interacting with the hazardous chemical and also reduces the risk of cross-contamination.
Handling of buffer solutions	Simplification	Each buffer has its own mixing tank and holding tank. This allows for fewer touches of the chemical.
Biohazard Exposure	Simplification	Risk of handling the biohazard is minimized as it is only directly being handled in the early stages of the process. The rest of the process uses pipes and pumps to move the cell broth to the next stages of the process.
Incompatible Chemicals	Simplification	Incompatible chemicals are not stored together nor do they come in contact with one another in our process.
Neutralization of kill tank contents	Simplification	Utilize a composition controller to measure the pH of kill tank and automatically add hydrochloric acid.

Hazards Identification and Risk Analysis

A detailed exploration of the hazards present in the design as well as thorough risk analysis of these hazards was conducted in the subsequent sections. These safety measures were considered in order to ensure that this process can be implemented in a safe manner and that there are no hazards that would prevent the progression of this endeavor.

Hazard Identification Summary

Material Properties

A summary of the potential hazards of the chemicals used in the out process can be seen in the following table (Table 11). The hazards outlined were taken from the Safety Data Sheet (SDS) information provided by the CAMEO Chemicals website as well as other online SDS sources for a select few chemicals.

Table 11 Hazard Summary

Material/Chemical	Hazards Found in SDS
Ex-Cell Advanced CHO Fed-batch medium	• Eye irritant • Hazardous decomposition products formed under fire conditions • Incompatible with strong oxidizing agents • Product cannot enter drains exposing it to the environment
Ex-Cell Advanced CHO Feed 1 with glucose	None
Acetic Acid Solution >10% but no more than 80% acid	• Toxic via touch, inhalation, and ingestion • Combustible
Carbon Dioxide	• Containers may explode when heated • High concentrations inhaled can cause death • Reactive
EDTA, Tri-sodium Salt	• Eye, skin, and respiratory irritant • Toxic if ingested • Toxic fumes produced when heated to decomposition • Dust explosion hazard
Potassium Chloride	• Toxic in large doses
Sodium Phosphate, Dibasic	• Eye, skin, and respiratory irritant • Corrosive towards metals
Nitrogen	• Vapors can cause dizziness or asphyxiation
Oxygen	• Strong oxidizing agent • Increases intensity of fire • Inhalation can cause serious health problems
Phosphoric Acid	• Decomposition upon heating produces corrosive and/or toxic fumes • Very toxic if ingested • Can burn eyes and skin • Reactive – weak acid
Polysorbate 80	• Probably combustible • Eye, skin, and respiratory irritant • When heated to decomposition it emits acrid smoke and fumes
Sodium Chloride	• Eye irritant • Releases toxic fumes when heated to decomposition
Sodium Hydroxide Solution	• Causes severe burns of eyes, skin, and mucous membranes • Fire hazard - can produce corrosive and/or toxic fumes • Highly reactive
Water	None
Hydrochloric Acid Solution	• Reactive – catalytic activity • Toxic vapors when heated • Vapor is a respiratory irritant • Liquid causes burns • Highly reactive
Zinc Sulfate	• Eye, skin, and respiratory irritant

Glucose (Dextrose Solution)	None
Ferrous Sulfate	• Can be toxic if ingested in large quantities
Ferric Ammonium Citrate	• Toxic oxides of nitrogen or ammonia gas may be formed in fires • Eye, respiratory, mouth, and stomach irritant
Ammonium Sulfate	• Reactive – Acidic salt
Tri-n-butyl Phosphate (TNBP)	• Toxic fumes if combusted • Can cause stimulation of central nervous system • Incompatible with strong oxidizing agents and strong bases
Acenaphthene	• Combustible • Skin, eye, and respiratory irritant • Health hazard if ingested • Reactive
TRIS Base	• Skin, eye, and respiratory irritant
TRIS HCL	• May be combustible at high temperatures • Skin, eye, and respiratory irritant
Sodium Di-H Phosphate	• Skin, eye, and respiratory irritant
Sodium Citrate	• Skin, eye, and respiratory irritant • May form combustible dust concentrations in air • Reactive with strong acids, strong bases, and oxidizing agents

Initial Interaction Matrix

When evaluating the reactivity hazards of all chemicals used in our facility, we consulted the CAMEO Chemicals website mentioned above to create the reactivity matrix shown below. This matrix includes every chemical found in any step of this manufacturing production process, even if they are highly unlikely to interact, especially in large quantities or concentrations. Several chemicals found within the process could not be found on the CAMEO Chemicals website. Three such substances are TRIS Base, TRIS HCL, and Sodium Di-H Phosphate. Upon consulting their Safety Data Sheets it was found that none of these chemicals are reactive and thus are not a concern in our matrix. However, sodium citrate could not be found on CAMEO Chemicals and is reactive with strong acids, strong bases, and oxidizing agents.

Figure 9 Chemical Reactivity Matrix

WATER

ACETIC ACID, SOLUTION, MORE THAN 10% BUT NOT MORE THAN 80% ACID | Compatible | ACETIC ACID, SOLUTION, MORE THAN 10% BUT NOT MORE THAN 80% ACID

CARBON DIOXIDE | Caution Corrosive Generates heat | Caution Corrosive Generates heat | CARBON DIOXIDE

Incompatible Corrosive Flammable Generates gas Generates heat | Incompatible Corrosive Flammable Generates gas Generates heat | Caution Generates heat

ETHYLENEDIAMINE TETRAACETIC ACID, TRISODIUM SALT | ETHYLENEDIAMINE TETRAACETIC ACID, TRISODIUM SALT

Intense or explosive reacti on | Intense or explosive reac tion Toxic | Caution Explosive

POTASSIUM CHLORIDE | Compatible | Compatible | Compatible | Flammable Intense or explosive react ion | POTASSIUM CHLORIDE

SODIUM PHOSPHATE, DIBASIC | Incompatible Flammable Generates gas Generates heat | Incompatible Flammable Generates gas Generates heat | Caution Generates heat | Compatible | Caution Flammable Intense or explosive reacti on | SODIUM PHOSPHATE, DIBASIC

Intense or explosive reacti on | Intense or explosive reac tion

NITROGEN | Compatible Incompatible Corrosive Generates gas Generates heat | Compatible Incompatible Corrosive Explosive Flammable | Compatible | Compatible Incompatible Explosive Flammable Generates gas | Compatible Incompatible Generates heat Intense or explosive reacti | Compatible Incompatible Explosive Generates gas Generates heat | NITROGEN

OXYGEN | Toxic | Generates gas Generates heat Intense or explosive reac Toxic | Compatible | Generates heat Intense or explosive react ion Toxic | Toxic | Compatible OXYGEN

PHOSPHORIC ACID | Caution Corrosive Generates heat | Caution Corrosive Generates heat | Compatible | Caution Generates heat | Compatible | Caution Generates heat | Compatible | Compatible Incompatible | PHOSPHORIC ACID

POLYSORBATE 80 | Compatible | Compatible | Compatible | Compatible | Compatible | Compatible | Compatible | Explosive Flammable Generates gas Generates heat Intense or explosive reacti Toxic | Compatible | POLYSORBATE 80

SODIUM HYDROXIDE SOLUTION | Caution Corrosive Generates gas Generates heat Toxic | Incompatible Corrosive Flammable Generates gas Generates heat Intense or explosive reac Toxic | Incompatible Corrosive Generates heat | Incompatible Corrosive Flammable Generates gas Generates heat Intense or explosive react | Compatible | Incompatible Flammable Generates gas Generates heat Intense or explosive reacti on | Compatible | Incompatible Corrosive Flammable Generates gas Generates heat Intense or explosive reacti on Toxic | Incompatib Corrosive Generates h | Compatible | SODIUM HYDROXIDE SOLUTION

SODIUM CHLORIDE | Compatible | Compatible | Compatible | Caution Explosive Flammable Intense or explosive react | Compatible | Caution Flammable Intense or explosive reacti | Compatible | Incompatible Generates heat Intense or explosive reacti | Compatible | Compatible | Compatible | SODIUM CHLORIDE

FERROUS SULFATE | Incompatible Corrosive Flammable Generates gas Generates heat Toxic | Incompatible Corrosive Flammable Generates gas Generates heat Toxic | Compatible | Compatible | Incompatible Generates gas Generates heat Toxic | Compatible | Compatible | Incompatible Explosive Flammable Generates gas Intense or explosive reacti Toxic | Compatible | Caution Explosive | Incompatible Corrosive Flammable Generates gas Generates heat Toxic | Incompatible Generates gas Generates heat Toxic | FERROUS SULFATE

FERRIC AMMONIUM CITRATE | Caution Corrosive Generates gas Generates heat | Caution Corrosive Generates gas Generates heat | Compatible | Incompatible Generates heat | Compatible | Incompatible Generates heat | Compatible | Incompatible Explosive Generates gas Intense or explosive reacti | Compatible | Incompatible Generates heat Intense or explosive react ion | Incompatible Corrosive Generates gas Generates heat | Compatible | Compatible | FERRIC AMMONIUM CITRATE

ZINC SULFATE | Caution Corrosive Generates gas Generates heat | Caution Corrosive Generates gas Generates heat | Compatible | Incompatible Generates heat | Compatible | Incompatible Generates heat | Compatible | Incompatible Explosive Generates gas Intense or explosive reacti | Compatible | Incompatible Generates heat Intense or explosive react ion | Incompatible Corrosive Generates gas Generates heat | Compatible | Compatible | Compatible ZINC SULFATE

DEXTROSE SOLUTION | Compatible | Caution Flammable Generates gas Generates heat Intense or explosive reac tion | Caution Corrosive Generates heat | Incompatible Corrosive Flammable Generates gas Generates heat Intense or explosive react | Compatible | Incompatible Corrosive Flammable Generates gas Generates heat Intense or explosive reacti on | Compatible | Incompatible Corrosive Explosive Flammable Generates gas Generates heat Intense or explosive reacti Toxic | Caution Corrosive Generates h | Compatible | Incompatible Corrosive Flammable Generates gas Generates heat Toxic | Compatible | Incompatible Corrosive Flammable Generates gas Generates heat Intense or explosive reacti Toxic | Caution Corrosive Generates ga Generates he | Caution Corrosive Generates ga Generates he | DEXTROSE SOLUTION

Caution Corrosive | Incompatible Corrosive | Caution Corrosive | Incompatible Corrosive | Incompatible Generates gas | Incompatible Flammable | Incompatible Corrosive | Caution Corrosive | Incompatible Explosive | Incompatible Corrosive | Incompatible Generates gas | Incompatible Corrosive | Caution Corrosive | Caution Corrosive | Caution Corrosive

HYDROCHLORIC ACID, SOLUTION	Generates gas Generates heat	Flammable Generates gas Generates heat Toxic	Generates heat	Flammable Generates gas Generates heat Intense or explosive react Toxic	Generates heat Generates gas Explosive Intense or explosive reacti on	Generates h Flammable Generates heat Intense or explosive reacti on	Generates gas Generates heat **Compatible**	Flammable Generates ga Flammable Generates gas Generates heat Intense or explosive reacti	Generates ga Generates	Generates gas Generates heat	Generates heat Intense or explosive reacti on Toxic	Intense or explosive reac tion	Generates gas Generates heat Toxic	Generates he at	Generates he at	Generates heat				HYDROCHLORIC ACID, SOLUTION
AMMONIUM SULFATE	**Caution** Corrosive Generates gas Generates heat	**Caution** Corrosive Generates gas Generates heat	**Compatible**	**Incompatible** Generates heat	**Compatible**	**Incompatible** Generates heat	**Compatible**	**Incompatible** Explosive Generates gas Intense or explosive reacti	**Compatible**	**Incompatible** Generates heat Intense or explosive react ion	**Incompatible** Corrosive Generates gas Generates heat	**Compatible**	**Compatible**	**Compatible**	**Compatible**	**Caution** Corrosive Generates gas Generates	**Caution** Corrosive Generates gas Generates heat			AMMONIUM SULFATE
TRIBUTYL PHOSPHATE	**Caution** Corrosive Generates gas	**Caution** Corrosive Generates gas	**Compatible**	**Caution** Flammable Generates heat	**Caution**	**Caution** Generates heat	**Compatible**	**Incompatible** Flammable Generates gas Generates heat Intense or explosive reacti Toxic	**Compatible**	**Compatible**	**Incompatible** Corrosive Flammable Generates gas Generates heat	**Caution**	**Incompatible** Flammable Generates gas Generates heat	**Compatible**	**Compatible**	**Caution** Corrosive Generates	**Incompatible** Corrosive Flammable Generates gas Generates heat Intense or explosive react ion	**Compat ible**		TRIBUTYL PHOSPHATE
ACENAPHTHENE	**Compatible**	**Compatible**	**Compatible**	**Compatible**	**Compatible**	**Compatible**	**Compatible**	**Incompatible** Explosive Generates gas Generates heat Intense or explosive reacti Toxic	**Compatible**	**Compatible**	**Compatible**	**Compatible**	**Compatible**	**Compatible**	**Compatible**	**Compatibl e**	**Compatible**	**Compat ible**	**Compatibl e**	

Inventory Estimates

Considering how much material is used in a year, inventory estimates are based on the assumption that the facility will receive monthly shipments and will only need to store a month's worth of material.

Table 12 Inventory Summary

Material	Amount in Inventory (kg)
Acetic Acid	39.83
Ammonium Sulfate	32,614.83
H3PO4 (5%)	5,396,149.07
Fed-Batch Medium	1,222.00
Feed 1 Medium	4,498.75
HCL	20,000
HIC-Elute Buffer	71,502.33
HIC-Equil Buffer	29,577.58
HIC-Wash Buffer	73,943.92
IEX-Elute Buffer	43,861.17
IEX-Equil Buffer	155,638.75
IEX-Wash Buffer	778,968.75
NaOH (.1 M)	5,840.83
NaOH (.5M)	3,185,732.67
NaOH (1M)	47,962.83
NaCl (1M)	479,007.67
PBS	38,236.50
Polysorbate 80	2.25
Protein A Equilibrium	53,993.42
Protein A Regeneration Buffer	31,609.75
Protein A Wash Buffer	63,219.50
Protein A Elute Buffer	52,945.00

Process Technology, Equipment, and Operating Conditions

There are several equipment hazards associated with several units in the process. They have been identified and are listed below.

Table 13 Equipment Hazards

Technology/Equipment/Conditions	Hazard(s)
Tanks and impellers	• Overfilling resulting in loss of containment • Mechanical hazard
Storage Facility	• Forklift traffic • Low temperatures
Pumps	• Cavitation • Mechanical hazard
Chromatography columns	• Seal failures resulting in loss of containment • Overfilling resulting in loss of containment
Pipes and lines	• Seal failures resulting in loss of containment
Reactors	• Mechanical hazard

Potential Consequence Summary

The potential consequence summary was developed and evaluated with the understanding that most of the hazards presented in this process are low risk. They are low risk because the hazards are either present in low quantities, which reduces chances of exposure, or they have low consequences in general. For example, if bio-hazard exposure were to occur, the worst that could happen if someone is exposed to a new virus that could lead to death. However, the probability of that occurring is very low. Nevertheless, precautions should still be taken to avoid bio-hazard exposure. Acid and base exposure run the greatest risk of violating environmental compliance if they are exposed to the environment. This would only happen if the kill tanks were not working as designed. Loss of life is low as these chemicals are present in small amounts. The steam used in this process has little risk of having major consequences because it is not highly pressurized. The worst that could happen is exposure to the steam that could result in very bad burns only if the steam system were to break.

Table 14 Consequence Summary

Potential Consequence Summary						
Hazard	**Equipment Damage**	**Environmental Compliance**	**Loss of Life**	**Disruption of Other Business Units**	**Legal/PR**	**Community Impact**
Bio-Hazard Exposure	None	None	Low	Low	Medium	Low
Acid Exposure	Low	Medium	Low	Low	Low	Low
Base Exposure	Low	Medium	Low	Low	Low	Low
High Temperature Steam	None	None	Low	Low	Low	None

Existing Safeguards "As-Designed"

We designed this process with several pre-identified safeguards. First of all, we used stainless steel for every process unit for sanitary reasons and to avoid corrosion and reactivity with chemicals. Our process facility has been designed with a fire protection system in the form of water and foam flame depressants. The facility is more than adequately sized and incorporates minimum or better than equipment spacing. A control dike will be built around the kill tank and proper personal protection equipment is required for all personnel. Additionally, the process will have alarms to alert operators and management that are associated with the regulatory control system, the design of which will be completed in the detailed design phase.

Additional Safeguard Evaluations and/or Requirements

Based on our process safety analysis, the potential loss of containment of chemicals could require additional safety assessment.

Table 15 Additional Safeguard Evaluation

Safeguard		
Hazard	**Evaluation**	**Requirement**
Loss of containment	Negative consequences to people and equipment exposed to spilled chemicals	Detailed standard operating procedure and cleanup process for each chemical spill

Safety Assessment Summary

After this intensive safety summary, we have determined that the potential for project termination due to safety concerns is very little to none. The major concerns that require significant attention are biohazard and chemical releases. Our facility will draft a specific risk management plan upon entering the detailed design phase. Overall, this is a generally safe manufacturing process and a very safe design.

Siting and Layout of Processes and Equipment

Our manufacturing facility is set to be located on a large piece of land adjacent to a research and development facility. The physical building will be 500,000 square feet, which allows us to place each process vessel with more than the required amount of space between them, plus room for product and parts storage. Extra space is reserved for additional lines or units that may be added in coming years. The building has a flat concrete floor, and the exact layout of vessels within the building will be determined in the detailed design phase.

OTHER IMPORTANT CONSIDERATIONS

Process Control

Another significant consideration for this design would be the addition of process controls. One very important process control that we discussed implementing in our design is the addition of a pH composition control loop on the kill tank. This control loop would allow the process to read the real-time pH of the waste. It would also allow for the controls to determine what flow of dilute hydrochloric acid would be required to neutralize the waste for proper disposal. The automation of the kill tanks would result in a more efficient process as it would not require technicians to manually read the pH and add the acid until they get a neutral pH reading. In addition to increasing efficiency, a pH control loop would also be inherently safer as it requires there to be less interaction with the hazardous chemicals that are present in the waste as well as with the hydrochloric acid. Other necessary controls that would need to be present in this process would include level controllers and alarms on all bioreactors, columns, and blending tanks, and temperature controllers and alarms on all bioreactors. A more detailed analysis of necessary controls would need to be explored further in the detailed design stage of the facility and the layout determined on a process and instrumentation diagram.

MANUFACTURING AND OPERATING COSTS

Utility Costs

In order to determine the facility's annual utility costs, the amount of electricity used by the process and auxiliary systems within the process plant must be calculated. In order to find the amount of electricity used by the production processes, the appropriate solution temperatures and process scheduling times were programmed into the SuperPro software. A report was provided with the amount of electricity, in kW-h, used by the process per batch. That number was then multiplied by the number of batches and the electricity cost of $0.05/kW-h to find the electrical cost per year. On top of the production processes, the cost of electricity used by the HVAC system and lighting must be accounted for. Per the brochure provided by Trane, the HVAC units are each rated at 114.8 kW [15]. The total electrical cost assumes 24-hour operation of the facility year-round. The lighting purchased for the facility is rated at 250-W per light, also assuming 24-hour operation of the facility year-round. The final major system using electricity is the final product cold storage room. This room must be maintained at -20℃ to ensure a prolonged storage life of the final product. The cold storage unit is powered by a 100-horsepower motor which equates to an electrical draw of 74.7 kW. This value was then used to calculate the electrical cost per year, assuming 24-hour, year-round operation of the storage unit. Electricity will be the most expensive utility in the process, estimated at just over $840 Thousand for one full year of operation. A summary of electrical usage in our facility can be seen in Figure 10.

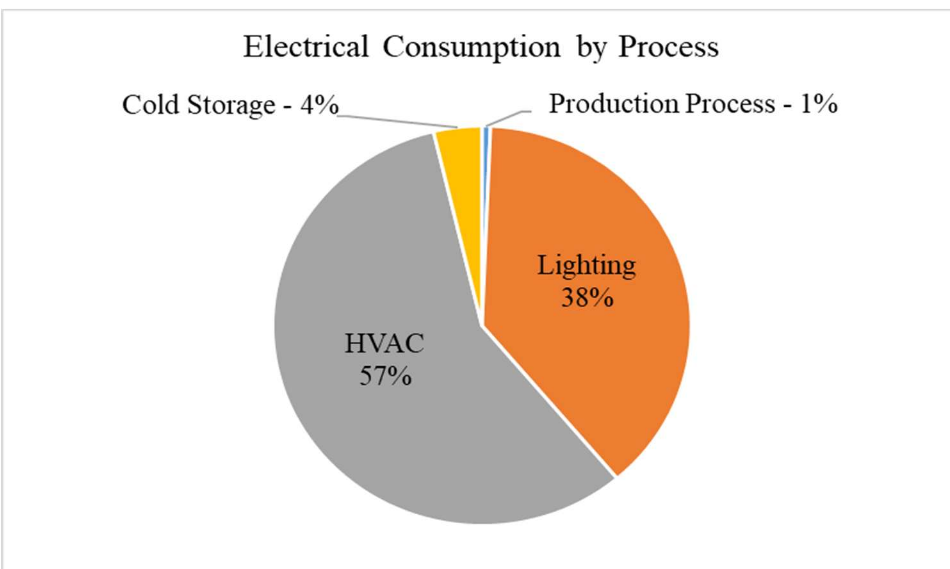

Figure 10 Electrical Consumption

As shown in the figure above, lighting and HVAC contribute to the majority of electrical consumption within our production facility. Another important utility used in the production process is water. Water is the major component in almost all of the solutions throughout the process and is also used to make water for injection. As aforementioned, WFI is used throughout the system and is produced using our in-house WFI system instead of purchasing it as a utility. A summary of the calculation of yearly utility costs can be found in Table 16.

Table 16 Utility Summary

Utility Usage Per Full Operating Year		
Utility	Amount	Price
Electricity (kWh)	16,857,175	$ 842,859
Steam (MT)	386	$ 4,632
Chilled Water (MT)	38,083	$ 20,679
Total Utilities	$ 868,170.01	

Raw Materials

There are significant volumes of raw materials and chemicals used in the production of monoclonal antibodies. The high volume of chemicals can in part be attributed to the rigorous cleaning operations that are implemented for each process vessel. Other raw materials such as chromatography buffers are used in large amounts in the purification process. A significant portion of our raw materials purchase cost is the cell media. A density was necessary to calculate the media purchase cost per year, but a density was not given in the purchase information. We assumed that both of our chosen media would have a density similar to another common "cell food", powdered sugar. Therefore, a density of 0.8 kg/L was assumed to calculate the purchase cost per year. A summary of each raw material can be seen in Table 17.

Table 17 Raw Materials Summary

Raw Materials of	Price ($/L)	Amount (L)	Cost ($)	
CD Fed Batch Medium (Seed Train)	61.82	18330	$	1,133,161
CD Feed 1 w/glucose Medium (Bioreactor)	104.1	67481.25	$	7,024,798
H3PO4	1.05	743365	$	780,533
NaOH (.1M)	0.41	357958	$	146,763
NaOH (.5M)	0.42	6936641	$	2,913,389
Polysorbate 80	46	34	$	1,564
Protein A Equil	1.98	647921	$	1,282,884
Protein A Regen	1.11	379317	$	421,042
Protein A Wash	1.09	758634	$	826,911
Protein A Elut	1.05	635340	$	667,107
WFI	0.000543	11796344	$	6,405
Acetic Acid	9.88	448	$	4,426
Ammonium Sulfate	70.6	391378	$	27,631,287
HIC EI	1.24	858028	$	1,063,955
HIC EQUIL	1.9	354931	$	674,369
HIC Wash	1.5	887327	$	1,330,991
IEX EI	1.88	526334	$	989,508
IEX EquiL	1.07	1867665	$	1,998,402
IEX Wash	1.1	9347625	$	10,282,388
NaCl (1M)	0.29	5748092	$	1,666,947
NaOH (1M)	0.81	287868	$	233,173
PBS	1.06	458838	$	486,368
HCl for Kill Tank	12	20000	$	240,000
	Total Raw Material Cost		$	61,806,369

Another large portion of the yearly cost is the price of consumables used throughout the production process. Disposable items are used throughout the process where cleaning reusable items would be impractical. Areas such as the beginning of the process where the cell division takes place in small containers, using disposables are much more practical than cleaning large amounts of small flasks and bottles. Filter cartridges are a one-time use item and must be replaced after every batch. Chromatography column resins are expensive and can only be used for a limited number of batches before replacement is required. Our selected chromatography resins can each be used between 40 and 100 cycles before a replacement is necessary. To be conservative, we budgeted for purchasing new resins for each column once per year. A summary of the consumables used throughout a year of operation can be found in Table 18.

Table 12 Consumables Summary

Disposables	Price	Amount/Batch	Number of Batches in a year	Total Cost per year
T-Flasks	$ 3.31	54	21	$ 3,753.54
Roller Bottles	$ 11.94	23	21	$ 5,767.02
RBS-1 Bags	$ 141.47	4	21	$ 11,883.48
RBS-2 Bags	$ 281.61	8	21	$ 47,310.48
DEF-1 Cartridge	$ 1,000.00	1	21	$ 21,000.00
DEF-2 Cartridge	$ 1,000.00	4	21	$ 84,000.00
DEF-3 Cartridge	$ 1,000.00	13	21	$ 273,000.00
DEF-4 Cartridge	$ 1,000.00	1	21	$ 21,000.00
DEF-6 Cartridge	$ 1,000.00	3	21	$ 63,000.00
PBA Resin	$ 16,802.00	1449.93	1	$ 24,361,723.86
DEF-7 Cartridge	$ 1,000.00	1	21	$ 21,000.00
DIA-1 Membrane	$ 4,979.86	1	1	$ 4,979.86
DEF-8 Cartridge	$ 1,000.00	1	21	$ 21,000.00
IEX Resin	$ 6,700.00	6524.64	1	$ 43,715,088.00
HIC Resin	$ 5,300.00	587.22	1	$ 3,112,266.00
DEF-9 Cartridge	$ 1,000.00	4	21	$ 84,000.00
DEF-10 Cartridge	$ 1,000.00	1	21	$ 21,000.00
DIA-2 Membrane	$ 2,619.46	1	1	$ 2,619.46
DEF-11 Cartridge	$ 1,000.00	1	21	$ 21,000.00
Product Bags	$ 6.13	63	21	$ 8,109.99
Media Prep	$ 3,409.26	1	1	$ 3,409.26
			Total Consumable Costs	$ 71,906,910.95

Operating Costs

In addition to the utility costs, there are many other costs associated with the operation of the facility. The various operating costs associated with the processing facility are discussed below. In all of the following formulas CC_{OOOO} is the total cost of operating labor in a year and CC_{TTTT} is the total fixed capital investment for the production process and facility.

One of the most important costs associated with a production facility is the cost of operating labor. The number of operator positions required for a facility is calculated using the following equation:

$$NN_{OOOO} = (6.29 + 3.17PP^2 + 0.23NN_{nnnn})^{0.5} \qquad \text{(Equation 2)}$$

NN_{OOOO} is the number of operating positions required for the facility, P is the number of particulate solids processing steps, and NN_{nnnn} is the total amount of major equipment located within the facility. For processes containing more than two particulate solids processing steps, the middle term is omitted and one operator position per particulate solid step is added after the calculation [59]. Based off of this calculation, we will need to fill 21 positions for a total need of 95 operators for our facility. Due to the batch nature of this process, not all equipment will be operating simultaneously. Therefore, the number of operators given through this calculation is likely an overestimate and would not provide and accurate representation of yearly operating labor costs. For this reason, we decided to calculate the cost of labor based on the actual number of hours required to service the process.

Labor hours were calculated using the scheduling and process features within SuperPro Designer. The total labor hours required for the process is roughly 59,000 hours per year. Assuming a standard 2,000-hour work year per operator, our process will need to employ roughly 30 full-time operators. The final cost of labor hours for the production process itself and for the media prep process were calculated using rates of $19.96/hour and $14/hour, respectively.

There are also supplies necessary for day-to-day operations of the facility. Operating supplies include paper for office operations, protective clothing and any other supplies necessary to operate the facility. These costs are calculated with the following equation:

$$OOOOOOOOOOOOOOOOO\ SSSSOOOOSSOOOSS = 0.009CC_{TTTT} \quad \text{(Equation 3)}$$

Plant Overhead costs must also be accounted for in operating expenditures. Plant overhead covers the cost of payroll, accounting services, medical and safety services, cafeteria and recreational facilities, as well as employee benefits. Plant overhead is calculated using the following equation:

$$PPSSOOOOOO\ OOOOOOOOhOOOOee\ CCCCSSOOSS = 0.708CC_{OOOO} + 0.036CC_{TTTT} \quad \text{(Equation 4)}$$

In order to ensure the delivery of a quality product, a testing laboratory will need to be on site to inspect the final products. The costs associated with this quality control are calculated with the following equation:

$$LLOOLLCCOOOOOOCCOOLL\ CChOOOOOOOOOSS = 0.15CC_{OOOO} \quad \text{(Equation 5)}$$

Since MAb production is a mechanical process, there will be maintenance required throughout the year to maintain a safe and orderly operation of our equipment. The total maintenance cost per year can be calculated as follows:

$$MM0000000000000000MM00 = 0.06CC_{TTTT} \quad \text{(Equation 6)}$$

As with any business, there will be administrative costs associated with the management of the process. These costs are calculated using the equation below:

$$AAeeAA0000SS000000000CC00\ CCCCSS00SS = 0.177CC_{0000} + 0.009CC_{TTTT} \quad \text{(Equation 7)}$$

The last cost to consider is the cost associated with liability insurance to cover any potential incidents that may occur in the production process. The yearly insurance cost can be calculated using the following equation:

$$LL0000LL00SS0000LL\ II00SSSS000000MM00 = 0.032CC_{TTTT} \quad \text{(Equation 8)}$$

The estimated yearly operating costs for the life of the project are summarized in Table 19.

Table 19 Operating Costs Summary

Yearly Operating Costs (Thousands USD)									
Year	Labor	Utilities	Plant Overhead	Operating Supplies	Maintenance	Lab Charges	Administrative Costs	Liability Insurance	Waste Treatment and Disposal
2019	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2020	618	434	960	131	871	93	240	465	443
2021	1,260	886	1,959	267	1,778	189	490	948	903
2022	1,286	903	1,998	272	1,813	193	500	967	922
2023	1,311	921	2,038	277	1,850	197	510	986	940
2024	1,338	940	2,079	283	1,887	201	520	1,006	959
2025	1,364	959	2,121	289	1,924	205	530	1,026	978
2026	1,392	978	2,163	294	1,963	209	541	1,047	997
2027	1,419	997	2,206	300	2,002	213	552	1,068	1,017
2028	1,448	1,017	2,250	306	2,042	217	563	1,089	1,038
2029	1,477	1,038	2,295	312	2,083	222	574	1,111	1,059
2030	1,506	1,058	2,341	319	2,125	226	585	1,133	1,080
2031	1,536	1,079	2,388	325	2,167	230	597	1,156	1,101
2032	1,567	1,101	2,436	332	2,210	235	609	1,179	1,123
2033	1,598	1,123	2,485	338	2,255	240	621	1,203	1,146
2034	1,630	1,146	2,534	345	2,300	245	634	1,227	1,169
2035	1,663	1,168	2,585	352	2,346	249	646	1,251	1,192
2036	1,696	1,192	2,637	359	2,393	254	659	1,276	1,216
2037	1,730	1,216	2,689	366	2,441	260	672	1,302	1,240
2038	1,765	1,240	2,743	373	2,489	265	686	1,328	1,265
2039	1,800	1,265	2,798	381	2,539	270	700	1,354	1,290
2040	1,836	1,290	2,854	388	2,590	275	713	1,381	1,316
2041	1,873	1,316	2,911	396	2,642	281	728	1,409	1,342
2042	1,910	1,342	2,969	404	2,695	287	742	1,437	1,369
2043	1,949	1,369	3,029	412	2,748	292	757	1,466	1,397
2044	1,988	1,396	3,089	421	2,803	298	772	1,495	1,425
2045	2,027	1,424	3,151	429	2,859	304	788	1,525	1,453

ECONOMIC ANALYSIS

Determination of Minimum Rate of Return

The first step that must be taken in evaluating the economic viability of a project is the determination of the minimum rate of return that would be considered acceptable. Also known as the hurdle rate, this rate of return must be achieved by the projected cash flows of the project for the company further consider its implementation. The minimum rate of return is typically determined by using a rate of return that can be achieved by investing in another alternative that has similar risk associated with it. Many companies have proprietary ways of calculating minimum rates of returns for their projects. For the purposes of this project, the team evaluated the expected rate of return that could be achieved by investing in a broad range of pharmaceutical companies. This provides indirect exposure to the same types of risk associated with the project. The market factors that would influence the equity value of these companies are the same factors that would influence the economic viability of this project. Therefore, calculating the projected rate of return by investing in these companies provides an accurate minimum rate of return for the project. This expected rate of return was calculated using the Capital Asset Pricing Model (CAPM). The estimated return is calculated using the following equation:

$$E_{R_i} = R_f + \beta_i (E_{R_m} - R_f) \qquad \text{(Equation 9)}$$

The CAPM calculates the expected rate of return on an investment (E_{R_i}) given the risk-free rate (R_f), equity beta of the asset (β_i), and the expected return on the market (E_{R_m}). The risk-free rate of return is the rate of return associated with the United States Treasury Bills, currently at 2.45%. The equity beta used for this calculation is the average beta of 237 publicly traded pharmaceutical companies, currently, the average is 1.47. The expected return on the market is based on historical data. The historical rate of return of the stock market since its inception has averaged 8-12% per year. Due to the inherently higher risk of actively producing versus passively investing, 12% was used for the CAPM calculation. Based on this calculation, the minimum rate of return required to invest in this project is just over 16%.

Determination of Depreciation Method

Following the completion of the technical design of the process, the team conducted a thorough economic analysis to justify the feasibility and economic viability of the project. The project was evaluated with a proposed project life of 25 years, with the installation of equipment beginning in the third quarter of 2019 and process startup in the third quarter of 2020. Prior to the selection of a depreciation method, the team evaluated the potential benefit of applying a bonus depreciation method in accordance with IRS Tax Code Sections 179 and 168(g) as amended by the Tax Cuts and Jobs Act of December 2017. The amended sections permit an increased amount of applicable depreciation in the first year of the project life, up to 100% in some cases. After a thorough investigation, it was determined that the bonus depreciation guidelines do permit bonus depreciation on the equipment used in this process. However, the maximum Section 179 expense allowed in the first year would be $1,000,000. For this reason, the team decided to apply a standard depreciation method.

This project requires two separate depreciation schedules with two different asset class lives. In accordance with Internal Revenue Service guidelines for science and engineering equipment, the applied asset class life will be 10 years, while the class life of the building itself will be 40 years. The project assets will be depreciated using the MACRS accelerated depreciation method in accordance with United States GAAP. The depreciation will be applied according to the corresponding asset class life depreciation schedules. These depreciation schedules can be found in Appendix B.

Capital Cost Estimates

As previously stated, the process was designed using Intelligen Inc.'s SuperPro Designer Software. The software has a built-in cost model for all pieces of equipment. After using the Turton method and CEPCI to calculate some of the costs of our equipment we found that this built-in model was unreliable and was therefore not an accurate representation of our capital costs for the project. The rest of the equipment was then costed using the Turton method to provide accurate estimates of capital costs for the project. All equations utilized in this method can be found in Appendix A. Contingencies and fees of 15% and 3%, respectively, were added to the capital costs to account for any potential issues that could arise during construction or installation of equipment. A summary of the capital costs can be found in Figure 8 in the Fixed Capital Investment Summary section.

Revenue

The final product is the monoclonal antibodies frozen in a storage solution. The sales price of the product is based on the mass of monoclonal antibodies within the solution. Based on the calculations shown in Table 2 in the Design Basis section, the sales price of our product is $12 million per kilogram of monoclonal antibodies. This sales price represents a 3.2% premium over the most similar product, Enbrel. This premium is justified because our product is being produced in a new and more technologically advanced facility, which we believe will provide a superior product.

Date	2019	2020	2021	2022	2023	2024	2025
Mab Production (kg)	$ -	622	1307	1307	1307	1307	1307
Sale Price (MIL$/kg)	$ -	12.00	12.24	12.48	12.73	12.99	13.25
Sales Revenue ($)	$ -	7,468,394,400	15,997,300,805	16,317,246,821	16,643,591,757	16,976,463,592	17,315,992,864
Salvage Value	$ -	-	-	-	-	-	-
Royalties (- basis)	$ -	-	-	-	-	-	-
Net Revenue	$ -	7,468,394,400	15,997,300,805	16,317,246,821	16,643,591,757	16,976,463,592	17,315,992,864
Cost of Cells	$ -	(3,098)	(6,195)	(6,195)	(6,195)	(6,195)	(6,195)
Raw Materials Costs	$ -	(66,856,640)	(133,713,280)	(136,387,546)	(139,115,297)	(141,897,602)	(144,735,555)
Cost of Uitlities	$ -	(434,085)	(885,533)	(903,244)	(921,309)	(939,735)	(958,530)
Manufacturing Costs	$ -	(3,820,766)	(7,794,362)	(7,950,249)	(8,109,254)	(8,271,439)	(8,436,868)
Depreciation	$ -	(3,240,065)	(7,457,226)	(6,304,290)	(5,369,148)	(4,608,227)	(3,989,572)
Amortization	$ -	-	-	-	-	-	-
Depletion	$ -	-	-	-	-	-	-
Loss Forward	$ -	(85,656,077)	-	-	-	-	-
Writeoff	$ -	-	-	-	-	-	-
Taxable Income	$ -	7,308,386,767	15,847,450,404	16,165,701,492	16,490,076,749	16,820,746,589	17,157,872,340
Tax @ 21%	$ -	(1,534,761,221)	(3,327,964,585)	(3,394,797,313)	(3,462,916,117)	(3,532,356,784)	(3,603,153,191)
Net Income	$ -	5,773,625,546	12,519,485,819	12,770,904,179	13,027,160,632	13,288,389,805	13,554,719,149
Depreciation	$ -	3,240,065	7,457,226	6,304,290	5,369,148	4,608,227	3,989,572
Amortization	$ -	-	-	-	-	-	-
Depletion	$ -	-	-	-	-	-	-
Loss Forward	$ -	85,656,076.53	-	-	-	-	-
Writeoff	$ -	-	-	-	-	-	-
Working Capital	$ -	-	-	-	-	-	-
Fixed Capital	(85,656,077)	-	-	-	-	-	-
Cash Flow	$ (85,656,077)	5,862,521,688	12,526,943,045	12,777,208,469	13,032,529,780	13,292,998,032	13,558,708,720
Discounted Cash Flow (millions USD)	(86)	5,033	9,232	8,083	7,078	6,197	5,427
NPV @ ROR min	**$ 65,657,943,917**						
DCFROR	**5956.05%**						
Before-Tax ROR	16.49%						

2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
1307	1307	1307	1307	1307	1307	1307	1307	1307	1307	1307
13.25	13.51	13.78	14.06	14.34	14.63	14.92	15.22	15.52	15.83	16.15
17,315,992,864	17,662,312,722	18,015,558,976	18,375,870,156	18,743,387,559	19,118,255,310	19,500,620,416	19,890,632,824	20,288,445,481	20,694,214,390	21,108,098,678
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
17,315,992,864	17,662,312,722	18,015,558,976	18,375,870,156	18,743,387,559	19,118,255,310	19,500,620,416	19,890,632,824	20,288,445,481	20,694,214,390	21,108,098,678
(6,195)	(6,195)	(6,195)	(6,195)	(6,195)	(6,195)	(6,195)	(6,195)	(6,195)	(6,195)	(6,195)
(144,735,555)	(147,630,266)	(150,582,871)	(153,594,528)	(156,666,419)	(159,799,747)	(162,995,742)	(166,255,657)	(169,580,770)	(172,972,386)	(176,431,833)
(958,530)	(977,700)	(997,254)	(1,017,200)	(1,037,544)	(1,058,294)	(1,079,460)	(1,101,049)	(1,123,070)	(1,145,532)	(1,168,443)
(8,436,868)	(8,605,606)	(8,777,718)	(8,953,272)	(9,132,337)	(9,314,984)	(9,501,284)	(9,691,310)	(9,885,136)	(10,082,838)	(10,284,495)
(3,989,572)	(3,623,569)	(3,559,037)	(3,499,675)	(3,436,766)	(2,667,890)	(1,421,400)	(1,368,190)	(1,316,677)	(1,275,354)	(1,275,354)
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
17,157,872,340	17,501,475,581	17,851,642,096	18,208,805,481	18,573,114,492	18,945,414,394	19,325,622,529	19,712,216,618	20,106,539,827	20,508,738,280	20,918,938,553
(3,603,153,191)	(3,675,309,872)	(3,748,844,840)	(3,823,849,151)	(3,900,354,043)	(3,978,537,023)	(4,058,380,731)	(4,139,565,490)	(4,222,373,364)	(4,306,835,039)	(4,392,977,096)
13,554,719,149	13,826,165,709	14,102,797,255	14,384,956,330	14,672,760,449	14,966,877,372	15,267,241,798	15,572,651,129	15,884,166,463	16,201,903,241	16,525,961,457
3,989,572	3,623,569	3,559,037	3,499,675	3,436,766	2,667,890	1,421,400	1,368,190	1,316,677	1,275,354	1,275,354
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
13,558,708,720	13,829,789,278	14,106,356,293	14,388,456,005	14,676,197,215	14,969,545,261	15,268,663,198	15,574,019,318	15,885,483,141	16,203,178,596	16,527,236,811
5,427	4,752	4,161	3,643	3,190	2,793	2,446	2,142	1,875	1,642	1,438

2036	2037	2038	2039	2040	2041	2042	2043	2044	2045
1307	1307	1307	1307	1307	1307	1307	1307	1307	1307
16.47	16.80	17.14	17.48	17.83	18.19	18.55	18.92	19.30	19.69
21,530,260,652	21,960,865,865	22,400,083,182	22,848,084,846	23,305,046,543	23,771,147,474	24,246,570,423	24,731,501,832	25,226,131,868	25,730,654,506
-	-	-	-	-	-	-	-	-	18,490,091.07
-	-	-	-	-	-	-	-	-	-
21,530,260,652	21,960,865,865	22,400,083,182	22,848,084,846	23,305,046,543	23,771,147,474	24,246,570,423	24,731,501,832	25,226,131,868	25,749,144,597
(6,195)	(6,195)	(6,195)	(6,195)	(6,195)	(6,195)	(6,195)	(6,195)	(6,195)	(6,195)
(179,960,470)	(183,559,679)	(187,230,873)	(190,975,490)	(194,795,000)	(198,690,900)	(202,664,718)	(206,718,013)	(210,852,373)	(215,069,420)
(1,191,811)	(1,215,648)	(1,239,961)	(1,264,760)	(1,290,055)	(1,315,856)	(1,342,173)	(1,369,017)	(1,396,397)	(1,424,325)
(10,490,185)	(10,699,989)	(10,913,989)	(11,132,268)	(11,354,914)	(11,582,012)	(11,813,652)	(12,049,925)	(12,290,924)	(12,536,742)
(1,275,354)	(1,275,354)	(1,275,354)	(1,275,354)	(1,275,354)	(1,275,354)	(1,275,354)	(1,275,354)	(1,275,354)	(1,275,354)
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
21,337,342,831	21,764,115,195	22,199,423,006	22,643,436,973	23,096,331,219	23,558,283,351	24,029,474,525	24,510,089,523	25,000,316,820	25,518,838,755
(4,480,841,995)	(4,570,464,191)	(4,661,878,831)	(4,755,121,764)	(4,850,229,556)	(4,947,239,504)	(5,046,189,650)	(5,147,118,800)	(5,250,066,532)	(5,358,956,138)
16,856,500,836	17,193,651,004	17,537,544,174	17,888,315,209	18,246,101,663	18,611,043,847	18,983,284,875	19,362,970,723	19,750,250,288	20,159,882,616
1,275,354	1,275,354	1,275,354	1,275,354	1,275,354	1,275,354	1,275,354	1,275,354	1,275,354	1,275,354
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
16,857,776,191	17,194,926,358	17,538,819,529	17,889,590,563	18,247,377,018	18,612,319,202	18,984,560,229	19,364,246,077	19,751,525,642	20,161,157,971
1,259	1,102	965	845	740	648	567	497	435	381

NPV and DCFROR Analyses

The two main metrics used to evaluate the economic viability of this project were the Net Present Value (NPV) and Discounted Cash Flow Rate of Return (DCFROR). The minimum internal rate of return used for these evaluations was 16.5%, based off of the Capital Asset Pricing Model discussed previously. The net present value of the projected cash flows was calculated and used to determine whether or not the project is economically attractive to the company. The discounted rate of return was also calculated to ensure it is higher than the hurdle rate of 16.5%. The net present value of $65.7 billion and the rate of return of 5956% make this project extremely economically attractive. Based on the high cash flows associated with the project, the payback period is very short. The capital costs will be recovered with the sales proceeds from the first batch of monoclonal antibodies. Assuming adequate sales at the end of the first batch the payback period will be equal to the first batch length of fifty-four days.

Sensitivity Analysis

In order to evaluate the effect of different factors on the net present value, we performed a sensitivity analysis of several variables. The four variables evaluated were the sales price of the product, the project life, the capital costs of the project and the operating costs of the facility. The parameters and results of this analysis can be seen in Table 21 and Figure 11 below.

Table 21 Sensitivity Analysis Paraments

Sensitivity Analysis Parameters		
Variable	Worst Case	Best Case
Capital Expenditures	+40%	-40%
Product Price	-20%	+20%
Project Life	-20%	+20%
Operating Costs	+20%	-20%

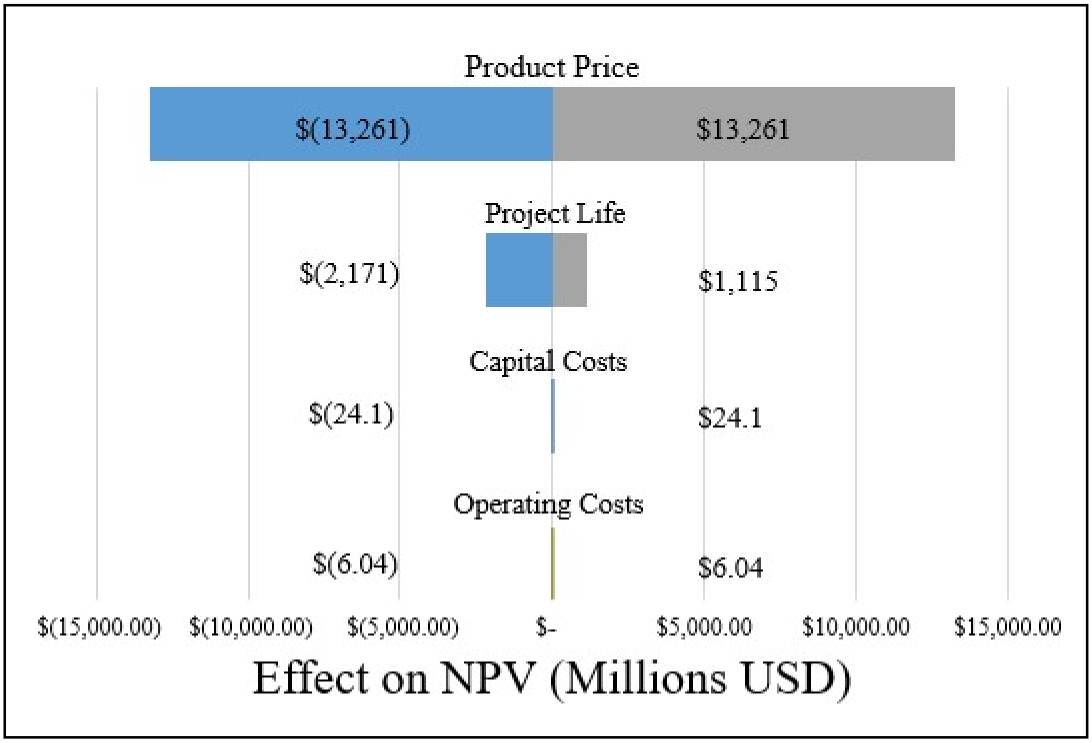

Figure 11 Sensitivity Analysis Tornado Chart

<u>Product Sales Price Analysis</u>

The first variable analyzed in the sensitivity analysis was the sales price of the product. This variable proves to have the biggest effect on the net present value. This was expected due to the nature of the project. The high sales price has a significant impact on the cash flows of the project and therefore a large effect on the net present value in the event that it is altered.

<u>Project Life Analysis</u>

The next variable investigated was the length of the project life. The length of the project was altered by adding five years as well as removing five years. The project is still very economically attractive with the loss of five years' worth of cash flows, therefore, any potential risk of early termination of the project is offset by the earlier cash flows in the project.

<u>Capital Costs Analysis</u>

Capital costs are an important metric to investigate while evaluating a project. The capital costs can have a large effect on the economic viability of a project. This metric was evaluated to account for any unforeseen events occurring during the construction and startup process. However, in this project, the capital costs being altered by as much as forty percent still have a negligible effect on the net present value of the project. This is due to the extremely high cash flows associated with pharmaceutical projects.

Operating Costs Analysis

The final metric evaluated was the yearly operating costs. This metric was evaluated to account for any potential repairs or events that may cause an increase in operating costs. This project has high operating costs associated with the specialized materials and equipment used in the process. Varying these costs could have had a large effect on the net present value, however, due to the high cash flows any changes in costs were easily offset by revenue proceeds. One specific situation that could affect the operating costs would be increasing the titers of raw Mab as seen in in Figure 12.

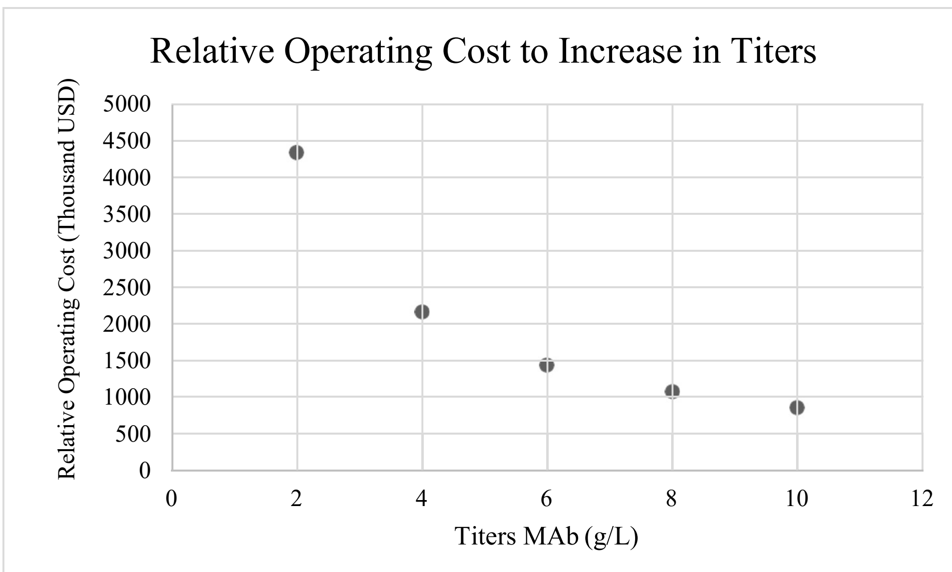

Figure 12 Relative Operating Cost to Increase in Titers

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on this design, CHO cells are utilized as a platform to produce monoclonal antibodies through a seed train and cell growth reactors and are then thoroughly purified. The recommended design is predicted to produce 1307 kilograms of monoclonal antibodies each year and meets its payback period within one production batch.

The aforementioned economic analysis reveals this proposed process to be extremely profitable. Even in the unlikely event of a 20% decrease in the product sales price, the process will maintain an attractive NPV at $52.5 Billion.

Recommendations

We highly recommend that this monoclonal antibody biopharmaceutical facility is constructed. We suggest that it be built in West Greenwich, Rhode Island adjacent to a research and development facility.

Further consideration should be taken for the produced waste in the kill tank. There are companies that can be contracted to take away and treat the biohazard/chemical waste. Such a service may be inherently safer than treating the waste on site. We also suggest that the option of collecting the biomass and selling it to biofuel producers be explored. This would require additional waste treatment and separation units but has the potential to be extremely profitable.

Another recommendation for the detailed design phase is to explore more disposable production units. Disposable units are more environmentally friendly, but there is currently limited knowledge for large-scale production with disposables. Thus, it is recommended that as disposable unit technology advances, this could form of cleaning in larger units could be explored to become a viable option.

This proposed design is a flexible manufacturing facility that has the ability to produce various monoclonal antibodies anywhere from 1-2 g/L and 5-10 g/L titers. This facility's flexible design allows for changes in technology and science to be quickly adapted to the facility in the future. In increase in titers would indicate that fewer batches would be needed to meet our product demand. At that point, the company could investigate contract manufacturing in this facility for added revenue.

Upon the conclusion of this report, it is the recommendation of the authors that this project moves from preliminary design to the detailed design phase.

ACKNOWLEDGEMENTS

The team would first and foremost like to acknowledge Intelligen, Inc. for the SuperPro Designer software utilized in the modeling and design of this process. Most calculations for capital and operating costs come from Richard Turton's book *Analysis, Synthesis, and Design of Chemical Processes.* The equipment costing, economic analysis, and summary tables were created and documented in Microsoft Excel. The process flow diagram was created in Microsoft Visio.

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APPENDIX

Appendix A: Capital Cost Equations

1) $CC_{nn} = CC^0_{nn} FF_{mm} FF_{nn}$

CC_{nn} = Actual purchased cost of equipment

CC^0_{nn} = “Vanilla” (Carbon steel and 50 psig) purchased cost

FF_{mm} = Material Cost factor

FF_{nn} = Pressure Cost factor

2) $SSCCOO_{10}\, CC^0_{nn} = KK_1 + KK_2\, SSCCOO_{10}\, AA + KK_3\, [SSCCOO_{10}\, AA]^2$

CC^0_{nn} = “Vanilla” (Carbon steel and 50 psig) purchased cost

KK_1, KK_2, KK_3 = Equipment sizing factors from Turton Appendix A

AA = “Capacity” of equipment being sized

3) $SSCCOO_{10} FF_{nn} = CC_1 + CC_2\, SSCCOO_{10} PP + CC_3 [SSCCOO_{10} PP]^2$

FF_{nn} = Pressure Cost factor

CC_1, CC_2, CC_3 = Equipment pressure rating factors

PP = Design pressure of equipment

4) $$FF_{mm} = \frac{\frac{(PP+1)DD}{2[850-0.6(PP+1)]} + 0.00315}{0.0063}$$

FF_{nn} = Pressure cost factor for a cylindrical process vessel

PP = Design pressure of the vessel

DD = Diameter of vessel

PP

5) $FF_{BBTT} = CC^{0}_{NN}(BB_1 + BB_2 FF_{TT} FF)$

FF_{BBTT} = Bare module cost factor (accounts for the material of construction, design pressure, and installation costs)

CC^0_{pp} = "Vanilla" (Carbon steel and 50 psig) purchased cost

BB_1, BB_2 = Bare module factors (accounts for installation costs)

FF_{TT} = Material Cost factor

FF_{PP} = Pressure Cost factor

6) $CC_{BBTT} = CC^0_{pp} FF_{BBTT}$

CC_{BBTT} = Bare module cost – Installed cost of specific equipment.

CC^0_{pp} = "Vanilla" (Carbon steel and 50 psig) purchased cost

FF_{BBTT} = Bare module cost factor – accounts for the material of construction, design pressure, and installation costs

7) $CCCCSS00\ 0000\ YY000000\ AA = CCCCSS00\ 0000\ YY000000\ BB\left[\frac{CCCCPPCCCC\ iinn\ YYYYYYYY\ AA}{CCCCPPCCCC\ iinn\ YYYYYYYY\ BB}\right]$

$CCEEPPCCII$ = Chemical engineering plant cost index (compares plant costs through time)

Appendix B: Depreciation Schedules

Table B-1: MACRS Equipment Depreciation Schedule

Table A-4. **3-, 5-, 7-, 10-, 15-, and 20-Year Property Mid-Quarter Convention Placed in Service in Third Quarter**

Year	Depreciation rate for recovery period					
	3-year	5-year	7-year	10-year	15-year	20-year
1	25.00%	15.00%	10.71%	7.50%	3.75%	2.813%
2	50.00	34.00	25.51	18.50	9.63	7.289
3	16.67	20.40	18.22	14.80	8.66	6.742
4	8.33	12.24	13.02	11.84	7.80	6.237
5		11.30	9.30	9.47	7.02	5.769
6		7.06	8.85	7.58	6.31	5.336
7			8.86	6.55	5.90	4.936
8			5.53	6.55	5.90	4.566
9				6.56	5.91	4.460
10				6.55	5.90	4.460
11				4.10	5.91	4.460
12					5.90	4.460
13					5.91	4.461
14					5.90	4.460
15					5.91	4.461
16					3.69	4.460
17						4.461
18						4.460
19						4.461
20						4.460
21						2.788

Table B-2: Process Facility Depreciation Schedule

Table A-14. *(Continued)*

Year	Recovery periods in years												
	18	19	20	22	24	25	26.5	28	30	35	40	45	50
1	4.17%	3.95%	3.750%	3.409%	3.125%	3.000%	2.830%	2.679%	2.500%	2.143%	1.875%	1.667%	1.500%
2	7.99	7.58	7.219	6.586	6.055	5.820	5.500	5.214	4.875	4.194	3.680	3.278	2.955
3	7.32	6.98	6.677	6.137	5.676	5.471	5.189	4.934	4.631	4.014	3.542	3.169	2.866
4	6.71	6.43	6.177	5.718	5.322	5.143	4.895	4.670	4.400	3.842	3.409	3.063	2.780
5	6.15	5.93	5.713	5.328	4.989	4.834	4.618	4.420	4.180	3.677	3.281	2.961	2.697
6	5.64	5.46	5.285	4.965	4.677	4.544	4.357	4.183	3.971	3.520	3.158	2.862	2.616
7	5.17	5.03	4.888	4.627	4.385	4.271	4.110	3.959	3.772	3.369	3.040	2.767	2.538
8	4.94	4.69	4.522	4.311	4.111	4.015	3.877	3.747	3.584	3.225	2.926	2.674	2.461
9	4.94	4.69	4.462	4.063	3.854	3.774	3.658	3.546	3.404	3.086	2.816	2.585	2.388
10	4.94	4.69	4.461	4.063	3.729	3.584	3.451	3.356	3.234	2.954	2.710	2.499	2.316
11	4.94	4.69	4.462	4.063	3.729	3.583	3.383	3.205	3.072	2.828	2.609	2.416	2.246
12	4.95	4.69	4.461	4.063	3.729	3.584	3.383	3.205	2.994	2.706	2.511	2.335	2.179
13	4.94	4.69	4.462	4.064	3.730	3.583	3.383	3.205	2.994	2.590	2.417	2.257	2.114
14	4.95	4.69	4.461	4.063	3.729	3.584	3.383	3.205	2.994	2.571	2.326	2.182	2.050
15	4.94	4.69	4.462	4.064	3.730	3.583	3.383	3.205	2.994	2.571	2.253	2.110	1.989
16	4.95	4.69	4.461	4.063	3.729	3.584	3.383	3.205	2.994	2.571	2.253	2.039	1.929
17	4.94	4.69	4.462	4.064	3.730	3.583	3.383	3.205	2.994	2.571	2.253	2.005	1.871
18	4.95	4.70	4.461	4.063	3.729	3.584	3.383	3.205	2.994	2.571	2.253	2.005	1.815
19	2.47	4.69	4.462	4.064	3.730	3.583	3.383	3.205	2.994	2.571	2.253	2.005	1.806
20		2.35	4.461	4.063	3.729	3.584	3.384	3.205	2.993	2.571	2.253	2.005	1.806
21			2.231	4.064	3.730	3.583	3.383	3.205	2.994	2.571	2.253	2.005	1.806
22				4.063	3.729	3.584	3.384	3.205	2.993	2.571	2.253	2.005	1.806
23				2.032	3.730	3.583	3.383	3.205	2.994	2.571	2.253	2.005	1.806
24					3.729	3.584	3.384	3.205	2.993	2.571	2.253	2.004	1.806
25					1.865	3.583	3.383	3.205	2.994	2.571	2.253	2.005	1.806
26						1.792	3.384	3.205	2.993	2.571	2.253	2.004	1.806
27							3.383	3.205	2.994	2.571	2.253	2.005	1.806
28								3.205	2.993	2.572	2.253	2.004	1.806
29								1.602	2.994	2.571	2.253	2.005	1.806
30									2.993	2.572	2.253	2.004	1.806
31									1.497	2.571	2.253	2.005	1.806
32										2.572	2.253	2.004	1.806
33										2.571	2.252	2.005	1.806
34										2.572	2.253	2.004	1.806
35										2.571	2.252	2.005	1.806
36										1.286	2.253	2.004	1.806
37											2.252	2.005	1.806
38											2.253	2.004	1.806
39											2.252	2.005	1.806
40											2.253	2.004	1.806
41											1.126	2.005	1.806
42												2.004	1.805
43												2.005	1.806
44												2.004	1.805
45												2.005	1.806
46												1.002	1.805
47													1.806
48													1.805
49													1.806
50													1.805
51													0.903

Appendix C: Equipment Costing Spreadsheets

Kill Tank - Vertical			
Table A.1 Constan	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constan	B1	B2	
	2.25	1.82	

Volume, m^3	284.7
Diameter, m	12.192
Pressure (barg)	0
Cp0	$ 175,862.12
Fp	0.5

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 87,931.06	$ 555,724.29	$ 83,358.64	$ 16,671.73	$ 655,754.66
SS clad	19	1.8	$ 158,275.90	$ 683,751.91	$ 102,562.79	$ 20,512.56	$ 806,827.25
SS	20	3.1	$ 272,586.28	$ 891,796.79	$ 133,769.52	$ 26,753.90	$ 1,052,320.21
Ni alloy clad	21	3.6	$ 316,551.81	$ 971,814.05	$ 145,772.11	$ 29,154.42	$ 1,146,740.58
Ni alloy	22	7	$ 615,517.41	$ 1,515,931.44	$ 227,389.72	$ 45,477.94	$ 1,788,799.10
Ti Clad	23	4.6	$ 404,482.87	$ 1,131,848.58	$ 169,777.29	$ 33,955.46	$ 1,335,581.32
Ti	24	9.4	$ 826,551.95	$ 1,900,014.30	$ 285,002.15	$ 57,000.43	$ 2,242,016.88

Production Bioreactor	
Volume, m^3	40

Type	K1	K2	K3	Cp0	Fbm	Cbm	Contingencies	Fees	Ctm
Jacketed Agitated	4.1052	0.532	-0.0005	$ 90,409.20	4	$ 361,636.79	$ 54,245.52	$ 10,849.10	$ 426,731.42

Seed Bioreactor 1	
Volume, m^3	10

Type	K1	K2	K3	Cp0	Fbm	Cbm	Contingencies	Fees	Ctm
Jacketed Agitated	4.1052	0.532	-0.0005	$ 43,321.15	4	$ 173,284.61	$ 25,992.69	$ 5,198.54	$ 204,475.84

Seed Bioreactor 2	
Volume, m^3	10

Type	K1	K2	K3	Cp0	Fbm	Cbm	Contingencies	Fees	Ctm
Jacketed Agitated	4.1052	0.532	-0.0005	$ 43,321.15	4	$ 173,284.61	$ 25,992.69	$ 5,198.54	$ 204,475.84

MPT-101: Vertical			
Table A.1 Constan	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constan	B1	B2	
	2.25	1.82	

Volume, m^3	3
Diameter, m	1.084
Pressure (barg)	0.507
Cp0	$ 5,442.99
Fp	0.551333778

MOC	ID#	Fm	Cp	Cbm	Contingencie	Fees	Ctm
CS	18	1	$ 3,000.91	$ 17,708.39	$ 2,656.26	$ 531.25	$ 20,895.90
SS clad	19	1.8	$ 5,401.63	$ 22,077.71	$ 3,311.66	$ 662.33	$ 26,051.70
SS	20	3.1	$ 9,302.81	$ 29,177.86	$ 4,376.68	$ 875.34	$ 34,429.87
Ni alloy clad	21	3.6	$ 10,803.26	$ 31,908.68	$ 4,786.30	$ 957.26	$ 37,652.24
Ni alloy	22	7	$ 21,006.35	$ 50,478.29	$ 7,571.74	$ 1,514.35	$ 59,564.39
Ti Clad	23	4.6	$ 13,804.17	$ 37,370.33	$ 5,605.55	$ 1,121.11	$ 44,096.99
Ti	24	9.4	$ 28,208.52	$ 63,586.25	$ 9,537.94	$ 1,907.59	$ 75,031.78

MPT-102: Horizontal			
Table A.1 Constan	K1	K2	K3
	3.5565	0.3776	0.0905
Table A.4 Constan	B1	B2	
	2.25	1.82	

Volume, m^3	12
Diameter, m	1.721
Pressure (barg)	0.507
Cp0	$ 11,732.70
Fp	0.581499475

MOC	ID#	Fm	Cp	Cbm	Contingencie	Fees	Ctm
CS	18	1	$ 6,822.56	$ 38,815.64	$ 5,822.35	$ 1,164.47	$ 45,802.45
SS clad	19	1.8	$ 12,280.61	$ 48,749.29	$ 7,312.39	$ 1,462.48	$ 57,524.16
SS	20	3.1	$ 21,149.94	$ 64,891.46	$ 9,733.72	$ 1,946.74	$ 76,571.93
Ni alloy clad	21	3.6	$ 24,561.22	$ 71,099.99	$ 10,665.00	$ 2,133.00	$ 83,897.99
Ni alloy	22	7	$ 47,757.92	$ 113,318.00	$ 16,997.70	$ 3,399.54	$ 133,715.24
Ti Clad	23	4.6	$ 31,383.78	$ 83,517.05	$ 12,527.56	$ 2,505.51	$ 98,550.12
Ti	24	9.4	$ 64,132.07	$ 143,118.94	$ 21,467.84	$ 4,293.57	$ 168,880.35

MPT-103: Horizontal			
Table A.1 Constan	K1	K2	K3
	3.5565	0.3776	0.0905
Table A.4 Constan	B1	B2	
	2.25	1.82	

Volume, m^3	45
Diameter, m	2.673
Pressure (barg)	0.507
Cp0	$ 26,797.83
Fp	0.626582276

MOC	ID#	Fm	Cp	Cbm	Contingencie	Fees	Ctm
CS	18	1	$ 16,791.05	$ 90,854.82	$ 13,628.22	$ 2,725.64	$ 107,208.69
SS clad	19	1.8	$ 30,223.88	$ 115,302.59	$ 17,295.39	$ 3,459.08	$ 136,057.05
SS	20	3.1	$ 52,052.24	$ 155,030.20	$ 23,254.53	$ 4,650.91	$ 182,935.64
Ni alloy clad	21	3.6	$ 60,447.77	$ 170,310.05	$ 25,546.51	$ 5,109.30	$ 200,965.86
Ni alloy	22	7	$ 117,537.32	$ 274,213.05	$ 41,131.96	$ 8,226.39	$ 323,571.40
Ti Clad	23	4.6	$ 77,238.81	$ 200,869.76	$ 30,130.46	$ 6,026.09	$ 237,026.31
Ti	24	9.4	$ 157,835.83	$ 347,556.34	$ 52,133.45	$ 10,426.69	$ 410,116.48

MPT-104: Horizontal			
Table A.1 Constan	K1	K2	K3
	3.5565	0.3776	0.0905
Table A.4 Constan	B1	B2	
	2.25	1.82	

Volume, m^3	6
Diameter, m	1.366
Pressure (barg)	0.507
Cp0	$ 8,037.66
Fp	0.564688137

MOC	ID#	Fm	Cp	Cbm	Contingencie	Fees	Ctm
CS	18	1	$ 4,538.77	$ 26,345.29	$ 3,951.79	$ 790.36	$ 31,087.44
SS clad	19	1.8	$ 8,169.78	$ 32,953.73	$ 4,943.06	$ 988.61	$ 38,885.41
SS	20	3.1	$ 14,070.18	$ 43,692.46	$ 6,553.87	$ 1,310.77	$ 51,557.10
Ni alloy clad	21	3.6	$ 16,339.57	$ 47,822.74	$ 7,173.41	$ 1,434.68	$ 56,430.83
Ni alloy	22	7	$ 31,771.38	$ 75,908.64	$ 11,386.30	$ 2,277.26	$ 89,572.20
Ti Clad	23	4.6	$ 20,878.34	$ 56,083.30	$ 8,412.49	$ 1,682.50	$ 66,178.29
Ti	24	9.4	$ 42,664.43	$ 95,733.99	$ 14,360.10	$ 2,872.02	$ 112,966.10

V-101: Horizontal			
Table A.1 Constan	K1	K2	K3
	3.5565	0.3776	0.0905
Table A.4 Constan	B1	B2	
	2.25	1.82	

Volume, m^3	60
Diameter, m	2.942
Pressure (barg)	0.507
Cp0	$ 32,664.41
Fp	0.639321009

MOC	ID#	Fm	Cp	Cbm	Contingencie	Fees	Ctm
CS	18	1	$ 20,883.04	$ 111,502.05	$ 16,725.31	$ 3,345.06	$ 131,572.42
SS clad	19	1.8	$ 37,589.48	$ 141,907.76	$ 21,286.16	$ 4,257.23	$ 167,451.16
SS	20	3.1	$ 64,737.43	$ 191,317.04	$ 28,697.56	$ 5,739.51	$ 225,754.11
Ni alloy clad	21	3.6	$ 75,178.95	$ 210,320.61	$ 31,548.09	$ 6,309.62	$ 248,178.32
Ni alloy	22	7	$ 146,181.30	$ 339,544.88	$ 50,931.73	$ 10,186.35	$ 400,662.95
Ti Clad	23	4.6	$ 96,061.99	$ 248,327.75	$ 37,249.16	$ 7,449.83	$ 293,026.74
Ti	24	9.4	$ 196,300.60	$ 430,762.01	$ 64,614.30	$ 12,922.86	$ 508,299.17

V-102: Horizontal			
Table A.1 Constan	K1	K2	K3
	3.5565	0.3776	0.0905
Table A.4 Constan	B1	B2	
	2.25	1.82	

Volume, m^3	55
Diameter, m	2.858
Pressure (barg)	0.507
Cp0	$ 30,744.89
Fp	0.635343115

MOC	ID#	Fm	Cp	Cbm	Contingencie	Fees	Ctm
CS	18	1	$ 19,533.56	$ 104,727.08	$ 15,709.06	$ 3,141.81	$ 123,577.96
SS clad	19	1.8	$ 35,160.40	$ 133,167.94	$ 19,975.19	$ 3,995.04	$ 157,138.17
SS	20	3.1	$ 60,554.02	$ 179,384.33	$ 26,907.65	$ 5,381.53	$ 211,673.51
Ni alloy clad	21	3.6	$ 70,320.80	$ 197,159.87	$ 29,573.98	$ 5,914.80	$ 232,648.65
Ni alloy	22	7	$ 136,734.89	$ 318,033.52	$ 47,705.03	$ 9,541.01	$ 375,279.55
Ti Clad	23	4.6	$ 89,854.36	$ 232,710.94	$ 34,906.64	$ 6,981.33	$ 274,598.91
Ti	24	9.4	$ 183,615.43	$ 403,356.09	$ 60,503.41	$ 12,100.68	$ 475,960.19

V-103: Horizontal			
Table A.1 Constan	K1	K2	K3
	3.5565	0.3776	0.0905
Table A.4 Constan	B1	B2	
	2.25	1.82	

Volume, m^3	20
Diameter, m	2.04
Pressure (barg)	0.507
Cp0	$ 15,883.87
Fp	0.596606002

MOC	ID#	Fm	Cp	Cbm	Contingencie	Fees	Ctm
CS	18	1	$ 9,476.41	$ 52,985.78	$ 7,947.87	$ 1,589.57	$ 62,523.23
SS clad	19	1.8	$ 17,057.54	$ 66,783.44	$ 10,017.52	$ 2,003.50	$ 78,804.46
SS	20	3.1	$ 29,376.88	$ 89,204.64	$ 13,380.70	$ 2,676.14	$ 105,261.47
Ni alloy clad	21	3.6	$ 34,115.09	$ 97,828.17	$ 14,674.23	$ 2,934.85	$ 115,437.24
Ni alloy	22	7	$ 66,334.89	$ 156,468.22	$ 23,470.23	$ 4,694.05	$ 184,632.50
Ti Clad	23	4.6	$ 43,591.50	$ 115,075.25	$ 17,261.29	$ 3,452.26	$ 135,788.79
Ti	24	9.4	$ 89,078.29	$ 197,861.19	$ 29,679.18	$ 5,935.84	$ 233,476.21

V-104: Vertical			
Table A.1 Constants	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	3.5
Diameter, m	1.141
Pressure (barg)	0.507
Cp0	$ 5,932.07
Fp	0.554033063

MOC	ID#	Fm	Cp	Cbm	Contingencie	Fees	Ctm
CS	18	1	$ 3,286.56	$ 19,328.69	$ 2,899.30	$ 579.86	$ 22,807.85
SS clad	19	1.8	$ 5,915.81	$ 24,113.92	$ 3,617.09	$ 723.42	$ 28,454.43
SS	20	3.1	$ 10,188.34	$ 31,889.93	$ 4,783.49	$ 956.70	$ 37,630.11
Ni alloy clad	21	3.6	$ 11,831.62	$ 34,880.70	$ 5,232.10	$ 1,046.42	$ 41,159.22
Ni alloy	22	7	$ 23,005.93	$ 55,217.93	$ 8,282.69	$ 1,656.54	$ 65,157.16
Ti Clad	23	4.6	$ 15,118.18	$ 40,862.24	$ 6,129.34	$ 1,225.87	$ 48,217.44
Ti	24	9.4	$ 30,893.67	$ 69,573.63	$ 10,436.04	$ 2,087.21	$ 82,096.89

V-105: Horizontal			
Table A.1 Constants	K1	K2	K3
	3.5565	0.3776	0.0905
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	50
Diameter, m	2.769
Pressure (barg)	0.507
Cp0	$ 28,791.17
Fp	0.631128441

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 18,170.92	$ 97,851.20	$ 14,677.68	$ 2,935.54	$ 115,464.42
SS clad	19	1.8	$ 32,707.66	$ 124,308.07	$ 18,646.21	$ 3,729.24	$ 146,683.52
SS	20	3.1	$ 56,329.86	$ 167,300.47	$ 25,095.07	$ 5,019.01	$ 197,414.55
Ni alloy clad	21	3.6	$ 65,415.32	$ 183,836.01	$ 27,575.40	$ 5,515.08	$ 216,926.49
Ni alloy	22	7	$ 127,196.46	$ 296,277.68	$ 44,441.65	$ 8,888.33	$ 349,607.67
Ti Clad	23	4.6	$ 83,586.25	$ 216,907.09	$ 32,536.06	$ 6,507.21	$ 255,950.37
Ti	24	9.4	$ 170,806.68	$ 375,648.27	$ 56,347.24	$ 11,269.45	$ 443,264.96

V-106: Horizontal			
Table A.1 Constants	K1	K2	K3
	3.5565	0.3776	0.0905
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	5
Diameter, m	1.285
Pressure (barg)	0.507
Cp0	$ 7,322.27
Fp	0.56085231

MOC	ID#	Fm	Cp	Cbm	Contingencie	Fees	Ctm
CS	18	1	$ 4,106.71	$ 23,949.32	$ 3,592.40	$ 718.48	$ 28,260.20
SS clad	19	1.8	$ 7,392.08	$ 29,928.69	$ 4,489.30	$ 897.86	$ 35,315.86
SS	20	3.1	$ 12,730.81	$ 39,645.17	$ 5,946.78	$ 1,189.36	$ 46,781.30
Ni alloy clad	21	3.6	$ 14,784.16	$ 43,382.28	$ 6,507.34	$ 1,301.47	$ 51,191.09
Ni alloy	22	7	$ 28,746.98	$ 68,794.61	$ 10,319.19	$ 2,063.84	$ 81,177.64
Ti Clad	23	4.6	$ 18,890.87	$ 50,856.49	$ 7,628.47	$ 1,525.69	$ 60,010.66
Ti	24	9.4	$ 38,603.09	$ 86,732.72	$ 13,009.91	$ 2,601.98	$ 102,344.61

V-107: Horizontal			
Table A.1 Constants	K1	K2	K3
	3.5565	0.3776	0.0905
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	5
Diameter, m	1.285
Pressure (barg)	0.507
Cp0	$ 7,322.27
Fp	0.56085231

MOC	ID#	Fm	Cp	Cbm	Contingencie	Fees	Ctm
CS	18	1	$ 4,106.71	$ 23,949.32	$ 3,592.40	$ 718.48	$ 28,260.20
SS clad	19	1.8	$ 7,392.08	$ 29,928.69	$ 4,489.30	$ 897.86	$ 35,315.86
SS	20	3.1	$ 12,730.81	$ 39,645.17	$ 5,946.78	$ 1,189.36	$ 46,781.30
Ni alloy clad	21	3.6	$ 14,784.16	$ 43,382.28	$ 6,507.34	$ 1,301.47	$ 51,191.09
Ni alloy	22	7	$ 28,746.98	$ 68,794.61	$ 10,319.19	$ 2,063.84	$ 81,177.64
Ti Clad	23	4.6	$ 18,890.87	$ 50,856.49	$ 7,628.47	$ 1,525.69	$ 60,010.66
Ti	24	9.4	$ 38,603.09	$ 86,732.72	$ 13,009.91	$ 2,601.98	$ 102,344.61

Filter #	Type	Area, m^2	K1	K2	K3	Cp0	Fbm	Cbm	Contingencies	Fees	Ctm
1	Plate-and-Frame	10	4.2756	0.352	0.0714	$ 50,003.45	1.65	$ 82,505.70	$ 12,375.85	$ 2,475.17	$ 97,356.72
2	Plate-and-Frame	40	4.2756	0.352	0.0714	$ 105,385.31	1.65	$ 173,885.77	$ 26,082.86	$ 5,216.57	$ 205,185.20
3	Plate-and-Frame	130	4.2756	0.352	0.0714	$ 218,161.08	1.65	$ 359,965.78	$ 53,994.87	$ 10,798.97	$ 424,759.62
4	Plate-and-Frame	10	4.2756	0.352	0.0714	$ 50,003.45	1.65	$ 82,505.70	$ 12,375.85	$ 2,475.17	$ 97,356.72
5	Plate-and-Frame	30	4.2756	0.352	0.0714	$ 89,399.16	1.65	$ 147,508.61	$ 22,126.29	$ 4,425.26	$ 174,060.16
6	Plate-and-Frame	10	4.2756	0.352	0.0714	$ 50,003.45	1.65	$ 82,505.70	$ 12,375.85	$ 2,475.17	$ 97,356.72
7	Plate-and-Frame	10	4.2756	0.352	0.0714	$ 50,003.45	1.65	$ 82,505.70	$ 12,375.85	$ 2,475.17	$ 97,356.72
8	Plate-and-Frame	10	4.2756	0.352	0.0714	$ 50,003.45	1.65	$ 82,505.70	$ 12,375.85	$ 2,475.17	$ 97,356.72
9	Plate-and-Frame	10	4.2756	0.352	0.0714	$ 50,003.45	1.65	$ 82,505.70	$ 12,375.85	$ 2,475.17	$ 97,356.72
10	Plate-and-Frame	10	4.2756	0.352	0.0714	$ 50,003.45	1.65	$ 82,505.70	$ 12,375.85	$ 2,475.17	$ 97,356.72

Pumps

Pump	Max Flow (m^3/mi	deltaP (bar)	Eff.	Power (kW)
UP 1	0.116753667	0.507	0.45	0.219675916
UP 2	0.108761833	0.507	0.45	0.204639015
DWN 1	0.1235565	0.507	0.45	0.232475673
DWN 2	0.05	0.507	0.45	0.094076667
DWN 3	0.119868333	0.507	0.45	0.225536265
DWN 4	0.053142	0.507	0.45	0.099988444

Upstream Skid 1

Table A.1 Constants	K1	K2	K3
	3.8696	0.3161	0.122
Table A.2 Constants	C1	C2	C3
P<10 barg	0	0	0
10<P<100 barg	-0.245382	0.259016	-0.01363
Table A.4 Constants	B1	B2	
	1.89	1.35	

Shaft power, kW	0.219675916
Discharge Pressure (bar	0.507
Cp0	$ 5,180.77
Fp	1

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
Cast Iron	25	1	$ 5,180.77	$ 16,785.68	$ 2,517.85	$ 503.57	$ 19,807.10
Carbon Steel	26	1.4	$ 7,253.07	$ 19,583.30	$ 2,937.49	$ 587.50	$ 23,108.29
Cu alloy	27	1.2	$ 6,216.92	$ 18,184.49	$ 2,727.67	$ 545.53	$ 21,457.70
SS	28	2.4	$ 12,433.84	$ 26,577.33	$ 3,986.60	$ 797.32	$ 31,361.25
Ni alloy	29	4	$ 20,723.06	$ 37,767.78	$ 5,665.17	$ 1,133.03	$ 44,565.98
Ti	30	6.4	$ 33,156.90	$ 54,553.47	$ 8,183.02	$ 1,636.60	$ 64,373.09

Upstream Skid 2

Table A.1 Constants	K1	K2	K3
	3.8696	0.3161	0.122
Table A.2 Constants	C1	C2	C3
P<10 barg	0	0	0
10<P<100 barg	-0.245382	0.259016	-0.01363
Table A.4 Constants	B1	B2	
	1.89	1.35	

Shaft power, kW	0.204639015
Discharge Pressure (bar	0.507
Cp0	$ 5,125.32
Fp	1

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
Cast Iron	25	1	$ 5,125.32	$ 16,606.05	$ 2,490.91	$ 498.18	$ 19,595.14
Carbon Steel	26	1.4	$ 7,175.45	$ 19,373.73	$ 2,906.06	$ 581.21	$ 22,861.00
Cu alloy	27	1.2	$ 6,150.39	$ 17,989.89	$ 2,698.48	$ 539.70	$ 21,228.07
SS	28	2.4	$ 12,300.78	$ 26,292.91	$ 3,943.94	$ 788.79	$ 31,025.64
Ni alloy	29	4	$ 20,501.30	$ 37,363.61	$ 5,604.54	$ 1,120.91	$ 44,089.06
Ti	30	6.4	$ 32,802.08	$ 53,969.66	$ 8,095.45	$ 1,619.09	$ 63,684.20

Downstream Skid 1

Table A.1 Constants	K1	K2	K3
	3.8696	0.3161	0.122
Table A.2 Constants	C1	C2	C3
P<10 barg	0	0	0
10<P<100 barg	-0.245382	0.259016	-0.01363
Table A.4 Constants	B1	B2	
	1.89	1.35	

Shaft power, kW	0.232475673
Discharge Pressure (bar	0.507
Cp0	$ 5,227.48
Fp	1

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
Cast Iron	25	1	$ 5,227.48	$ 16,937.03	$ 2,540.55	$ 508.11	$ 19,985.69
Carbon Steel	26	1.4	$ 7,318.47	$ 19,759.87	$ 2,963.98	$ 592.80	$ 23,316.64
Cu alloy	27	1.2	$ 6,272.97	$ 18,348.45	$ 2,752.27	$ 550.45	$ 21,651.17
SS	28	2.4	$ 12,545.95	$ 26,816.96	$ 4,022.54	$ 804.51	$ 31,644.01
Ni alloy	29	4	$ 20,909.91	$ 38,108.31	$ 5,716.25	$ 1,143.25	$ 44,967.81
Ti	30	6.4	$ 33,455.86	$ 55,045.34	$ 8,256.80	$ 1,651.36	$ 64,953.50

Downstream Skid 2

Table A.1 Constants	K1	K2	K3
	3.8696	0.3161	0.122
Table A.2 Constants	C1	C2	C3
P<10 barg	0	0	0
10<P<100 barg	-0.245382	0.259016	-0.01363
Table A.4 Constants	B1	B2	
	1.89	1.35	

Shaft power, kW	0.094076667
Discharge Pressure (bar	0.507
Cp0	$ 4,717.09
Fp	1

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
Cast Iron	25	1	$ 4,717.09	$ 15,283.36	$ 2,292.50	$ 458.50	$ 18,034.37
Carbon Steel	26	1.4	$ 6,603.92	$ 17,830.59	$ 2,674.59	$ 534.92	$ 21,040.09
Cu alloy	27	1.2	$ 5,660.50	$ 16,556.97	$ 2,483.55	$ 496.71	$ 19,537.23
SS	28	2.4	$ 11,321.01	$ 24,198.65	$ 3,629.80	$ 725.96	$ 28,554.41
Ni alloy	29	4	$ 18,868.35	$ 34,387.56	$ 5,158.13	$ 1,031.63	$ 40,577.32
Ti	30	6.4	$ 30,189.35	$ 49,670.92	$ 7,450.64	$ 1,490.13	$ 58,611.69

Downstream Skid 3

Table A.1 Constants	K1	K2	K3
	3.8696	0.3161	0.122
Table A.2 Constants	C1	C2	C3
P<10 barg	0	0	0
10<P<100 barg	-0.245382	0.259016	-0.01363
Table A.4 Constants	B1	B2	
	1.89	1.35	

Shaft power, kW	0.225536265
Discharge Pressure (bar	0.507
Cp0	$ 5,202.21
Fp	1

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
Cast Iron	25	1	$ 5,202.21	$ 16,855.16	$ 2,528.27	$ 505.65	$ 19,889.09
Carbon Steel	26	1.4	$ 7,283.09	$ 19,664.35	$ 2,949.65	$ 589.93	$ 23,203.94
Cu alloy	27	1.2	$ 6,242.65	$ 18,259.76	$ 2,738.96	$ 547.79	$ 21,546.51
SS	28	2.4	$ 12,485.30	$ 26,687.34	$ 4,003.10	$ 800.62	$ 31,491.06
Ni alloy	29	4	$ 20,808.84	$ 37,924.11	$ 5,688.62	$ 1,137.72	$ 44,750.45
Ti	30	6.4	$ 33,294.14	$ 54,779.27	$ 8,216.89	$ 1,643.38	$ 64,639.53

Downstream Skid 4

Table A.1 Constants	K1	K2	K3
	3.8696	0.3161	0.122
Table A.2 Constants	C1	C2	C3
P<10 barg	0	0	0
10<P<100 barg	-0.245382	0.259016	-0.01363
Table A.4 Constants	B1	B2	
	1.89	1.35	

Shaft power, kW	0.099988444
Discharge Pressure (bar	0.507
Cp0	$ 4,736.92
Fp	1

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
Cast Iron	25	1	$ 4,736.92	$ 15,347.63	$ 2,302.14	$ 460.43	$ 18,110.21
Carbon Steel	26	1.4	$ 6,631.69	$ 17,905.57	$ 2,685.84	$ 537.17	$ 21,128.57
Cu alloy	27	1.2	$ 5,684.31	$ 16,626.60	$ 2,493.99	$ 498.80	$ 19,619.39
SS	28	2.4	$ 11,368.62	$ 24,300.42	$ 3,645.06	$ 729.01	$ 28,674.49
Ni alloy	29	4	$ 18,947.69	$ 34,532.17	$ 5,179.83	$ 1,035.97	$ 40,747.96
Ti	30	6.4	$ 30,316.31	$ 49,879.81	$ 7,481.97	$ 1,496.39	$ 58,858.17

Vessels

Upstream Skid 1

Table A.1 Constants	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	2
Diameter, m	0.947
Pressure (barg)	0
Cp0	$ 4,386.77
Fp	0.5

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 2,193.38	$ 13,862.18	$ 2,079.33	$ 415.87	$ 16,357.37
SS clad	19	1.8	$ 3,948.09	$ 17,055.75	$ 2,558.36	$ 511.67	$ 20,125.78
SS	20	3.1	$ 6,799.49	$ 22,245.29	$ 3,336.79	$ 667.36	$ 26,249.44
Ni alloy clad	21	3.6	$ 7,896.18	$ 24,241.27	$ 3,636.19	$ 727.24	$ 28,604.70
Ni alloy	22	7	$ 15,353.68	$ 37,813.92	$ 5,672.09	$ 1,134.42	$ 44,620.43
Ti Clad	23	4.6	$ 10,089.56	$ 28,233.22	$ 4,234.98	$ 847.00	$ 33,315.20
Ti	24	9.4	$ 20,617.80	$ 47,394.62	$ 7,109.19	$ 1,421.84	$ 55,925.65

Upstream Skid 2

Table A.1 Constants	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	2
Diameter, m	0.947
Pressure (barg)	0
Cp0	$ 4,386.77
Fp	0.5

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 2,193.38	$ 13,862.18	$ 2,079.33	$ 415.87	$ 16,357.37
SS clad	19	1.8	$ 3,948.09	$ 17,055.75	$ 2,558.36	$ 511.67	$ 20,125.78
SS	20	3.1	$ 6,799.49	$ 22,245.29	$ 3,336.79	$ 667.36	$ 26,249.44
Ni alloy clad	21	3.6	$ 7,896.18	$ 24,241.27	$ 3,636.19	$ 727.24	$ 28,604.70
Ni alloy	22	7	$ 15,353.68	$ 37,813.92	$ 5,672.09	$ 1,134.42	$ 44,620.43
Ti Clad	23	4.6	$ 10,089.56	$ 28,233.22	$ 4,234.98	$ 847.00	$ 33,315.20
Ti	24	9.4	$ 20,617.80	$ 47,394.62	$ 7,109.19	$ 1,421.84	$ 55,925.65

Downstream Skid 1

Table A.1 Constants	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	2.5
Diameter, m	0.985
Pressure (barg)	0
Cp0	$ 4,930.42
Fp	0.5

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 2,465.21	$ 15,580.11	$ 2,337.02	$ 467.40	$ 18,384.53
SS clad	19	1.8	$ 4,437.37	$ 19,169.46	$ 2,875.42	$ 575.08	$ 22,619.96
SS	20	3.1	$ 7,642.14	$ 25,002.14	$ 3,750.32	$ 750.06	$ 29,502.52
Ni alloy clad	21	3.6	$ 8,874.75	$ 27,245.48	$ 4,086.82	$ 817.36	$ 32,149.66
Ni alloy	22	7	$ 17,256.46	$ 42,500.19	$ 6,375.03	$ 1,275.01	$ 50,150.22
Ti Clad	23	4.6	$ 11,339.96	$ 31,732.16	$ 4,759.82	$ 951.96	$ 37,443.94
Ti	24	9.4	$ 23,172.95	$ 53,268.21	$ 7,990.23	$ 1,598.05	$ 62,856.49

Downstream Skid 2

Table A.1 Constants	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	1
Diameter, m	0.752
Pressure (barg)	0
Cp0	$ 3,143.40
Fp	0.5

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 1,571.70	$ 9,933.15	$ 1,489.97	$ 297.99	$ 11,721.12
SS clad	19	1.8	$ 2,829.06	$ 12,221.55	$ 1,833.23	$ 366.65	$ 14,421.43
SS	20	3.1	$ 4,872.27	$ 15,940.19	$ 2,391.03	$ 478.21	$ 18,809.43
Ni alloy clad	21	3.6	$ 5,658.12	$ 17,370.44	$ 2,605.57	$ 521.11	$ 20,497.12
Ni alloy	22	7	$ 11,001.91	$ 27,096.13	$ 4,064.42	$ 812.88	$ 31,973.43
Ti Clad	23	4.6	$ 7,229.83	$ 20,230.94	$ 3,034.64	$ 606.93	$ 23,872.51
Ti	24	9.4	$ 14,773.99	$ 33,961.32	$ 5,094.20	$ 1,018.84	$ 40,074.36

Downstream Skid 3

Table A.1 Constants	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	2
Diameter, m	0.947
Pressure (barg)	0
Cp0	$ 4,386.77
Fp	0.5

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 2,193.38	$ 13,862.18	$ 2,079.33	$ 415.87	$ 16,357.37
SS clad	19	1.8	$ 3,948.09	$ 17,055.75	$ 2,558.36	$ 511.67	$ 20,125.78
SS	20	3.1	$ 6,799.49	$ 22,245.29	$ 3,336.79	$ 667.36	$ 26,249.44
Ni alloy clad	21	3.6	$ 7,896.18	$ 24,241.27	$ 3,636.19	$ 727.24	$ 28,604.70
Ni alloy	22	7	$ 15,353.68	$ 37,813.92	$ 5,672.09	$ 1,134.42	$ 44,620.43
Ti Clad	23	4.6	$ 10,089.56	$ 28,233.22	$ 4,234.98	$ 847.00	$ 33,315.20
Ti	24	9.4	$ 20,617.80	$ 47,394.62	$ 7,109.19	$ 1,421.84	$ 55,925.65

Downstream Skid 4

Table A.1 Constants	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	1
Diameter, m	0.752
Pressure (barg)	0
Cp0	$ 3,143.40
Fp	0.5

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 1,571.70	$ 9,933.15	$ 1,489.97	$ 297.99	$ 11,721.12
SS clad	19	1.8	$ 2,829.06	$ 12,221.55	$ 1,833.23	$ 366.65	$ 14,421.43
SS	20	3.1	$ 4,872.27	$ 15,940.19	$ 2,391.03	$ 478.21	$ 18,809.43
Ni alloy clad	21	3.6	$ 5,658.12	$ 17,370.44	$ 2,605.57	$ 521.11	$ 20,497.12
Ni alloy	22	7	$ 11,001.91	$ 27,096.13	$ 4,064.42	$ 812.88	$ 31,973.43
Ti Clad	23	4.6	$ 7,229.83	$ 20,230.94	$ 3,034.64	$ 606.93	$ 23,872.51
Ti	24	9.4	$ 14,773.99	$ 33,961.32	$ 5,094.20	$ 1,018.84	$ 40,074.36

Skid	Cp0	Cbm	Ctm
Upstream 1	$ 18,341.06	$ 77,744.56	$ 91,738.59
Upstream 2	$ 18,285.62	$ 77,460.15	$ 91,402.98
Downstream 1	$ 20,018.73	$ 84,325.33	$ 99,503.89
Downstream 2	$ 14,167.13	$ 60,863.30	$ 71,818.70
Downstream 3	$ 18,362.51	$ 77,854.57	$ 91,868.39
Downstream 4	$ 14,167.13	$ 60,965.07	$ 71,938.78

Rocking Bioreactor 1

Volume, m^3	0.1

Type	K1	K2	K3	Cp0	Fbm	Cbm	Contingenci	Fees	Ctm
Inoculum tank	3.7957	0.4593	0.016	$ 2,251.13	4	$ 9,004.51	$ 1,350.68	$ 270.14	$ 10,625.32

Rocking Bioreactor 2

Volume, m^3	0.2

Type	K1	K2	K3	Cp0	Fbm	Cbm	Contingenci	Fees	Ctm
Inoculum tank	3.7957	0.4593	0.016	$ 3,037.25	4	$ 12,148.99	$ 1,822.35	$ 364.47	$ 14,335.80

Location	Power, kW	Type	K1	K2	K3	Cp0	Fbm	Cbm	Contingencie	Fees	Ctm
Seed Bioreactor 1	1.234977686	Impeller	3.8511	0.7009	-0.0003	$ 8,228.89	1.38	$11,355.87	$ 1,703.38	$ 340.68	$13,399.93
Seed Bioreactor 2	1.558738818	Impeller	3.8511	0.7009	-0.0003	$ 9,687.32	1.38	$13,368.50	$ 2,005.28	$ 401.06	$15,774.83
Production Bioreact	2.505874624	Impeller	3.8511	0.7009	-0.0003	$13,510.86	1.38	$18,644.98	$ 2,796.75	$ 559.35	$22,001.08
Buffer Tank 1	2.083225609	Impeller	3.8511	0.7009	-0.0003	$11,870.58	1.38	$16,381.40	$ 2,457.21	$ 491.44	$19,330.05
Buffer Tank 2	2.435685375	Impeller	3.8511	0.7009	-0.0003	$13,244.57	1.38	$18,277.51	$ 2,741.63	$ 548.33	$21,567.46
Buffer Tank 3	3.075867674	Impeller	3.8511	0.7009	-0.0003	$15,597.14	1.38	$21,524.06	$ 3,228.61	$ 645.72	$25,398.39
Buffer Tank 4	2.962282049	Impeller	3.8511	0.7009	-0.0003	$15,191.34	1.38	$20,964.06	$ 3,144.61	$ 628.92	$24,737.59
Buffer Tank 5	3.017445038	Impeller	3.8511	0.7009	-0.0003	$15,388.99	1.38	$21,236.81	$ 3,185.52	$ 637.10	$25,059.44
Buffer Tank 6	1.468256652	Impeller	3.8511	0.7009	-0.0003	$ 9,289.73	1.38	$12,819.83	$ 1,922.97	$ 384.59	$15,127.40
Buffer Tank 7	3.543731864	Impeller	3.8511	0.7009	-0.0003	$17,223.70	1.38	$23,768.71	$ 3,565.31	$ 713.06	$28,047.08
Buffer Tank 8	2.091596179	Impeller	3.8511	0.7009	-0.0003	$11,903.98	1.38	$16,427.49	$ 2,464.12	$ 492.82	$19,384.44
Buffer Tank 9	1.646137361	Impeller	3.8511	0.7009	-0.0003	$10,064.84	1.38	$13,889.48	$ 2,083.42	$ 416.68	$16,389.59
Buffer Tank 10	1.664169138	Impeller	3.8511	0.7009	-0.0003	$10,141.98	1.38	$13,995.93	$ 2,099.39	$ 419.88	$16,515.20
Buffer Tank 11	1.888463838	Impeller	3.8511	0.7009	-0.0003	$11,081.58	1.38	$15,292.58	$ 2,293.89	$ 458.78	$18,045.25

Buffer Tank	Volume, m^3	Type	K1	K2	K3	Cp0	Fbm	Cbm	Contingencie	Fees	Ctm
1	25	Jacketed Agitated	4.1052	0.532	-0.0005	$ 70,457.46	4	$ 281,829.83	$ 42,274.47	$ 8,454.89	$ 332,559.20
2	40	Jacketed Agitated	4.1052	0.532	-0.0005	$ 90,409.20	4	$ 361,636.79	$ 54,245.52	$ 10,849.10	$ 426,731.42
3	80	Jacketed Agitated	4.1052	0.532	-0.0005	$ 130,566.87	4	$ 522,267.49	$ 78,340.12	$ 15,668.02	$ 616,275.63
4	70	Jacketed Agitated	4.1052	0.532	-0.0005	$ 121,643.80	4	$ 486,575.18	$ 72,986.28	$ 14,597.26	$ 574,158.72
5	70	Jacketed Agitated	4.1052	0.532	-0.0005	$ 121,643.80	4	$ 486,575.18	$ 72,986.28	$ 14,597.26	$ 574,158.72
6	8	Jacketed Agitated	4.1052	0.532	-0.0005	$ 38,480.09	4	$ 153,920.36	$ 23,088.05	$ 4,617.61	$ 181,626.03
7	120	Jacketed Agitated	4.1052	0.532	-0.0005	$ 161,868.72	4	$ 647,474.87	$ 97,121.23	$ 19,424.25	$ 764,020.35
8	25	Jacketed Agitated	4.1052	0.532	-0.0005	$ 70,457.46	4	$ 281,829.83	$ 42,274.47	$ 8,454.89	$ 332,559.20
9	12	Jacketed Agitated	4.1052	0.532	-0.0005	$ 47,724.58	4	$ 190,898.32	$ 28,634.75	$ 5,726.95	$ 225,260.01
10	12	Jacketed Agitated	4.1052	0.532	-0.0005	$ 47,724.58	4	$ 190,898.32	$ 28,634.75	$ 5,726.95	$ 225,260.01
11	16	Jacketed Agitated	4.1052	0.532	-0.0005	$ 55,598.99	4	$ 222,395.95	$ 33,359.39	$ 6,671.88	$ 262,427.22

Buffer Storage 2

Vertical			
Table A.1 Constants	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	40
Diameter, m	2.570097614
Pressure (barg)	0.507
Cp0	$ 31,015.33
Fp	0.621709243

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 19,282.51	$ 104,878.66	$ 15,731.80	$ 3,146.36	$ 123,756.82
SS clad	19	1.8	$ 34,708.53	$ 132,954.00	$ 19,943.10	$ 3,988.62	$ 156,885.72
SS	20	3.1	$ 59,775.79	$ 178,576.43	$ 26,786.46	$ 5,357.29	$ 210,720.18
Ni alloy clad	21	3.6	$ 69,417.05	$ 196,123.52	$ 29,418.53	$ 5,883.71	$ 231,425.75
Ni alloy	22	7	$ 134,977.60	$ 315,443.71	$ 47,316.56	$ 9,463.31	$ 372,223.58
Ti Clad	23	4.6	$ 88,699.57	$ 231,217.69	$ 34,682.65	$ 6,936.53	$ 272,836.88
Ti	24	9.4	$ 181,255.64	$ 399,669.74	$ 59,950.46	$ 11,990.09	$ 471,610.29

Buffer Storage 1

Vertical			
Table A.1 Constants	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	25
Diameter, m	2.19740255
Pressure (barg)	0.507
Cp0	$ 21,590.42
Fp	0.604059939

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 13,041.91	$ 72,314.71	$ 10,847.21	$ 2,169.44	$ 85,331.36
SS clad	19	1.8	$ 23,475.43	$ 91,303.73	$ 13,695.56	$ 2,739.11	$ 107,738.40
SS	20	3.1	$ 40,429.91	$ 122,160.88	$ 18,324.13	$ 3,664.83	$ 144,149.84
Ni alloy clad	21	3.6	$ 46,950.87	$ 134,029.02	$ 20,104.35	$ 4,020.87	$ 158,154.24
Ni alloy	22	7	$ 91,293.35	$ 214,732.34	$ 32,209.85	$ 6,441.97	$ 253,384.16
Ti Clad	23	4.6	$ 59,992.77	$ 157,765.29	$ 23,664.79	$ 4,732.96	$ 186,163.04
Ti	24	9.4	$ 122,593.93	$ 271,699.39	$ 40,754.91	$ 8,150.98	$ 320,605.28

Buffer Storage 3

Vertical			
Table A.1 Constants	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	80
Diameter, m	3.238120084
Pressure (barg)	0.507
Cp0	$ 54,942.95
Fp	0.653344037

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 35,896.65	$ 188,953.54	$ 28,343.03	$ 5,668.61	$ 222,965.17
SS clad	19	1.8	$ 64,613.97	$ 241,219.06	$ 36,182.86	$ 7,236.57	$ 284,638.49
SS	20	3.1	$ 111,279.61	$ 326,150.53	$ 48,922.58	$ 9,784.52	$ 384,857.62
Ni alloy clad	21	3.6	$ 129,227.93	$ 358,816.48	$ 53,822.47	$ 10,764.49	$ 423,403.44
Ni alloy	22	7	$ 251,276.54	$ 580,944.94	$ 87,141.74	$ 17,428.35	$ 685,515.03
Ti Clad	23	4.6	$ 165,124.58	$ 424,148.38	$ 63,622.26	$ 12,724.45	$ 500,495.09
Ti	24	9.4	$ 337,428.50	$ 737,741.50	$ 110,661.22	$ 22,132.24	$ 870,534.97

Buffer Storage 4

Vertical			
Table A.1 Constants	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	70
Diameter, m	3.097150441
Pressure (barg)	0.507
Cp0	$ 49,040.81
Fp	0.646668295

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 31,713.14	$ 168,059.72	$ 25,208.96	$ 5,041.79	$ 198,310.47
SS clad	19	1.8	$ 57,083.64	$ 214,234.05	$ 32,135.11	$ 6,427.02	$ 252,796.18
SS	20	3.1	$ 98,310.72	$ 289,267.33	$ 43,390.10	$ 8,678.02	$ 341,335.44
Ni alloy clad	21	3.6	$ 114,167.29	$ 318,126.28	$ 47,718.94	$ 9,543.79	$ 375,389.01
Ni alloy	22	7	$ 221,991.95	$ 514,367.16	$ 77,155.07	$ 15,431.01	$ 606,953.25
Ti Clad	23	4.6	$ 145,880.42	$ 375,844.18	$ 56,376.63	$ 11,275.33	$ 443,496.14
Ti	24	9.4	$ 298,103.47	$ 652,890.13	$ 97,933.52	$ 19,586.70	$ 770,410.36

Buffer Storage 5

Vertical			
Table A.1 Constants	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	70
Diameter, m	3.097150441
Pressure (barg)	0.507
Cp0	$ 49,040.81
Fp	0.646668295

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 31,713.14	$ 168,059.72	$ 25,208.96	$ 5,041.79	$ 198,310.47
SS clad	19	1.8	$ 57,083.64	$ 214,234.05	$ 32,135.11	$ 6,427.02	$ 252,796.18
SS	20	3.1	$ 98,310.72	$ 289,267.33	$ 43,390.10	$ 8,678.02	$ 341,335.44
Ni alloy clad	21	3.6	$ 114,167.29	$ 318,126.28	$ 47,718.94	$ 9,543.79	$ 375,389.01
Ni alloy	22	7	$ 221,991.95	$ 514,367.16	$ 77,155.07	$ 15,431.01	$ 606,953.25
Ti Clad	23	4.6	$ 145,880.42	$ 375,844.18	$ 56,376.63	$ 11,275.33	$ 443,496.14
Ti	24	9.4	$ 298,103.47	$ 652,890.13	$ 97,933.52	$ 19,586.70	$ 770,410.36

Buffer Storage 6

Vertical			
Table A.1 Constants	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	8
Diameter, m	1.503002202
Pressure (barg)	0.507
Cp0	$ 9,773.01
Fp	0.571175997

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 5,582.11	$ 32,148.70	$ 4,822.31	$ 964.46	$ 37,935.47
SS clad	19	1.8	$ 10,047.79	$ 40,276.25	$ 6,041.44	$ 1,208.29	$ 47,525.98
SS	20	3.1	$ 17,304.53	$ 53,483.52	$ 8,022.53	$ 1,604.51	$ 63,110.55
Ni alloy clad	21	3.6	$ 20,095.59	$ 58,563.24	$ 8,784.49	$ 1,756.90	$ 69,104.62
Ni alloy	22	7	$ 39,074.75	$ 93,105.32	$ 13,965.80	$ 2,793.16	$ 109,864.27
Ti Clad	23	4.6	$ 25,677.69	$ 68,722.67	$ 10,308.40	$ 2,061.68	$ 81,092.75
Ti	24	9.4	$ 52,471.81	$ 117,487.96	$ 17,623.19	$ 3,524.64	$ 138,635.79

Buffer Storage 7

Vertical			
Table A.1 Constants	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	120
Diameter, m	3.706722179
Pressure (barg)	0.507
Cp0	$ 78,379.49
Fp	0.675535103

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 52,948.09	$ 272,719.38	$ 40,907.91	$ 8,181.58	$ 321,808.87
SS clad	19	1.8	$ 95,306.57	$ 349,811.80	$ 52,471.77	$ 10,494.35	$ 412,777.93
SS	20	3.1	$ 164,139.09	$ 475,086.99	$ 71,263.05	$ 14,252.61	$ 560,602.65
Ni alloy clad	21	3.6	$ 190,613.14	$ 523,269.76	$ 78,490.46	$ 15,698.09	$ 617,458.32
Ni alloy	22	7	$ 370,636.66	$ 850,912.57	$ 127,636.89	$ 25,527.38	$ 1,004,076.83
Ti Clad	23	4.6	$ 243,561.24	$ 619,635.29	$ 92,945.29	$ 18,589.06	$ 731,169.65
Ti	24	9.4	$ 497,712.09	$ 1,082,189.85	$ 162,328.48	$ 32,465.70	$ 1,276,984.02

Buffer Storage 8

Vertical			
Table A.1 Constants	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	25
Diameter, m	2.19740255
Pressure (barg)	0.507
Cp0	$ 21,590.42
Fp	0.604059939

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 13,041.91	$ 72,314.71	$ 10,847.21	$ 2,169.44	$ 85,331.36
SS clad	19	1.8	$ 23,475.43	$ 91,303.73	$ 13,695.56	$ 2,739.11	$ 107,738.40
SS	20	3.1	$ 40,429.91	$ 122,160.88	$ 18,324.13	$ 3,664.83	$ 144,149.84
Ni alloy clad	21	3.6	$ 46,950.87	$ 134,029.02	$ 20,104.35	$ 4,020.87	$ 158,154.24
Ni alloy	22	7	$ 91,293.35	$ 214,732.34	$ 32,209.85	$ 6,441.97	$ 253,384.16
Ti Clad	23	4.6	$ 59,992.77	$ 157,765.29	$ 23,664.79	$ 4,732.96	$ 186,163.04
Ti	24	9.4	$ 122,593.93	$ 271,699.39	$ 40,754.91	$ 8,150.98	$ 320,605.28

Buffer Storage 9

Vertical			
Table A.1 Constants	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	12
Diameter, m	1.720508028
Pressure (barg)	0.507
Cp0	$ 12,778.92
Fp	0.581476178

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 7,430.64	$ 42,276.34	$ 6,341.45	$ 1,268.29	$ 49,886.08
SS clad	19	1.8	$ 13,375.15	$ 53,095.35	$ 7,964.30	$ 1,592.86	$ 62,652.52
SS	20	3.1	$ 23,034.98	$ 70,676.25	$ 10,601.44	$ 2,120.29	$ 83,397.97
Ni alloy clad	21	3.6	$ 26,750.30	$ 77,438.13	$ 11,615.72	$ 2,323.14	$ 91,376.99
Ni alloy	22	7	$ 52,014.48	$ 123,418.93	$ 18,512.84	$ 3,702.57	$ 145,634.34
Ti Clad	23	4.6	$ 34,180.94	$ 90,961.90	$ 13,644.28	$ 2,728.86	$ 107,335.04
Ti	24	9.4	$ 69,848.01	$ 155,875.96	$ 23,381.39	$ 4,676.28	$ 183,933.64

Buffer Storage 10

Vertical			
Table A.1 Constants	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	12
Diameter, m	1.720508028
Pressure (barg)	0.507
Cp0	$ 12,778.92
Fp	0.581476178

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 7,430.64	$ 42,276.34	$ 6,341.45	$ 1,268.29	$ 49,886.08
SS clad	19	1.8	$ 23,475.43	$ 53,095.35	$ 7,964.30	$ 1,592.86	$ 62,652.52
SS	20	3.1	$ 40,429.91	$ 70,676.25	$ 10,601.44	$ 2,120.29	$ 83,397.97
Ni alloy clad	21	3.6	$ 46,950.87	$ 77,438.13	$ 11,615.72	$ 2,323.14	$ 91,376.99
Ni alloy	22	7	$ 91,293.35	$ 123,418.93	$ 18,512.84	$ 3,702.57	$ 145,634.34
Ti Clad	23	4.6	$ 59,992.77	$ 90,961.90	$ 13,644.28	$ 2,728.86	$ 107,335.04
Ti	24	9.4	$ 122,593.93	$ 155,875.96	$ 23,381.39	$ 4,676.28	$ 183,933.64

Buffer Storage 11			
Vertical			
Table A.1 Constants	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constants	B1	B2	
	2.25	1.82	

Volume, m^3	16
Diameter, m	1.893664113
Pressure (barg)	0.507
Cp0	$ 15,601.54
Fp	0.589676137

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 9,199.86	$ 51,847.22	$ 7,777.08	$ 1,555.42	$ 61,179.72
SS clad	19	1.8	$ 16,559.75	$ 65,242.21	$ 9,786.33	$ 1,957.27	$ 76,985.81
SS	20	3.1	$ 28,519.56	$ 87,009.08	$ 13,051.36	$ 2,610.27	$ 102,670.71
Ni alloy clad	21	3.6	$ 33,119.49	$ 95,380.95	$ 14,307.14	$ 2,861.43	$ 112,549.52
Ni alloy	22	7	$ 64,399.01	$ 152,309.68	$ 22,846.45	$ 4,569.29	$ 179,725.42
Ti Clad	23	4.6	$ 42,319.35	$ 112,124.69	$ 16,818.70	$ 3,363.74	$ 132,307.14
Ti	24	9.4	$ 86,478.67	$ 192,494.66	$ 28,874.20	$ 5,774.84	$ 227,143.70

Pump	Flow Rate (L/h	Pump power required (k	Cpo	Cbm	Ctm
1	2,107.80	2.20	$ 3,468.87	$ 6,556.17	$ 7,736.27
2	8,452.00	4.00	$ 4,078.52	$ 7,708.40	$ 9,095.91
3	32,066.40	7.00	$ 4,941.84	$ 9,340.08	$ 11,021.30
4	11.28	0.05	$ 3,506.45	$ 6,627.20	$ 7,820.09
5	23,506.44	5.00	$ 4,382.44	$ 8,282.81	$ 9,773.71
6	5,641.54	4.00	$ 4,078.52	$ 7,708.40	$ 9,095.91
7	2.18	0.05	$ 3,506.45	$ 6,627.20	$ 7,820.09
8	514.50	0.37	$ 2,790.09	$ 5,273.28	$ 6,222.47
9	3,061.97	2.20	$ 3,468.87	$ 6,556.17	$ 7,736.27
10	612.57	0.37	$ 2,790.09	$ 5,273.28	$ 6,222.47
11	603.32	0.37	$ 2,790.09	$ 5,273.28	$ 6,222.47
12	603.34	0.37	$ 2,790.09	$ 5,273.28	$ 6,222.47
13	21,463.60	5.00	$ 4,382.44	$ 8,282.81	$ 9,773.71
14	1,626.32	2.20	$ 3,468.87	$ 6,556.17	$ 7,736.27
15	935.13	0.37	$ 2,790.09	$ 5,273.28	$ 6,222.47
16	2,496.27	2.20	$ 3,468.87	$ 6,556.17	$ 7,736.27

Filter #	Type	Area, m^2	K1	K2	K3	Cp0	Fbm	Cbm	Contingencie	Fees	Ctm
1	Plate-and-Frame	80	4.2756	0.352	0.0714	$ 159,985.54	1.65	$ 263,976.14	$ 39,596.42	$ 7,919.28	$ 311,491.85
2	Plate-and-Frame	80	4.2756	0.352	0.0714	$ 159,985.54	1.65	$ 263,976.14	$ 39,596.42	$ 7,919.28	$ 311,491.85

Diafilter Tank 1: Vertical			
Table A.1 Constan	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constan	B1	B2	
	2.25	1.82	

Volume, m^3	20
Diameter, m	2.039887828
Pressure (barg)	0.507
Cp0	$ 18,310.73
Fp	0.59660069

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 10,924.19	$ 61,081.18	$ 9,162.18	$ 1,832.44	$ 72,075.79
SS clad	19	1.8	$ 19,663.55	$ 76,986.81	$ 11,548.02	$ 2,309.60	$ 90,844.43
SS	20	3.1	$ 33,865.00	$ 102,833.45	$ 15,425.02	$ 3,085.00	$ 121,343.47
Ni alloy clad	21	3.6	$ 39,327.10	$ 112,774.47	$ 16,916.17	$ 3,383.23	$ 133,073.87
Ni alloy	22	7	$ 76,469.36	$ 180,373.39	$ 27,056.01	$ 5,411.20	$ 212,840.60
Ti Clad	23	4.6	$ 50,251.30	$ 132,656.50	$ 19,898.48	$ 3,979.70	$ 156,534.67
Ti	24	9.4	$ 102,687.43	$ 228,090.27	$ 34,213.54	$ 6,842.71	$ 269,146.52

Diafilter Tank 2: Vertical			
Table A.1 Constan	K1	K2	K3
	3.4974	0.4485	0.1074
Table A.4 Constan	B1	B2	
	2.25	1.82	

Volume, m^3	5
Diameter, m	1.285048807
Pressure (barg)	0.507
Cp0	$ 7,300.61
Fp	0.560854621

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
CS	18	1	$ 4,094.58	$ 23,878.52	$ 3,581.78	$ 716.36	$ 28,176.65
SS clad	19	1.8	$ 7,370.25	$ 29,840.23	$ 4,476.03	$ 895.21	$ 35,211.47
SS	20	3.1	$ 12,693.20	$ 39,528.01	$ 5,929.20	$ 1,185.84	$ 46,643.05
Ni alloy clad	21	3.6	$ 14,740.50	$ 43,254.08	$ 6,488.11	$ 1,297.62	$ 51,039.81
Ni alloy	22	7	$ 28,662.08	$ 68,591.36	$ 10,288.70	$ 2,057.74	$ 80,937.80
Ti Clad	23	4.6	$ 18,835.08	$ 50,706.22	$ 7,605.93	$ 1,521.19	$ 59,833.34
Ti	24	9.4	$ 38,489.07	$ 86,476.49	$ 12,971.47	$ 2,594.29	$ 102,042.26

Diafilter 1 Pump: Centrifugal			
Table A.1 Constants	K1	K2	K3
	3.3892	0.0536	0.1538
Table A.2 Constants	C1	C2	C3
P<10 barg	0	0	0
10<P<100 barg	-0.3995	0.3957	-0.00226
Table A.4 Constants	B1	B2	
	1.89	1.35	

Shaft power, kW	0.0102059
Discharge Pressure	2.04
Cp0	7802.6211
Fp	0

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
Cast Iron	37	1	0	14746.95	2212.043095	442.408619	17401.40568
Carbon Steel	38	1.6	0	14746.95	2212.043095	442.408619	17401.40568
SS	39	2.3	0	14746.95	2212.043095	442.408619	17401.40568
Ni Alloy	40	4.4	0	14746.95	2212.043095	442.408619	17401.40568

Diafilter 2 Pump: Centrifugal			
Table A.1 Constants	K1	K2	K3
	3.3892	0.0536	0.1538
Table A.2 Constants	C1	C2	C3
P<10 barg	0	0	0
10<P<100 barg	-0.3995	0.3957	-0.00226
Table A.4 Constants	B1	B2	
	1.89	1.35	

Shaft power, kW	0.0102059
Discharge Pressure	2.04
Cp0	7802.6211
Fp	0

MOC	ID#	Fm	Cp	Cbm	Contingencies	Fees	Ctm
Cast Iron	37	1	0	14746.95	2212.043095	442.408619	17401.40568
Carbon Steel	38	1.6	0	14746.95	2212.043095	442.408619	17401.40568
SS	39	2.3	0	14746.95	2212.043095	442.408619	17401.40568
Ni Alloy	40	4.4	0	14746.95	2212.043095	442.408619	17401.40568

Reference	Volume (L)	Price			
2012 2.12L Millipore Ga071711	2.12	$ 4,792.00			
	Volume	Price	Contengencies	Fees	Ctm
Protein A	1487.74	$ 244,473.35	$ 36,671.00	$ 7,334.20	$ 288,478.55
IEX	6739.94	$ 605,213.92	$ 90,782.09	$ 18,156.42	$ 714,152.43
HIC	606.59	$ 142,709.35	$ 21,406.40	$ 4,281.28	$ 168,397.04

March 13, 2019

Materials & Streams Report

for Design Project Upstream with Stream Numbers

1. OVERALL PROCESS DATA

Annual Operating Time	7,609.37h
Recipe Batch Time	1,242.70h
Recipe Cycle Time	318.33h
Number of Batches per Year	21.00

MP = Undefined

2.1 STARTING MATERIAL REQUIREMENTS (per Section)

Section	Starting Material	Active Product	Amount Needed (kg Sin/kg MP)	Molar Yield (%)	Mass Yield (%)	Gross Mass Yield (%)
Main Section	(none)	(none)	Unknown	Unknown	Unknown	Unknown
Cell Culture	(none)	(none)	Unknown	Unknown	Unknown	Unknown
Chromatography	(none)	(none)	Unknown	Unknown	Unknown	Unknown

Sin = Section Starting Material, Aout = Section Active Product

2.2 BULK MATERIALS (Entire Process)

Material	kg/yr	kg/batch	kg/kg MP
Air	1,162,624	55,363.03	
H3PO4 (5% w/w)	391,520	18,643.82	
Innoculum Media	14,664	698.28	
NaOH (0.1 M)	70,090	3,337.60	
NaOH (0.5 M)	201,291	9,585.30	
Polysorbate 80	5	0.24	
Prot A Equil	647,921	30,853.39	
Prot A Reg Buff	379,317	18,062.71	
Prot A Wash Buf	758,634	36,125.42	
Protein A Elut	635,340	30,254.29	
Serum Free Medi	53,985	2,570.72	
WFI	1,858,003	88,476.33	
TOTAL	6,173,394	293,971.15	

2.3 BULK MATERIALS (per Section)

SECTIONS IN: Main Branch

Main Section			
Material	**kg/yr**	**kg/batch**	**kg/kg MP**
Air	1,162,624	55,363.03	
H3PO4 (5% w/w)	391,520	18,643.82	
Innoculum Media	14,664	698.28	
NaOH (0.1 M)	70,090	3,337.60	
NaOH (0.5 M)	201,291	9,585.30	
Polysorbate 80	5	0.24	
Prot A Equil	647,921	30,853.39	
Prot A Reg Buff	379,317	18,062.71	
Prot A Wash Buf	758,634	36,125.42	
Protein A Elut	635,340	30,254.29	
Serum Free Medi	53,985	2,570.72	
WFI	1,858,003	88,476.33	
TOTAL	6,173,394	293,971.15	

2.4 BULK MATERIALS (per Material)

Air				
Procedure	**% Total**	**kg/yr**	**kg/batch**	**kg/kg MP**
Main Section (Main Branch)				
P-8	2.79	32,404	1,543.02	
P-10	11.17	129,868	6,184.21	
P-15	86.04	1,000,352	47,635.79	
TOTAL	100.00	1,162,624	55,363.03	

H3PO4 (5% w/w)				
Procedure	**% Total**	**kg/yr**	**kg/batch**	**kg/kg MP**
Main Section (Main Branch)				
P-6	3.93	15,394	733.07	
P-8	5.16	20,188	961.34	
P-5	6.25	24,457	1,164.64	
P-10	13.02	50,972	2,427.26	
P-11	9.74	38,145	1,816.43	
P-12	5.03	19,683	937.26	
P-15	20.92	81,896	3,899.80	
P-16	11.07	43,334	2,063.52	
P-17	4.48	17,536	835.05	
P-19	6.22	24,359	1,159.96	
P-22	7.07	27,676	1,317.92	
P-23	2.99	11,691	556.70	

P-24	4.13	16,188	770.86	
TOTAL	100.00	391,520	18,643.82	

Innoculum Media

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-1	1.54	226	10.74	
P-2	4.87	714	34.02	
P-3	18.63	2,732	130.11	
P-4	74.96	10,992	523.41	
TOTAL	100.00	14,664	698.28	

NaOH (0.1 M)

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-20	100.00	70,090	3,337.60	
TOTAL	100.00	70,090	3,337.60	

NaOH (0.5 M)

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-6	3.51	7,058	336.12	
P-8	4.60	9,256	440.78	
P-5	5.57	11,214	533.99	
P-10	11.61	23,371	1,112.91	
P-11	8.69	17,490	832.84	
P-12	4.48	9,025	429.74	
P-15	18.65	37,550	1,788.08	
P-16	9.87	19,869	946.13	
P-17	7.99	16,081	765.75	
P-19	9.71	19,545	930.74	
P-22	6.30	12,690	604.27	
P-23	5.33	10,721	510.50	
P-24	3.69	7,422	353.44	
TOTAL	100.00	201,291	9,585.30	

Polysorbate 80

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-24	100.00	5	0.24	
TOTAL	100.00	5	0.24	

Prot A Equil

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-20	100.00	647,921	30,853.39	
TOTAL	100.00	647,921	30,853.39	

Prot A Reg Buff

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-20	100.00	379,317	18,062.71	
TOTAL	100.00	379,317	18,062.71	

Prot A Wash Buf

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-20	100.00	758,634	36,125.42	
TOTAL	100.00	758,634	36,125.42	

Protein A Elut

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-20	100.00	635,340	30,254.29	
TOTAL	100.00	635,340	30,254.29	

Serum Free Medi

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-6	1.81	978	46.56	
P-5	7.26	3,921	186.71	
P-11	79.96	43,165	2,055.46	
P-12	10.97	5,922	282.00	
TOTAL	100.00	53,985	2,570.72	

WFI

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-6	3.80	70,558	3,359.93	
P-8	1.94	36,072	1,717.72	
P-5	11.64	216,333	10,301.59	
P-10	4.90	91,077	4,336.99	
P-11	37.40	694,821	33,086.71	
P-12	6.53	121,269	5,774.69	
P-15	7.88	146,330	6,968.12	
P-16	4.17	77,428	3,687.07	
P-17	5.06	94,000	4,476.17	
P-19	3.42	63,474	3,022.55	
P-20	2.25	41,778	1,989.41	
P-22	2.22	41,210	1,962.37	
P-23	7.25	134,724	6,415.42	

P-24	1.56	28,930	1,377.60
TOTAL	100.00	1,858,003	88,476.33

2.5 BULK MATERIALS: SECTION TOTALS (kg/batch)

Raw Material	Main Section	Cell Culture	Chromatography
Air	55,363.03	0.00	0.00
H3PO4 (5% w/w)	18,643.82	0.00	0.00
Innoculum Media	698.28	0.00	0.00
NaOH (0.1 M)	3,337.60	0.00	0.00
NaOH (0.5 M)	9,585.30	0.00	0.00
Polysorbate 80	0.24	0.00	0.00
Prot A Equil	30,853.39	0.00	0.00
Prot A Reg Buff	18,062.71	0.00	0.00
Prot A Wash Buf	36,125.42	0.00	0.00
Protein A Elut	30,254.29	0.00	0.00
Serum Free Medi	2,570.72	0.00	0.00
WFI	88,476.33	0.00	0.00
TOTAL	293,971.15	0.00	0.00

2.6 BULK MATERIALS: SECTION TOTALS (kg/yr)

Raw Material	Main Section	Cell Culture	Chromatography
Air	1,162,624	0	0
H3PO4 (5% w/w)	391,520	0	0
Innoculum Media	14,664	0	0
NaOH (0.1 M)	70,090	0	0
NaOH (0.5 M)	201,291	0	0
Polysorbate 80	5	0	0
Prot A Equil	647,921	0	0
Prot A Reg Buff	379,317	0	0
Prot A Wash Buf	758,634	0	0
Protein A Elut	635,340	0	0
Serum Free Medi	53,985	0	0
WFI	1,858,003	0	0
TOTAL	6,173,394	0	0

3. STREAM DETAILS

Stream Name	1	2	3	4
Source	**INPUT**	**P-1**	**INPUT**	**P-2**
Destination	**P-1**	**P-2**	**P-2**	**P-3**
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	37.00	25.00	25.00
Pressure (bar)	1.01	9.82	1.01	9.14
Density (g/L)	994.70	990.50	994.70	994.85
Total Enthalpy (kW-h)	0.31	0.46	0.99	1.31
Specific Enthalpy (kcal/kg)	25.11	37.10	25.11	25.11
Heat Capacity (kcal/kg-°C)	1.00	1.00	1.00	1.00
Component Flowrates (kg/batch)				
Biomass	0.00	0.03	0.00	0.13
Impurities	0.00	0.00	0.00	0.01
MAB	0.00	0.00	0.00	0.01
Media	0.23	0.07	0.74	0.24
Water	0.00	0.13	0.00	0.58
WFI	10.51	10.51	33.28	43.79
TOTAL (kg/batch)	10.74	10.74	34.02	44.76
TOTAL (L/batch)	10.80	10.85	34.20	44.99

Stream Name	5	6	7	8
Source	INPUT	P-3	P-3	INPUT
Destination	P-3	OUTPUT	P-4	P-4
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.00	25.00	25.00
Pressure (bar)	1.01	1.01	1.01	1.01
Density (g/L)	994.70	1.32	994.81	994.70
Total Enthalpy (kW-h)	3.80	0.00	5.10	15.27
Specific Enthalpy (kcal/kg)	25.11	22.66	25.11	25.11
Heat Capacity (kcal/kg-°C)	1.00	0.23	1.00	1.00
Component Flowrates (kg/batch)				
Biomass	0.00	0.00	0.34	0.00
Carb. Dioxide	0.00	0.05	0.00	0.00
Impurities	0.00	0.00	0.10	0.00
MAB	0.00	0.00	0.03	0.00
Media	2.81	0.00	0.92	11.31
Nitrogen	0.00	0.08	0.00	0.00
Oxygen	0.00	0.03	0.00	0.00
Water	0.00	0.00	2.18	0.00
WFI	127.30	0.00	171.09	512.10
TOTAL (kg/batch)	130.11	0.16	174.66	523.41
TOTAL (L/batch)	130.80	118.82	175.57	526.20

Stream Name	9	10	14	16
Source	P-4	P-4	P-7	INPUT
Destination	OUTPUT	P-8	P-8	P-8
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	37.03	37.00	25.00	25.00
Pressure (bar)	1.01	1.01	10.13	1.01
Density (g/L)	1.27	990.43	994.70	1.18
Total Enthalpy (kW-h)	0.02	30.06	61.18	10.85
Specific Enthalpy (kcal/kg)	25.43	37.10	25.11	6.05
Heat Capacity (kcal/kg-°C)	0.23	1.00	1.00	0.24
Component Flowrates (kg/batch)				
Biomass	0.00	1.20	0.00	0.00
Carb. Dioxide	0.22	0.00	0.00	0.00
Impurities	0.00	0.44	0.00	0.00
MAB	0.00	0.11	0.00	0.00
Media	0.00	3.67	0.00	0.00
Nitrogen	0.37	0.00	0.00	1,183.68
Oxygen	0.11	0.00	0.00	359.34
Serum Free Medi	0.00	0.00	46.56	0.00
Water	0.00	8.60	0.00	0.00
WFI	0.00	683.19	2,050.09	0.00
TOTAL (kg/batch)	0.71	697.21	2,096.65	1,543.02
TOTAL (L/batch)	559.51	703.95	2,107.81	1,308,510.79

Stream Name	18	17	11	12
Source	P-8	P-8	INPUT	INPUT
Destination	OUTPUT	P-10	P-6	P-6
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	37.00	37.00	25.00	25.00
Pressure (bar)	1.01	1.01	1.01	1.01
Density (g/L)	1.13	990.47	994.70	994.70
Total Enthalpy (kW-h)	16.36	120.30	59.83	1.36
Specific Enthalpy (kcal/kg)	9.08	37.10	25.11	25.11
Heat Capacity (kcal/kg-°C)	0.24	1.00	1.00	1.00
Component Flowrates (kg/batch)				
Biomass	0.00	6.79	0.00	0.00
Carb. Dioxide	3.72	0.00	0.00	0.00
Impurities	0.00	1.93	0.00	0.00
MAB	0.00	0.49	0.00	0.00
Media	0.00	3.67	0.00	0.00
Nitrogen	1,186.26	0.00	0.00	0.00
Oxygen	360.12	0.00	0.00	0.00
Serum Free Medi	0.00	9.31	0.00	46.56
Water	0.00	34.68	0.00	0.00
WFI	0.00	2,733.28	2,050.09	0.00
TOTAL (kg/batch)	1,550.10	2,790.13	2,050.09	46.56
TOTAL (L/batch)	1,366,288.73	2,816.99	2,061.00	46.81

Stream Name	13	22	24	26
Source	P-6	P-9	INPUT	P-10
Destination	P-7	P-10	P-10	OUTPUT
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.00	25.00	37.00
Pressure (bar)	10.13	10.13	1.01	1.01
Density (g/L)	994.70	994.70	1.18	1.14
Total Enthalpy (kW-h)	61.18	245.34	43.48	72.03
Specific Enthalpy (kcal/kg)	25.11	25.11	6.05	10.05
Heat Capacity (kcal/kg-°C)	1.00	1.00	0.24	0.24
Component Flowrates (kg/batch)				
Carb. Dioxide	0.00	0.00	0.00	125.39
Nitrogen	0.00	0.00	4,744.02	4,754.35
Oxygen	0.00	0.00	1,440.19	1,286.59
Serum Free Medi	46.56	186.71	0.00	0.00
WFI	2,050.09	8,220.63	0.00	0.00
TOTAL (kg/batch)	2,096.65	8,407.34	6,184.21	6,166.33
TOTAL (L/batch)	2,107.81	8,452.10	5,244,314.32	5,415,119.54

Stream Name	25	19	20	21
Source	P-10	INPUT	INPUT	P-5
Destination	P-15	P-5	P-5	P-9
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	37.00	25.00	25.00	25.00
Pressure (bar)	1.01	1.01	1.01	10.13
Density (g/L)	990.60	994.70	994.70	994.70
Total Enthalpy (kW-h)	484.14	239.90	5.45	245.34
Specific Enthalpy (kcal/kg)	37.10	25.11	25.11	25.11
Heat Capacity (kcal/kg-°C)	1.00	1.00	1.00	1.00
Component Flowrates (kg/batch)				
Biomass	53.83	0.00	0.00	0.00
Impurities	11.34	0.00	0.00	0.00
MAB	6.76	0.00	0.00	0.00
Media	3.67	0.00	0.00	0.00
Serum Free Medi	39.20	0.00	186.71	186.71
Water	160.13	0.00	0.00	0.00
WFI	10,953.91	8,220.63	0.00	8,220.63
TOTAL (kg/batch)	11,228.84	8,220.63	186.71	8,407.34
TOTAL (L/batch)	11,335.39	8,264.40	187.70	8,452.10

Stream Name	30	35	37	39
Source	P-13	P-14	INPUT	P-15
Destination	P-15	P-15	P-15	OUTPUT
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.00	25.00	37.00
Pressure (bar)	10.13	10.13	1.01	1.01
Density (g/L)	994.70	994.70	1.18	1.14
Total Enthalpy (kW-h)	930.81	94.31	334.93	547.72
Specific Enthalpy (kcal/kg)	25.11	25.11	6.05	9.93
Heat Capacity (kcal/kg-°C)	1.00	1.00	0.24	0.24
Component Flowrates (kg/batch)				
Carb. Dioxide	0.00	0.00	0.00	858.25
Nitrogen	0.00	0.00	36,542.27	36,585.12
Oxygen	0.00	0.00	11,093.53	10,020.14
Serum Free Medi	2,055.46	207.98	0.00	0.00
WFI	29,841.13	3,023.82	0.00	0.00
TOTAL (kg/batch)	31,896.59	3,231.80	47,635.79	47,463.51
TOTAL (L/batch)	32,066.40	3,249.00	40,395,964.91	41,703,363.22

Stream Name	38	27	28	29
Source	**P-15**	**INPUT**	**INPUT**	**P-11**
Destination	**P-16**	**P-11**	**P-11**	**P-13**
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	37.00	25.00	25.00	25.00
Pressure (bar)	1.01	1.01	1.01	10.13
Density (g/L)	990.91	994.70	994.70	994.70
Total Enthalpy (kW-h)	2,008.54	870.83	59.98	930.81
Specific Enthalpy (kcal/kg)	37.10	25.11	25.11	25.11
Heat Capacity (kcal/kg-°C)	1.00	1.00	1.00	1.00
Component Flowrates (kg/batch)				
Biomass	477.64	0.00	0.00	0.00
Impurities	54.81	0.00	0.00	0.00
MAB	93.70	0.00	0.00	0.00
Media	3.67	0.00	0.00	0.00
Serum Free Medi	1,215.94	0.00	2,055.46	2,055.46
Water	920.82	0.00	0.00	0.00
WFI	43,818.86	29,841.13	0.00	29,841.13
TOTAL (kg/batch)	46,585.43	29,841.13	2,055.46	31,896.59
TOTAL (L/batch)	47,012.88	30,000.00	2,066.40	32,066.40

Stream Name	32	33	34	41
Source	**INPUT**	**INPUT**	**P-12**	**P-16**
Destination	**P-12**	**P-12**	**P-14**	**P-17**
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.00	25.00	37.00
Pressure (bar)	1.01	1.01	10.13	10.54
Density (g/L)	994.70	994.70	994.70	990.91
Total Enthalpy (kW-h)	119.65	8.23	94.31	2,008.45
Specific Enthalpy (kcal/kg)	25.11	25.11	25.11	37.10
Heat Capacity (kcal/kg-°C)	1.00	1.00	1.00	1.00
Component Flowrates (kg/batch)				
Biomass	0.00	0.00	0.00	477.64
Impurities	0.00	0.00	0.00	54.81
MAB	0.00	0.00	0.00	93.70
Media	0.00	0.00	0.00	3.67
Serum Free Medi	0.00	282.00	207.98	1,215.94
Water	0.00	0.00	0.00	920.82
WFI	4,100.00	0.00	3,023.82	43,818.86
TOTAL (kg/batch)	4,100.00	282.00	3,231.80	46,585.43
TOTAL (L/batch)	4,121.83	283.50	3,249.00	47,012.85

Stream Name	43	44	45	48
Source	P-17	P-17	P-18	P-19
Destination	P-18	OUTPUT	P-19	P-20
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	43.10	43.10	43.10	43.09
Pressure (bar)	10.54	1.01	10.54	10.75
Density (g/L)	988.12	999.87	988.11	988.11
Total Enthalpy (kW-h)	2,220.71	117.62	2,219.78	2,219.39
Specific Enthalpy (kcal/kg)	43.19	43.17	43.19	43.18
Heat Capacity (kcal/kg-°C)	1.00	1.00	1.00	1.00
Component Flowrates (kg/batch)				
Biomass	9.55	468.09	0.00	0.00
Impurities	52.58	2.23	52.57	52.57
MAB	89.88	3.81	89.86	89.86
Media	3.52	0.15	3.52	3.52
Serum Free Medi	1,166.46	49.48	1,166.22	1,166.22
Water	883.35	37.47	883.17	883.17
WFI	42,035.67	1,783.19	42,027.13	42,027.13
TOTAL (kg/batch)	44,241.00	2,344.42	44,222.46	44,222.46
TOTAL (L/batch)	44,772.96	2,344.72	44,754.76	44,754.64

Stream Name	47	Prot A Equil - 51	Prot A Wash - 52	Prot A Elut - 53
Source	**P-18**	**INPUT**	**INPUT**	**INPUT**
Destination	**OUTPUT**	**P-20**	**P-20**	**P-20**
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	43.10	25.00	25.00	25.00
Pressure (bar)	10.54	1.01	1.01	1.01
Density (g/L)	1,019.05	1,030.00	1,005.00	1,010.00
Total Enthalpy (kW-h)	0.93	895.13	1,050.91	880.17
Specific Enthalpy (kcal/kg)	43.13	24.96	25.03	25.03
Heat Capacity (kcal/kg-°C)	1.00	0.99	1.00	1.00
Component Flowrates (kg/batch)				
Acetic-Acid	0.00	0.00	0.00	181.53
Biomass	9.55	0.00	0.00	0.00
EDTA Sodium	0.00	61.71	0.00	0.00
Impurities	0.01	0.00	0.00	0.00
KCl	0.00	0.00	0.04	0.00
KH2PO4	0.00	0.00	0.04	0.00
MAB	0.02	0.00	0.00	0.00
Media	0.00	0.00	0.00	0.00
Na2HPO4	0.00	0.00	19.87	0.00
Serum Free Medi	0.24	0.00	0.00	0.00
Sodium Chloride	0.00	30.85	173.40	0.00
Sodium Citrate	0.00	0.00	32.51	0.00
TRIS Base	0.00	30.85	0.00	0.00
TRIS HCl	0.00	92.56	0.00	0.00
Water	0.18	0.00	0.00	0.00
WFI	8.54	30,637.42	35,899.57	30,072.77
TOTAL (kg/batch)	18.54	30,853.39	36,125.42	30,254.29
TOTAL (L/batch)	18.20	29,954.75	35,945.70	29,954.75

Stream Name	Prot A Reg - 54	55	56	62
Source	INPUT	P-20	P-20	P-23
Destination	P-20	P-21	OUTPUT	P-22
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.12	30.43	25.83
Pressure (bar)	1.01	1.01	1.01	1.01
Density (g/L)	1,005.00	994.93	994.35	994.50
Total Enthalpy (kW-h)	526.23	356.28	5,215.54	73.37
Specific Enthalpy (kcal/kg)	25.07	25.16	30.46	25.91
Heat Capacity (kcal/kg-°C)	1.00	1.00	1.00	1.00
Component Flowrates (kg/batch)				
Acetic-Acid	0.00	72.61	108.92	5.20
EDTA Sodium	0.00	0.00	61.71	0.00
Impurities	0.00	3.15	49.41	0.23
KCl	0.00	0.00	0.04	0.00
KH2PO4	0.00	0.00	0.04	0.00
MAB	0.00	80.88	8.99	80.88
Media	0.00	0.00	3.52	0.00
Na2HPO4	0.00	0.00	19.87	0.00
Serum Free Medi	0.00	0.00	1,166.22	0.00
Sodium Chloride	0.00	0.00	204.26	0.00
Sodium Citrate	32.51	0.00	65.03	0.00
TRIS Base	0.00	0.00	30.85	0.00
TRIS HCl	0.00	0.00	92.56	0.00
Water	0.00	0.00	883.17	0.00
WFI	18,030.20	12,029.11	144,637.97	2,350.49
TOTAL (kg/batch)	18,062.71	12,185.75	147,332.53	2,436.79
TOTAL (L/batch)	17,972.85	12,247.87	148,170.18	2,450.27

Stream Name	57	68	58	66
Source	P-21	P-22	P-22	P-22
Destination	P-22	OUTPUT	P-23	P-24
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.12	25.82	25.12	25.82
Pressure (bar)	1.01	1.01	10.14	1.01
Density (g/L)	994.93	1.18	994.93	994.50
Total Enthalpy (kW-h)	356.25	0.02	356.27	73.36
Specific Enthalpy (kcal/kg)	25.15	6.25	25.16	25.90
Heat Capacity (kcal/kg-°C)	1.00	0.24	1.00	1.00
Component Flowrates (kg/batch)				
Acetic-Acid	72.61	0.00	72.61	5.20
Impurities	3.15	0.00	3.15	0.23
MAB	80.88	0.00	80.88	80.88
Nitrogen	0.00	2.24	0.00	0.00
Oxygen	0.00	0.68	0.00	0.00
WFI	12,029.11	0.00	12,029.11	2,350.49
TOTAL (kg/batch)	12,185.75	2.93	12,185.75	2,436.79
TOTAL (L/batch)	12,247.87	2,487.90	12,247.87	2,450.27

Stream Name	60	61	64	65
Source	INPUT	INPUT	P-23	P-23
Destination	P-23	P-23	OUTPUT	OUTPUT
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.00	25.00	25.83
Pressure (bar)	1.01	1.01	1.01	1.01
Density (g/L)	994.70	994.70	994.70	994.65
Total Enthalpy (kW-h)	71.11	29.03	29.03	366.25
Specific Enthalpy (kcal/kg)	25.11	25.11	25.11	25.86
Heat Capacity (kcal/kg-°C)	1.00	1.00	1.00	1.00
Component Flowrates (kg/batch)				
Acetic-Acid	0.00	0.00	0.00	67.41
Impurities	0.00	0.00	0.00	2.93
WFI	2,436.60	994.70	994.70	12,115.22
TOTAL (kg/batch)	2,436.60	994.70	994.70	12,185.56
TOTAL (L/batch)	2,449.57	1,000.00	1,000.00	12,251.09

Stream Name	69	72	70	73
Source	INPUT	P-24	P-24	P-25
Destination	P-24	OUTPUT	P-25	OUTPUT
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.82	25.82	25.82
Pressure (bar)	1.01	1.01	1.01	1.01
Density (g/L)	870.19	1.18	994.47	994.47
Total Enthalpy (kW-h)	0.01	0.02	73.37	73.37
Specific Enthalpy (kcal/kg)	13.77	6.25	25.90	25.90
Heat Capacity (kcal/kg-°C)	0.55	0.24	1.00	1.00
Component Flowrates (kg/batch)				
Acetic-Acid	0.00	0.00	5.20	5.20
Impurities	0.00	0.00	0.23	0.23
MAB	0.00	0.00	80.88	80.88
Nitrogen	0.00	2.22	0.00	0.00
Oxygen	0.00	0.67	0.00	0.00
Polysorbate 80	0.24	0.00	0.24	0.24
WFI	0.24	0.00	2,350.74	2,350.74
TOTAL (kg/batch)	0.49	2.89	2,437.28	2,437.28
TOTAL (L/batch)	0.56	2,458.36	2,450.83	2,450.83

4. OVERALL COMPONENT BALANCE (kg/batch)

COMPONENT	INITIAL	INPUT	OUTPUT	FINAL	IN-OUT
Acetic-Acid	0.00	181.53	181.53	0.00	0.00
Biomass	0.00	0.00	477.64	0.00	- 477.64
Carb. Dioxide	0.00	0.00	987.63	1.11	- 988.74
EDTA Sodium	0.00	61.71	61.71	0.00	0.00
Impurities	0.00	0.00	54.81	0.00	- 54.81
KCl	0.00	0.04	0.04	0.00	0.00
KH2PO4	0.00	0.04	0.04	0.00	0.00
MAB	0.00	0.00	93.70	0.00	- 93.70
Media	0.00	15.09	3.67	0.00	11.42
Na2HPO4	0.00	19.87	19.87	0.00	0.00
Nitrogen	225.31	42,469.97	42,530.64	166.85	- 2.21
Oxygen	68.40	12,893.06	11,668.35	50.26	1,242.84
Phosphoric Acid	0.00	932.19	932.19	0.00	0.00
Polysorbate 80	0.00	0.24	0.24	0.00	0.00
Serum Free Medi	0.00	2,570.72	1,215.94	74.02	1,280.77
Sodium Chloride	0.00	204.26	204.26	0.00	0.00
Sodium Citrate	0.00	65.03	65.03	0.00	0.00
Sodium Hydroxid	0.00	251.95	251.95	0.00	0.00
TRIS Base	0.00	30.85	30.85	0.00	0.00
TRIS HCl	0.00	92.56	92.56	0.00	0.00
Water	0.00	12,670.95	13,591.77	0.00	- 920.82
WFI	0.00	221,511.10	220,434.92	1,076.18	- 0.00
TOTAL	293.71	293,971.15	292,899.32	1,368.43	2.88
				Overall Error:	0.001%

5. EQUIPMENT CONTENTS

TFR-101

Procedure	Operation	Time (in h)	Volume (in L)
P-1	START	0.00	0.00
P-1	HOLD-1 (Holding)	1.00	0.00
P-1	CHARGE-1 (Charge)	1.50	10.80
P-1	REACT-1 (Batch Stoich. Reaction)	97.50	10.85
P-1	TRANSFER-OUT-1 (Transfer Out)	98.00	0.00

RBR-101

Procedure	Operation	Time (in h)	Volume (in L)
P-2	START	96.50	0.00
P-2	HOLD-1 (Holding)	97.50	0.00
P-2	TRANSFER-IN-1 (Transfer In)	98.00	10.85
P-2	CHARGE-1 (Charge)	98.50	45.05
P-2	REACT-1 (Batch Stoich. Reaction)	242.50	44.99
P-2	TRANSFER-OUT-1 (Transfer Out)	243.50	0.00

RBS-101

Procedure	Operation	Time (in h)	Volume (in L)
P-3	START	240.50	0.00
P-3	HOLD-1 (Holding)	242.50	0.00
P-3	TRANSFER-IN-1 (Transfer In)	243.50	44.99
P-3	CHARGE-1 (Charge)	244.50	175.79
P-3	REACT-1 (Batch Stoich. Reaction)	388.50	175.57
P-3	TRANSFER-OUT-1 (Transfer Out)	389.00	0.00

RBS-102

Procedure	Operation	Time (in h)	Volume (in L)
P-4	START	386.50	0.00
P-4	HOLD-1 (Holding)	388.50	0.00
P-4	TRANSFER-IN-1 (Transfer In)	389.00	175.57
P-4	CHARGE-1 (Charge)	389.50	701.77
P-4	REACT-1 (Batch Stoich. Reaction)	533.50	703.95
P-4	TRANSFER-OUT-1 (Transfer Out)	534.00	0.00

V-101

Procedure	Operation	Time (in h)	Volume (in L)
P-6	START	530.67	0.00
P-6	SIP-1 (In-Place-Steaming)	531.50	0.00
P-6	CHARGE-1 (Charge)	532.00	2,061.00
P-6	PULL-IN-1 (Pull In)	532.50	2,107.81
P-6	TRANSFER-OUT-1 (Transfer Out)	533.50	0.00
P-6	CIP-1 (In-Place-Cleaning)	535.33	0.00

DE-101

Procedure	Operation	Time (in h)	Volume (in L)
P-7	START	532.00	0.00
P-7	HOLD-1 (Holding)	532.50	0.00
P-7	FILTER-1 (Dead-End Filtration)	533.50	0.00

SBR-101

Procedure	Operation	Time (in h)	Volume (in L)
P-8	START	507.67	0.00
P-8	SIP-1 (In-Place-Steaming)	508.50	0.00
P-8	HOLD-1 (Holding)	532.50	0.00
P-8	TRANSFER-IN-1 (Transfer In)	533.50	2,107.81
P-8	TRANSFER-IN-2 (Transfer In)	534.00	2,811.75
P-8	FERMENT-1 (Batch Stoich. Fermentation)	678.00	2,816.99
P-8	TRANSFER-OUT-1 (Transfer Out)	682.98	0.00
P-8	CIP-1 (In-Place-Cleaning)	684.82	0.00

V-102

Procedure	Operation	Time (in h)	Volume (in L)
P-5	START	674.86	0.00
P-5	SIP-1 (In-Place-Steaming)	675.69	0.00
P-5	CHARGE-1 (Charge)	676.69	8,264.40
P-5	PULL-IN-1 (Pull In)	677.00	8,452.10
P-5	TRANSFER-OUT-1 (Transfer Out)	678.00	0.00
P-5	CIP-1 (In-Place-Cleaning)	679.83	0.00

DE-102

Procedure	Operation	Time (in h)	Volume (in L)
P-9	START	676.50	0.00
P-9	HOLD-1 (Holding)	677.00	0.00
P-9	FILTER-1 (Dead-End Filtration)	678.00	0.00

SBR-102

Procedure	Operation	Time (in h)	Volume (in L)
P-10	START	653.17	0.00
P-10	SIP-1 (In-Place-Steaming)	654.00	0.00
P-10	HOLD-1 (Holding)	678.00	0.00
P-10	TRANSFER-IN-1 (Transfer In)	678.00	8,452.10
P-10	TRANSFER-IN-2 (Transfer In)	682.98	11,269.07
P-10	FERMENT-1 (Batch Stoich. Fermentation)	826.98	11,335.39
P-10	TRANSFER-OUT-1 (Transfer Out)	828.32	0.00
P-10	CIP-1 (In-Place-Cleaning)	831.15	0.00

V-103

Procedure	Operation	Time (in h)	Volume (in L)
P-11	START	819.39	0.00
P-11	SIP-1 (In-Place-Steaming)	820.22	0.00
P-11	CHARGE-1 (Charge)	822.22	30,000.00
P-11	PULL-IN-1 (Pull In)	825.98	32,066.40
P-11	TRANSFER-OUT-1 (Transfer Out)	826.98	0.00
P-11	CIP-1 (In-Place-Cleaning)	828.82	0.00

V-104

Procedure	Operation	Time (in h)	Volume (in L)
P-12	START	825.48	0.00
P-12	SIP-1 (In-Place-Steaming)	826.32	0.00
P-12	CHARGE-1 (Charge)	827.32	4,121.83
P-12	CHARGE-2 (Charge)	828.32	4,405.33
P-12	PULL-OUT-1 (Pull Out)	1,116.32	1,156.33
P-12	CIP-1 (In-Place-Cleaning)	1,118.15	1,156.33

DE-103

Procedure	Operation	Time (in h)	Volume (in L)
P-13	START	825.48	0.00
P-13	HOLD-1 (Holding)	825.98	0.00
P-13	FILTER-1 (Dead-End Filtration)	826.98	0.00

DE-104

Procedure	Operation	Time (in h)	Volume (in L)
P-14	START	827.82	0.00
P-14	HOLD-1 (Holding)	828.32	0.00
P-14	FILTER-1 (Dead-End Filtration)	1,116.32	0.00

BR-101

Procedure	Operation	Time (in h)	Volume (in L)
P-15	START	801.15	0.00
P-15	SIP-1 (In-Place-Steaming)	801.98	0.00
P-15	HOLD-1 (Holding)	825.98	0.00
P-15	TRANSFER-IN-1 (Transfer In)	826.98	32,066.40
P-15	TRANSFER-IN-2 (Transfer In)	828.32	43,401.75
P-15	FERMENT-1 (Batch Stoich. Fermentation)	1,116.32	47,012.88
P-15	TRANSFER-OUT-1 (Transfer Out)	1,117.65	0.00
P-15	CIP-1 (In-Place-Cleaning)	1,119.48	0.00

V-105

Procedure	Operation	Time (in h)	Volume (in L)
P-16	START	1,115.48	0.00
P-16	SIP-1 (In-Place-Steaming)	1,116.32	0.00
P-16	TRANSFER-IN-1 (Transfer In)	1,117.65	47,012.85
P-16	TRANSFER-OUT-1 (Transfer Out)	1,125.98	0.00
P-16	CIP-1 (In-Place-Cleaning)	1,127.82	0.00

DE-105

Procedure	Operation	Time (in h)	Volume (in L)
P-18	START	1,117.15	0.00
P-18	HOLD-1 (Holding)	1,117.65	0.00
P-18	FILTER-1 (Dead-End Filtration)	1,125.98	18.20
P-18	TRANSFER-OUT-1 (Transfer Out)	1,125.98	0.00

V-106

Procedure	Operation	Time (in h)	Volume (in L)
P-19	START	1,116.82	0.00
P-19	SIP-1 (In-Place-Steaming)	1,117.65	0.00
P-19	HOLD-1 (Holding)	1,120.65	0.00
P-19	TRANSFER-IN-1 (Transfer In)	1,125.98	44,754.64
P-19	TRANSFER-OUT-1 (Transfer Out)	1,212.97	0.00
P-19	CIP-1 (In-Place-Cleaning)	1,214.80	0.00

C-101

Procedure	Operation	Time (in h)	Volume (in L)
P-20	START	1,118.98	0.00
	AFTER AUTO-INIT	1,118.98	11,188.66
P-20	EQUILIBRATE-1 (Column Equilibration (Simplified))	1,210.03	11,188.66
P-20	HOLD-1 (Holding)	1,212.03	11,188.66
P-20	LOAD-1 (PBA Column Loading (Simplified))	1,212.97	0.00
P-20	WASH-1 (Column Wash (Simplified))	1,221.97	0.00
P-20	ELUTE-1 (Column Elution (Simplified))	1,229.47	0.00
P-20	REGENERATE-1 (Column Regeneration (Simplified))	1,232.47	0.00
P-20	CIP-1 (In-Place-Cleaning)	1,233.72	0.00

DE-106

Procedure	Operation	Time (in h)	Volume (in L)
P-21	START	1,135.42	0.00
P-21	HOLD-1 (Holding)	1,135.92	0.00
P-21	FILTER-1 (Dead-End Filtration)	1,155.22	0.00

V-107

Procedure	Operation	Time (in h)	Volume (in L)
P-22	START	1,132.08	0.00
P-22	SIP-1 (In-Place-Steaming)	1,132.92	0.00
P-22	HOLD-1 (Holding)	1,135.92	0.00
P-22	TRANSFER-IN-1 (Transfer In)	1,229.47	12,247.87
P-22	TRANSFER-OUT-1 (Transfer Out)	1,229.72	0.00
P-22	TRANSFER-IN-2 (Transfer In)	1,233.47	2,450.27
P-22	TRANSFER-OUT-2 (Transfer Out)	1,233.72	0.00
P-22	CIP-1 (In-Place-Cleaning)	1,235.55	0.00

DF-101

Procedure	Operation	Time (in h)	Volume (in L)
P-23	START	1,228.47	0.00
	AFTER AUTO-INIT	1,228.47	12,247.87
P-23	SIP-1 (In-Place-Steaming)	1,229.30	12,247.87
P-23	FLUSH-1 (Flush)	1,229.47	12,247.87
P-23	DIAFILTER-1 (Diafiltration)	1,233.47	2,450.27
P-23	CIP-1 (In-Place-Cleaning)	1,235.30	2,450.27
P-23	END	1,235.30	0.00

V-108

Procedure	Operation	Time (in h)	Volume (in L)
P-24	START	1,232.64	0.00
P-24	SIP-1 (In-Place-Steaming)	1,233.47	0.00
P-24	TRANSFER-IN-1 (Transfer In)	1,234.72	2,450.27
P-24	PULL-IN-1 (Pull In)	1,235.05	2,450.83
P-24	HOLD-1 (Holding)	1,236.55	2,450.83
P-24	TRANSFER-OUT-1 (Transfer Out)	1,240.87	0.00
P-24	CIP-1 (In-Place-Cleaning)	1,242.70	0.00

DE-107

Procedure	Operation	Time (in h)	Volume (in L)
P-25	START	1,236.55	0.00
P-25	HOLD-1 (Holding)	1,237.05	0.00
P-25	FILTER-1 (Dead-End Filtration)	1,240.87	0.00

Materials & Streams Report

March 13, 2019

for Design Project IEX to end with Stream Numbers

1. OVERALL PROCESS DATA

Annual Operating Time	7,672.99h
Recipe Batch Time	1,663.56h
Recipe Cycle Time	353.50h
Number of Batches per Year	18.00

MP = Undefined

2.1 STARTING MATERIAL REQUIREMENTS (per Section)

Section	Starting Material	Active Product	Amount Needed (kg Sin/kg MP)	Molar Yield (%)	Mass Yield (%)	Gross Mass Yield (%)
Main Section	(none)	(none)	Unknown	Unknown	Unknown	Unknown

Sin = Section Starting Material, Aout = Section Active Product

2.2 BULK MATERIALS (Entire Process)

Material	kg/yr	kg/batch	kg/kg MP
Acetic-Acid	94	5.20	
Amm. Sulfate	76,574	4,254.11	
H3PO4 (5% w/w)	68,839	3,824.40	
HIC-El-Buff	167,875	9,326.39	
HIC-Eq-Buff	69,443	3,857.94	
HIC-Wash-Buff	173,607	9,644.86	
IEX El Buffer	102,978	5,721.02	
IEX Equil Buffe	365,413	20,300.70	
IEX Wash Buffer	1,828,883	101,604.62	
Impurities	4	0.23	
MAB	1,456	80.88	
NaCl (1 M)	1,124,627	62,479.26	
NaOH (0.1 M)	56,322	3,129.00	
NaOH (0.5 M)	1,317,786	73,210.33	
NaOH (1 M)	56,322	3,129.00	
PBS	89,773	4,987.37	
Polysorbate 80	4	0.24	
WFI	1,953,267	108,514.84	
TOTAL	7,453,267	414,070.38	

2.3 BULK MATERIALS (per Section)

SECTIONS IN: Main Branch

Main Section

Material	kg/yr	kg/batch	kg/kg MP
Acetic-Acid	94	5.20	
Amm. Sulfate	76,574	4,254.11	
H3PO4 (5% w/w)	68,839	3,824.40	
HIC-El-Buff	167,875	9,326.39	
HIC-Eq-Buff	69,443	3,857.94	
HIC-Wash-Buff	173,607	9,644.86	
IEX El Buffer	102,978	5,721.02	
IEX Equil Buffe	365,413	20,300.70	
IEX Wash Buffer	1,828,883	101,604.62	
Impurities	4	0.23	
MAB	1,456	80.88	
NaCl (1 M)	1,124,627	62,479.26	
NaOH (0.1 M)	56,322	3,129.00	
NaOH (0.5 M)	1,317,786	73,210.33	
NaOH (1 M)	56,322	3,129.00	
PBS	89,773	4,987.37	
Polysorbate 80	4	0.24	
WFI	1,953,267	108,514.84	
TOTAL	7,453,267	414,070.38	

2.4 BULK MATERIALS (per Material)

Acetic-Acid

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-1	100.00	94	5.20	
TOTAL	100.00	94	5.20	

Amm. Sulfate

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-2	100.00	76,574	4,254.11	
TOTAL	100.00	76,574	4,254.11	

H3PO4 (5% w/w)

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-2	49.37	33,983	1,887.93	
P-5	21.89	15,066	836.99	
P-7	21.89	15,066	836.99	
P-8	6.86	4,725	262.50	
TOTAL	100.00	68,839	3,824.40	

HIC-El-Buff

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-3	100.00	167,875	9,326.39	
TOTAL	100.00	167,875	9,326.39	

HIC-Eq-Buff

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-3	100.00	69,443	3,857.94	
TOTAL	100.00	69,443	3,857.94	

HIC-Wash-Buff

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-3	100.00	173,607	9,644.86	
TOTAL	100.00	173,607	9,644.86	

IEX El Buffer

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-1	100.00	102,978	5,721.02	
TOTAL	100.00	102,978	5,721.02	

IEX Equil Buffe

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-1	100.00	365,413	20,300.70	
TOTAL	100.00	365,413	20,300.70	

IEX Wash Buffer

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-1	100.00	1,828,883	101,604.62	
TOTAL	100.00	1,828,883	101,604.62	

Impurities				
Procedure	**% Total**	**kg/yr**	**kg/batch**	**kg/kg MP**
Main Section (Main Branch)				
P-1	100.00	4	0.23	
TOTAL	100.00	4	0.23	

MAB				
Procedure	**% Total**	**kg/yr**	**kg/batch**	**kg/kg MP**
Main Section (Main Branch)				
P-1	100.00	1,456	80.88	
TOTAL	100.00	1,456	80.88	

NaCl (1 M)				
Procedure	**% Total**	**kg/yr**	**kg/batch**	**kg/kg MP**
Main Section (Main Branch)				
P-1	100.00	1,124,627	62,479.26	
TOTAL	100.00	1,124,627	62,479.26	

NaOH (0.1 M)				
Procedure	**% Total**	**kg/yr**	**kg/batch**	**kg/kg MP**
Main Section (Main Branch)				
P-1	100.00	56,322	3,129.00	
TOTAL	100.00	56,322	3,129.00	

NaOH (0.5 M)				
Procedure	**% Total**	**kg/yr**	**kg/batch**	**kg/kg MP**
Main Section (Main Branch)				
P-1	84.60	1,114,800	61,933.32	
P-2	1.25	16,522	917.89	
P-3	12.69	167,220	9,290.00	
P-5	0.56	7,325	406.93	
P-7	0.56	7,325	406.93	
P-8	0.35	4,595	255.25	
TOTAL	100.00	1,317,786	73,210.33	

NaOH (1 M)				
Procedure	**% Total**	**kg/yr**	**kg/batch**	**kg/kg MP**
Main Section (Main Branch)				
P-3	100.00	56,322	3,129.00	
TOTAL	100.00	56,322	3,129.00	

PBS				
Procedure	**% Total**	**kg/yr**	**kg/batch**	**kg/kg MP**
Main Section (Main Branch)				
P-8	100.00	89,773	4,987.37	
TOTAL	100.00	89,773	4,987.37	

Polysorbate 80

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-1	100.00	4	0.24	
TOTAL	100.00	4	0.24	

WFI

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-1	90.85	1,774,497	98,583.15	
P-2	3.30	64,386	3,577.00	
P-3	1.10	21,486	1,193.65	
P-5	1.46	28,545	1,585.82	
P-7	1.46	28,545	1,585.82	
P-8	1.83	35,809	1,989.41	
TOTAL	100.00	1,953,267	108,514.84	

2.5 BULK MATERIALS: SECTION TOTALS (kg/batch)

Raw Material	Main Section
Acetic-Acid	5.20
Amm. Sulfate	4,254.11
H3PO4 (5% w/w)	3,824.40
HIC-El-Buff	9,326.39
HIC-Eq-Buff	3,857.94
HIC-Wash-Buff	9,644.86
IEX El Buffer	5,721.02
IEX Equil Buffe	20,300.70
IEX Wash Buffer	101,604.62
Impurities	0.23
MAB	80.88
NaCl (1 M)	62,479.26
NaOH (0.1 M)	3,129.00
NaOH (0.5 M)	73,210.33
NaOH (1 M)	3,129.00
PBS	4,987.37
Polysorbate 80	0.24
WFI	108,514.84
TOTAL	414,070.38

2.6 BULK MATERIALS: SECTION TOTALS (kg/yr)

Raw Material	Main Section
Acetic-Acid	94
Amm. Sulfate	76,574
H3PO4 (5% w/w)	68,839
HIC-El-Buff	167,875
HIC-Eq-Buff	69,443
HIC-Wash-Buff	173,607
IEX El Buffer	102,978
IEX Equil Buffe	365,413
IEX Wash Buffer	1,828,883
Impurities	4
MAB	1,456
NaCl (1 M)	1,124,627
NaOH (0.1 M)	56,322
NaOH (0.5 M)	1,317,786
NaOH (1 M)	56,322
PBS	89,773
Polysorbate 80	4
WFI	1,953,267
TOTAL	7,453,267

3. STREAM DETAILS

Stream Name	IEX Equil - 74	IEX Wash - 75	IEX WFI - 76	IEX EI - 77
Source	**INPUT**	**INPUT**	**INPUT**	**INPUT**
Destination	**P-1**	**P-1**	**P-1**	**P-1**
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.00	25.00	25.00
Pressure (bar)	1.01	1.01	1.01	1.01
Density (g/L)	1,004.00	1,005.00	994.70	1,030.00
Total Enthalpy (kW-h)	589.83	2,942.01	2,773.43	162.30
Specific Enthalpy (kcal/kg)	25.00	24.91	25.11	24.41
Heat Capacity (kcal/kg-°C)	1.00	0.99	1.00	0.97
Component Flowrates (kg/batch)				
KCl	0.04	0.20	0.00	0.00
KH2PO4	0.04	0.20	0.00	0.00
Na2HPO4	22.33	111.77	0.00	0.00
NaH2PO4	0.00	0.00	0.00	56.07
Sodium Chloride	182.71	1,828.88	0.00	295.46
WFI	20,095.59	99,663.56	95,038.76	5,369.49
TOTAL (kg/batch)	20,300.70	101,604.62	95,038.76	5,721.02
TOTAL (L/batch)	20,219.82	101,099.12	95,544.73	5,554.39

Stream Name	IEX Strip - 78	IEX Rinse - 79	73	80
Source	INPUT	INPUT	INPUT	P-1
Destination	P-1	P-1	P-1	P-2
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.00	25.80	25.00
Pressure (bar)	1.01	1.01	1.01	1.01
Density (g/L)	1,030.00	1,021.00	994.48	996.40
Total Enthalpy (kW-h)	1,784.22	1,790.30	73.30	1,176.49
Specific Enthalpy (kcal/kg)	24.57	24.87	25.88	25.07
Heat Capacity (kcal/kg-°C)	0.98	0.99	1.00	1.00
Component Flowrates (kg/batch)				
Acetic-Acid	0.00	0.00	5.20	0.00
Impurities	0.00	0.00	0.23	0.01
MAB	0.00	0.00	80.88	72.79
NaH2PO4	0.00	0.00	0.00	22.43
Polysorbate 80	0.00	0.00	0.24	0.00
Sodium Chloride	3,542.57	0.00	0.00	118.18
Sodium Hydroxid	0.00	1,213.89	0.00	0.00
Water	58,936.68	60,719.43	0.00	0.00
WFI	0.00	0.00	2,350.75	40,163.30
TOTAL (kg/batch)	62,479.26	61,933.32	2,437.30	40,376.72
TOTAL (L/batch)	60,659.47	60,659.47	2,450.83	40,522.43

Stream Name	IEX Waste - 81	82	83	HIC Equil - 85
Source	**P-1**	**INPUT**	**P-2**	**INPUT**
Destination	**OUTPUT**	**P-2**	**P-3**	**P-3**
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.00	25.00	25.00
Pressure (bar)	1.01	1.01	10.13	1.01
Density (g/L)	1,005.90	1,769.00	1,039.69	1,060.00
Total Enthalpy (kW-h)	8,938.91	42.00	1,218.46	103.94
Specific Enthalpy (kcal/kg)	24.88	8.50	23.49	23.18
Heat Capacity (kcal/kg-°C)	0.99	0.34	0.94	0.92
Component Flowrates (kg/batch)				
Acetic-Acid	5.20	0.00	0.00	0.00
Amm. Sulfate	0.00	4,254.11	4,254.11	0.00
Impurities	0.21	0.00	0.01	0.00
KCl	0.24	0.00	0.00	0.00
KH2PO4	0.24	0.00	0.00	0.00
MAB	8.09	0.00	72.79	0.00
Na2HPO4	134.10	0.00	0.00	11.96
NaH2PO4	33.64	0.00	22.43	0.00
Polysorbate 80	0.24	0.00	0.00	0.00
Sodium Chloride	5,731.44	0.00	118.18	756.16
Sodium Hydroxid	1,213.89	0.00	0.00	0.00
Water	119,656.11	0.00	0.00	0.00
WFI	182,354.85	0.00	40,163.30	3,089.83
TOTAL (kg/batch)	309,138.26	4,254.11	44,630.83	3,857.94
TOTAL (L/batch)	307,325.85	2,404.81	42,927.21	3,639.57

Stream Name	HIC Wash - 86	HIC El - 87	HIC Reg - 88	89
Source	INPUT	INPUT	INPUT	P-3
Destination	P-3	P-3	P-3	P-4
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.00	25.00	25.00
Pressure (bar)	1.01	1.01	1.01	1.01
Density (g/L)	1,060.00	1,025.00	1,021.00	1,014.85
Total Enthalpy (kW-h)	270.08	267.45	268.54	108.89
Specific Enthalpy (kcal/kg)	24.09	24.67	24.87	24.68
Heat Capacity (kcal/kg-°C)	0.96	0.98	0.99	0.98
Component Flowrates (kg/batch)				
MAB	0.00	0.00	0.00	65.51
Na2HPO4	30.68	26.76	0.00	10.70
Sodium Chloride	961.24	365.21	0.00	146.08
Sodium Hydroxid	0.00	0.00	182.08	0.00
Water	0.00	0.00	9,107.91	0.00
WFI	8,652.93	8,934.42	0.00	3,573.77
TOTAL (kg/batch)	9,644.86	9,326.39	9,290.00	3,796.07
TOTAL (L/batch)	9,098.92	9,098.92	9,098.92	3,740.53

Stream Name	HIC Waste - 90	91	92	97
Source	P-3	P-4	P-5	INPUT
Destination	OUTPUT	P-5	P-6	P-8
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.00	25.00	25.00
Pressure (bar)	1.01	1.01	10.13	1.01
Density (g/L)	1,037.12	1,014.85	1,014.85	1,000.00
Total Enthalpy (kW-h)	2,019.58	108.89	108.89	144.96
Specific Enthalpy (kcal/kg)	23.82	24.68	24.68	25.01
Heat Capacity (kcal/kg-°C)	0.95	0.98	0.98	1.00
Component Flowrates (kg/batch)				
Amm. Sulfate	4,254.11	0.00	0.00	0.00
Impurities	0.01	0.00	0.00	0.00
KCl	0.00	0.00	0.00	0.01
KH2PO4	0.00	0.00	0.00	0.01
MAB	7.28	65.51	65.51	0.00
Na2HPO4	58.69	10.70	10.70	5.49
NaH2PO4	22.43	0.00	0.00	0.00
Sodium Chloride	2,054.71	146.08	146.08	39.90
Sodium Hydroxid	182.08	0.00	0.00	0.00
Water	9,107.91	0.00	0.00	0.00
WFI	57,266.71	3,573.77	3,573.77	4,941.96
TOTAL (kg/batch)	72,953.95	3,796.07	3,796.07	4,987.37
TOTAL (L/batch)	70,343.09	3,740.53	3,740.53	4,987.37

Stream Name	95	98	99	100
Source	P-7	INPUT	P-8	P-8
Destination	P-8	P-8	P-7	OUTPUT
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.00	25.62	25.00
Pressure (bar)	10.13	1.01	1.01	1.01
Density (g/L)	1,014.85	994.70	1,000.83	994.70
Total Enthalpy (kW-h)	108.89	14.51	74.27	14.51
Specific Enthalpy (kcal/kg)	24.68	25.11	25.58	25.11
Heat Capacity (kcal/kg-°C)	0.98	1.00	0.99	1.00
Component Flowrates (kg/batch)				
KCl	0.00	0.00	0.00	0.00
KH2PO4	0.00	0.00	0.00	0.00
MAB	65.51	0.00	62.24	0.00
Na2HPO4	10.70	0.00	3.27	0.00
Sodium Chloride	146.08	0.00	29.88	0.00
WFI	3,573.77	497.35	2,402.95	497.35
TOTAL (kg/batch)	3,796.07	497.35	2,498.35	497.35
TOTAL (L/batch)	3,740.53	500.00	2,496.27	500.00

Stream Name	101	94	102	105
Source	P-8	P-6	P-7	P-9
Destination	OUTPUT	P-7	P-9	P-10
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.62	25.00	25.62	25.62
Pressure (bar)	1.01	10.13	2.54	2.54
Density (g/L)	1,007.49	1,014.85	1,000.83	1,000.83
Total Enthalpy (kW-h)	185.82	108.89	74.27	74.27
Specific Enthalpy (kcal/kg)	25.44	24.68	25.58	25.58
Heat Capacity (kcal/kg-°C)	0.99	0.98	0.99	0.99
Component Flowrates (kg/batch)				
KCl	0.01	0.00	0.00	0.00
KH2PO4	0.01	0.00	0.00	0.00
MAB	0.00	65.51	62.24	62.24
Na2HPO4	12.92	10.70	3.27	3.27
Sodium Chloride	156.10	146.08	29.88	29.88
WFI	6,116.06	3,573.77	2,402.95	2,402.95
TOTAL (kg/batch)	6,285.09	3,796.07	2,498.35	2,498.35
TOTAL (L/batch)	6,238.39	3,740.53	2,496.27	2,496.27

Stream Name	**106**
Source	**P-10**
Destination	**OUTPUT**
Stream Properties	
Activity (U/ml)	0.00
Temperature (°C)	25.62
Pressure (bar)	4.89
Density (g/L)	1,000.83
Total Enthalpy (kW-h)	74.27
Specific Enthalpy (kcal/kg)	25.58
Heat Capacity (kcal/kg-°C)	0.99
Component Flowrates (kg/batch)	
KCl	0.00
KH2PO4	0.00
MAB	62.24
Na2HPO4	3.27
Sodium Chloride	29.88
WFI	2,402.95
TOTAL (kg/batch)	2,498.35
TOTAL (L/batch)	2,496.27

4. OVERALL COMPONENT BALANCE (kg/batch)

COMPONENT	INITIAL	INPUT	OUTPUT	FINAL	IN-OUT
Acetic-Acid	0.00	5.20	5.20	0.00	0.00
Amm. Sulfate	0.00	4,254.11	4,254.11	0.00	0.00
Impurities	0.00	0.23	0.23	0.00	0.00
KCl	0.00	0.25	0.25	0.00	0.00
KH2PO4	0.00	0.25	0.25	0.00	0.00
MAB	0.00	80.88	77.60	0.00	3.28
Na2HPO4	0.00	208.98	208.98	0.00	0.00
NaH2PO4	0.00	56.07	56.07	0.00	0.00
Nitrogen	53.52	0.00	0.00	53.52	0.00
Oxygen	16.25	0.00	0.00	16.25	0.00
Phosphoric Acid	0.00	191.22	191.22	0.00	0.00
Polysorbate 80	0.00	0.24	0.24	0.00	0.00
Sodium Chloride	0.00	7,972.14	7,972.14	0.00	0.00
Sodium Hydroxid	0.00	1,615.15	1,615.15	0.00	0.00
Water	0.00	136,789.86	136,789.86	0.00	0.00
WFI	0.00	262,895.80	262,899.08	0.00	- 3.28
TOTAL	69.76	414,070.38	414,070.38	69.76	0.00

5. EQUIPMENT CONTENTS

C-101

Procedure	Operation	Time (in h)	Volume (in L)
P-1	START	1,239.70	0.00
	AFTER AUTO-INIT	1,239.70	816.94
P-1	EQUILIBRATE-1 (Column Equilibration (Simplified))	1,297.56	816.94
P-1	HOLD-1 (Holding)	1,299.56	816.94
P-1	LOAD-1 (PBA Column Loading (Simplified))	1,299.75	0.00
P-1	WASH-1 (Column Wash (Simplified))	1,307.25	0.00
P-1	ELUTE-1 (Column Elution (Simplified))	1,314.75	0.00
P-1	REGENERATE-1 (Column Regeneration (Simplified))	1,319.25	0.00
P-1	WASH-2 (Column Wash (Simplified))	1,323.75	0.00
P-1	CIP-1 (In-Place-Cleaning)	1,325.00	0.00

V-101

Procedure	Operation	Time (in h)	Volume (in L)
P-2	START	1,250.38	0.00
P-2	SIP-1 (In-Place-Steaming)	1,251.22	0.00
P-2	TRANSFER-IN-1 (Transfer In)	1,314.75	40,522.41
P-2	PULL-IN-1 (Pull In)	1,315.75	42,927.21
P-2	TRANSFER-OUT-1 (Transfer Out)	1,317.75	0.00
P-2	CIP-1 (In-Place-Cleaning)	1,319.58	0.00

C-102

Procedure	Operation	Time (in h)	Volume (in L)
P-3	START	1,309.66	0.00
	AFTER AUTO-INIT	1,309.66	14,309.07
P-3	EQUILIBRATE-1 (Column Equilibration (Simplified))	1,548.41	14,309.07
P-3	HOLD-1 (Holding)	1,550.41	14,309.07
P-3	LOAD-1 (PBA Column Loading (Simplified))	1,623.28	0.00
P-3	WASH-1 (Column Wash (Simplified))	1,638.73	0.00
P-3	ELUTE-1 (Column Elution (Simplified))	1,654.18	0.00
P-3	REGENERATE-1 (Column Regeneration (Simplified))	1,661.90	0.00
P-3	CIP-1 (In-Place-Cleaning)	1,663.15	0.00

DE-101

Procedure	Operation	Time (in h)	Volume (in L)
P-4	START	1,402.57	0.00
P-4	HOLD-1 (Holding)	1,403.07	0.00
P-4	FILTER-1 (Dead-End Filtration)	1,654.18	0.00

V-102

Procedure	Operation	Time (in h)	Volume (in L)
P-5	START	1,353.07	0.00
P-5	SIP-1 (In-Place-Steaming)	1,353.90	0.00
P-5	TRANSFER-IN-1 (Transfer In)	1,654.18	3,740.53
P-5	TRANSFER-OUT-1 (Transfer Out)	1,656.48	0.00
P-5	CIP-1 (In-Place-Cleaning)	1,658.31	0.00

DE-102

Procedure	Operation	Time (in h)	Volume (in L)
P-6	START	1,653.68	0.00
P-6	HOLD-1 (Holding)	1,654.18	0.00
P-6	FILTER-1 (Dead-End Filtration)	1,656.48	0.00

V-103

Procedure	Operation	Time (in h)	Volume (in L)
P-7	START	1,650.34	0.00
P-7	SIP-1 (In-Place-Steaming)	1,651.18	0.00
P-7	HOLD-1 (Holding)	1,654.18	0.00
P-7	TRANSFER-IN-1 (Transfer In)	1,656.48	3,740.53
P-7	TRANSFER-OUT-1 (Transfer Out)	1,660.48	0.00
P-7	TRANSFER-IN-2 (Transfer In)	1,660.48	2,496.27
P-7	TRANSFER-OUT-2 (Transfer Out)	1,661.73	0.00
P-7	CIP-1 (In-Place-Cleaning)	1,663.56	0.00

DF-101

Procedure	Operation	Time (in h)	Volume (in L)
P-8	START	1,595.64	0.00
	AFTER AUTO-INIT	1,595.64	3,740.53
P-8	SIP-1 (In-Place-Steaming)	1,596.48	3,740.53
P-8	FLUSH-1 (Flush)	1,597.48	3,740.53
P-8	DIAFILTER-1 (Diafiltration)	1,660.48	2,496.27
P-8	CIP-1 (In-Place-Cleaning)	1,662.31	2,496.27
P-8	END	1,662.31	0.00

DE-103

Procedure	Operation	Time (in h)	Volume (in L)
P-9	START	1,659.98	0.00
P-9	HOLD-1 (Holding)	1,660.48	0.00
P-9	FILTER-1 (Dead-End Filtration)	1,661.73	0.00

DCS-101

Procedure	Operation	Time (in h)	Volume (in L)
P-10	START	1,660.48	0.00
P-10	TRANSFER-IN-1 (Transfer In)	1,661.73	2,496.27
P-10	END	1,661.73	0.00

Materials & Streams Report

March 13, 2019

for Buffer Prep with Stream Numbers

1. OVERALL PROCESS DATA

Annual Operating Time	7,919.08h
Recipe Batch Time	4.42h
Recipe Cycle Time	4.42h
Number of Batches per Year	1,793.00

MP = Undefined

2.1 STARTING MATERIAL REQUIREMENTS (per Section)

Section	Starting Material	Active Product	Amount Needed (kg Sin/kg MP)	Molar Yield (%)	Mass Yield (%)	Gross Mass Yield (%)
Main Section	(none)	(none)	Unknown	Unknown	Unknown	Unknown

Sin = Section Starting Material, Aout = Section Active Product

2.2 BULK MATERIALS (Entire Process)

Material	kg/yr	kg/batch	kg/kg MP
H3PO4 (5% w/w)	64,361,917	35,896.22	
hic el buff	16,562,515	9,237.32	
hic wash buff	23,908,084	13,334.12	
iex ei buff	10,213,913	5,696.55	
iex equil buff	36,236,952	20,210.24	
iex wash	181,984,552	101,497.24	
NaCI (1 M)	111,251,885	62,047.90	
NaOH (0.5 M)	156,888,498	87,500.56	
prot a elute	53,438,995	29,804.24	
prot a equil/wa	117,845,735	65,725.45	
prot a regen	32,081,476	17,892.62	
WFI	121,944,908	68,011.66	
TOTAL	926,719,431	516,854.12	

2.3 BULK MATERIALS (per Section)

SECTIONS IN: Main Branch

Main Section			
Material	**kg/yr**	**kg/batch**	**kg/kg MP**
H3PO4 (5% w/w)	64,361,917	35,896.22	
hic el buff	16,562,515	9,237.32	
hic wash buff	23,908,084	13,334.12	
iex ei buff	10,213,913	5,696.55	
iex equil buff	36,236,952	20,210.24	
iex wash	181,984,552	101,497.24	
NaCl (1 M)	111,251,885	62,047.90	
NaOH (0.5 M)	156,888,498	87,500.56	
prot a elute	53,438,995	29,804.24	
prot a equil/wa	117,845,735	65,725.45	
prot a regen	32,081,476	17,892.62	
WFI	121,944,908	68,011.66	
TOTAL	926,719,431	516,854.12	

2.4 BULK MATERIALS (per Material)

H3PO4 (5% w/w)				
Procedure	**% Total**	**kg/yr**	**kg/batch**	**kg/kg MP**
Main Section (Main Branch)				
P-1	3.93	2,532,366	1,412.36	
P-2	3.93	2,532,366	1,412.36	
P-3	4.66	3,002,452	1,674.54	
P-4	4.66	3,002,452	1,674.54	
P-5	6.07	3,904,964	2,177.89	
P-6	6.07	3,904,964	2,177.89	
P-7	5.90	3,798,572	2,118.56	
P-8	5.90	3,798,572	2,118.56	
P-9	5.90	3,798,572	2,118.56	
P-10	5.90	3,798,572	2,118.56	
P-11	2.66	1,712,115	954.89	
P-12	2.66	1,712,115	954.89	
P-13	7.00	4,503,706	2,511.83	
P-14	7.00	4,503,706	2,511.83	
P-15	4.09	2,633,783	1,468.93	
P-16	4.09	2,633,783	1,468.93	
P-17	3.14	2,018,293	1,125.65	
P-18	3.14	2,018,293	1,125.65	
P-19	3.14	2,018,293	1,125.65	
P-20	3.14	2,018,293	1,125.65	

P-21	3.51	2,257,842	1,259.25	
P-22	3.51	2,257,842	1,259.25	
TOTAL	100.00	64,361,917	35,896.22	

hic el buff

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-19	100.00	16,562,515	9,237.32	
TOTAL	100.00	16,562,515	9,237.32	

hic wash buff

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-21	100.00	23,908,084	13,334.12	
TOTAL	100.00	23,908,084	13,334.12	

iex ei buff

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-11	100.00	10,213,913	5,696.55	
TOTAL	100.00	10,213,913	5,696.55	

iex equil buff

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-15	100.00	36,236,952	20,210.24	
TOTAL	100.00	36,236,952	20,210.24	

iex wash

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-13	100.00	181,984,552	101,497.24	
TOTAL	100.00	181,984,552	101,497.24	

NaCl (1 M)

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-9	100.00	111,251,885	62,047.90	
TOTAL	100.00	111,251,885	62,047.90	

NaOH (0.5 M)

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-1	0.78	1,231,212	686.68	
P-2	0.78	1,231,212	686.68	
P-3	0.93	1,459,764	814.15	
P-4	0.93	1,459,764	814.15	
P-5	1.21	1,898,556	1,058.87	
P-6	1.21	1,898,556	1,058.87	
P-7	70.79	111,061,045	61,941.46	

P-8	1.18	1,846,830	1,030.02	
P-9	1.18	1,846,830	1,030.02	
P-10	1.18	1,846,830	1,030.02	
P-11	0.53	832,414	464.26	
P-12	0.53	832,414	464.26	
P-13	1.40	2,189,659	1,221.23	
P-14	1.40	2,189,659	1,221.23	
P-15	0.82	1,280,520	714.18	
P-16	0.82	1,280,520	714.18	
P-17	11.07	17,363,407	9,684.00	
P-18	0.63	981,275	547.28	
P-19	0.63	981,275	547.28	
P-20	0.63	981,275	547.28	
P-21	0.70	1,097,741	612.24	
P-22	0.70	1,097,741	612.24	
TOTAL	100.00	156,888,498	87,500.56	

prot a elute

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-3	100.00	53,438,995	29,804.24	
TOTAL	100.00	53,438,995	29,804.24	

prot a equil/wa

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-5	100.00	117,845,735	65,725.45	
TOTAL	100.00	117,845,735	65,725.45	

prot a regen

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-1	100.00	32,081,476	17,892.62	
TOTAL	100.00	32,081,476	17,892.62	

WFI

Procedure	% Total	kg/yr	kg/batch	kg/kg MP
Main Section (Main Branch)				
P-1	3.93	4,798,011	2,675.97	
P-2	3.93	4,798,011	2,675.97	
P-3	4.66	5,688,671	3,172.71	
P-4	4.66	5,688,671	3,172.71	
P-5	6.07	7,398,636	4,126.40	
P-6	6.07	7,398,636	4,126.40	
P-7	5.90	7,197,060	4,013.98	
P-8	5.90	7,197,060	4,013.98	
P-9	5.90	7,197,060	4,013.98	
P-10	5.90	7,197,060	4,013.98	
P-11	2.66	3,243,902	1,809.20	
P-12	2.66	3,243,902	1,809.20	

P-13	7.00	8,533,058	4,759.10
P-14	7.00	8,533,058	4,759.10
P-15	4.09	4,990,163	2,783.14
P-16	4.09	4,990,163	2,783.14
P-17	3.14	3,824,009	2,132.74
P-18	3.14	3,824,009	2,132.74
P-19	3.14	3,824,009	2,132.74
P-20	3.14	3,824,009	2,132.74
P-21	3.51	4,277,876	2,385.88
P-22	3.51	4,277,876	2,385.88
TOTAL	100.00	121,944,908	68,011.66

2.5 BULK MATERIALS: SECTION TOTALS (kg/batch)

Raw Material	Main Section
H3PO4 (5% w/w)	35,896.22
hic el buff	9,237.32
hic wash buff	13,334.12
iex ei buff	5,696.55
iex equil buff	20,210.24
iex wash	101,497.24
NaCI (1 M)	62,047.90
NaOH (0.5 M)	87,500.56
prot a elute	29,804.24
prot a equil/wa	65,725.45
prot a regen	17,892.62
WFI	68,011.66
TOTAL	516,854.12

2.6 BULK MATERIALS: SECTION TOTALS (kg/yr)

Raw Material	Main Section
H3PO4 (5% w/w)	64,361,917
hic el buff	16,562,515
hic wash buff	23,908,084
iex ei buff	10,213,913
iex equil buff	36,236,952
iex wash	181,984,552
NaCI (1 M)	111,251,885
NaOH (0.5 M)	156,888,498
prot a elute	53,438,995
prot a equil/wa	117,845,735
prot a regen	32,081,476
WFI	121,944,908

3. STREAM DETAILS

Stream Name	137	138	HIC Wash/Equil Out -139	134
Source	**INPUT**	**P-21**	**P-22**	**INPUT**
Destination	**P-21**	**P-22**	**OUTPUT**	**P-19**
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.00	25.00	25.00
Pressure (bar)	1.01	10.13	10.13	1.01
Density (g/L)	1,046.76	1,046.76	1,046.76	1,015.21
Total Enthalpy (kW-h)	373.38	373.38	373.38	264.90
Specific Enthalpy (kcal/kg)	24.09	24.09	24.09	24.67
Heat Capacity (kcal/kg-°C)	0.96	0.96	0.96	0.98
Component Flowrates (kg/batch)				
Na2HPO4	42.42	42.42	42.42	26.50
Sodium Chloride	1,328.93	1,328.93	1,328.93	361.72
WFI	11,962.78	11,962.78	11,962.78	8,849.09
TOTAL (kg/batch)	13,334.12	13,334.12	13,334.12	9,237.32
TOTAL (L/batch)	12,738.49	12,738.49	12,738.49	9,098.92

Stream Name	135	HIC El Out - 136	131	132
Source	**P-19**	**P-20**	**INPUT**	**P-17**
Destination	**P-20**	**OUTPUT**	**P-17**	**P-18**
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.00	25.00	25.00
Pressure (bar)	10.13	10.13	1.01	10.13
Density (g/L)	1,015.21	1,015.21	1,004.15	1,004.15
Total Enthalpy (kW-h)	264.90	264.90	264.11	264.11
Specific Enthalpy (kcal/kg)	24.67	24.67	24.87	24.87
Heat Capacity (kcal/kg-°C)	0.98	0.98	0.99	0.99
Component Flowrates (kg/batch)				
Na2HPO4	26.50	26.50	0.00	0.00
Sodium Chloride	361.72	361.72	0.00	0.00
Sodium Hydroxid	0.00	0.00	179.08	179.08
Water	0.00	0.00	8,957.64	8,957.64
WFI	8,849.09	8,849.09	0.00	0.00
TOTAL (kg/batch)	9,237.32	9,237.32	9,136.72	9,136.72
TOTAL (L/batch)	9,098.92	9,098.92	9,098.92	9,098.92

Stream Name	HIC Reg Out - 133	128	129	IEX Equil Out - 130
Source	**P-18**	**INPUT**	**P-15**	**P-16**
Destination	**OUTPUT**	**P-15**	**P-16**	**OUTPUT**
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.00	25.00	25.00
Pressure (bar)	10.13	1.01	10.13	10.13
Density (g/L)	1,004.15	999.53	999.53	999.53
Total Enthalpy (kW-h)	264.11	587.20	587.20	587.20
Specific Enthalpy (kcal/kg)	24.87	25.00	25.00	25.00
Heat Capacity (kcal/kg-°C)	0.99	1.00	1.00	1.00
Component Flowrates (kg/batch)				
KCl	0.00	0.04	0.04	0.04
KH2PO4	0.00	0.04	0.04	0.04
Na2HPO4	0.00	22.23	22.23	22.23
Sodium Chloride	0.00	181.89	181.89	181.89
Sodium Hydroxid	179.08	0.00	0.00	0.00
Water	8,957.64	0.00	0.00	0.00
WFI	0.00	20,006.03	20,006.03	20,006.03
TOTAL (kg/batch)	9,136.72	20,210.24	20,210.24	20,210.24
TOTAL (L/batch)	9,098.92	20,219.82	20,219.82	20,219.82

Stream Name	125	126	IEX Wash Out - 127	122
Source	**INPUT**	**P-13**	**P-14**	**INPUT**
Destination	**P-13**	**P-14**	**OUTPUT**	**P-11**
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.00	25.00	25.00
Pressure (bar)	1.01	10.13	10.13	1.01
Density (g/L)	1,003.94	1,003.94	1,003.94	1,025.59
Total Enthalpy (kW-h)	2,938.90	2,938.90	2,938.90	161.61
Specific Enthalpy (kcal/kg)	24.91	24.91	24.91	24.41
Heat Capacity (kcal/kg-°C)	0.99	0.99	0.99	0.97
Component Flowrates (kg/batch)				
KCl	0.20	0.20	0.20	0.00
KH2PO4	0.20	0.20	0.20	0.00
Na2HPO4	111.65	111.65	111.65	0.00
NaH2PO4	0.00	0.00	0.00	55.83
Sodium Chloride	1,826.95	1,826.95	1,826.95	294.20
WFI	99,558.24	99,558.24	99,558.24	5,346.52
TOTAL (kg/batch)	101,497.24	101,497.24	101,497.24	5,696.55
TOTAL (L/batch)	101,099.12	101,099.12	101,099.12	5,554.39

Stream Name	123	IEX El Out - 124	119	120
Source	**P-11**	**P-12**	**INPUT**	**P-9**
Destination	**P-12**	**OUTPUT**	**P-9**	**P-10**
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.00	25.00	25.00
Pressure (bar)	10.13	10.13	1.01	10.13
Density (g/L)	1,025.59	1,025.59	1,022.89	1,022.89
Total Enthalpy (kW-h)	161.61	161.61	1,771.90	1,771.90
Specific Enthalpy (kcal/kg)	24.41	24.41	24.57	24.57
Heat Capacity (kcal/kg-°C)	0.97	0.97	0.98	0.98
Component Flowrates (kg/batch)				
NaH2PO4	55.83	55.83	0.00	0.00
Sodium Chloride	294.20	294.20	3,518.12	3,518.12
Water	0.00	0.00	58,529.78	58,529.78
WFI	5,346.52	5,346.52	0.00	0.00
TOTAL (kg/batch)	5,696.55	5,696.55	62,047.90	62,047.90
TOTAL (L/batch)	5,554.39	5,554.39	60,659.47	60,659.47

Stream Name	IEX Strip Out - 121	116	117	IEX Rinse Out - 118
Source	**P-10**	**INPUT**	**P-7**	**P-8**
Destination	**OUTPUT**	**P-7**	**P-8**	**OUTPUT**
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.00	25.00	25.00
Pressure (bar)	10.13	1.01	10.13	10.13
Density (g/L)	1,022.89	1,004.15	1,004.15	1,004.15
Total Enthalpy (kW-h)	1,771.90	1,760.76	1,760.76	1,760.76
Specific Enthalpy (kcal/kg)	24.57	24.87	24.87	24.87
Heat Capacity (kcal/kg-°C)	0.98	0.99	0.99	0.99
Component Flowrates (kg/batch)				
Sodium Chloride	3,518.12	0.00	0.00	0.00
Sodium Hydroxid	0.00	1,193.86	1,193.86	1,193.86
Water	58,529.78	59,717.58	59,717.58	59,717.58
TOTAL (kg/batch)	62,047.90	60,911.44	60,911.44	60,911.44
TOTAL (L/batch)	60,659.47	60,659.47	60,659.47	60,659.47

Stream Name	113	114	Equil/Wash Out - 115	110
Source	**INPUT**	**P-5**	**P-6**	**INPUT**
Destination	**P-5**	**P-6**	**OUTPUT**	**P-3**
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.00	25.00	25.00
Pressure (bar)	1.01	10.13	10.13	1.01
Density (g/L)	997.34	997.34	997.34	994.98
Total Enthalpy (kW-h)	1,910.48	1,910.48	1,910.48	867.08
Specific Enthalpy (kcal/kg)	25.01	25.01	25.01	25.03
Heat Capacity (kcal/kg-°C)	1.00	1.00	1.00	1.00
Component Flowrates (kg/batch)				
Acetic-Acid	0.00	0.00	0.00	178.83
Sodium Chloride	65.73	65.73	65.73	0.00
TRIS Base	65.73	65.73	65.73	0.00
TRIS HCl	197.18	197.18	197.18	0.00
WFI	65,396.82	65,396.82	65,396.82	29,625.41
TOTAL (kg/batch)	65,725.45	65,725.45	65,725.45	29,804.24
TOTAL (L/batch)	65,900.44	65,900.44	65,900.44	29,954.75

Stream Name	111	112	107	108
Source	**P-3**	**P-4**	**INPUT**	**P-1**
Destination	**P-4**	**OUTPUT**	**P-1**	**P-2**
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	25.00	25.00	25.00
Pressure (bar)	10.13	10.13	1.01	10.13
Density (g/L)	994.98	994.98	995.54	995.54
Total Enthalpy (kW-h)	867.08	867.08	521.27	521.27
Specific Enthalpy (kcal/kg)	25.03	25.03	25.07	25.07
Heat Capacity (kcal/kg-°C)	1.00	1.00	1.00	1.00
Component Flowrates (kg/batch)				
Acetic-Acid	178.83	178.83	0.00	0.00
Sodium Citrate	0.00	0.00	32.21	32.21
WFI	29,625.41	29,625.41	17,860.42	17,860.42
TOTAL (kg/batch)	29,804.24	29,804.24	17,892.62	17,892.62
TOTAL (L/batch)	29,954.75	29,954.75	17,972.85	17,972.85

Stream Name	Regen Out - 109
Source	**P-2**
Destination	**OUTPUT**
Stream Properties	
Activity (U/ml)	0.00
Temperature (°C)	25.00
Pressure (bar)	10.13
Density (g/L)	995.54
Total Enthalpy (kW-h)	521.27
Specific Enthalpy (kcal/kg)	25.07
Heat Capacity (kcal/kg-°C)	1.00
Component Flowrates (kg/batch)	
Sodium Citrate	32.21
WFI	17,860.42
TOTAL (kg/batch)	17,892.62
TOTAL (L/batch)	17,972.85

4. OVERALL COMPONENT BALANCE (kg/batch)

COMPONENT	INITIAL	INPUT	OUTPUT	FINAL	IN-OUT
Acetic-Acid	0.00	178.83	178.83	0.00	0.00
KCl	0.00	0.24	0.24	0.00	0.00
KH2PO4	0.00	0.24	0.24	0.00	0.00
Na2HPO4	0.00	202.80	202.80	0.00	0.00
NaH2PO4	0.00	55.83	55.83	0.00	0.00
Nitrogen	789.93	0.00	0.00	789.93	0.00
Oxygen	239.81	0.00	0.00	239.81	0.00
Phosphoric Acid	0.00	1,794.81	1,794.81	0.00	0.00
Sodium Chloride	0.00	7,577.54	7,577.54	0.00	0.00
Sodium Citrate	0.00	32.21	32.21	0.00	0.00
Sodium Hydroxid	0.00	1,715.01	1,715.01	0.00	0.00
TRIS Base	0.00	65.73	65.73	0.00	0.00
TRIS HCl	0.00	197.18	197.18	0.00	0.00
Water	0.00	144,315.33	144,315.33	0.00	0.00
WFI	0.00	360,718.38	360,718.38	0.00	0.00
TOTAL	1,029.74	516,854.12	516,854.12	1,029.74	0.00

5. EQUIPMENT CONTENTS

V-101

Procedure	Operation	Time (in h)	Volume (in L)
P-1	START	0.00	0.00
P-1	SIP-1 (In-Place-Steaming)	0.83	0.00
P-1	CHARGE-1 (Charge)	1.83	17,972.85
P-1	AGITATE-1 (Agitation)	2.33	17,972.85
P-1	TRANSFER-OUT-1 (Transfer Out)	2.58	0.00
P-1	CIP-1 (In-Place-Cleaning)	4.42	0.00

V-102

Procedure	Operation	Time (in h)	Volume (in L)
P-2	START	0.00	0.00
P-2	SIP-1 (In-Place-Steaming)	0.83	0.00
P-2	TRANSFER-IN-1 (Transfer In)	1.00	17,972.85
P-2	TRANSFER-OUT-1 (Transfer Out)	2.00	0.00
P-2	CIP-1 (In-Place-Cleaning)	3.83	0.00

V-103

Procedure	Operation	Time (in h)	Volume (in L)
P-3	START	0.00	0.00
P-3	SIP-1 (In-Place-Steaming)	0.83	0.00
P-3	CHARGE-1 (Charge)	1.83	29,954.75
P-3	AGITATE-1 (Agitation)	2.33	29,954.75
P-3	TRANSFER-OUT-1 (Transfer Out)	2.58	0.00
P-3	CIP-1 (In-Place-Cleaning)	4.42	0.00

V-104

Procedure	Operation	Time (in h)	Volume (in L)
P-4	START	0.00	0.00
P-4	SIP-1 (In-Place-Steaming)	0.83	0.00
P-4	TRANSFER-IN-1 (Transfer In)	1.00	29,954.75
P-4	TRANSFER-OUT-1 (Transfer Out)	2.00	0.00
P-4	CIP-1 (In-Place-Cleaning)	3.83	0.00

V-105

Procedure	Operation	Time (in h)	Volume (in L)
P-5	START	0.00	0.00
P-5	SIP-1 (In-Place-Steaming)	0.83	0.00
P-5	CHARGE-1 (Charge)	1.83	65,900.44
P-5	AGITATE-1 (Agitation)	2.33	65,900.44
P-5	TRANSFER-OUT-1 (Transfer Out)	2.58	0.00
P-5	CIP-1 (In-Place-Cleaning)	4.42	0.00

V-106

Procedure	Operation	Time (in h)	Volume (in L)
P-6	START	0.00	0.00
P-6	SIP-1 (In-Place-Steaming)	0.83	0.00
P-6	TRANSFER-IN-1 (Transfer In)	1.00	65,900.44
P-6	TRANSFER-OUT-1 (Transfer Out)	2.00	0.00
P-6	CIP-1 (In-Place-Cleaning)	3.83	0.00

V-107

Procedure	Operation	Time (in h)	Volume (in L)
P-7	START	0.00	0.00
P-7	SIP-1 (In-Place-Steaming)	0.83	0.00
P-7	CHARGE-1 (Charge)	1.83	60,659.47
P-7	AGITATE-1 (Agitation)	2.33	60,659.47
P-7	TRANSFER-OUT-1 (Transfer Out)	2.58	0.00
P-7	CIP-1 (In-Place-Cleaning)	4.42	0.00

V-108

Procedure	Operation	Time (in h)	Volume (in L)
P-8	START	0.00	0.00
P-8	SIP-1 (In-Place-Steaming)	0.83	0.00
P-8	TRANSFER-IN-1 (Transfer In)	1.00	60,659.47
P-8	TRANSFER-OUT-1 (Transfer Out)	2.00	0.00
P-8	CIP-1 (In-Place-Cleaning)	3.83	0.00

V-109

Procedure	Operation	Time (in h)	Volume (in L)
P-9	START	0.00	0.00
P-9	SIP-1 (In-Place-Steaming)	0.83	0.00
P-9	CHARGE-1 (Charge)	1.83	60,659.47
P-9	AGITATE-1 (Agitation)	2.33	60,659.47
P-9	TRANSFER-OUT-1 (Transfer Out)	2.58	0.00
P-9	CIP-1 (In-Place-Cleaning)	4.42	0.00

V-110

Procedure	Operation	Time (in h)	Volume (in L)
P-10	START	0.00	0.00
P-10	SIP-1 (In-Place-Steaming)	0.83	0.00
P-10	TRANSFER-IN-1 (Transfer In)	1.00	60,659.47
P-10	TRANSFER-OUT-1 (Transfer Out)	2.00	0.00
P-10	CIP-1 (In-Place-Cleaning)	3.83	0.00

V-111

Procedure	Operation	Time (in h)	Volume (in L)
P-11	START	0.00	0.00
P-11	SIP-1 (In-Place-Steaming)	0.83	0.00
P-11	CHARGE-1 (Charge)	1.83	5,554.39
P-11	AGITATE-1 (Agitation)	2.33	5,554.39
P-11	TRANSFER-OUT-1 (Transfer Out)	2.58	0.00
P-11	CIP-1 (In-Place-Cleaning)	4.42	0.00

V-112

Procedure	Operation	Time (in h)	Volume (in L)
P-12	START	0.00	0.00
P-12	SIP-1 (In-Place-Steaming)	0.83	0.00
P-12	TRANSFER-IN-1 (Transfer In)	1.00	5,554.39
P-12	TRANSFER-OUT-1 (Transfer Out)	2.00	0.00
P-12	CIP-1 (In-Place-Cleaning)	3.83	0.00

V-113

Procedure	Operation	Time (in h)	Volume (in L)
P-13	START	0.00	0.00
P-13	SIP-1 (In-Place-Steaming)	0.83	0.00
P-13	CHARGE-1 (Charge)	1.83	101,099.12
P-13	AGITATE-1 (Agitation)	2.33	101,099.12
P-13	TRANSFER-OUT-1 (Transfer Out)	2.58	0.00
P-13	CIP-1 (In-Place-Cleaning)	4.42	0.00

V-114

Procedure	Operation	Time (in h)	Volume (in L)
P-14	START	0.00	0.00
P-14	SIP-1 (In-Place-Steaming)	0.83	0.00
P-14	TRANSFER-IN-1 (Transfer In)	1.00	101,099.12
P-14	TRANSFER-OUT-1 (Transfer Out)	2.00	0.00
P-14	CIP-1 (In-Place-Cleaning)	3.83	0.00

V-115

Procedure	Operation	Time (in h)	Volume (in L)
P-15	START	0.00	0.00
P-15	SIP-1 (In-Place-Steaming)	0.83	0.00
P-15	CHARGE-1 (Charge)	1.83	20,219.82
P-15	AGITATE-1 (Agitation)	2.33	20,219.82
P-15	TRANSFER-OUT-1 (Transfer Out)	2.58	0.00
P-15	CIP-1 (In-Place-Cleaning)	4.42	0.00

V-116

Procedure	Operation	Time (in h)	Volume (in L)
P-16	START	0.00	0.00
P-16	SIP-1 (In-Place-Steaming)	0.83	0.00
P-16	TRANSFER-IN-1 (Transfer In)	1.00	20,219.82
P-16	TRANSFER-OUT-1 (Transfer Out)	2.00	0.00
P-16	CIP-1 (In-Place-Cleaning)	3.83	0.00

V-117

Procedure	Operation	Time (in h)	Volume (in L)
P-17	START	0.00	0.00
P-17	SIP-1 (In-Place-Steaming)	0.83	0.00
P-17	CHARGE-1 (Charge)	1.83	9,098.92
P-17	AGITATE-1 (Agitation)	2.33	9,098.92
P-17	TRANSFER-OUT-1 (Transfer Out)	2.58	0.00
P-17	CIP-1 (In-Place-Cleaning)	4.42	0.00

V-118

Procedure	Operation	Time (in h)	Volume (in L)
P-18	START	0.00	0.00
P-18	SIP-1 (In-Place-Steaming)	0.83	0.00
P-18	TRANSFER-IN-1 (Transfer In)	1.00	9,098.92
P-18	TRANSFER-OUT-1 (Transfer Out)	2.00	0.00
P-18	CIP-1 (In-Place-Cleaning)	3.83	0.00

V-119

Procedure	Operation	Time (in h)	Volume (in L)
P-19	START	0.00	0.00
P-19	SIP-1 (In-Place-Steaming)	0.83	0.00
P-19	CHARGE-1 (Charge)	1.83	9,098.92
P-19	AGITATE-1 (Agitation)	2.33	9,098.92
P-19	TRANSFER-OUT-1 (Transfer Out)	2.58	0.00
P-19	CIP-1 (In-Place-Cleaning)	4.42	0.00

V-120

Procedure	Operation	Time (in h)	Volume (in L)
P-20	START	0.00	0.00
P-20	SIP-1 (In-Place-Steaming)	0.83	0.00
P-20	TRANSFER-IN-1 (Transfer In)	1.00	9,098.92
P-20	TRANSFER-OUT-1 (Transfer Out)	2.00	0.00
P-20	CIP-1 (In-Place-Cleaning)	3.83	0.00

V-121

Procedure	Operation	Time (in h)	Volume (in L)
P-21	START	0.00	0.00
P-21	SIP-1 (In-Place-Steaming)	0.83	0.00
P-21	CHARGE-1 (Charge)	1.83	12,738.49
P-21	AGITATE-1 (Agitation)	2.33	12,738.49
P-21	TRANSFER-OUT-1 (Transfer Out)	2.58	0.00
P-21	CIP-1 (In-Place-Cleaning)	4.42	0.00

V-122

Procedure	Operation	Time (in h)	Volume (in L)
P-22	START	0.00	0.00
P-22	SIP-1 (In-Place-Steaming)	0.83	0.00
P-22	TRANSFER-IN-1 (Transfer In)	1.00	12,738.49
P-22	TRANSFER-OUT-1 (Transfer Out)	2.00	0.00
P-22	CIP-1 (In-Place-Cleaning)	3.83	0.00