



Singtein Productions

"The Production of Single Cell Protein"

Martin Team #3

Kaylon Atkinson

Shanelle Bryant

Chad Gardner

Oluwatoyosi Idowu

PROJECT OVERVIEW

- Problem Statement/ Project Scope
- Project Management
 - Project schedule
- Process Evaluation
 - Choice of Microorganism
 - Bacteria Strand
- Process Description
 - Design Basis
 - Process Chemistry
 - Block Flow Diagram
 - Process Flow Diagram
 - Hysys Simulation
- Equipment Design
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 - Spray Dryer
- Safety
 - HAZOP Analysis and P&ID
 - Safety Process Conditions
- Plant Location/Land Laws
- Market Analysis
- Economic Analysis
- Recommendations
- Closing Remarks
- Questions

Problem Statement

Objective:

- ❑ Single cell protein (SCP) as an alternative source of protein due to malnutrition
- ❑ United States, China, India, Indonesia, Vietnam, and Bangladesh are projecting an increase in SCP production by 2030 on a large scale
- ❑ Produce Single Cell Protein from Methylococcus capsulatus.



What is “Single Cell Protein”?

- SCP is an alternative source of protein due to malnutrition
- Our SCP will be used in animal feed
- Single cell protein (SCP) is cell mass or protein taken from bacteria
- Our goal is to produce SCP that will help tackle the increased issue of malnutrition and protein deficiency.



PROJECT MANAGEMENT



PROJECT DESIGN SCHEDULE

Single Cell Protein Production

Martin Team 3: Oluwatoyosi Idowu, Shanelle Bryant, Kaylon Atkinson, Chad Gardner
Project Lead: Oluwatoyosi Idowu

Project Start:

Tue, 1/18/2022

Display Week:

1

TASK	ASSIGNED TO	PROGRESS	START	END
Phase 1 Process Review			1/18/22	4/9/22
Plant Production Analysis	All	100%	1/18/22	2/1/22
Equipment Functions	All	100%	1/18/22	2/1/22
Mass and Energy Balance Calculations	All	100%	1/18/22	2/1/22
Process Flow Diagram	All	100%	1/18/22	2/1/22
Process Modeling Assumption	All	100%	1/18/22	2/1/22
Phase 2 Equipment Sizing and Design			2/1/22	3/15/22
Identify all equipment and functions	All	100%	2/1/22	2/15/22
Heuristics for each equipment	All	100%	2/1/22	2/15/22
Equipment sizing	All	100%	2/15/22	3/15/22
Design of major and minor equipment	All	100%	2/15/22	3/15/22
Phase 3 Safety & Environmental Regulations			2/15/22	3/26/22
Storage & Handling: Physical and Chemical Properties	Shanelle	100%	2/15/22	3/15/22
Packaging & Waste Disposal	Shanelle	100%	2/15/22	3/1/22
OSHA Safety Regulations	Shanelle	100%	2/21/22	3/11/22
FDA & EPA Safety Regulations	Shanelle	100%	2/21/22	3/11/22
HAZOP Analysis	Shanelle	100%	2/21/22	3/31/22
Phase 4 Economic/Profitability Analysis			3/13/22	4/9/22
Cost of Raw Materials	Toyosi	100%	3/13/22	3/31/22
Direct Cost (Equipment, Land, etc...)	Toyosi	100%	3/13/22	3/31/22
Indirect Costs (Utilities, Salaries, etc...)	Toyosi	100%	3/13/22	3/31/22
Analyze fixed and transportation costs	Toyosi	100%	3/13/22	3/31/22
Formulate cash flow & profitabilty analysis	Toyosi	100%	3/13/22	3/31/22
Phase 5 Flow Chart Development			3/28/22	4/19/22
Process Chemistry	All	100%	3/28/22	4/11/22
Process Flow Diagram and P&ID	All	100%	3/28/22	4/14/22
Material and Energy Balance	All	100%	3/28/22	4/16/22
Simulation- Process Flow Diagram	Toyosi	100%	3/28/22	4/17/22

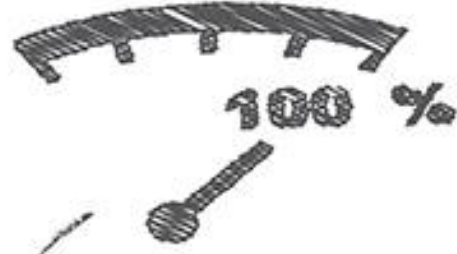
CRITERIA



ANALYSIS



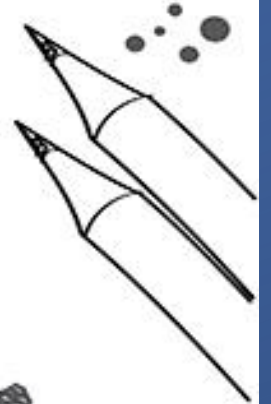
PERFORMANCE



APPROACH



EVALUATION



IMPROVEMENT



RESULTS



FEEDBACK



ASSESSMENT

MICROORGANISM SELECTION

Table 3. Macromolecular Composition and General Properties of Microorganisms
(Champagnat, Vernet, Laine and Filosa, 1963)

PARAMETERS	BACTERIA	YEAST	FUNGI	ALGAE
Doubling time (hours)	1-3	2-6	5-12	6-24
Crude protein (% dry cell weight)	40-80	40-60	30-45	40-50
Nucleic acids (%)	8-20	5-15	6-13	45-51 ^a
Carbohydrates and fats (%)	10-30	10-40	10-45	34.6-45

PROCESS DESCRIPTION



DESIGN BASIS

Plant Capacity

Design capacity:	50,000 tons/year
Design operating time:	8160 hrs/year
Days of operation:	340 days/year

Raw Materials

Methanol	at 20°C and 100 kpa
Ammonia	at 20°C and 100 kpa
Medium	at 20°C and 100 kpa
Stock Culture	at -80°C and 100 kpa

Utilities

- Cooling water
- Steam
- Electricity

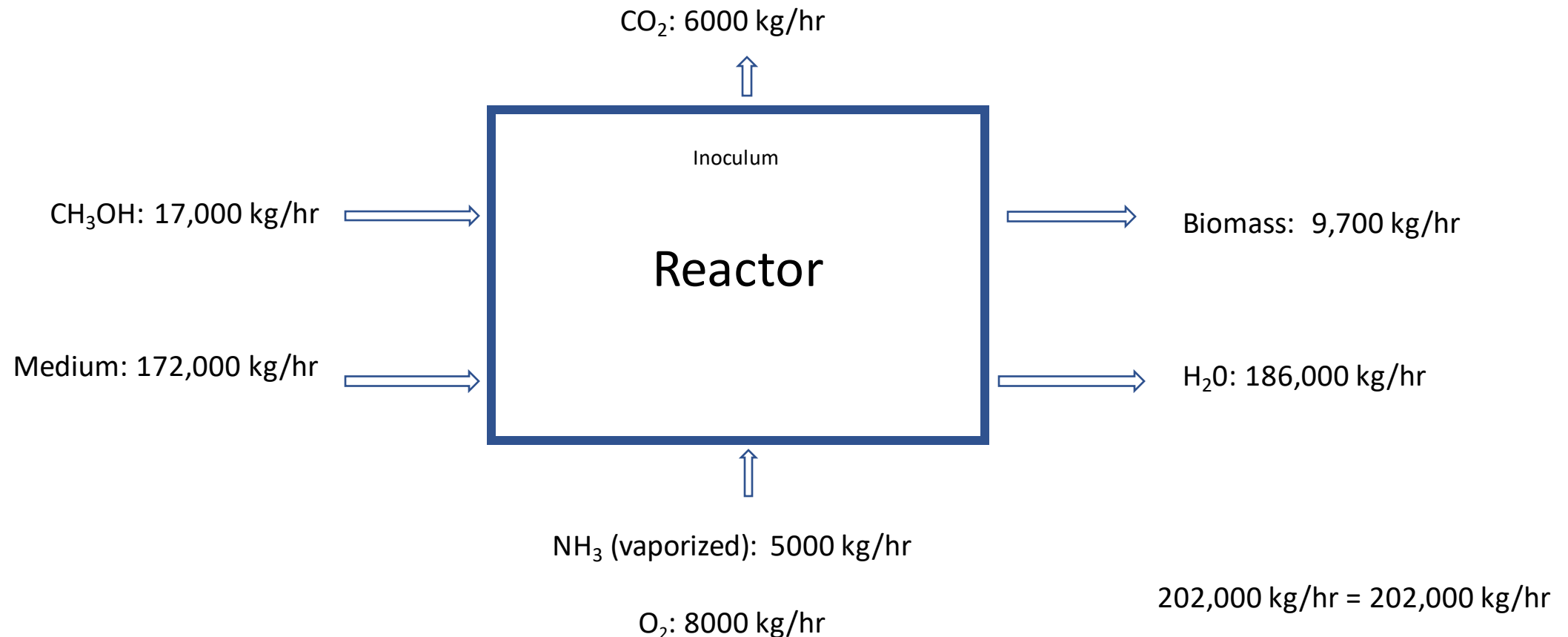
Product Specification

Solid, 99.9% purity

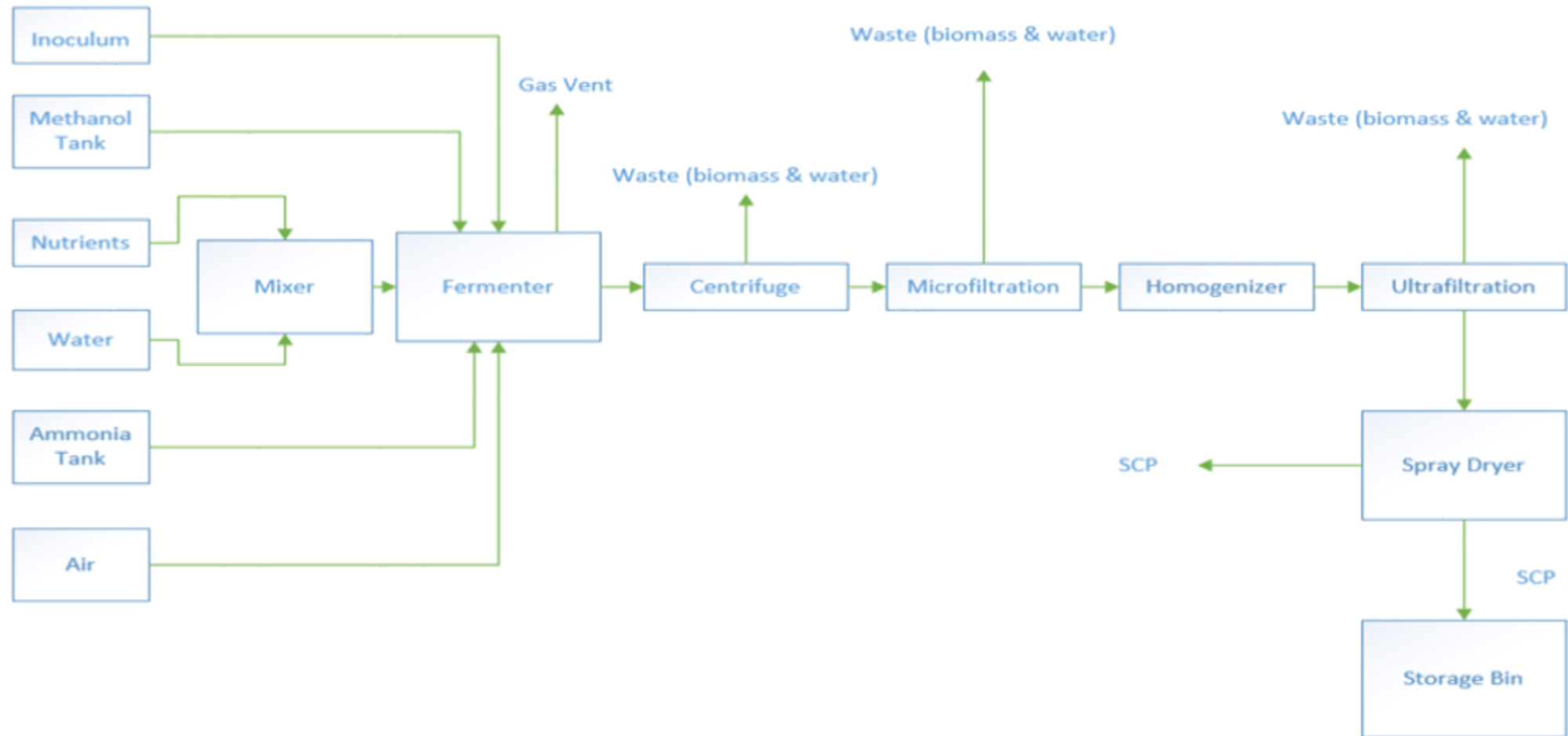
Location Conditions

Maximum Wind speed: 20 mph
Maximum temperature: 40°C
Minimum temperature: -12°C
Relative Humidity: 30–85%

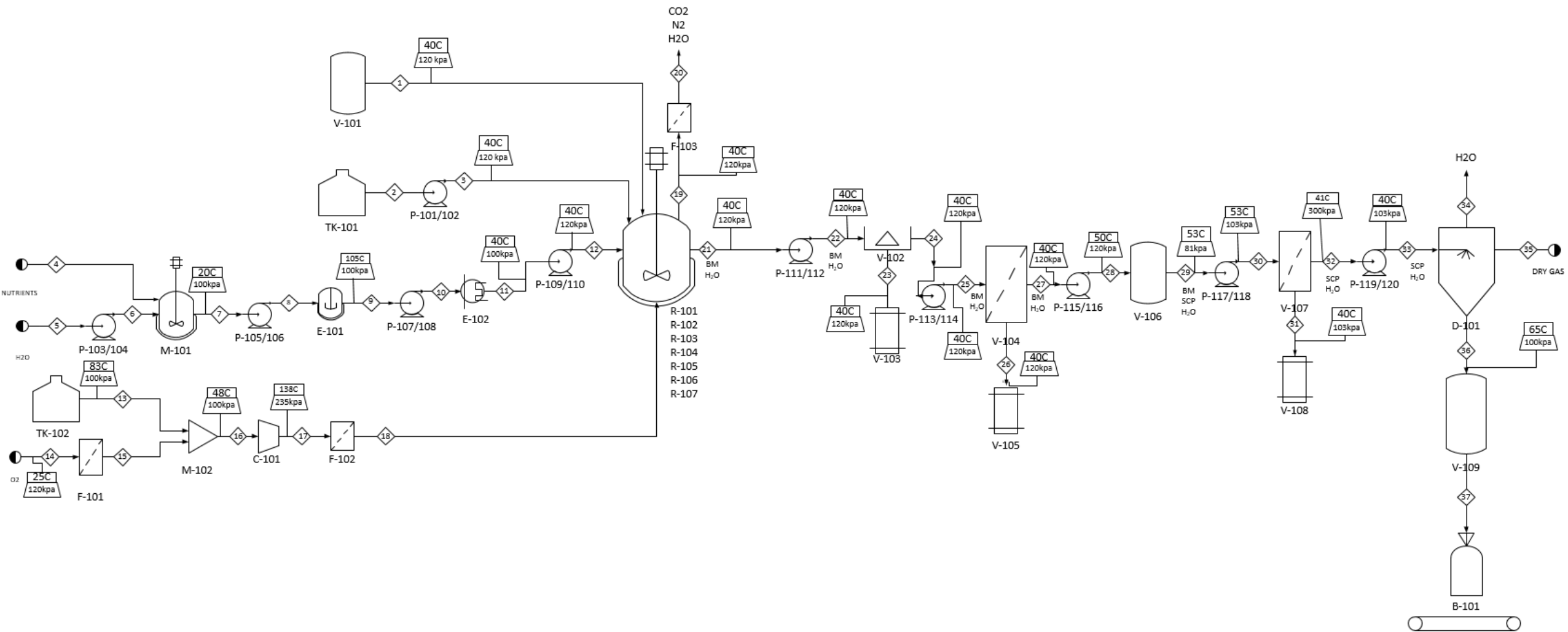
PROCESS CHEMISTRY/MATERIAL BALANCE



BLOCK FLOW DIAGRAM

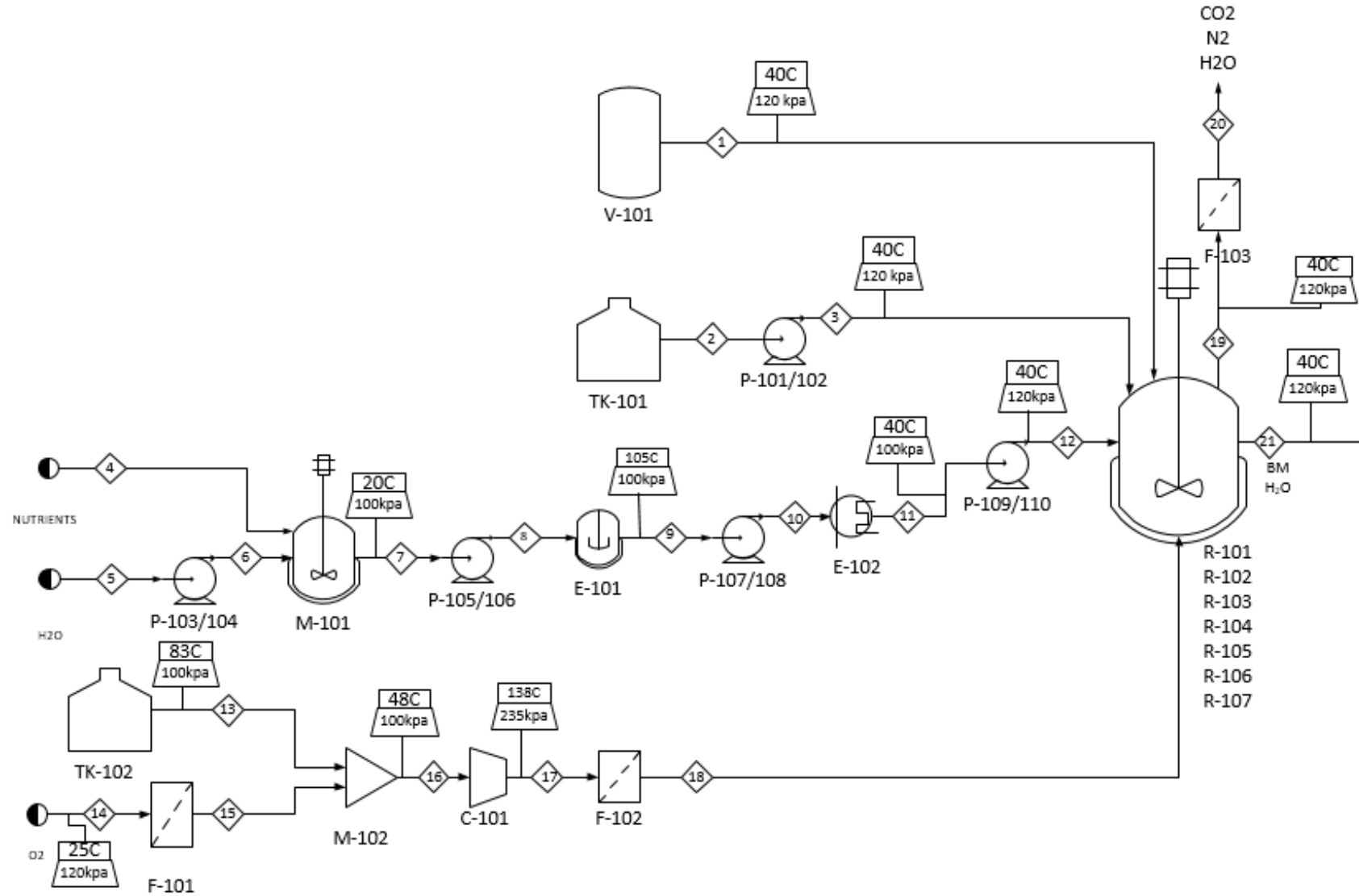


PROCESS FLOW DIAGRAM

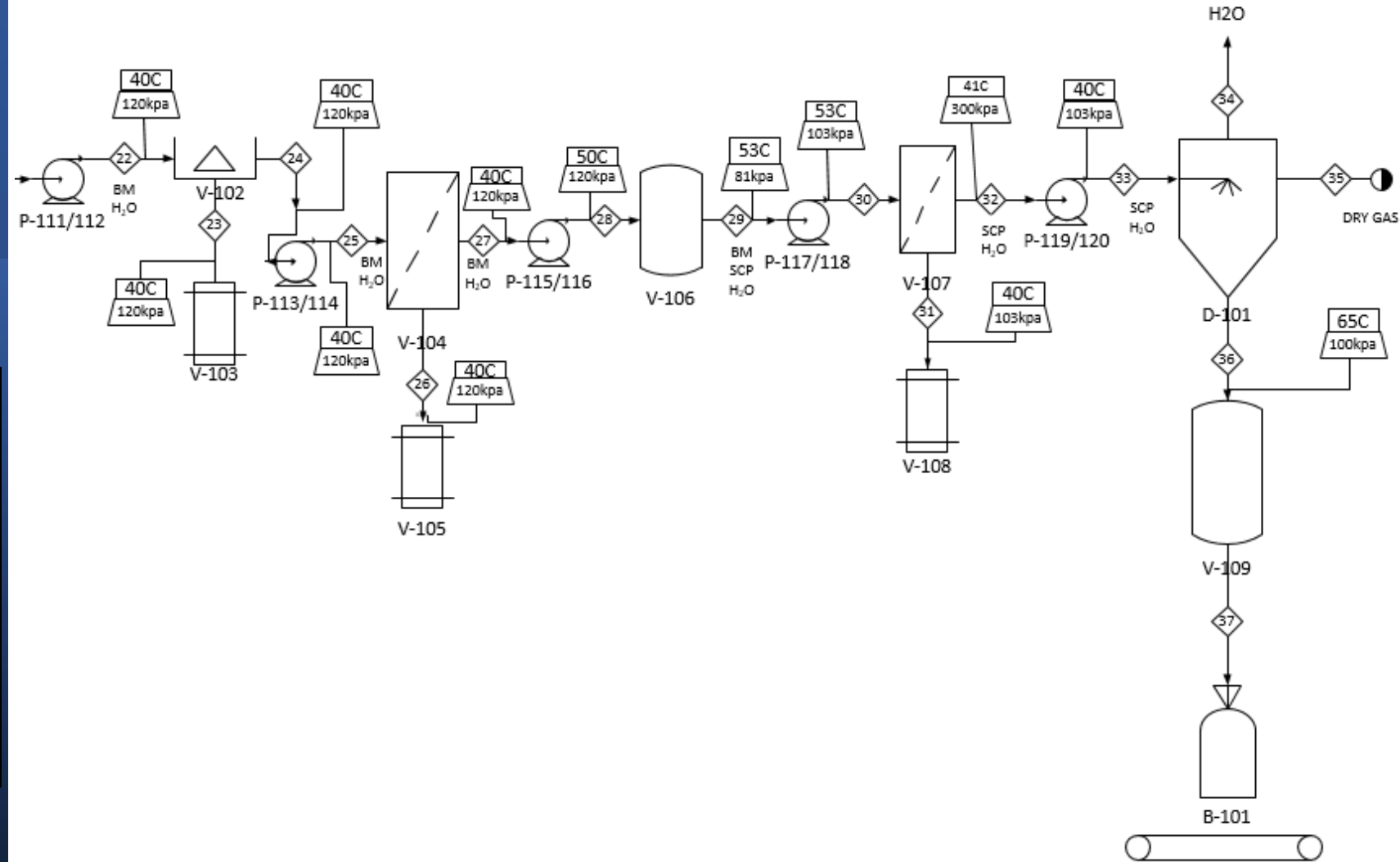


PFD SECTION 1

V-101 INOCULUM	TK-101 METHANOL TANK	P-101/102 METHANOL PUMP	E-101 METHANOL HEATER
P-103/104 WATER PUMP	M-101 MEDIUM MIXER	P-105/106 MEDIUM MIXER PUMP	E-102 MEDIUM STERILIZER
P-107/108 STERILIZED MEDIUM PUMP	E-103 MEDIUM COOLER	P-109/110 MEDIUM COOLER PUMP	TK-102 AMMONIA TANK
F-101 COURSE FILTER	M-102 REDUCER	C-101 COMPRESSOR	F-102 FILTER
R-101-107 BATCH BIOREACTOR		F-103 FILTER	

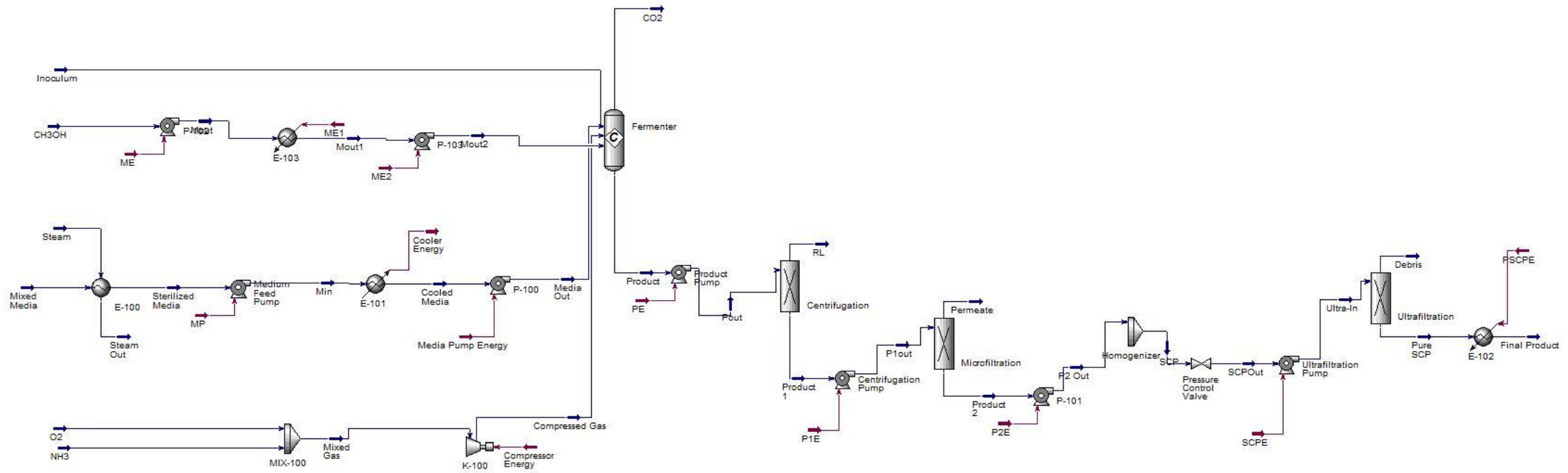


PFD SECTION 2

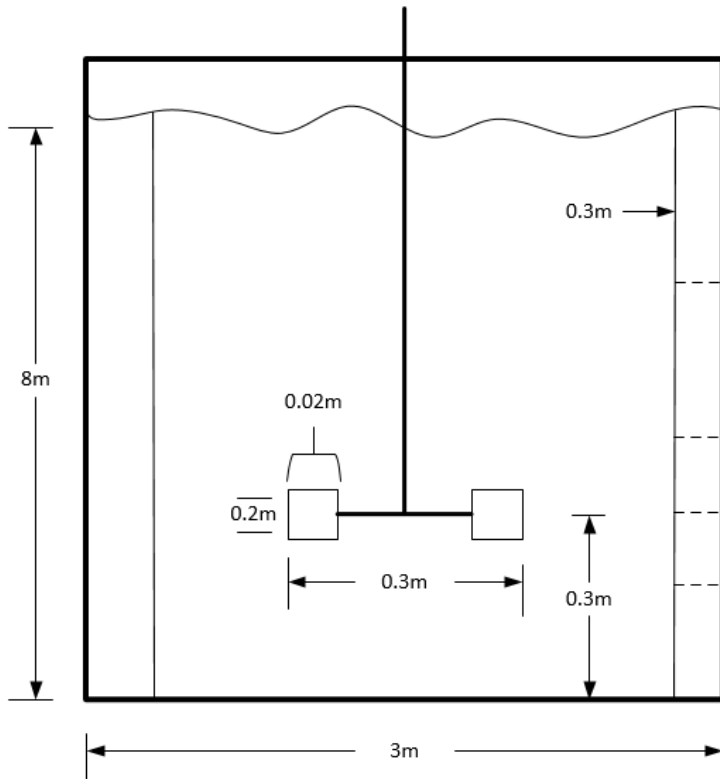


P-111/112 BIOMASS SLURRY PUMP	V-102 CENTRIFUGE	V-103 CENTRIFUGE WASTE BARREL	P-113/114 CENTRIFUGE PRODUCT PUMP
V-104 MICROFILTRATION	V-105 MICROFILTRATION WASTE BARREL	P-115/116 MICROFILTRATION PRODUCT PUMP	V-106 HOMOGENIZER
P-117/118 HOMOGENIZER PRODUCT PUMP	V-107 ULTRAFILTRATION	V-108 ULTRAFILTRATION WASTE BARREL	P-119/120 ULTRAFILTRATION PRODUCT PUMP
D-101 SPRAY DRYER	V-109 COLLECTION CHAMBER	B-101 SUPER SACKS	

HYSYS SIMULATION



REACTOR DESIGN

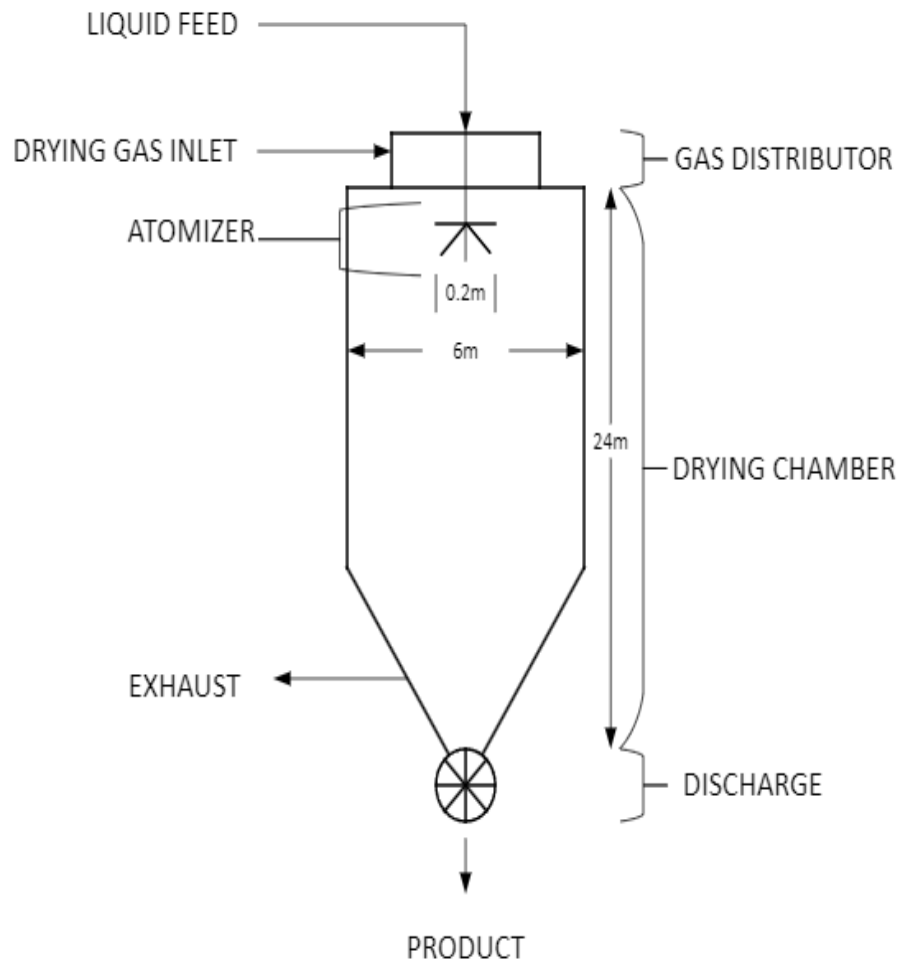


PARAMETER	DESIGN EQUATION	TERM
Reactor Volume	$V_R = \frac{m_1 \times t_B}{\rho}$	m_1 - Mass flow in t_B - Batch Time ρ - Density of Feed
Wall Thickness	$W_T = \frac{P \times r_i}{S E_j - 0.6 P} + C_c$	P - Pressure in vessel r_i - radius of vessel S - Working stress of material E_j - Joint efficiency C_c - Corrosion allowance
Reactor Head	$T_H = \frac{1.104 P D}{2 E_j S - 0.2 P} + C_c$	P - Pressure D - Diameter of vessel E_j - Joint efficiency S - Working stress of material C_c - Corrosion allowance
Power	$P = \frac{N_P \times N^3 \times D_A^5 \times \rho}{g_c}$	N_p - Power number N - Shaft RPM D_A - Impeller diameter ρ - Density in vessel g_c - Gravitational constant

REACTOR SPECIFICATION

Identification	Equipment No/Name: Jacketed Stirred Tank Reactor		
	No Required: 7		Bare Module Cost (\$): 9,100,000
	Service/Function: Generate Biomass		
PROCESS DATA			
FEED		PRODUCT	
Materials Handled	Methanol	Cell Mass Water CO2	
	Ammonia		
	Water		
	Oxygen		
	Disodium Phosphate		
	Potassium Phosphate		
	Magnesium Sulfate		
	Calcium Chloride		
Iron (II) Sulfate			
Total Flow (kg/hr)	29,310	29,310	
Component Flow (kg/hr)	FEED	PRODUCT	
Methanol	2,500	-	
Ammonia	710	-	
Oxygen	1100	-	
Water/Nutrient	25,000	-	
Biomass	-	1,400	
Water	-	27,000	
Carbon Dioxide	-	910	
OPERATING CONDITIONS			
Temperature(oC)	40		
Pressure(kpa)	120		
DESIGN DATA			
Vessel		Agitator	
Volume (m3)	30	Depth of Dished Bottom (m)	1
Height to Diameter Ratio	2.5	No. of Baffles	4
Height (m)	8	Width of Baffle (m)	0.3
Diameter (m)	3	Height of Baffle (m)	8
Outer Diameter (m)	3	Agitator Type	Rushton Turbine
Wall Thickness (m)	0.021	No. of Blades	6
Type of Head	Torispherical	Impeller Diameter (m)	1
Cooling Jacket Fluid	Cooling water	Length of Blade (m)	0.3
Inlet Temperature (oC)	20	Width of Blade (m)	0.2
Outlet Temperature (oC)	105	Impeller Above Floor (m)	1
Cooling Jacket Area(m2)	42	Speed of Impeller (RPM)	57
Fluid Flowrate (kg/hr)	60,500	Power Required (Kw)	33
Comments:			

SPRAY DRYER DESIGN



PARAMETER	DESIGN EQUATION	TERM
Chamber Volume	$V_{ch} = \frac{G * t_d}{\rho_{gas}}$	G = Dry Air flow rate ρ_{gas} = Density of Air t_d = Residence time
Chamber Height	$h_{ch} = \frac{V_{ch}}{\frac{\pi}{4} * D_{ch}^2} - \frac{\sqrt{3}}{2} * D_{ch}$	D_{ch} = Chamber diameter
Solids Settling Velocity	$V_s = \frac{D_p * (p_p - p_f) * g}{18\mu}$	D_p = Droplet diameter p_p = Density of droplet p_f = Density of air g = Gravity μ = Viscosity of air
Power	$P = 1.02 * 10^{-8} * F * (N * d)^2$	F = Solids feed rate N = Rotational Speed d = Diameter of disk

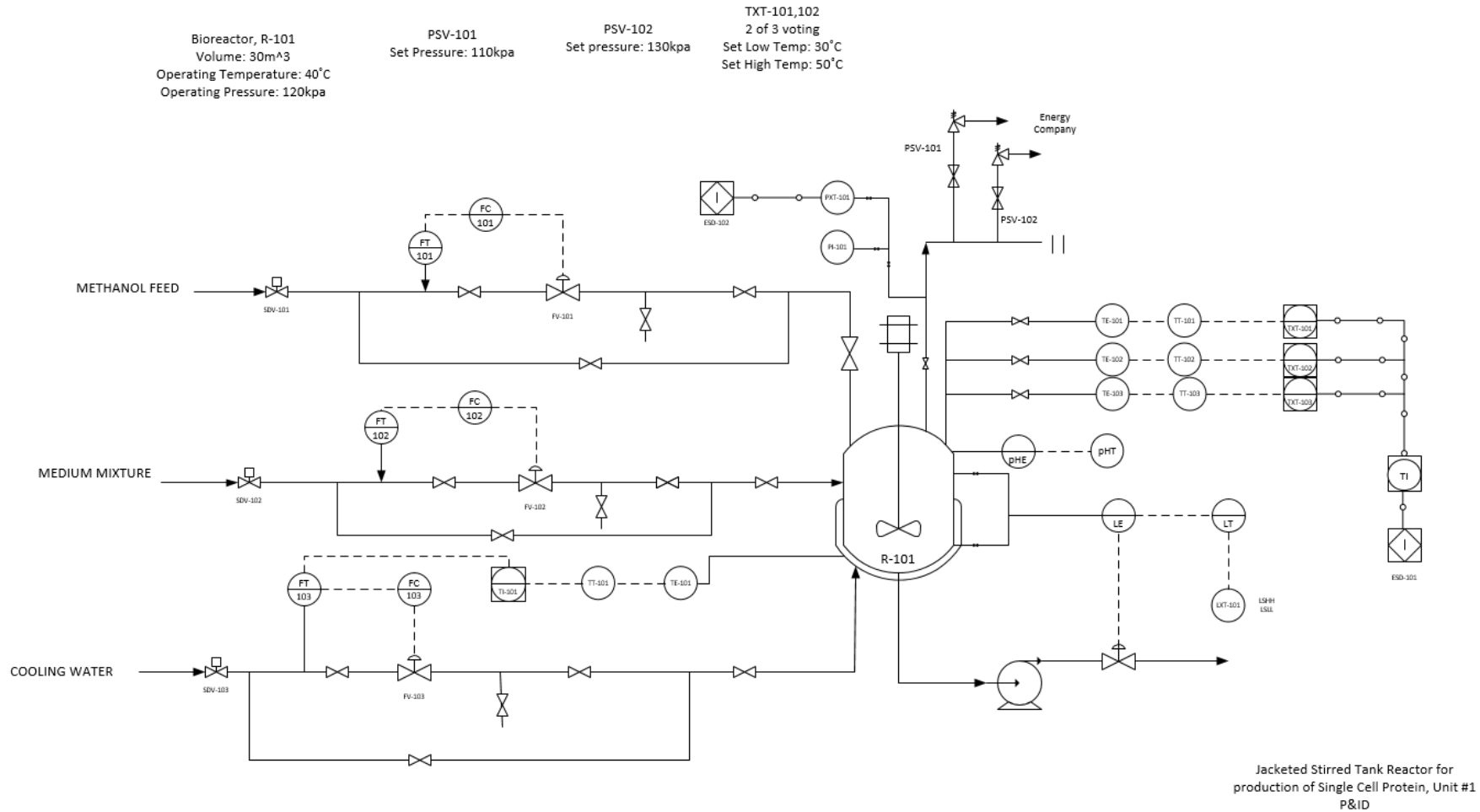
SPRAY DRYER SPECIFICATION

Identification	Equipment No/Name: D-101		
	No Required: 1		Bare Module Cost: \$ 715,430
	Service/Function: Removal of moisture from SCP by application of dry air contact		
	PROCESS DATA		
FEED		PRODUCT	
Materials Handled	Wet Protein Solids Water	Dried Protein Solids Water	
Total Flow (kg/hr)			
Component Flow (kg/hr)	FEED	PRODUCT	
Protein Solids	6000	6000	
Water	9000	-	
OPERATING CONDITIONS			
Temperature	110°C		
Pressure	120 kpa		
DESIGN DATA			
Vessel Internals/Externals		Atomizer	
Volume (m3)	282	Type	Centrifugal Disk
Height to Diameter Ratio	4	Diameter of disk (m)	0.3
Height (m)	24	Vane height (m)	-
Diameter (m)	6	Vane length (m)	-
Outer Diameter (m)	-	Number of vanes	-
Wall Thickness (m)	-	Rotational Speed (rpm)	6500
Inlet Temperature (°C)	110	Power Required (kW)	48
Outlet Temperature (°C)	50		
Gas Flowrate (kg/hr)	15,000		
Surface Area	170		
Comments:			

HAZOP ANALYSIS ON REACTOR

Parameter	Deviation	Initiation Cause	Consequence	Safe Guard
Flow	High methanol flow to R-101	1. FV-101 malfunction, inadvertently fail open	2. Potential increase of MAWT (50°C) & MAWP (130kpa) leading to possible inhibition of cell growth 3. Potential leaks or rupture leading to loss of containment 4. Injury to personnel	1. TXT-101,102,103 2. PSV-101,102
Flow	No/Low Flow	1. FV-101 malfunction, inadvertently close. 2. SDV-101 malfunction, inadvertently close 3. Manual block valve inadvertently close	1. Off spec product 2. Economic loss	1. FV-101 bypass
Pressure	High pressure more than 130kpa desired in R-101	1. FV-102 malfunction, inadvertently fail open	2. Potential for temperature and pressure to increase leading to possible vessel leak or rupture 3. Injury to personnel 4. Off-spec of product	1. PSV-101,102 2. PXT-101
Pressure	Lower pressure than 130kpa desired in R-101	1. FV-102 malfunction, inadvertently fail close	1. Potential low pressure leading to loss of nutrients for cell which leads to off spec production	1. PXT-101 2. Manual bypass around FV-102
Temperature	More than 50°C desired temperature in R-101	1. FV-103 malfunction, 2. SDV-103 malfunction, inadvertently fail close	1. Potential for temperature and pressure leading to possible vessel leak, rupture and runaway reaction 2. Off spec production 3. Injury to personnel due to exposure	1. TXT-101,102,103 2. PSV-101,102 3. PXT-101
Temperature	Less than desired 50°C temperature in R-101	1. FV-101,102 malfunction 2. SDV-101,102 malfunction, inadvertently fail close 3. Manual block valves inadvertently close	1. Potential low temperature leading to no reaction and/or off spec production	1. TSLL-101,102

P&ID AROUND REACTOR



SAFETY PROCESS CONDITIONS



➤ **Methanol**

- Boiling point: 64°C
- Melting point: (-98)°C
- Vapor Pressure: 13 kpa
- Stored 20°C at 100 kpa

➤ **Ammonia**

- Boiling point: (-33)°C
- Melting point: (-77)°C
- Stored below (-33)°C at 6 kpa

➤ **Bioreactor**

- 40°C and 120 kpa

➤ **Spray dryer**

- Dry air inlet at 110°C
- A co-current spray dryer
- Spray dryer will be open-loop

HAZARDS

- Methanol
 - Highly flammable liquid and vapor
 - Toxic if swallowed
 - Causes damage to organs
- Ammonia
 - Highly flammable
 - Corrosive
 - Causes damage to eyes

SAFETY

- When handling methanol and ammonia, avoid contact with eyes and skin
- EPA classifies methanol as toxic in high concentrations
- CO₂ will be collected by Howards Energy company to be disposed of





STORAGE & HANDLING

➤ Methanol Tank

- Stored in 300 series stainless steel alloy tanks
- Ventilated to prevent accumulation of vapors

➤ Ammonia Tank

- Stored in a carbon steel tank with enough vapor space above for thermal expansion
- Dry and well-ventilated location

➤ Single Cell Protein

- Stored in an airtight bin with less than 10% of moisture to prevent spoilage
- Packaged in super sacks (1m³)

➤ Methylococcus capsulatus

- Stored(- 80)°C or lower



Plant Location: Corpus Christi, Texas

Reasons:

- Ease of access to feed stock raw materials
- Environmental impact solutions
- Availability of labor
- Availability of suitable land



MARKET ANALYSIS

❖ Raw Materials:

- ✓ “Lab Alley”
- ✓ “Chemical and Filtration Chemicals of Texas”

❖ Consumers:

- ✓ Tyson
- ✓ Bluehouse Salmon



MARKET ANALYSIS (cont.)

- Transparency Market Research US\$ 27.3 billion
- Compound Annual Growth Rate of 9.3%
 - global demand of 600 million pounds per year



PROFITABILITY ANALYSIS

Profitability Equations		
Gross Earnings	$S - C$	S – Total annual sales revenue C – Total annual production cost
Net Earnings	$0.63 (S - C)$	S – Total annual sales revenue C – Total annual production cost
Income Tax	$0.37 (S - C)$	S – Total annual sales revenue C – Total annual production cost
Total capital investment (C_{TCI})	$C_{TDC} + C_{start} + C_{WC}$	C_{TDC} - Total depreciable capital investment C_{start} - Start – up capital C_{WC} - Working capital
Return on Investment (ROI)	$\frac{(S - C) \times (1 - t)}{C_{TCI}}$	S – Total annual sales revenue C – Total annual production cost t – Total tax rate C_{TCI} - Total capital investment
Payback Period (PBP)	$\frac{C_{TDC}}{(1 - t) \times (S - C) + D}$	C_{TDC} - Total depreciable capital investment t – Total tax rate S – Total annual sales revenue D – Depreciation to production cost
Net Present Value (NPV)	$\frac{R_t}{(1 + i)^t}$	R_t - Net cash flow at time i – Discount rate t – time of the cash flow

PROFITABILITY ANALYSIS (cont.)

Fixed Cost Summary

Operations

Direct Wages and Benefits	\$	1,123,200
Direct Salaries and Benefits	\$	168,480
Operating Supplies and Services	\$	67,392
Technical Assistance to Manufacturing	\$	1,080,000
Control Laboratory	\$	1,170,000

Total Operations \$ **3,609,072**

Maintenance

Wages and Benefits	\$	151,913
Salaries and Benefits	\$	37,978
Materials and Services	\$	151,913
Maintenance Overhead	\$	7,596

Total Maintenance \$ **349,399**

Operating Overhead

General Plant Overhead:	\$	105,192
Mechanical Department Services:	\$	35,558
Employee Relations Department:	\$	87,413
Business Services:	\$	109,636

Total Operating Overhead \$ **337,798**

Property Taxes and Insurance

Property Taxes and Insurance:	\$	67,517
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Other Annual Expenses

Rental Fees (Office and Laboratory Space):	\$	-
Licensing Fees:	\$	-
Miscellaneous:	\$	-

Total Other Annual Expenses \$ **-**

Total Fixed Costs

\$ 4,363,786

Variable Cost Summary

Variable Costs at 100% Capacity:

General Expenses

Selling / Transfer Expenses:	\$	3,162,816
Direct Research:	\$	5,060,506
Allocated Research:	\$	527,136
Administrative Expense:	\$	2,108,544
Management Incentive Compensation:	\$	1,317,840

Total General Expenses \$ **12,176,842**

Raw Materials

\$1.71 per kg of Single Cell Protein \$94,995,456

Byproducts

\$0.09 per kg of Single Cell Protein (\$4,971,725)

Utilities

\$0.19 per kg of Single Cell Protein \$10,331,644

Total Variable Costs

\$ 112,532,216

PROFITABILITY ANALYSIS (cont.)

Investment Summary

Installed Equipment Costs:

Total Direct Materials and Labor Costs	\$	100,500
Miscellaneous Installation Costs	\$	2,500,300
Material and Labor G&A Overhead and Contractor Fees	\$	-
Contractor Engineering Costs	\$	-
Indirect Costs	\$	-

Total: \$ 2,600,800

Direct Permanent Investment

Cost of Site Preparations:	\$	130,040
Cost of Service Facilities:	\$	130,040
Allocated Costs for utility plants and related facilities:	\$	-

Direct Permanent Investment \$ 2,860,880

Total Depreciable Capital

Cost of Contingencies & Contractor Fees	\$	514,958
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Total Depreciable Capital \$ 3,375,838

Total Permanent Investment

Cost of Land:	\$	2,025,503
Cost of Royalties:	\$	-
Cost of Plant Start-Up:	\$	337,584

Total Permanent Investment - Unadjusted \$ 5,738,925
Site Factor 1.00

Total Permanent Investment \$ 5,738,925

Working Capital

	2022	2023	
Accounts Receivable	\$ 6,044,011	\$ 2,014,670	\$
Cash Reserves	\$ 842,471	\$ 280,824	\$
Accounts Payable	\$ (6,038,273)	\$ (2,012,758)	\$
Single Cell Protein Inventory	\$ 6,044,011	\$ 2,014,670	\$
Raw Materials	\$ 1,270,727	\$ 423,576	\$
Total	\$ 8,162,948	\$ 2,720,983	\$
Present Value at 15%	\$ 7,098,215	\$ 2,057,454	\$

Total Capital Investment

\$ 14,894,595

Profitability Measures

The Internal Rate of Return (IRR) for this project is

37.19%

The Net Present Value (NPV) of this project in 2021 is

\$ 80,159,500

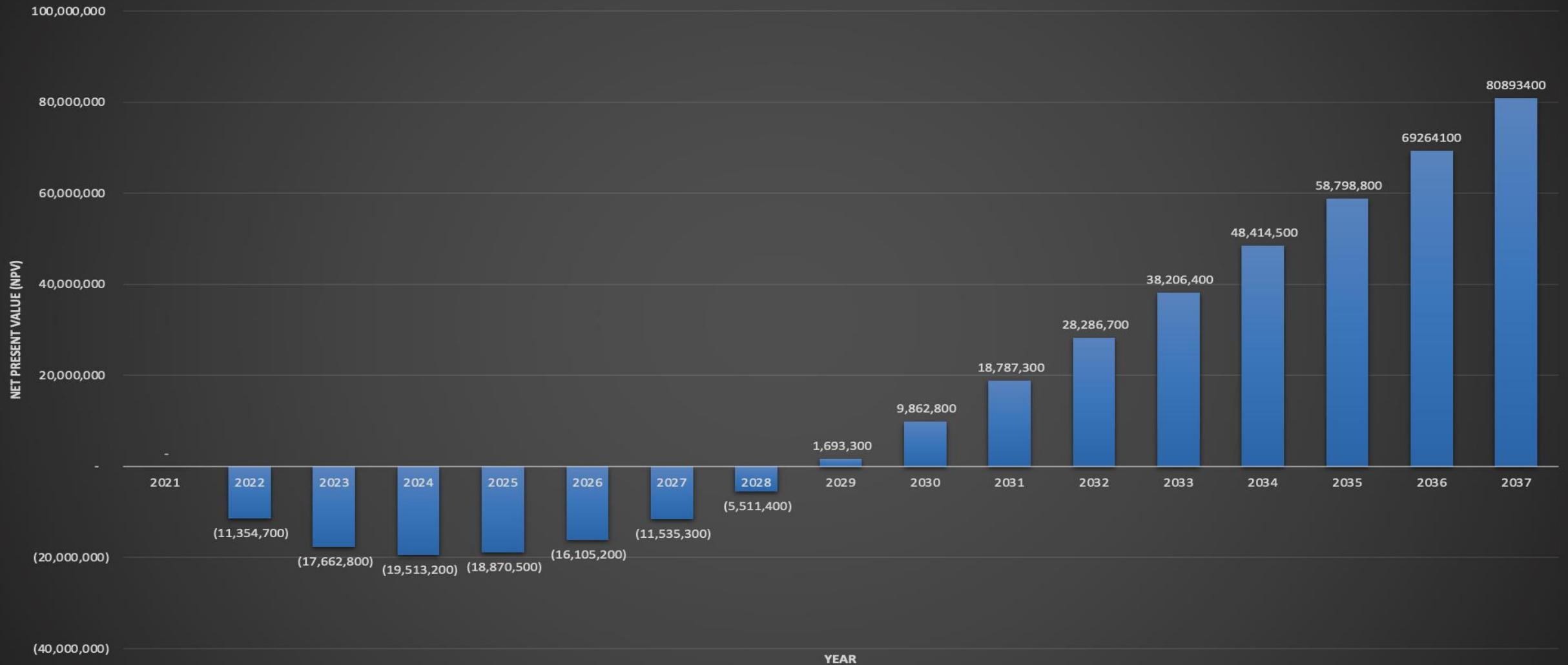
ROI Analysis (Third Production Year)

Annual Sales	115,423,728
Annual Costs	(114,020,180)
Depreciation	(459,114)
Income Tax	(349,441)
Net Earnings	594,993
Total Capital Investment	16,622,856
ROI	3.58%

PBP – 3 years

PROFITABILITY ANALYSIS (cont.)

CASH FLOW DIAGRAM - SINGLE CELL PROTEIN



RECOMMENDATIONS

- Spray dryer redesign considerations to safely circulate drying medium
- Alternative methods for cooling systems
- Biomass waste consideration for producing electricity
- Alternative feed-stock raw materials





QUESTIONS
COMMENTS
CONCERNS

PROFITABILITY ANALYSIS (cont.)

TOTAL EQUIPMENT COST BREAKDOWN

■ Storage ■ Process Machinery ■ Other Equipment ■ Spares

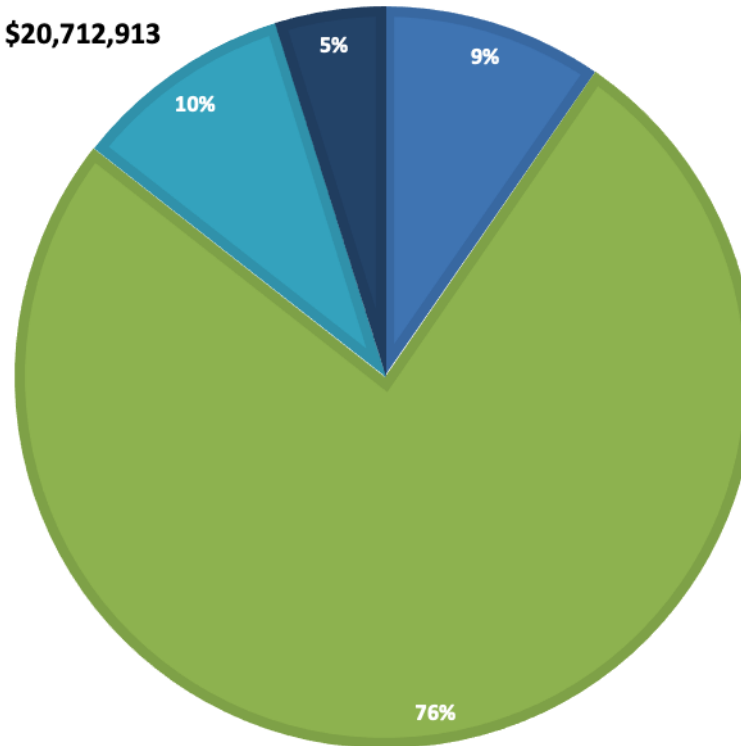
Equipment Bare Module Cost: \$20,712,913

Storage: 1,642,878

Process Machinery: 16,272,778

Other Equipment: 1,840,420

Spares: 956,837

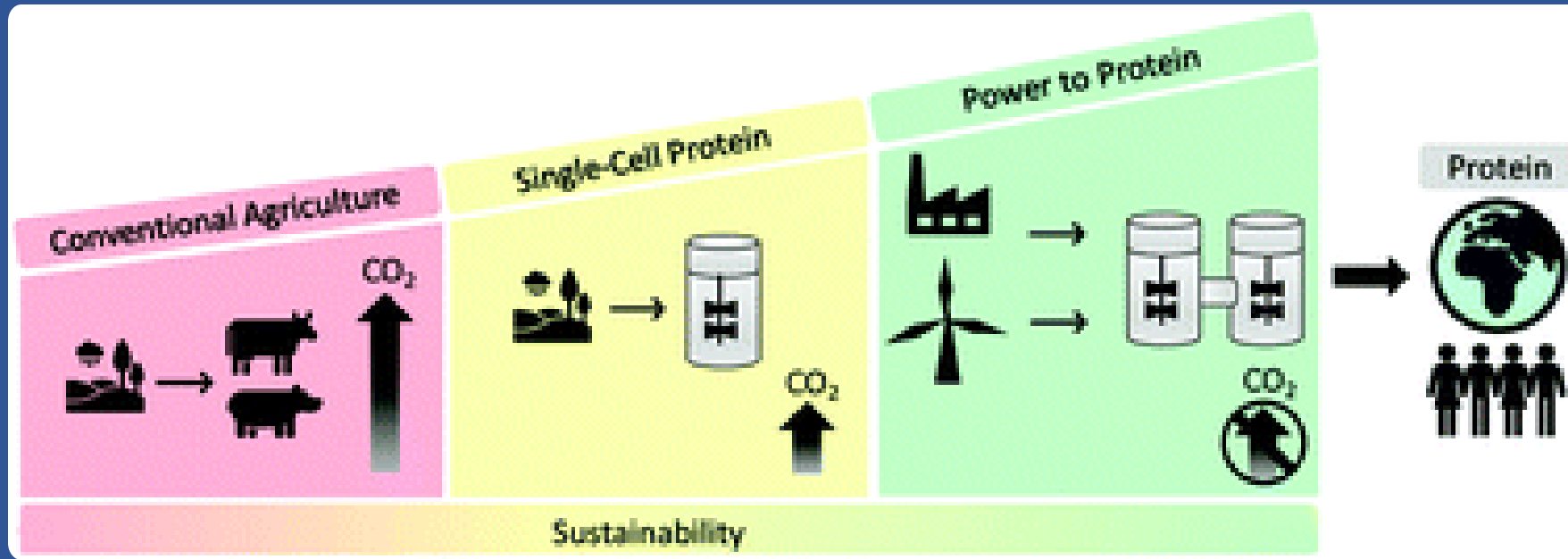


EQUIPMENT PRICE SUMMARY

Equipment Description	Type	Purchase Cost	Bare Module Factor	Bare Module Cost
Name	(must be filled-in!)		(default 3.21 if blank)	
Methanol Storage tank	Storage	\$294,000		\$943,740
Ammonia Storage tank	Storage	\$142,000		\$455,820
Nutrient Holding Tank	Storage	\$75,800		\$243,318
Medium Mixer	Process Machinery	\$100,000		\$321,000
Air Compressor	Process Machinery	\$798,000		\$2,561,580
Pumps	Process Machinery	\$70,080		\$224,957
Bioreactor	Process Machinery			\$9,100,000
Centrifuge	Process Machinery	\$32,400		\$104,004
Ultrafiltration	Process Machinery	\$107,665		\$345,605
Homogenizer	Process Machinery	\$520,000		\$1,669,200
Microfiltration	Process Machinery	\$107,665		\$345,605
Spray Dryer	Process Machinery	\$161,000		\$516,810
Cooler	Process Machinery	\$32,700		\$104,967
Autoclave	Process Machinery	\$133,000		\$426,930
Ammonia Vaporizer	Process Machinery	\$172,000		\$552,120
Coarse Air Filter	Other Equipment	\$22,000		\$70,620
Micron air filter	Other Equipment	\$28,000		\$89,880
Collection chamber	Other Equipment	\$352,000		\$1,129,920
Super sacs	Other Equipment			\$510,000
Waste Bags	Other Equipment			\$40,000

TOTAL :

\$ 20,712,912



History and Uses

➤ History

- WWI & II, Germany attempted to supplement protein by using Torula yeast
- Torula yeast was grown on sulfite waste liquor
- Animal feed supplement on the commercial level called “pruteen”

➤ Uses

- Animal feed to fatten cattle, pigs, chicken and fish
- Pharmaceuticals such as supplements for hair and face
- Food additives such as vitamins, enhance foods such as soups and ready made meals

Schedule Part 1

TASKS	ASSIGNED TO	START	END
Phase 1 Project Definition			
Literature review/ Process research	ALL	9/13/21	11/19/21
Business Model & Analysis	ALL	9/13/21	11/19/21
Phase 2 Business Analysis			
Market & Consumer Interest	Kaylon & Chad	9/13/21	9/27/21
Raw Material Research	Toyosi & Kaylon	9/13/21	9/20/21
Phase 3 Safety & Environmental Regulations			
Storage & Handling	Shanelle	9/13/21	9/27/21
Packaging & Waste Disposal	Shanelle & Toyosi	9/27/21	10/4/21
Safety Regulations (OSHA, FDA,EPA)	Shanelle & Chad	9/27/21	10/4/21
Phase 4 Preliminary Process Design			
Preliminary BFD & PFD	Kaylon, Toyosi & Shanelle	10/21/21	11/15/21
Material & Energy Balances	Chad & Toyosi	10/21/21	11/19/21
Preliminary Simulation	Toyosi	10/21/21	11/21/21

Bacteria Strand: Methylococcus capsulatus



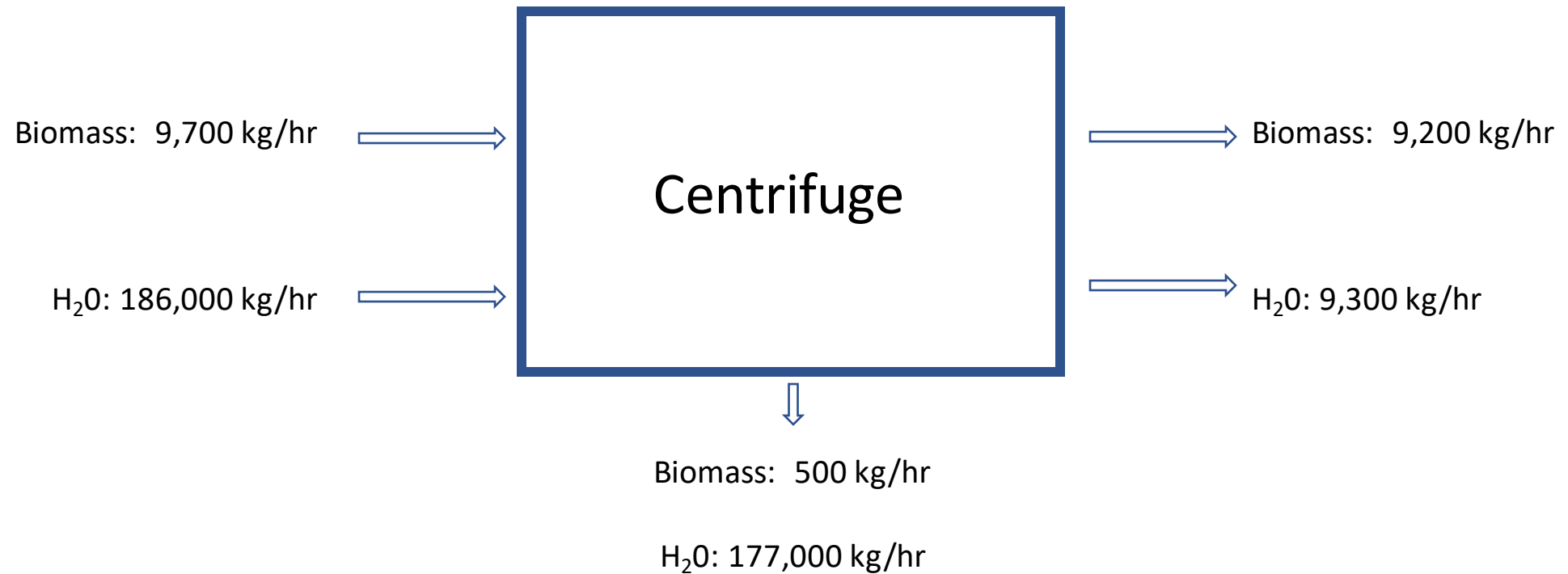
Composition of *M. Capsulatus*

Crude protein	70%
Fat	10%
Fiber	1%
Carbohydrates	12%
Minerals	1%

- Methanotroph family
- Utilizes methanol as its source of carbon and energy

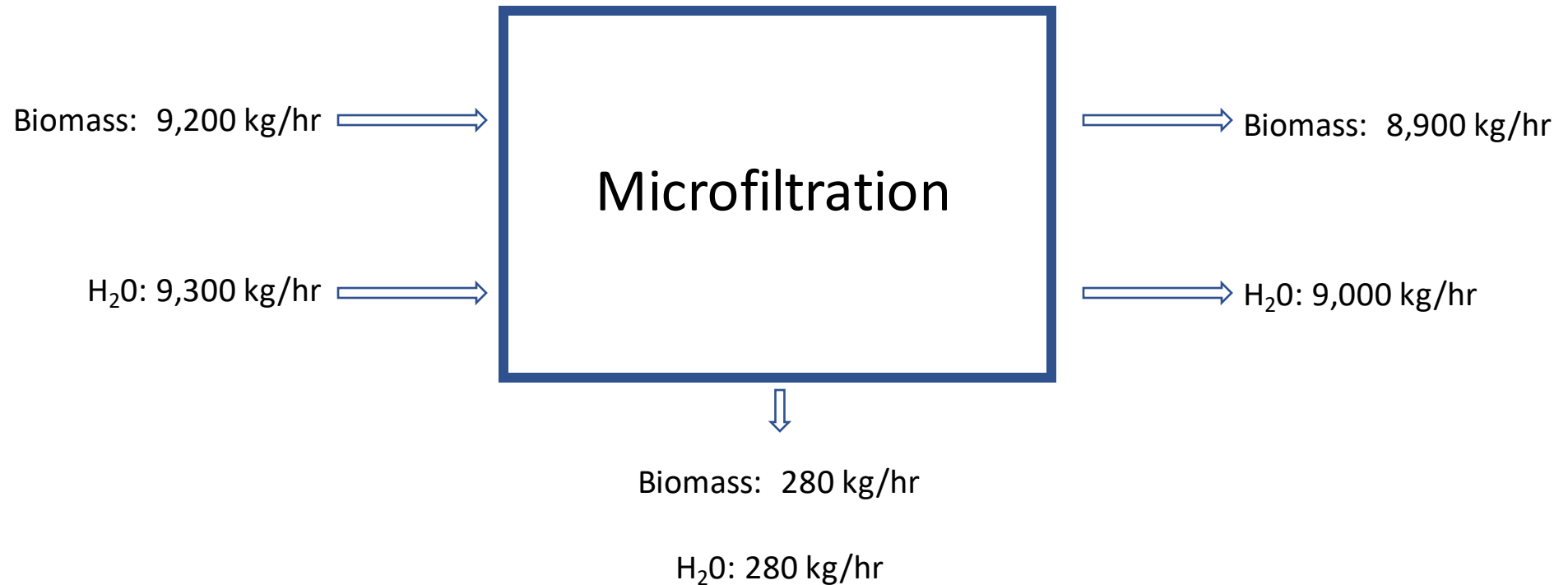
MATERIAL BALANCE- CENTRIFUGE

Working at 95%



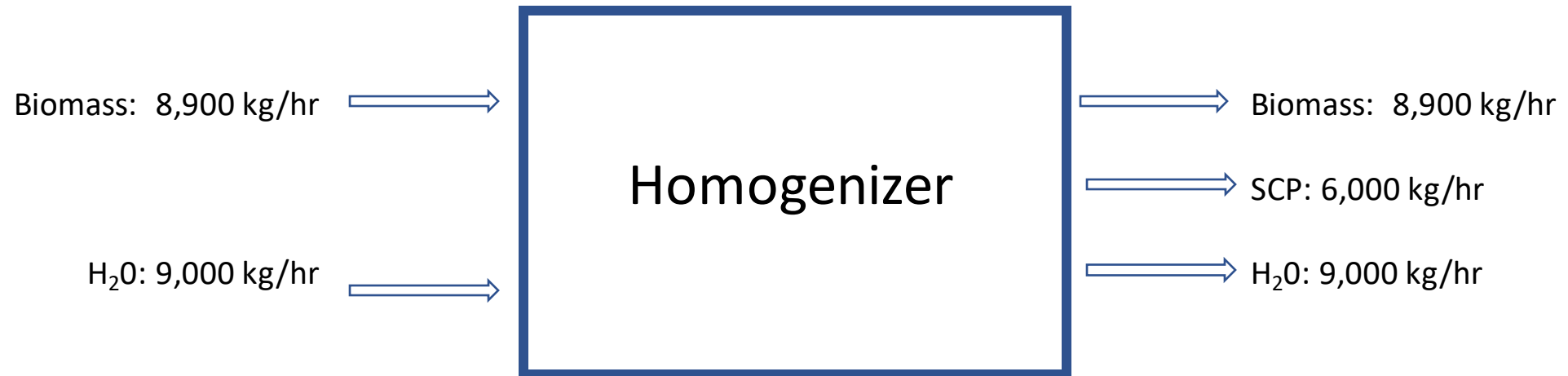
MATERIAL BALANCE - MICROFILTRATION

Working at 97%



MATERIAL BALANCE - HOMOGENIZER

Working at 100%



MATERIAL BALANCE - ULTRAFILTRATION

Working at 98%

