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Glass factory in Mongolia: A conceptual Idea

Bachelor Thesis

by

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Glass factory in Mongolia: A conceptual Idea

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Nalaikh, 5/13/2023

Place, Date

Signature

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Abstract

The thesis is aimed to conduct a conceptual study of the technical, environmental, and economic aspects of a glass factory in Mongolia. Given the current state of the glass industry in Mongolia, which is fully dependent on imports, the need for a local glass factory is crucial, particularly with the emerging demand for the container glass industry.

To achieve this, a historical review of glass usage and previous local glass factory will be conducted, followed by market analysis and demand projection for the Mongolian glass industry. The conceptualization of a potential glass factory will be based on international best practices and modern technology. This study provides insights into the viability of a glass factory in Mongolia.

After conceptualizing the factory the results are as follows. The production capacity is determined based on projected demand, assuming 60% production and operation 365 days a year with 12 years of use of an electric furnace. The chosen location is Dornogovi near Bayan-Uul deposit considering several factors such as market demand, proximity to raw materials, access to energy and transportation infrastructure.

The capital cost for the factory is estimated at $25,854,703.67, with an annual operational cost of $14,858,038.59. The NPV value of the concept factory is $64,748,904.27, the IRR value is 37%, and the payback period is 3 years. The report concludes that the factory is financially viable, and the metrics presented can inform investment decisions.

Table of Contents

1. Introduction

1.1 Problem statement

We use glass for many purposes in our daily life such as bottles, jars, tableware, window glass, drinking glasses, bowls, and products for construction purposes. As the research and technology improves, the glass quality of durability, resistance to chemical corrosion and change in thermometric properties enhances in every sector. In 2020, the global container glass market size was $82.2 billion and is expected to generate $155.9 billion by 2030, witnessing CAGR at 6.7% (1). While in Mongolia, the production of beverage was 1.4 trillion MNT which is larger than the previous year by 217.1 billion MNT and the production of soft drinks increased by 9.1%, alcohol by 11.3%, wine by 23.5% and beer by 9.7% in 2021(2). Therefore by considering these, the demand for container glass is expected to grow in the future. However, Mongolia is 100% dependent on importing glass products from other countries since it has no manufacturing company and 80% of the products are imported from China. As of 2020, 55 million dollars were spent on importing 21 types of glass products (3). The majority of the glass products are imported from Hebei, Shaanxi, Anhui Province of China and transported from the producers approximately in 15 days (4). Also due to multiple shipping processes, 5% of the total products become deficient and increase the cost. Currently, the glass producers' offering cost is influenced by the international and domestic transportation, customs duty fees, shipping and handling, and percentage of defects and is on average with 60% increase in cost (4). Besides, sudden interruptions have occurred in importing glasses from China in previous years due to the pandemic and border closure which caused a glass bottle shortage in Mongolia.

Additionally, waste pollution is considered a crucial element in the environmental issue of Mongolia. From which, glass waste contributes nothing less. Glass cullets, which are recycled glasses resulting from rejected products in the production process or collected from the market, are a high-value raw material since it has several environmental benefits including reprocessing the glasses which goes directly into the landfill. If the glass collection, sorting and purifying processes are sufficient and the purity is high, the share of glass cullet in the glass mixture can be even more than 90% (5).

Thus, in order to centralize the cash flow, which is flowing to other countries, inward, reducing the additional costs and deficient products, and ensuring the risks of depending solely on import for example; product shortage while ensuring sustainability, producing import-substituting glass products in Mongolia is much needed.

1.2 Research questions

The overall goal of the thesis is to conduct a conceptual study on a potential glass factory in Mongolia by considering the technological, environmental and economic aspects. Within the thesis frame, these questions will be answered:

1. Historical review: what was there and what are the lessons learned?

   It is essential to look back and learn from the previous works. From 1958 to 1990, Mongolia had a glass factory with a capacity of producing 15000 glass products in a year. However, due to economical transitions the factory was shut down in early 1990s. Within the context, the factory's condition and operations will be studied.

2. Current situation: what is currently there, and why is the situation the way it is?

   The present situation of Mongolian glass industry and its disadvantages and potential risks for future continuation of the process will be investigated.

3. Future perspectives: what are the future possibilities?

   In order to determine whether Mongolia has the opportunity for the market, the market analysis has to be made. In which the determination of the demand size and familiarizing with the global market and current glass suppliers which in the future will be the factory's competitors. Lastly, the majority of the glass consumers; beverage and preserves producers would be studied.

4. Conceptualisation of a potential glass factory: what can be suggested?

   The last but most important question is **"What are the technical, economical, environmental opportunities and concerns in Mongolia and what can be suggested?"** In order to answer this question, the studies on the respective sectors will be made at a conceptual level.

1.3 Methodology

The main feature of the conceptual framework is that the study is done by summarizing and integrating the concept subjects from existing international projects and researches and previous local factory. And the study is accurate to within 40-50% (6). Thus, the research is mostly structured from literature review and analysis. The research data is acquired by using both quantitative and qualitative methods. Qualitative method involves gathering and observing the major concepts information on historical reviews, current situation and conceptualization sections' technical parts where the previous projects and researches of Mongolia and current methods used in other countries especially the importing nations. Quantitative methods are mostly used in the market research and conceptualization sections' economics parts by gathering statistical data and formulating the demand size, production capacity, and calculating economic variables such as cost estimation and financial results.

2. Historical review

2.1 Origin of glass

Originally, people were using naturally occurring glass formed from quartz sand on earth's ground that melts in high temperatures for example volcanic eruption and then cools down. Sharp edges of it were used as scrapers and wedges. It is not sure what was the first date of the glass making, but it is believed that glass making originated in Egypt and Mesopotamia during 3500 BC. Later it developed in China, Greece and Northern Tyrol separately (28). The glass was used for purposes of jewelry and for small vessels since the glass's aesthetic appealing property was considered luxurious. With the technology of molding glass around a sand to make larger and practical items such as bowls, containers and cups, the glass production notably improved from around 1500 BC. The glass blowing pipe, which originated from Palestine or in Syria in the first century AD, was the beginning of a technical revolution in glass production. This method enables the different kinds of design and shapes and then spread across Italy and France and other European countries. In 1688, plate pouring process was discovered under Louis XIV, large surface mirrors which are popular in churches could be created.

Figure 1. Roman cage cup

Figure 2. Windows in the choir of the Basilica Saint-Denis

During that time, lead crystals, which have properties of high brilliance and purity, were developed in England. In the 18th century, some factories were already producing more than one million bottles per year, by manual mouth-blown techniques. During the industrial revolution of the 19th century, technology is improved significantly, for example:

1. Heating furnaces with coal instead of wood
2. Using automatic machines
3. Using compressed air in metallic molds for the blowing process

At the end of the 19th century, Friedrich Siemens invented the continuous furnace, which allowed large-scale continuous production and the machinery use. In the 20th century, the first automatic individual section (IS) machine was discovered in 1920 and the invention of the float process for flat glass in 1962.

Today, glass is used broadly in industries playing a crucial role in both traditional (construction, packaging, automotive) and innovative sectors which change glass properties by adding specific substances for high technology products including space exploration, pharmaceutical, optics, and telecommunications. (7)

2.2 Former glass factory in Mongolia

During 1958 to 1960, the Chinese government gave Mongolia a loan of 67.5 million rubles and a grant of 41 million rubles, which is approximately 176.2 million and 107.01 million in today's dollars, and agreed to construct a total of approximately 50 factories, agricultural buildings and apartments (4). Within this contract, a glass factory had been built in 1958, located in Nalaikh district, Ulaanbaatar, Mongolia. However, during the early 1990s economic change, the factory was shut down. Until 1963 the factory had a capacity to produce 15000 glass products per annum. In 1967 a capacity of 6000 bottle per day half-automated machine and a pressing machine with a capacity of 1800 glassware in a total of 8 working hours were installed and extended the operation (8). 73.2% of the factory's raw materials were from Mongolia, and 26.8% came from other countries. And this composites from silicon oxide (42.5%), sand (18.9%), lime (11.8%) and sodium carbonate (19.7%), magnesium (3.9%), ammonium nitrate (2.4%), arsenic (0.9%) respectively (4). 1500 tons of sand were utilized in 1981 by the Nalaikh glass factory to make 1.4 million bottles. The plant could also produce 20 different kinds of items, including decorative and home goods (8).

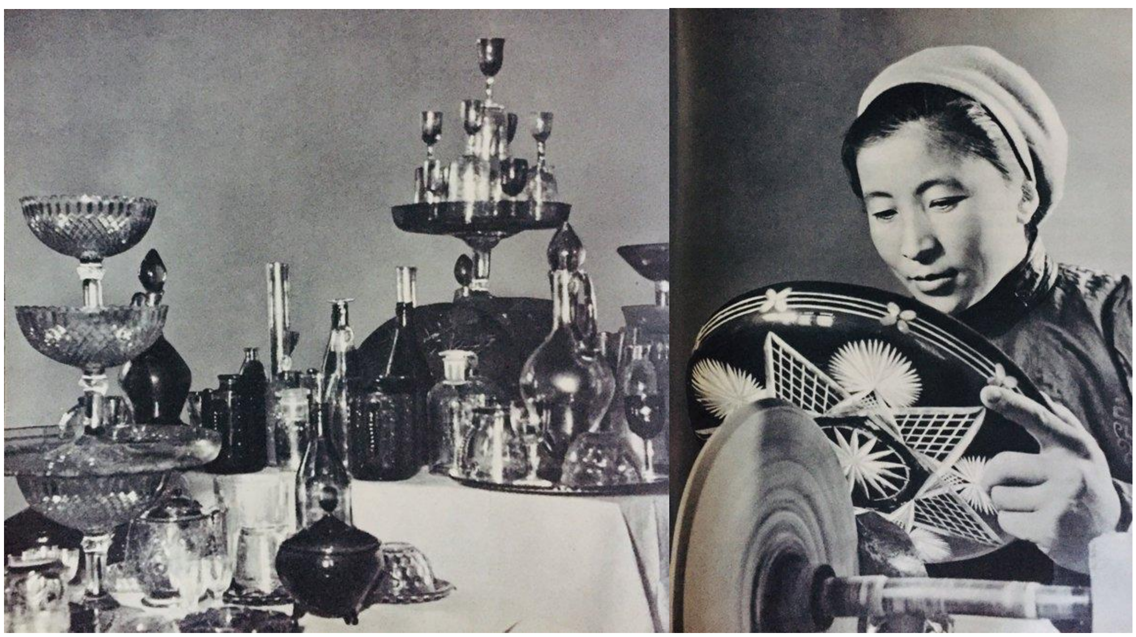

Figure 3. Nalaikh factory 1961 from

One of their primary functions was to provide APU, which was then a state owned factory, and the other 14 beverage producers with glass bottles (for juice, beer, and vodka). The factory produced bowls, plates, flower pots, souvenirs, and other glassware in addition to supplying manufacturers. With the exception of windshields and brown glass bottles, the facility used to recycle all forms of glass. Beer bottles, for example, could not be produced in commercially viable quantities due to a lack of equipment and experience (8).

3. Current situation & Future perspectives

3.1 Mongolian situation

As mentioned before, Mongolia's glass industry is totally dependent on imported products dominantly by 80% from our neighbor country China and others from Russia, France, Ukraine and Europe (8). Based on Export and Import by Commodities 2006-2021 report from Mongolian statistical information service, the previous five (2017-2021) years' average of $54.5 million was spent on importing a total 18 types of glasswares. From which, the container glass sector constitutes approximately 59.5%, flat glass sector 11.7%, mineral wool 6%, pharmaceutical 0.74% and others 22.06% including signal and optical glass items, watch glassware, road glass blocks, building glass tiles, decorative glass jewelries and other articles of glasses. According to Mongolian customs by 2022, importing container glass with HS code of 7010 including bottles, carboys, flasks, jars, pots, phial and ampoules costed $43,64 M which is almost 80% of the previous five years average and almost doubled the previous years (2021) amount. Which can be the result of glass bottle shortage during the pandemic and demand for container glass peaked in 2022 to fill the gap. Globally due to the pandemic, glass for the pharmaceutical sector's demand increased dramatically which can be the same in Mongolia. As a consequence of increasing demand and glass production cost, which resulted from energy, raw material and labor, glass price is persistently increasing. These all influenced the major difference between 2021 and 2022 years for glass imports.

Table 1. Container glass import from Mongolian customs

Year	HS code	Quantity /unit/	Amount /thousand $/
2013	7010	92,387,231.00	22,918.57
2014	7010	95,716,500.00	24,331.90
2015	7010	85,503,209.00	23,971.09
2016	7010	96,015,627.00	26,970.49
2017	7010	98,228,779.00	28,337.62
2018	7010	118,282,322.00	33,528.19
2019	7010	111,522,308.00	33,912.48
2020	7010	107,200,125.00	26,159.47
2021	7010	98,398,046.00	22,912.26
2022	7010	151,150,209.00	43,635.43

By 2018, Ulaanbaatar generated 41.6% of 3.4 Mio tons of total waste across Mongolia (9). From which, around 319,000 tons was glass waste. Glass recycling and reusing system is not installed sufficiently in Mongolia because of people not sorting the waste in the first place. Although there are glass collecting sites, a certain amount of glass waste goes directly into the landfill without being reused and recycled causing environmental problems such as soil pollution, wildfires from broken glass. In Ulaanbaatar, there are around 20 waste recycling factories and the majority of them are for recycling plastic and paper. There is only a glass factory which recycles glasses to produce insulation material for construction. Additionally, glass using companies collect and reuse produced glass and try to implement circular economy by initiating projects or trying new methods on their own, for example; APU, one of the biggest beverage companies in Mongolia, had a return rate of 10% for vodka bottles and 46% for beer bottles in 2021. Also, they initiated a project called "Let's revive glass bottles" which aimed to increase the numbers of returned glass to 2 million by appealing customers to return their RGB in 2021, but they collected only 1 million return-back glass bottles as a result (8).

3.2 Risks of import dependency

Import dependency ratio defines to what extent the country is dependent on import and scaled from 1-100%. In 2019, Mongolia's import dependency ratio was 68% (10), which shows that our country is highly dependent on import.

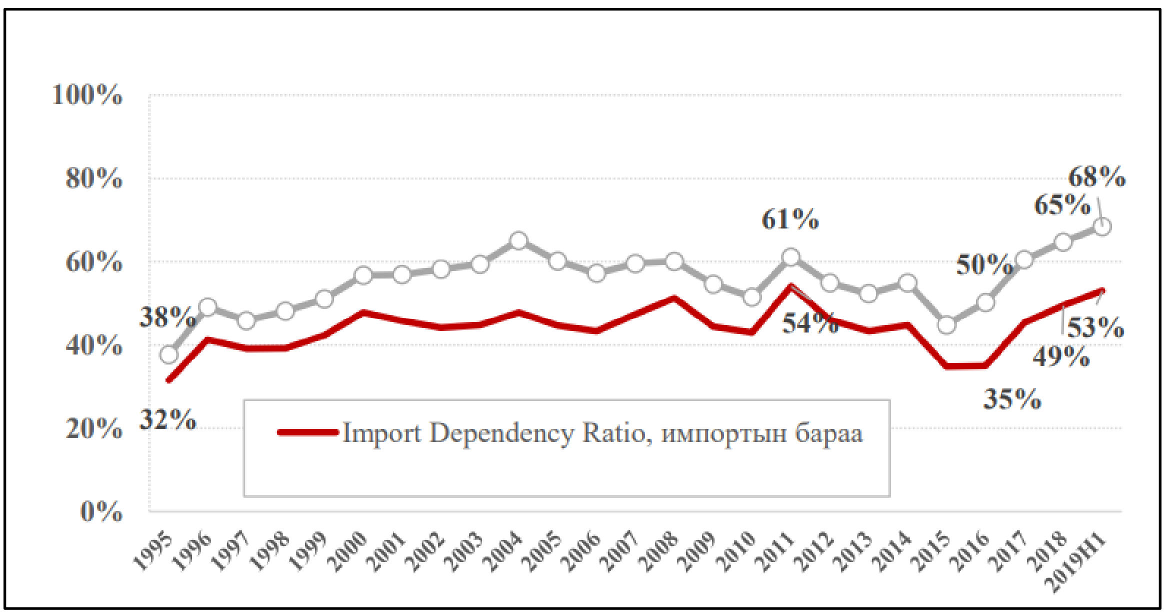

Figure 4. Import Dependency Ratio

In 2021, Mongolian imports equaled $6.8 billion which is greater than previous year by $1.5 billion. The top importing products are categorized into 4 sectors; investment products (40%), consumer goods (32%), petroleum (17%), and industrial raw materials and others (11%) (11).

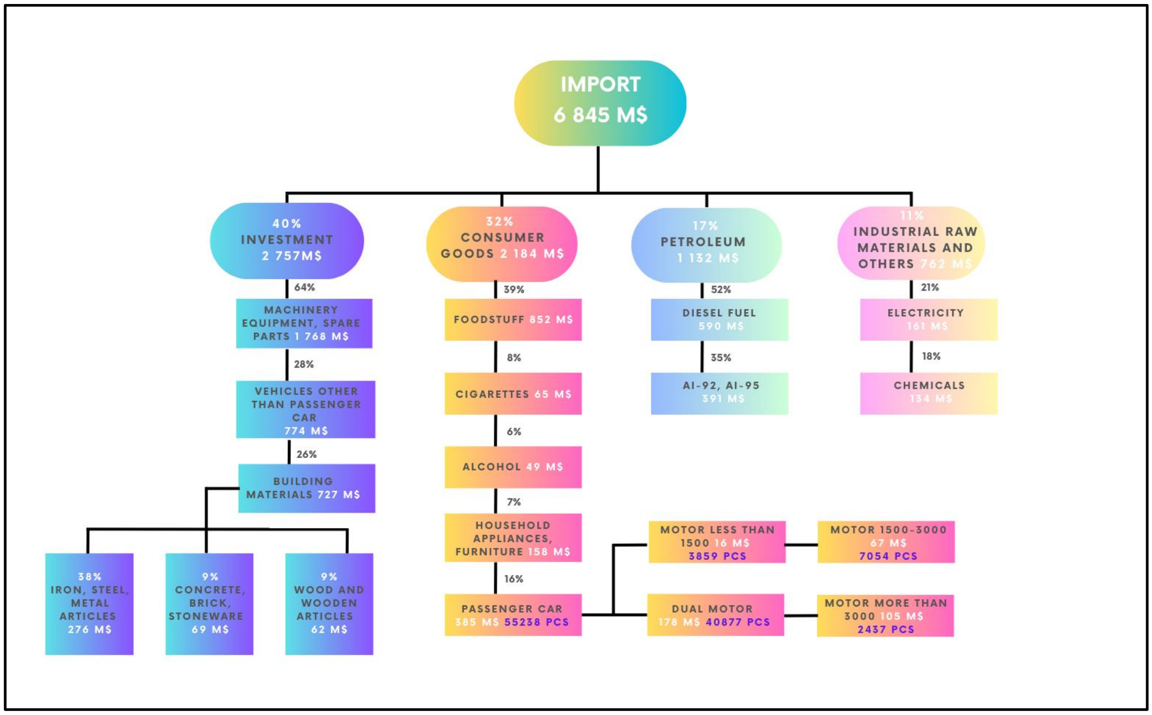

Figure 5. Mongolian import distributions in 2021 by sector

The glass imports constitute 0.713% of the $6.8 billion total imports. Which seems relatively insignificant, however it is important to notice that the glass industry is fully dependent on import. Because of this reason, there are several risks or difficulties of being import-dependent on commodities.

1. Value added cost

   As it mentioned in chapter 1, due to multiple shipping processes, the 5 percent of the total product is deficient and increases the cost. Currently, the glass producers' offering cost is influenced by the international and domestic transportation, customs duty fees, shipping and handling, and percentage of defects and is on average with 60% increase in cost. Which is going to increase in the future, since the production cost is increasing due to rising energy and raw materials costs.

2. Exchange rate

The growing amount of imports and the size of the trade deficit can both hurt a nation's currency. In 2021, Mongolian trade balance was -0.31 billion US dollars with 192.54% decline from previous year (12).

3. Unexpected product shortage

   Moreover, manufacturers were severely impacted by the interruption in the supply of new glasses as a result of the Covid pandemic's effects, such as border restrictions with China. For instance, the price of importing glass nearly doubled, shipping costs rose, and packing became more expensive. Thus to prevent unexpected situations further, import substitution should be developed in the future.

3.3 Market research

3.3.1 Glass Industry

Global market research is helpful to gain insights into the industry, understand current global trends, demands, and unique challenges for new market entries. Today, globally glass is considered a valuable material, which is used in various industries such as construction, food & beverage, automotive, pharmaceuticals, electronics, space and technology etc, since it has a property of inert, recyclable, and reusable. In 2021, the global glass industry was estimated at $106.44 billion and expected to reach a CAGR of 5.2% until 2030 and also in 2022, global market demand for glass manufacturing was estimated at 166.92Mt and expected to reach 231.01 Mt by 2030 (13). Glass market share by applications are as follows:

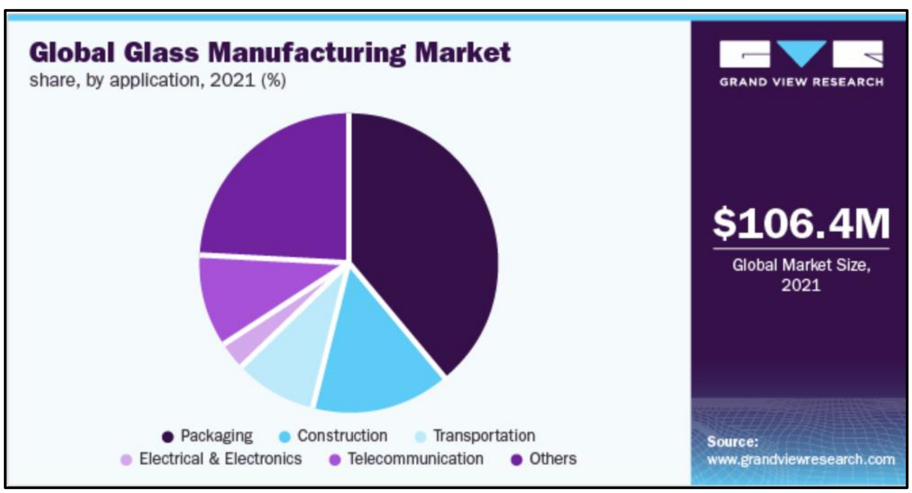

Figure 6. Global glass market by application 2021

Worldwide, the packaging industry is taking the highest share, over 35% because of surging environmental issues in hand by promoting glasses over plastics or other non recyclable packaging. Glass wools are used in construction for insulation material and considered as environmentally beneficial while it reduces energy consumption by 300 times (14). From this, the global trend is to boost energy efficiency and environmental awareness for the manufacturing sector.

Container glass industry took a hit in the beginning of 2020 because of a pandemic which restricted the transportation, and caused raw material shortage resulting in supply interruption of the product and a great number of companies had to close their business. However, the growing demand helped to get up from the crisis soon.

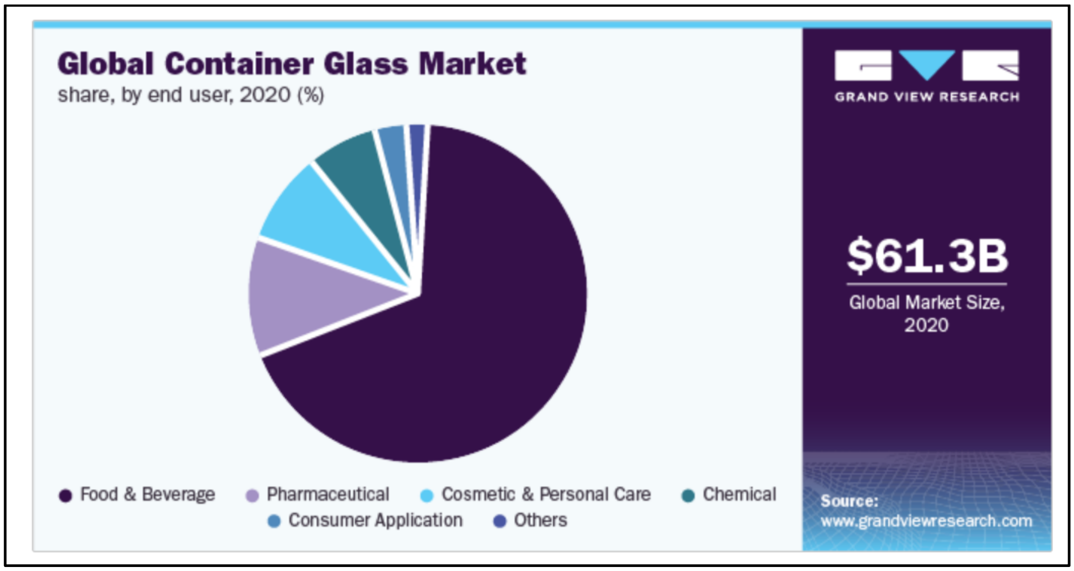

Figure 7. Global glass market by end-user 2020

In 2020, the Food & beverage sector's global revenue share was 68% due to increasing demand for alcohols and soft drinks from which *beer* has the most of it. Also due to global medicine demand, the pharmaceutical market was considerably high and expected to witness 6.6.% CAGR by 2028 (15).

Current trends in container global glass market for the segments based on color, end-user and region are as follows:

1. Color

   Although flint container glasses are not prevented from UV radiation. The market has growing interest in flint glasses because of its high resolution of visibility, which is taking advantage from the competitor packaging such as plastics.

2. End-user

   Surprisingly, in the European and US market, the usage of glass bottles for dairy products are increasing. This trend is due to the alcohol and beverage industry's downfall because of COVID. Also it seems much more effective since one England milk producer's glass bottled products increased by 85% (16).

3. Region

   Table 2. Regional segmentation

Region	Contributing countries	Description
Asia Pacific	China, India, Japan, Australia	In Japan and China, the pharmaceutical sector is developed broadly. Thus, the inert glasses are crucial and needed as well as their population.
North America	United states	The US is the second largest consumer of the container glass since it takes almost 13% of the beer consumption. (15)
Europe	Germany, Russia, France	Largest container glass market with up to 35%. Alcoholic beverage sector contributes the majority of it because of famous factories across Germany, Russia and France accounting for 40% of the entire Europe market. (16)

In China, a 300ml and 500 ml glass bottle is around $0.079-0.15 for a piece and it can be various in design, size, color and shape (17). In 2015, it was estimated at 200 naira and 150 naira for a 330ml bottle and a 250ml tumbler respectively in Nigeria (18).

3.3.2 Demand and Demand Forecast

Total demand for the glass industry from imports in 2022 was estimated at 81288.37 thousand USD in Mongolia.

Table3. Mongolian Glass Demand 2022 from Mongolian customs

Year	**HS code**	**Unit**	**Quantity**	**Amount /thousand $/**
2022	7002	kg	8,815.16	10.07
2022	7003	m2	549.57	4.41
2022	7004	m2	43,138.65	300.4
2022	7005	m2	3,321,851.85	17,067.30
2022	7006	kg	7,012.52	36.88
2022	7007	m2	20,771.01	655.61
2022	7007	piece	32,584.00	886.96
2022	7008	kg	3,332,766.08	4,923.67
2022	7009	piece	142,229.00	1,647.34
2022	**7010**	**piece**	**151,150,209.00**	**43,635.43**
2022	7011	piece	2,228.00	1.11
2022	7013	piece	3,812,954.00	5,905.80
2022	7014	piece	1,556.00	5.99
2022	7015	piece	303	0.07
2022	7016	piece	345,165.00	548.87
2022	7017	piece	3,420,719.00	280.51
2022	7018	kg	48,210.00	220.98
2022	7018	piece	12,126.00	40.11
2022	7019	kg	2,867,417.68	4,781.95
2022	7020	piece	71,763.00	334.91
			TOTAL	**81288.37**

As mentioned above, Mongolian demand size for container glass for 2022 was 151,150,209 and cost at $43,635.43 thousand which accounts for almost 54% of the whole glass industry's total (19). So that future glass factory's production scope is container glass, mainly for the food and beverage sector.

- Demand Forecast

Demand forecast is made for 16 years from 2022, assuming that the construction phase of the factory will take 4 years and the glass factory will run 12 years until its rebuild. The demand forecast comprises three scenarios; worst, average and best case based on the historical data of container glass import from 2013 to 2022. Worst case scenario is where the demand is constant without increasing. Average case scenario is calculated using the moving average formula. Lastly, the best case scenario is based on the CAGR of the global container market described in chapter one.

Table 4. Demand Forecast

Worst case scenario (All constant)	**Average case scenario**	**Best case scenario (CAGR 6.7%)**	
Quantity /piece/	Quantity /piece/	Quantity /piece/	Year
151,150,209.00	151,150,209.00	151,150,209.00	2022
129,530,295.27	**129,530,295.27**	**129,530,295.27**	**2023**
129,530,295.27	135,685,384.57	138,208,825.05	2024
129,530,295.27	142,714,110.38	147,468,816.33	2025
129,530,295.27	147,166,189.95	157,349,227.03	2026
129,530,295.27	152,388,352.71	167,891,625.24	2027
129,530,295.27	156,879,516.92	179,140,364.13	2028
129,530,295.27	164,904,120.03	191,142,768.52	2029
129,530,295.27	171,762,747.66	203,949,334.02	2030
129,530,295.27	176,653,456.73	217,613,939.39	2031
129,530,295.27	176,849,053.52	232,194,073.33	2032
129,530,295.27	180,424,053.78	247,751,076.25	2033
129,530,295.27	191,268,210.72	264,350,398.36	2034
129,530,295.27	196,559,861.71	282,061,875.05	2035
129,530,295.27	202,136,978.25	300,960,020.67	2036
129,530,295.27	207,542,445.87	321,124,342.06	2037
129,530,295.27	212,837,958.05	342,639,672.98	2038

2023’s quantity and amount numbers are calculated from moving average calculation and used as reference number because 2022’s demand is exaggerated due to pandemic shock.

3.3.3 Customers

It is crucial to consider the factory’s potential customers, which are mainly B2B. Container glass using Mongolian companies in *Food & Beverage* sector:

- APU JSC

  APU JSC is one of the premier beverage companies of Mongolia with a history of 98 years. It produces vodka, beer, wine, soft drinks and dairy products. In 2016, APU had the highest share (57.7%) of clear glass in Mongolia followed by Spirt Bal Buram LLC (31.4%), which soon merged with APU JSC in 2017. Currently, it imports glass bottles from China, Russia, and France and also reuses RGBs by cooperating with RGB supplying company “Depod LLC” (20). APU JSC’s vodka factory has a capacity of producing 200,000 hectoliter, and beer factory 900,000 hectoliter annually (21).

- Gem International LLC

  Gem International LLC is a beverage company producing vodka, draft beer, and water. Over 10 million dollars were spent by Gem on the purchase of vodka bottles. imports brand-new bottles from Europe, France, the Ukraine, and Russia for about $1 each bottle (7). The business offers carton cartons of bottled drinks for sale.

- Arvain Undes Beverage (AUB)

  AUB is a beverage company, which is owned by Altan Joloo Group, producing vodka, beers, and distilled water. In 2012, it had a capacity of producing 15-20 million liters of final products annually.

- MCS Coca Cola

  In 2001, MCS Coca-Cola Group received exclusive permission to manufacture and market Coca-Cola Company goods in Mongolia. 250 ml glass bottles of sparkling drinks are produced by it. In 2016, around 670 thousand bottles were imported by the company for Coca Cola and Sprite drinks.

- Bagro LLC

  Bagro LLC was established in 2009. It produces pickled vegetables, and salads, with a capacity of 500,000 tons of vegetables annually (22). Also it produces fruit compote and syrups. Overall technology has a capacity of producing 3000-3500 glasses of product in an hour (23).

- Gazar shim

Since its founding in 1999, "Gazar shim" has been making pickled vegetables, salad, compote, and artichoke juice. The company produces 8 million jars from seven types of products annually.

- Ulemj organic

Ulemj organic produces dairy products and was established in 2011. It has its glass collecting 36 points, shops and markets, throughout the UB city.

- Milkman Delivery LLC

Milkman was established in 2021 producing dairy products such as milk, yogurt, clotted cream /urum/,melted butter /khailmag/, dried curds /aaruul/.

- Sarana Goods

Sarana Goods is a new Mongolian brand, which grows flowers, produces honey in 500 g, 280 g, 45 g, and 35 g glass packages and sells different goods.

By rough estimation made on the Food and Beverage sector's potential customer's annual production, it consists of approximately 67% amber bottles, 15% clear bottles, and 17% clear jars. These estimates can aid further production capacity planning.

3.3.4 Competitors

Competitors are products or businesses that compete for market share and consumer demand. In the context of a market where there are no domestic producers, imported products or alternative products are referred to as competitors. Whether domestic or imported, they compete for the same customers and strive to capture a share of the market. Thus, major glass importing countries; China and Europe, and Alternative material packaging are studied as competitors, since there are no competing container glass factories in Mongolia.

- **China**

In 2020, the China Container Glass Packaging market was estimated to be worth $10.99B. By 2026, it is anticipated to have grown a CAGR of 4.71% to reach $14.97B (24). Since the beginning of 1990, the Chinese glass market has increased promptly due to investments from abroad and expansion of the economy (25). Due to the nation's growing demand for food and beverage resulting from increasing urbanization rate 60.6% (2019)

and urban households' annual per capita disposable income (National Bureau of Statistics of China).

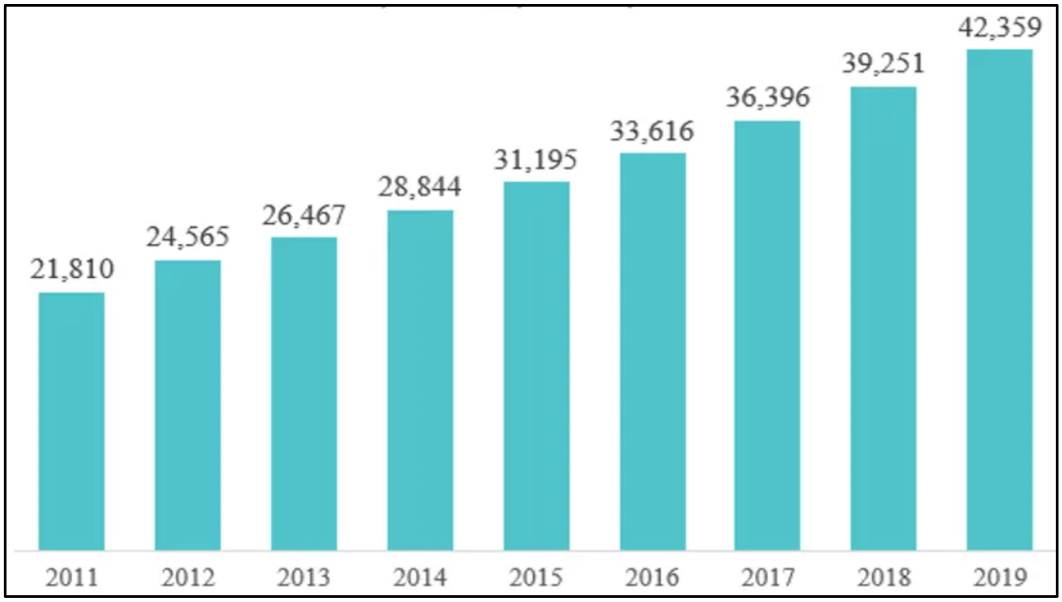

Figure 8. Chinese Urban household's annual per capita disposable income in CNY

In 2021, China was the largest exporter of glass bottles with a total amount of 2.41 billion USD (26). Hence, over 51.6 billion liters of alcoholic beverages are anticipated to be consumed in China per year by 2023 according to Bank of Northeast. As mentioned above, China is one of the largest markets of pharmaceutical glass. As a consequence of COVID 19, surging demand for vaccine glass vials increased dramatically.

China has a container glass market of few dominating competitors, implementing strategies of partnering. The leading companies in container glass industry in China:

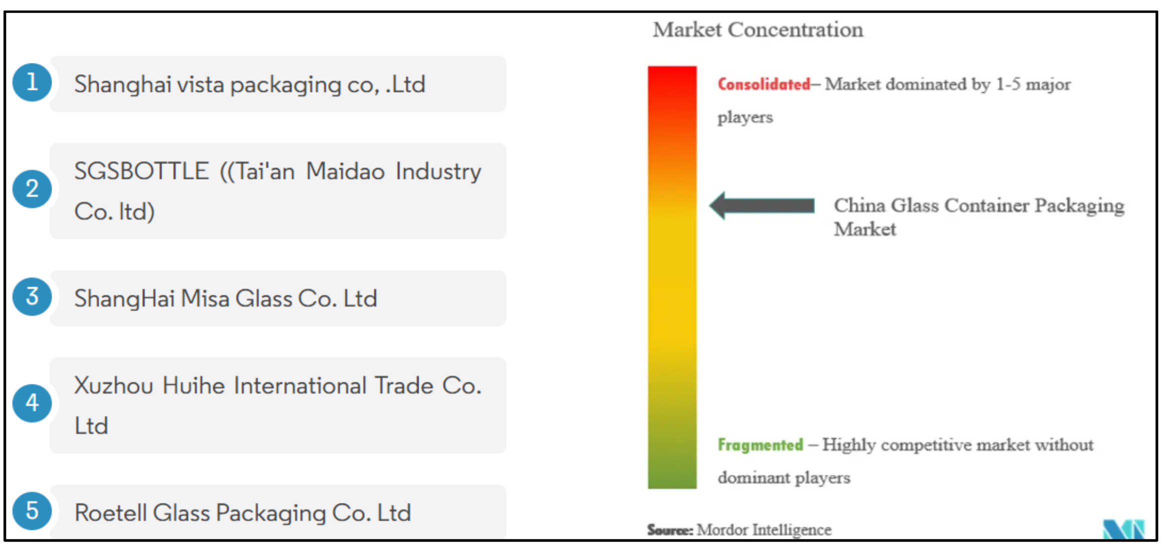

Figure 9. China leading glass producers

- **Europe**

In 2021, the European glass industry produced 39.12 million tonnes of glass which is greater than previous year by 6.1%. From which, the container glass industry accounted for 61.7% followed by flat glass 30.8%. Which indicated that the European glass industry recovered from the 8.1% fall of 2020 (27) resulted from the pandemic. In 2010, there were almost 70 container glass companies with 170 installations, employing 70,000 employees (28). However, today there are 162 facilities, employing 125,000 people (29). Also indicating that the container glass industry in Europe expanded. The major players in Europe are Germany being the top producer sharing 20% of the overall, followed by Italy, France, Spain, UK, and Poland. The main feature of Europe's glass industry, especially container glass, is that they have a profound system of glass recycling and prospering sustainability and circular economy. In 2020, Europe's container glass industry reached a peak of 79% recycling rate and is aiming to achieve 90% by 2030 (30).

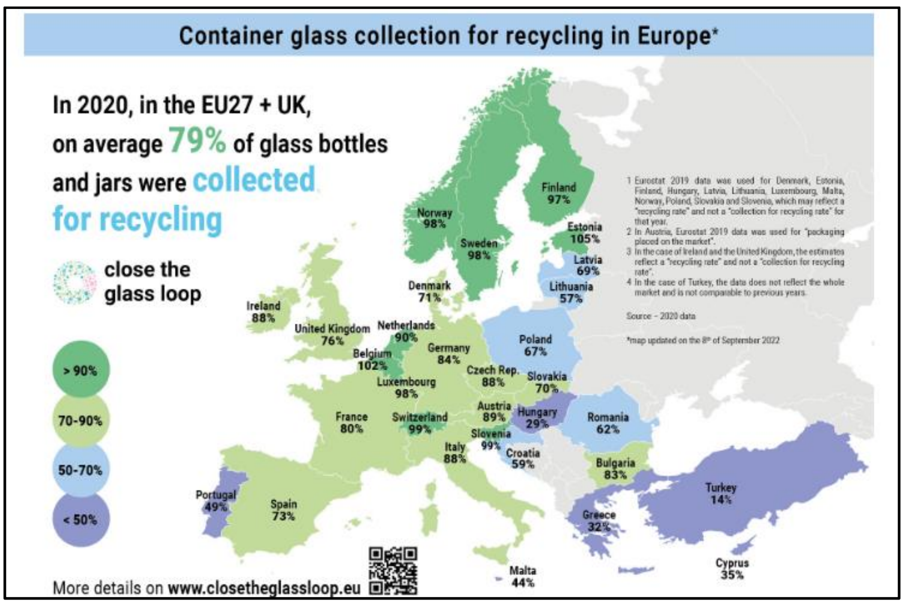

Figure 10. Europe's container glass recycling rate

Also the European glass packaging market is highly competitive and without dominance. The top producers of European container glass are as follows:

- ➢ Gerresheimer AG
- ➢ Owens-illinois Inc
- ➢ Vidrala SA
- ➢ Ardagh Packaging Group PLC
- ➢ Piramal glass Ltd

- **Alternative material container products**

There are numerous threats for the container glass market and the main concern is alternative material containers. Especially plastic materials;

-PET

-Metals (steel and aluminum)

and cartons with laminates (28). The main benefits of container glass include its high chemical resistance, barrier properties (which protect and preserve the quality of the contents), and aesthetic appeal (transparency, color, design, etc. for the presentation of goods and the identification of brands), as well as its capacity to be recycled into new bottles, resealable, reusable, and easy to clean. Also, nature provides an abundance of the virgin raw elements needed to make glass. Glass's position in relation to its rivals changes significantly across locations and goods, based on consumer preferences, price points, and packaging innovations. Glass' primary drawbacks are its weight and risk of fracture.

4. Conceptualization

By considering the above research made in the past, current and future perspectives, a concept idea for a factory will be built. In this chapter technical, environmental and economical aspects of the concept factory will be studied and demonstrated.

4.1 Technical study

4.1.1 Types of glass

Glass industry consists of many different glass product types including:

- *Container*
- *Flat*
- *Domestic*
- *Continuous filament glass fiber*
- *Special*
- *Mineral wool*
- *Insulation wool*
- *Frits glasses*

and all delivering different purposes and providing the necessities of different fields. In this section only the container glass will be in detail since the factory will produce container glass products firstly.

Container glass, which is used for glass packaging; bottles, jars for food and drink, cosmetics, perfumes and pharmaceuticals, is a largest sector of the glass industry. As mentioned above, Mongolian container glass industry covers (59.5%) majority of the glass industry therefore container glass, specially bottles and jars, will be produced and the details will be described in further sub-chapters. Usually, container glass is melted in fossil fuel fired furnaces or electrically heated furnaces. Automated Individual Section (IS) machines are used for manufacturing container glass with pressing and blowing methods which will be discussed in detail in further sections.

4.1.2 Classification of glass

Glass is classified in different categories according to its properties and purpose. Thus, it is essential to know each glass classifications for choosing the appropriate formulation for the glass type. There are four categories of glass classification: soda-lime, lead crystal, borosilicate, and special glass. In commercial container glass formulation, simple soda-lime glass is used because it is most suitable for bottle and jar glass properties. The other formulations can be utilized in the future factory expansion. For example, borosilicate glass is preferred for applications that require product purity and stability, making it an important material in the pharmaceutical and cosmetic industries. Here are four classifications of glass and their composition, purpose and properties explained.

Table 5. Classification of glass

	Composition	**Products**	**Properties**
Soda-lime glass	71-75% SiO_2 12-16% Na_2O or K_2O 10-15% CaO or MgO	Bottles, jars, flaconnage, tableware and window glass	➢ Light transmission ➢ Smooth, non-porous surface ➢ Easily cleanable ➢ Not affect the taste of contents
Lead Crystal /Crystal glass/	54-65% SiO_2 25-30% PbO 13-15% Na_2O or K_2O	Drinking glass, decanters, bowls and decorative items	➢ High density ➢ High refractive index-brilliance sonority ➢ Wide variety of shape and decoration

Borosilicate glass	70-80% SiO_2 7-15% B_2O_3 4-8% Na_2O or K_2O 2-7% Al_2O_3	Chemical process component, lab equipment, pharma-containers, lighting, cookware oven doors, hobs	➢ High resistance to chemical corrosion, temperature change ➢ Low thermal expansion coefficient
Special glass		specialist borosilicate products; optical glass, glass for electrotechnology and electronics; cathode ray tubes; fused silica items; glass seals; X-ray tubes; glass solders; LCD panels, sintered glass; electrodes; and glass ceramics	

4.1.3 The factory specifications

The factory produces three types of container products - flint and amber bottles, and flint jars - made from soda lime glass. The following table shows percentages of these products from total production and their cullet content.

Table 7. Container products percentages

Products	From total production	Color	Cullet content
Bottles	80%	Amber 70%	60%
		Flint 30%	50%
Jars	20%	Flint	50%

The percentage for product lines, bottles and jars, and their color are derived from the glass using companies annual production ratios estimated roughly in chapter 3.3.3. In which the annual production of bottles and jars consuming companies consisted of approximately 67% amber bottles, 15% clear bottles and 17% clear jars. Thus, the total bottles production make up approximately 80% and jars 20%. Among the bottles produced, 70% are amber-colored, while the remaining 30% are flint, since the beer production is relatively higher than vodka and soft drinks. The cullet content for each type of container is explained in chapter 4.1.5 "Glass cullet recycling".

Table 8. Production capacity

Year	Average case scenario demand projection	pieces/year production	tonnes/day production
2027	152,388,352.71	91,433,012	100.201
2028	156,879,516.92	94,127,710	103.154
2029	164,904,120.03	98,942,472	108.430
2030	171,762,747.66	103,057,649	112.940
2031	176,653,456.73	105,992,074	116.156
2032	176,849,053.52	106,109,432	116.284
2033	180,424,053.78	108,254,432	118.635
2034	191,268,210.72	114,760,926	125.765
2035	196,559,861.71	117,935,917	129.245
2036	202,136,978.25	121,282,187	132.912
2037	207,542,445.87	124,525,468	136.466
2038	212,837,958.05	127,702,775	139.948

The production capacity is determined by the projected demand and assumes that the factory will produce 60% of the total demand and operate 365 days in a year because of continuous behavior of the glass factory. (assumed that bottles weigh between 0.35-0.45 kg and contain 0.5-0.75 liters of liquid). Due to the continuous production process, the furnaces in a glass factory operate nonstop, consuming a high amount of energy. As a result, the furnaces depreciate over time and require partial or total reconstruction after 10 to 12 years of use (28). Therefore, glass factories typically need to be rebuilt after this period to ensure continued efficient and safe production. In this case, the factory will require reconstruction after 12 years of operation. As mentioned in chapter 3 demand projection, the factory's construction will be done between 2023-2026 and the production will begin from 2027. The average case scenario made in demand projection was chosen for the production capacity determination. Hence, the worst case scenario's demand doesn't change, which is not aligning with the market, where the demand is increasing. The best case scenario's annual change in tonnage per day was high for production capacity planning and unutilized because it requires to install a big furnace for the final stage demand projection while the initial production showing only 47% utilization rate given the big installation.(Appendix B)

4.1.4 Raw materials

Composition of raw material

For the composition of container glass formulation following components are used.

Table 9. Glass composition

Components	Mass percentage
Silicon oxide (SiO_2)	71-73
Sodium oxide (Na_2O)	12-14
Calcium oxide (CaO)	9-12
Magnesium oxide (MgO)	0.2-3.5
Aluminum oxide (Al_2O_3)	1-3
Potassium oxide (K_2O)	0.3-1.5
Sulfur trioxide (SO_3)	0.05 – 0.3
Ferric oxide (Fe_2O_3)	0.015
Chromium(III) oxide (Cr_2O_3)	0.003

Source: ("BAT Reference Document for the Manufacture of Glass, 2013", "Шилэн савлагааны үйлдвэрлэлийг Монгол улсад нэвтрүүлэх боломжийн судалгаа, 2018")

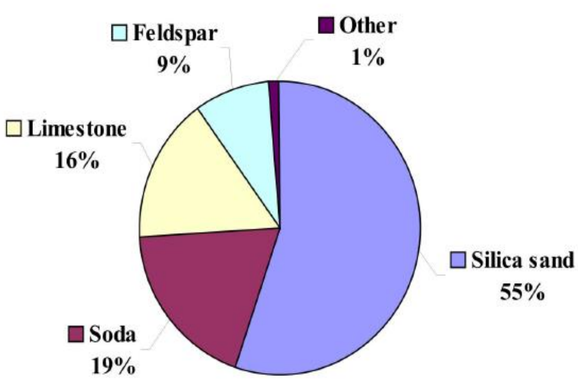

Figure 11. Raw material composition of glass (5)

Generally, the raw materials in the left-side, with the given percentage, are used for container glass production. However, glass-producing countries follow certain standards that are regulated within their respective countries, for example British (BS), Chinese (GB), British European International (BS EN ISO), American (ASTM), Russian (GOST) standards.

In Mongolia, there are no certain standards available for glass formulation so far and certainly need a common standard in the near future. Therefore, for producing the above components, the following raw materials will be used according to the Russian GOST standard because MNS 3157:1988 and other glass related standards currently used in Mongolia are originated from and corresponded to the GOST standard.

- Quartz sand

Quartz sand or silica sand is the principal source of silicon oxide, which is the most important compound for glass formulation. According to GOST 22551-2019, sand quality standard for glass industry, silicon oxide (SiO_2) content of high-grade and translucent glass sands are above 99% and low-grade sands could be up to 95%. Also the glass sand should contain ferric oxide (Fe_2O_3) 0.01-0.25 %, Aluminum oxide (Al_2O_3) 0.1-4.0 %, heavy fraction for high-grade <0.05% and for low-grade there is no norm (GOST 22551-2019). There are a small number of researches about silica sand for glass formulation and reserve size in Mongolia. According to a research made in Gorkhi pegmatit crystal deposit, Zuunmod deposit, Tuv province, Altangol, Buir Nuur deposit, Dornod province, Bornuruu deposit, Sukhbaatar province in 2005, sand from all deposits except Zuunmod deposit can melt transparent, high quality glass (33). On the other hand, Moltsog deposit in Tuv province is classified as II group of glass-grade sand according to "Classification and instructions of mineral and deposit resources, 2015" (34). Some quartz sand deposits of Mongolia's location, reserve amount, and contents are given below:

Table 10: Mongolian glass-grade quartz deposits from an expert

Deposit, type	Location, distance from UB	Reserve (t)	SiO2%	Al2O3%	Fe2O3%
Bayan-Uul deposit, vein quartz	Dornogovi province, 390 km	800,000	99.75	0.01	0.0019
Elstein deposit, quartz, feldspar	Nalaikh district, 50 km	1,822,780	76	14-18	1
Moltsog deposit, quartz sand	Tuv province, 80 km	4,859,000	81.6-84.3	6.2-9.3	11.25-3.18
Kharmagtai deposit, vein quartz	Dundgovi province, 350 km	5,300,000	99.86-99.97	0.0005	0.0043
Altangol deposit, quartz sand	Dornod province, 1100 km	201,006,000	89.09-93.92	1.21-5.54	2.9

Hence, there are possible glass-grade sand deposits in Mongolia, the factory can use local raw material of quartz sand with the additional laboratory testing on components of glass sand. Furthermore, the rest of the components should be according to the standard.

- Soda ash

In glass production, sand is a crucial ingredient, but its high melting point requires a significant amount of energy and time to melt. To reduce the melting temperature, a fluxing agent is added, and the main source of Sodium oxide (Na_2O) is soda ash. The quality of soda ash used in glass production is regulated by the GOST 5100-85 standard, which sets requirements for the chemical composition and particle size. According to the standard, granular higher sort soda ash should contain no less than 99.4% Na2CO3, no more than 0.2% NaCl, and no more than 0.003% Fe2O3, among other specifications. (ГОСТ 5100-85).

- Feldspar

In order to enhance the chemical durability and elevate the thickness at reduced temperatures, Aluminum oxide (Al_2O_3) is added. Feldspar is a key ingredient used in glass production, particularly in the manufacturing of clear glass. It contains high levels of aluminum and potassium or sodium. In Mongolia, feldspar deposits are found in regions including Khangai, Khuvsgul, and Khentei, with Khangai having the highest quality feldspar. However, the majority of feldspar used in glass production is imported from China and Russia due to limited local production. The GOST 1987-92 standard regulates the quality of feldspar used in glass production, setting requirements for the chemical composition and particle size.

- Dolomite and Limestone

Dolomite is mainly used for MgO and CaO sources. When there is a need for supplementing CaO, limestone is added. Magnesium oxide increases the durability and chemical stability, reducing crystallinity, reduces the coefficient of expansion and lowers the working temperature during molding. Calcium oxide increases the heat resistance and chemical reaction and weathering stability of the glass, but has the disadvantage of effectively crystallizing the glass. These raw materials are controlled by GOST 23672-79 "Glass production standard for dolomite" and GOST 23671-79 "Glass production standard for limestone". Depending on the brand, the content of MgO in dolomite should not be less than 18-19%, and iron oxide should not exceed 0.05-0.4%. In limestone, CaO is 51-54%, while Fe2O3 is no more than 0.1-0.3%, and the size of fragments is in the range of 20-300 mm. Limestone and dolomite with an iron oxide content of 0.6-0.8% are practically used in glass production, especially in the production of bottles. (37)

- Sodium sulfate

Sodium sulfate is a commonly used material in container glass production. It reduces the melting point of the mixture, increases the fluidity of the glass and homogenizes the glass melt. The quality of sodium sulfate is regulated by the GOST 5962-2018 standard which requires a minimum purity of 99% and a maximum content of water-insoluble substances of 0.05%. The particle size of sodium sulfate should not exceed 1.0 mm. Sodium sulfate is typically used in powder form, and the amount used varies depending on the specific production requirements.

- Cullets

Glass cullet is a valuable raw material due to its ability to reduce the consumption of raw materials such as silica sand, soda, dolomite, and others. In addition, its usage can result in the reduction of CO2 emissions generated during the melting of raw materials, leading to a longer service-life of the glass furnace by up to 30% due to the lower melting temperature of cullet compared to raw materials (31). The cullet content will take up to 50% for flint, and 60% for amber container glass in the concept factory. As mentioned in chapter one, glass cullet is either produced from the production process due to quality rejection (in-house cullet) or collected from the market (external cullet). The factory's cullet ratio will be 20:80 for in-house cullet and external cullet respectively, assuming that a collecting system from the market is available.

Sourcing raw materials for production locally is crucial due to the additional costs associated with transportation and customs, as well as the potential shortages and interruptions that can occur when importing raw materials from other countries. However, despite the importance of sourcing raw materials locally for glass production, the research and production of such materials is currently insufficient in Mongolia. For example, even if some resources are available locally there are no processing plants currently and thorough research is needed for obtaining the appropriate raw materials for glass formulation of final production. As a result, for the proposed glass factory, the above raw materials except silica sand and cullets will need to be imported from neighboring countries such as China and Russia.

4.1.5 Glass manufacturing process

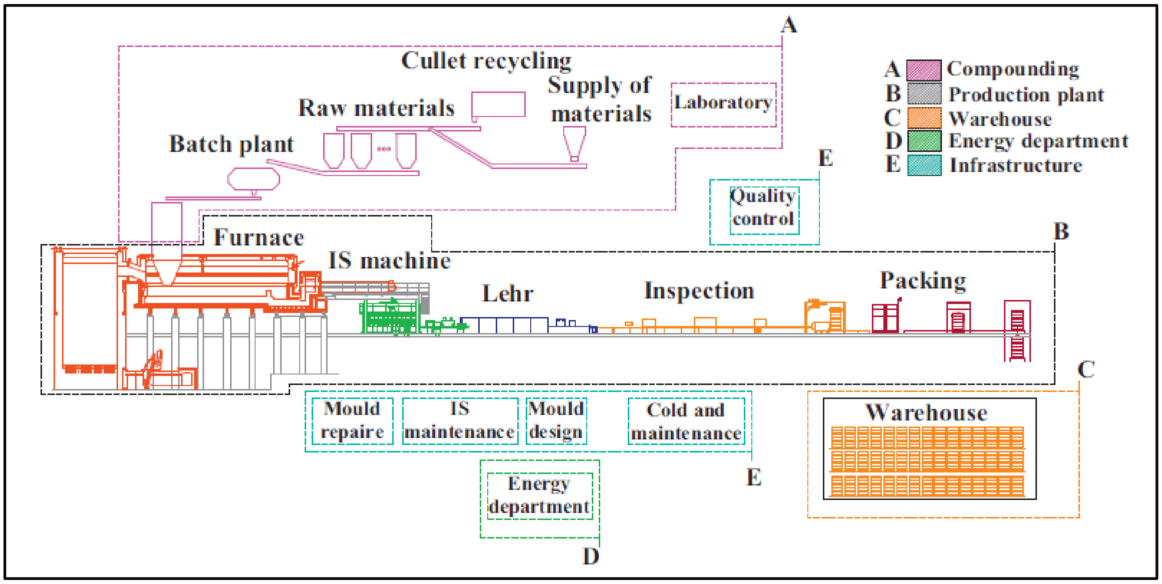

Figure 12. Container glass production process schema (31)

Depending on the furnace type and glass types, the production process of the glass differs. However, the following three processes; batching, melting, and forming are typical in every container glass factory. Addition to that, cullet recycling is a vital point in circular manufacturing.

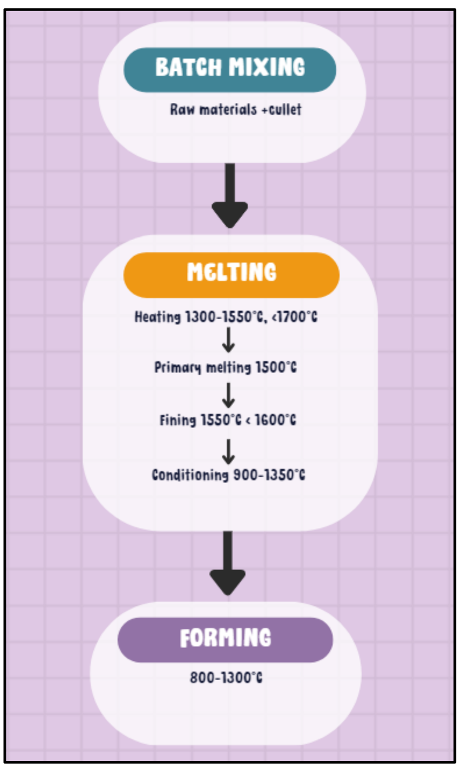

Figure 13. Procedure of glass manufacturing

1. **Batching**

As in the figure above, raw materials are prepared for the batching process, according to the glass composite specifications including cullets with transporting, weighing, and sorting processes. In the batch house, the mixture should provide a suited humidity and homogeneity because the quality largely depends on them. From the batch plant, the mix is usually transported via conveyor belt to the furnace silos. (32)

2. **Melting process**

There are several proceedings in melting the glass while ensuring the high glass quality and process control. Because a fixed or given specific temperature must be setted, the energy efficiency is crucial. Thus, each and every step must be controlled carefully. The melting process is comprised of the following:

- Heating

As shown in fig.11, the compound is continuously fed into the furnace from the batch house to the furnace which is burning by a fossil fuel. The heating temperature is commonly 1300-1550°C and can even exceed 1700°C. For container furnaces, the mean residence time is in the range of 24 hours of production while the mass of molten glass inside the furnace is kept constant.

- Primary melting

Because of the glass raw materials' low thermal conductivity, it takes a time initially until the first reactions (decarbonisation) occur at 500 ºC, then the batch materials begin to melt at 750-1200 ºC. Due to the loss of gasses and the elimination of space between the materials, the volume of the melt is approximately 35 to 50% of the volume of the virgin batch materials (28). The production of 1 kg of container glass requires 3.5 to 5 MJ/kg of energy (5).

- Fining

Before creating finished products, the molten glass must be thoroughly homogenized and bubble-free.The fining process comprises two-stage refining processes, which are primary and secondary. In the primary refining process, the molten glass will be free from bubbles, which consists of a trapped air (oxygen, nitrogen) and decomposition of raw materials (CO2), by

- ➢ bubble growth,
- ➢ bubble ascension, enhancing the bubble growth rate
- ➢ gasstripping, removing dissolved gas by gas absorption and preventing from recurrence of bubbles

This process occurs in the highest temperature area in the melting tank, thus the temperature control must be dealt with extreme care. For container glass, the maximum crown temperature in furnaces is 1600 ºC. In order to increase the dissolution rate, fining agents are added in the batch. Common fining agents are sodium sulphate, oxides of arsenic, and antimony.

The remaining bubbles are then reabsorbed during the secondary refining process, which leads to a reduction in bubble size or complete bubble disintegration by carefully regulated cooling of the molten glass.

- Conditioning

All residual soluble bubbles are reabsorbed into the melt during the conditioning stage. The melt also gradually cools to a working temperature of between 900 and 1350 ºC at this time. In contrast to discontinuous batch melting, continuous furnaces allow the melting process to occur simultaneously in different sections of the system.

3. **Glass container forming**

After coming from the melting process, the gob, molten glass to be formed, is transferred by gob feeders to the forming section in the Individual section (IS) machines. IS machines have around 6-20 sections each performing individually by producing up to 4 bottles simultaneously. Production rate of a typical container glass factory's round beer bottle is 750 pieces per minute on Individual Section machines with 12 sections and quadruple gob (28). Thus, for the concept factory, 7 section-double gob IS machines will be installed to fulfill production rate per minute. (Appendix A) Container glass forming has a 2-stage moulding process, which is "press and blow" and "blow and blow" forming.

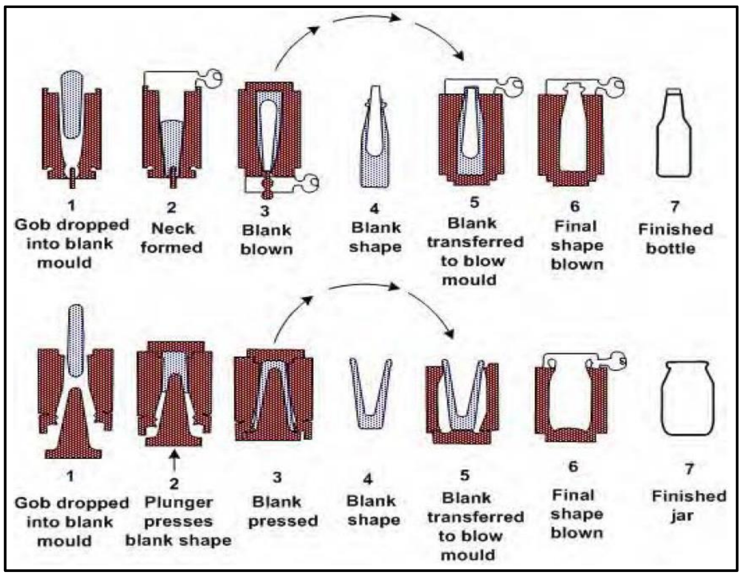

Figure 14. 2-stage moulding process (28)

2-stage moulding process is as follows:

First stage:

1. Obtain gob at correct mass and temperature
2. Form primary shape in first mould by **blow method** (compressed air) forming versatile, standard weight bottles or more complex forms or **press method** (metal plunger) forming jars or lightweight bottles.
3. Transfer primary shape into final mould

Second stage:

4. Complete shaping by blowing to the shape of final mould
5. Remove finished product

Compressed air, which is used in the blow method for moulding, is not only used here but is required in several other sections; beginning with sorting, transporting, forming, cooling and tempering, and lastly packaging of glass manufacturing. Since its presence is huge in the factory, it is crucial to know the requirements and supply. Compressed air should be devoid of oil, particles, and moisture to ensure continuity of the system. Depending on the purpose, the standards and regulations of it can differ. Most press-and-blow glass container manufacturers usually employ two air systems, namely low-pressure (50-70 psig) and high-pressure (90-100 psig). (35) Typically, these systems use separate compressed air supplies and piping distributions. The low-pressure air is typically directed to the "hot end" of the plant, specifically to the furnace forehearth and IS units, while the high-pressure air is used for selected purposes in the "hot end" and for applications at the "cold end" of the plant, such as packaging, palletizing, and shipping. Almost all applications at the "cold end" require high-pressure air. In general, a 100% oil-free air compressor with air dryer and filters is required for supplying compressed air in the factory. (36)

After the glass formation, annealing process takes place in a continuous annealing oven or Lehr. In order to prevent quality degradation of high differential stress and fragility resulting from rapid cooling, the produced glass is heated to 550 °C and then carefully chilled. Following the annealing process, automatic inspections are carried out by checking tolerance and other quality parameters. To examine the overall efficiency of production, pack to melt ratio is used.

$$pack\ to\ melt\ ratio = \frac{tonnage\ of\ containers\ packed\ for\ shipment}{tonnage\ of\ glass\ melted\ in\ the\ furnace}$$

Average pack to melt ratio of the food and beverage sector is around 85-94% (28). Furthermore, to improve surface quality, the coating process can be implemented.

- Hot-end coating

  When the coating is applied after glass forming at a high temperature of 500 with stannic oxide (SnO_2).
- Cold-end coating

  When the coating is applied after annealing process with polymeric.

4. Glass cullet recycling

As mentioned in chapter one, glass cullet is either produced from the production process due to quality rejection (in-house cullet) or collected from the market (external cullet). After the inspection process rejected glasses are crushed then melted in the batch house as below.

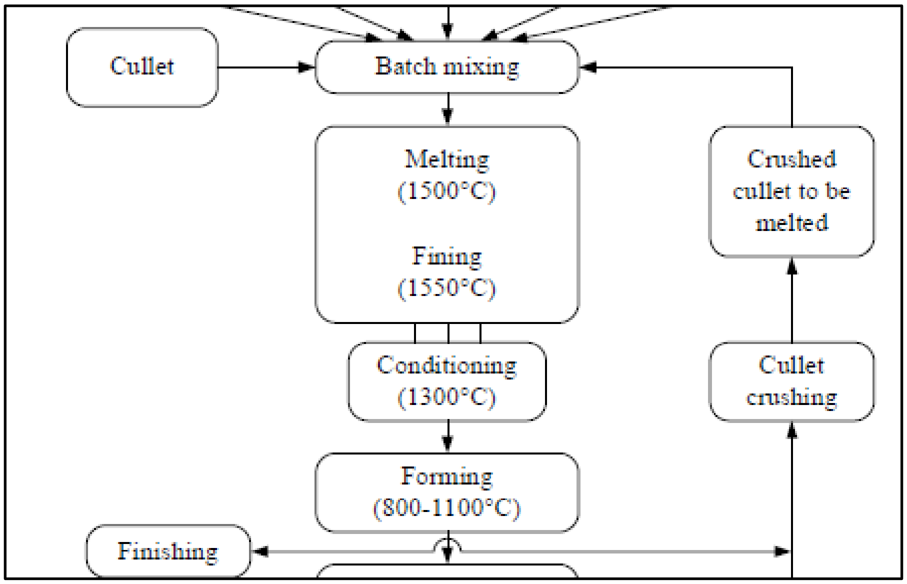

Figure 15. Cullet recycling in production process (5)

However, the external cullets are first removed from impurities, then sorted by colors, and crushed in the recycling plant. The impurities impact glass quality substantially for example:

Table 6. Impacts of impurities on glass quality (5)

Impurities	**Impacts**	**Bearable amount**
Ceramics (stones and chinaware)	Hard to melt into molten glass	< 10 - 50 g/ton in recycled cullet from collection banks
Non-ferrous metals (Al,Pb)	Al particles larger than 1-1.5 mm may not melt into molten glass entirely	< 1 - 5 g/ton in recycled cullet from collection banks
Other glass types (vitreous silica, glass ceramics)	Produces stress concentration	
Organic components (paper, food waste, plastic)	Reducing effects in glass melt, fining problems, color variations	

After impurity removal, cullets are needed to be sorted by colors using a color separating device. The higher the color sortation (purity) of the cullet, the greater amount of it can be used in the production process. Green, amber and flint glasses are common in the market. Glass cullet can make up even more than 90% of the glass mixture, with typical percentages of green glass exceeding 80%, amber hovering around 60%, and flint falling between 45 and 50%. On the other hand, iron (Fe) and chromium (Cr) contents influence the color of glass and the proper amounts of them are as below:

Glass color	Fe-content as wt % Fe_2O_3	Cr-content as wt % Cr_2O_3
white	0.05	< 0.001
green	0.3 – 0.5	0.25
amber	0.2 – 0.4	< 0.04

Figure 16. Fe-, Cr- content in glass color (5)

4.1.6 Melting technique

There are several types of melting techniques for glass factory such as:

- Cross or end fired regenerative furnace
- Conventional recuperative furnace
- Oxy-fuel melting
- Electric melting
- Combined fossil fuel and electric melting

For choosing from these techniques, capacity of the factory, glass formulation, fuel availability and cost, existing infrastructure and environmental factors should be carefully considered. In container glass manufacturing, an end-fired regenerative furnace is suitable since it enables a broad range of capacity, high efficiency and agility to market demand. However, regenerative furnaces use fuel oil, natural gas or sometimes coal for its energy source.

Fuel oil is not an ideal energy source for our country due to high price and availability for an economically reasonable number. Although Mongolia has abundant resources of ***coal***, which is mostly used in heating systems and thermal plants, it is not suitable for glass factories. Because using coal for an energy source of glass factory can lead to:

- Impurities**,** resulting from quality affecting ashes and heavy metals consisting in coal, can cause impurities such as glass discoloration, cloudiness, and other defects.
- Inconsistent heating**,** coal is the least consistent heating energy source from other sources (fuel oil, natural gas and electricity). Thus, use of coal is not desired because precise temperature control is of utmost importance in the glass industry.
- Environmental concerns, the glass industry is shifting more towards greener choices. However, coal combustion produces high levels of greenhouse gas emissions and air pollution, which can have negative impacts on the environment and public health.

But, there are several researches made on using coal as an energy source for glass melting. For conveying coal firing directly into technology, systems for coal handling and preparation, coal-firing, particulate controlling, and ash handling are additionally required (38). Also utilizing it in the long run is not recommended.

Compared to coal as an energy source, ***natural gas*** is a profound choice for glass melting, especially coal bed methane gas (CBM). Coal bed methane gas (CBM) can be used as a fuel in glass making. CBM is a type of natural gas that is extracted from coal seams. It is typically made up of methane, with small amounts of other gasses like carbon dioxide and nitrogen. CBM is considered a cleaner-burning fuel compared to other fossil fuels, because it emits fewer pollutants when burned. The use of CBM in glass making can offer several benefits, including lower costs, reduced emissions, and increased energy efficiency. However, it also has some potential drawbacks, such as the need for specialized equipment and the possibility of methane leakage during extraction and transportation. In Mongolia, several CBM exploration works are being carried out and accelerated the progression after the 2014 Petroleum Law amended to create a legal framework for the rights of exploration and exploitation of coalbed methane gas. One of the results of which shows that 93 billion m3 of methane gas resource was estimated at Naryn Sukhait and Tavan Tolgoi coal deposits (41). And overall Mongolian methane gas resource was estimated to be 3.2 trillion cubic meters in 2015 (42). Currently only exploration and production sharing agreements are in the process. Thus, regenerative furnace choice is currently limited by the energy sources options. However, with additional research, findings and further developments of using these sources on glass melting technology, the melting technique of the factory can vary enormously.

An electric furnace uses resistance heating to generate heat by passing current through a suitable resistance. This can be the charge itself, a resistor embedded in the charge, or a resistor surrounding the charge. The heat is transferred to the material by radiation, convection, or conduction. They consist of a working chamber lined with firebrick and insulated from a metal casing by a layer of heat insulation (39). Most electric furnaces are fitted with a bag filter system to recycle collected materials, making them a more environmentally friendly option.

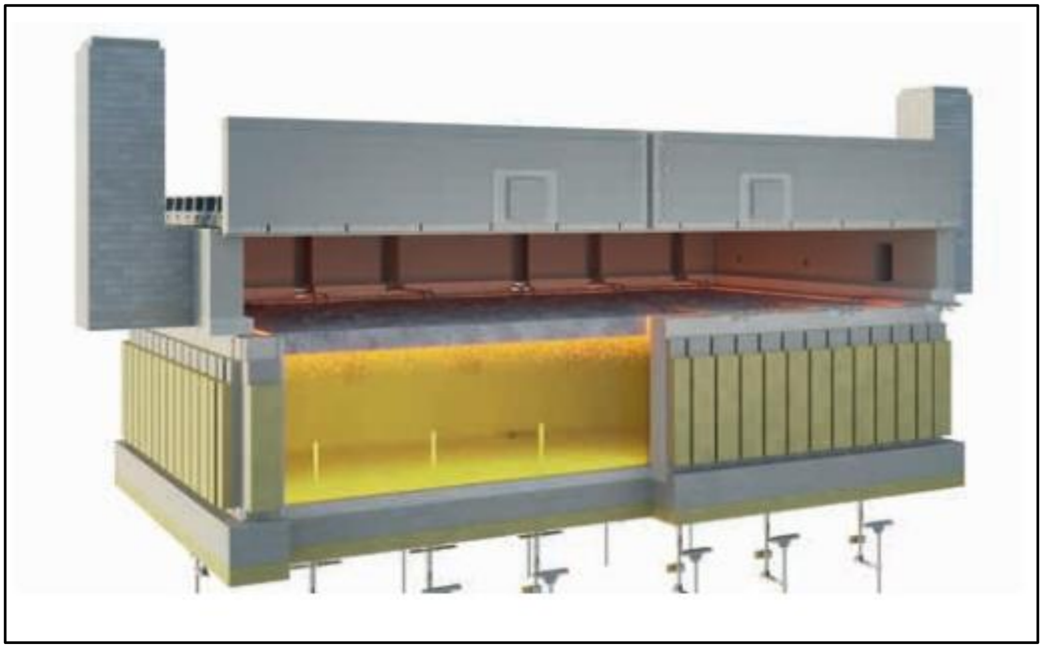

Figure 17. Electric melting furnace

Although this technique is considered to have higher operating costs due to electricity consumption, there are plenty of advantages associated with the method. (38)

1. Less air pollution- The batch has minimal dust losses and retains volatiles, with the only emission being carbon dioxide produced during glass production.
2. Glass uniformity- The glass properties are more consistent and uniform when delivered to the machines.
3. Quick furnace rebuilding- The glass furnace can be rebuilt in 10 days with excellent condition of crown and breast walls. Side walls and floor pavers need maintenance as they are exposed to high temperatures in fuel-fired furnaces.
4. Minimal space needed- Regenerators, flues, and chimneys are not needed, so additional space is not required.
5. CO2 recovery as a byproduct- Around 15 tons of high-purity carbon dioxide is generated for every 100 tons of glass produced by an electric glass melter. This

carbon dioxide can be efficiently collected, purified, condensed, and sold as a valuable byproduct.

6. Higher melt rates- Electric furnaces can generally melt at faster rates per furnace area, and their thermal efficiency (based on energy delivered to the furnace, not the primary energy needed for generating electricity) is about two to three times greater than that of furnaces powered by fossil fuels.
7. Lastly the main advantage which even can outweigh the fuel-fired furnaces is energy efficiency which in terms of ratio of energy used in the process of converting cold batch into fully molten and refined glass, to the total energy used in the process. Remaining rest is the energy loss which is resulted from the structural heat loss and released combustion gasses to the environment (40).

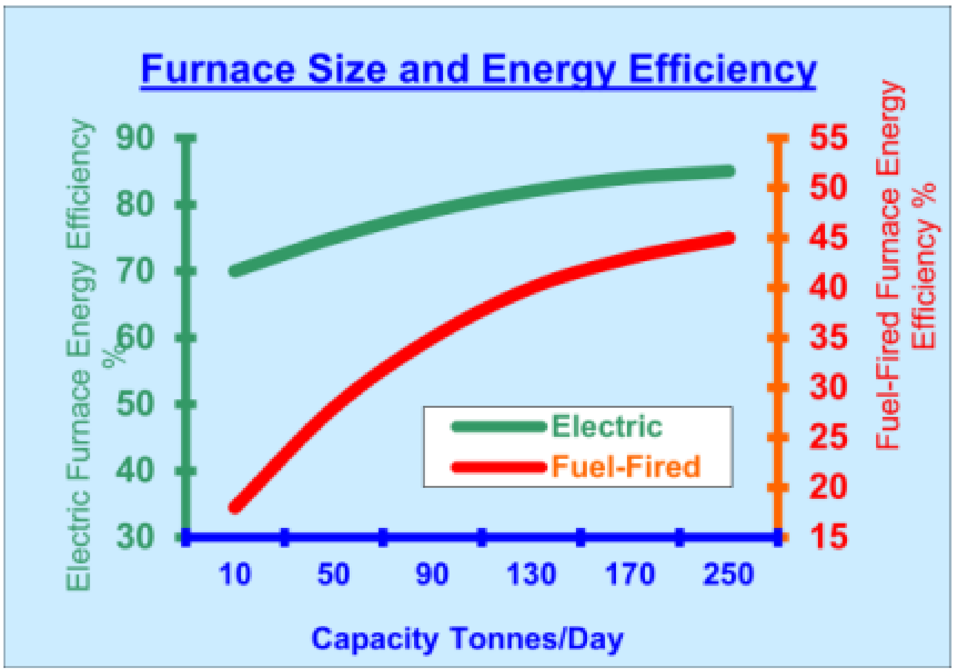

Figure 18. Electric and Fuel-fired furnace Energy Efficiency (40)

- Furnace Specifications

Therefore, electric melting will be our choice in the melting technique. The concept factory needs one continuous electric melting furnace of 100-150 tons/day capacity with 60-150 square meters surface area and 1-1.5 meters depth of the furnace. And forehearth, refractory structures designed to receive molten glass from the distributors and regulate its flow to the glass-forming machines, is within 54 inches width.

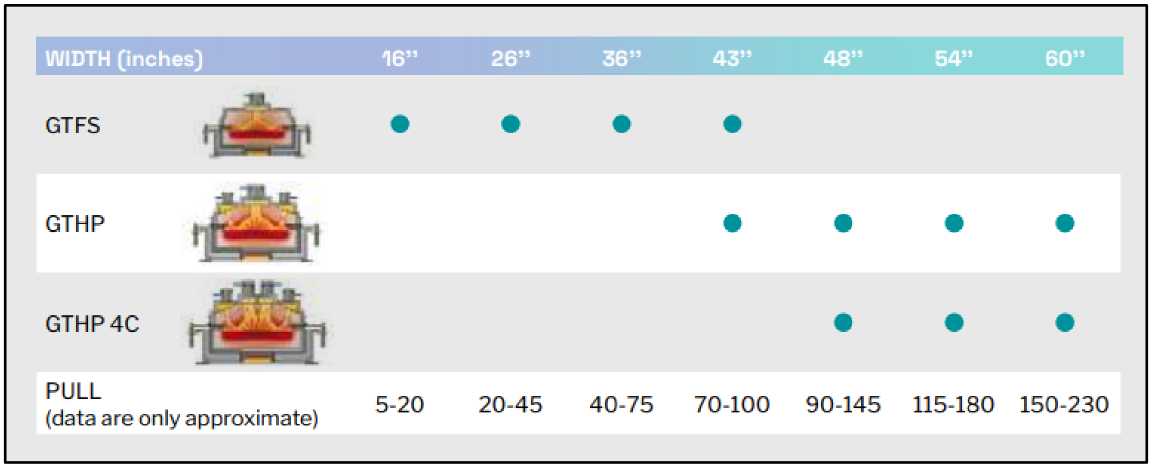

Figure 19. Width and capacity of forehearth

To produce soda lime glass in medium all-electric furnaces (120 tons/day), the power consumption is approximately 780 kWh per ton of glass (38). Thus, approximate power consumption for melting of the concept factory will be the following in the production years:

Table 7. Power consumption of melting process

Year	**Production capacity per day**	**Power consumption per ton**	**Power consumption per day**
unit	tonnes	kWh	kW
2027	101	656.5	2762.77
2028	104	676	2929.33
2029	109	708.5	3217.77
2030	113	734.5	3458.27
2031	117	760.5	3707.44
2032	117	760.5	3707.44
2033	119	773.5	3835.27
2034	126	819	4299.75
2035	130	845	4577.08
2036	133	864.5	4790.77
2037	137	890.5	5083.27
2038	140	910	5308.33

4.1.7 Infrastructure

- **Substation**

In glass manufacturing facilities, there are numerous energy intensive processes and devices. In addition to the glass melting, there are raw material processing, compressed air systems, motor driven equipment, lighting systems and other end-uses of energy. To define the power source option for the factory, approximate estimation of total facility power consumption should be made.

Table 8. Factory power consumption in the first year

Processes with their share of total energy consumption (45)	Purpose of use	Estimated energy consumption (kWh per ton)	Estimated energy consumption (kW per day)
Preparation (0.9%)	Raw material processing	8.2	34.5
Melting (72.2%)	Glass melting	656.5	2762.8
Forehearth (6.5%)	Conditioning Coloring Distribution	59.1	248.7
Forming (10.3%)	IS machines	93.6	391.4
Annealing (5.2%)	Cooling Finishing	47.3	199.1
Others (4.8%)	Compressed air system Lighting system Motor driven equipments	43.6	183.5
Total		**908.3**	**3820**

From this calculation, it is expected to have approximately 3.82 - 6.37MW power needed in the production years. To provide this need, the 110/10kV substation could either be supplied from transmission line, renewable energy source, or co-generation with back-up diesel generators.

Transmission line

Mongolian energy sector contains five main power distribution systems which are generated from coal, hydropower, and renewable energy with 220/110 kV substations, transmission systems and 35/10/6/0.4 kV distribution systems.

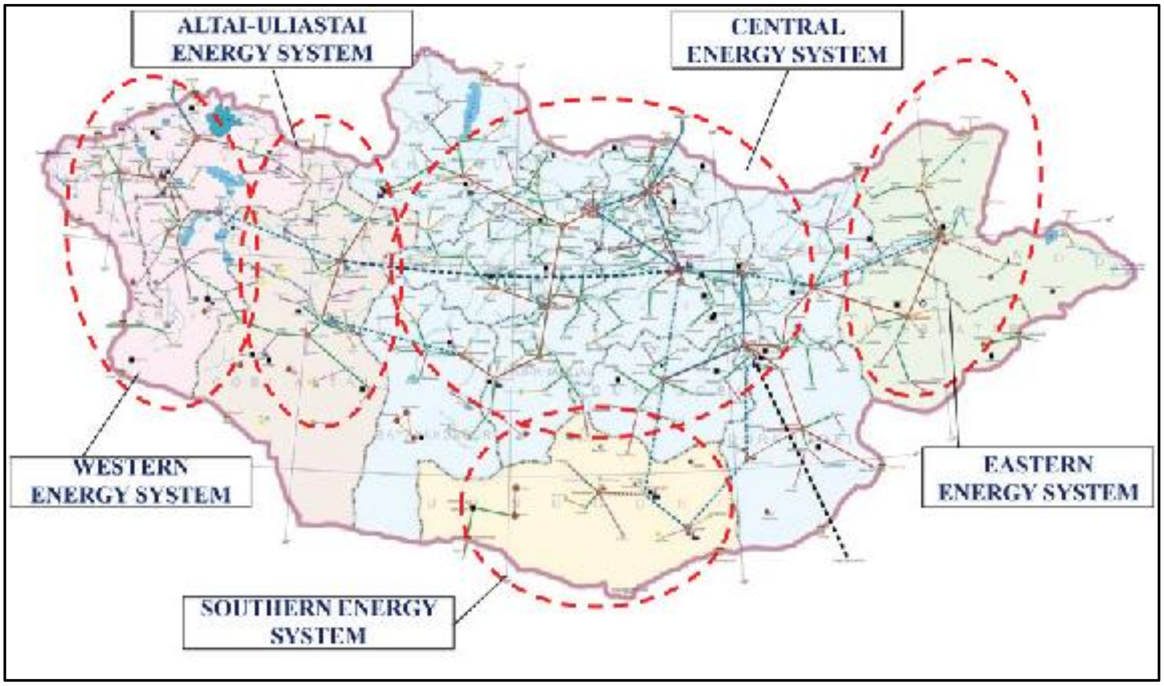

Figure 20. Mongolian power distribution system

Depending on the location of the factory, from the near main power grid or substation the power will have to be supplied. The step-down transformer 35kV network distribution will be used for the primary electrical distribution and for feeding the secondary electrical rooms in the factory. However, it is necessary to consider the capacity of nearby stations.

Renewable energy

As mentioned in previous chapters, greener and cleaner energy usage is highly recommended in the glass industry. Thus, substations can also be powered by renewable energy sources such as solar, wind, or hydroelectric power. Mongolia has a total capacity of 155 MW of wind power, 60 MW solar power, and 26.21 MW hydro power. The followings are the renewable energy power plants in Mongolia:

Table 9. Renewable energy power plants in Mongolia

Renewable energy	Power plant	Installed capacity MW
Wind	Salkhit	50
	Tsetsii	50
	Sainshand	55
Solar	Darkhan	10
	Monnaran	10
	Gegeen	15
	Bukhug	15
	Sumber	10
Hydro	Taishir	11
	Durgun	12
	Other minors	3.2

Source: https://nautilus.org/napsnet/napsnet-special-reports/mongolian-grid-data/

Co-generation

Co-generation is a process in which waste heat from an industrial process is used to generate electricity, and the power generated can be used to power the substation. Co-generation can also help to reduce the environmental impact of a glass factory, as it can reduce the amount of greenhouse gas emissions generated by the manufacturing process. By using waste heat or natural gas to generate electricity and heat, the factory can reduce its carbon footprint. In summary, co-generation can be a useful tool for glass factories to generate electricity and provide heat for the manufacturing process. By using waste heat to generate energy, the factory can reduce its energy costs and environmental impact, while also improving its overall efficiency.

- **Location**

For every factory, location choosing is a crucial decision defining the factory success in many aspects. To decide on the factory locations these factors are mainly considered:

1. Market demand

   The factory should be near the target market for reducing transportation cost and delivery time. In our case all the target customers are within the Ulaanbaatar, therefore the factory should be near Ulaanbaatar or have an additional warehouse for storing the final products and delivering them on time.

2. Proximity to raw materials

   The glass factory's main raw material is sand. In subchapter 4.1.4, possible glass grade sand deposits are introduced. From which, Bayan-Uul deposit in Dornogovi (390 km) and Kharmagtai deposit in Dundgovi (350 km) have higher quality sand with both above 99.7% silicon dioxide and small amounts of toxicating materials, ferric oxide and aluminum oxide. Thus depending on the other factors, location is chosen from these two deposits.

3. Access to energy

   In Sainshand Dornogovi, there are several renewable energy power plants such as Sainshand wind power plant 55 MW, Gegeen solar power plant 15 MW, and Govi solar power plant 30 MW (47), which can be the concept factory's energy source considering the approximate 3.82 - 6.37MW power need. On the other hand, in Dundgovi 35kV 782 km powerline with 72 substations are available.

4. Transportation infrastructure

   A factory should be located near major transportation routes such as highways, railways, and ports to facilitate the shipment of raw materials and finished products. In case of deposit in Dornogovi, it is connected to the railway routes of both Ulaanbaatar and the Chinese border which enables it to transport final products to customers in Ulaanbaatar and receive other raw materials from China by railcars. However, in the case of Dundgovi deposit, it is not connected via railway which requires transportation by trucks.

Figure 21. Mongolian railway system

By considering these factors, it is concluded that the location of the factory is in Dornogovi near Bayan-Uul deposit.

4.2 Environmental perspective

4.2.1 Emissions from manufacturing process

Glass manufacturing involves various chemical reactions that release toxic compounds into the air. These reactions can involve metals, nitrates, sulfur oxides, and other chemicals that contribute to air pollution. The emissions and their levels depend on the specific manufacturing processes used.

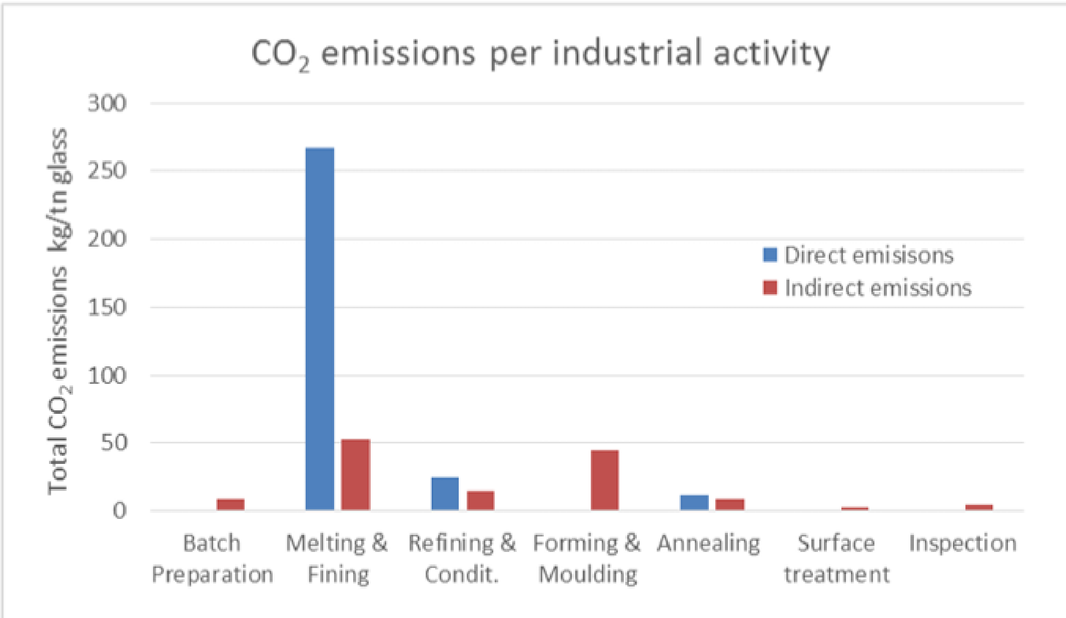

Figure 22. Carbon dioxide emission from manufacturing processes

For example, raw materials for glass manufacturing are mostly in granular and powder forms, which can result in dust emissions. In order to protect from dust emissions, glass factories implement dust control measures to reduce the amount of dust released during handling, transportation and batching processes of raw materials by installing filter systems in silos and mixing vessels to decrease the amount of dust emissions to a level lower than 5 milligrams per cubic meter. As illustrated in figure 19, the most emission releasing process is the melting and fining process. However, emission types and amounts are directly related to the melter option. In terms of electric furnaces, emissions except carbon dioxide such as nitrate oxides are not produced. Which is the major advantage, since the circular economy and greener process is crucial in the modern glass industry. Therefore, carbon dioxide CO2 is the sole dominating amount of emission which should be kept at minimum level.

4.2.2 Emissions mitigation options and energy efficiency

Hence, the carbon dioxide emissions in the melting and fining process are inevitable to be fully discarded, mitigating, reducing and controlling methods must be implemented. According to the Midden Report 2019, electric furnaces produce 39 kg direct carbon dioxide emission per ton molten glass (43). There are several ways to reduce this amount of carbon dioxide emissions during electric melting in a glass factory:

- Using cleaner energy sources: Switching to cleaner energy sources such as renewable energy (e.g. solar, wind, hydroelectric power) or low-carbon energy sources (e.g. natural gas) can help to reduce carbon dioxide emissions. In the factory case, generating electricity from renewable energy can help reduce the carbon footprint.
- Optimizing furnace operation: Improving the efficiency of the electric melting furnace can also reduce carbon dioxide emissions. This can be achieved by reducing energy losses and increasing the efficiency of the melting process. To do that, regular monitoring furnace performance and using control systems. Such as: *Simulation software for glass melting*- Furnace efficiency rises by 5%, *Image-based Control system* - Melting furnace energy use reduces by 2-8% (44)
- Cullet usage: Recycling and reusing glass can significantly reduce carbon dioxide emissions. When glass is recycled, it reduces the need for new raw materials and decreases the energy required to produce new glass. Which results in less carbon dioxide. Substituting 10% of the regular batch with cullet typically leads to an energy reduction of about 2.5% to 3.3%. (5)

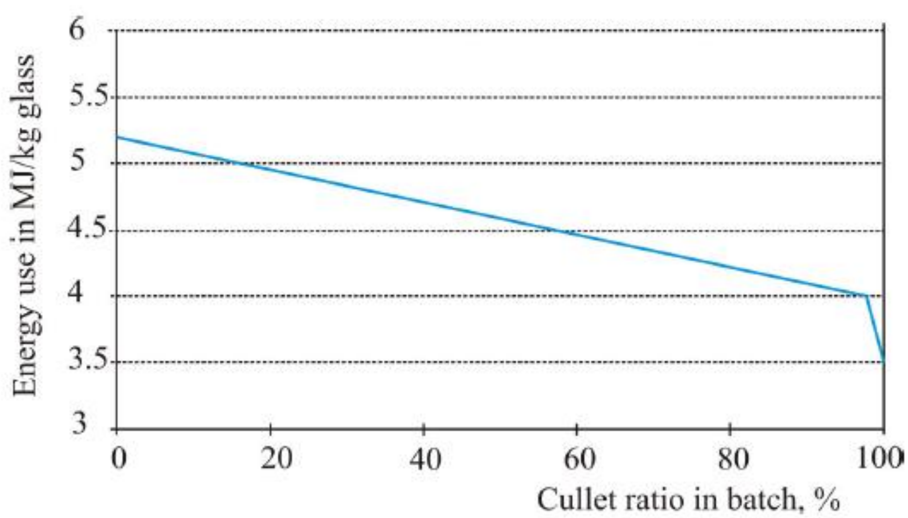

Figure 23. Energy usage vs Cullet ratio

- Improving insulation: Improving the insulation of the furnace can reduce heat losses and the amount of energy needed to maintain high temperatures, which can in turn lower carbon dioxide emissions.
- Capturing and storing carbon (CCS): Carbon capture and storage technologies can capture carbon dioxide emissions from the melting process and store them in underground geological formations or use them for other purposes. Also, for every 100 tons of glass that is produced in an electric glass melter, around 15 tons of carbon dioxide is generated, with a purity of 99.5%. (38) However, installing this technology is costly and it is not fully developed yet.

4.3 Economics

4.3.1 Cost estimation

Within the economics perspective, costs including capital and operational costs, cost-benefit analysis, and further expansion opportunities will be made for determining the economical viability.

1. **Capital cost**

For estimating the concept factory's capital cost, referential costs are used assuming that the discount rate is 2.2%. Total of $25,854,703.67 capital cost is estimated. The following is the capital cost for the concept factory and its details are included further.

Table 10. Capital cost estimation

Capital cost	**Referential cost**	**Estimated cost**
Land acquisition cost	Industry purpose land cost 10,000 mnt/m2 (average 20,000 m2 area)	57,400.00
Sand deposit extraction	Témisca Silicé Ltée. 350 Rideau Blvd. Noranda, Que. (46)	1,272,599.84
Construction cost	47.78 $ per m2 Adeyemo Victor Adedayo (2018)	1,070,000.00
Machinery and Equipment cost	20069937.1$ discounted Adeyemo Victor Adedayo (2018)	22,716,703.83
Substation	Referential supplies illustrated below	721,500.00
Office equipment	20 set office supplies Adeyemo Victor Adedayo (2018)	16,500.00
Contingency	2%	517,094.07
Total		**$25,854,703.67**

Table 11. Machinery and equipment cost

Description	unit	quantity
Machineries		
Raw material processing plant	set	1
Electric Furnace	set	1
IS machine	sections	7
Annealing Lehr	piece	1
Decoration, packaging machine	piece	1
Cullet recycling plant	set	1
Installing systems		
Control panel system	set	1
Cooling system	set	1
Lighting system	set	1
Compressed air system	set	1
Equipments		
Generator	pcs	2
Vehicles	pcs	3
Boiler	pcs	1
Pump	pcs	1
Total cost	**$22,716,703.83**	

Table 12. Substation cost

Substation & power supply	unit	Quantity
Main transformers	pcs	3
Surge arresters	set	3
Circuit breakers	pcs	6
Electrical bus	pcs	1
Secondary electrical rooms	set	3
Safety and security	set	1
Distribution	set	1
Below grade	set	1
Total cost	**$ 721,500.00**	

2. **Operational cost**

The annual operational cost at full operation capacity is estimated at 14,858,038.59 US dollars in the first year. The estimation is made upon considering 1 US dollar= 3842.48 MNT.

Table 14. Operational costs

Operating cost	**Estimated cost**
Labour	12,719,888.00
Raw materials	734,203.50
Ancillary materials	14,684.07
Utilities	1,341,528.00
Maintenance repair	44,434.15
Administration	2,221.71
Sand deposit extraction	1,079.16
Total	**14,858,038.59**

Table 15. Labour cost

Departments	**Quantity**	**Cost Annually**
Administration department		**2,854,500.00**
General Manager	1	
Executive secretary	1	
Secretary	1	
Plan and Statistics Head	1	
Production and Technical manager	1	
Commercial and Marketing	1	
Manager	1	
Financial Manager	1	

Administration Manager	1	
Personnel	1	
Manufacturing factory		**9,852,585.00**
Glass Technologist	1	
Quality manager	1	
Operators	30	
Technicians	10	
Electricians	3	
Finance		**12,803.00**
Sales man	4	
General Accountant	2	
Finance and Budget Accountant	2	
General Service	10	
Marketer	1	
Total cost	**74**	**12,719,888.00**

Table 16. Raw materials cost

Raw materials	**Quantity**	**Cost per ton**	**Cost**
Soda ash	2111.015	88.45	186,719.24
Feldspar	324.771	75	24,357.86
Dolomite and Limestone	2273.400	50	113,670.02
Sodium sulfate	16.2386	170	2,760.56
Cullets	16267.833	25	406,695.82
Subtotal			734,203.50
Ancillary materials			
Packaging materials			14,684.07

Total cost			**748,887.57**

Table 17. Utility cost

Utilities	**unit**	**quantity**	**unit cost**	**cost**
Electric power	kWh	33,463,200	0.04	1,338,528
Water	m3	50,000	0.06	3000
Total cost				**1,341,528**

4.4.2 Cost-benefit analysis

For determining overall financial viability of the concept factory cost-benefit analysis is made. The analysis includes various factors such as total benefits, net present value (NPV), internal rate of return (IRR), and payback period.

The total benefits of the concept factory are calculated to be $191,730,320.01, which is determined by analyzing the revenue stream and operational costs. The operational costs for the subsequent years are estimated based on the costs incurred during the first year.

The NPV value of the concept factory is calculated to be $64,748,904.27, which takes into account the time value of money and the expected cash flows. The IRR value of the concept factory is 37%, which indicates the rate of return that can be expected from the investment.

Additionally, the payback period of the concept factory is calculated to be 3 years, which means that the initial investment is expected to be recovered within 3 years of the factory's operation. All of these metrics are important in determining the financial viability of the concept factory and help to inform investment decisions.

Table 18. Cash flow for twelve years

Year	Products	Price per unit	Quantity	Revenue	Operational cost	Benefits
2027	bottles	0.3	73,146,409.60	25,204,937.72	14,858,038.59	13,339,985.49
	jars	0.2	18,286,602.40	2,993,086.35		
2028	bottles	0.3	75,302,168.00	25,947,773.31	15,295,916.34	13,733,155.06
	jars	0.2	18,825,542.00	3,081,298.08		
2029	bottles	0.3	79,153,977.60	27,275,037.65	16,078,253.95	14,435,694.42
	jars	0.2	19,788,494.40	3,238,910.72		
2030	bottles	0.3	82,446,119.20	28,409,450.46	16,747,007.30	15,036,065.40
	jars	0.2	20,611,529.80	3,373,622.24		
2031	bottles	0.3	84,793,659.20	29,218,370.54	17,223,883.30	15,464,168.74
	jars	0.2	21,198,414.80	3,469,681.50		
2032	bottles	0.3	84,887,545.60	29,250,722.11	17,242,863.44	15,481,381.92
	jars	0.2	21,221,886.40	3,473,523.25		
2033	bottles	0.3	86,603,545.60	29,842,024.86	17,591,475.22	15,794,290.09
	jars	0.2	21,650,886.40	3,543,740.45		
2034	bottles	0.3	91,808,740.80	31,635,641.54	18,648,728.29	16,743,645.69
	jars	0.2	22,952,185.20	3,756,732.43		
2035	bottles	0.3	94,348,733.60	32,510,877.40	19,164,750.83	17,206,793.26
	jars	0.2	23,587,183.40	3,860,666.69		
2036	bottles	0.3	97,025,749.60	33,433,328.98	19,708,502.16	17,695,034.64
	jars	0.2	24,256,437.40	3,970,207.82		
2037	bottles	0.3	99,620,374.40	34,327,390.04	20,235,497.59	18,168,270.02
	jars	0.2	24,905,093.60	4,076,377.57		
2038	bottles	0.3	102,162,220.00	35,203,264.34	20,751,816.69	18,631,835.29

	jars	0.2	25,540,555.00	4,180,387.64		
					Total Benefits	**191,730,320.01**

Table 19. Net present value

Period	**Cashflow**	**Discounted net cash flow**	**NPV**	**IRR**
0	(25,854,703.67)	(25,854,703.67)	**64,748,904.27**	**37%**
1	13,339,985.49	11,805,296.89		
2	13,733,155.06	10,755,074.83		
3	14,435,694.42	10,004,660.36		
4	15,036,065.40	9,221,900.50		
5	15,464,168.74	8,393,331.24		
6	15,481,381.92	7,435,994.57		
7	15,794,290.09	6,713,531.11		
8	16,743,645.69	6,298,287.45		
9	17,206,793.26	5,727,880.51		
10	17,695,034.64	5,212,751.02		
11	18,168,270.02	4,736,425.36		
12	18,631,835.29	4,298,474.10		

4.4.3 Further expansion opportunities

The proposed factory specializes in the production of container glass, including bottles and jars. This type of glass is used extensively in the packaging industry for a wide variety of products, ranging from food and beverages to pharmaceuticals and cosmetics. Based on market research, the demand for pharmaceutical and cosmetic container glass is on the rise, making it a lucrative area for investment.

As the factory continues to develop and grow, there is a potential opportunity to expand its product range by producing various shapes and sizes of pharmaceutical and cosmetic glass products in different colors. This would enable the factory to cater to a broader range of customers and potentially capture a larger share of the market.

In addition to container glass, the factory could also produce flat glass, which is the second most demanding glass type in the market. Flat glass is commonly used in the construction industry for windows, doors, and other architectural applications. The raw materials and fundamental technology used to produce container glass and flat glass are essentially the same, which makes it feasible for the factory to diversify its product offerings in this way. However, instead of IS machines the float process machine is required to be installed additionally.

In terms of expanding to international markets by exporting the products in the future, there are several target markets or countries which have a certain amount of market share of glass bottle imports. The following figure shows Asian glass bottles importer countries with their percentages. From which Vietnam taking up the highest percentage 12.1% with 237 million dollars import value with China being the major exporter 92.1%.

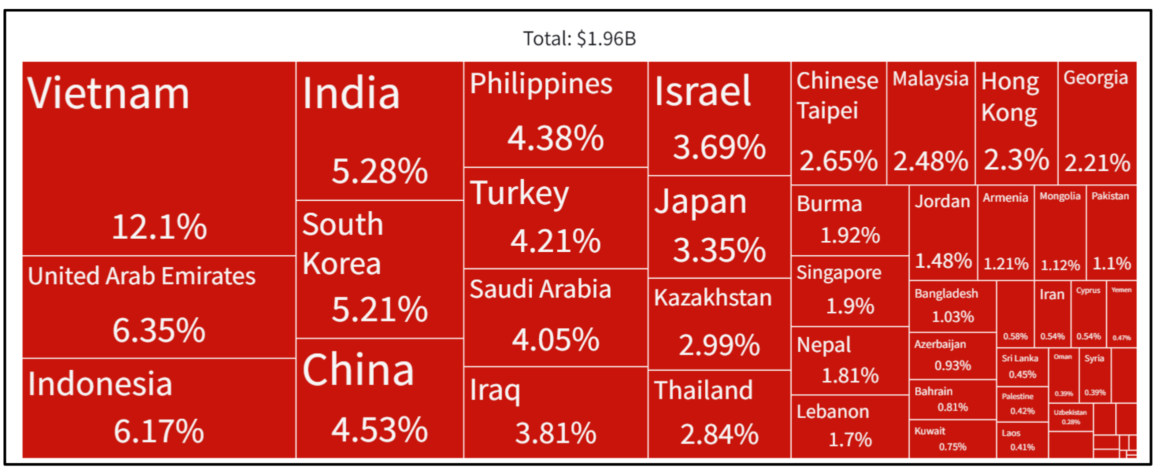

Figure 24. Asian glass bottle importers 2021

Considering the condition of transportation, Asian countries are especially the central Asian countries such as:

- Kazakhstan- $58.5M (2.99%)
- Kyrgyzstan- $6.5M (0.33%)
- Uzbekistan- $5.49M (0.28%)

are becoming a possible target market.

Overall, the proposed factory has significant potential for growth and profitability, given the increasing demand for container glass and the potential to expand into new product categories. By leveraging its expertise in glass manufacturing and exploring new opportunities, the factory can establish itself as a leading player in the glass industry.

5. Conclusion and Recommendations

In conclusion, this thesis aimed to conduct a conceptual study of the technical, environmental, and economic aspects of a glass factory in Mongolia. Given the current state of the glass industry in Mongolia, which is fully dependent on imports, the need for a local glass factory is crucial, particularly with the emerging demand for the container glass industry.

The study began by defining the glass market in Mongolia through market research, including demand forecasting of 16 years, target customer identification locally, and potential competitor analysis. The results of this research were used to conceptualize a glass factory that would be sustainable and profitable, while also meeting the needs of the local market.

The technical study focused on the viability of a container glass factory in Mongolia, considering factors such as raw material availability (especially silica sand), manufacturing process, and the capacity and capability of the techniques used in terms of energy source, location, etc. The production capacity is determined based on projected demand, assuming 60% production and operation 365 days a year with 12 years of use of an electric furnace with IS machine of 7 section-double gob. The chosen location is Dornogovi near Bayan-Uul deposit considering several factors such as market demand, proximity to raw materials, access to energy and transportation infrastructure.

From an environmental perspective, the melting process in glass factories releases high levels of emissions, particularly carbon dioxide. In order to control and mitigate these emissions, the study identified several potential solutions, including the use of cleaner energy sources and cullet (recycled glass) in the production process. For energy sources, renewable energy is suggested to be used to fulfill 3.82 - 6.37MW power needed in the production years and cullet share of 60% for amber and 50% for flint glass products from total production is used in the manufacturing process.

In order to determine the economic and financial viability of the proposed glass factory, cost estimations were made, including capital and operating costs. Cost-benefit analyses were also conducted to determine the profitability of the factory. The capital cost for the factory is estimated at $25,854,703.67, with an annual operational cost of $14,858,038.59. The NPV value of the concept factory is $64,748,904.27, the IRR value is 37%, and the payback period is 3 years. The report concludes that the factory is financially viable, and the metrics presented can inform investment decisions.

Overall, this study provides an analysis of the technical, environmental, and economic aspects of a conceptual glass factory in Mongolia. The proposed factory is found to be both technically feasible and economically viable, making it an attractive investment opportunity for those interested in the glass industry. Furthermore, the incorporation of environmentally sustainable practices into the design of the factory demonstrates a commitment to responsible manufacturing and provides a model for other industries looking to improve their environmental impact.

Recommendations for the further research on the topic:

There were some limitations that impacted the solutions and results of the thesis. Therefore, it is recommended to conduct further research on the topic.

- Regarding the composition of glass making cullets, it is suggested to take up 50-60% of cullets, out of which 80% is to be collected from the market. However, the glass collecting system in Mongolia is not fully developed, and it is dependent on government regulations and citizen contributions. Therefore, it is recommended to take appropriate actions to establish a robust glass collecting system for future glass factories and environmental purposes.

- In terms of energy sources, methane gas was identified as an interesting and environmentally-friendly solution for the glass factory. However, its current availability for production is limited, and further development is needed. Therefore, it is recommended to conduct more research on the production of methane gas and its potential as a sustainable energy source for glass manufacturing.
- Raw materials for local production are crucial for the success of the glass factory. Therefore, it is recommended to research the technology and processes required for local production of raw materials to ensure a steady supply of necessary materials.

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Appendix

Appendix A

Production rate

pieces/year production	tonnes/day production	bottles		jars	bottles		jars	production per minute
		amber	flint	flint	amber	flint	flint	
91,433,012	100.201	51,202,486.72	21,943,922.88	18,286,602.40	97.42	41.75	34.79	173.96
94,127,710	103.154	52,711,517.60	22,590,650.40	18,825,542.00	100.29	42.98	35.82	179.09
98,942,472	108.43	55,407,784.32	23,746,193.28	19,788,494.40	105.42	45.18	37.65	188.25
103,057,649	112.94	57,712,283.44	24,733,835.76	20,611,529.80	109.80	47.06	39.22	196.08
105,992,074	116.156	59,355,561.44	25,438,097.76	21,198,414.80	112.93	48.40	40.33	201.66
106,109,432	116.284	59,421,281.92	25,466,263.68	21,221,886.40	113.05	48.45	40.38	201.88
108,254,432	118.635	60,622,481.92	25,981,063.68	21,650,886.40	115.34	49.43	41.19	205.96
114,760,926	125.765	64,266,118.56	27,542,622.24	22,952,185.20	122.27	52.40	43.67	218.34
117,935,917	129.245	66,044,113.52	28,304,620.08	23,587,183.40	125.65	53.85	44.88	224.38
121,282,187	132.912	67,918,024.72	29,107,724.88	24,256,437.40	129.22	55.38	46.15	230.75
124,525,468	136.466	69,734,262.08	29,886,112.32	24,905,093.60	132.68	56.86	47.38	236.92
127,702,775	139.948	71,513,554.00	30,648,666.00	25,540,555.00	136.06	58.31	48.59	242.97

Appendix B

Production capacity

Year	Worst	unit/ year	tonn/day	Average	unit/ year	tonn/day	Best	unit/ year	tonn/day
2023	129,530,295.27	51,812,118	62.803	129,530,295.27	77,718,177	85.171	129,530,295.27	77,718,177	94.204
2024	129,530,295.27	51,812,118	62.803	135,685,384.57	81,411,231	89.218	138,208,825.05	82,925,295	100.516
2025	129,530,295.27	51,812,118	62.803	142,714,110.38	85,628,466	93.839	147,468,816.33	88,481,290	107.250
2026	129,530,295.27	51,812,118	62.803	147,166,189.95	88,299,714	96.767	157,349,227.03	94,409,536	114.436
2027	**129,530,295.27**	**51,812,118**	**62.803**	**152,388,352.71**	**91,433,012**	**100.201**	**167,891,625.24**	**100,734,975**	**122.103**
2028	129,530,295.27	51,812,118	62.803	156,879,516.92	94,127,710	103.154	179,140,364.13	107,484,218	130.284
2029	129,530,295.27	51,812,118	62.803	164,904,120.03	98,942,472	108.430	191,142,768.52	114,685,661	139.013
2030	129,530,295.27	51,812,118	62.803	171,762,747.66	103,057,649	112.940	203,949,334.02	122,369,600	148.327
2031	129,530,295.27	51,812,118	62.803	176,653,456.73	105,992,074	116.156	217,613,939.39	130,568,364	158.265
2032	129,530,295.27	51,812,118	62.803	176,849,053.52	106,109,432	116.284	232,194,073.33	139,316,444	168.868
2033	129,530,295.27	51,812,118	62.803	180,424,053.78	108,254,432	118.635	247,751,076.25	148,650,646	180.183
2034	129,530,295.27	51,812,118	62.803	191,268,210.72	114,760,926	125.765	264,350,398.36	158,610,239	192.255
2035	129,530,295.27	51,812,118	62.803	196,559,861.71	117,935,917	129.245	282,061,875.05	169,237,125	205.136
2036	129,530,295.27	51,812,118	62.803	202,136,978.25	121,282,187	132.912	300,960,020.67	180,576,012	218.880
2037	129,530,295.27	51,812,118	62.803	207,542,445.87	124,525,468	136.466	321,124,342.06	192,674,605	233.545
2038	129,530,295.27	51,812,118	62.803	212,837,958.05	127,702,775	139.948	342,639,672.98	205,583,804	249.192
Initial utilization rate			95.0			68.0			46.5
Capacity			66.10797			147.314			262.308
Total tonnage needed						525650			
SiO2 tonnage						383724			