

Assessment of Technical and Financial Viability of Nairit Chemical Plant Operation

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Prepared by Jacobs Consultancy Ltd for
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Section A



Introduction

The Nairit chemical plant is based in the city of Yerevan and was commissioned in 1936 and possesses technology for production of 20 types of polychloroprene rubber and latex based on both acetylene (natural gas based) and butadiene feedstocks. Its key product is synthetic rubber. During the Soviet times the plant accounted for a large share of global synthetic rubber production. Specifically, in 1987, the plant accounted for 15% of global supply. The plant was shut down in 1989 and restarted operations at a smaller capacity in 1993. Several attempts were made to re-commission the plant to its full capacity, but most of these attempts failed given the underlying economics, i.e. the costs associated with importing the feedstock butadiene from Russia and the high cost of process energy given increasing gas import costs. The plant produced some output in early 2000s. In 2006, the plant was sold to a UK-based company, Rhinoville Property Limited. The plant has not been operational since 2011 and is in major financial distress.

The objective of this assignment is to assess the technical and technological feasibility and financial viability of Nairit chemical plant operation. We have considered the operation of the Nairit chemical plant operation under three different production scenarios:

- 12 kta of polychloroprene rubber, via acetylene route
- 24 kta of polychloroprene rubber, via acetylene route
- 25 kta of polychloroprene rubber, via butadiene route

The report is structured as follows:

- **Section A, Project Introduction** (this section): The Project, the Study objectives and the structure of this report.
- **Section B, Executive Summary:** Major findings of the various sections within the report presented as a high level summary.
- **Section C, Chloroprene Rubber Market Review:** Review of the global supply and demand position for the Polychloroprene rubber (PCR) that has been historically produced at the Nairit production site.
- **Section D, Assessment of the technical feasibility of production:** Summarised assessment of the various process technology options that are available to produce the products at the Nairit site. Options that are available to restart the existing facilities along with a brief discussion on possible future production at the site, as well as assessment of the capital costs required to operate the plant under each production scenario.
- **Section E, Assessment of the financial viability of production:** In this section:
 - Forecast of supply and demand balance of butadiene and its estimated cost from various sources of supply
 - Assessment of the expected cost of production considering all of the required capital, O&M and other expenses, including capital and O&M expenses required for environmental compliance.
 - Assessment of the logistical challenges associated with sourcing of butadiene and other feedstock required for operation of the plant.
 - Assessment of the expected revenue under the normal market conditions and prices for polychloroprene rubber.
 - Calculation of the key financial metrics for assessing the financial viability of the three considered future production scenarios.
 - Assessment of the cost competitiveness position of Nairit plant in comparison to other similar plants.

- **Section F, SWOT Analysis:** A detailed SWOT analysis is presented for each of the potential options for production restart at the Nairit chemical production site, evaluating the strengths, weaknesses, opportunities and threats involved in operating Nairit plant under each scenario.

Section B



Executive Summary

Key Findings and Recommendations

The Government requested the World Bank to assess the technical and financial viability of Nairit chemical plant operation. This Note presents the key conclusions emerging from the ongoing assessment, conducted by the Jacobs Consultancy Ltd, and proposes some steps the Government could take with regard to Nairit.

The ongoing technical, commercial and financial assessment of Nairit indicates that:

1. **The Nairit plant is an unsustainable liability for the Government and continues to be a major drain on the Government.**¹ The plant has not been operational since 2010 when the private owner abandoned it. The liabilities of the plant exceed AMD121 billion (\$250 million), including the sovereign guaranteed loan from the CIS Inter-state Bank, which has not been repaid. The company has not generated any revenues and relied on borrowing from Yerevan TPP to finance the salaries and maintenance costs since 2010. The total debt of the company to Yerevan TPP is AMD23 billion (\$48 million), including the payables for steam. If this situation is not addressed, Nairit will remain an unsustainable burden for the state-owned power companies given that the plant needs about AMD2-3 billion/year (\$4-6 million) for salaries and maintenance expenses.

The book value of assets is less than 50% of the outstanding value of debts and payables.

This means that the company's assets are not sufficient to meet its liabilities. The current book value of property, plant and equipment is AMD57 billion (\$119 million). However, a substantial share of equipment has significantly deteriorated and this has not yet been reflected in the financial statements since stock taking and revaluation of assets has not been carried out recently.

2. **The cost of supply by Nairit is estimated to exceed the forecast market price for polychloroprene rubber (CR), which makes it uncompetitive globally.** The assessment of cash costs of PCR production under various processes and technologies (both butadiene and acetylene based) suggests that even under the least-cost butadiene-based process, Nairit would have one of the highest production costs:

- Under butadiene-based process: due to the high cost of chloroprene monomer production based on imported butadiene with a large transportation overhead as well as high prices for gas and electricity.
- Under acetylene-based process: due to high costs of electricity and gas, which are among the highest in the industry.

At current and forecast PCR prices, Nairit would not be able to compete globally due to high production costs, large expenses to get the PCR to main export markets (e.g. Europe or Asia), and the pricing policy of the main competitors. Even if one or two main producers have higher costs than Nairit, it would still not be able to compete given: (a) transportation costs of \$150/ton, which is 5% of the final product price, to get the product to main markets, whereas other main exporters have lower export-related costs; (b) the need to recover \$210-346 million of capital costs that will be required to restart the operations, whereas the existing large exporters have already recovered the capital costs; and (c) trade policy to protect the domestic market in China, one of the largest markets today and in the future.

3. **Unrealistic cost reductions or PCR price increases would be required to make Nairit financially viable.** For example, a 45% increase of the market price of PCR or a 90% reduction

¹ The responsibility for the Nairit plant falls under the Ministry of Energy and Natural Resources, and it became a financial burden for the power sector.

in the price of gas would be required to make Nairit commercially viable under all of the production technologies considered.

4. **These technical and financial considerations suggest that the Government should consider developing and implementing a liquidation plan.** Such a plan should include the key steps below:
 - **Conduct stock taking of assets and assess their current market value.** Nairit should hire an independent evaluator to carry out stock taking and revaluation of assets, which can be sold to meet the liabilities of the plant to its employees, the state budget, and other creditors in the order of seniority.
 - **Negotiate with creditors to settle the outstanding debts, which is most unlikely to be redeemed through asset sale.** There is a court ruling mandating Nairit to pay to the CIS Inter-state bank AMD51 billion (\$108 million), including interest and fines.
 - **Design and implement a social mitigation plan.** The Government should ensure the retrenched employees are paid a severance package and the existing social safety net provides the required redeployment assistance to them.
 - **Conduct a detailed environmental assessment of the plant.** The Government should commission a study to conduct a thorough assessment of legacy environmental issues of the plant in order to remedy them and allow for environmentally sustainable decommissioning.
 - **Implement the liquidation plan, including environmental clean-up.** The Government should allocate resources to decommission the plant in an orderly way, including addressing environmental legacy issues.

The Government should conduct the steps highlighted above transparently and communicate on this sensitive issue, so that the information, arguments and justifications behind its decision become publicly available.

Global Demand, Supply and Trade of PCR

The Global market for PCR has been growing at a pace equal to 1/4th of the global GDP growth rate. The demand elasticity (ratio of demand growth to GDP growth) was about 0.24 between 2000 and 2014. Overall the product had a low demand elasticity as a result of the deceleration of industrial output in some large industries using PCR and substitution by other rubbers in industries like automotive and manufacturing. Historically demand for PCR has always grown more slowly than GDP, mainly because its end-use industries are not directly linked to the macroeconomic parameters except for automotive manufacturing. During the forecast period (2015-2040), the major demand for the product is assumed to come from Asia where the demand is likely to grow owing to the higher demand from manufacturing segments. Regions like North America and Western Europe, where markets are already saturated, are likely to contribute less to the global demand.

Table B-1: Global Demand by Region and Expected Growth Rates (in thousand tons)

Region	2000	2005	2010	2014	2020f	2025f	2030f	2040f	CAGR
Asia	122	146	167	163	178	197	215	245	1.6%
North America	63	59	64	66	68	69	70	72	0.3%
Western Europe	63	74	80	80	83	86	87	90	0.5%
Eastern Europe	9	13	11	10	12	14	17	21	2.9%
South America	16	14	16	18	20	22	24	27	1.7%
Middle East/Africa	7	10	11	7	8	9	10	11	1.7%
Total	280	317	350	344	370	397	423	466	1.2%

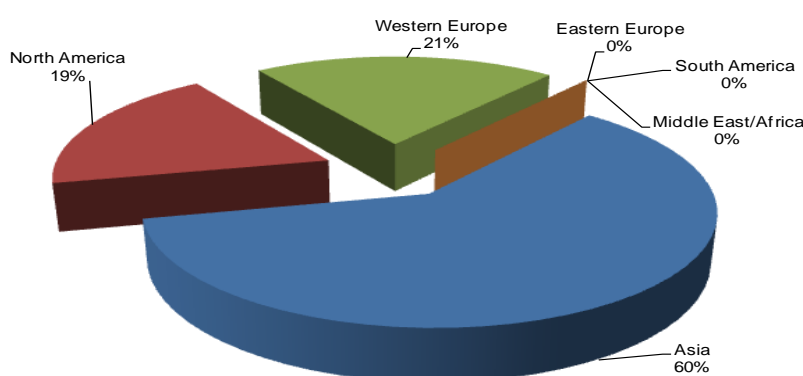
Source: Jacobs Consulting Ltd.

In the long term, PCR demand is likely to grow at about 1.2% per year, with demand volumes increasing from 345,000 tons in 2014 to about 423,000 in 2030, with average demand additions of 5,000 tons per annum. North America and Western Europe are likely to grow at very low rates of 0.3-0.5% in the long term as demand matures and end-use industries like automotive and adhesive manufacturers move to lower-cost manufacturing hubs. Asia, as well as Middle East/Africa, is expected to grow at 1.7%, with China leading the growth in Asia.

The global PCR production capacity has been shrinking. In 2014, the global capacity for PCR was estimated to be 400,000 tons. In 2000-2014, the capacity contracted by 17,000 tons with the shut-down of major facilities in North America and Western Europe, while some new capacity was added in Asia either through expansion of existing Japanese plants or construction of new plants in China.

In 2014, Asia accounted for about 60% of the total installed capacity while Western Europe comprised 21% of the total installed capacity. North America constituted about 19%.

Figure B-1: Global Capacity by Region in 2014



Source: Jacobs Consultancy Ltd.

Japan is the dominant producer of PCR globally. Japanese producers account for 59% of the global market for PCR. In the period 2006-2013, the Japanese producers inCReased the capacity by 80,000 tons/year. Since Japan is a net exporter of the product, all capacity additions are aimed mainly at the export markets. Chinese capacities inCReased by 40,000 tons with the new Chinese/Armenian joint venture plant, Shanxi Synthetic Rubber Group, starting up its 30,000 tons/year plant in mid-2010 at half capacity, but gradually inCReasing capacity utilization in subsequent years.

The only North American producer has exited PCR production. In North America, there has been only one producer, DuPont Dow Elastomers, a joint venture of DuPont and Dow. It shut down one of its two facilities and sold the other to the Japanese Denka joint venture (Denka 70%, Mitsui 30%).

Germans are the only manufacturer in Western Europe. The German company, Lanxess, has about 83,000 tons/year of capacity, which includes both solid rubber and latex. The only other PCR plant in Western Europe was in France, a 43,000 tons/year plant owned by Enichem. However, due to poor economic conditions and other issues, the older Enichem plant was closed down in 2005, and now Lanxess is the sole producer of the product in Western Europe.

Nairit accounted for 3% of the global capacity before discontinuation of production in 2010. Nairit used to supply roughly 10,000 tons/year of PCR using acetylene-based process. The butadiene-based process was not used given feedstock unavailability (Nairit could not compete with domestic demand for butadiene in the Russian Federation) and costs associated with sourcing butadiene from Russia.

Table B-2: Global PCR Production Capacity by Country

Company	Country	Total Capacity 2014 (KTA) ²	% of Market Share
Denki Kagaku Kogyo K.K.(Denka)/Mitsui JV USA	Japan/USA	175	38%
Lanxess	Germany	83	21%
Shanxi Synthetic Rubber Group Co Ltd/Nairit	China/Armenia	50	10%
Tosoh Corporation	Japan	34	9%
Chongqing Changshou Chemical Co., Ltd.	China	30	8%
Showa Denko	Japan	23	6%
China Others	China	5	1%
Total		400	100%

Source: Jacobs Consulting Ltd.

Global capacity is expected to remain flat, but will be sufficient to serve the global demand at least until 2025.

Table B-3: Total Capacity Additions vs. Demand Outlook, 2014-2021

Polychloroprene Rubber		2013	2014	2015	2016	2017	2018	2019	2020	2021
Total Global Capacity	ktons	402	400	405	405	405	405	405	405	405
Total Global Demand	ktons	344	344	348	352	357	361	365	370	375
Global Operating Rate	%	83%	82%	86%	87%	88%	88%	88%	87%	87%
Net Capacity Additions	ktons		-2	5	0	0	0	0	0	0
Global Demand Growth (%)	%	1.5%	0.0%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.4%
Capacity Addition a percentage of Annual Demand	%	0%	-1%	1%	0%	0%	0%	0%	0%	0%

Source: Jacobs Consulting Ltd.

In 2013, Asia accounted for largest share of exports/imports of PCR. Asia was the largest importer of PCR in 2013 with nearly 83,000 tons imported. Asia was also one of the largest exporters of PCR, exporting about 100,000 tons in 2013, with Japan accounting for 95% of exports. The Asian region is more or less a balanced market and will convert to a minor exporter in the forecast years. Japan is expected to satisfy the demand of China and the rest of Asia.

² Kilotons per annum.

North America is a net importer and Western Europe is a net exporter. The North American is a net importer after the closure of its plants. The Western Europe is a net exporter as demand has fallen within the region. The Middle East, Africa and South America currently have no capacity and hence are net importers of the product. Due to sporadic production, Eastern Europe has historically been a net importer.

Foreign suppliers struggle to compete on the Chinese market due to import duties. China is likely to continue to impose anti-dumping duties on PCR from the European Union, North America and Japan. China had previously imposed antidumping duties of 2-151% on PCR imported from Japan, the United States and the European Union for 5 years from May 2005. A fresh probe was undertaken in May 2010 and the duties were imposed for another five years in May 2011.

Any future PCR rubber capacity additions will most likely be directly related to the availability of both low-cost butadiene and cheap electricity. As butadiene demand in recent years has led to large price differential between butadiene and butanes (competing output from refineries), efforts are under way to develop alternative processes for manufacturing butadiene.

Snapshot of Financial Standing of Nairit

Nairit has been idle since 2010 and became a major liability for the Government. The company has not produced any output since 2010. Although 90% of the company was sold to Rhinoville Property Limited, the owner left in 2010, saddling the company with a combined debt of AMD90 billion (\$188 million) including AMD51 billion (\$108 million) to the CIS Inter-state Bank. The debt has been steadily increasing since 2010 due to almost AMD16 billion (\$33 million) borrowed from Yerevan TPP to finance the salaries of the staff, numbering some 2,200 initially, and some basic maintenance expenses. The number of staff has been brought down recently to around 600, which include mostly technical personnel. The company also has AMD31 billions (\$65 million) of payables with the largest payables being salaries and energy (steam) from the Yerevan TPP.

Table B-4: Largest Payables

Items	Amount in billion AMD
Salaries	8.9
Energy and other trade payables	8.7
Taxes	5.6
Other (not disclosed in financial statements)	7.6
Total	31

Source: World Bank team.

Nairit's assets are not sufficient to meet its liabilities. Nairit has some assets, but the market value is not known. The balance sheet value of the property, plant and equipment is estimated at AMD57 billion (\$119 million), which is significantly lower than the AMD90 billion in debts (\$188 million). However, there has been no re-evaluation of the value of assets and their total market value might be even lower.

Assessment of Financial Viability of Commercial Operation of Nairit

Production of PCR is not financially viable at Nairit. Although the main product of the plant is PCR, the production process results in some by-products, the largest being caustic soda, which have value and can be sold to augment the plant's revenues (5% of total revenue). The assessment suggests that

production of PCR at Nairit was estimated to be financially not viable for both butadiene³- and acetylene⁴-based processes, the two main processes that Nairit can use to produce PCR.

The Table below summarizes the results of the assessment of the financial viability of Nairit operations for various feedstock/inputs and technologies.

Table B-5: Summary of Financial Viability of Nairit Operations Under Various Technologies

	Annual output (in tons/per year)	Capital Cost (in million \$)	Project pre-tax IRR ⁵	NPV ⁶	
				10% rate	15% rate
Butadiene-based process	25,000	264	negative	-186	-178
Acetylene-based using existing process	12,000	210	negative	-207	-179
Acetylene-based using the process of International Specialty Products (Germany)	24,000	346	negative	-216	-214
Acetylene-based using existing process	24,000	346	negative	-328	-287

Source: Jacobs Consulting Ltd.

The return on investments is negative for all production scenarios and technologies. The results suggest that operations are not financially viable irrespective of the annual outputs and associated economies of scale. Nairit will not generate the required cash flows even assuming that investors expect only a 10% return on capital, which is below the levels expected for such projects due to: (a) the country risks and negative macroeconomic outlook; and (b) the higher required rate of return on capital invested in this project. Such low returns mean that capital investments into this project would be recovered after 30-35 years, which would be unattractive to investors.

Nairit is among the highest cost producers in the industry due to the high cost of chloroprene monomer production. The operating profit from unit of PCR sales are low (even negative) under all production scenarios due to the high cost of chloroprene monomer production, which is the largest cost item in the PCR production cost structure. Chloroprene monomer is produced either from butadiene or acetylene.

Butadiene costs are high due to large transport costs, contributing to 20% of the plant gate price. Butadiene is not manufactured locally and needs to be sourced from abroad. The largest net exporters with the historically lowest price are the European manufacturers (Germany and the Netherlands). The European manufacturers are forecast to have the lowest prices for butadiene in the future as well. If Nairit decides to source butadiene from Europe, the transport costs would be quite high, given the geographical location and complicated logistics. It is estimated that the cost of butadiene at the Nairit plant gate would be \$1,330/metric ton, with transport cost accounting for 20%. The only technically feasible way of transporting butadiene from Europe is by: (a) trucks through Russia and down all the way to Georgia and then Armenia; or (b) rail to Romanian ports first, ferry to Poti next, and finally rail to Armenia. Maritime transport is not feasible given that the terminals at Georgian ports do not have

³ PCR from butadiene is produced in three steps – chlorination, isomerization and dehydrochlorination.

⁴ Acetylene is dimerized to give vinyl acetylene, which is combined with hydrogen chloride to form an allene derivative, which in the presence of cuprous chloride forms chloroprene. The process is very energy-intensive, requires high capital costs, and has substantial environmental and safety risks.

⁵ Internal Rate of Return.

⁶ Net Present Value.

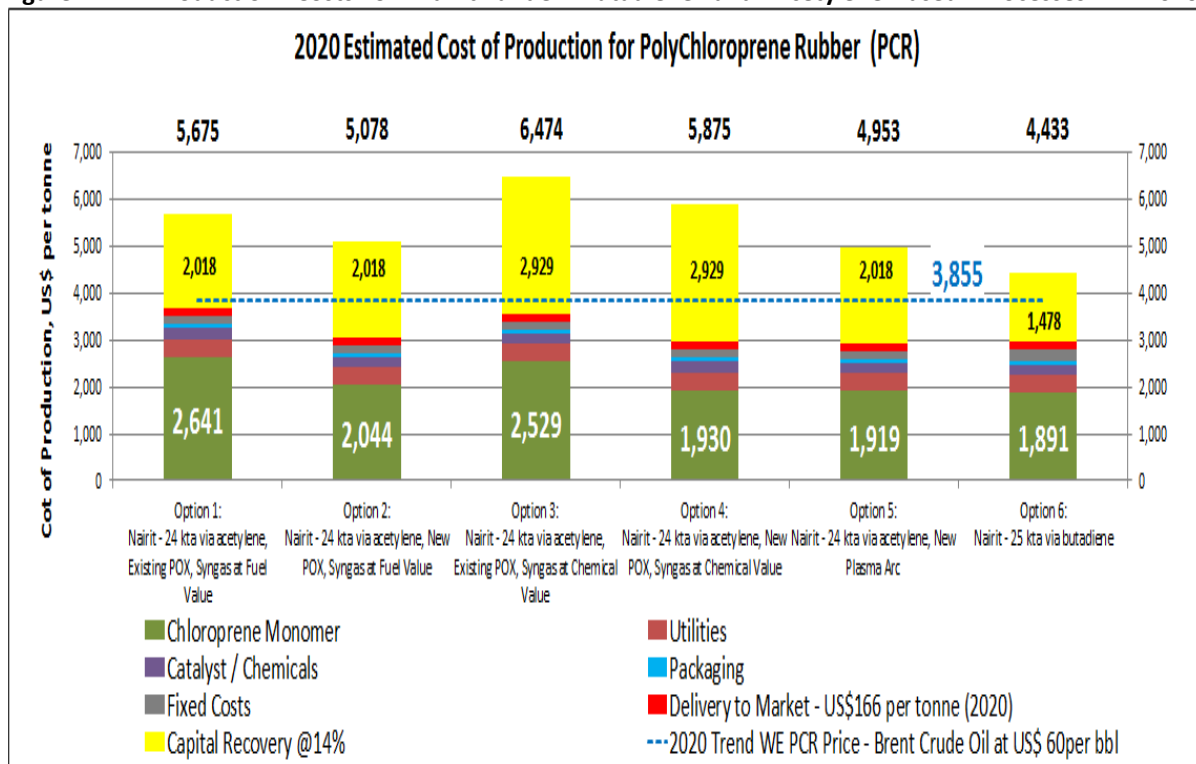
the required facilities for handling/temporary storage of butadiene (which loses its useful chemical properties if it is not constantly in motion).

- Imports from Russia, where Nairit historically bought butadiene from, are not feasible. This is due to the following reasons: (a) Russia has only two manufactures supplying mostly the local market with very limited exports. The outlook for increased future capacity of butadiene manufacturing in Russia is bleak due to the current economic environment, which is expected to delay the projects in the pipeline; (b) shipments from Russia will need to come through either rail or ground transport, neither of which is feasible for the foreseeable future given the current situation.
- Imports from the Esfahan facility in the Islamic Republic of Iran are not certain. Nairit made several attempts to reach an agreement with the Iranians. However, it is our understanding that the Iranians did not want to enter into a long-term sale agreement given that all of their exports have already been committed under long-term contracts.
- Imports from the Middle East are not available given that all of the output is committed under long-term contracts.

Acetylene-based process is expensive due to its energy-intensity and high cost of energy in Armenia.

The current acetylene-based process at Nairit consumes twice as much gas and 50% more electricity than butadiene-based process. However, even if Nairit invests in modern acetylene-based processes—such as BASF and ISP, which would reduce energy consumption—the energy costs will still account for a large share of the total production costs. Nairit is estimated to have the highest energy cost per ton of PCR compared to all its competitors.

Figure B-2: Production Costs of Nairit under Butadiene and Acetylene-Based Processes in 2020⁷



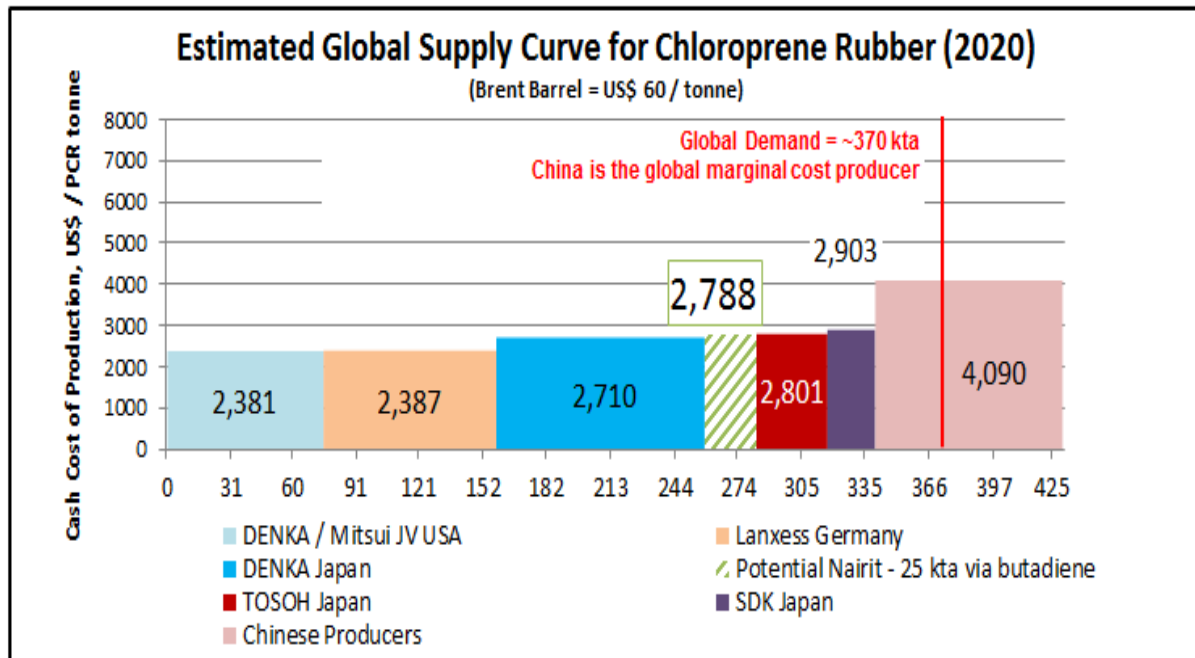
Source: Jacobs Consultancy Ltd.

Nairit will not be able to compete on the European, Asian or other markets given high production costs and distance to markets.

⁷ The 2020 forecast price of PCR is used because implementation of hypothetical capital investment project at Nairit would require 4 years from now.

Nairit is estimated to have one of the highest cost of production among PCR plants. Assuming a butadiene-based process and annual output of 25,000 tons, Nairit’s cost of production will be the second highest globally after the Chinese producers. Such high costs of production are due to high cost of feedstock driven by substantial transportation costs to get it to Armenia and the high cost of energy (both steam and electricity). Currently Nairit cannot receive steam from the nearby Yerevan TPP and will have to install a new steam boiler. With investments required and current gas prices of \$277/thousand cubic meters, the cost of steam is going to be quite high. The current electricity cost of AMD30/kWh⁸ (which is expected to increase further) is 20-30% higher than for the most of the competitors.

Figure B-3: Global Supply Curve for PCR⁹



Source: Jacobs Consulting Ltd.

The cash costs of production based on other processes (acetylene) and technologies (new BASF technology for acetylene or Plasma Arc technology of ISP) have even higher cash costs and much poorer financial viability due to high costs of chloroprene monomer production (input into production of PCR), which means Nairit will not be able to compete with foreign manufacturers.

Most of the existing large producers are located in the largest demand centres. Transportation costs of the PCR to main markets (e.g. Europe, South America and/or Asia) are prohibitively high. Nairit could sell up to 10% of the output to Turkey, Russia and the Islamic Republic of Iran, but it should also target other large demand centres with above-average growth if Nairit wants to sell all of its production. However, Nairit will not be able to compete on the Western European or the Asian markets (let alone in South America with the highest transportation costs).

Specifically, the JV of Japanese/U.S. producers and the German company have the lowest costs of production and are located in the region in close proximity to the market. Nairit will not be able to compete in the European market either, given that the largest European producer (Lanxess) has one of the lowest cash costs and is also located in the demand center, which leads to negligible transportation costs.

⁸ 35 kV and higher voltage consumers.

⁹ Assuming Brent price of \$60/barrel.

Although China is the most expensive producer, Nairit is not likely to be able to compete on Chinese market because: (a) it will need to compete with low-cost Japanese producers located very close to the demand center; and (b) it will need to compete with the Chinese producers which, although having high production costs, benefits from government protection. Thus, the small share of marginal demand that Nairit may look to fill is very much dependent on the pricing behaviour of struggling Chinese producers and the Government policy on market protection (there are already custom duties in place against low-cost Japanese producers).

Most of the existing large producers have already recovered the capital costs and can aggressively compete on price. The plants owned by the largest producers have been operating for more than 10-12 years and have already recovered their capital costs, providing greater flexibility for price reduction to these producers and putting Nairit at a price disadvantage. For example, even the Chinese Shanxi Synthetic Group, to which Nairit-2 sold its technology and where the Government of Armenia owns a stake, is increasingly struggling to compete with the low-cost Japanese PCR producers even on its domestic market. Nairit will not be able to reduce prices to compete, given the need to recover the large capital investment that will be required. Nairit will require those investments to upgrade its facilities. The upgrade costs are different for butadiene- and acetylene-based process, given varying degrees of dilapidation of equipment used for these processes at Nairit. The capital investment cost is estimated in the range of \$210-346 million, depending on the process and the related capacity of the plant. The high capital costs are also driven by the need to improve safety and ensure compliance with environmental standards.

Sensitivity Analysis

Under all of the considered scenarios, the project yields negative project returns. The 25 kta butadiene based scenario results in the least negative results, followed by 12 kta acetylene based scenario, as the project generates less absolute negative monies than a larger 24 kta acetylene based scenario. For the acetylene based cases, the option of using ISP plasma arc process for acetylene generation, yields the least negative results at current prices for natural gas and electricity. For all cases, the IRR/NPV figures are based on 20 years of cash flow modelling and the payback estimate is a simple, undiscounted measure of the payback period.

Butadiene Based Production of 25 kta PCR Financial Results

Table below provides our estimates of the financials for the Base Case where 25 kta of PCR is produced based on a butadiene feedstock.

Table B-1: 25 butadiene kta PCR Financial Results, new chlor-alkali unit.

	Project	Equity	IRR %	NPV \$M		
	Capex \$m	Capex \$m	(20 years)	5%	10%	15%
Project Pre-Tax	264	-	negative	-193	-186	-178

Source: Jacobs Consulting Ltd.

The project will not be able to recoup the required investments within the 20 years operational period of the project.

Acetylene Based Production of 12 kta PCR Financial Results

The table below shows our estimates of the financial analysis for the Base Case where 12 kta of PCR is produced based on an acetylene feedstock.

Table B-2: 12 kta acetylene PCR Financial Results, existing POx, existing chlor-alkali

	Project	Equity	IRR %	NPV \$M		
	Capex \$m	Capex \$m	(20 years)	5%	10%	15%
Project Pre-Tax	210	-	negative	-249	-207	-179

Source: Jacobs Consulting Ltd.

The project will not be able to recoup the required investments within the 20 years operational period of the project.

Acetylene Based Production of 24 kta PCR Financial Results

The tables below shows our estimates of the financial analysis for the JC case where 24 kta of PCR is produced based on an acetylene feedstock. Table B-7 shows IRR/NPV figures for a similar configuration to that of 12 kta PCR acetylene based scenario (Table B-6), albeit at twice the production rate. Table B-8 shows the improvement offered by making use of improved acetylene production process.

Table B-3: 24 kta acetylene PCR Financial Results, new ISP Plasma Arc, existing chlor-alkali

	Project	Equity	IRR %	NPV \$M		
	Capex \$m	Capex \$m	(20 years)	5%	10%	15%
Project Pre-Tax	346	-	negative	-206	-216	-214

Source: Jacobs Consulting Ltd.

In all cases, the project will not be able to recoup the required investments within the 20 years operational period of the project.

Table B-4: 24 kta acetylene PCR Financial Results, existing POx, existing chlor-alkali

	Project	Equity	IRR %	NPV \$M		
	Capex \$m	Capex \$m	(20 years)	5%	10%	15%
Project Pre-Tax	346	-	negative	-390	-328	-287

Source: Jacobs Consulting Ltd.

In all cases, the project will not be able to recoup the required investments within the 20 years operational period of the project.

Section C



Polychloroprene Rubber Market Review

Polychloroprene Rubber Market Overview

Introduction

Polychloroprene Rubber (referred as CR in the report henceforth) was the first commercially produced synthetic rubber, which was accidentally synthesized by DuPont in 1930. CR is often known by its now pseudo-generic name 'neoprene' – DuPont's trademark for CR or even 'polychloroprene'. CR is produced in both dry rubber (rigid) as well as latex forms. The dry form of CR is used for the manufacture of industrial and automotive rubber goods like hoses and belts (more often than not as a CR-linked rubber), while the latex form is used in water based adhesives, dipped goods like gloves and others. CR is usually available in the form of chips and can be vulcanized by using various accelerator systems over a wide range of temperatures.

While the market information is generally based on the overall CR demand (i.e. both latex and solid dry rubber, we have tried to focus on the dry rubber (rigid CR) market segments as was the manufacturing focus for Nairit in the years prior to shutdown, where possible.

The material properties advantages of CR include:

- Excellent rubber elastic behaviour
- Resistance to weathering, both in dry and humid climates
- Excellent combustion behaviour
- Good resistance to oils
- Aging and heat resistance
- Good tensile strength, tear and wear resistance
- High dynamic fatigue resistance
- Resistance to water and a large number of chemicals over a long period
- Good adhesion to suitably pre-treated reinforcing substrates consisting of textiles, metals or glass fibres
- Resistance to fungi and soil bacteria
- Low gas permeability
- Electrical properties sufficient for a large number of applications

CR has thus carved a niche market where at least some of these properties are critical and where other lower cost elastomers and rubbers cannot fulfil the requirements. More recently polyolefinic crosslinkable elastomers such as EPDM have been eating away at the low end of the CR markets where not necessarily all the above properties are required in one application. Other materials such as Thermoplastic Elastomers (TPEs) and Polyurethane Elastomers have also been successful in taking away established applications from CR. This trend continues and can be considered still somewhat from completion.

The areas where it remains advantaged against the polyolefins competition is in its higher continuous usage temperature, weatherability and chemical resistance, fatigue resistance, and low gas permeability.

Manufacturing Process

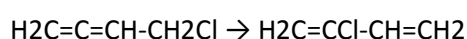
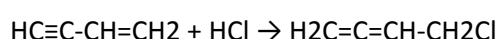
CR is produced by the polymerisation of chloroprene monomer. There are two methods of manufacture for chloroprene:

- Acetylene route
- Butadiene route

The Acetylene Route

The older route for the manufacture of chloroprene included the acetylene being dimerized to give vinyl acetylene, which was combined with hydrogen chloride to form 4-chloro-1,2-butadiene (an allene derivative), which in the presence of cuprous chloride, forms 2-chlorobuta-1,3-diene (chloroprene).

The chemical reaction is as follows



This process is extremely energy intensive with high investments costs, apart from the environmental and safety implications of producing and handling acetylene.

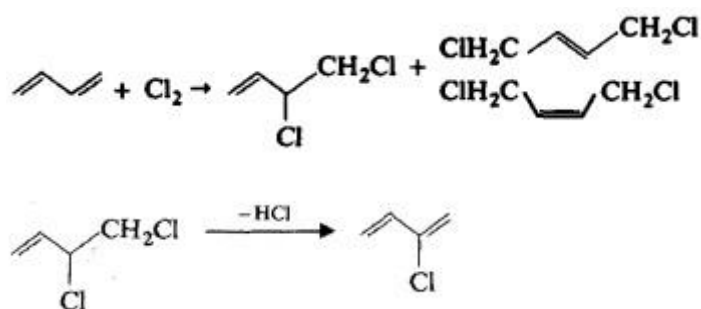
The Butadiene Route

In the butadiene route, chloroprene is produced in three steps from 1,3-butadiene – chlorination, isomerisation and dehydrochlorination of 3,4-dichloro-1-butene.

Chlorine is added to 1,3-butadiene to produce a mixture of 3,4-dichloro-1-butene and 2,3-dichloro-2-butene. The 2,3-chloro isomer is then isomerized to 3,4 isomer, which in turn is treated with a base to undergo dehydrochlorination to form 2-chlorobuta-1,3-diene (chloroprene). The chief impurity in chloroprene prepared in this way is 1-chlorobuta-1,3-diene, which is usually separated by distillation.

Figure C-1 gives the chemical reaction for the production of chloroprene from butadiene.

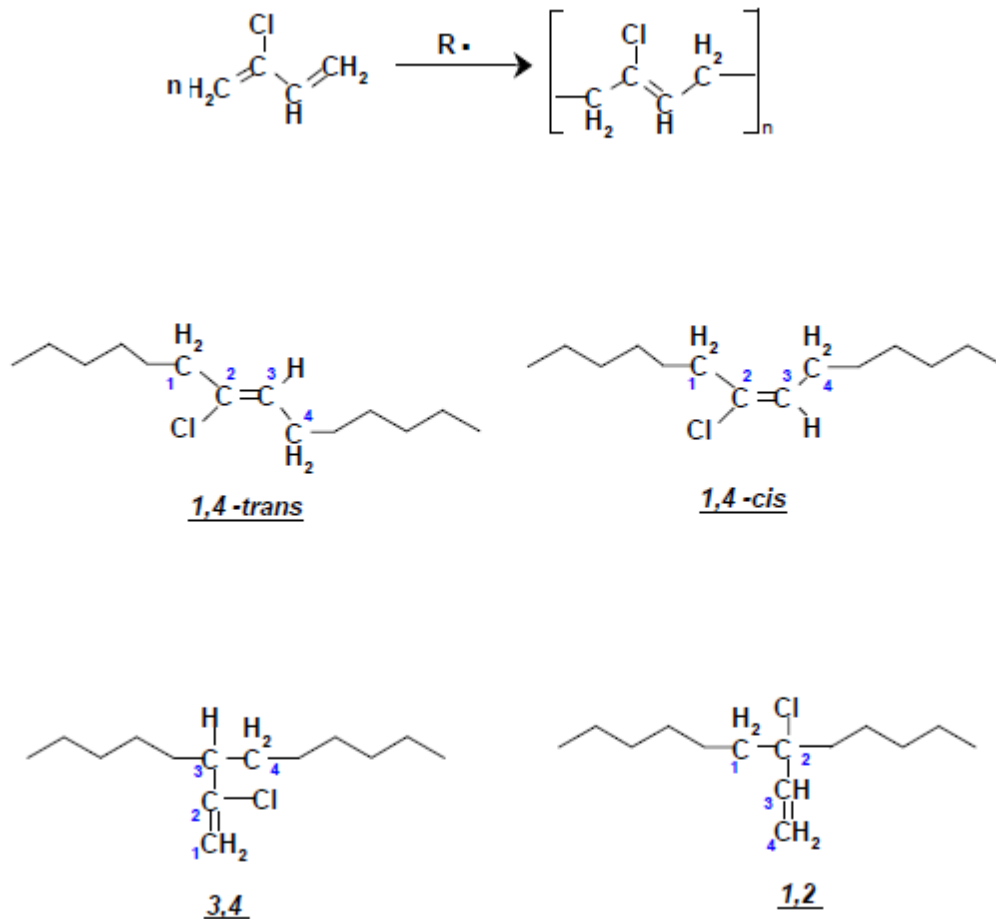
Figure C-1: Chloroprene from Butadiene, Chemical reaction



Polychloroprene is manufactured by polymerizing the chloroprene monomer. It is possible to polymerize chloroprene by anionic, cationic and Ziegler-Natta catalysts. However, because of the product properties and economic considerations, free radical polymerisation is used which can be carried out in batch as well as continuous process. Using radical initiators, chloroprene in form of an aqueous emulsion is converted into homopolymers or, in the presence of co-monomers into copolymers. The polymerization is stopped at the desired conversion by the addition of a short stopping agent. The latex is freeze-coagulated on large, refrigerated revolving drums, from which it is drawn as a thin sheet. After washing and drying,

the sheet is dried and chopped into small pieces or chips. Figure C-2 below summarizes the key reaction schemes.

Figure C-2: Chloroprene Polymerization



Source: IISRP

The properties of CR depend on various factors including the polymerisation temperatures, monomer conversion levels and polymerisation aids as well as finishing conditions. Depending on these factors, physical, chemical and rheological properties of the CR produced can be determined.

Globally, it is estimated that about 40 percent of CR produced is based on the acetylene processes. These plants are based in Asia, mainly in China and Japan. One of the largest plant of Denki Kagaku Kogyo K.K. (Denka) is based on the acetylene process. The remainder 60 percent plants are based on the butadiene process.

Acetylene (carbide) chemistry is a strong driver in China due to the immense coal reserves in the country. Acetylene chemistry for instance dominates VCM (Vinyl Chloride Monomer – pre-cursor for PVC production) production in China, and is almost non-existent elsewhere in the world.

Main Types of Rigid CR

General Purpose Grades (Normal Linear Grades)

General-purpose grades are mostly produced with n-dodecyl mercaptan as the chain transfer agent and occasionally with xanthogen disulfides. If xanthogen disulfides are used, the elastomers are more readily processible and have improved mechanical properties.

Precrosslinked Grades

Precrosslinked grades consist of a blend of soluble polychloroprene and Cross-linked polychloroprene. They show less swelling after extrusion (die swell) and are suitable for the extrusion of profiled parts.

Sulphur Modified Grades

Sulphur-modified grades are copolymers of chloroprene and elemental sulphur. The viscosity is adjusted – in contrast to general-purpose grades - mostly after polymerization by “peptization” of the polysulfide bonds by e.g. thiuramdisulfides as peptization agents. Sulphur modification improves the breakdown of the rubber during mastication (lowering of viscosity) and is used in particular for parts exposed to dynamic stress, such as driving belts, timing belts or conveyor belts because of their excellent mechanical properties. But the polymers are less stable during storage and less resistant to aging.

Slow Crystallizing Grades

Slow crystallizing grades are polymerized with 2, 3-dichloro-1, 3-butadiene as a co-monomer. The co-monomer reduces the degree of crystallization by introducing irregularities into the polymer chain. High polymerization temperatures also make structural irregularities, if this co-monomer is not available. Crystallization resistant grades are used to produce rubber articles, which have to retain their rubbery properties at very low temperatures.

Applications and Uses of Rigid CR

CR is used mainly in the automotive, building, construction and cable and wire industry and has a large usage as adhesives in the mentioned industries as well as other industries.

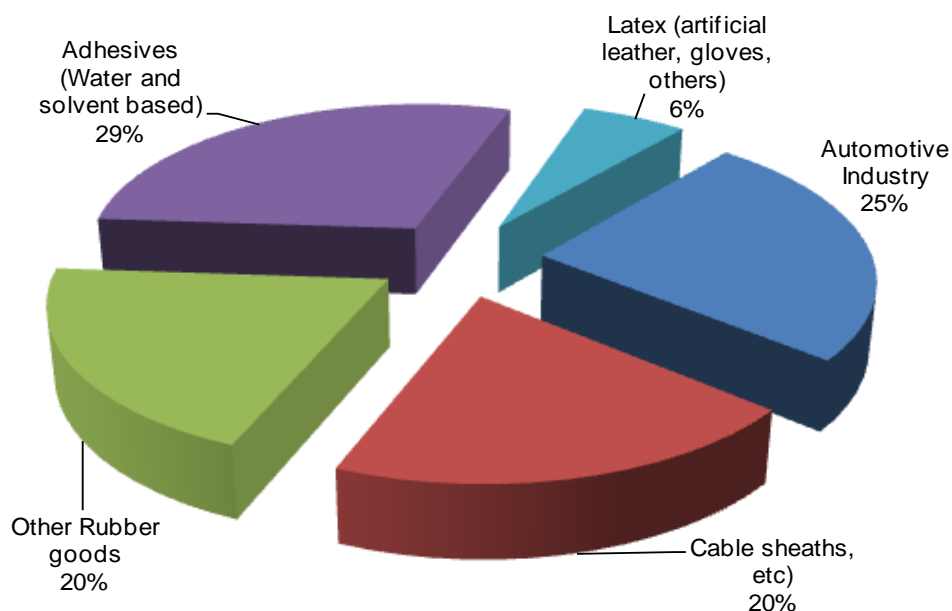
In automotive industry, CR goes into the manufacture of hoses to withstand high pressure, oil and fuel hoses, as well as moulded parts like bellows, axle boots, membranes, spring elements, dampeners, and windshield wipers.

In the general industrial use, CR is as a raw material for manufacture of hoses to withstand high pressure, hoses for use in the petroleum industry, floating hoses, power transmission belts, conveyor belts and other smaller uses like cover for rollers in printing industry, textile and paper industry, as well as rubberized fabrics for containers, tarpaulins and boats.

One of the most well-known uses of CR is in the manufacture of foam rubber sheet for wet suits used during diving operations in the sea.

In the building and construction industry, CR is mainly used in form of sealing strips for windows, doors, facades as well as expansion joints for civil engineering applications. Apart from this, CR finds extensive usage in flexible cables for underground and mining operations, transport and conveying systems, domestic appliances, suspension units for elevators as well as machine tools. Figure C-3 gives an overview of the global application split for CR in 2014.

Figure C-3: CR Downstream Use Segmentation 2014



Source: Jacobs Consulting Ltd.

The largest end use application for CR has been in rubber (elastomeric applications, cross-linked rubber as well as non-cross-linked) goods, which accounted for about 60% of the market in 2014. This has been divided into the demand by the automotive industry, which was about 25% of the total demand, as well as demand by the cable sheaths and other electrical applications which was estimated to be about 20% of the demand. Another 20% of the demand was accounted by the general rubber goods like hoses, pipes, belts and other minor applications. Another major use for CR has been the adhesives segment, which accounted for about 29% of the total demand for CR, with water based adhesives gaining prominence over the solvent based ones. The remaining 6% is used for other applications like artificial leather, gloves and others. This final segment is under quite some threat from newer materials such as polyurethane elastomers.

Market Overview

Global Market Overview

In 2014, the total demand for CR was estimated to be about 345 kta, stagnant over the previous year demand. The demand growth trend has witnessed similar movements to the trends in GDP growth rates, declining by 2.0% and 1.8% in 2008 and 2009 respectively owing to the economic downturn. The demand grew strongly in 2010, by 10%, overcoming the decline of the preceding years. In 2011, demand growth was at 4.6%. However in 2012, the demand contracted by 7.3% as the Eurozone CRisis loomed and the Chinese economy witnessed sluggish growth. The demand in 2013 increased modestly by 1.5%. Overall the demand for CR has increased from 280 kta in 2000 to the current levels showing a CAGR of about 1.5%. This relatively lower growth rates is a result of decline in usage of chloroprene in certain applications where substitution has taken place mainly by rubbers like EPDM. In matured markets like North America and Western Europe, the market has remained more or less stagnant in the past 14 years. The demand for CR has grown at about 0.24 times the GDP in the past 14 years, owing to the economic downturn in 2008 and 2009 affecting the overall market demand. Prior to the economic downturn, the demand grew by about 2.4% between 2000 and 2007; which in absolute numbers indicate the growth of the demand from 280 kta in 2000 to 330 kta in 2007.

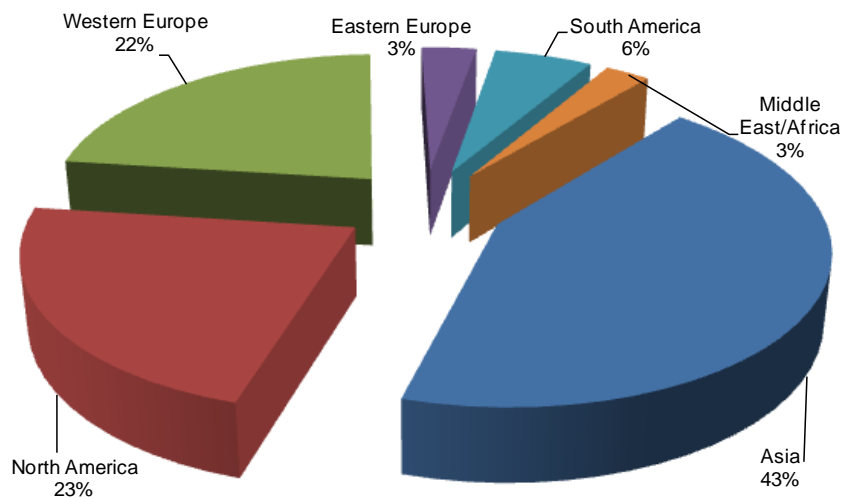
In the period 2011-2014, the review update period, the demand for CR has been thus almost stagnant. While the economic factors have some impact, CR has been under pressure from other elastomers such as TPEs (Thermoplastic Elastomers), EPDM and polyurethane elastomers that have eaten into the possible growth for CR, thus keeping CR growth well below GDP.

Between 2014 and 2019, the demand for CR is likely to grow by a CAGR of 1.0% as the product continues to face challenges owing to substitution by other rubber products. In the long term forecast, between 2014 and 2040, the CAGR is likely to be about 1.2%, growing at about 0.38 times the estimated GDP growth rates.

Demand by Region

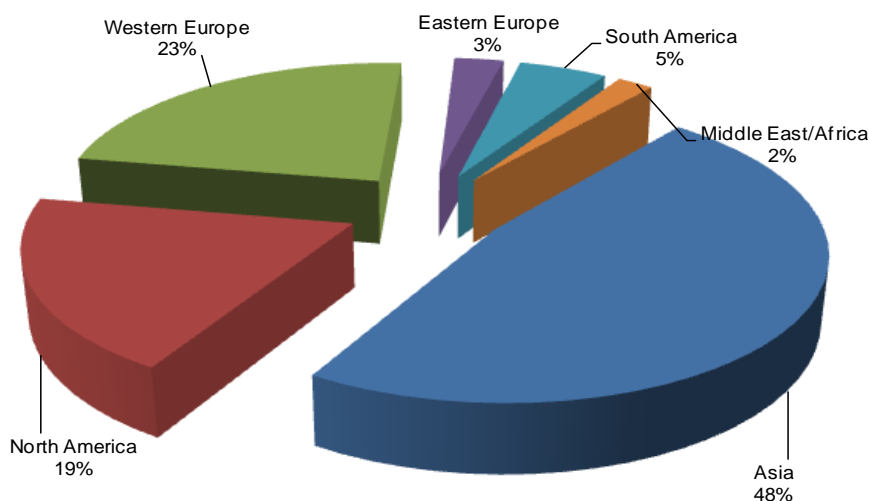
Globally in 2014, Asia accounted for about 48% of the total demand for CR, followed by Western Europe at 23% and North America at 19%. Figures C-4 and C-5 give the overall break up of demand by region for CR in 2000 and 2014 and the regional market share evolution between 2000 and 2014.

Figure C-4: Global CR Demand Break up - 2000 (280 kta)



Source: Jacobs Consulting Ltd.

Figure C-5: Global CR Demand Break up - 2014 (345 kta)



Asia, which was already the biggest market for CR in 2000, consolidated further its position by 2014, but not as much as seen in other rubber and elastomers, and thermoplastics. This has been due to more modest demand for CR in Asia compared to other rubber and elastomeric products, and the maintenance of relatively stable growth rates in the other regions. CR has had a longer time to establish in the developed economies and remains susceptible to substitution, whereas in the emerging economic power houses, it competes head to head with TPEs etc in new and emerging applications and thus there is limited room for substitution. CR is also a highly priced product and can be almost seen as a niche elastomer, and the price sensitive regions in Asia thus are more resistant to CR unless applications absolutely demand the unique mix of CR's properties. The demand in Asia comes in mainly from China as well as India. While China has its own production base, India is totally dependent on imports. The demand in Asia grew from 122 kta in 2000 to about 163 kta in 2014, witnessing a CAGR of 2.2% the span of 14 years. This growth in demand is driven by adhesives as well as the automotive applications. However, it must be noted that in the past few years, demand for CR has been affected mainly due to substitution as well as the market being affected by the economic downturn. North American demand has witnessed little growth in the past 14 years, with demand growing from 63 kta in 2000 to 66 kta in 2014. The demand has been stable, and owing to this, its share in the global demand decreased from 23% in 2000 to 19% in 2014 as Asian demand grew.

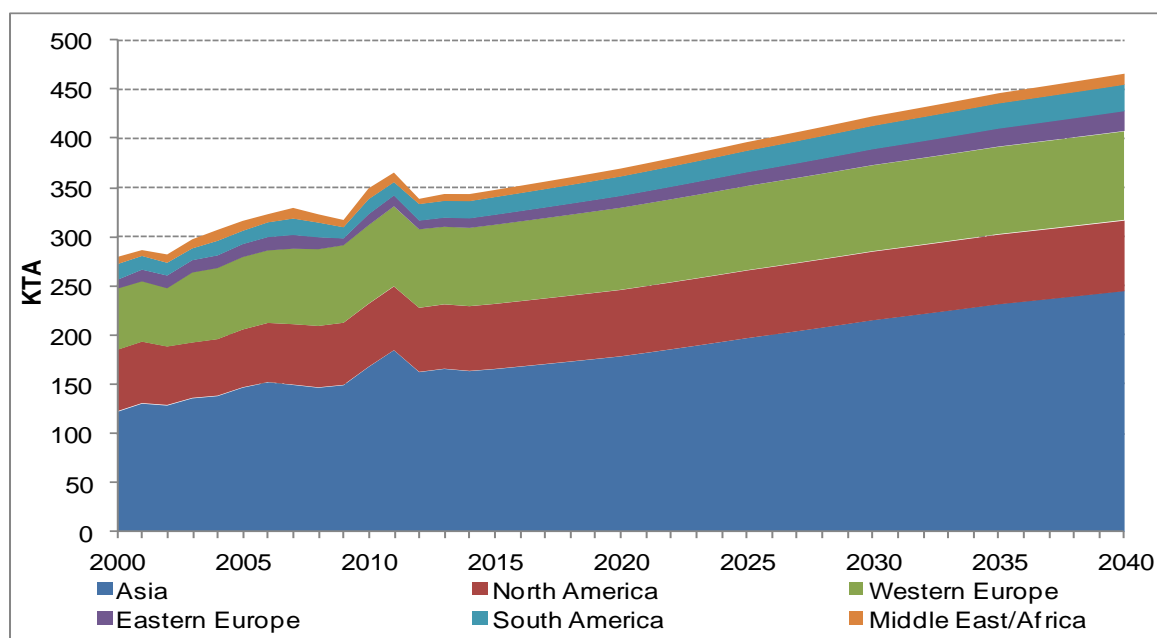
The Western European demand increased from 63 kta in 2000 to about 80 kta in 2014, witnessing a CAGR of 1.6% in the past 14 years. Its share in the global demand has remained at 22-23% over the years. The demand growth has been mainly supported by high growth levels in Germany. The usage in adhesives, as well as industrial rubber products drove the demand for CR to increase in the past 14 years.

Eastern European demand has been low historically, following the dissolution of USSR. The demand in 2000 was estimated to be about 9 kta while increasing to 10 kta in 2014, with a CAGR of 0.4%. Demand peaked at 14 kta in the 2007 before the onset of the economic downturn. The region's share in the global demand has been stable at 3%.

The South American increased from 16 kta in 2000 to about 18 kta in 2014. The South American demand has remained between 12 kta to 18 kta in the past 14 years. The region witnessed a decline in this share in the global demand from 6% in 2000 to about 5% in 2014.

The Middle East/Africa has been the only region (not counting Japan) which has witnessed a contraction in CAGR by 0.3% between 2000 and 2014. The demand peaked at 11 kta in 2007 and 2010. It must be noted that all demand requirements for CR in the Middle East/African region has been met via imports. The Middle Eastern region share in the global demand declined from 3% to 2%. Figure C-6 gives the regional CR growth profiles between 2000 and 2040.

Figure C-6: Regional CR Growth Profile 2000-2040



Source: Jacobs Consulting Ltd.

The following Table C-5 gives the regional demand for CR in kta between 2000 and 2040.

Table C-5: Global Demand by Region, 2000-2040

Region	2000	2005	2010	2014	2020	2025	2030	2035	2040
Asia	122	146	167	163	178	197	215	231	245
North America	63	59	64	66	68	69	70	71	72
Western Europe	63	74	80	80	83	86	87	89	90
Eastern Europe	9	13	11	10	12	14	17	19	21
South America	16	14	16	18	20	22	24	26	27
Middle East/Africa	7	10	11	7	8	9	10	10	11
Total	280	317	350	344	370	397	423	446	466

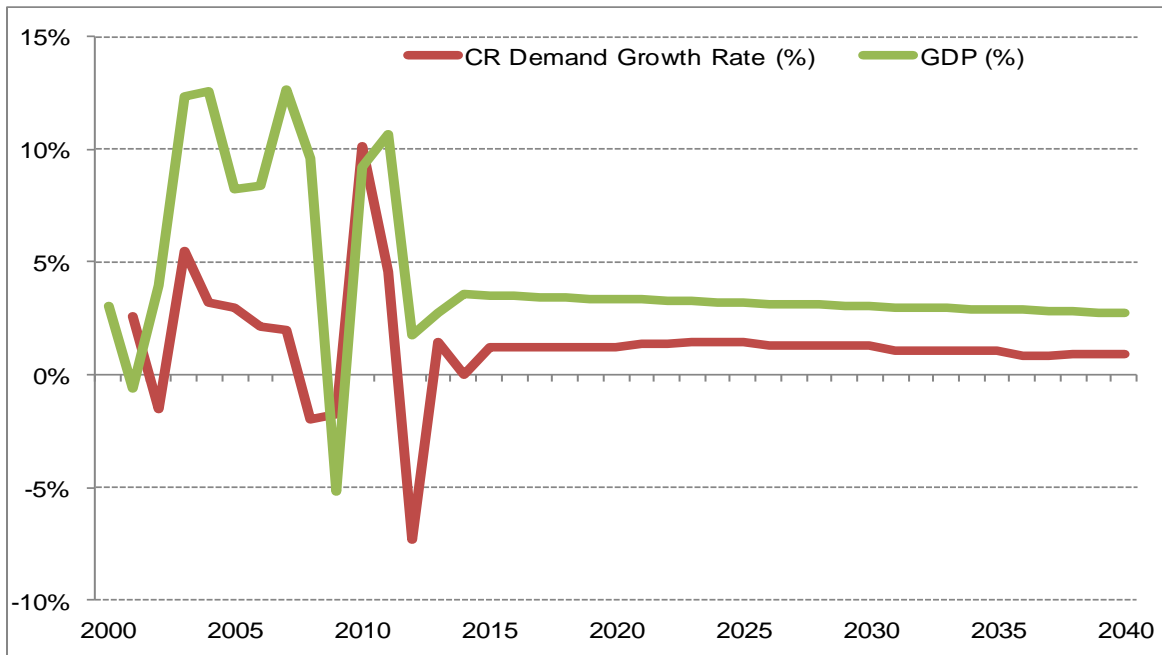
Source: Jacobs Consulting Ltd.

Demand Outlook

The demand elasticity (Demand/GDP Ratio) has been historically at about 0.24 between 2000 and 2014 (taking into account the downturn years of 2001, 2002, 2009 and 2012). The demand drop has been significant in Asia, North America, South America and Middle East/African region. 2010 has been the only year which has witnessed a strong demand/GPD ratio of 1.1. Overall the product has had a low demand elasticity as a result of the economic downturn and substitution by other rubbers in industries like automotive and manufacturing. These industries collapsed as the overall macroeconomic situation was affected, in turn resulting in lower demand for CR. In the short term forecast till 2019, the demand elasticity is anticipated at about 0.35, while in the long term forecast till 2040, it is expected that the demand will grow at about 0.38 times the GDP growth rates.

Figure C-7 gives an overview of the demand outlook for CR versus the global GDP growth.

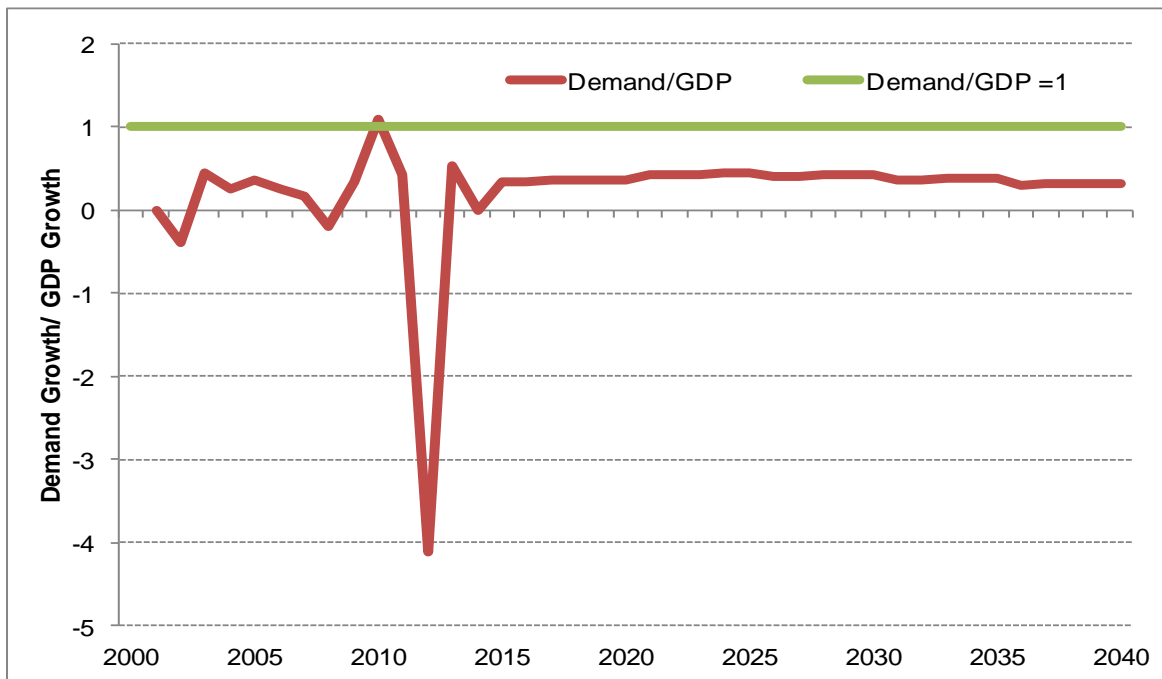
Figure C- 7: Demand Growth versus Global GDP Growth 2000-2040



Source: Jacobs Consulting Ltd.

Figure C-8 highlights the stable trend in the ratio of GDP growth to CR demand growth from 2000 to 2040.

Figure C-8: CR Elasticity Evolution 2000-2040



Source: Jacobs Consulting Ltd.

Between 2000 and 2014, the global demand for CR was about 1.5% taking the economic downturn years into account. During this time the average demand grew at about 0.24 times the GDP. Historically CR has always grown below GDP levels, mainly because its end use industries are not directly linked to the macroeconomic parameters except for automotive. In the forecast, the major

demand for the product is likely to come in from Asia where the demand is likely to grow owing to the higher demand from manufacturing segments. Regions like North America and Western Europe which are already saturated are likely to contribute to a lower extent to the global demand.

The following Table C-6 gives the regional CAGRs of CR till 2040.

Table C-6: Regional CAGR, 2000-2040

Region	2000-2008	2008-2014	2000-2014	2014-2015	2016-2020	2021-2025	2026-2030	2031-2035	2036-2040	2014-2040
Asia	2.3%	1.8%	2.2%	1.2%	1.5%	2.0%	1.8%	1.5%	1.1%	1.6%
North America	0.0%	0.9%	0.3%	0.5%	0.4%	0.4%	0.3%	0.3%	0.2%	0.3%
Western Europe	2.8%	0.3%	1.6%	1.0%	0.7%	0.5%	0.4%	0.3%	0.3%	0.5%
Eastern Europe	4.0%	-3.5%	0.4%	4.5%	3.5%	3.0%	3.0%	2.5%	2.0%	2.9%
South America	-0.8%	2.7%	0.5%	2.5%	2.0%	2.0%	1.8%	1.5%	1.0%	1.7%
Middle East/Africa	1.8%	-2.7%	-0.3%	2.0%	2.0%	1.8%	1.7%	1.5%	1.5%	1.7%
Total	1.8%	1.0%	1.5%	1.2%	1.2%	1.4%	1.3%	1.1%	0.9%	1.2%

Source: Jacobs Consulting Ltd.

In the long term forecast till 2040, CR demand is likely to grow at about 1.2%, with demand volumes increasing from 345 kta in 2014 to about 465 kta in 2040, with average demand additions of 5 kta per annum. North America and Western Europe are likely to grow at very low levels at about 0.3 to 0.5% in the long term forecast till 2040, as demand matures and end use industries like automotive and adhesive manufacture move to cheaper labour zones like Asia. Asia, as well as Middle East/Africa is expected to grow at 1.7% in the long term forecast till 2040, with China leading the growth in the region. In case of Middle East, Government incentives are likely to encourage companies to set shop for downstream derivatives like automotive which will increase the demand for CR in the region.

As the substitution cycle reached and end, possibly by 2020-ish, one can expect a stable growth rate in application areas where CR has unique mix of performance and price balance.

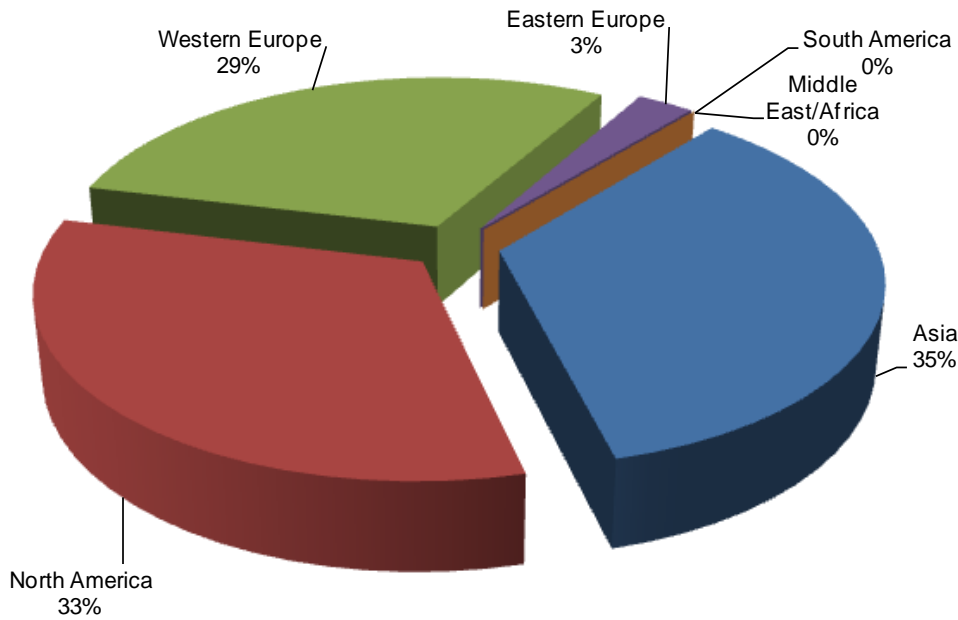
Global Supply

In 2014, the global capacity for CR was estimated to be 400 kta. Between 2000 and 2014, capacity contracted by about 17 kta with the shut-down of major facilities in North America and Western Europe, while some new capacity additions occurred in Asia; either due to expansion of existing Japanese plants or new plants in China.

In 2014, Asia accounted for about 60% of the total installed capacity while Western Europe comprised 21% of the total installed capacities. North America constituted about 19%.

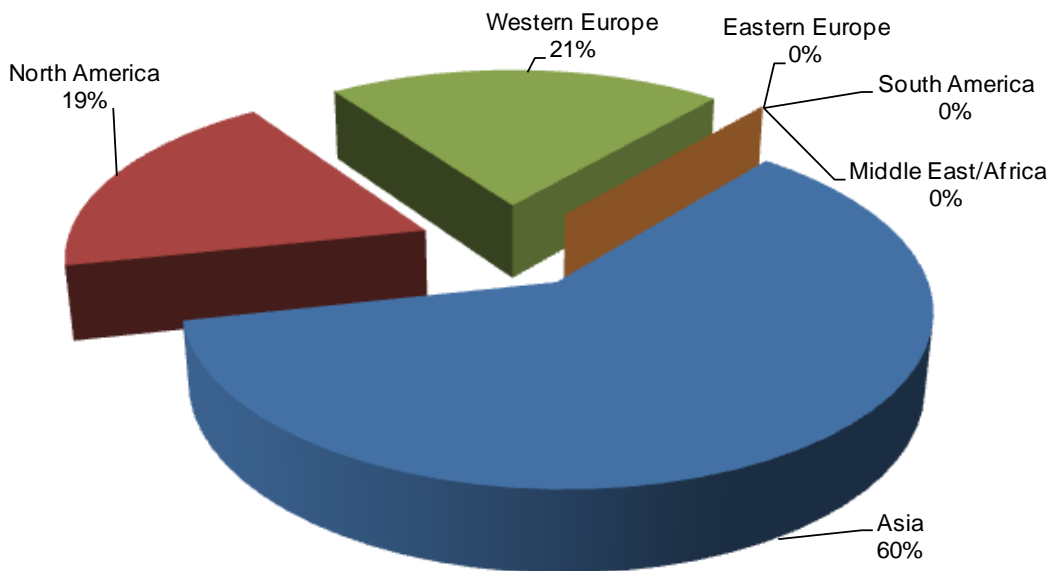
Figures C-9 and C-10 give an overview of the regional split for CR capacity in 2000 and 2014.

Figure C-9: Global CR Capacity, regional split, 2000



Source: Jacobs Consulting Ltd.

Figure C-10: Global CR Capacity, regional split, 2014



Source: Jacobs Consulting Ltd.

Historically since the start of the decade, Asia has been the dominant region for capacities. In 2000, Asia, mostly led by Japan was about 35% of the total installed capacity, with North America and Western Europe at 33% and 29% respectively. However, by 2014, these percentages have changed and now Asia (mainly Japan and China) constitutes about 60% of the market. The share of North America has gone down to 19% due to shutting down of capacities, while Western Europe has gone down to 21% owing to similar reasons.

In Asia, capacities are present mainly in Japan and China. Historically, Japan has been the dominant country for chloroprene production, with three companies catering to large exports. In 2006, Denki Kagaku raised its capacity from 48 kta to 66 kta, further strengthening Japan's position in the CR market, while in 2008; Tosoh Corporation increased its capacity by 2 kta from 32 kta to 34 kta. The subsequent years, saw more capacity additions in Japan, with Denki Kagaku increasing capacity to 70 kta in 2008 and a further to total of 100 kta in 2010 (new line). Since Japan is a net exporter of the product, all capacity additions are mainly aimed at catering to the export markets. Chinese capacities increased from 48kta in 2000 to about 85 kta in 2014, with the new Chinese/Armenian joint venture plant, Shanxi Synthetic Rubber Group starting up its 30 kta plant in mid-2010 at half capacity, but gradually increasing towards its nameplate in the subsequent years.

In North America, there has been only one producer DuPont Dow Elastomers – a joint venture of DuPont and Dow, who shut down its capacity in Kentucky and resulted in consolidation of capacity at its plant in Louisiana. Now the region has a total capacity of approximately 75 kta. This joint venture of DuPont-Dow recently sold the plant to Denka Joint Venture (Denka 70%, Mitsui 30%) with the deal scheduled for completion in 2H2015 as stated in industry news.

In Western Europe, the original Bayer plant was bought over by Lanxess in 2005, and now the plant in Germany has approximately 83 kta of capacity which includes both solid rubber and latex. The only other plant of CR in Western Europe was in France, a 43 kta plant owned by Enichem. However due to poor economic conditions and other issues, the older Enichem plant was closed down in 2005, and now Lanxess is the sole producer of the product in Western Europe. Lanxess have recently completed their proposed expansion works on the solids finishing line, increasing the overall solids rubber output rate to 63 kta. These works however did not affect the overall facility production rate. Trade statistics in Eurostat suggest that Lanxess may have a higher capacity in Germany of nearly 105 kta, but this could not be confirmed from any other additional sources.

In Eastern Europe, Nairit has been the sole producer of the product, with the plant located in Armenia. In the earlier years, the plant was converted into a butadiene based plant from an acetylene based plant, however due to lack of raw material; about 12 kta of the capacity from acetylene route has been retained up to 2010, when all production ceased due to accrued debts. The butadiene based plant stopped production in 1994 due to lack of raw materials and has not been in use since then. Attempts are underway to revamp and restart the plant.

In India, Pidilite Industries Ltd has previously undertaken efforts to relocate the old Enichem plant from France to a site at Dahej, Gujarat, India. However, it appears that efforts to set up production in India have not been successful to date and the project is currently on-hold, with Pidilite looking for a strategic partner willing to bring their technical know-how.

Thus, if the Nairit capacity addition in Eastern Europe should come online, the dynamics of the capacity percentages will change globally, with the Asian share declining to 58%, while the Eastern European share will increase to 7% of the global capacity. North America will further decline to 17% while Western Europe will come down to 18% of the global installed capacities.

In the long term forecast, Middle East Africa as well as South America is also likely to start some production CR to cater to local demand.

The following Table C-7 gives an overview of the total upcoming investments vs the demand outlook between 2014 and 2021.

Table C-7: Total Capacity Additions vs. Demand Outlook, 2014-2021

Polychloroprene Rubber		2013	2014	2015	2016	2017	2018	2019	2020	2021
Total Global Capacity	ktons	402	400	405	405	405	405	405	405	405
Total Global Demand	ktons	344	344	348	352	357	361	365	370	375
Global Operating Rate	%	83%	82%	86%	87%	88%	88%	88%	87%	87%
Net Capacity Additions	ktons		-2	5	0	0	0	0	0	0
Global Demand Growth (%)	%	1.5%	0.0%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.4%
Capacity Addition a percentage of Annual Demand	%	0%	-1%	1%	0%	0%	0%	0%	0%	0%

Source: Jacobs Consulting Ltd.

While there is no direct relation between the capacity additions and the demand, it must be noted that the CR market is currently over supplied.

Chloroprene Rubber Trade Balance

In 2014, the net trade position was approximately 35,000 tons of CR – with Eastern Europe, South America, Middle East and Africa as a group having this net import position, and Asia, North America and Western Europe having the corresponding net export position. This quantity is equivalent to nearly 10% of the total production in 2014. Since the production is clustered only in certain countries, there significant trade of the production throughout the globe between the major regional geographies. Japan continues to dominate the global market as net exporter, while the Rest of Asia (excluding China and Japan) is on balance the largest importer¹⁰.

In 2014, nearly 35,000 tons of CR got traded in between regions, which is equivalent to nearly 10% of the total production in 2014. Since the production is clustered only in certain countries, there is ample trade of the production throughout the globe. Japan continues to dominate the global market as net exporter, while Rest of Asia is a dominant net importer.

The trade for non-latex CR was almost three times of latex CR. In 2013, almost 170 kta of non-latex CR got imported as compared to 56 kta of latex CR, as per UN statistics. On a regional basis, Asia was the largest importer of non-latex CR with nearly 83 kta imported in 2013. Asia was also one of the largest exporters of non-latex CR, exporting about 105 kta in 2013, with Japan accounting over 96 kta out of the 105 kta. In case of latex CR, China has been the largest importer of the product in 2013, while Germany has been the largest exporter of the product.

The Asian region is more or less a balanced market and will convert to a minor exporter in the forecast years; Japan expected to satisfy the demand of China and Rest of Asia. The North American market has been a net exporter of the product till 2007, but turned into a small importer after the closure of capacities. Similarly the Western European region has been a net exporter as demand lowered within the region. Middle East/Africa and South America have no capacities currently and hence are net importer of the product. In case of Eastern Europe, due to sporadic production, the region has been a net importer of the product historically.

In the future, Asia and North America are expected to be more or less balanced markets, while Western Europe is expected to convert to a minor net importer, albeit in small volumes, as no new capacity is expected in the region. South America as well as Middle East/ Africa are likely to remain net importers of the product, those the volumes are expected to decline once few new capacities come up in the region. Eastern Europe will convert to net exporter if the Nairit plant comes on-stream. However, if the Nairit plant does not come online, the region is likely to remain a net importer of the product, though volumes will be low.

As per the latest reports, China has decided to continue to impose anti-dumping duty on imports of CR from European Union, North America and Japan. China had previously imposed antidumping duties

¹⁰ Please note that due to inconsistencies in the trade information databases, the statistics do not always balance out the net exports versus the net imports as a zero sum game at a global level

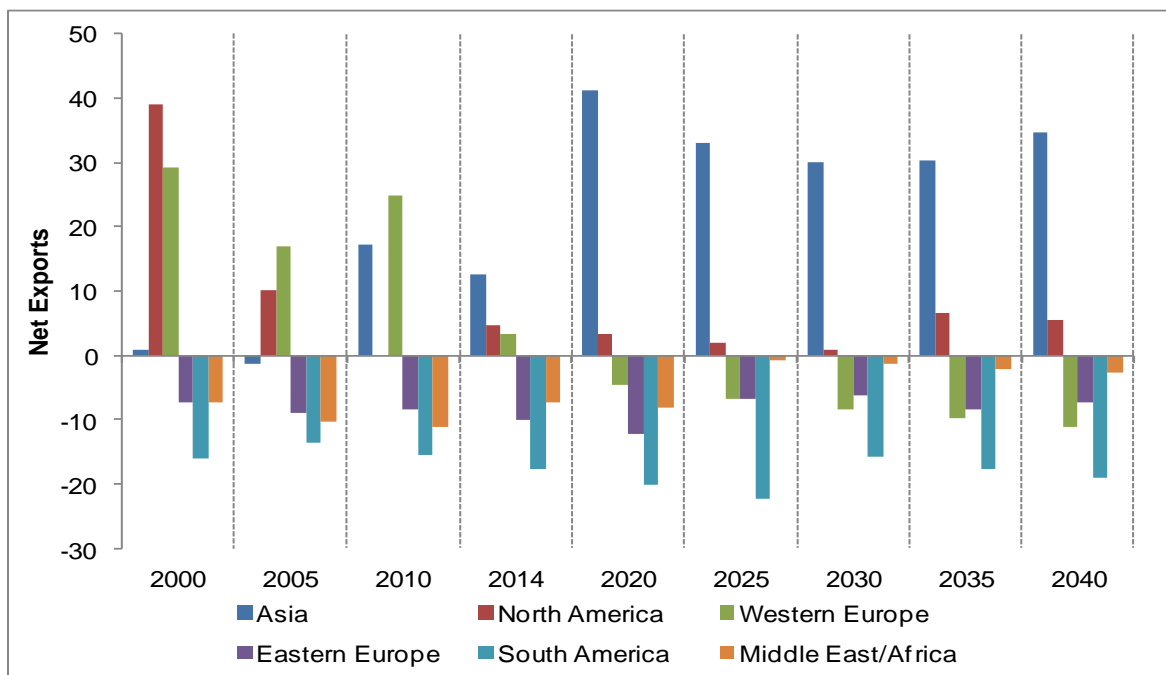
of 2-151% on chloroprene rubber imported from Japan, the US and the European Union for 5 years from May 2005. A fresh probe in May 2010 was undertaken and in May 2011 the duties have been imposed for another five years.

In August 2010, US announced that it is removing a 36 year anti-dumping duty on imports of CR from Japan. In August 2013, Showa Denka expanded its operations in the US, setting up a storage and distribution facility for CR latex and solids in the country.

Any future CR rubber capacity additions will most likely be directly related to both the availability of low cost butadiene, as well as cheap electric power. As butadiene demand in recent years has led to large price differential between butadiene and butanes, efforts are under way to develop alternative and on-purpose processes for butadiene, with the dehydrogenation of butane-1 (BDH process) being at the forefront. The capacity will be added in countries with “wet” gas (including shale gas) and LPG. Thus the Middle East, Eastern Europe, and North America can be expected to add capacity while South America and Asia will continue to dominate the imports picture in the long term.

Figure C-11 provides the overall global trade balance scenario for CR.

Figure C-11: CR Global Trade Balance



Source: Jacobs Consulting Ltd.

Table C-8 below shows the swing in the trade balance.

Table C-8: CR Global Trade Balance

Trade Status	2014 Net Exports		2020 Net Exports	
	Region	Volume (KT)	Region	Volume (KT)
Net Exporters	Asia	13	Asia	41
	Western Europe	3	North America	3
	North America	5	Western Europe (importer)	-5
Net Importers	Eastern Europe	-10	Eastern Europe	-12
	South America	-18	South America	-20
	Middle East/Africa	-7	Middle East/Africa	-8

Source: Jacobs Consulting Ltd.

Industry Structure

Currently, there are a total of 9 companies supplying the CR market. Key producers have their plants in Japan, Western Europe, China and North America, exclusive of additional speculative capacity in Armenia or India.

Most producers use the butadiene route for manufacture of CR which is the dominant production process. The key producers include DENKA (Denki Kagaku Kogyo K.K.), Lanxess (earlier Bayer), Shanxi Synthetic Rubber Group, Tosoh, Showa Denko, Chongqing Changshou Chemical Company. Both Mitsui and Armenia governments are minority stakeholders in USA and Chinese plants respectively.

Table C-9 gives a listing of various industry structure metrics for the CR industry

Table C- 9: Global CR Industry Structure Metrics, 2014

Global Production Capacity	400 KTA
Global Number of Producers	9
Concentration Ratio (C5)	83%
Market share of largest producer	38%
Herfindahl Index	0.219

Source: Jacobs Consulting Ltd.

The total global production capacity of CR was 400 kta in 2014.

The concentration ratio is the proportion of the total industry production capacity owned by the five largest firms. It is therefore a straightforward measurement of the degree of consolidation. A concentration ratio of 83% is indicative of a high concentration market with reasonably high degree of competition.

The Herfindahl Index (HI) is a measure of the degree of consolidation and the amount of competition in an industry. It is equal to the sum of the squares of the market shares of each firm. The HI can range from 0 to 1 moving from a large number amount of small firms to a single monopolistic producer. HI values between 0.100 and 0.180 are generally considered to indicate a 'moderately concentrated' market and above 0.180 to be a 'concentrated' market. The benefit of the HI over the concentration ratio is that it gives more weight to larger firms.

The Herfindahl Index (HI) index for the CR industry is 0.219 indicating that the degree of concentration in the market is high. This is not an indication of a commodity product and there are changes of control over the price. There have been cases of cartel formation by some companies including Bayer (now the plant is a part of Lanxess), Showa Denko, DuPont/Dow, ENI and Tosoh. Between 1993 and 2002, these companies shared the market and fixed prices for chloroprene rubber globally as per Department of Justice, Canadian Competition Bureau and European Commission reports.

Table C-10 gives the market shares of the producers in the CR industry globally for 2014. The capacities stated include the individual capacities of the producer as well as any capacity which they have in joint venture with other companies or with subsidiaries.

Table C- 10: CR Production Capacity by Company, 2014

Company	Total Capacity 2014 (KTA)	% Market Share
Denki Kagaku Kogyo K.K.(Denka)	152.5	38%
Lanxess	83	21%
Shanxi Synthetic Rubber Group Co Ltd	40	10%
Tosoh Corporation	34	9%
Chongqing Changshou Chemical Co., Ltd.	30	8%
Mitsui	22.5	6%
Showa Denko	23	6%
China Others ¹	5	1%
Armenian Gov. / Nairit	10	3%
Total	400	

Note 1: We have left an allowance for 5 kta of additional “other” Chinese producers to cover for the eventuality that either the old Chinese Qingdao or Shandong Laizhou plants is still able to operate.

As shown in Table C-6, two producers have above 20% market share in the industry. Denki Kagaku in Japan has the largest market share in the industry, followed by Lanxess in Western Europe. Other producers control 10% or less.

Note on Dormagen (LANXESS) and LaPlace (Denka/Mitsui) plants

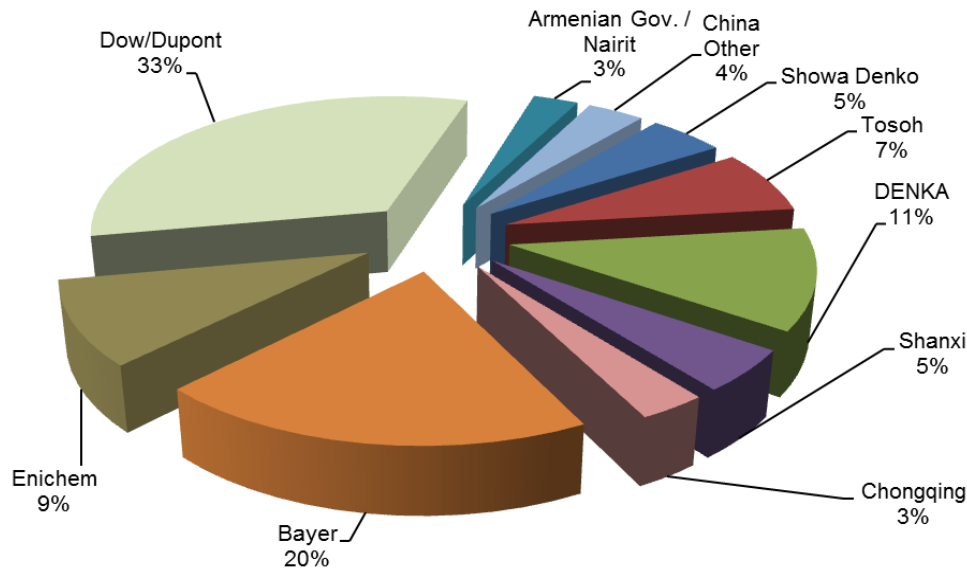
As part of Lanxess spin-off from Bayer, Lanxess inherited CR business in 2005, and the CR production facility then had a capacity of 83 kta. Soon after that it was announced that the capacity had been upgraded to 80kta. However in 2008, news reports indicated that the plant only had a capacity of 57 kta and that Lanxess was planning to upgrade the capacity to 65 kta. At the same time Lanxess announced that it was seeking and environmental permit for up to 105 kta. All the import/export data bases indicate that the production capacity in Germany has to be in the region of at least 100 kta to be able to run at full capacity and a little above that to be able to match the trade numbers. These trade numbers are consistent across all databases and normally extremely reliable. However, we have not been able to confirm the capacity of Lanxess and hence it has been considered at 83 kta in our model.

DuPont and Dow Chemical formed the Dow-DuPont Elastomers JV in the early 1990s capitalizing on the metallocene olefins elastomers boom. This JV was broken up in 2005, and the CR plants reverted back to DuPont. At that time DuPont had a total capacity of 100 kta with two plants – Louisville, KY and La Place, LA with capacities of 55 and 45 kta respectively. Crucially, the monomer production facility is located at La Place, LA. In 2005, DuPont tried to obtain approvals to move the LaPlace plant to Louisville but encountered major environmentalists pressure and was not allowed to do so. It thus

shut down the Louisville plant in 2006. There has been limited mention made that some of the polymerisation and final finishing lines were moved from Louisville to La Place. All indications are that the resulting capacity at the La Place plant was expanded to 75kta, and this is the capacity that matches the trade information. Recent industry reports indicate that DuPont has signed an agreement to sell its Neoprene business to Denka JV (Denka 70%, Mitsui 30%) and the deal is scheduled to be completed in H2 2015.

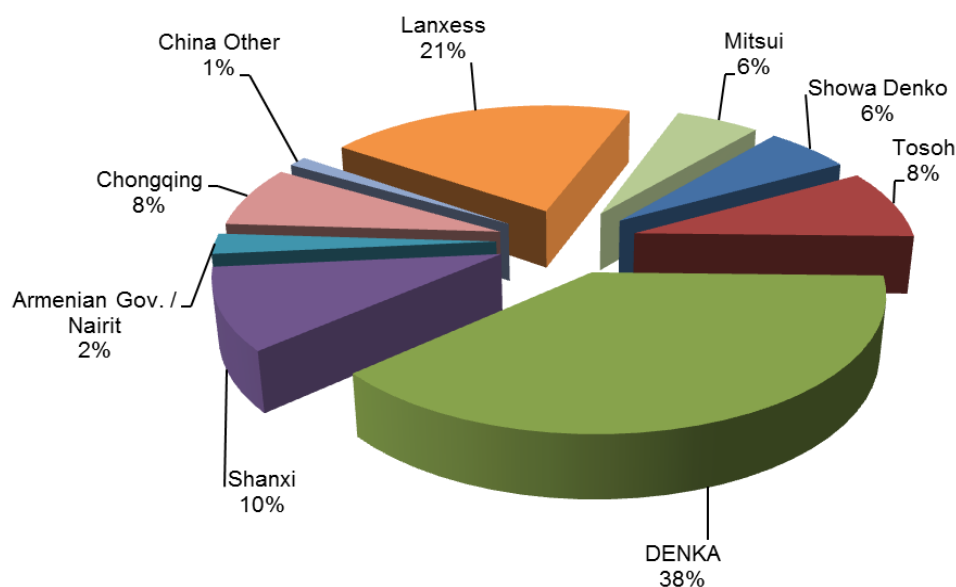
Figure C-12 and Figure C-13 below give the comparison between the capacities of the key producers in 2000 and 2014.

Figure C-12: Global CR capacity, key producers 2000 (417 kta)



Source: Jacobs Consulting Ltd.

Figure C-13: Global CR capacity, key producers 2014 (400 kta)



Source: Jacobs Consulting Ltd.

The global share for CR has seen changes in the past 14 years. New producers have entered the market, and some producers have shut shop due to poor market conditions. Bayer now bought over by Lanxess continues to dominate the global capacity in both the years, maintaining its share at 21% and now is the second largest producer of CR globally. In case of DuPont/Dow, its market share has dropped from 34% in 2000 to 19% in 2014, as it closed one of its plants in the USA and the other plant went to DuPont as the JV dissolved. Following the sale of LaPlace plant, DuPont will exit the business completely. Conversely, Denki Kagaku has increased its share from 12% in 2000 to about 25% in 2014, making it the largest producer of CR, mainly due to capacity expansion in Japan. Once, the sale of LaPlace is finalised, Denki Kagaku will further increase its market leader position.

Supply/Demand Balance

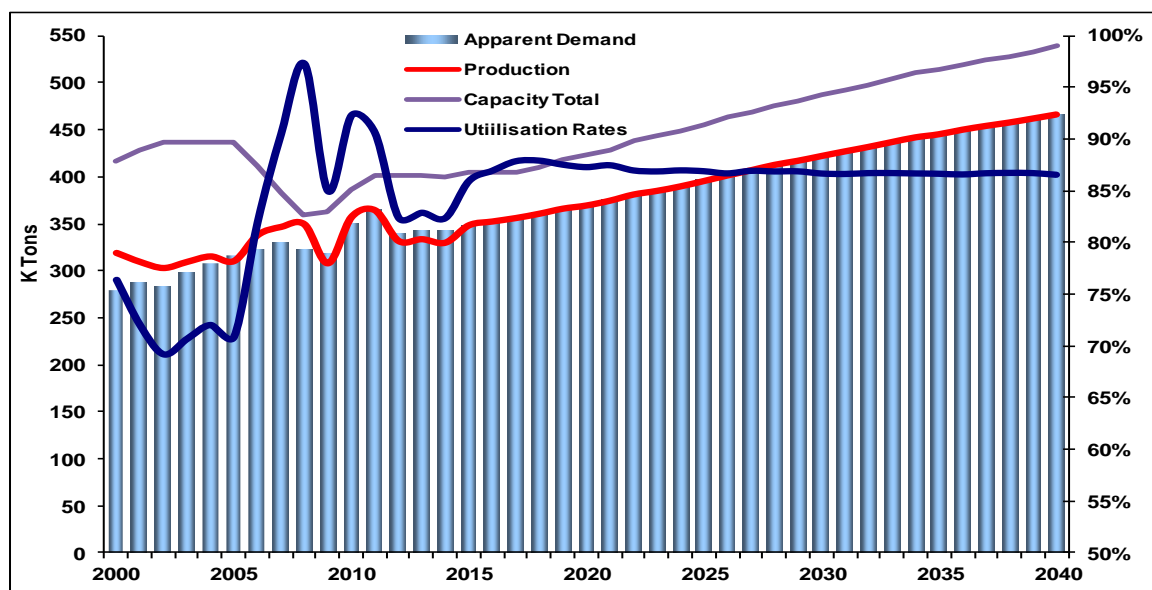
Global Scenario

The global demand for CR was estimated to be about 344 kta in 2014, growing at a CAGR of 1.5% from a total demand of 280 kta in 2000. In the past 14 years, the demand witnessed an average growth of 5 kta per annum; however saw the demand contract in the recession years of 2008, 2009 and 2012. Between 2014 and 2019, the demand is likely to grow at a CAGR of 1.0% as demand stagnates in developed economies and grows at slightly levels in Asia. In the long term forecast, the demand is likely to grow at about 0.38 times the GDP levels, at a CAGR of 1.2% between 2014 and 2040.

The utilisation rates for CR have been fluctuating between 78% and 97% in the past 14 years; averaging to about 81%. The utilisation rates averaged 72% between 2000 and 2005, but the rates have since moved up reaching up to nearly 82% in 2006, as demand grew and capacities shut down. The utilisation rates peaked at 97% in 2008. However, due to the economic downturn, the rates declined again, to 85% in 2009. After that they have shown some recovery and global utilisation rates were 92% in 2010 and 91% in 2011. In 2012, as demand contracted by 7.3%, the utilisation rates lowered to 82% and have remained so in 2014. In the long term future till 2040, the utilisation rates are likely to be in the higher-80s.

Figure C-14 gives the global overview of capacity, demand and utilisation rates for CR from 2000 to 2040.

Figure C-14: CR capacity, demand, utilisation rates 2000-2040



Source: Jacobs Consulting Ltd.

North America

North American demand for CR was estimated to be about 66 kta, showing a small growth of 0.5% over the previous year. The market has grown by a CAGR of 0.3% in the past 14 years, from 63 kta in 2000, to the current level. Demand for the product is likely to come in from segments like automotive parts and construction. Though the market has been affected in the near past, this demand is likely to come up in the short term and midterm forecast marginally. Between 2014 and 2019, the demand is likely to grow at about 0.4% to as the product faces competition from substitute materials. In the long term forecast till 2040, the demand is expected to increase by a CAGR of 0.3%, as the market matures even further.

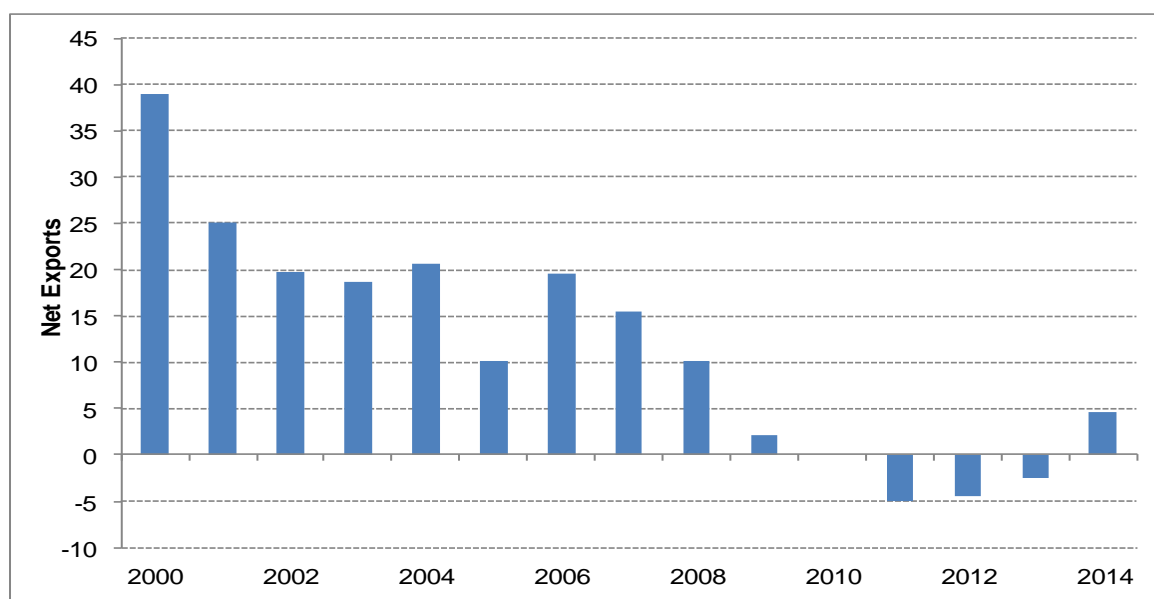
There has been only one producer of CR in the region, a joint venture of Dow and DuPont. Earlier there were two locations within the US producing CR, however the joint venture of Dow/DuPont, shut down its capacity in Kentucky and moved some of its capacity to its plant at Louisiana. The plant has now been bought over by Denka/Mitsui JV with final agreements expected to be signed in H2 2015. There are no capacity additions announced in the near future till 2019, and there may be some speculative capacity additions expected towards the end of the forecast period till 2040.

The utilisation rates for CR in North America have been fluctuating to 97% to as low as 69% depending on the local demand and export requirements. In the past few years, the utilisation rates have averaged towards mid to higher 80s. In 2009, the utilisation rate was about 88%, while in 2010; it lowered to 86%. Similarly in 2011, the rates went down even further to about 80% despite no capacity additions mainly due to decline of local demand as well as export demand as well as issues related to non-availability of raw material. In 2014, the operating rates returned to 95% and in the long term forecast are expected to remain in the mid-90s till 2040.

The region has been a net exporter of CR historically but in 2011, converted into net importer. In 2014, the region went back to being a net exporter of the product. Germany is the key import country for trade with the US. In the long term forecast, the region is likely to be more or less balanced in its requirements of CR, with very few marginal exports expected in the long term forecast.

Figure C-15 indicates that North America has been a net exporter of CR since 2000 to 2010 and turned into an importer in 2011, and continued this status for the subsequent two years.

Figure C-15: North America CR Net Exports, 2000-2014

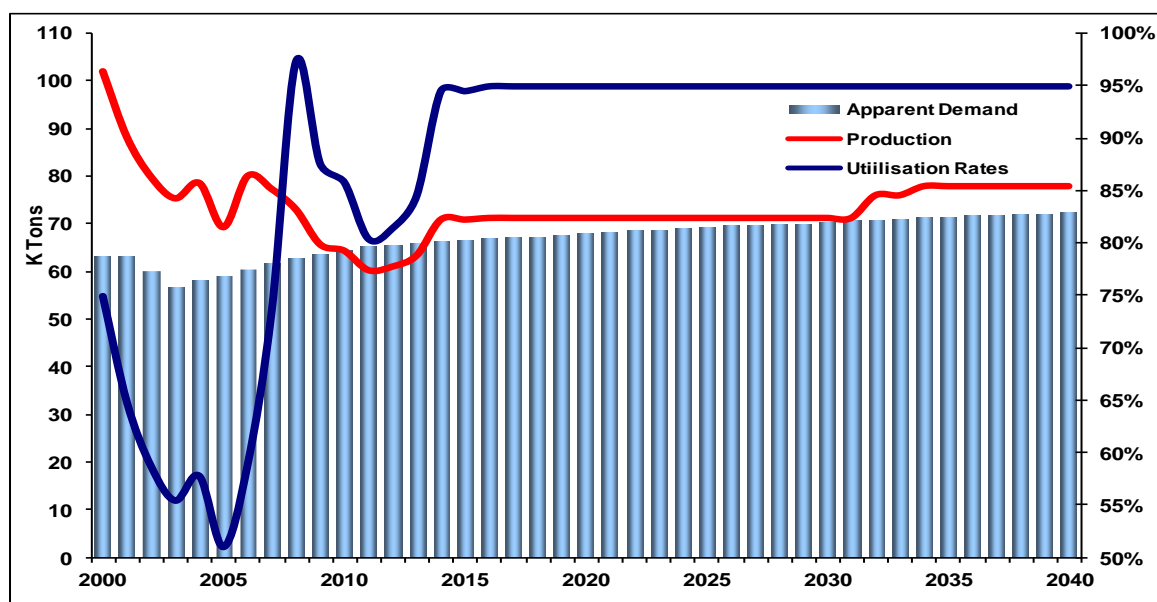


Source: Jacobs Consulting Ltd.

The exports from North America have declined through the years, mainly because of capacity shut down. In 2000, the exports were about 39 kta, which declined to about 10 kta in 2005, before increasing in 2006, and then again declining in 2007. In 2011, the region converted to a net importer, as utilisation rates went down. The region will be more or less balanced in its requirements of CR, converting to net exporter again when the speculative capacities come on-stream towards the end of the forecast period.

Figure C-16 gives the overall demand, capacity and utilisation rates for CR in North America from 2000 to 2040.

Figure C- 16: North America CR Supply-Demand-Operating Rate 2000-2040



Source: Jacobs Consulting Ltd.

Table C- 11: Actual Demand of CR in North America, 2000-2040

	CR Demand (kta)									Growth Rates	
	2000	2005	2010	2014	2020	2025	2030	2035	2040	2000-2014	2014-2040
North America	63	59	64	66	68	69	70	71	72	0.3%	0.3%

Source: Jacobs Consulting Ltd.

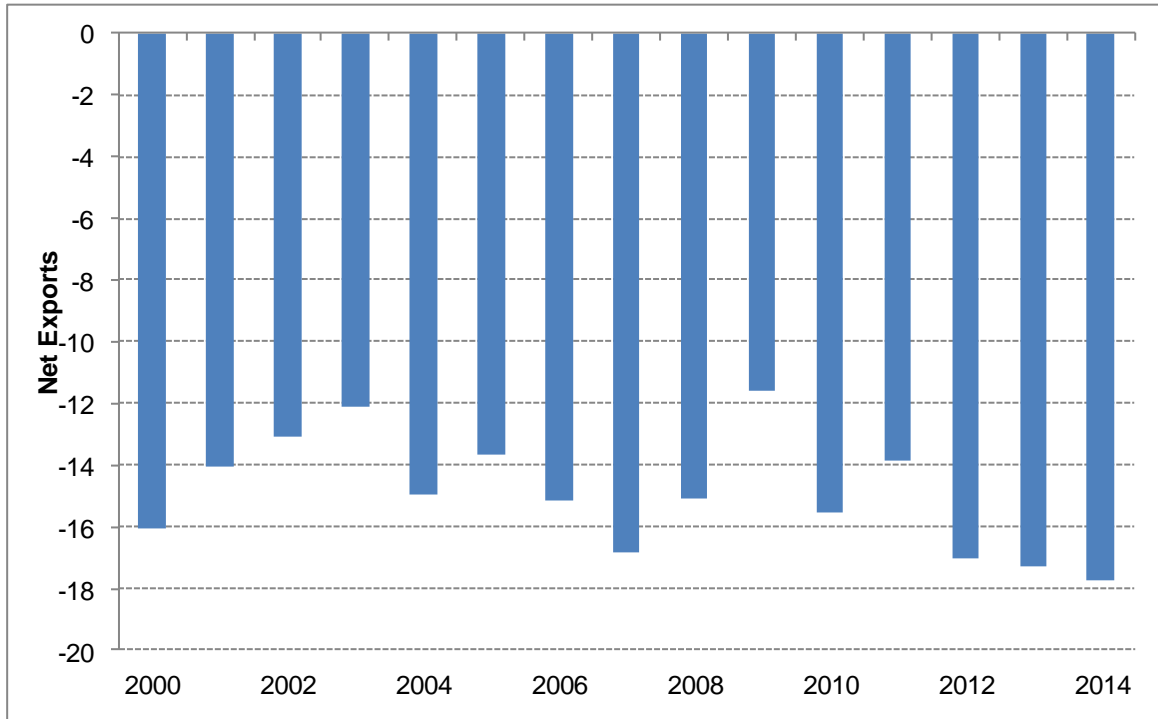
South America

The total demand for CR in South America in 2014 was estimated to be 18 kta. The demand improved by 2.5% over the previous year demand, which was about 17 kta. Historically the demand for CR in South America has fluctuated between 12 kta to 17 kta, with demand peaking in 2014. The region has been affected by the economic downturn in 2008 and 2009 with demand contracting in the two years. The region posted a CAGR of 0.5% between 2000 and 2014; however, it should be noted that the demand is a fluctuating one dependent on imports. In the short term forecast between 2014 and 2019, the demand for CR is estimated to rise at about 2.1% mainly due to demand from the automotive and construction segments. Even in the long term forecasts till 2040, demand is likely to be positive and increase at a CAGR of 1.7% between 2014 and 2040.

There are no capacities for CR in the region currently and no announcements are anticipated in the near future till 2019. Even in the long term forecast, capacities are likely to come up only post 2028, as the region continues to rely on imports owing to its small demand base. Future utilisation rates are likely to be in the lower to mid-80s.

The following chart Figure C-17 gives an overview of the net exports of South America from 2000 to 2014 which shows that the region has always been a major importer of the product.

Figure C-17: South America, Net Exports, 2000-2014

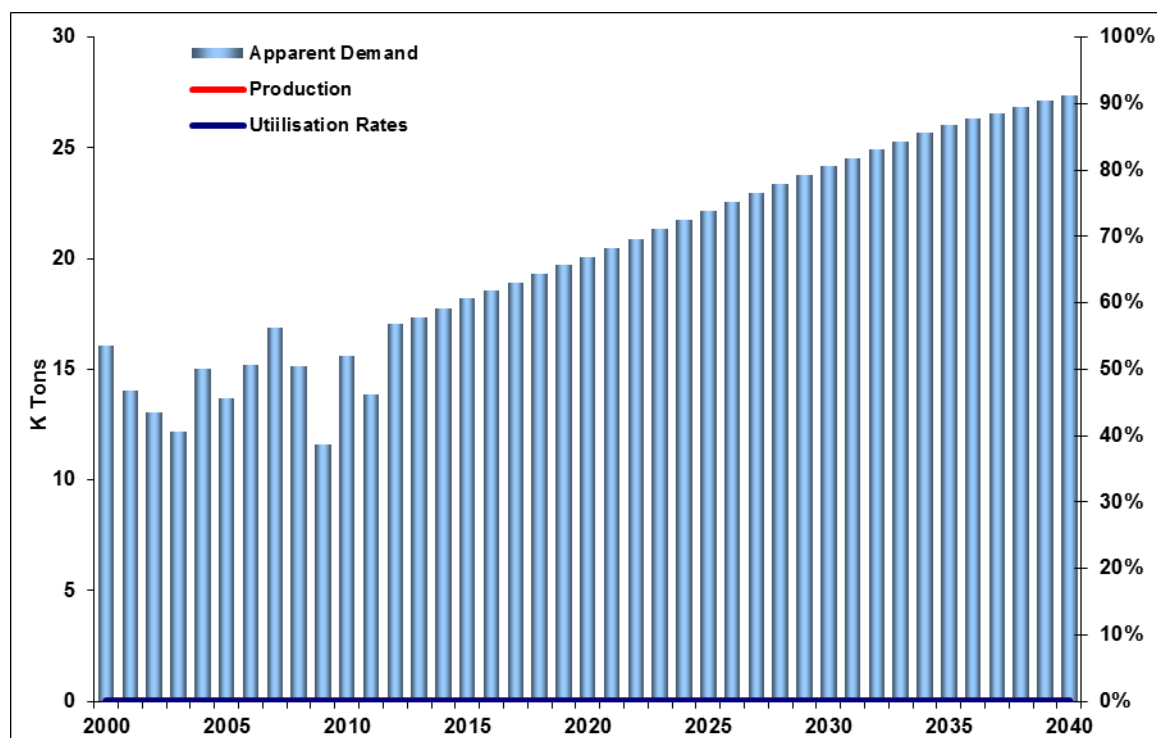


Source: Jacobs Consulting Ltd.

In line with the demand fluctuations the region’s import demands have fluctuated, peaking at 17 kta in 2007 before dropping in 2008. This trend is likely to continue and the region is expected to CR in the long term forecast mainly because of lack of any new capacities in the region.

Figure C-18 gives the overall demand, capacity and utilisation rates for the CR in South America from 2000 to 2040.

Figure C-18: South America CR Supply-Demand-Operating Rate 2000-2040



Source: Jacobs Consulting Ltd.

Table C- 12: Actual Demand of CR in South America, 2000-2040

	Chloroprene Rubber Demand (kta)									Growth Rates	
	2000	2005	2010	2014	2020	2025	2030	2035	2040	2000-2014	2014-2040
South America	16	14	16	18	20	22	24	26	27	0.5%	1.7%

Source: Jacobs Consulting Ltd.

Western Europe

In 2014, the Western European demand was estimated to be about 80 kta, higher than the previous year by about 1.0%. The demand has grown from 63 kta in 2000 to the current levels witnessing a CAGR of 1.6% in a span of 14 years. The economic downturn did not have a very profound effect on the growth rates of Western Europe and the demand has been consistently increasing. However, the demand contracted in 2012 and 2013 by 1.6% and 1.3% respectively. In the short term forecast, the demand is likely to grow at a slightly lower level, mainly as end user industries move out of the region to low cost locations. Between 2014 and 2019, the demand for CR in the region is anticipated to increase at a CAGR of 0.8% while in the long term forecast from 2014 to 2040; the regional demand is estimated to grow at a CAGR of 0.5%, as the market matures.

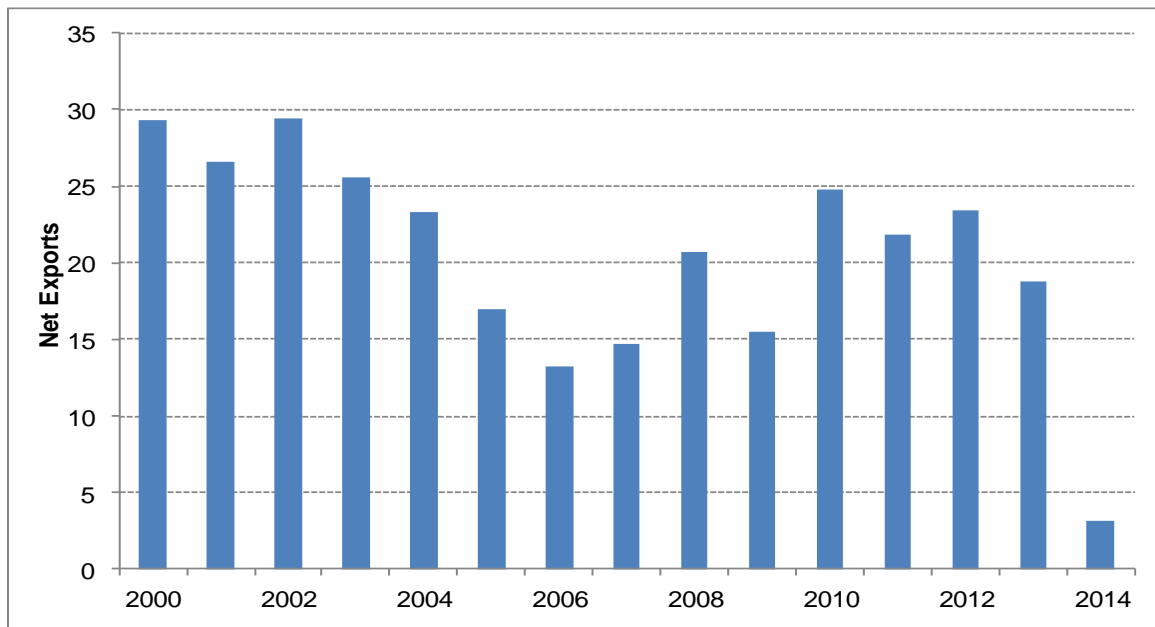
Between 2000 and 2005, there have been only two producers of CR in the region. Bayer sold off its CR business to Lanxess in 2005, and ENI closed its 45 kta capacity in France. However, Lanxess has also added capacities over the past few years, and now the overall capacity of CR in the region is estimated to be about 83 kta including both solid and latex CR. Trade statistics indicate that Lanxess may have a higher capacity up to nearly 100 kta, but this could not be confirmed. In the near forecast, no capacity additions have been announced. The region will be a small importer of the product and no speculative capacity is likely to come up by 2040 as per our estimates.

The region has had one of the highest utilisation rates globally, with rates averaging about 99% in the past 14 years between 2000 and 2014. Our model depicts utilisation rates above 100% in certain years based on demand and trade statistics giving an indication that Lanxess capacity may be under reported. The rates are likely to be around the mid-90s in the long term forecast till 2040.

Western Europe, specifically Germany, has strengthened its position as a net exporter of CR globally. However, as the domestic demand increased by 1.6% in the past 14 years, net exports have fluctuated between 17 kta to 30 kta. These exports are likely to decline as demand increases modestly in the region and more importantly, no new capacities additions are expected. In the long term forecast, the region is likely to be a marginal importer, importing 9 to 10 kta volumes.

The following chart Figure C-19 gives an overview of the net exports of Western Europe from 2000 to 2014 which shows that the region has always been a major exporter of the product.

Figure C-19: Western Europe, Net Exports, 2000-2014

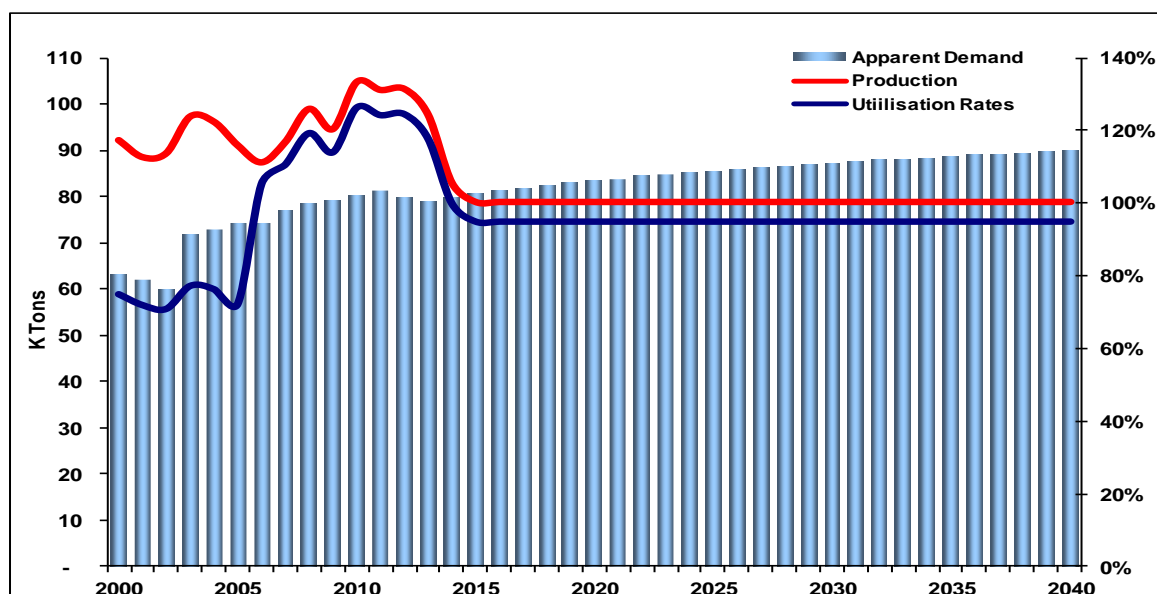


Source: Jacobs Consulting Ltd.

The region has been consistently exporting CR since 2000. In 2006, the exports declined marginally owing to shut down of the ENI plant, but increased again in 2007.

Figure C-20 gives the overall demand, capacity and utilisation rates for the CR in Western Europe from 2000 to 2040.

Figure C-20: Western Europe CR Supply-Demand-Operating Rate 2000-2040



Source: Jacobs Consulting Ltd.

Table C- 13: Actual Demand of CR in Western Europe, 2000-2040

	CR Demand (kta)									Growth Rates	
	2000	2005	2010	2014	2020	2025	2030	2035	2040	2000-2014	2014-2040
Western Europe	63	74	80	80	83	86	87	89	90	1.6%	0.5%

Source: Jacobs Consulting Ltd.

Central and Eastern Europe (C&E Europe)

In 2014, the C&E European market demand was estimated to be 10 kta, growing at a CAGR of 0.4% between 2000 and 2014. Before the economic downturn the region grew at over 7.2% between 2000 and 2007, however, the demand declined in 2008, by -12.8% and again in 2009, by over -40% to 7 kta. In 2010, the market recovered but again declined in 2011 and 2012. The market improved in 2013 and 2014 to reach the current levels of demand. Post 2011, all demand in the market has been met via imports as the sole producer in the region, Nairit, has not been able to produce any CR. In the short term forecast between 2014 and 2019, we estimate that, the region’s demand is likely to grow at a CAGR of 3.7% supported by the strong demand from the automotive and adhesives market, while in the long term forecast till 2040, the regional demand is estimated to grow by a CAGR of 2.9% till 2040.

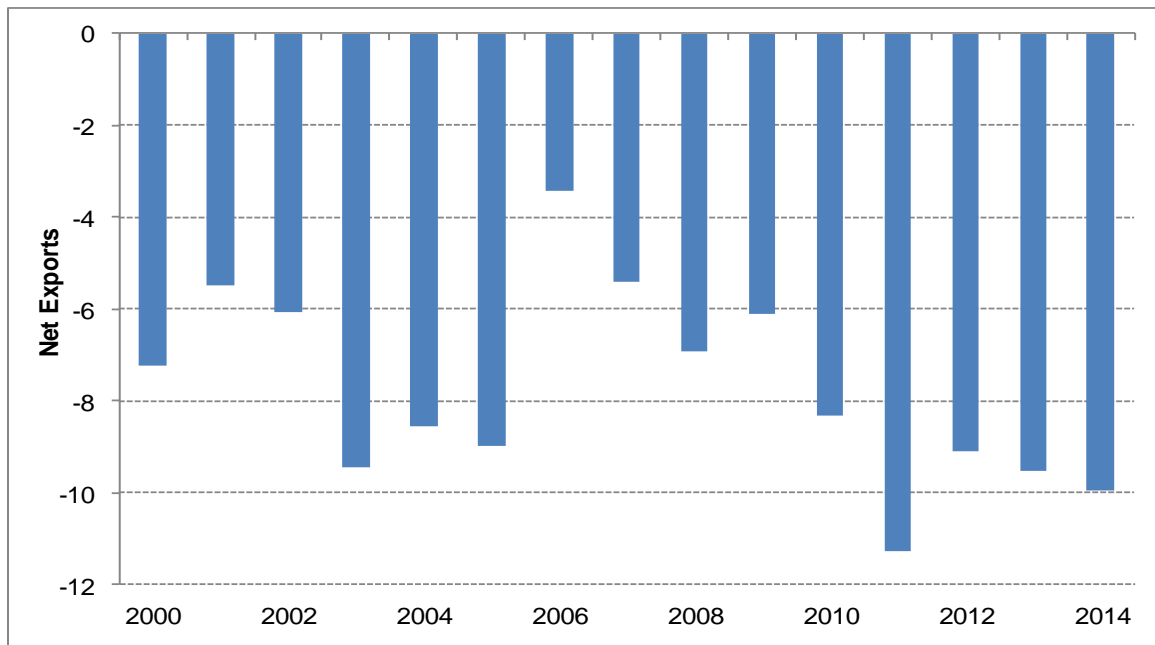
Nairit was the only plant in the entire C&E European region for CR. The plant had a capacity of 12 kta from the acetylene route up to 2010 and this has been the case since 1991. The plant has produced CR sporadically depending on the availability of the raw material, mechanical reliability of the plant and the demand in the region. At present, the plant is shut down and additional investment is required before production may be resumed. Thus, all of the region’s demand is catered via imports. Nairit is looking to expand the plant, where both acetylene and butadiene routes are being considered. In the case of the former option, the plant capacity would be increased in stages, first to 12 kta and then 24 kta. The butadiene option focusses on a 25 kta capacity addition. Either way, this project is some way

off from being realised and at best can be described as speculative capacity. . Apart from this no other capacity is expected to come up in the region in the mid-term forecast.

C&E Europe has historically been a net importer of CR since the dissolution of USSR, and is only likely to convert to a net exporter, albeit in small volumes, if the expansion of the Nairit plant were to take place.

The following chart Figure C-21 gives an overview of the net imports of C&E Europe from 2000 to 2014 which shows that the region has always been a major importer of the product.

Figure C-21: C&E Europe, Net Exports, 2000-2014

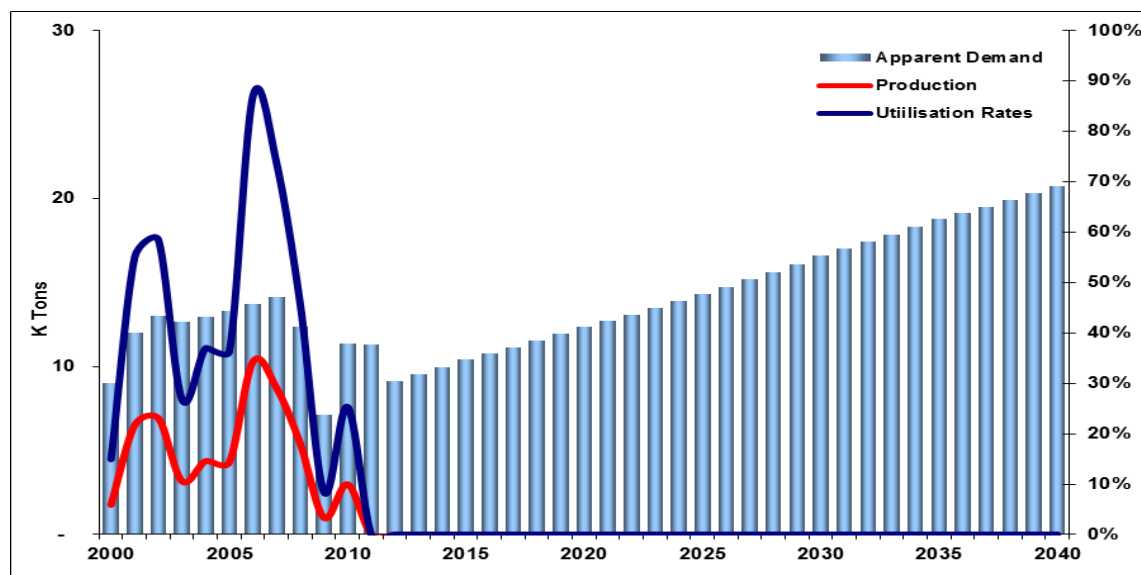


Source: Jacobs Consulting Ltd.

The region has maintained its position as a net importer, with imports increasing from 7 kta in 2000 to over 10 kta in 2014. In the forecasted years, the region is likely to convert into net exporter once the 30 kta plant comes on-stream in 2019. However, if the plant will not come on-stream by the expected date of 2019, then the region is likely to remain a net importer of the product in small volumes of 6-7 kta.

Figure C-22 gives the overall demand, capacity and utilisation rates for CR in C&E Europe from 2000 to 2040.

Figure C-22: C&E Europe CR Supply-Demand-Operating Rate 2000-2040



Source: Jacobs Consulting Ltd.

Table C- 14: Actual Demand of CR in C&E Europe, 2000-2040

	Chloroprene Rubber Demand (kta)									Growth Rates	
	2000	2005	2010	2014	2020	2025	2030	2035	2040	2000-2014	2014-2040
C&E Europe	9	13	11	10	12	14	17	18	21	0.4%	2.9%

Source: Jacobs Consulting Ltd.

The revival of the Nairit plant will be a catalyst for modest demand improvement in C&E Europe.

Asia

Asia has been the key region for both production and demand for CR. The Asian demand was estimated to be 163 kta in 2014, with China driving the demand growth. The Asian demand has grown by a CAGR of 2.2% in the past 14 years, from levels of 122 kta in 2000. The region witnessed a decline in demand during the economic downturn years, with demand falling by -1.9% in 2008. In 2009, the demand recovered by a small value of 1.7%, and more strongly at 12.5% and 10.1% respectively in 2010 and 2011. The year 2012 witnessed a contraction in demand by 12% mainly due to the sluggish economy of India and China. The demand increased again in 2013, while declined marginally by 1.3% in 2014. In the short term forecast between 2014 and 2019, the demand is likely to grow by a CAGR of 1.8% with higher demand expected from automotive and industrial segments. This growth rate is likely to be maintained even in the long term forecast till 2040, as demand grows steadily initially from China and then from South East Asia. Japan will continue to grow at lower growth rates, owing to its mature market conditions.

Japan has been the key region for exports in Asia since the start of the decade. Asian capacities increased from 146 kta in 2000 to 242 kta in 2014, adding about 96 kta of capacities within 14 years. Japanese producers further expanded their existing plants, while producers in China set up new capacities to decrease its reliance on Japanese CR, with the latest being the Shanxi Synthetic Rubber company / Nairit JV plant, adding additional notional 30 kta of capacity in 2010. We understand that

the plant output was limited to 15 kta due to calcium carbide shortages up to 2014, when another older 12 kta CR facility was shut, resulting in 12 kta of capacity being removed. Although there were some announcements as to further additional CR projects, these seem unlikely to ever be progressed further, given the low Chinese utilisation rates (55%). Overall, the Chinese plants have struggled to operate consistently due to mechanical reliability, quality control (unable to produce on-spec product) and EPDM substitution issues, as well as excess Japanese volumes (despite the anti-dumping measures).

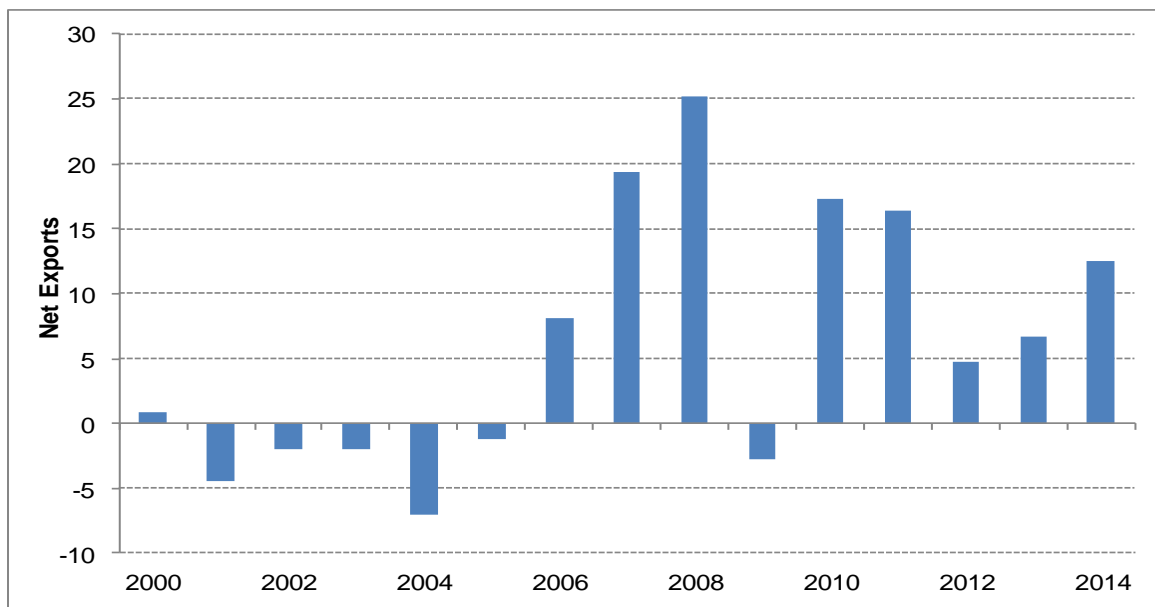
In addition to the above, Pidilite Industries Ltd, was planning to set up a CR plant in India (based on the equipment relocated from the old EniChem French facility), but has run into serious execution issues. There has been no recent progress on the project and Pidilite Industries are currently looking for some external assistance to enable further progress. Sources believe that the plant is not likely to come up in the near future.

Asian utilisation rates averaged 81% in the past 14 years, declining from 84% in 2000 to 77% in 2003, as new capacities got added, and rising again to 92% in 2007 as demand peaked. However, due to the effect of the economic downturn as well as new capacity additions, the rates have been between 76% to 85%. The utilisation rates are likely to be in the mid-80s in the long term forecast till 2040.

Asia has been fluctuating between being a net importer and net exporter of CR. This is mainly because Japan has been a strong exporter globally while China and Rest of Asia relies on imports for its domestic demand. Post 2006, with new capacities coming on-stream in China, the Asian region has been a net exporter of the product. The market is likely to remain a net exporter of the product in the forecast period till 2040.

The following chart Figure C-23 gives an overview of the net exports of Asia from 2000 to 2014.

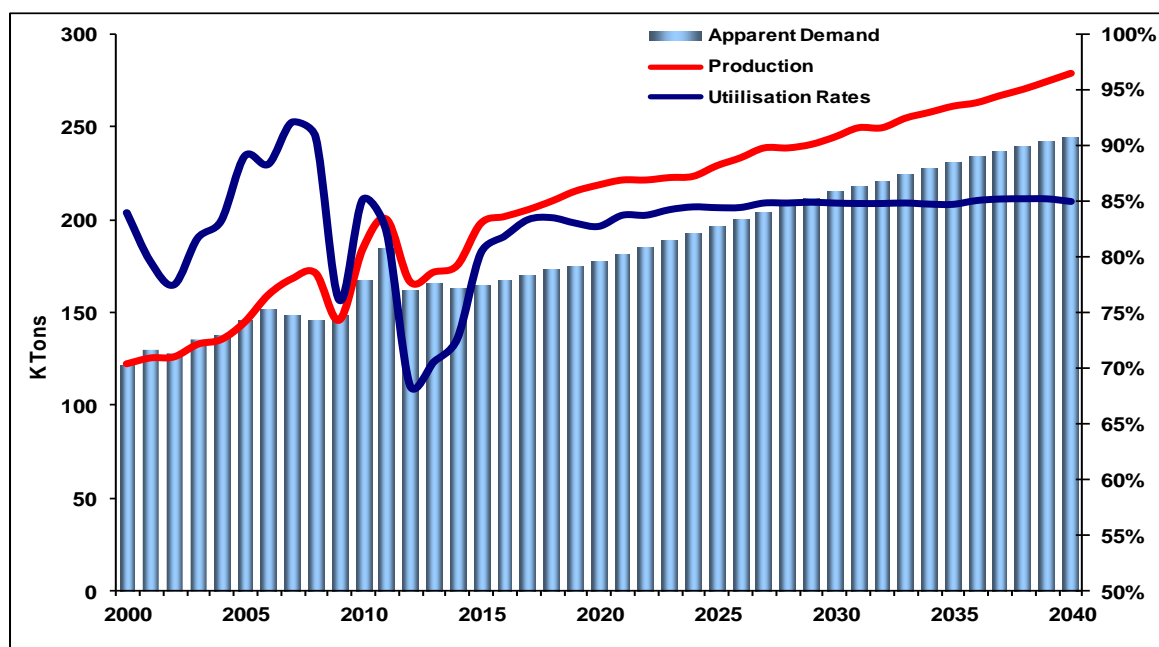
Figure C-23: Asia, Net Exports, 2000-2014



Source: Jacobs Consulting Ltd.

Figure C-24 gives the overall demand, capacity and utilisation rates for CR in Asia from 2000 to 2040.

Figure C-24: Asia CR Supply-Demand-Operating Rate 2000-2040



Source: Jacobs Consulting Ltd.

Table C- 15: Actual Demand of CR in Asia, 2000-2040

	Chloroprene Rubber Demand (kta)									Growth Rates	
	2000	2005	2010	2014	2020	2025	2030	2035	2040	2000-2014	2014-2040
Asia	122	146	167	163	178	197	215	231	245	202%	1.6%

Source: Jacobs Consulting Ltd.

Middle East and Africa

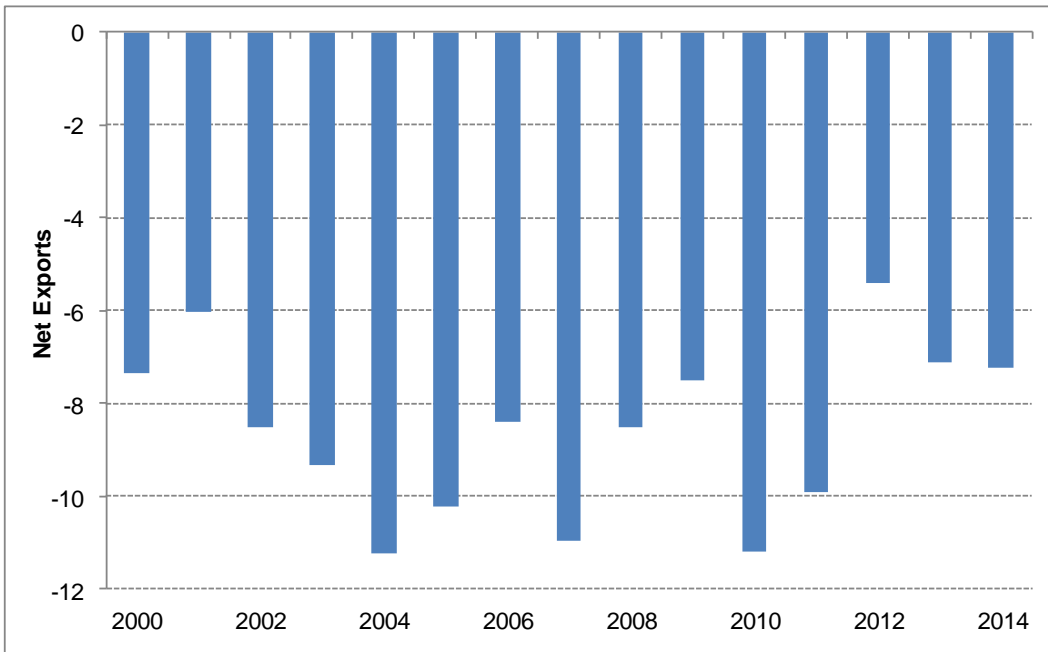
The demand for CR in Middle East/Africa was estimated to be about 7 kta in 2014. The region has historically been a low demand region with all demand catered via imports due to lack of a capacity in the region. The demand has fluctuated between 7 kta to 11 kta in the historical period. The CAGR of the region in the time period between 2000 and 2014 was about --0.3%, becoming the only region to witness a negative growth rate in demand during this time period. However, as local Middle East Governments encourage downstream derivative products to be set up, the region is expected to witness growth rates of about 2.0% in the short term forecast till 2019, and after that it is expected to grow at a CAGR of 1.7% between 2014 and 2040.

Currently there are no CR capacities in the region and none have been announced for the short term forecast. However due to incentives offered by the Government to encourage downstream petrochemical products, the chances of a new plant being set up in the region is very high and the region is likely to have new capacities post 2025. Future utilisation rates are expected to be in the lower 80s.

The region has been completely reliant on imports to meet its demand and until new capacities come up this situation is likely to continue. Turkey is one of the largest importers of the product in the region importing non-latex CR mainly from Germany and Japan. Turkey imported nearly 4.1 kta of CR in 2013.

The following chart Figure C-25 gives an overview of the net imports of Middle East/Africa from 2000 to 2014 which shows that the region has always been a major importer of the product.

Figure C-25: Middle East/Africa, Net Exports, 2000-2014

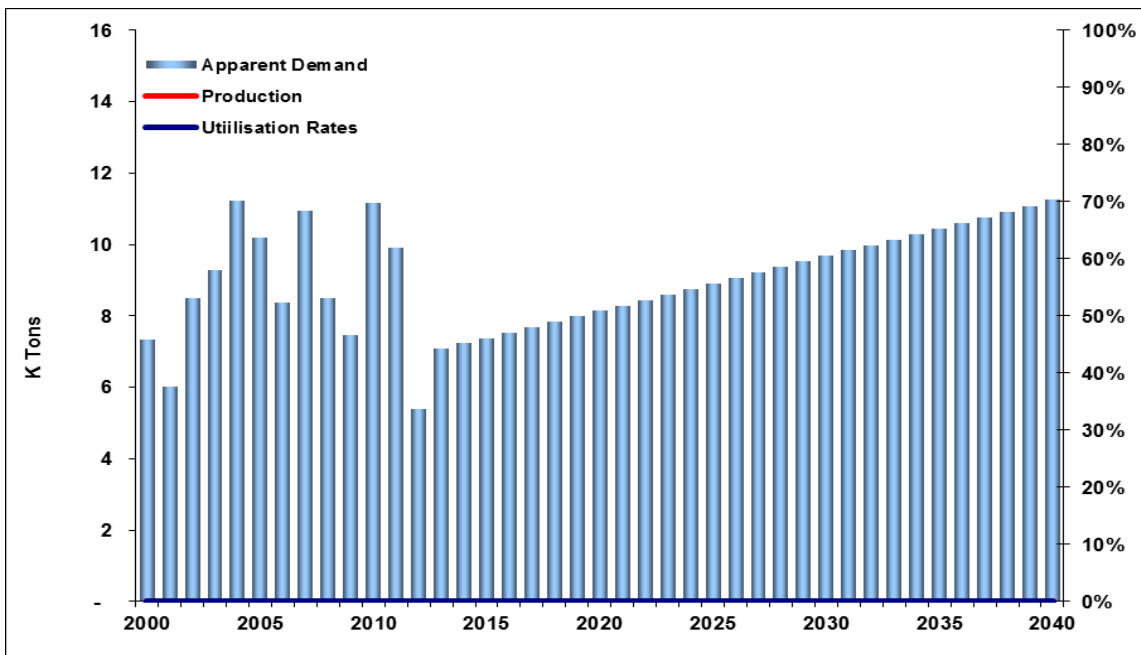


Source: Jacobs Consulting Ltd.

The region has maintained its position as a net importer, with imports increasing from 7 kta in 2000 to over 11kta in 2011 before declining to 7 kta in 2014. In the forecasted years, the region is likely to be more or less balanced in its CR requirements, importing very small volumes.

Figure C-26 gives the overall demand, capacity and utilisation rates for CR in Middle East/Africa from 2000 to 2040.

Figure C-26: Middle East/Africa CR Supply-Demand-Operating Rate 2000-2040



Source: Jacobs Consulting Ltd.

Table C- 16: Actual Demand of CR in Middle East/Africa, 2000-2040

	Chloroprene Rubber Demand (kta)	Growth Rates

	2000	2005	2010	2014	2020	2025	2030	2035	2040	2000-2014	2014-2040
Middle East/Africa	7	10	11	7	8	9	10	10	11	0.3%	1.7%

Source: Jacobs Consulting Ltd.

It is anticipated that as the Middle East moves into manufacturing more sophisticated industries such as oil well components, perhaps even automobiles that the CR demand will rise in the medium and longer term. As the governments encourage more specialised elastomers production with the GCC countries, one can expect a medium sized investment being made in CR rubber in the region.

Apart from the Republic of South Africa, and the Mediterranean coastal countries, demand in Africa remains small.

Chloroprene Rubber Target Markets

To identify the target markets for the project, we need to evaluate the major CR markets in the regions located near the project as well as large markets which are significant importers of the product. The key regions mainly evaluated include countries of Asia mainly China and India, Western Europe and Eastern Europe

All of these prima-facie short listed markets were reviewed for their long term attractiveness with respect to;

- Total imports in 2013
- Long term trade status as net importer or net exporter
- Key market factors affecting the prospects, such as – market size, domestic competition, long term demand growth and logistics considerations.

Table C-17 reviews the attractiveness for each target market for CR. Whilst China's import position and geographic location means that it remains the focus for CR exports, India has very little non-commodity petrochemicals, plastics and elastomers capacity and has a thriving and growing automobile and construction services industry, thus it would be next in line despite the logistics challenges. Thailand is becoming a low cost manufacturing centre for heavy construction industries and is thus also exhibiting growth in demand for CR.

Other relevant markets are Eastern Europe, Turkey, Brazil and USA. While Eastern Europe and Turkey won't be able to absorb significant portion of the product, they location relative to Armenia makes them attractive from a logistics point of view. Brazil is a major importer of polychloroprene within South American markets, where other competitors also have significant logistical overheads, somewhat balancing out the logistical costs from Armenia, whereas USA has been historically a price premium market, so any product sold there should give a nice boost to the margin.

Table C- 17: CR Target Markets

Region	Country	2013 Net Imports (KT)	Long Term Trade Status	Market Factors	Market Attractiveness for Project
Asia	China	18	Net importer	<ul style="list-style-type: none"> • Market size: large • New capacities in the future forecasted but none announced as of now • Anti-dumping duties imposed on imports from EU, USA and Japan till 2015 • Strong demand growth likely in the future 	High
	India	15.0	Net importer	<ul style="list-style-type: none"> • Market size: medium • No new capacities currently announced • Strong demand growth especially in the automotive sector 	High
	South Korea	9.1	Net importer	<ul style="list-style-type: none"> • Market size: medium • No new capacities likely to come up • No installed capacities • Relatively stable market 	Moderate
	Thailand	12.1	Net importer	<ul style="list-style-type: none"> • Market size: small • No capacity currently • Moderate growth rates expected • Transportation may be an issue 	Moderate

Region	Country	2013 Net Imports (KT)	Long Term Trade Status	Market Factors	Market Attractiveness for Project
Eastern Europe	Russia	3.1	Net importer	<ul style="list-style-type: none"> Market size: small Moderate growth market No new capacities likely to come up and no current capacities present Location proximity advantage 	High
	Poland	3.5	Net importer	<ul style="list-style-type: none"> Market size: small No capacity in the country as of now Moderate growth rates expected in the future Location proximity advantage 	Moderate
Western Europe	Italy	10.0	Net importer	<ul style="list-style-type: none"> Market size: small Mature market 	Moderate
	France	3.9	Net importer	<ul style="list-style-type: none"> Market size: small No capacity in the country as of now and one plant closed down, hence completely reliant on imports Low growth market 	Moderate
	United Kingdom	2.9	Net importer	<ul style="list-style-type: none"> Market size: small Low growth rates expected in the future 	Moderate
	Netherlands	6.5	Net importer	<ul style="list-style-type: none"> Market size: small Low growth rates expected in the future 	Moderate
Middle East	Turkey	4.1	Net importer	<ul style="list-style-type: none"> Market size small Proximity to country Moderate growth rates expected in future Location proximity advantage 	High

Region	Country	2013 Net Imports (KT)	Long Term Trade Status	Market Factors	Market Attractiveness for Project
South America	Brazil	6.8	Net importer	<ul style="list-style-type: none"> • No local producer, mainly imports from Japan and Germany • Moderate growth rates likely in future 	Moderate
North America	USA	17.7	Net exporter	<ul style="list-style-type: none"> • Balanced market but imports from Germany and Japan • Premium pricing 	Moderate

Source: Jacobs Consulting Ltd.

Section D



Assessment of the Technical Feasibility of Production

Introduction

In accordance with our technical assignment, Jacobs Consultancy visited the Nairit plant during the last week of February 2015. The purpose of the site visit was to assess the present condition of the assets of CJSC “Nairit Plant” and collect all the necessary information with regards to the examined assets.

The present report contains our assessment of the technical viability of the potential restart of chloroprene rubber production on Nairit site. Thus, it contains the following topics:

- Location & History
- Existing Facilities Overview
- Condition of the existing facilities for production of chloroprene via Acetylene Route (Existing Process Units – Acetylene Route)
- Condition of the existing facilities for production of chloroprene via Butadiene Route (Existing Process Units – Butadiene Route)
- Utilities and Offsites Overview
- Additional Options Considered
- Required Capital Cost Investments
- Required Staffing Levels

The above was considered with a view to restarting production under one of the three currently considered production scenarios:

- 12 kta of polychloroprene rubber, via acetylene route
- 24 kta of polychloroprene rubber, via acetylene route
- 25 kta of polychloroprene rubber, via butadiene route

Overall Summary

Generally, the condition of the assets is such that the plant cannot be easily brought back into operation without significant capital cost investment, regardless of which scenario is chosen:

- 12 kta of polychloroprene rubber, via acetylene route
- 24 kta of polychloroprene rubber, via acetylene route
- 25 kta of polychloroprene rubber, via butadiene route

The main obstacles to operation and overall capital costs investments required for each scenario are summarised below.

Polychloroprene rubber, via acetylene route – 12 kta

- The main technical obstacles are as follows:
- In order to ensure safe and efficient operation, effectively a completely new monomer production unit is required:
 - New brine pipeline connecting Abovyan salt wells and the main site
 - Largely rebuilt Chlor-Alkali unit (Areas 1-1, 1-3, 1-4, 1-5, 1-20)
 - New Air Separation Unit (Area 1-6)
 - Capital repairs on the oxygen line between Air Separation and main production sites.
 - New Oxygen Boost Compressors (Area 1-7 a, b)
 - New Methane Partial Oxidation Unit (Area 1-7 a, b)
 - New Cracked Gas Compressors (Area 1-7 a, b)
 - New Acetylene Extraction Unit (NMP Solvent) (Area 1-7 c)
 - New Acetylene Gas Holder
 - New Acetylene Dimerization Reaction section (Area 1-12 a)
 - New Acetylene Compressors (Area 1-12 a)
 - New Toluene Absorbers (Area 1-12 a)
 - New MVA hydrochlorination section (Area 1-12 b)
 - Relocated chloroprene distillation section (Area 1-12 b)
 - New auxiliary storage tanks
 - Utility distribution network to be retested and repaired where necessary.
 - New control system, instrumentation, cabling and operator control rooms.
- The past performance of the Methane Partial Oxidation Unit was substantially below that of original design and what a modern unit should be achieving. However, access to BASF technology and specialists is an open question at present.
- For both of the considered scenarios of polychloroprene rubber production via acetylene, we have also considered an additional new Syngas Utilisation Unit, so as to make chloroprene production from acetylene more cost effective. However, any such option represents a significant added capital cost that is unlikely to be justified given the relatively small quantities of syngas available.

- There is a potential option to further expand acetylene production and diversify into other chemical businesses such 1,4-Butanediol. However, this requires further assessment, with the main risks being:
 - Relatively high cost of natural gas
 - Access to technology
 - Logistics costs
- Operation with both highly corrosive and explosive fluids requires additional careful thought as to the existing unit spacing, personnel exposure and training.
- **The indicative investment costs for this option are approximately US\$ 192 million.**

It is estimated that some 436 staff will be required to enable Nairit operations under this scenario.

Polychloroprene rubber, via acetylene route – 24 kta

- The main technical obstacles are mainly the same as for the 12 kta scenario. The exceptions are as follows:
- In order to ensure safe and efficient operation, effectively a completely new monomer production unit line is required, which is of larger capacity, and thus requires further additional investment.
- In all cases, in order to make chloroprene production from acetylene cost effective, a new syngas utilisation unit is required. However, this is a significant added capital cost that is barely justified given the relatively small quantities of syngas available.
- **The indicative investment costs for this option are approximately US\$ 316 million.**

It is estimated that some 488 staff will be required to enable Nairit operations under this scenario.

Polychloroprene rubber, via butadiene route – 25 kta

- The production from butadiene is both significantly safer and requires less capital investment. The main challenges are:
- Refit of the existing production unit for monomer from butadiene. The unit equipment is largely there, and owing to the exotic materials of construction is thought to be generally fit for production.
- The rail terminal for import of butadiene will need to be upgraded.
- Utility distribution network to be retested and repaired where necessary.
- New control system, instrumentation, cabling and operator control rooms will be required, as well as a new mechanical spares storage house, to be relocated a safe distance from the monomer unit.
- Any reconstruction work on the unit will need to rely on Nairit's own knowledge of the process, as the past process licensor (BP Chem / Distillers) has not licensed a plant using this technology since the 1970s. Thus, the technical know-how outside of Nairit rests with current operators of such plants (Lanxess, DENKA, SDK and Tosoh) only.
- **The indicative investment costs for this option are approximately US\$ 236 million.**

It is estimated that some 380 staff will be required to enable Nairit operations under this scenario.

Location & History

The CJSC “Nairit Plant” complex occupies a large plot area to the south of Yerevan city centre, within the industrial park area. Originally, the site was located away from residential areas but, with the passage of time, it has now been absorbed and is currently within the city limits. Thus, the health, safety and environmental performance of the site has a direct impact on the health and welfare of Yerevan’s residents.

Production on the site commenced in 1940, based on the calcium carbide route to acetylene (now largely abandoned everywhere except China), which was then hydrochlorinated to chloroprene monomer, from which the main synthetic Polychloroprene Rubber (PCR) product was obtained. Over the years the production was expanded first to 14 kta of PCR in 1942 and then up to 45 kta of PCR in 1961. Due to the expansion of the city towards the site and the environmental impact of acetylene production from calcium carbide, the site switched to the natural gas route to acetylene and, in 1965, the acetylene production from natural gas was launched. This, together with a revamp of the chloroprene production unit, allowed further expansion of acetylene-based PCR production to 75 kta.

In parallel, a new Acetic Acid (AA) unit, based on the British Distillers process using light naphtha as a feedstock, under a BP Chemicals licence, was started up in the 1970s, but only achieved design capacity in early 1980s.

Likewise, due to the poor safety record of the chloroprene production from acetylene, a parallel 75 kta chloroprene-from-butadiene production process was set up under licence from BP Chemicals. The plant was started up in 1983, and reached design capacity in 1987. In addition to this, a new PCR line based on DuPont technology was installed in 1986, so as to allow production of up to 50 kta of PCR. These changes allowed a shutdown of chloroprene production from acetylene, improving the inherent process safety, as well as decommissioning of the old PCR lines which came to the end of their effective working lives in 1988.

The demise of the USSR and the resultant logistics issues for the site resulted in the supply of both light naphtha and butadiene from the newly formed Russian Federation being either cut or greatly reduced, due to a break out in hostilities elsewhere in the Caucasus mountains region and revised feedstock pricing.

To overcome the shortage, and prevent site closure, chloroprene production from acetylene was restarted, albeit at a reduced maximum PCR production rate of circa 10 kta, by making use of spare equipment retained from previously much larger decommissioned acetylene based chloroprene production unit. The site has struggled to be profitable since then, due to small plant throughputs and thus an unprofitable operating rate. In the last decade, the technology used at Nairit site to produce chloroprene from acetylene was licensed to China, and one of the three PCR drying, extrusion and packaging lines was disassembled and relocated in China as part of that deal. This reduced the maximum PCR rubber output to 25 kta, which is its present maximum capacity.

Since then, the unit has operated intermittently, due to global economy uncertainty and a major explosion which resulted in 4 fatalities in May 2009. In March 2010, it was decided to idle all production of PCR on site due to mounting debts with regard to natural gas and other utilities providers.

As a result, all PCR production on site has been idled for the last 5 years.

Existing Facilities Overview

Nairit facilities are located on 4 separate sites, as follows:

- Main site, where the main ISBL process units are located. The site comprises of four main ISBL units, as well as the necessary utilities and offsite facilities to enable continuous production.
- ASU site, some 3 km away from the main site – location of the existing Air Separation Units (Area 1-6), which supply oxygen and nitrogen, as well as instrumentation air to the main site. The existing units are now defunct, and new Air Separation Units will be required if the site requires high purity oxygen for acetylene production. Conversely, where butadiene based production is required
- Kapuyt Lich water intake site, some 22 km away from the main site – location of the raw water intake. The interconnecting water pipeline is considered to be relatively satisfactory condition, as the site has continued to make use of water.
- Abovyan salt wells (Area 1-4a), providing the salt brine for the main site, originally connected to the main site via a 28 km pipeline. The old pipeline is now defunct, and a new 42 km pipeline will need to be installed, in order to bring brine supply to the main site.

The main process site is unique in the sense that it still contains chloroprene monomer production units both from acetylene (derived from natural gas), as well as butadiene. Thus, Nairit have access to two separate process routes for chloroprene rubber production.

A further discussion of the present condition of the process assets located on the above sites is presented below. In order to avoid unnecessary repetition, the discussion is largely split into two parts:

- Production of chloroprene via acetylene, covering both scenarios for 12 and 24 kta of polychloroprene production respectively, via this intermediate.
- Production of chloroprene via butadiene, covering the third scenario – 25 kta of polychloroprene production from imported butadiene.

Existing Process Units – Acetylene Route

Summary of Main Process Units (ISBL)

The In Side Battery Limit (ISB) units are listed below:

- **Chlor-Alkali (C-A) Unit:**
- Area 1-1: Solvay process area for CO₂ production
- This area includes lime kilns for CO₂ production that is required to produce sodium bicarbonate, Na₂CO₃. This in turn is required to precipitate out the impurities contained within raw brine prior to its electrolysis. Depending on the production scenario undertaken, it may be more cost effective to simply import sodium carbonate rather than operate these rather old kilns.
- Area 1-4 a, b: Brine Production and Treatment
- This area includes the brine extraction well-sand planned brine solution treatment.
- Area 1-3 a, c: Caustic Soda (NaOH) Production
- This area includes the brine treatment unit, as well as caustic soda production facilities
- Area 1-3 b: Brine Electrolysis

- This area is the heart of the Chlor-Alkali unit; it comprises the diaphragm electrolysis cells which use purified brine to produce both hydrogen and chlorine, as required by the site, leaving behind residual cell liquor, which is re-circulated back to Area 1-3 a, c for caustic soda production
- Area 1-5: Hydrogen Chloride (HCl) production
- This area contains HCl furnaces as well as falling film absorber packages
- Area 1-20: Liquid Chlorine and Sodium Hypochlorite Production
- This area contains the chlorine liquefaction and sodium hypochlorite unit.
- **Acetylene Production Unit (Natural Gas based):**
- Area 1-6: Air Separation Unit, for the production of oxygen, nitrogen, and instrumentation air
- Area 1-7a: Partial Oxidation Unit, for the production of cracking gas, containing a large acetylene fraction. This area also includes a black water treatment plant and a solids incineration unit.
- Area 1-7b: Acetylene Extraction Unit, which uses NMP solution as an extraction medium for acetylene separation from the rest of the cracking gas.
- **Chloroprene (CR) Monomer Unit:**
- Area 1-12a: Production of Mono-Vinyl-Acetylene (MVA) from acetylene. This unit includes acetylene compression and MVA synthesis and absorption into toluene.
- Area 1-12b: Production of Chloroprene from MVA. This unit includes MVA desorption from toluene solvent, MVA hydro-chlorination synthesis section and Chloroprene distillation (involving stabilization with NO)
- Stabilized chloroprene from Area 1-12b is then sent to Area 1-18 (described below) for neutralization before being sent to the PCR rubber unit.
- Area 1-19: Liquid and chlorinated hydrocarbon waste incineration unit. This area is used to incinerate any liquid and chlorinated hydrocarbon waste generated within chloroprene monomer unit based.
- Area 1-18: Although the equipment of this area relates mostly to the monomer production from butadiene, it also includes a nitric oxide preparation unit (from nitric acid), which is then fed to Area-12b (chloroprene distillation), to stabilize chloroprene monomer. Furthermore, the final neutralisation of the chloroprene monomer from acetylene is also carried out here.
- **Poly-Chloroprene Rubber (PCR) Unit:**
- Area 1-21: Recovery of recycled chloroprene. In this area, crude chloroprene monomer incoming from the chloroprene monomer unit (Area 1-18) is mixed with chloroprene recycle stream from chloroprene polymerization and degassing (Area 1-22), is distilled and sent to polymerization reactors within Area 1-22.
- Area 1-22: Chloroprene polymerization and degassing. This area consists of a batch polymerization reaction section and subsequent degassing of the crude PCR latex product.
- Area 1-23: Rubber finishing lines. This area includes two latex drying and extrusion lines, as well as associated PCR rubber packaging lines.

Condition of the Main Process Units – ISBL

Chlor-Alkali Unit

Process Overview

The key function of the chlor-alkali unit is produce HCl, necessary for the hydrochlorination of the mono-vinyl acetylene (MVA), which is the final synthesis step of the chloroprene monomer production from acetylene. The unit by-products are caustic soda, NaOH (part used for internal needs, part exported), hydrogen (utilised for internal fuel needs) and sodium hypochlorite NaOCl (bleach, also exported).

Each area is reviewed in more detail below.

Areas 1-4 a, b: Brine Production and Treatment

This area includes the brine extraction wells, and initial brine solution treatment.

The raw brine, produced from underground leaching wells (Area 1-4 a) located outside Yerevan city. The existing brine pipeline is now defunct. The new proposed route, due to land ownership issues, currently is supplied for treatment via a 42 km-long pipeline to a raw brine treatment Area (1-4 b).

The brine field was commissioned in 1971 with a design capacity of 45,000 m³ of brine per year, operating with 5 wells.

As of present, the brine field consists of 5 wells, which are linked to CJSC “Nairit Plant” via a single pipeline. The amount of wells in operation can be varied depending on brine consumption rate.

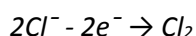
Given that construction works in the Area 1-4 b are currently in progress, brine treatment takes place in Area 1-3 a instead.

Area 1-3 a: Brine Treatment

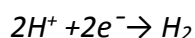
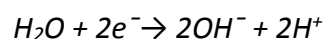
This area receives brine from the incoming feed pipe to the site, as well as the recycled brine from the caustic production. The brine is purified using a Solvay type process, so that Chlorinated Lime is also produced. As such, Lime furnace area 1-1 is considered part of this process area 1-3a.

Area 1-3b: Brine Electrolysis

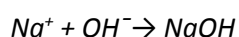
After the treatment, purified brine solution, with NaCl concentration of 300-310 g/l is fed to electrolysis cell rooms, located in Chlor-Alkali production Area 1-3b, where diaphragm electrolysis process takes place. Direct current is applied to the electrolysis cells. The main reaction taking place at the anode is the reduction of chloride ions into chlorine gas which can be summarized by the following reaction:



The main electrolytic process at the cathode is the dissociation of water molecules and the formation of hydrogen, which can be summarised by following reactions:



In the remaining solution, Na⁺ and Cl⁻ ions form sodium hydroxide:



The chlorine gas is then fed through titanium heat exchangers, where it is cooled with circulating water and fed to drying towers. Wet chlorine gas undergoes drying with 98% sulphuric acid to reduce its moisture content to at least 150 ppm.

The current unit was first commissioned in 1986.

Area 1-3 c: Caustic Soda Production

Spent cell liquor from the electrolysis cells contains NaOH at a concentration of 110-140 g/l which is pumped into an Evaporation Area (Area 1-3ac), where, at least 44 % caustic soda (NaOH) is formed through a 3-stage evaporation, part of which is used for the operation's own needs and the remaining part is sold.

Quicklime is produced in a Lime Separation Section by limestone calcining in lime kilns and is used for production of calcium chloride solution and waste water neutralization. Lime surplus is sold to outside consumers. The resultant flue gas by-products are used for the treatment of brine supplied to electrolysis and for production of caustic soda needed for acetylene production from natural gas.

Year of commissioning 1936;

Design capacity 50 000 t/year in terms of lime;

Actual capacity 15 800 t/year; (nominal due to idling)

The last large scale revamp of this section took place in 1983.

Part of this equipment needs complete replacement. For the remaining part, some parts and assemblies should be replaced.

Area 1-20: Liquid Chlorine Production

Dried chlorine gas is compressed and is either used for chlorine liquefaction in the Chlorine Liquefaction Area (1-20) if the plant is operating to produce butadiene rubber, or used for the production of hydrogen chloride and 31% hydrochloric acid, if the plant is producing acetylene rubber. This latter production mode also uses electrolytic hydrogen with minimum concentration of 98%.

The Chlorine Liquefaction and Chlorine Gas Production section was commissioned in 1980 with a design capacity of 60 000 tonnes per year of liquid chlorine. Chlorine liquefaction is a combined one stage process, which yields liquid chlorine at a pressure of 2.5 kg/cm² (2.42 atm) when cooled with brine at -30°C. Hydrogen chloride production is based on the combustion of hydrogen in chlorine gas in specially designed furnaces.

Hydrogen chloride is used as a feed in Area 1-12ab, for MonoVinylAcetylene (MVA) hydrochlorination, which in turn is used for chloroprene production.

Hydrogen Chloride and Synthetic Hydrochloric Acid Section has the following nominal capacity:

- 34 000 ton/year of hydrogen chloride
- 23 000 ton/year of synthetic hydrochloric acid

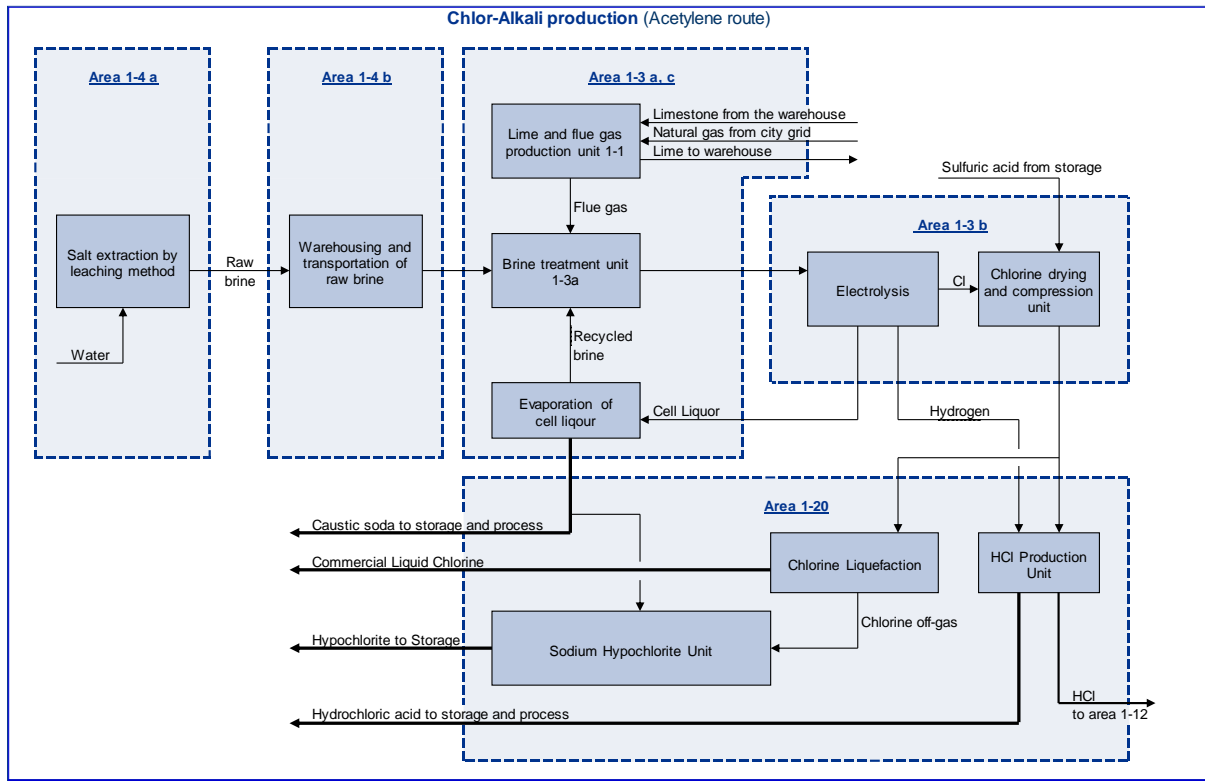
Liquefaction off-gases containing 45-80% of chlorine are either delivered to produce hydrochloric acid or supplied to the off-gases neutralization unit to produce commercial sodium hypochlorite (Area 1-20) according to the following reaction:



Block Flow Diagram

Schematic Block Flow diagram of Chlor-Alkali production for acetylene route is shown below.

Figure D- 1: Chlorine Production (Acetylene Route) Block Flow Diagram



Source: Jacobs Consultancy Ltd.

Material Balance

The material balances for Chlor-Alkali Production, via Acetylene route are shown below.

Table D-1: Material Balance of Chlor-Alkali Production (Acetylene Route) (as per design)

Plant/Acetylene route		Area 1-4a	Area 1-3c			Area 1-3b	Area 1-20					
Product		Brine Make-up	Quicklime	Treated Brine	Caustic Soda 100%	Cell Liqour	HCl	Hydrochloric Acid	Liquid Cl ₂	Liquid Cl ₂ in small packages	Sodium Hypochlorite	Calcium Hypochlorite
Units:		m ³	t	m ³	t	t	t	t	t	t	t	t
Mass Balance		Units										
Nat. Gas	000 Nm ³		-0.139									
Limestone	t		-1.780									
Quicklime	t		1.000									-0.500
Brine Make-up	t (of NaCl)	0.310		-0.164								
Treated Brine	m ³			1.000		-10.600						
Recycled Brine	t (of NaCl)			-0.146	1.657							
Cell Liqour (100% basis)	t				-1.071	1.000						
Sodium Hyperchlorite	t										1.000	
Calcium Hyperchlorite	t											1.000
Oxygen (95%)	000 Nm ³											
Calcinated soda (100%)												
Syngas	000 Nm ³											
Caustic Soda	t	-0.005		-0.001857	1.000						-0.1981	-0.0500
Sodium Nitrite	t											
Nitric Acid (100%)	t											
Acetylene	t											
Butadiene (99.3%)	t											
Hydrochloric acid	t			-0.00468	-0.007	-0.0022		1.000				
H ₂	t					0.025	-0.0311					
Cl gas	t					0.886	-1.000				-0.154	
Liq Cl	t							1.000		-1.035		-0.450
Liq Cl in small package									1.000			
100% NO	t											
HCl	t						1.000	-0.318				
Raw CR	t											
Dry CR	t											
Chloroprene to Recycle (internal)	t											
Chloroprene from Recycle (internal)	t											
Rubber	t											
Flue gases (100% CO ₂ basis)	m ³			-1.100								
Sulphuric Acid (100%)	t					-0.03267			-0.0019			
Sodium Sulphite	t					-0.00046						
Sodium Sulphate	t											
Waste (to Incinerator)	t											
CaCl ₂	t											

Utilities Requirements

The utility requirements for Chlor-Alkali Production, via Acetylene route are shown below.

Table D-2: Chlor-Alkali Production (Acetylene Route) Utilities Requirements (as per design)

Plant/Acetylene route		Area 1-4a	Area 1-3c			Area 1-3b	Area 1-20					
Product		Brine Make-up	Quicklime	Treated Brine	Caustic Soda 100%	Cell Liqour	HCl	Hydrochloric Acid	Liquid Cl ₂	Liquid Cl ₂ in small packages	Sodium Hypochlorite	Calcium Hypochlorite
Units:		m ³	t	m ³	t	t	t	t	t	t	t	t
Utilities - Annual Consumption (000's GJ/kWh/t/m³)												
Steam	GJ				-20	-4			-1	-1		
River Water	t											
Process Water	m ³		-8	-1	-50	-70	-18	-36	-35	-15	0	-20
Cooling Water	m ³											
Filtered Water	m ³					-3						
Demineralised water	m ³											
Power	kWh	-5	-13	-4	-141	-3000	-4	-3	-130	-257	-39	-65
Process Nitrogen	m ³											
Compressed Air	m ³			-5	-8	-18	-20			-36		
High Purity N2	m ³					-21	-21		-60	-145	-3	
Refrig at -15°C	Mcal											
Refrig at -30°C	Mcal					-7			-100		-20	

Source: Jacobs Consulting Ltd.

General Condition of the Chlor-Alkali Unit

The general condition of the Chlor-Alkali process unit is such that it cannot be at present operated. The building infrastructure is dilapidated and is in need of major repair. Over the last 20 years, it has been operated at a reduced capacity and with the minimum of maintenance required to keep this process unit operational.

There is a wider question is that the present chlor-alkali electrolyser technology is based on asbestos diaphragm electrolysis, thereby resulting in asbestos waste. The performance indicators at Nairit also show that the unit is rather inefficient in terms of electric power consumption when compared to both membrane and modern diaphragm electrolysis units. Given the present outdated control systems, it is also very labour intensive.

Since the plant has not been operated, the unit has benefited from some works. Critically, Nairit have gone some way towards repairing the existing electrolysers, as well unloaded the redundant piping from the overhead piperacks, restored enclosed chlorine storage tankage, as well as replaced some columns in the chlorine drying section (by means of relocation of spare equipment from acetylene extraction unit) and enforced general housekeeping.

In principle, the unit may be restored for operation, if chloroprene monomer production via acetylene is to be entertained. The process unit does require further additional investment to remedy its current condition, with the magnitude of investment highly dependent on the proposed capacity of the unit.

The type of works required is summarised below.

12 kta of Polychloroprene Rubber (PCR) production via acetylene:

- Restore brine wells at Abovyan and associated tankage and pumps
- Install new 42 km brine pipeline between Abovyan wells and the main site
- Install new brine storage on site
- Restore lime kiln (for Na_2CO_3 production, necessary to purify the brine).
- Replace the cathode grids of the electrolysers,
- Complete the refractory works on the replaced columns in the chlorine drying unit
- Install additional columns in the chlorine drying unit
- Install / replace existing chlorine compressors
- Install a number of new pumps (generally)
- Install new rotors for the existing centrifuge(s) within NaOH evaporation area.
- Install new H_2SO_4 solution storage (for chlorine drying)
- Install new HCl production unit equipment
- Further reinforce a number of supporting structures, especially that of the hypochlorite column, as well as install chemically resistant floors.
- **There is a large number of equipment that has not been tested for operation since 2010-2012 period and thus poses a degree of uncertainty as to its suitability of operation.**
- Purchase of adequate spares to enable reliable unit operation.
- Install a number of interconnecting pipe connections
- Install new instrumentation, associated cabling and new Direct Control System (DCS), together with new operators' room.

- Largely replace and reinstall insulation where necessary, due to poor condition of the present.
- Restore drainage

24 kta of Polychloroprene Rubber (PCR) production via acetylene:

- In addition to the works listed above, a subsequent expansion to 24 kta of production would largely require the same type of works. The obvious difference is the magnitude of works and the number of equipment that may be replaced / repaired, so as to reach this capacity. For example, it is thought that the existing electrolyzers may be brought back into production relatively cost effectively for a 12 kta scenario, given the rather large number of units that are redundant, allowing to interchange internals where necessary during the repair works. Conversely, for the 24 kta of PCR production scenario, additional and more substantial costs will be required to ensure that the electrolyzers overall capacity is adequate.
- However, for other types of works, the cost is roughly the same. For example, the brine pipeline involves largely the same costs regardless whether it supplies the site for 12 kta or 24 kta of PCR production, since the difference is down to a notional increase in the pipeline diameter, but all of the installation costs are still the same.

Condition of the Chlor-Alkali Unit Structures

The condition of the associated supporting structures is summarised below.

Table D-3: Condition of Buildings and Associated Infrastructure for C-A unit

Equipment name	No. of	Condition	Comment
Area 1-4 a: Brine Production			
1458 m ² building	1	Adequate	General maintenance only
Warehouse	1	Adequate	General maintenance only
Area 1-1: Lime and Carbonic Acid Production			
Lime area building 3 stories high	1	Requires Capital Repair	
Carbonic Acid Building	1	Requires Capital Repair	
Area 1-3 b: Electrolysis			
Operators House	1	-	Should be moved away from electrolyzers
Area 1-3 c: Caustic Soda Production			
Cell Liquor Evaporation Building	1	Requires Capital Repair	
Cell Liquor Evaporation Building / 4 stories high	1	Requires Capital Repair	Partly restored, but requires further work
Building X-14 / 1 floor	1	Requires Capital Repair	
Caustic Storage	2	Requires Capital Repair	
CW Towers	1	To be replaced	
Area 1-3 d: Sulphuric Acid Transfer Area			

Sulphuric Acid Transfer Building	1	Requires Capital Repair	
Area 1-5: Chlorine Drying			
Chlorine Drying Building	1	Requires Capital Repair	
Area 1-5: HCl			
HCl building	1	Requires Capital Repair	
Operators House	1	Requires Capital Repair	
Area 1-20: Liquid Chlorine Production			
3 stories high. Power Distribution Centre + Instr. Air Building	1	Requires Capital Repair	
Liquid chlorine storage - 7 bunkers – V 780m ³	1	Adequate	
Area 1-20 Chlorine Vapours Neutralisation (hypochlorite) and Drying	1	Requires Capital Repair	

Source: Jacobs Consulting Ltd.

Utilities Supply

The following list of issues was noted with regards to the Chlor-Alkali unit:

- Area 1-4 a, b: Brine Production & Treatment requires new water well.
- Area 1-3 b: Electrolysis Cells will be replaced with membrane units, so it is assumed that adequate utilities supply and return lines will be part of that scope.
- Area 1-3 a, c: Caustic Soda Production will be replaced (as above), so it is assumed that adequate utilities supply and return lines will be part of that scope.
- Area 1-3 d: Sulphuric Acid Transfer Area will be replaced, so it is assumed that adequate utilities supply and return lines will be part of that scope.
- Area 1-20: Liquid Chlorine Production will be replaced, so it is assumed that adequate utilities supply and return lines will be part of that scope.

Unit Operability & Condition of the Process Instrumentation and Control Systems

The overall process unit control is manual, operated by field operators on a pneumatic control system, whereby measurements are made by local instrumentation. While this is an acceptable mode of operation, it is an outdated one, having largely been replaced with automatic distributed control system (DCS). There are a large number of field operating staff in the Chlor-Alkali unit is also a safety concern.

We consider that a new DCS system is required to bring the unit to modern standards of operation. The introduction of the DCS system will allow the site/business/plant management to clearly identify performance improvement measures to further maximise project returns, maintain a clear log of environmental performance, as well as reduce the manning to a more manageable level.

During our site visit, Nairit have confirmed that in the event of a restart of production, their intention is to switch to a new DCS and have shown that their respective designs for such system are in a fairly advanced stage.

Acetylene Production from Natural Gas

The acetylene produced within this unit, is used as the main raw material for the production of the chloroprene monomer. The unit also co-produces synthesis gas, which at present is utilised for fuel needs. Nairit are considering the possibility to route this synthesis gas for additional chemical or liquid fuel production, so as to increase by-product credit and therefore lower the costs of production of the chloroprene monomer. However, in order for this to be achieved, a new dedicated production unit must be erected.

Each area is reviewed in more detail below.

Process Overview

Area 1-6: Air Separation Unit, ASU

Initially, according to the design, an air intake for the ASU was located 10 km away. However, due to dilapidation of the facilities and equipment, the air intake was moved closer and is now located 3 km away. The ASU process area is divided into two sub-units:

- General ASU

This sub-unit originally included 3 Soviet “BR-1A” type ASUs, producing 95 vol.% oxygen and 97 vol.% nitrogen. These units were initially commissioned in 1964.

A single Soviet “BR-1A” type ASU had a design capacity of 10 000 – 11 000 Nm³/hr of 95 vol% oxygen. Only one unit remains in a barely operable condition, achieving 8 000–8 500 Nm³/hr of 93-95 vol.% oxygen.

- Additional High Purity Nitrogen Section

This sub-unit originally included 3 Soviet “AK-1.5” type ASUs, producing 99.999 vol.% nitrogen. These units were initially commissioned in 1978.

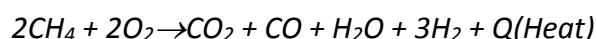
A single Soviet “AK-1.5” type ASU had a design capacity 1 750 Nm³/hr of 99.999 vol.% nitrogen. Two units remain in an adequate operating condition.

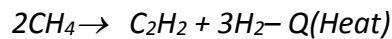
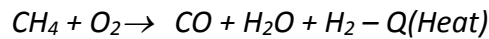
Area 1-7 a,b: Methane Partial Oxidation (POX) Unit

The acetylene production process via partial thermal oxidation was based on the German “BASF” Sachsse-Bartholomé water quench process, but the bulk of the equipment was manufactured within USSR, with the exception of compressors which were supplied by German “GHH”.

Year of commissioning:	1965
Original Design capacity:	75 000 tonnes/annum
Current capacity:	10 000 tonnes/annum

Natural Gas from the Yerevan city grid and oxygen from Area 1-6 are pre-heated to circa 600°C in their dedicated pre-heaters and fed to the POx reactors’ proprietary burners, where, natural gas is partially oxidised to acetylene and syngas components, using the direct heat of reaction provided by the in-situ combustion of natural gas. The reactions can be approximately summarised as follows:





The resultant cracked gases from the POX reactor, containing up to 8% acetylene, are then quenched and passed through an electrostatic filter, a water scrubber and a wet cyclone to remove as much soot as possible, before being fed to a pre-scrubber, where they are mixed with recycle CO₂ and subjected to an oil wash to remove any residual soot, naphthalene or polymers arising from acetylene cracking and polymerisation.

The resultant grey water from the quench vessels, electrostatic filters, the scrubbers and the wet cyclones is collected together and sent to a soot removal and incineration unit for further disposal.

The original design for this process area (Area 1-7 a, b) included six separate acetylene partial oxidation lines, each of which is made up of the following process units:

- One Natural Gas Pre-Heater
- One Oxygen Pre-Heater
- One POX Reactor+Quench Vessel
- One Water Scrubber
- One Electrostatic Precipitator

These six lines are then fed to three oil wash pre-scrubbers (one per each two POx lines). During the last years of operation, they have only operated 2 POx lines, feeding one pre-scrubber. The remainder of the process equipment has been slowly decommissioned and taken apart for spare parts.

The cracked gas from the top of the pre-scrubber is sent to a cracked gas collector and fed to a dedicated a five stage raw gas compressor, where it is compressed up to 8-9 atmospheres. Originally, there were three compressors units in parallel, but in the last 20 years they have only operated one unit at a time, keeping another one on stand-by and gradually using up the third one for spare parts. Due to the constant cracking of acetylene, the compressors' suction lines often foul up and have to be cleaned at an approximate monthly interval. This is a dangerous activity, as some residual acetylene is present and comes in contact with air. The soot vent line is not connected to a dedicated flare and at present is vented to the atmosphere. The compressors are manually controlled.

Soot Removal and Incineration Unit

The incoming grey water is fed to six parallel settling tanks at a sufficient velocity to enable the soot to float to the top of the process water, where it is then scooped up by a mechanical arm. The wet soot is then fed to the cyclone furnaces, where it is incinerated to produce steam. Plant operators commented that this is an unreliable part of operation, as the soot pulp feeding nozzles often block with soot.

Area 1-7 c: NMP Absorption Cycle

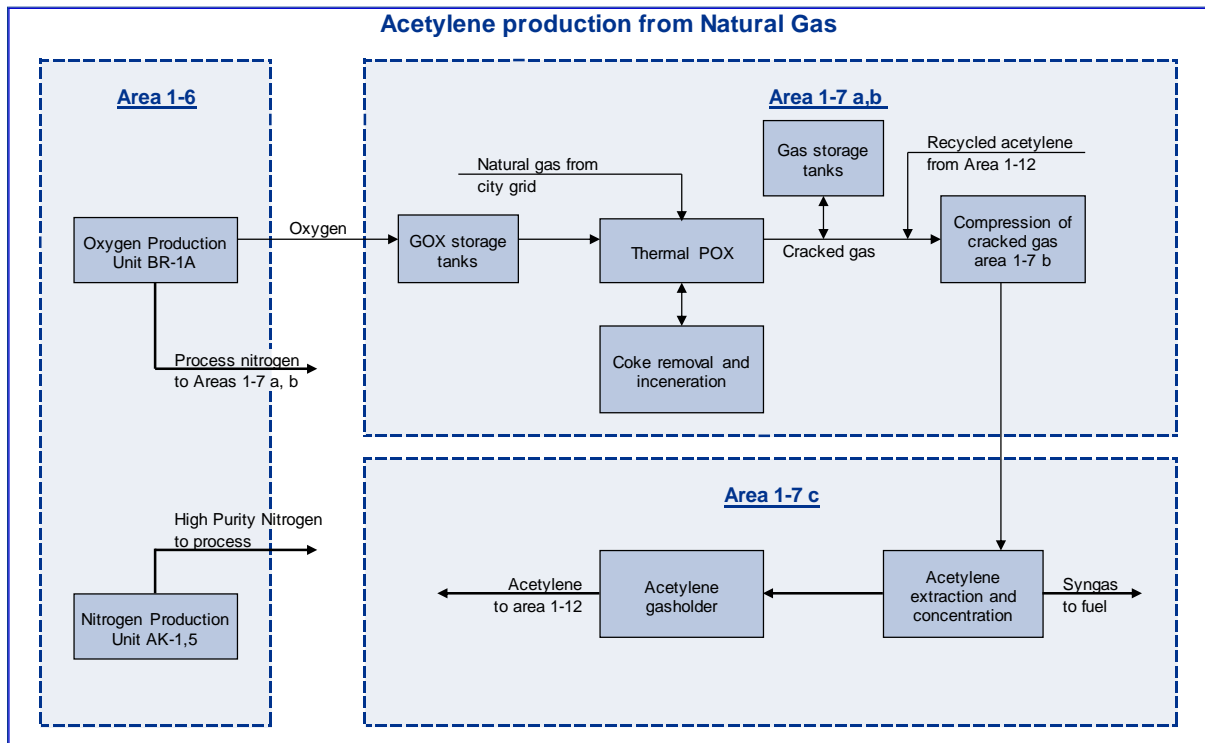
Compressed raw gas from the compressor hall is then passed to Area 1-7b, where it is fed to the bottom of the NMP absorber columns, which selectively absorb acetylene. Originally there were five NMP absorption sub-units, but at present only one remains in an operating condition, effectively limiting the whole unit to 10 kta of acetylene.

The loaded NMP solution leaves the bottom of the absorber column. The remaining gas is removed from the top as a syngas by-product stream and used as fuel gas elsewhere on site. The loaded solution is fed to the bottom of the stripper column, where both acetylene and residual CO₂ are selectively extracted. CO₂ is recycled back to the pre-scrubber, so as to purge it into the syngas stream, whereas acetylene is sent to the gas-holders for check buffer storage, before being sent to the Chloroprene Production Unit.

Block Flow Diagram

A Block Flow Diagram for the production of acetylene from natural gas is shown below.

Figure D- 2: BFD for the Acetylene Production Unit



Source: Jacobs Consulting Ltd.

Material Balance

The overall material balance for the process unit is shown below:

Table D-4: Material Balance for Acetylene Production Unit (as per design)

Plant/Acetylene route		Area 1-7	Area 1-6
Product		Acetylene	O ₂ (ASU)
Units of the product		t	000 Nm ³
Mass Balance		Units	
Nat. Gas	000 Nm ³	-8.200	
Oxygen (95%)	000 Nm ³	-4.800	1.000
Calcinated soda (100%)		-0.00040	
Syngas	000 Nm ³	9.680	
Acetylene	t	1.000	

Source: Jacobs Consulting Ltd.

Utilities and Chemicals Requirements

The overall utilities and chemicals requirements for the process unit are shown below:

Table D-5: Utilities Requirements for Acetylene Production Unit (as per design)

Plant/Acetylene route		Area 1-7	Area 1-6	New
Product		Acetylene	O ₂ (ASU)	O ₂ (ASU)
Units of the product		t	000 Nm ³	000 Nm ³
Utilities, Catalysts and Chemicals (per ton product)				
Additional Chemicals				
NMP, t/t		-0.0164		
Utilities - Specific Consumption (per ton/ 000 Nm³ of product)				
Steam	GJ	-31.1624	-0.1891	
River Water	t			
Process Water	m ³	-80.00	-5.1	-0.1
Cooling Water	m ³	-1090.00	150	30
Filtered Water	m ³	-158.00		
Demineralised water	m ³			
Power	kWh	-3355.00	-502.2	-300.0
Process Nitrogen	m ³			
Compressed Air	m ³	-2236.00		
High Purity N ₂	m ³	-1075.00		
Refrig at -15°C	Mcal			
Refrig at -30°C	Mcal			

Source: Jacobs Consulting Ltd.

General Condition of the Acetylene Production Unit

The general condition of the Acetylene Production Unit is very poor. We consider that the present condition of the unit does not allow for safe and environmentally safe operation. The process equipment generally appeared to be very old, with significant exterior corrosion and welding scars where 'patching up work' was done. The process controls are antiquated and do not appear appropriate for such a delicate process. There are no gas detectors and the flare headers seem to be corroded. Currently only one ASU, two POX reactors, two compressors and one NMP absorbent cycle were in a condition that may be considered as adequate for operation, albeit with signs of heavy wear. Restart of production at this unit will require a major capital investment.

A further point must be made about the efficiency of the present equipment. Thus, the existing ASU unit is about 50% less efficient than its modern analogue in terms of power consumption. Nairit themselves have indicated that a new ASU unit is proposed for both acetylene scenarios.

Likewise, the natural gas consumption of the Partial Oxidation (POx) unit per tonne of acetylene is around 8,500 Nm³/hr of natural gas. This is around 30% higher than design and 40% than best achieved by BASF at their own facility at Ludwigshafen, Germany. **Thus, in the event of acetylene route scenario being chosen, it is highly recommended that BASF are approached and engaged throughout to improve the performance of the POx unit.**

A more detailed overview of the type of works required is summarised below.

12 kta of Polychloroprene Rubber (PCR) production via acetylene:

- New Air Separation Unit (ASU) is required (inclusive of buffer storage and product gases compression).
- The interconnecting pipework between the ASU site and the main site will need to undergo large integrity assessment and undergo localised repairs.
- New oxygen compression will be required at the main site.
- New acetylene production unit
 - While there may be an argument that some of the equipment is salvageable for future operation, such operation will most certainly fall short of what is considered as good practice or compliant with international standards for acetylene production. Given the explosive nature of acetylene, we consider it is too dangerous an approach, especially considering the location of Nairit within city limits.
- New cracked gas compressors
- New acetylene extraction unit
- New acetylene gas holder
- Purchase of adequate spares to enable reliable unit operation.
- Install a number of interconnecting pipe connections, in particular due to safety issues;
 - New oxygen lines
 - New cracked gas collector lines
- Install new instrumentation, associated cabling and new Direct Control System (DCS), together with new operators' room.
- Largely replace and reinstall insulation where necessary, due to poor condition of the present.
- Restore drainage

24 kta of Polychloroprene Rubber (PCR) production via acetylene:

- In addition to the works listed above, a subsequent expansion to 24 kta of production would largely require the same works. The obvious difference is the scale of the unit will double, which will require some additional equipment. However, most of the capacity increase should be met through equipment sizes increase rather than additional equipment being bought and purchased in parallel.

Condition of the Acetylene Production Unit Structures

The condition of the associated supporting structures is summarised below.

Table D-6: Condition of Buildings & Associated Infrastructure for Acetylene Production Unit

Equipment name	No. of	Condition	Comment
Air Separation Unit Compressor Hall	1	Inadequate	Largely ok, but new ASU is required
Compressor Hall	1	Adequate	Needs roof repairs and internal capital repairs
CW Towers & Substation N23	1	Adequate	Capital Repairs
Mechanical Workshop, Control Room and Substation	1	Adequate	Capital Repairs
Instrumentation Building	1	Adequate	Needs roof repairs
Gas Analysers Building	1	Adequate	Needs roof repairs
Central Control Point and substation N26	1	Adequate	Needs roof repairs
Gas Analysers Building	1	Adequate	Needs roof repairs
HVAC Building	1	Adequate	Needs roof repairs
Soot removal baths	1	Adequate	
3 stories high waste incineration process structure	1	Adequate	New Paint
2 stories process structure	1	Adequate	New Paint
HVAC Building	1	Adequate	Capital Repairs
Pump House	1	Adequate	Needs roof repairs
Process CW Towers	1	Inadequate	Needs replacement
Process Area	1	Adequate	Needs roof repairs
HVAC Building	1	Adequate	Needs roof repairs

Source: Jacobs Consulting Ltd.

The general condition of pipe racks and their supporting pylons varies from adequate to poor and thus some will have to be replaced. As a general comment, there is a lot of redundant equipment and scrap materials scattered across the Acetylene Production Unit plot space. This must be cleaned up and stored in a designated area. It should not be located near a live operating unit.

Utilities Supply

The following list of issues was noted with regards to the Acetylene Production Unit:

- Area 1-6: New dedicated CW cycle will be required adjacent to the ASU
- Area 1-6: A new gaseous oxygen (GOX) holder for interim storage is required
- Area 1-7a: New CW cycle will be required
- Area 1-7a: A new cracked gases holder for interim storage is required
- Area 1-7a,b: The chemical sewer will have to be rechecked for integrity

These issues are ancillary, as we do not recommend the restart of this unit due to its lack of economic competitiveness, associated safety and environmental issues, as well as the expected lack of reliability due to general wear and tear.

Unit Operability & Condition of the Process Instrumentation and Control Systems

The overall process unit control is manual, operated by field operators on a pneumatic control system, whereby measurements are made by local instrumentation. While this is an acceptable mode of operation, it is an outdated one, having largely been replaced with digital DCS control systems. A large number of field operating staff, due to manual control system that is at present implemented in the Acetylene Production Unit, is also a safety concern.

We consider that a new DCS system is required to bring the unit up to modern standards of operation. The introduction of the DCS system will allow management to clearly identify performance improvement measures to further maximise project returns, maintain a clear log of environmental performance as well as reduce the manning to a more manageable level.

During our site visit, Nairit have confirmed that in the event of a restart of production, their intention is to switch to a new DCS and have shown that their respective designs for such system are in a fairly advanced stage.

Venting

A particular concern was the past venting practice in this unit, in particular the purging and release of soot which is environmentally undesirable poor and requires urgent general attention. For example, there was evidence of certain practices with regards to clearing of the accumulated soot in the cracked gas pipework, whereby some of the cracked gas together with the soot was vented together to atmosphere resulting in large amounts of particulates being released to the atmosphere within Yerevan city limits.

This is an unacceptably poor environmental practice and requires a management initiative to radically change the operating culture on site, in order to prevent safety incidents which will inevitably cause expensive down time due to loss of production.

Chloroprene Production Unit

Process Overview – Chloroprene Production from Acetylene

This is one of the oldest units on-site, although it has been completely refurbished throughout its operation on this site. It was first commissioned in 1940 with a capacity to supply enough chloroprene monomer for 7 kta of PCR rubber based on acetylene produced via the Calcium Carbide process at the time, which existed at an adjacent location. The unit was progressively expanded to reach a capacity of 75 kta in 1970s, but was shut down in 1985 due to the introduction of the butadiene route for chloroprene monomer production.

The fall of the USSR, and the consequent disruption in butadiene supply to site, has led to the restart of the unit at a demonstration capacity in 1994, so as to enable PCR rubber production on site. The unit largely followed 1970s design, with a few control loop improvements. The equipment and process control systems contained in this demonstration unit were partly salvaged from the previously operating chloroprene unit, which was shut down in 1985.

Effective Start-up Date: 1994

Design Capacity: 10 kta of Chloroprene Monomer

Actual Capacity: 9 kta of Chloroprene Monomer

Chloroprene Production from Acetylene is divided into three following process areas:

- Area 1-12a: Chloroprene Production Unit (Acetylene) – MVA synthesis
- Area 1-12b: Chloroprene Production Unit (Acetylene) – MVA hydrochlorination
- Area 1-19: Liquid and Chlorinated Waste Incineration

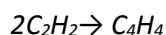
Area 1-12a: Chloroprene Production Unit (Acetylene) – MVA Synthesis

Area 1-12a contains the following Sections:

- Acetylene Feed Compression
- Acetylene Dimerization Synthesis (Fluidized bed) to Mono-Vinyl-Acetylene (MVA)
- Drying and MVA absorption by Toluene
- Catalyst (CuCl/NH₄Cl solution) preparation and regeneration

Acetylene Compression & Dimerization Synthesis

Acetylene from Buffer Storage Gas Holders is fed to the compression section of the Area 1-12a, where it is compressed in Liquid-Ring Compressors to approximately 1.9 bar a, mixed with safety superheated steam (which preheats to 70°C) and fed to the bottom of the Dimerization Reactor, where it is allowed to bubble through a weak HCl acid / catalyst (CuCl/NH₄Cl) solution at about 80-85°C, and thus convert to Mono-Vinyl-Acetylene (MVA) via the following reaction:



Other by-products of the reaction include Vinyl Chloride, Acetaldehyde, as well as higher waste polymers, which are consequence of the acetylene's and MVA's high propensity to polymerise. Dimerization solid waste is a resin, made of higher polymers and up to 17% of copper. This solid waste is periodically taken out to the city's landfill.

Drying and MVA absorption by Toluene

Saturated effluent gas exiting the top of the MVA synthesis reactor is first passed through an overhead KO pot, where some of the condensate is removed and passed through a series of sCRubbers where it is first washed with water and then brine solution to further chill the gases to -7°C to -10°C, which both dries the effluent gas and scrubs out waste polymers.

SCRubbed effluent gas is then passed through a series of toluene absorbers where MVA and other light by-products of MVA synthesis are counter-currently contacted with toluene solvent. The remaining acetylene gas, as well as inerts, is then split, with the bulk recycled to the Acetylene production unit's NMP absorber cycle for acetylene recovery, whereas a small purge stream is taken off, further scrubbed with toluene solvent and sent to an atmospheric vent. Loaded toluene solution leaves the bottom of the first absorber and is pumped to Area 1-12b for further synthesis to chloroprene.

Catalyst Preparation Area

This area consists of a single open roof vessel, which is used to mix HCl, ammonia and manually added bars of copper to prepare adequate strength solution for MVA synthesis.

Area 1-12b: Chloroprene Production Unit (Acetylene) – MVA hydrochlorination

Area 1-12b contains the following Sections:

- Mono-Vinyl-Acetylene (MVA) Extraction and Desorption (from Toluene),
- MVA Hydrochlorination Synthesis (to Chloroprene)
- Chloroprene Distillation

Mono-Vinyl-Acetylene (MVA) Extraction and Desorption

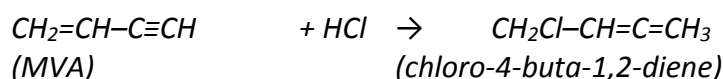
Loaded toluene solution is partially pre-heated and fed to a phase separator, where it is contacted counter-currently with off gases from the chloroprene distillation section, in order to strip out most of the dissolved acetylene. The gases are then recycled back to the feed point of the first toluene absorber within Area 1-12a. Loaded toluene solvent is then fed to a toluene desorber column, where remaining acetylene, MVA and other MVA synthesis by-products are steam reboiled out of the solvent at about 130°C (thus catching some of the toluene) and removed overhead via a condensing cooler within the desorber column. The remaining toluene, recovered at the bottom of the column, is split, with a side-stream sent through a batch distillation process to remove fouling waste polymers that form due to MVA's high reactivity. Regenerated solvent is then chilled and returned to the process.

Gas exiting the desorber column is then fed to the first MVA distillation column, which is used to recover vapour losses of toluene from the desorber column, as well as remove MVA and acetaldehyde from DVA and other heavier hydrocarbons. Gaseous MVA and acetaldehyde are condensed in several stages (by indirect cooling with water and refrigerant brine solution) and then washed with water in a dedicated scrubbing column. The resulting acetaldehyde solution from the bottom of the scrubbing column is then recycled back to the toluene absorption cycle, whereas the washed gas is almost acetaldehyde free, so it is then fed to a second MVA distillation column, to remove the last traces of acetaldehyde and DVA, via a calcium chloride dryer. The bottoms from this column are recycled back to Area 1-12a and used to scrub the MVA reactor effluent gas. MVA product (99.99 wt.%) is taken off at the top, condensed in a series of water and refrigerant brine solution condensers, collected in a dedicated holder vessel, from where it is pumped to MVA Hydrochlorination Synthesis section. All of the MVA distillation columns are operated at slightly above atmospheric pressure due to safety considerations associated with handling a highly concentrated MVA stream.

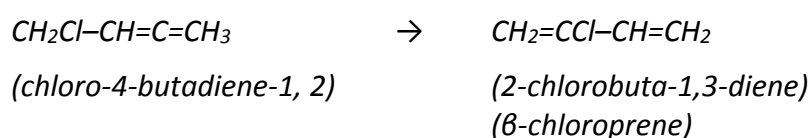
MVA Hydrochlorination Synthesis (to Chloroprene)

Liquid MVA from the holding vessel is diluted in process water and is vaporised under saturated conditions by superheated steam addition. The resultant vapour is fed to the bottom of the hydrochlorination synthesis reactor at a temperature of 40-50°C, where it is bubbled through a weak HCl acid / catalyst (CuCl/NH₄Cl) solution. The make-up HCl reagent is added as a 15 % weak HCl acid solution to one of the three reactor risers. Notably, both ammonia and copper make-ups are also added continuously to maintain the correct concentration of the catalyst and the acid, so that the following reactions take place:

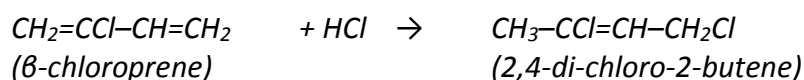
1) *Hydrochlorination:*



2) *Isomerisation:*



3) *Undesired side reaction due to excessive HCl:*



Other by-products of the reaction include Methyl Vinyl Ketone (MVK) and higher dimers and waste polymers, which are a consequence of chloroprene reactivity and residence time in the reactor. The gas effluent from the top of the reactor contains chloroprene, di-chloro-butenes, MVK, steam and HCl and is fed to the bottom of the wet MVA recovery column, where most of the unreacted MVA is recovered as a wet condensate stream in the overhead chiller/condenser system and returned back to the hydrochlorination reactor.

The remaining non-condensable gases are then fed to a MVA recovery column #1, where they are scrubbed against MVA recovery column #2 bottoms, to further recover MVA and chloroprene. The remaining inert gas stream is then washed with caustic and vented to atmosphere. The bottoms product, loaded with MVA is sent to the crude chloroprene collector.

Bottom product from the wet MVA recovery column #1 is collected in a settling vessel to separate out the aqueous phase. The resultant organic phase is then further indirectly chilled using brine refrigerant solution, passed through a calcium chloride dryer and is then sent to the crude chloroprene collector, where it is mixed with the bottoms product from the chloroprene recovery column.

Chloroprene Distillation

Crude chloroprene is pumped from its collector drum to a light ends chloroprene column, where MVA is recovered as a condensate in an overhead CW condenser / brine refrigerant chiller system. The remaining off-gases are then passed through MVA recovery column #2, where they are washed to recover MVA vapours prior to venting to atmosphere. The bottoms of the light ends chloroprene column are collected in a dedicated degassed crude chloroprene collector vessel, from where they are pumped to the final product distillation column, where chloroprene it is separated from di-chloro-butenes, collected in the overhead CW condenser / brine refrigerant chiller system as a condensate and further passed through a final calcium chloride dryer before being sent to polymerisation. The dichlorides are collected as a bottom by-product and at present are incinerated. The remaining off-gases are ejected to the fuel gas system.

Area 1-19: Liquid Waste Incineration

Liquid and chlorinated waste from chloroprene production is thermally destroyed in this unit by co-firing it with natural gas, in order to capture some of its energy value as steam and dispose of the hazardous wastes. The flue gas is cooled and scrubbed with caustic to capture any traces of HCl. Saturated steam is produced at the pressure of 13 atm. (g) as a by-product.

Year of commissioning: 1981.

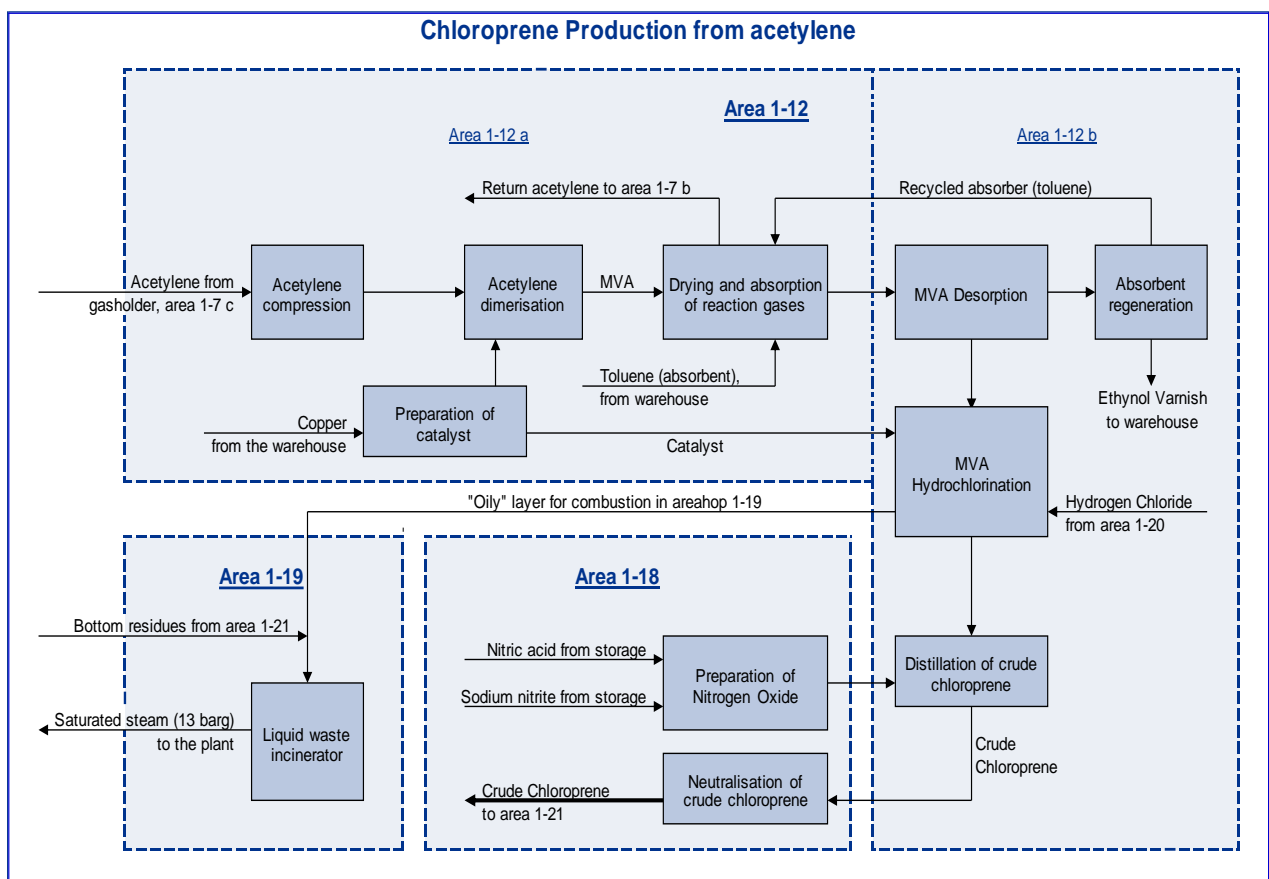
Design capacity: 1.4 t/hr of liquid wastes

Actual capacity: 1.1 t/hr

Block Flow Diagram

Block Flow Diagram for the production of chloroprene from acetylene is shown below.

Figure D- 3: BFD for the Chloroprene Production Unit (based on Acetylene)



Source: Jacobs Consulting Ltd.

Material Balances

The overall material balance for the process unit shown below.

Table D-7: Material Balance for Chloroprene Production from Acetylene (as per design)

Plant/Acetylene route		Area 1-12		Area 1-18	Area 1-19
Product		CR from Acetylene	Dry CR	10% NO-nitric oxide (on 100% basis)	Waste Incineration
Units of the product		t	t	t	t (of feed)
Mass Balance		Units			
Nat. Gas	000 Nm ³				-63.500
Brine Make-up	t (of NaCL)	-0.2330			
Caustic Soda	t	-0.0057	-0.0030	-3.5000	-0.0357
Sodium Nitrite	t			-4.470	
Nitric Acid (100%)	t			-2.730	
Acetylene	t	-0.8860			
Hydrochloric acid	t	-0.0608			
Cl gas	t	-0.0033			
100% NO	t	-0.0004950		1.000	
HCl	t	-0.4906			
Raw CR	t	1.0000	-1.004		
Dry CR	t		1.000		
Chloroprene to Recycle (internal)	t				
Chloroprene from Recycle (internal)	t		-0.513		
Waste (to Incinerator)	t				-1.000

Utilities, Catalysts and Chemicals Requirements

The overall utilities requirements for the process unit are shown below.

Table D-8: Utilities, Catalyst and Chemicals Requirements for Chloroprene Production from Acetylene (as per design)

Plant/Acetylene route		Area 1-12		Area 1-18	Area 1-19
Product		CR from Acetylene	Dry CR	10% NO-nitric oxide (on 100% basis)	Waste Incineration
Units of the product		t	t	t	t (of feed)
Utilities, Catalysts and Chemicals (per ton product)					
Additional Chemicals (per ton of product)					
NMP, t/t				-0.010	
Ammonia, t/t		-0.002			
Copper, t/t		-0.005			
Nitrosodiphenylamine, t/t		-0.002			
Fentiazin, t/t		-0.001			
4-methyl-2,6-di-TRT-butylphenol, t/t		-0.002			
Toluene (petroleum), t/t		-0.080			
Utilities - Specific Consumption (per ton of product)					
Steam	GJ	-22.1			
Process Water	m ³	-89.0	-4.0	-100.0	-80.0
Cooling Water	m ³	-350			
Filtered Water	m ³	-6.7			-.01230
Power	kWh	-702.2	-1.4		-420.0
High Purity N2	m ³	-180	-245	-16700	-16700
Refrig at -15°C	Mcal	-2700			
Refrig at -30°C	Mcal	-100	-115		

General Condition of the Chloroprene Production Unit – Acetylene

The general condition of the equipment contained within this process area inadequate for production restart, due to wrong choice of materials of construction, generally old equipment coming to the end of its useful operating life, localised heavy corrosion associated with a process of this nature, as well as insufficient maintenance over the years. In particular, both dimerization synthesis and MVA hydrochlorination reaction sections do not appear safe and will need to be replaced. There is a large number of equipment that is made from materials not suitable for handling acids or brines or ammonium chloride catalyst that are present in the system. If this production unit is to be restarted the equipment that is not already protected via acid resistant tiling will require replacing to ensure adequate materials of construction are used such as certain types of FRP (Fibre Reinforced Plastic)¹¹.

Thus, all equipment and process lines around both dimerization section and hydrochlorination section that are made from carbon steel; should either be replaced by equipment made from a more suitable acid resistant material. **Thus, we consider that the present condition of the overall unit does not allow for safe and environmentally friendly operation. Given that this section deals mostly with explosive, toxic and corrosive substances, there is a fundamental question of safety of operation.**

The process controls are antiquated and do not appear appropriate for such a delicate process. There are no gas detectors in the area and we did not see that operators are provided with adequate PPE. The operator house is located in the direct vicinity of the process, and will need to be moved. Nairit have indicated that in the event of a restart, the operators' house will be relocated.

In 2009, there was a serious explosion in the section of the plant where MVA is desorbed from toluene, which led to 4 fatalities and blast wave damage around the site and to adjacent buildings. Of particular concern is that this unit seems to be located so close to the public road, posing significant danger to civilians outside the plant. Thus, the whole section will need to be relocated further away from public roadways, and other unit areas, to ensure safe operation of the site overall.

Restart of production at this unit will require a major capital investment, as most of the unit needs to be replaced, part of it relocated to a different plot location and fully refurbished for modern operation.

A more detailed overview of the type of works required is summarised below.

12 kta of Polychloroprene Rubber (PCR) production via acetylene:

- New dimerization catalyst preparation unit
- At least one new dimerization reactor is required, and the existing reactors must undergo checks for adequacy of internal acid resistant tiles, as well as the inner corrosion of the outer steel shells, before they can be declared safe to operate.
 - **Even though the existing reactors are lined with acid resistant tiles, there is evidence of corrosion on the outer shells, which suggests that the lining is not adequate and results in corrosive fluids permeating through.**
 - If long term operation is to be considered, FRP is a safer and more cost effective choice of material of construction than internal lining with acid resistant tiles.
- Reinforce dimerization section supporting structure
- New hydrochlorination reactors will be required.
- Most of the process columns will also need to be replaced. The existing units suffer from either corrosion, gumming up or both.

¹¹ E.g. Epoxy Vinyl Ester Resins (EVER) can be used in applications where up to 200°C service is required

- **Major column equipment has not be tested or inspected in detail since at least the plant has shutdown (5 years).**
- Operation of carbon steel equipment with fluids containing acids, brines, ammonium chloride catalyst as well as moisture, is bound to result in excessive corrosion and therefore jeopardize the safety of the overall plant.
- Brine scrubber column is made from carbon steel, which will result in excessive corrosion during operation of the unit. Same issues as outlined above.
- Even toluene absorber is at danger of having unacceptable levels of internal corrosion due to brine carry over that has very likely occurred over years of operation.
- Similarly, chloroprene monomer distillation column is made from carbon steel, whereas it receives a feed line from the hydrochlorination reactor that is likely to contain traces of HCl.
- There is also a question of polymer gums and resins that were formed as part of previous operation and whether these can be removed without damaging equipment.
- In all cases, it is recommended that any metal column internals are also inspected and replaced with more efficient FRP analogues where possible.
- Conversely, internal refitting of the existing units (to install new corrosion resistant lining) will also pose a very significant cost, where the level of safety afforded is much lower, since the lining may be cracked or damaged during installation or subsequent maintenance, denying its protective function.
- Most process heat exchanger equipment will require replacing / undergo reconstruction so as to ensure protection of the surfaces exposed to acids, brines and catalyst traces that almost certainly are present in the system, for reasons outlined in the previous comment.
- New compression equipment throughout
- New heavy residue storage tanks.
- New toluene solvent storage tank.
- Chloroprene monomer distillation unit will need to be relocated away from current position due to its proximity to public road, which poses a danger to the public.
- A new waste incineration unit is required.
- **Works related to the final chloroprene monomer neutralisation, as well as those required for the NO inhibitor production unit (both located within Area 1-18), are covered as part of the butadiene section discussion (please refer to p. 2-101)**
- Purchase of adequate spares to enable reliable unit operation.
- Replace interconnecting carbon steel pipe connections with FRP.
- Install new instrumentation, associated cabling and new Direct Control System (DCS), together with new operators' room.
- Largely replace and reinstall insulation where necessary, due to poor condition of the present.
- Restore drainage
- Install suitable acid resistant flooring to manage any process spillages in an environmental responsible way

24 kta of Polychloroprene Rubber (PCR) production via acetylene:

- In addition to the works listed above, a subsequent expansion to 24 kta of production would largely require the same works, as well as:
- Install additional 3 dimerization reactors, together with accompanying supporting structure.
- New hydrochlorination reactors will need to be resized to accommodate for new flows. This will also require the redesign of the existing section that houses both hydrochlorination and final chloroprene monomer distillation.

Condition of the Chloroprene Production Unit Structures

The condition of the associated supporting structures is summarised below.

Table D-9: Condition of buildings & associated infrastructure for Chloroprene Production from Acetylene

Equipment name	No. of	Condition	Comment
Dimerization Synthesis Structure	1	Inadequate	Heavy corrosion, appears to be structurally unsafe and will require reinforcement
Acetylene Compressors House	1	Adequate	
Structure for Drying and MVA absorption into toluene	1	Adequate	
MVA hydrochlorination and distillation support structure, plus operators house	1	Inadequate	The whole unit will need to be moved away the site perimeter
Toluene regeneration support structure	1	Adequate	
Catalyst Preparation support structure	1	Inadequate	Structurally unsafe, will need to be re-erected
Liquid Waste Incineration support structure	1	Inadequate	Structurally unsafe, will need to be re-erected
Waste Incineration Building	1	Adequate	New Paint

Source: Jacobs Consulting Ltd.

The general condition of pipe racks and their supporting pylons ranges from adequate to poor, and thus will have to be reviewed should this unit be placed in operation again.

Liquid and Chlorinated Waste Incinerator

At present, the site has four separate incinerator units, based on a soviet GosNIIChlorProject¹² design. The condition of these units is extremely poor owing to years of operation in a highly corrosive environment without adequate funds being made available for their maintenance.

The Jacobs Consultancy team has not been convinced that the existing incinerators, even after proposed refurbishment, will be able to reliably destroy chlorinated organics and meet the latest environmental discharge regulations. Emissions of dioxins are a particular concern, owing to short residence times. EU BAT specify at least 2 seconds of residence time are required to ensure dioxins destruction, whereas the present unit even lacks measurements to confirm these.

¹² RUS: ГОСНИИхлорпроект

It is therefore proposed that 2 x 50 new incinerator units are procured. These packages can be procured from well-known international vendors such as John Zink, Zeeco or Caloric, specialising in supply of halogenated waste thermal oxidizer systems.

Utilities Supply

The following list of issues was noted with regards to the Chloroprene Production from Acetylene Unit:

- Area 1-12a, b: The chemical sewer will have to be rechecked for integrity
- Area 1-19: New Chlorinated and Liquids Waste Incinerator is required
- New CW supply is presumed

Unit Operability & Condition of the Process Instrumentation and Control systems – Acetylene based Chloroprene Production

The overall process unit control is manual, operated by field operators on a pneumatic control system, whereby measurements are made by local instrumentation. We consider this is an unacceptable mode of operation for such a dangerous process and an outdated one. We cannot recommend this process to be operated without installation of a new digital DCS control system, which will minimise the amount of personnel and their time spent in the vicinity of the process unit. A large number of field operating staff allocated to this unit is an added safety concern, due to the increase in likely human cost of a potential operation incident.

Venting

A particular concern was the venting practice in this unit, in particular the purging and release of soot which is very poor and requires urgent general attention. For example, there was evidence of certain practices with regards to clearing of the accumulated soot in the cracked gas pipework, whereby some of the cracked gas together with the soot was vented together to atmosphere resulting in large amounts of particulates being released to the atmosphere within Yerevan city limits.

This is unacceptably poor environmental practices and requires a management initiative to radically change the operating culture on site, in order to prevent safety incidents which will invariably cause expensive down time due to loss of production.

PolyChloroprene Production Unit

Process Overview – PolyChloroprene Production

Nairit's Polychloroprene production unit has been licensed from DuPont and was installed by a Japanese contractor in 1986.

Start-up Date:	1986.
Design Capacity:	50 kta
Actual Capacity:	25 kta
Planned Revamp:	+10 kta

Area 1-21: 2,3-DCB co-monomer Production and Recovery of Recycled CR

Area 1-21 is intended for production of 2,3-dichlorobutadiene-1,3 co-monomer, which is used within the polymerisation area 1-22 together with chloroprene, as well as additional treatment of the

chloroprene product (which is derived from acetylene if the plant is operating the acetylene route) or for recovery of recycled chloroprene from Area 1-22.

2,3-dichlorobutadiene-1,3 (2, 3 DCB) Production:

This process unit uses some of 1, 3-DCB available from the Chloroprene Production Unit (butadiene route) to produce necessary quantities of 2, 3-DCB co-monomer on a batch basis. 2, 3-DCB co-monomer is used for the production of certain grades of chloroprene rubber, as it helps to restrict the crystallisation tendency of the PCR chain. The unit itself was licensed from DuPont and comprises of the following stages:

- 1,3-dichlorobutene-2 Chlorination
- 1,2,3-trichlorobutene-3 Distillation
- 1,2,3-trichlorobutene-3 Dehydrochlorination
- 2,3-dichlorobutadiene-1,3 Distillation

The unit capacity is 5.8kta (based on 7,200 operating hr/annum).

The unit has been mothballed since 1992, but it did not appear to be in an overly poor state. This unit is not essential to PCR production, but its absence does restrict the range of PCR products that Nairit's plant will be able to produce. The unit is missing all of its instrumentation.

Distillation of acetylene based and recycled Chloroprene

Nairit carried out the design of this section in-house, using equipment and utilities available on site at the time, in order to accelerate the commissioning of the Chloroprene Production Unit (based on Acetylene) in 1994, due to perceived CAPEX savings and lack of available plot space within the Chloroprene Production Unit (Area 1-12). The purpose of the unit is to distil out the inert α -chloroprene and thus improve the specification of the processed chloroprene. The unit capacity is 30 kta of recycle chloroprene (based on 7200 operating hr/annum).

Unfortunately, this sub-unit has not been adequately maintained and is in need of capital repair. Since it has been taken offline, Nairit operators have used the back end distillation equipment of the butadiene based Chloroprene Production Unit (Area 1-18) instead. Thus, chloroprene derived from either butadiene or acetylene must undergo final distillation within Area 1-18 of the Chloroprene Production unit. At present, this distillation unit is not critical for operation at 35 kta of PCR capacity, due to the possibility of using the existing equipment within Area 1-18. However, its restoration in the future, will allow increasing the throughput capacity of Area 1-18 process equipment. The unit requires installation of new reboilers and pumps

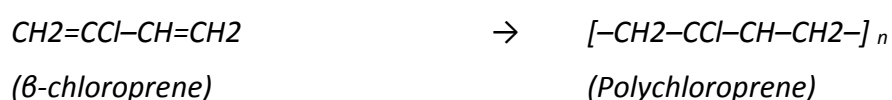
We recommend that no further action to bring this unit online is taken at present, as we do not recommend that acetylene based production of chloroprene is resumed and the existing chloroprene production unit based on butadiene (Area 1-18) has enough capacity in its final distillation section to process the additional chloroprene recycle from the chloroprene polymerisation unit (Area 1-22). It might be of interest to continue to mothball this unit, with a view for future capacity expansion, whereby the existing distillation section within Area 1-18 becomes the bottleneck. However, this is not a present concern.

Area 1-22: Chloroprene Polymerisation

Polymerisation Reactors

Chloroprene from intermediate storage is first collected in a monomer holding drum. The polymerisation itself is done as a batch process (there are six such reactors in parallel), so a measured quantity of monomer is pumped from this drum into a monomer holding vessel above each reactor. At the same time, measured quantities of demineralized water, initiators, promoters, regulators, emulsifiers, modifying/stabilizing agents and caustic soda is also pumped to their respective holding vessels above the reactor. Each bin has its own set of weights so that the quantity of each reagent is correctly measured.

The monomer and demineralized water are then introduced and to the mixture is agitated by means of an internal stirrer. The exothermic polymerisation reaction is then started by introduction of the initiator and emulsifier at 35°C:



The extent of polymerisation required varies on the type of rubber that is being made in any particular batch (see Table D-10 below). The extent of conversion is measured by taking regular samples and analysing them for density, and this is controlled by varying the flow of a brine refrigerant through the reactor's cooling jacket. The polymerisation reaction can be put on hold by maintaining a constant temperature inside the reactor, while the samples are analysed in the adjacent building's lab. The end product of polymerisation is a latex, which is a stable colloidal mixture of polychloroprene and unreacted chloroprene in an aqueous state.

Table D-10: Extent of Polymerization depending on the type of PCR rubber production

PCR Rubber Type			Chloroprene Monomer Conversion (wt.%)
1	ДМ	DM	67
2	ДВ	DV	67
3	ДСР	DSR	85
4	ДН	DN	65
5	ДХ	DH	65
6	ДСН	DSN	86
7	ДКР	DKR	85
8	ДКТ	DKT	90
9	ДКМ	DKM	85
10	ДП	DP	67

The product aqueous latex is then discharged into a crude latex holding drum underneath the reactor, from where it is pumped to the degassing section.

Degassing

Crude latex in its aqueous state is first preheated by direct steam (105°C) injection to vaporise any unreacted chloroprene, which is then separated in a two stage cyclone separator system (0.2 bar g and vacuum), condensed against brine refrigerant and collected in a dedicated unreacted chloroprene solution tank, from where it is then pumped back to the Chloroprene Production Unit for recovery, final purification and reuse. Non-condensable gases from the brine chillers are vacuum ejected to atmosphere.

The resultant 38-40% latex solution is recovered from the bottom of the second cyclone separator and stored in a check tank under nitrogen blanket for 24 hours to observe latex quality. Latex is not neutralised at this stage, but a small quantity of mercaptan regulator is added to maintain its stability.

Pilot Unit (Labs)

As part of Area 1-22, there is also a pilot plant facility, which is an exact replica of the polymerisation unit and as such it is used to test run the entire chain (batch polymerisation, degassing and rubber extraction). This unit is in a good condition and in the future it will allow Nairit to experiment with different reagents for polymerisation in order to optimise cost/performance.

Latex Production

Originally, there was also a latex production line, but this has not been maintained and is now decommissioned.

Area 1-23: Rubber Extraction

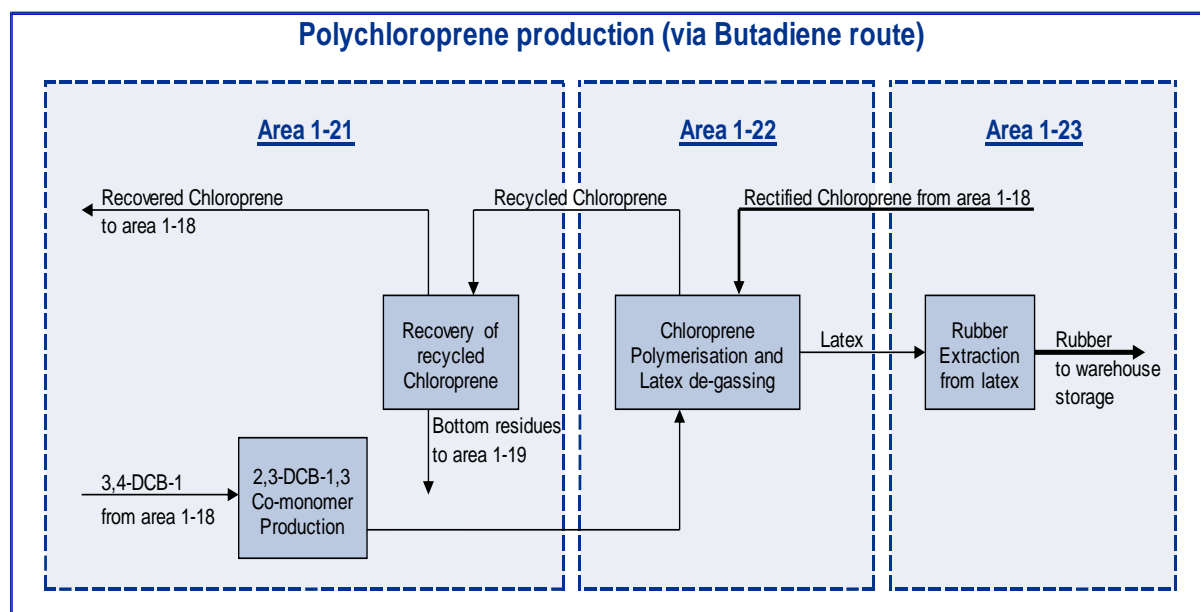
Neutralised latex solution from Area 1-22 is pumped onto a rotating cooling drum, which is internally chilled using brine refrigerant. As the drum rotates, it coagulates the latex contained in the solution by solidifying it and thus forming a thick latex film, allowing the remaining water to be collected underneath it. Small quantity of acetic acid is added to this tank to neutralise the condensate.

The latex film band is then peeled off the rotating drum and directed through a washing conveyer where it is washed with water to remove any remaining impurities and fed to a dryer unit which contains stacks of rotating rolls, allowing the latex film band to be blow dried with hot process air. The dry latex film band is then cooled on a specially chilled roll and conveyed to a chopping machine, where talc is added and the rubber is chopped into 2x1 inch irregular rubber 'chunks', which can then be packaged into 25 kg bags and sent to storage as saleable product.

Block Flow Diagram

A Block Flow Diagram for the production of PCR rubber from chloroprene monomer is shown below.

Figure D- 4: BFD for PCR Unit



Source: Jacobs Consulting Ltd.

Material Balance

The overall material balance for the process unit shown below:

Table D-11: Material Balance for PCR Unit (as per design)

Plant/Acetylene route		Area 1-21	Area 1-22 & 1-23
Product		Treated Recycled CR	Rubber
Units of the product		t	t
Mass Balance		Units	
Caustic Soda	t		-0.0085
100% NO	t	-0.0002	
Dry CR	t		-0.975
Chloroprene to Recycle (internal)	t	-1.004	0.500
Chloroprene from Recycle (internal)		1.000	
Rubber	t		1.000
Waste (to Incinerator)	t		0.100

Source: Jacobs Consulting Ltd.

Utilities, Catalyst and Chemicals Requirements

The overall specific consumptions of utilities, catalyst and chemicals for the PCR unit are shown below:

Table D-12: Utilities, Catalyst and Chemicals Requirements for PCR Unit (as per design)

Plant/Acetylene route	Area 1-21	Area 1-22 & 1-23	
Product	Treated Recycled CR	Rubber	
Units of the product	t	t	
Utilities, Catalysts and Chemicals (per ton product)			
Additional Chemicals (per ton of product)			
Nitrosodiphenylamine, t/t	-0.000005	-0.000050	
Fentiazin, t/t	-0.000010		
Fentiazin 95%, t/t		-0.000304	
4-methyl-2 ,6-di-TRT-butylphenol, t/t			
Toluene (petroleum), t/t			
Acetic acid 99.5%, t/t		-0.014300	
Toluene, t/t		-0.019000	
Sodium sulfite 96%, t/t		-0.002250	
Carbon white, t/t		-0.000008	
Ethylene glycol 99.8%, t/t		-0.003330	
100% sodium lauryl sulfate, t/t		-0.000220	
Potassium persulfate 98%, t/t		-0.000060	
Pine Rosin disproportion. (Resin 731-S), t/t		-0.043970	
The silver salt (imported) 90%, t/t		-0.000003	
Lomar PW, t/t		-0.008370	
Silicon (PMS), t/t		-0.000146	
P-tert-butylpirokatehin (Import), t/t		-0.000244	
Talc, t/t		-0.012350	
Ethylene glycol 99.8%, t/t		-0.000080	
Sodium Bichromate			
Cation Resin, t/thous m3			
Anion resin, t/thous. M3			
Utilities - Specific Consumption (per ton of product)			
Steam	GJ	-7.95	-38.31
River Water	t		
Process Water	m ³	-4.0	-4.5
Cooling Water	m ³		
Filtered Water	m ³		0.00
Demineralised water	m ³		
Power	kWh	-11.2	-724.0
Process Nitrogen	m ³		
Compressed Air	m ³		-37.4
High Purity N2	m ³	-200.0	-154.2
Refrig at -15°C	Mcal	-60.0	-644.0
Refrig at -30°C	Mcal	-100.0	-976.3

Source: Jacobs Consulting Ltd.

General Condition of the Polychloroprene Rubber (PCR) Unit

The condition of the equipment contained within the PCR unit varies. While some of the process units (such as Area 1-21) have been mothballed and require significant testing, as well as the acquisition of new process equipment, the critical process equipment appears to be generally in an adequate condition.

While there was evidence of surface corrosion throughout the unit's process equipment, those vessels that we inspected (reactors, cyclones) appeared to be generally corrosion free.

Our major concerns with regards to the present condition of this process unit are as follows:

- Area 1-21's 2,3 DCB co-monomer production unit has been mothballed since 1992 restricting the ability of Nairit to produce a full spectrum of PCR grades. The inability of the plant to commercially produce latex grades of PCR will limit the access to certain markets.
- There are insufficient HSE measures taken, so far, with regards to the safe operation of this process unit:
 - The current process includes utilisation of existing atmospheric vents, which will lead to some unnecessary halo-hydrocarbon emissions into atmosphere, nor does it contain adequate sensors to measure these emissions. Nairit have indicated that the revamp design includes routing of such vents to a suitable hydrocarbon collector for safe disposal at flare, but this is yet to materialise and will require additional investment.
 - There are no gas detectors in the area and we did not see that operators are provided with adequate PPE.
 - The ventilation system was in poor condition and must be repaired/renewed.

However, none of these concerns is an overriding one. Commissioning risks can be offset with adequate careful planning and provision of contingency budgets and schedules. We have assumed that a new dedicated DCS system will be installed to operate this unit, as suggested by Nairit's management and their cost estimate forwarded to us.

A more detailed overview of the type of works required is summarised below.

12 kta of Polychloroprene Rubber (PCR) production via acetylene:

- Within section 1-21, we identified a number of main process equipment items that should be replaced before the plant re-enters operation. This list is limited to all pumps and reboiler # 26-132-*1E only. Although 2,3-DCB co-monomer production unit is a very nice add-on, since it would allow Nairit to produce a full spectrum of PCR grades and thus expand its market reach, it is not essential for start-up and may be brought online once the plant is running.
- In addition to these costs, it will also be necessary to introduce a number of changes to the overhead vent within unit 1-21. At present, this vent is expected to discharge small quantities of Nitric (I) Oxide, NO, inhibitor and β -chloroprene directly to atmosphere, after dilution with nitrogen to bring the concentrations down to safe levels for field operators to be near the vent. This is not an acceptable technical solution from the point of view of good international practice or for example EU regulations, especially since NO rapidly oxidises to NO₂, a major pollutant responsible for brown smog from car exhausts. As such, an alternative process revamp will be required.
- One solution would be to install a selective catalytic mini-reactor to decompose NO into elemental nitrogen and oxygen, using technology readily available for nitric acid plants. However, this would still leave the problem of β -chloroprene to be addressed.

- Given the small volume of this stream, the most cost-effective solution would be to pump this stream towards the chlorinated liquids waste incinerator, via a collector gas line proposed to aggregate process vents from unit 1-18. This would limit the works to simply install a transfer line to take NO and β -chloroprene back to unit 1-18, where it will be mixed with process vent streams and the aggregate sent to incinerator for disposal. The expected quantity of NO from unit 1-21 during normal operations is ~ 0.5 kg/hr, which is expected to add about ~ 5 -15 ppm of NOx to the incinerator emissions (depending on quantity of co-fed liquid waste). This solution should be reviewed during engineering design.
- Within section 1-22, based on visual inspection of the process plant equipment and their internals, most of the main process equipment items contained within this process unit were found to be in a generally adequate condition and of good integrity. However, we note the following equipment items need attention:
 - The main volatile extraction system should be completely replaced to comply with European safe exposure limits for the process operators.
 - It is recommended that all pumps are replaced (for reliability purposes).
 - The stirrer shaft bearings on the main reaction vessels appear to be in poor condition and require further inspection and possible replacement. This is a key process management issue where a failure would result in loss of product.
 - A number of heat exchangers in the overhead system must be replaced.

The piping in the area appears to be in an adequate condition but there were areas of external surface corrosion due to carbon steel surfaces. The true integrity of the piping will not be known until the process is re-started but there should be an allowance in the budget to replace a significant amount of this piping to ensure process integrity.

Nairit's chloroprene polymerisation area has 6 independently operated batch reactors installed in parallel. Currently, only 2 are in an operational condition, but the others appear to be in an adequate condition, with signs of only minor external surface corrosion but lacking instrumentation. We do not expect that Nairit will have to replace these reactors, but a detailed investigation must be carried out to determine the cost of the works involved.

- Within section 1-23, based on visual inspection of the process plant equipment and their internals, the final product packaging line appears largely adequate for the initial production volumes but will require an intensive period of maintenance to bring the line back to full commercial production. A new more modern final product packaging line will be required at some stage in the future.

24 kta of Polychloroprene Rubber (PCR) production via acetylene:

A major concern is that despite having most of the equipment in place, the existing plant has not been operated at the proposed 24 kta capacity since 1994 and therefore there is the possibility that last minute replacements might be required as issues arise during the commissioning process of the existing lines, various process equipment and associated unit's pipework may be found unfit for purpose and will have to be replaced at short notice.

However, in principle all of the major equipment required to achieve production rates of up to 24 kta is already installed.

Condition of the PCR Unit structures

The condition the process sub-units is summarised below.

Table D-13: Condition of buildings & associated infrastructure for PCR Production

Equipment name	No. of	Condition	Comment
Area 1-21: Storage Tanks Park	1	Adequate	Dilapidated, need to repair piperacks
Area 1-21: Storage Pump House	1	Adequate	Dilapidated, need to repair roof, new pumps
Area 1-21: Main Process Housing Structure	1	Adequate	Dilapidated, need to repair piperacks, repairs the CRacking conCRete
Area 1-21: Process Control Building	1	Adequate	Dilapidated, needs new windows
Area 1-21: Firewater pump house	1	Adequate	Dilapidated, need to repair roof and new windows and firewater supply line
Area 1-22: Main Process Housing for polymerisation and degassing	1	Adequate	Need to repair windows, repair/replace ventilation system, clear out redundant kit, replace acid resisting brick where necessary
Area 1-22: Process Control Building& Labs (including pilot unit)	1	Adequate	
Area 1-22: DMW water and resin melting building	1	Adequate	
Area 1-22: Instr. and Plant Air Building	1	Adequate	
Area 1-23: Rubber Extraction Building	1	Inadequate	See note below
Area 1-23: Heat Distribution Building	1	Adequate	
Area 1-23: CW pump-house	1	Adequate	
Area 1-23: CW towers	1	Adequate	
Area 1-23: New Rubber Extraction Building	1	-	Need a new building for an additional line

Source: Jacobs Consultancy Ltd.

Area 1-22: Process Control Building & Labs (including pilot unit)

The building is in good condition, but we anticipate substantial work will be done to fit a new DCS system for improved process control.

Area 1-23: Rubber Extraction Building

While the building appears to be in a sound structural condition, the following improvements must be implemented before restarting production:

- **Need to contain off the latex freezing drum, latex washing and final cooling rod areas to minimise unreacted chloroprene emissions**
- Repair parts of the flooring areas with acid resistant tiles
- Repair roof and provide new windows
- Install new gas detectors and chloroprene monitoring devices to measure emissions within the operator area.
- New DCS control system

Utilities Supply

The following list of issues was noted with regards to the PCR Unit:

- General: Lack of firewater supply to the process (generally)
- General: The chemical sewer will have to be rechecked for integrity
- General: Need to provide for liquid and gas waste streams from this unit to be routed to the proposed new incinerator for thermal destruction of its hydrocarbon content, prior to release to atmosphere.

Unit Operability & Condition of the process instrumentation and control systems

At present, the overall process unit control is largely manual, operated by field operators on a pneumatic control system, whereby measurements are made by local instrumentation. However, the revamp work cost estimate provided to us by Nairit management includes a suitable cost estimate for a new DCS to be installed prior to unit restart. We consider this to be the correct approach.

Venting

A particular concern is the current presence of atmospheric vents within the design of this unit, which will lead to some chloroprene and related compounds being released to the atmosphere within Yerevan city limits.

This is not current best practice and does not comply with the best available technologies requirements in the West. We recommend that the design of the plant is reviewed to route these vents to a suitable source of thermal destruction.

Existing Process Units – Butadiene Route

Summary of Main Process Units (ISBL)

The site comprises of three main Inside Battery Limits (ISBL) units, as well as the necessary utilities and offsite facilities to enable continuous production. The ISBL units are listed below:

- **Chlor-Alkali (C-A) Unit:**
- This is the same unit, as per Acetylene route.
- Area 1-1: Solvay process area for sodium carbonate production
- Area 1-4 a, b: Brine Production and Treatment
- Area 1-3 a, c: Caustic Soda (NaOH) Production
- Area 1-3 b: Brine Electrolysis

- Area 1-5: Hydrogen Chloride (HCl) production. **This unit is not required for butadiene route.**
- Area 1-20: Liquid Chlorine and Sodium Hypochlorite Production
- **Chloroprene (CR) Monomer Unit:**
- Area 1-18: Chloroprene production from butadiene. This area includes butadiene storage, chlorination, Di-Chloro-Butene (DCB) treatment, isomerization and dehydrochlorination sections, as well as chloroprene neutralization. Chloroprene neutralization unit combines both acetylene and butadiene derived chloroprene for neutralization purposes, prior to it being sent across to the PCR rubber unit for further polymerization.
- This area also includes a nitric oxide preparation unit (from nitric acid), which is then fed to Area-12b (chloroprene distillation), as well as used internally to stabilize chloroprene monomer.
- Liquids and chlorinated hydrocarbon waste generated within this area of the chloroprene monomer unit are sent to Area 1-19 for disposal via incineration.
- **Poly-Chloroprene Rubber (PCR) Unit:**
- This is the same unit, as per Butadiene route.
- Area 1-21: Recovery of recycled chloroprene
- Area 1-22: CR polymerization and degassing.
- Area 1-23: Rubber finishing lines.

Condition of the Main Process Units – ISBL

Chlor-Alkali Unit

The condition of the existing chlor-alkali unit has been discussed in some detail above (please refer to p.2-58)

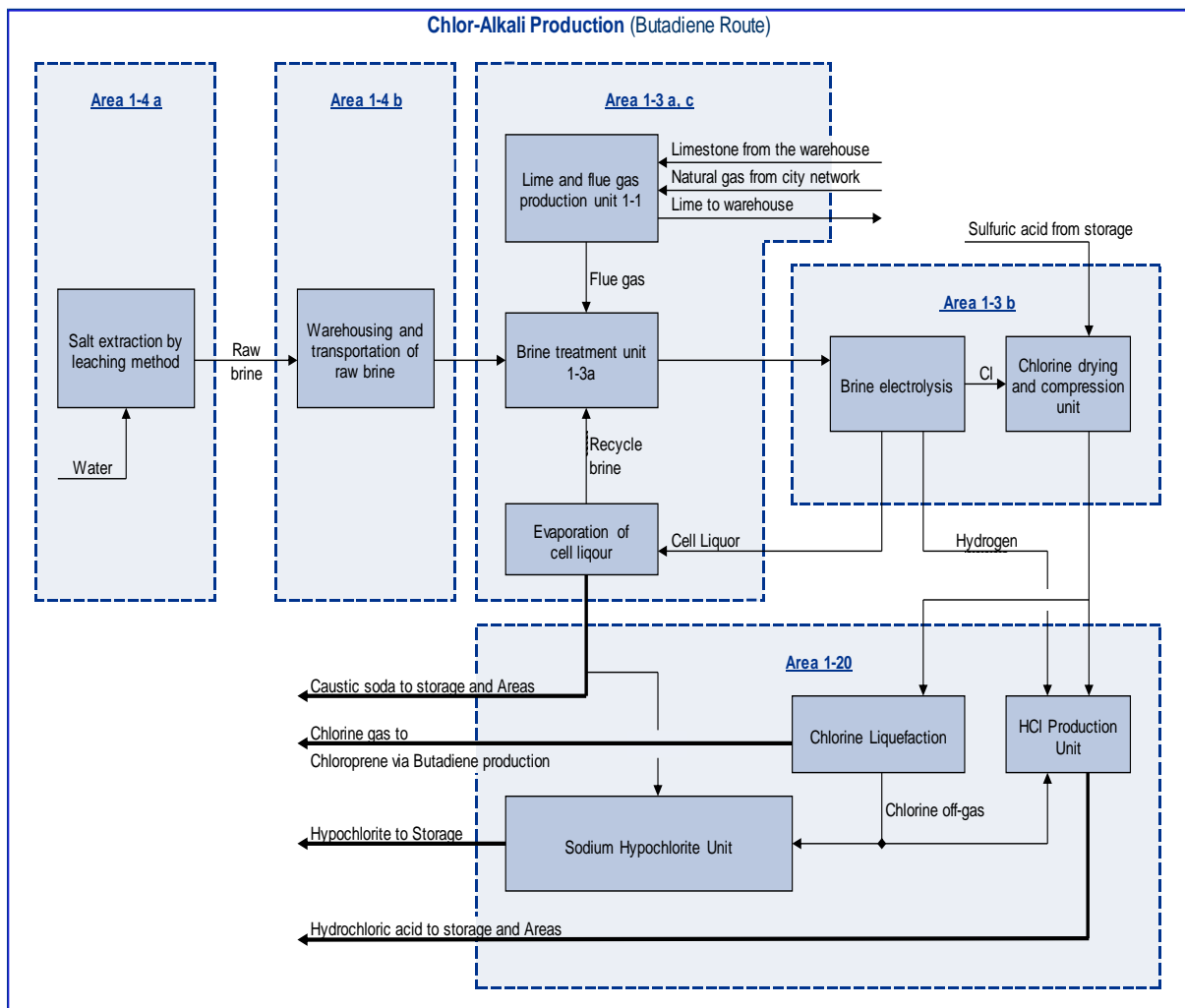
In the event of chloroprene monomer production from butadiene, the key required chlor-alkali product is chlorine gas rather than HCl. Critically, due to both high purity requirements for chlorine gas that may be used within chloroprene production from butadiene, as well as the increased chlorine throughputs required; the existing diaphragm electrolysis units are not well suited. **Thus, we consider that a new modular unit has to be installed instead.**

New Chlor-Alkali Unit

Block Flow Diagram

Schematic Block Flow diagram of Chlor-Alkali production for butadiene route is shown below.

Figure D- 5: Chlorine Production (Butadiene Route) Block Flow Diagram



Source: Jacobs Consulting Ltd.

Material Balance

The material balances for Chlor-Alkali Production, via Butadiene route are shown below.

Table D-14: Material Balance of Chlor-Alkali Production (Butadiene Route) (as per design)

Plant/Butadiene route		Area 1-4a	Area 1-3c & 1-3a			Area 1-3b	Area 1-20					
Product		Brine Make-up	Quicklime	Treated Brine	Caustic Soda 100%	Cell Liquor	HCl (100%)	Hydrochloric Acid	Liquid Cl ₂	Liquid Cl ₂ in small packages	Sodium Hypochlorite	Calcium Hypochlorite
Units of the product		m ³	t	m ³	t	t	t	t	t	t	t	t
Mass Balance - t/t product		Unit										
Nat. Gas	000 Nm ³		-0.139									
Limestone	t		-1.780									
Quicklime	t		1.000									-0.500
Brine Makeup	t (of NaCl)	0.310		-0.164								
Treated Brine	m ³			1.000		-10.600						
Recycled Brine	t (of NaCl)			-0.146	1.620							
Cell Liquor (100% basis)	t				-1.043	1.000						
Sodium Hyperchlorite	t										1.000	
Calcium Hyperchlorite	t											1.000
Caustic Soda	t			-0.002	1.000						-0.1981	-0.0500
Hydrochloric Acid	t			-0.00468	-0.007	-0.0022		1.000				
H ₂	t					0.025	-0.030					
Cl gas	t					0.886	-1.000		-1.175		-0.154	
Liq Cl 100%	t								1.000	-1.035		-0.450
Liq Cl in small package	t									1.000		
HCl	t						1.000	-0.318				
Flue gases (100% CO ₂ basis)	Nm ³		139.000	-1.100								
Sulphuric Acid (100%)	t				0.000	-0.02700				-0.00186		
Sodium Sulphate	t					-0.00046						

Source: Jacobs Consulting Ltd.

Utilities Requirements

The utility requirements for Chlor-Alkali Production, via Butadiene route are shown below.

Table D-15: Chlor-Alkali Production (Butadiene Route) Utilities Requirements (as per design)

Plant/Butadiene route	Area 1-4a	Area 1-3c & 1-3a			Area 1-3b	Area 1-20						
Product	Brine Make-up	Quicklime	Treated Brine	Caustic Soda 100%	Cell Liqour	HCl (100%)	Hydrochloric Acid	Liquid Cl2	Liquid Cl2 in small packages	Sodium Hypochlorite	Calcium Hypochlorite	
Units of the product	m ³	t	m ³	t	t	t	t	t	t	t	t	
Utilities, Catalysts and Chemicals (per ton product)												
Utilities - Specific Consumption (per ton or m³ of product)												
Steam (GJ), *yearly average	GJ			-15.26	-3.62			-0.59	-0.60	-0.22		
River Water (t)	t	-0.0011										
Process Water (m3)	m ³		-8.00	-1.00	-50.00	-70.00	-18.00	-35.50	-3.00	-15.00	-0.46	-20.00
Cooling Water (m3)	m ³											
Filtered Water (m3)	m ³				-2.80							
Demineralised water, (m3)	m ³											
Power (kWh)	kWh	-4.80	-13.00	-3.88	-141.00	-2900.00	-4.00	-2.91	-30.00	-257.00	-105.50	-65.00
Process Nitrogen, m3/t	m ³											
Compressed Air, (m3)	m ³			-5.30	-7.60	-18.00	-20.00			-36.00		
High Purity N2, (m3)	m ³					-21.00	-21.00		-60.00	-145.00	-3.00	
Refrig at -15°C (Mcal)	Mcal											
Refrig at -30°C, (tMcal)	Mcal					-6.60			-100.00		-20.00	

Source: Jacobs Consulting Ltd.

Licensing for New Process Unit

Three processes are used commercially for the production of chlorine and caustic soda:

- The mercury cell process
- The diaphragm process
- The membrane process

All of the above processes consume large amounts of electrical power. **The power demand per ton of chlorine ranges from around 3 200 – 3 600 kW-hr for the mercury process to 2 800 – 3 100 kW-hr for the diaphragm process, to around 2 800 – 3 000 kW-h for a modern membrane process.**

Not least because of the higher power consumptions, the mercury cell and diaphragm processes are now considered wholly obsolete for new construction, though existing plants with these processes continue to operate. Both these types of obsolete plant are also now under severe environmental pressure; mercury cells due to their mercury emissions and diaphragm cells since the diaphragm is composed of asbestos and hence poses a hazard in fabrication, replacement and disposal.

For the last 20 years all new construction has been based on the membrane process. In the membrane process the anode and cathode are separated by an ion exchange membrane. This membrane only allows Na^+ ions and a certain quantity of water to diffuse into the cathode chamber. The fresh brine (NaCl) enters the anode compartment where chlorine gas (Cl_2) is generated at the anodes. The brine leaving the anode chamber is thus depleted, and caustic soda (NaOH) is removed from the cathode chamber. Hydrogen gas is also evolved at the cathode.

Thus, the new chlorine production unit will be a membrane process. The technology can be licensed from the following leading providers of membrane technology.

- Asahi Kasei
- Chlorine Engineers
- Ineos
- Uhde

Chloroprene Production Unit

Process Overview – Chloroprene Production from Butadiene

Nairit's chloroprene production unit operated on butadiene feedstock is based on the BP/Distillers original process, developed in the UK in 1971.

Start-up Date:	1980
Design Capacity:	75 kta (briefly reached in 1987)
Actual Capacity:	Has not been run since 1995

Area 1-18 Chloroprene Production from Butadiene

The process is based on 3 key reaction stages:

- Butadiene Chlorination to di-chlorinated isomers
- Isomerisation of 1,4-di-chloro-2-butene to 3,4-di-chloro-1-butene
- Dehydrochlorination of 3,4- di-chloro-1-butene to chloroprene

All of the stationary equipment was manufactured in the USSR, whereas the rotating equipment and pneumatic control system were supplied by firms from UK and Japan.

Chlorination

There are three chlorination reactors, each with an equivalent capacity of 25 kta of chloroprene monomer. Butadiene from storage is first passed through a series of brine refrigerant chillers and dryers, to achieve a water content of less than 10 ppm, before it is fed to the overhead condenser system of the degassing column downstream of the chlorination reactors. The overhead product from the degassing column contains mainly unreacted butadiene, HCl and other light end inerts. The mix of this recovered butadiene stream and fresh feed is then compressed and preheated with steam, before being fed to the chlorination reactors, of which Nairit have 2+1, due to a much large throughput of the unit when originally operated. These contain an inlet mixer through which chlorine gas from the chlor-alkali unit is mixed into the butadiene stream, always maintaining a large excess of butadiene to limit the formation of super-chlorinated products (e.g. tetra-chloro-butane) and act as a heat carrier, absorbing the heat from the exothermic reactions. The reactor is an empty shell, containing no catalyst, where the following reactions take place at about 270°C and 1 atm:

- $CH_2=CH-CH=CH_2 + Cl_2 \rightarrow CH_2Cl-CH=CH-CH_2Cl$
(butadiene) (1,4-dichloro-2-butene or 1,4-DCB)
- $CH_2=CH-CH=CH_2 + Cl_2 \rightarrow CH_2Cl-CHCl-CH=CH_2$ (butadiene)
(3,4-dichloro-1-butene or 3,4-DCB)
- $2CH_2=CH-CH=CH_2 + Cl_2 \rightarrow 2CHCl=CH-CH=CH_2$
(butadiene) (α -chloroprene or 1-chlorobutadiene)
- $2CH_2=CH-CH=CH_2 + Cl_2 \rightarrow 2CH_2=CCl-CH=CH_2$
(butadiene) (β -chloroprene or 2-chlorobutadiene)

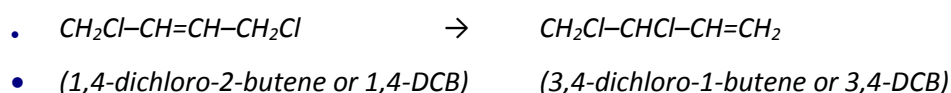
Other by-products of the reaction are tri-chloro-butanenes, tetra-chloro-butanenes and polymeric tars. The reactor effluent is then quenched against cooled reactor effluent down to 100°C, passed through a water cooler to reduce the temperature down to 40°C and fed to a check tank, from where both liquid (primarily DCBs) and gaseous (mainly unreacted butadiene) phases are then separately fed to a degassing column directly downstream. Nairit have two twin degasser trains. In the degassing column, unreacted butadiene, HCl and inerts are separated from the reactor effluent, recovered in the overhead condenser system, to be mixed with fresh butadiene feed and recycled back to the chlorination reactor inlet.

In order to prevent a build-up of inerts, a purge stream is taken from the stream routed to the chlorination reactors, cooled to -25°C and routed to a butadiene recovery column, where the butadiene in the purge is recovered in the counter-current wash with chilled circulating butadiene (recirculated from the column's bottom), and then a portion of the chilled degasser column bottom product. Some caustic is added to capture any HCl present. The inerts exiting the column in the overheads are then further scrubbed with water and vented to atmosphere. Butadiene captured in the wash, is chilled and then split. A part of the stream is pumped back to the top of the column to capture more butadiene in the incoming purge stream, while the rest is pumped back to the degassing column.

The bottoms product from the degassing column is then water cooled and fed to a heavy ends column, where higher chloro-butanenes and polymeric tars are removed at the bottom of the column, whereas di-chloro-butanenes and chloro-butadienes (1,4-DCB; 3,4-DCB; α - and β -chloroprenes) are recovered in the overhead condenser system, from where they are pumped to Isomerisation.

Isomerisation

Nairit have two twin isomerisation trains, each with an equivalent plant capacity of 50 kta of chloroprene monomer. Di-chloro-butanenes and chloro-butadienes from the heavy ends column in the chlorination section are first introduced to 3,4-DCB extraction column, where 3,4-DCB and light ends are separated from 1,4-DCB and recovered in the overhead condenser system. The bottom product is 1,4-DCB, which is partially reboiled, partially fed to an isomerisation reactor (using cuprous chloride catalyst solution – 200 ppm CuCl), which is an empty shell. A small quantity of phenothiazine inhibitor is added to prevent polymerisation, so that the following isomerisation reaction is favoured at about 115°C and partial vacuum:

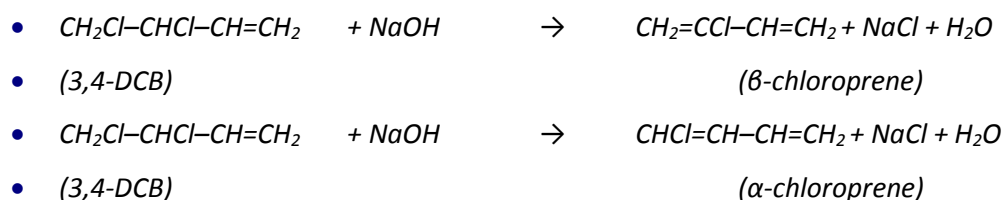


The liquid effluent is then circulated through four dedicated thermo-syphons (set in parallel) to vaporise the more volatile 3,4-DCB isomer, so that when the two phase flow is returned to the reactor, 3,4-DCB isomer product is taken as a gas product overhead and returned to 3,4-DCB extraction column.

3,4-DCB and light ends recovered in the overhead condenser system are water cooled and condensed. The remaining non-condensed gas is then further chilled against brine refrigerant and ejected to flare. The liquid 3,4-DCB and light ends are then fed to a light ends column, where the light ends are separated as an overhead product in both liquid and gas phases. The gas phase is then ejected to flare, whereas the liquid phase is pumped to the liquid and chlorinated waste incinerator area 1-19 for thermal destruction. 3,4-DCB is recovered as a bottoms product, from where it is dosed with polymerisation inhibitor and pumped to intermediate storage before being fed to dehydrochlorination.

Dehydrochlorination

3,4-DCB from intermediate storage is first used to wash outgoing off-gas from the chloroprene distillation to recover any traces of chlorohydrocarbons and then fed to the dehydrochlorination CSTR type reactor, to which fresh caustic, steam and polymerisation inhibitor are also added. The chloroprene recycle stream's liquid phase from downstream PCR rubber production unit is also routed to this column so as to maximise the recovery of useful halide hydrocarbons from the PCR rubber production unit. In the resultant alkali environment, 3,4-DCB is reacted at about 90°C and 5 bara:



Most of the reaction occurs in the liquid phase, which is continuously taken off at the bottom of the CSTR together with the formed brine and passed through a series of settlers to separate organic and aqueous phases. The organic phase is then returned for further chloroprene distillation, whereas the aqueous phase is then passed through a stripper column and sent to the OSBL wastewater facilities. The overhead organics gas is fed to the bottom of the chloroprene stripper column.

The effluent gas phase from the CSTR is fed to the middle of the same chloroprene stripper column, where the resulting distillation separates chloroprenes from the entrained aqueous phase. Crude β -chloroprene is collected overhead and sent to a final chloroprene product distillation column to remove the undesired α -chloroprene from β -chloroprene that is suitable for PCR rubber production. The chloroprene recycle stream's gas phase from the downstream PCR rubber production unit is also routed to this column so as to prevent a build-up of α -chloroprene impurity in the PCR rubber production unit.

β -chloroprene (99.5 wt.%) product is recovered overhead, condensed and sent to intermediate storage before being used as feedstock for batch polymerisation within PCR production plant. The off-gases are washed with incoming 3,4-DCB from intermediate storage to recover any trace 3,4-DCB and are then sent to flare. The bottom product is α -chloroprene, which is recycled back to dehydrochlorination reactor via the chloroprene stripper column.

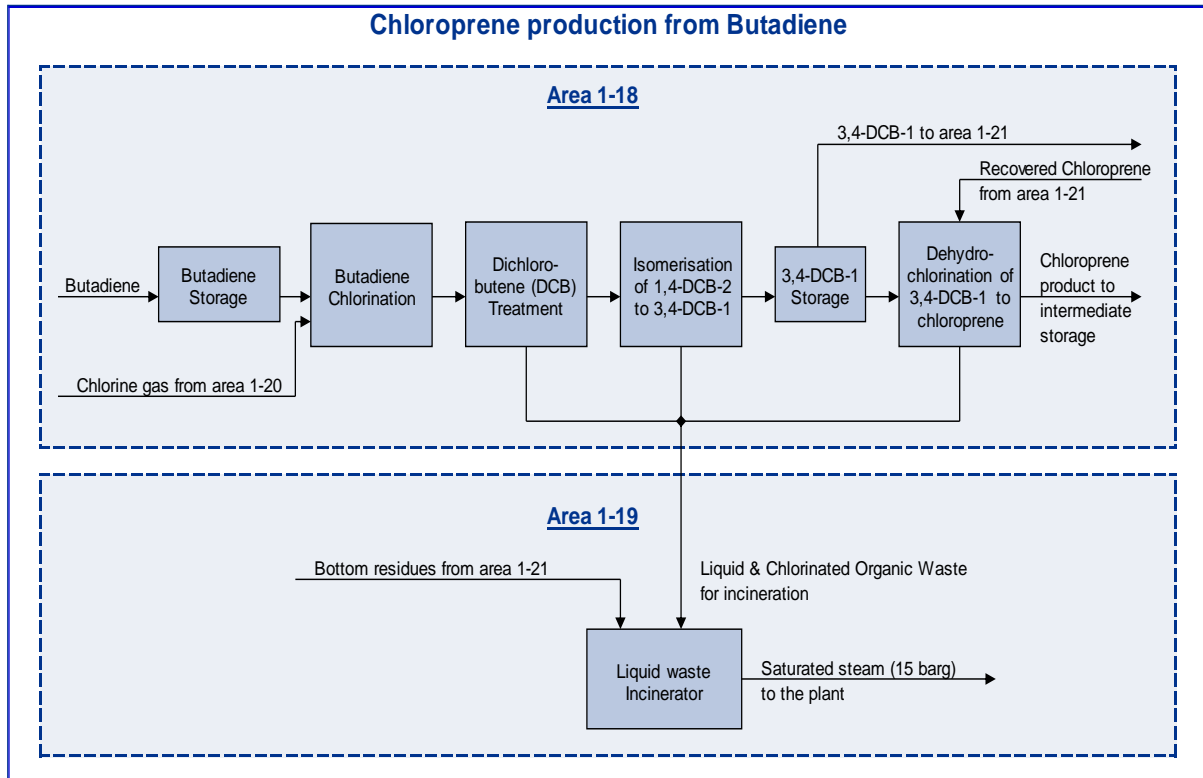
Area 1-19: Liquid Waste Incineration

This unit forms part of the chloroprene monomer production unit that is based on acetylene feedstock and further overview of the unit is provided within the associated discussion (please refer to p.2-76).

Block Flow Diagram

Block Flow Diagram for the production of chloroprene from butadiene shown below.

Figure D- 6: BFD for the Chloroprene Production Unit (based on Butadiene)



Source: Jacobs Consulting Ltd.

Material Balance

The overall material balance for the process unit shown below.

Table D-16: Material Balance for Chloroprene Production from Butadiene (as per design)

Plant / Butadiene Production		Area 1-18		Area 1-19
Product		10% NO-nitric oxide (on 100% basis)	CR from Butadiene	Waste Incineration
Per Unit of Product Produced		t	t	t
Mass Balance - t/t product		Unit		
Nat. Gas	000 Nm ³			-0.064
Caustic Soda	t	-3.5000	-0.8513	-0.0357
Sodium Nitrite	t	-4.470	-0.0056	
Nitric Acid (100%)	t	-2.730	-0.0034	
Butadiene (99.3%)	t		-0.8000	
Liq Cl 100%	t		-1.0200	
Liq Cl in small package	t			
100% NO	t	1.000		
Chloroprene Intermediate	t		1.0000	
Chloroprene to Recycle	t			
Chloroprene from Recycle	t		-0.4769	
Sodium Sulphate	t			0.008
Waste (to Incinerator)	t		0.231	-1.000
CaCl ₂	t		-0.00031	

Utilities, Catalysts and Chemicals Requirements

The overall utilities requirements for the process unit are shown below.

Table D-17: Utilities, Catalyst and Chemicals Requirements for Chloroprene Production from Butadiene (as per design)

Plant / Butadiene Production		Area 1-18		Area 1-19
Product		10% NO-nitric oxide (on 100% basis)	CR from Butadiene	Waste Incineration
Per Unit of Product Produced		t	t	t
Utilities, Catalysts and Chemicals (per ton product)				
Additional Chemicals (per ton of product)				
Zeolite K-3M			-0.000085	
Tertiary dodecyl mercaptane			-0.002400	
Isomerisation catalyst			-0.003300	
White spirit			-0.016000	
Ethylene glycol			-0.000110	
Tetrachloromethane			-0.000160	
Nitrosodiphenylamine			-0.000200	
Phenothiazine			-0.000070	
Butyl cellosolve			-0.040000	
Mordenite			-0.000050	
Utilities - Specific Consumption (per ton of product)				
Steam, yearly average	GJ		-35.77	
Process Water	m ³	-100.00	-17.50	-80.00
Cooling Water	m ³		-650.00	
Demineralised water	m ³		-8.99	-12.30
Power	kWh	-700.00	-335.00	-401.60
Compressed Air	m ³		-28.80	
High Purity N ₂	m ³	-16.70	-252.20	-20.50
Refrig at -15°C	Mcal		-394.00	
Refrig at -30°C	Mcal		-114.00	

Source: Jacobs Consulting Ltd.

General Condition of the Chloroprene Production Unit – Butadiene

The general condition of the equipment contained within Chloroprene Production from Butadiene section of the unit appears to be generally in an adequate condition and of good integrity. However, the plant has not been in operation since 1994 and therefore it is uncertain what actions or equipment replacements might be needed as a result of the commissioning process.

Generally, the unit's process equipment appeared to be corrosion free and well maintained, due to what appears to be carefully mothballing of the unit and continuous repairs that have been done on the unit's process equipment over the recent years, as Nairit's management have been trying to restore this route for some time now. Without doubt, it is the best kept process unit onsite.

Our major concern with regards to the present condition of this process is two-fold:

- It has not been operated since 1994, so despite visual appearance and Nairit's own testing of the equipment, there is a significant chance that a fraction of the process equipment and associated unit's pipework will be found unfit for purpose and will have to be replaced at the last minute.
- There are insufficient HSE measures taken so far with regards to operation of this process unit:
 - The current process design includes utilisation of existing atmospheric vents, which will lead to some unnecessary halo-hydrocarbon emissions into atmosphere, nor does it contain adequate sensors to measure these emissions.
 - There are no warning signs with regards to level drops within the supporting building structure for the unit
 - There are no gas detectors in the area and we did not see that operators are provided with adequate PPE.
 - The acid resistant brick at the foundations of the support structure is in a bad condition and must be restored/replaced where necessary
 - The fire-hose towers around the unit are severely corroded and must be replaced
 - The gangways around the high rise columns appear to be of inadequate quality standard, appearing both brittle and slippery.

However, neither of these concerns is an overriding one. Commissioning risks can be offset with adequate careful planning and provision of contingency budgets and schedules. HSE measures are not a major investment, but will require a significant change in site culture. We have assumed that a new dedicated DCS system will be installed to operate this unit, as suggested by Nairit's management and their cost estimate forwarded to us.

The upside of the current situation is that this unit was originally designed to produce 75 kta of chloroprene monomer, therefore suggesting that there is a fair chance that future revamp opportunities can be achieved at a minimised cost.

Condition of the Chloroprene Production Unit (Butadiene) Structures

The condition of the associated supporting structures is summarised below.

Table D-18: Condition of Buildings & Associated Infrastructure for Chloroprene Production from Butadiene

Equipment name	No. of	Condition	Comment
Area 1-18 Support Structure	1	Inadequate	See comment below
Chloroprene Intermediate storage	1	Adequate	

Nitrous oxide inhibitor preparation Support Structure	1	Adequate	
Nitrous oxide inhibitor preparation Support Structure	1	Adequate	
Central Operating Building & Labs	1	Inadequate	Too close to the process unit's blast zone
Fire Pond & Firewater pump-house	1	Adequate	Subject to commissioning of the pumps
Liquids and Chlorinated Waste Incinerator Support Structure	1	-	Need a new structure for the new dedicated incinerator
Liquids and Chlorinated Waste Incinerator Operator House	1	-	Need a new operator house for the new dedicated incinerator

Area 1-18 Support Structure

At present the condition of the support structure is considered inadequate due to lack of HSE measures observed while visiting this unit. The major concerns are as follows:

- The gangways around high rise columns appear to be of inadequate quality standard, appearing to be both brittle and slippery.
- There are no warning signs with regards to in-between level drops within the supporting building structure for the unit.
- The fire-hose towers around the unit are severely corroded and must be replaced.

Furthermore, there was evidence that some of the structure's foundations were becoming dilapidated and therefore must be repaired.

Utilities Supply

The following list of issues was noted with regards to the Chloroprene Production from Butadiene Unit:

- Area 1-18: Lack of firewater supply to the process
- Area 1-18: The chemical sewer will have to be rechecked for integrity
- Area 1-19: New Chlorinated and Liquids Waste Incinerator is required
- New CW supply is presumed

Unit Operability & Condition of the Process Instrumentation and Control systems – Butadiene based Chloroprene Production

At present, the overall process unit control is manual, operated by field operators on a pneumatic control system, whereby measurements are made by local instrumentation. However, the revamp work cost estimate provided to us by Nairit management includes a suitable cost estimate for a new DCS to be installed prior to unit restart. We consider this to be the correct approach.

Venting

A particular concern is the current presence of atmospheric vents within the design of this unit, which will lead to some chloroprene and related compounds being released to the atmosphere within Yerevan city limits.

This is not the current world class practice and does not comply with best available technology requirements in the West. We recommend that the design of the plant is reviewed to route these vents to a suitable source of thermal destruction.

Polychloroprene Production Unit

Process Overview – Polychloroprene Production

Nairit's Polychloroprene production unit has been licensed from DuPont and was installed by a Japanese contractor in 1986.

Start-up Date: 1986.

Design Capacity: 50 kta

Actual Capacity: 25 kta

The performance of the unit is discussed in detail within overall Acetylene route discussion (please see p.2-81)

General Condition of the Polychloroprene Production

The condition of the existing unit is discussed in detail within overall Acetylene route discussion (please see p.2-81)

Utility and Offsites (OSBL)

Utilities

For utilities, we expect the following process units will be required:

- Process & Instrument Air systems
- Demineralisation Water (DMW) plant
- Deaerator (DEA)
- New Auxiliary Steam Boiler Plant
- Liquid & Chlorinated Waste Incinerator
- Cooling Water Systems
- Nitrogen Supply
- Refrigeration Systems

The utilities required for each scenario will broadly be the same, albeit at different capacities, so the condition of the existing units is reviewed jointly, with a special note if any of the scenarios does not require it.

A brief overview of each of these process units is presented below.

Process & Instrumentation Air systems

The existing unit, located at the site location of the existing Air Separation Unit (ASU) will be made redundant since a new ASU will be installed, as well as a new DCS and instrumentation. Thus, a whole new system will be required for any of the considered scenarios.

It is our recommendation that it is installed at the main site rather than at the site of the ASU, so as to avoid the need for interconnecting piping, associated pressure loss, as well as increased maintenance.

Demineralisation Water (DMW) plant

The current DMW plant / building is in an adequate condition, provided some civil works are undertaken to ensure there no sudden “unmarked” drops in the floor and the plant is fitted with better lighting.

However, it is insufficient to accommodate a new auxiliary steam boiler facility that will be required to provide steam to the main process units. Also, the location of the unit, adjacent to butadiene storage tanks is between 1 and 2 km away from the main process units, where the connecting pipework has an excessive number of flanges.

Our recommendation is that a new DMW plant is purchased and installed near the auxiliary steam boiler (largest DMW consumer), even perhaps in the same process building

Conversely, if no steam boiler installation is undertaken, and steam may be imported from a third party, then a refit of the existing DMW plant is perhaps more cost effective.

Deaerators (DEA) plant

The current four DEA units are located adjacent to the existing DMW plant. Their condition also appears to be adequate, provided some civil works are undertaken to ensure that floor panels and stairs are made safe.

The main issues with its re-use are the same as those of the DMW plant:

- Its present capacity is not sufficient to meet the throughput requirements should a new boiler plant be required;
- The location of the unit, adjacent to butadiene storage tanks is between 1 and 2 km away from the main process units, where the connecting pipework has an excessive number of flanges.

Again, our recommendations are similarly split on whether a new auxiliary steam boiler facility is installed.

If a new auxiliary steam boiler is installed, then it seems common sense to invest in some new DEA units that can be housed within the same process building as the new auxiliary steam boilers and new DMW plant.

Conversely, if no steam boiler installation is undertaken, then a refit of the existing DEA plant is perhaps more cost effective.

New Auxiliary Steam Boiler Plant

In the past, the plant operation was highly dependent on the ability to import steam from a third party in order to provide several key duties around the site such as re-boiling, process heating, etc. In the past, the steam was imported from a CHP power plant located a few kilometres away. Since the site has been shut for a few years now, the feasibility of this is now under question and would require extensive refitting for the steam import pipeline, which we do not see as a cost effective solution.

One of the main concerns is that relying on steam import for the operation of the unit will result in the plant's ability to operate being highly dependent on the operations of the nearby power plant. The aforementioned power plant configuration relies on combined cycle built around a natural gas fired turbine, Alstom GT13E2. A typical outage rate for such natural gas fired turbines is typically around 10% a year. Thus, if Nairit were to import steam from this facility, they will be left with no steam at least 10% of the year, causing interruptions in Nairit's production rates.

For this reason alone, we strongly recommend that Nairit's reconstruction project includes a new auxiliary steam boiler. In order to provide additional reliability, we would suggest that 2 x 50% configuration is preferred to a single large boiler, as this would allow the site to remain operational even if one of the boilers is undergoing maintenance.

Cooling Water Systems

At present, the site has a number of cooling water tower cells in various state of disrepair. The Nairit site team has proposed to reutilize the concrete basins at two locations:

- First location is to be adjacent to the existing refrigeration unit 2-3 and unit 1-18, providing the bulk of its CW load to these two units.
- Second location is to be adjacent to the proposed location of the new refrigeration unit and the polychloroprene plant units 1-21, 1-22 and 1-23.

Both of the proposed locations previously housed CW towers.

The CW distribution is both over-ground and underground. Nairit claim that the underground corridors are regularly checked and are expected to require little investment to bring them up to operating standard. The condition of over-ground distribution systems also seems adequate with only minor localised spend expected for any particular pipe replacement segments.

Thus, we agree with Nairit's proposed plan for reconstruction of CW systems and propose to budget accordingly.

Nitrogen Supply

The current nitrogen supply is provided from the Area 1-6 and is located at a separate site, connected to the main site via an existing 3 km long underground pipeline. The unit consists of three separate mini-ASUs (cryogenic Air Separation Units), producing high purity N₂ with less than 10 ppm of oxygen. It also contains 8 hours of gaseous nitrogen storage and its own cooling water system.

The unit is currently operational. It is expected that only 2 ASUs are required to meet both normal and maximum demand, effectively allowing for a spare ASU. This allows for highly reliable operation.

Conversely, the ASUs are fairly old and look quite worn. This results in inefficient power consumption (40-60% higher than a modern ASU); mainly due to the use of old reciprocal compressors and the distance that nitrogen has to be piped to before it can be used on site.

Acetylene route scenarios – 12 and 24 kta

The new nitrogen supply will be provided as part of the by-product nitrogen utilisation from the new Air Separation Unit (ASU).

Butadiene route scenarios – 12 and 24 kta

For this scenario, procurement of new ASU is expected to be prohibitively expensive, where only nitrogen is required. In principle, the existing ASUs, worn as they are, are operational and there is no reason to foresee reliability trouble, provided that a spare ASU unit is kept live. Thus, we recommend that ASU reconstruction budget is limited to procurement of an extra ASU compressor and a full set of spares, so as to enhance the reliability of the existing unit and improve its efficiency.

Refrigeration Systems

The current refrigeration facility is capable of 3 Mcal of cooling, which is sufficient for all scenarios. The condition of that unit is largely adequate, although the condition and efficiency of the ammonia compressors must be investigated further.

Offsites

For offsites, these are:

- Fresh Water Intake and Transfer (from Kapuyt Licht)
- Brine Wells & Transfer (from Abovyan)
- Effluent Treatment Plant
- Butadiene Storage Tank Farm
- Rail Terminal
- Warehousing
- Fire Fighting Systems
- Auxiliary workshops (mechanical maintenance shop, electric equipment and instrumentation repair shops)
- Security Systems
- Laboratories
- Common Site Infrastructure

The offsites required for each scenario will broadly be the same, albeit at different capacities, so the condition of the existing units is reviewed jointly, with a special note if any of the scenarios does not require it.

An overview of each of these process units is presented below.

Fresh Water Intake and Transfer (from Kapuyt Lich)

The existing water supply to the Nairit plant come from groundwater piped from a borehole 22km away in Kapuyt Lich. Nairit would like to increase the water supply by commencing abstraction from four additional existing wells which will require permits. Although the groundwater wells are owned by Nairit, it does not have sole ownership of the water supply pipeline. At the moment only one of the groundwater wells has a permit for abstraction (well No.5). It is believed that up to 400 parties may have partial ownership of the pipeline and rights to use the water. Some of the pipeline passes through private land and built up residential areas where access is difficult.

The availability of a secure and adequate water supply for the future Nairit operations is a Critical consideration to ensure the viability of the site.

Nairit are currently in discussions with the municipality to obtain sole ownership of this pipeline. However, until this sole ownership exists there could be risks with water supply to the site, in the event that more influential or demanding users come on board. Nairit provide water to some commercial greenhouses that are located on the water pipeline. No other official water users currently exist, due to lack of industry in the area.

Nairit have not undertaken or commissioned any assessment to determine the quantities of groundwater available within the aquifer. However, Nairit believe there is sufficient available for the operational requirements of the plant and any other third party users. In the event of there not being sufficient groundwater resource, Nairit plan to utilise water from the lake. It should be noted that

water from the lake contains a significant covering of algae and sediments. The poor quality of the lake water is one of the reasons for Nairit's plans to utilise groundwater instead, which is understood to be of a better quality making it more suitable for cooling water in the plant's operational processes.

Once abstracted, the water will be pumped along the water pipeline to an intermediate storage area. At the intermediate storage area there are four tanks of 5 000 m³ capacity each and a switching station. The 20 000m³ storage capacity provides fourteen hours of plant operation. In the case of emergency repair to the storage area or abstraction points, Nairit can utilise municipal water from the adjacent intermediate storage area.

In all cases, Jacobs Consultancy recommend that the implications of the shared water supply pipeline for the future operation of the plant are evaluated further and necessary actions are taken to ensure that Nairit will have the right to control supply of water to the plant. The sustainability of obtaining a long term water supply from the aquifer will also need to be confirmed, especially in light of the proposal to significantly increase the abstraction rate.

No assessment of the quantities of groundwater available for abstraction has been undertaken. As the plant demands are for a significant quantity, groundwater levels in the wells should be monitored, both for the protection of water supply to the plant and for third parties i.e. nearby residential areas and agricultural users. The sustainability of obtaining a long term water supply from the aquifer will also need to be confirmed, especially in light of the proposal to significantly increase the abstraction rate.

Abstraction should be monitored at the general outlet connecting all the boreholes and a study and installation of piezometers (to measure ground water pressure changes) undertaken to assess water usage and drawdown. This study should identify whether or not there is adequate groundwater available to meet the plant's demands for an appropriate timescale without impacts on water resources for third party users.

Although the existing permits do not set an abstraction limit, one should be set that ensure sustainable use of the groundwater supplies. To do this it is recommended that meters are installed at each of the boreholes to measure abstraction and water levels. This will establish the demand requirements from the plant and enable determination of an average abstraction rate for the existing operations.

Brine Wells and Transfer (from Abovyan)

Unit 1-4 a: Brine Production and Transfer

The brine supply for the production of chlorine at the Nairit plant comes from a solution cavity mining facility located approximately 27 km from the site. The present condition of the brine holding tanks and pumps is unsatisfactory, although the wells appear functional. For additional comments regarding the present status of the brine wells, please refer to Section E. Likewise, it appears that the existing brine pipeline has lost its integrity due to disuse over recent years. The existing pipeline is not fit for repair due to land availability and dispute issues.

Thus, a new brine pipeline will be installed between the well and the production facility. The new trajectory will be along the main roads and has been estimated at 27 km, although it is not clear whether Nairit has the permission of the Government to lay the pipe for the proposed route.

The current Nairit design proposes that the pipeline is built out of carbon steel. Jacobs Consultancy recommends that the new pipeline (if over-ground) is built out of FRP pipe, since this will increase the useful life of the pipeline and minimise both operating expenses as well as spillages of brine.

Also, we note that the elevation difference at approximately 600 m is significant, forcing the design of the pipe to be able to withstand transfer of brine at significant pressures prior to receipt on site.

Unit 1-4 b: Brine Storage

Brine supplied to site via the pipeline is received in 3 x 3,000 m³ open roofed tanks. This represents 12 days storage capacity. The condition of these tanks is deemed adequate.

Brine from these tanks is pumped across to the chlor-alkali unit.

Effluent Treatment Plant

The current Effluent Treatment Plant (ETP) is located at two separate locations:

- The main ETP facility is located approximately one kilometre away from the main site
- 2 x equalisation and 2 x settling tanks are located onsite, marked as units 206, 207 and 208, near the railroad tracks.

The original main ETP was designed to process effluents from a number of enterprises nearby — Nairit included — and has been inherited by Nairit, as all other enterprises closed down in the 1990s. It is clear that no investment has gone into these facilities, and as such the condition of the ETP facilities is not fit for purpose.

The additional equalisation and settling tanks located on site were operated to remove the bulk of latex entrained in the chemical sewer waters from units 1-21, 1-22 and 1-23 before discharge to main ETP units. Again, it is clear that no investment has gone into these facilities, and as such the condition of the ETP facilities is not fit for purpose.

The Nairit site team has previously indicated that it is allowed to discharge its chemical sewer waters into the main municipal sewer, since:

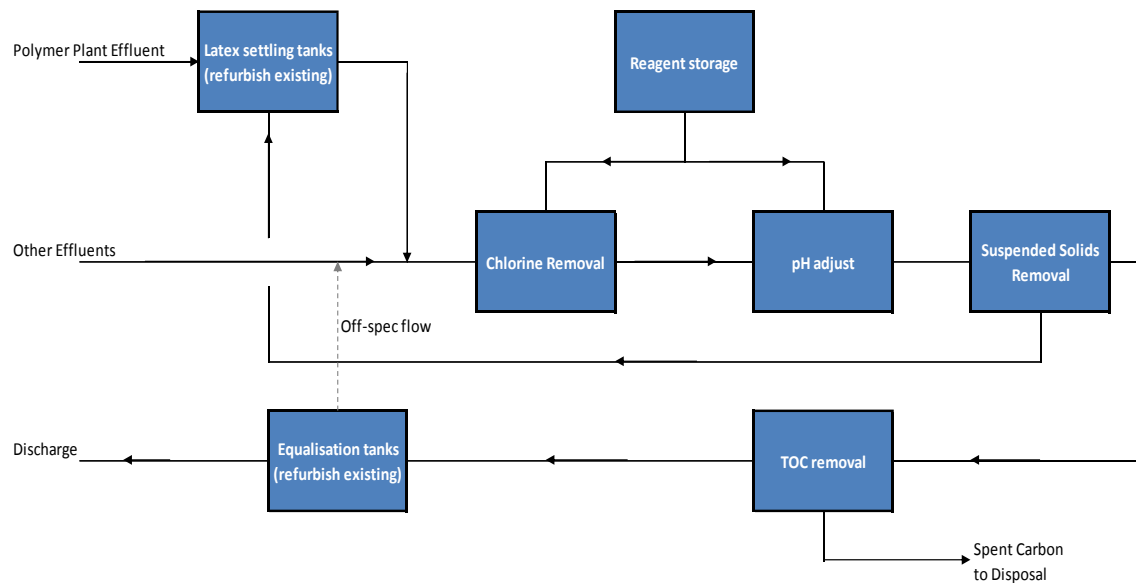
- Flows from the site are a fraction of the sewer flows;
- The downstream municipal waste treatment plant can process their effluent.

Nevertheless, Jacobs Consultancy team does not consider this a viable strategy for future plant operation, as it is both questionable on environmental grounds, as well as leaving the site operations vulnerable to both the operation of the municipal waste treatment plant or a change in Government permitting policies.

Thus, it is proposed that the majority of the main waste water treatment is replaced with a new plant located on the main site (see Figure D- 7 for block diagram). Upon inspection of the plot plan, it appears there are large areas available around the existing location of the onsite equalisation and settling tanks. Given the existing connection from that location to the main discharge point, we recommend that the new ETP is built at that location, making use, where possible, of the restored equalisation and settling tanks that are already there.

An additional unit operation — TOC removal — will be added to the new ETP. It is acknowledged that there may be problems with latex blockages if carbon filtration is used, but for now the TOC removal plant has been estimated based on this basis. It will be necessary to further investigate technologies for TOC removal (e.g. bio-treatment) at the next engineering stage. **However, the inclusion of this unit into the present cost estimate is not warranted at the present stage.**

Figure D- 7: Schematic for the new existing waste water treatment plant



Source: Jacobs Consulting Ltd.

Butadiene Storage Tank Farm

This unit is applicable to butadiene scenario only.

The existing butadiene storage tank farm is located adjacent to the existing DMW / DEA plants, approximately one kilometre away from the main ISBL units. Despite a major public road between the main site and the location of the tank farm, the tank farm is suitably far away from this road not to pose any danger. It is effectively shielded via blast walls from the existing rail unloading terminal, and other nearby units belonging to Nairit.

The tank farm itself consists of 7 x butadiene and 1 x nitrogen storage tanks. The tank farm capacity is sufficient for 21 days of process operation of the chloroprene monomer plant at 35 kta rates. In addition to these, the tank farm has:

- Its own chiller unit, to refrigerate the nitrogen blanket overheads, so as to prevent/minimise butadiene losses to atmosphere via butadiene spheres breathing line.
- Its own water pumps used to pump water to the top of the butadiene spheres, so as to provide an external cooling jacket.
- A protective bund, to avoid release during accidental spillage.

The tank farm is in an adequate condition, with all 8 spheres tested as of 2012, and declared operational. The Nairit site team has proposed to reroute the existing breathing line vent to the scrubber #1113 within chloroprene production unit 1-18, so as to eliminate the atmospheric vent. We find such a proposal acceptable.

With regards to further revamp of the unit, we consider that for operation at 25 kta, the overall butadiene storage is required.

It should be noted that for compliance with EU regulations, any new butadiene tanks would have to be located in a double bund, with external refrigeration, resulting in substantial capital investments. The existing storage is compliant with these regulations, as such stipulation does not extend to previously installed butadiene tanks.

- Another observation is that the current water cooling system for butadiene tanks is water wasteful, but is perhaps the most cost-effective way, since the installation of new butadiene cooling water jackets will be onerous in investment costs.

Rail Terminal

This unit is applicable to butadiene scenario only.

At present, it is assumed that butadiene supply is most likely to be delivered to site via rail. However, the existing rail terminal has not been used since 1990s and the terminal shows signs of corresponding decay. As such, both rail tracks and unloading butadiene platform will have to be extensively refurbished before the operations can resume. Likewise, we recommend that the unloading system is fully refit and fitted with suitable pressure equalization systems.

Conversely, the site does possess a diesel engine which is in good working order, so minimal maintenance will be required for that unit. Finally, the metering station, while rudimentary, is also considered adequate.

Warehousing

The condition of the PCR product storage is deemed acceptable and we expect that only minor investment for gas and temperature sensors will be required.

Fire Fighting Systems

The condition of both the fire water pond and underground water corridors is deemed adequate, with minor investment required for corridor clean up prior to start-up. Conversely, a complete refit of all fire water jockey pumps is required, as their current state is unacceptable.

Furthermore, the fire fighters' quarters are presently located outside the site, across the main road. We consider such arrangement sub-optimal from the point of view of response times. We recommend that they are relocated onto the site, with a special building provided for them near the plant security gates.

Mechanical Workshop

Nairit possesses an extensive mechanical workshop space with a large amount of personnel, which has enabled it to continue to slowly rebuild some of its process units, while scrapping some of the redundant equipment, by only using its in-house capabilities. We consider this workshop to be more than adequate for day-to-day plant needs, with the exception that perhaps more modern machinery will allow improved worker productivity.

Electrical (High and Low Voltage) Workshops

Nairit possesses an extensive low voltage electrical workshop space with a large amount of personnel, which allows it to maintain and refurbish old electrical drives, which would otherwise have been decommissioned decades ago. We consider this workshop to be more than adequate for day-to-day plant needs, with the exception that perhaps more modern machinery will allow improved worker productivity.

Instrumentation Workshop

Nairit possesses a large instrumentation workshop building with a large amount of personnel, which has enabled it to continue operations despite lack of funds and new control equipment. We consider this workshop to be more than adequate for day-to-day plant needs in terms of the area available. However, as the new DCS is introduced to the plant operations, all of the instrumentation technicians will have to be retrained in the maintenance skills needed for the new system.

Security Systems

At present, the security system of the plant is limited to occasional observational posts spread around the periphery of the plant and the main security building next to the administration building. We find such arrangements acceptable, but recommend that additional closed circuit television cameras (CCTV) are installed around the periphery of the site for added security.

Laboratories

These are generally located in close proximity to the process units that they serve, due to lack of automated logging equipment for measuring emissions and effluents. We found most of the labs to be in a very tidy and neat condition, but bereft of modern equipment, which negatively affects the productivity of the lab technicians. Our other concern is that these labs are located very close to their assigned process units, well within the blast zone.

We recommend a relocation of the labs to one central location and a switch to automatic instrumentation where possible, to minimise the workload on the lab. We recommend that labs equipment is completely renewed.

General Comments on Roads and Common Site Infrastructure

The general condition of the roads on the Nairit site varies from adequate to unsatisfactory. Most of the main roads and access roads to process units on the main site are paved, albeit with potholes which must be remedied. There is a general question with regards to the large amount of vegetation growing near process units and roads, which reduces operators' ability to see from one unit to another and thus spot potential hazards on the adjacent units.

The road connections to some of the utilities, such as the waste water treatment plant, are not paved, and are in an unsatisfactory condition, as they will not be traversable in adverse weather conditions. This should be remedied.

As a general comment, there is no clear signposting on the roads, relying on the personnel to naturally know their way around the site. There are no clear signs as to where the evacuation areas are. These are serious safety deficiencies and the site needs to undergo a significant generational shift in terms of its safety culture, should the production be restarted.

Additional Options Considered

In addition to the existing facilities, regardless of the expansion scenario undertaken, additional new facilities are considered in order to lower production costs of the chloroprene monomer. These are briefly summarised below.

Production of chloroprene via Acetylene Route

Alternative Acetylene Production Technology

The existing Nairit site production technology is based on partial oxidation of methane to co-produce acetylene and synthesis gas. This method results in fairly high consumptions of natural gas, especially when considering Nairit past performance – circa 8 650 Nm³ of natural gas per tonne of acetylene produced.

There is an alternative process, as employed by International Specialty Products, ISP, at their Marl production site in Germany – plasma arc, also colloquially known as the 'sun of Hüls', owing the name to the plasma current generated inside the unit. The Marl units are operated on LPG feedstock, but can be operated on natural gas, which is actually a simpler feedstock. The main attraction of such process is the lower natural gas consumption – circa 2 450 Nm³ of natural gas per tonne of acetylene produced. Conversely, the unit requires much larger electric power consumption, to generate the

plasma arc current inside. **Thus, given that we consider the existing acetylene production unit, as well as the associated Air Separation Unit will need to be replaced for either of the considered acetylene production scenarios, this technology allows for an arbitrage on the electric power / natural gas price ratio.**

The critical issues, as with the proposed new POx unit, is the access to technology, and ISP willingness to license this process to Nairit. In principle, ISP are not in the chloroprene business, so there isn't an obvious reason for them to withhold the licensing from Nairit, provided Nairit agree not to enter any business where ISP is a player, such as 1,4-butanediol.

The high level performance comparison of the process options per tonne of acetylene produced is summarised over page.

Table D-19: Performance Comparison for Acetylene Production Unit

	Units	Existing POx ¹	New POx ¹	Plasma Arc
Feedstock:				
- Natural Gas	Nm ³	8 200	6 500	2 450
- Oxygen	Nm ³	4 800	3 400	-
Co-product:				
- Syngas	Nm ³	9 680	10 150	-
- Hydrogen	Nm ³	-	-	3 350
- Pyrolysis gasoline	kg	-	-	150
- Carbon black	kg	-	-	350
Utilities:				
- Power	kW-h	3 350 (7 217) ²	3 100 (4 780) ²	14 000
- Steam	GJ	1.6	10.5	2
- CW	m ³	1090	210	180
Utilities:				
- Sulphuric acid	kg	-	160	-
- Caustic Soda	kg	0.4	5	-

Note 1: Inclusive of Air Separation Power Consumption, where a new POx unit also assumes a new ASU.

The plasma arc process also benefits from:

- No Air Separation Unit is required
- Plasma arc does not require additional sulphuric acid or any other significant chemical consumption.
- Much smaller acetylene extraction unit, as the volume of co-products is approximately 3 times less, which results in much smaller capital investment, utility and chemical consumptions required for that part of the plant.
- Final hydrogen product may be more easily utilised for further synthesis (e.g. ammonia production)

- Conversely, the plasma arc section itself will require a relatively higher capital investment than the partial oxidation of methane (POx). Overall, the capital costs will still be a little bit lower, due to smaller NMP section and lack of Air Separation Unit.

Syngas Utilisation Unit

Although, the options reviewed below are outside the current assessment scope, it is thought that utilisation of syngas at chemicals rather than fuel value would result in substantial reductions in the cost of production of acetylene and therefore the acetylene derived polychloroprene rubber (PCR).

In the past, this syngas was sent to the nearby power plant for use as fuel. This option is no longer feasible, as that power plant has been renovated and the new facility does not allow for syngas import. In all cases, utilisation of syngas at fuel value is sub-optimal and results in relatively high production costs for acetylene when compared to chemical utilisation options. Conversely, such options would require additional capital investment that may be hard to justify.

The past performance of the existing acetylene production unit resulted in some 9,680 Nm³ of syngas co-produced per tonne of acetylene product. This is equivalent to ~8,400 Nm³ of syngas co-produced per tonne of polychloroprene rubber (PCR). Thus, depending on the scenario chosen, there may be either 101 or 202 million Nm³/annum of CO + H₂ syngas available for by-product chemistry.

However, depending on the application, this by-product syngas requires further conditioning before it can be reacted to produce value-added chemicals. In all cases, it must be further compressed to the pressures required by the reaction conditions of the desired syngas synthesis step (methanol, STG¹³ or ammonia) and passed through a series of oxygen scavenger and olefin hydrogenation reactors to remove traces of oxygen, ethylene and acetylene present before it can be fed to the synthesis unit itself.

The specific requirements for each of the above options are further discussed below.

Methanol

If the syngas is to be used for methanol synthesis, then an additional syngas compressor is required to compress the available syngas to pressures closer to 80 kg/cm². In between the compression stages, the syngas should be passed through a trim CO₂ removal unit, so as to bring the stoichiometry R¹⁴ ratio of the feed syngas above 2.05.

The resulting gas is then fed to a classical methanol loop and the obtained crude methanol is then distilled to a chemical grade specification.

The product yields, based on volumes of syngas available from the existing acetylene production unit, are as follows:

- 12 kta of PCR production results in ~44 kta of methanol
- 24 kta of PCR production results in ~88 kta of methanol

These are relatively small volumes, which are unlikely to make investment in such an option attractive due to poor economy of scale of the resulting syngas utilisation unit, as dictated by the need to install:

- A new syngas compressor + methanol synthesis loop circulator
- A new hydrogenation unit to remove trace O₂, acetylene and ethylene
- A new trim CO₂ removal unit
- A new methanol synthesis loop

¹³ Syngas To Gasoline process – e.g. TIGAS from Haldor-Topsøe

¹⁴ Stoichiometry Ratio required for feed gas to Methanol loop = (H₂ – CO₂)/(CO+CO₂)

- A new methanol distillation unit
- A new methanol storage and export infrastructure

The resulting scope will result in both a relatively large investment required, as well as relatively large fixed costs required to maintain such unit in operation.

Syngas derived Gasoline, STG process

The description below is based on the relatively more proven Haldor-Topsøe process, although all of the syngas to gasoline type processes have a relative weakness in that the catalyst-aided conversion from syngas to a mixture of methanol and DME (first synthesis step) is relatively unproven at a large scale.

The advantages of such a route are that, unlike methanol synthesis, the process may be operated at a lower pressure of around 50 kg/cm² without such a drastic drop in reactor efficiency and the resulting gasoline product may be realised locally. Thus, a syngas utilisation step based on a STG plant would require an additional second reaction stage where the mixture of methanol and DME produced in the initial reaction loop is then further dehydrated to gasoline using a proven MTG catalyst. The resulting hydrocarbon mix is then fractionated to obtain a pool of gasoline and LPG products.

The resulting product yields, based on volumes of syngas available from the existing acetylene production unit, are as follows:

- 12 kta of PCR production results in ~19 kta of gasoline and 2.5 kta of LPG
- 24 kta of PCR production results in ~38 kta of gasoline and 5 kta of LPG

Similar to methanol, the main barrier to investment is the relative lack of economy of scale, since the following new units must be installed:

- A new syngas compressor + methanol/DME synthesis loop circulator
- A new hydrogenation unit to remove trace O₂, acetylene and ethylene
- A new trim CO₂ removal unit
- A new methanol/DME synthesis loop
- A new gasoline synthesis reaction section and associated catalyst regeneration system
- A new gasoline and LPG fractionation unit
- A new fuels storage and export infrastructure

The resulting scope will result in both a relatively large investment required, as well as relatively large fixed costs required to maintain such unit in operation.

Ammonia

A potential advantage of the acetylene production unit at Nairit site is that as part of the oxygen production (Air Separation Unit) for the natural gas pyrolysis, there are relatively large quantities of high purity nitrogen by-product available, far in excess of the nitrogen required for purging of the process pipework during start-up and shut-down periods or for providing blanketing to the storage tanks.

Thus, if the ammonia production is to be entertained, the by-product syngas would need to be first compressed to a pressure of around 40 kg/cm². It is then passed through O₂, acetylene and ethylene hydrogenation section and fed to a CO shift to maximise the hydrogen yield. The resulting shifted gas is then passed through a CO₂ removal unit to remove the CO₂ present in the gas, mixed with high purity nitrogen from the Air Separation Unit and fed to a trim methanation unit that converts the remaining traces of CO₂ and CO to methane, as these are ammonia catalyst poisons. The gas is then

compressed further to a pressure of 150-180 kg/cm² and fed to an ammonia synthesis loop. The resulting ammonia is then refrigerated and sent for storage (refrigerated at -33°C).

The following ammonia production rates may be anticipated based on volumes of syngas available from the existing acetylene production unit:

- 12 kta of PCR production results in ~46.5 kta of ammonia product
- 24 kta of PCR production results in ~93 kta of ammonia product

Similar to the other options, the main challenges to investment are the relative lack of economy of scale, since the following new units must be installed:

- A new syngas compressor + ammonia synthesis loop circulator
- A new hydrogenation unit to remove trace O₂, acetylene and ethylene
- A new CO₂ removal unit
- A new trim methanation unit
- A new ammonia synthesis loop
- A new ammonia storage and export infrastructure, as well as associated refrigeration capacities.

The resulting scope will result in both a relatively large investment required, as well as relatively large fixed costs required to maintain such unit in operation.

Alternative Scenario– 1,4 butanediol (BDO)

Although the present option is outside the current assessment scope, should chloroprene production from acetylene be undertaken as the preferred production method, it is worth considering other potential options that may alleviate the lack of economy of scale associated with acetylene production at Nairit plant. Namely, there may be a case for a potential acetylene scale up and utilisation of excess acetylene via additional process units that consume acetylene such as 1,4 – butanediol (and its specialty derivatives). The former is still predominantly produced from acetylene both in the USA (BASF and INVISTA) and Western Europe (BASF, ISP), as well as playing an important part in the Asian Pacific capacity mix (mainly Chinese producers).

The feasibility of such an option is out of scope of the present report. The major barrier to such an option is that the technology holders for acetylene conversion to BDO are the producers themselves (BASF, ISP and INVISTA). Therefore, there is an open question as to whether they would agree to license their knowhow to a direct competitor. However, should such a barrier be solvable (e.g. Chinese license or long term offtake by one of the western producers), then the idea has some advantages such that it drastically improves the economy of scale of key production units such as acetylene production unit and its associated air separation unit. It allows for back-integration with resulting syngas, since acetylene conversion to BDO requires formaldehyde, which in turn is produced from methanol. Thus, some 62% of syngas co-produced with acetylene that is utilised for BDO may be back-integrated via synthesis to methanol first and then oxidation to formaldehyde.

In all cases, such investment requires further consideration so as to resolve the product logistics, technology access rights and raise the investment required to achieve a suitable economy of scale between 100 to 200 kta of BDO, equivalent to 31 – 62 kta of acetylene.

The raw material consumption for production of 1 t of BDO from acetylene is as follows:

- 0.31 tonnes of acetylene

- 0.72 tonnes of formaldehyde
- 0.05 tonnes of hydrogen

The net major utility consumptions are as follows:

- 0.22 MWe of electric power
- 10.5 tonnes of 11 kg/cm² steam for re-boiling duties

This option is not considered further within the scope of the present study, as it implies a completely new business structure for Nairit operations and must be assessed on its own merits, so as to establish whether the following issues can be feasibly resolved:

- Access to technology and know-how
- Competiveness of BDO produced in Armenia relative to major international players
- Volume of capital investments required
- Marketing strategy for the BDO exports
- Project execution plan for the erection of the new facilities
- The overall economics of such an option

Required Capital Investments

Basis and Assumptions

The capital cost estimates for the process areas of the plant were primarily developed by the unit capacity factoring technique. This technique uses the cost of a unit for which the direct construction costs are known from previous work. The known costs are multiplied by a factor developed from the ratio of the new unit's capacity and the capacity of the unit for which costs are known. Capacity ratios are adjusted by exponents chosen on the basis of the unit type to reflect the economy of scale usually observed for larger plants. An adjustment is made for design differences, number of trains, location and time frame. Price escalation due to time elapsed between the date of the reference quote and the present day have been allowed for using the Chemical Engineering Plant Cost Index.

This methodology is consistent with the American Association of Cost Engineers' (AACE) Class 5 type cost estimate. The typical accuracy of such a cost estimate is +50% / - 40%.

Plant cost inflation indices such as Nelson-Farrar Construction and Chemical Engineering Plant Cost are used, together with our own experiences of project costs, to estimate how the reference project CAPEX would change over time.

Adjusting the reference project CAPEX for all of these factors results in an "overnight" or instantaneous replacement constructed cost for the project on a 1st quarter 2015 basis.

Escalation during development and execution of the project is included and has been set at 2.0% p.a. for the duration of the overall period of reconstruction prior to restart, which is in line with our assumption embedded in our price forecasts.

Worldwide procurement of equipment and materials for new process units has been assumed. The restoration of existing process units (chloroprene monomer from butadiene and existing PCR rubber production units) as well as some of the OSBL units has been assumed to be carried out in line with Nairit's own project execution strategy, which would see them take control of the construction management using local construction sub-contractors, which we consider realistic.

The costs were developed on a US Gulf Coast basis and then converted to an Armenia location by the application of an overall capital cost location factor. We have applied a location factor of 1.3 for this

purpose to reflect the fact that most equipment will need to be imported, and the installation costs will be somewhat lower, owing to lower labour rates in Armenia (even at reduced productivity).

For obvious reasons, the actual cost of the project will be driven by the chosen contracting strategy. This is outlined below separately for each of the considered scenarios.

Contracting Strategy

The contracting strategy for the present cases will be based on the full works being financed via balance sheet, with no recourse to project financing, so as to reduce the cost of financing charges and shorten the project execution period. Nairit will perform its own construction management, hiring construction sub-contractors as necessary at its own risk.

Scope of Estimate

The capital cost includes the following major areas in the plant, as applicable for each case:

12 kta of PCR Rubber from Acetylene

ISBL

- Restoration of Existing Chlor-Alkali Production Unit
- New Acetylene Production Unit (inclusive of ASU)
- New Chloroprene Production from Acetylene Unit
- Restoration of Existing Polychloroprene Production Unit

OSBL

- Restoration of the salt wells
- New brine pipeline from Abovyan to the main site
- New Liquids + Chlorinated Waste Utilization Unit
- New Auxiliary Steam Boiler Unit, DMW and DEA plants.
- Renovation of the existing emergency power substations
- New Cooling Water Towers
- New Effluent Treatment Plant
- Restoration of the existing refrigeration stations
- Renovation and installation of new fire-fighting systems throughout the site
- Installation of new emergency flare system

The capital cost estimates also include the following utilities and support facilities for ISBL units:

- Electrical distribution
- Restoration and inclusion of new communications systems
- Restoration and inclusion of new DCS systems
- New plant control and management information system
- Site preparation

- Renovation of general infrastructure on site (including roads, pipe racks and their supporting pylons, fencing, lighting)
- Renovation of the existing administration, labs and workshop buildings
- Renovation of natural gas, water (utilities, demineralised and boiler feed), steam & condensate, effluent distribution and collection pipework systems
- Interconnecting piping between units

Connections to the surrounding infrastructure such as that given below are excluded:

- Power connection between the transmission network and the facility

The estimated capital cost includes the following components:

- Direct Field costs for key ISBL and OSBL units, which include the following:
 - Equipment
 - Bulk materials (concrete, piping, electrical cable, instruments, etc.)
 - Direct field labour including supervision
 - The allocated Detailed Engineering Package cost
 - The allocated Procurement budget for purchase of necessary equipment
 - A specific commissioning allowance for the restoration of existing process units, to allow for additional expense incurred due to unforeseen necessary equipment and bulk materials replacement.
- Home office (Owner's) costs
 - Engineering costs

Excluded Costs

The following are excluded from the capital cost estimate:

- Connections to the surrounding infrastructure:
 - Power connection between the facility and the transmission network
 - Facilities for long-term disposal of solid wastes, if required
- Any costs associated with the freight of feedstocks or products
- Cost of any additional land acquisition, should there be a need.
- Financing costs
- Pre-Operation and Operation costs
- Monies to cover the decommissioning of the redundant process units.
- Monies to cover environmental reviews and studies during the project implementation phase
- Escalation over construction period
- Taxes
- Insurances
- Capital spares
- Authority / Permitting costs

- Soil investigation
- Cleaning cost (cleaning of contaminated soil included)
- Wastes disposal cost
- Escalation cost for delayed project execution
- General Project Contingency
- Dealing with underground obstructions (the brownfield area for existing units is assumed to have the necessary connection, new units are assumed to be located in an area free of any obstacles, both above and underground)

24 kta of PCR Rubber from Acetylene

This scope is the same as per the previous scenario of 12 kta.

25 kta of PCR Rubber from Butadiene

ISBL

- New Chlor-Alkali Production Unit
- Restoration of Existing Chloroprene Production from Butadiene Unit
- Restoration of Existing Polychloroprene Production Unit
- New Liquids + Chlorinated Waste Utilization Unit

OSBL

- New Auxiliary Steam Boiler Unit
- Butadiene Tank Farm
- Renovation of the existing nitrogen generation units
- Renovation of the existing emergency power substations
- New Cooling Water Towers
- New Effluent Treatment Plant
- Restoration of the existing refrigeration stations
- Renovation and installation of new fire-fighting systems throughout the site
- Installation of new emergency flare system

The capital cost estimates also include the following utilities and support facilities for ISBL units:

- Electrical distribution
- Restoration and inclusion of new communications systems
- Restoration and inclusion of new DCS systems
- New Plant control and management information system
- Site preparation

- Renovation of general infrastructure on site (including roads, rail yard area, piperacks and their supporting pylons, fencing, lighting)
- Renovation of the existing administration, labs and workshop buildings
- Renovation of natural gas, water (utilities, demineralised and boiler feed), steam & condensate, effluent distribution and collection pipework systems
- Interconnecting piping between units

Connections to the surrounding infrastructure such as that given below are excluded:

- Power connection between the transmission network and the facility

The estimated capital cost includes the following components:

- Direct Field costs for key ISBL and OSBL units, which include the following:
 - Equipment
 - Bulk materials (concrete, piping, electrical cable, instruments, etc.)
 - Direct field labour including supervision
 - The allocated Detailed Engineering Package cost
 - The allocated Procurement budget for purchase of necessary equipment
 - A specific commissioning allowance for the restoration of existing process units, to allow for additional expense incurred due to unforeseen necessary equipment and bulk materials replacement.
- Home office (Owners) costs
 - Engineering Costs

Excluded Costs

The following are excluded from the capital cost estimate:

- Connections to the surrounding infrastructure:
 - Power connection between the facility and the transmission network
 - Facilities for long-term disposal of solid wastes, if required
- Any costs associated with the freight of feedstocks or products
- Cost of any additional land acquisition, should there be a need.
- Financing costs
- Pre-Operation and Operation costs
- Monies to cover the decommissioning of the redundant process units.
- Monies to cover environmental reviews and studies during the project implementation phase
- Escalation over construction period
- Taxes
- Insurances

- Capital spares
- Authority / Permitting costs
- Soil investigation
- Cleaning cost (cleaning of contaminated soil included)
- Wastes disposal cost
- Escalation cost for delayed project execution
- General Project Contingency
- Dealing with underground obstructions (the brownfield area for existing units is assumed to have the necessary connection, new units are assumed to be located in an area free of any obstacles, both above and underground)

12 kta of PCR Rubber from Acetylene

Based on the assumptions previously listed, and technical review of the existing facilities, the capital cost estimate summary is as follows:

Table D-20: Capital Cost Summary for 12 kta of Chloroprene via Acetylene from Natural Gas

	US\$ million
ISBL Costs:	159.76
- Refurbish existing Chlor-Alkali Unit	10.06
- New 10.4 kta Acetylene Unit	40.51
- New 12 kta CR monomer Unit	84.35
- Refurbish existing PCR Rubber Unit	14.83
- Common ISBL communications	10.00
OSBL Costs:	31.88
TOTAL Costs:	191.64

Source: Jacobs Consulting Ltd.

24 kta of PCR Rubber from Acetylene

Based on the assumptions previously listed, and technical opinions provided in Section 4 of this report, the capital cost estimate summary is as follows:

Table D-21: Capital Cost Summary for 25 kta of Chloroprene via Acetylene from Natural Gas

	US\$ million
ISBL Costs:	264.70
- Refurbish existing Chlor-Alkali Unit	18.14
- New 20.8 kta Acetylene Unit	65.81
- New 24 kta CR monomer Unit	137.03
- Refurbish existing 24 kta PCR Rubber Unit	27.72
- Common ISBL communications	16.00

OSBL Costs:	51.79
TOTAL Costs:	316.49

Source: Jacobs Consulting Ltd.

25 kta of PCR Rubber from Butadiene

Based on the assumptions previously listed, and technical opinions provided within this report, the capital cost estimate summary is as follows:

Table D-22: Capital Cost Summary for 25 kta of Chloroprene from Butadiene

	US\$ million
ISBL Costs:	125.64
- New 25 kta Chlor-Alkali Unit	55.36
- Refurbish existing 25 kta CR Monomer Unit	41.76
- Refurbish existing 25 kta PCR Rubber Unit	28.52
- Common ISBL communications	12.00
OSBL Costs:	110.56
ISBL+OSBL Costs:	236.20

Source: Jacobs Consulting Ltd.

In addition to the above costs, there will be a small license and engineering documentation package cost for the new chlor-alkali unit (approximately ~ US\$ 2 millions).

Required Staffing Levels

At present, Nairit staff levels – at 478 – are not exceedingly over to those we would expect to see should the plant restart operation under any of the considered scenarios. We have provided below our own estimate of the level of staffing required to operate the site after the proposed revamp. Please note these figures relate to mature plant operation, and during the initial year of operation after revamp, the number of personnel might be higher, as the transition from the current staffing levels takes place.

12 kta of PCR Rubber from Acetylene

The estimated level plant personnel required to operate the facility under this scenario, up to Western Europe standard, 3rd quartile of performance, is as follows:

Table D-23: Overall Plant Staffing Levels

Employee Category		Type	No. Off
Operations			
1	Engineers — Qualified	Day	8
2	Operators — Supervisors	4 shifts	28
3	Operators — Operators (DCS + Field)	4 shifts	268
4	Bagging/Warehousing/Despatch	4 shifts	16
5	Customs Controls	Day	2
6	Qualified Technicians	Day	5
7	HSE	Day	2
8	Laboratory staff	Day	5
9	Security (shift staff)	4 shifts	20
10	Fire-fighters (shift staff)	4 shifts	16
11	Maintenance — craftsmen	Day	25
12	Maintenance — Clerks	Day	10
TOTAL OPERATIONS			405
General & Admin			
1	Management	Day	3
2	Finance / Accounting / IT	Day	4
3	Legal	Day	1
4	Office Admin / HR	Day	12
5	Translation	Day	2
6	Marketing/Sales/Customer Support	Day	5
7	Logistics	Day	2
8	Planning/Projects	Day	2
TOTAL G&A			31
TOTAL NAIRIT SITE STAFF			436

Source: Jacobs Consulting Ltd.

We consider that the installation of the new centralised DCS system and the subsequent automation of Nairit site plant operations will greatly reduce the number of operators required to run the associated process plants at Nairit site. At present, we have assumed that the plant can be operated with a 4 shift split, which is typical for petrochemicals operation in Europe, but Nairit might want to consider implementing its own internal procedure for this. In order to facilitate the relevant discussions, we have compiled a relevant breakdown for the operators required to operate the process units involved in PCR production from butadiene. This breakdown is provided below.

Table D-24: Number of Required Operators per unit

	Process Unit	Operators (per shift)		Total
		DCS	Field	
Unit 1-7	Acetylene Production Unit ¹	5	3	32
Unit 1-12	Chloroprene Monomer	7	5	48
Unit 1-18	Chloroprene Neutralisation	1	1	8
Unit 1-19	Waste Utilisation	1	1	8
Unit 1-21	Return Chloroprene Distillation	1	1	8
Unit 1-22	Chloroprene Polymerisation	2	4	24
Unit 1-23	Polychloroprene Rubber Extraction	1	3	16
Unit 1-3	Chlor-Alkali Production	5	3	32
	Utilities	9	7	64
	Offsites	3	4	28
	TOTAL OPERATORS	35	32	268

Source: Jacobs Consulting Ltd.

Note 1: Inclusive of the air separation unit

24 kta of PCR Rubber from Acetylene

The estimated level of plant personnel required to operate the facility under this scenario is as follows:

Table D-25: Overall Plant Staffing Levels

Employee Category	Type	No. Off	
Operations			
1	Engineers — Qualified	Day	8
2	Operators — Supervisors	4 shifts	28
3	Operators — Operators (DCS + Field)	4 shifts	320
4	Bagging/Warehousing/Despatch	4 shifts	16
5	Customs Controls	Day	2
6	Qualified Technicians	Day	5
7	HSE	Day	2
8	Laboratory staff	Day	5
9	Security (shift staff)	4 shifts	20
10	Fire-fighters (shift staff)	4 shifts	16

11	Maintenance — craftsmen	Day	25
12	Maintenance — Clerks	Day	10
TOTAL OPERATIONS			457
General & Admin			
1	Management	Day	3
2	Finance / Accounting / IT	Day	4
3	Legal	Day	1
4	Office Admin / HR	Day	12
5	Translation	Day	2
6	Marketing/Sales/Customer Support	Day	5
7	Logistics	Day	2
8	Planning/Projects	Day	2
TOTAL G&A			31
TOTAL NAIRIT SITE STAFF			488

Source: Jacobs Consulting Ltd.

Again, for this scenario, we consider that the labour synergies afforded by the installation of the new centralised DCS system and the subsequent automation of Nairit site plant operations will greatly reduce the number of operators required to run the associated process plants at Nairit site. This breakdown is provided below.

Table D-26: Number of Required Operators per unit

	Process Unit	Operators (per shift)		Total
		DCS	Field	
Unit 1-7	Acetylene Production Unit ¹	5	3	32
Unit 1-12	Chloroprene Monomer	7	7	56
Unit 1-18	Chloroprene Neutralisation	1	1	8
Unit 1-19	Waste Utilisation	1	1	8
Unit 1-21	Return Chloroprene Distillation	1	1	8
Unit 1-22	Chloroprene Polymerisation	2	4	24
Unit 1-23	Polychloroprene Rubber Extraction	2	6	32
Unit 1-3	Chlor-Alkali Production	10	5	60
	Utilities	9	7	64
	Offsites	3	4	28
	TOTAL OPERATORS	41	39	320

Note 1: Inclusive of the air separation unit

25 kta of PCR Rubber from Butadiene

The estimated level plant personnel to operate the facility under this scenario is as follows:

Table D-27: Overall Plant Staffing Levels

Employee Category		Type	No. Off
	Operations		
1	Engineers — Qualified	Day	8
2	Operators — Supervisors	4 shifts	20
3	Operators — Operators (DCS + Field)	4 shifts	220
4	Bagging/Warehousing/Despatch	4 shifts	16
5	Customs Controls	Day	2
6	Qualified Technicians	Day	5
7	HSE	Day	2
8	Laboratory staff	Day	5
9	Security (shift staff)	4 shifts	20
10	Fire-fighters (shift staff)	4 shifts	16
11	Maintenance — CRaftsmen	Day	25
12	Maintenance — Clerks	Day	10
	TOTAL OPERATIONS		349
	General & Admin		
1	Management	Day	3
2	Finance / Accounting / IT	Day	4
3	Legal	Day	1
4	Office Admin / HR	Day	12
5	Translation	Day	2
6	Marketing/Sales/Customer Support	Day	5
7	Logistics	Day	2
8	Planning/Projects	Day	2
	TOTAL G&A		31
	TOTAL NAIRIT SITE STAFF		380

Source: Jacobs Consulting Ltd.

Again, for this scenario, we consider that the labour synergies afforded by the installation of the new centralised DCS system and the subsequent automation of Nairit site plant operations will greatly reduce the number of operators required to run the associated process plants at Nairit site. This breakdown is provided below.

Table D-28: Number of Required Operators per unit

	Process Unit	Operators (per shift)		Total
		DCS	Field	
Unit 1-18	Chloroprene Monomer	6	3	36

Unit 1-19	Waste Utilisation	1	1	8
Unit 1-21	Return Chloroprene Distillation	1	1	8
Unit 1-22	Chloroprene Polymerisation	2	4	24
Unit 1-23	Polychloroprene Rubber Extraction	2	6	32
Unit 1-3	Chlor-Alkali Production	4	1	20
	Utilities	9	7	64
	Offsites	3	4	28
	TOTAL OPERATORS	27	26	220

Source: Jacobs Consulting Ltd.

Section E



Assessment of the Financial Feasibility of Production

Introduction

In accordance with our technical assignment, Jacobs Consultancy visited the Nairit plant during the last week of February 2015. The purpose of the site visit was to assess the present condition of the assets of CJSC “Nairit Plant” and collect all the necessary information with regards to the examined assets.

The present report contains our assessment of the financial viability of the potential restart of chloroprene rubber production on Nairit site. Thus, it contains the following topics:

- Butadiene Market Overview
- Price Forecasts
- Project Cost Competiveness Analysis
- Project Financial Modelling Analysis

The above was considered with a view to restarting production under one of the three currently considered production scenarios:

- 12 kta of polychloroprene rubber, via acetylene route
- 24 kta of polychloroprene rubber, via acetylene route
- 25 kta of polychloroprene rubber, via butadiene route

Overall Summary

The overall summary is as follows:

Butadiene Market Overview

- Butadiene is widely traded on international markets
- Butadiene supply to Nairit plant is feasible, subject to transit being made available via Georgia (political and commercial risk)
- Unavailability of butadiene supply from Russia suggests that, in the event of Nairit operations being resumed, butadiene will most likely be sourced from Western Europe (Germany, Netherlands or Austria).
- Due to unavailability of the rail connection with either Russia or Turkey, butadiene will need to be shipped to a Georgian port, from where it may be transported by rail to the plant.
- At present, Georgian ports do not have suitable port terminal facilities for receipt of butadiene from tankers. Thus, two options are available:
 - Low CAPEX, high OPEX. Rail cars may be ferried directly or small portable containerised tanks used for transfer of butadiene.
 - Higher CAPEX, low OPEX. A receipt terminal to be built in a Georgian port (main investment will be a new butadiene storage tank farm, provided an adequate jetty is available)

Cost Competitiveness Analysis Results

- Production of PCR via the butadiene route represents the more cost efficient method, despite high costs of butadiene delivery (at least US\$250/ton) due to high natural gas and electricity prices available to Nairit, which adversely affect acetylene route based process.
- Generally, Nairit will be a lagging cost producer, with both USA and Germany based producers being significantly more cost competitive, effectively shutting Nairit from US and Western Europe markets.
- Due to more favourable logistics costs, as well as generally lower cost of production and product delivery, Japanese producers are more competitive than Nairit in Asian, African and Latin American markets.
- Once effects of capital charge are considered, Nairit becomes a sole marginal cost producer, unable to compete even with Chinese plants. It is also worth considering that the latter have historically benefitted from Chinese government protection, resulting in high import tariffs being imposed on all other foreign producers seeking to export into Chinese market.
- Overall, butadiene-based production at Nairit suffers from a weak cost competitive position, requiring a number of favourable conditions such as:
 - Low crude oil prices
 - Allowed entry into Chinese markets
 - Reduced project return expectations to mitigate the effect of the capital charge
 - Reduced competitor operating rates
- In order for production via the acetylene route to be viable, a significant reduction in the price of natural gas and electricity tariffs is required.

Financial Modelling Analysis Results

- Under all of the considered scenarios, the project yields a negative project return.
- The 25 kta butadiene-based scenario results in the least negative results, followed by the 12 kta acetylene-based scenario, which generates less absolute negative revenues than a larger 24 kta acetylene-based scenario.
- For the acetylene-based cases, the option of using the ISP plasma arc process for acetylene generation yields the least negative results at current prices for natural gas and electricity.

Butadiene Market Overview

Introduction

Butadiene is a versatile raw material used in the production of a wide variety of synthetic rubbers and polymer resins as well as a few chemical intermediates. When the word butadiene is used, most of the time it refers to 1,3-butadiene with the chemical formula C_4H_6 . Butadiene is a colourless, non-corrosive liquefied gas with a mild aromatic or gasoline-like odour. Butadiene is soluble in alcohol and ether, insoluble in water and polymerizes readily, particularly if oxygen is present. Butadiene is a commodity product of the petrochemical industry which is both explosive and flammable because of its low flash point.

In 1863, a French chemist isolated a previously unknown hydrocarbon from the pyrolysis of amyl alcohol. This hydrocarbon was identified as butadiene in 1886, after Henry Edward Armstrong isolated it from among the pyrolysis products of petroleum. In 1910, the Russian chemist Sergei Lebedev polymerized butadiene, and obtained a material with rubber-like properties. This polymer was, however, too soft to replace natural rubber in many roles, especially automobile tyres.

The butadiene industry originated in the years leading up to World War II. Many of the belligerent nations realized that in the event of war, they could be cut off from rubber plantations controlled by the British Empire, and sought to remove their dependence on natural rubber. In 1929, Eduard Tschunker and Walter Bock, working for IG Farben in Germany, made a copolymer of styrene and butadiene that could be used in automobile tires. Worldwide production quickly ensued, with butadiene being produced from grain alcohol in the Soviet Union and the United States and from coal-derived acetylene in Germany.

The pattern of commercial production of 1,3-butadiene parallels the overall development of the petrochemical industry. The butadiene industry began on a commercial scale in the late 1930s, when the U.S. government built several butadiene producing plants to supply the developing synthetic rubber industry. The butadiene plants built by the government used catalytic dehydrogenation to convert normal butane to butadiene. Production from this type of unit was the primary source of butadiene in the US for many years. A very little butadiene was generated as a co-product by early US ethylene plants as they were mainly based on ethane or propane feedstock. In fact, it was not until the early 1980s that the quantity of butadiene produced from US ethylene plants as a co-product exceeded that produced in dehydrogenation units. Worldwide dehydrogenation capacity had their presence in Mexico, Argentina, Romania, Poland and China. All of these plants have been shut down since the 1990's except a few still operating in Russia.

At the current time, nearly all of the world's butadiene is produced by extracting the monomer from crude C4. Crude C4, in turn, is produced from cracking heavy feedstock such as naphtha. Butadiene production from ethylene plants is now becoming insufficient to adequately supply butadiene demand in many areas of the world due to the trend of crackers shifting towards lighter feedstock and hence is affecting the price economics of butadiene with a sharp increase seen recently. In light of this, producers are once again considering building on-purpose dehydrogenation facilities. The growing supply crunch of butadiene is likely to be met by on-purpose production.

In the US, crackers have switched to lighter natural gas-based feedstock because of the advent of shale gas. This trend has reduced production of crude C4. The United States, a major butadiene importer, already has a dehydrogenation plant which used to operate intermittently but has not run since late 2000 and is now planned to be restarted. A few other plants in China are set to start on-purpose butadiene production through oxy-dehydrogenation process, which has not yet seen successful commercialization anywhere in the world. Considering the current scenario, on-purpose technologies will become important and will be economical under high price scenarios.

Butadiene Production Processes Overview

The major source of butadiene is as a by-product in the steam cracking of LPGs, naphtha and gas oil to make ethylene and propylene. The butadiene is extracted from the C4 cracker stream using extractive distillation. Almost all butadiene is produced as a by-product of the ethylene production steam cracking process. In certain parts of the world (mainly in Central & Eastern Europe and North America) there are still some production units based on on-purpose routes to butadiene (i.e. Dehydrogenation technology), though not in operation. In the past, ethanol has also been used as a feedstock for on-purpose butadiene.

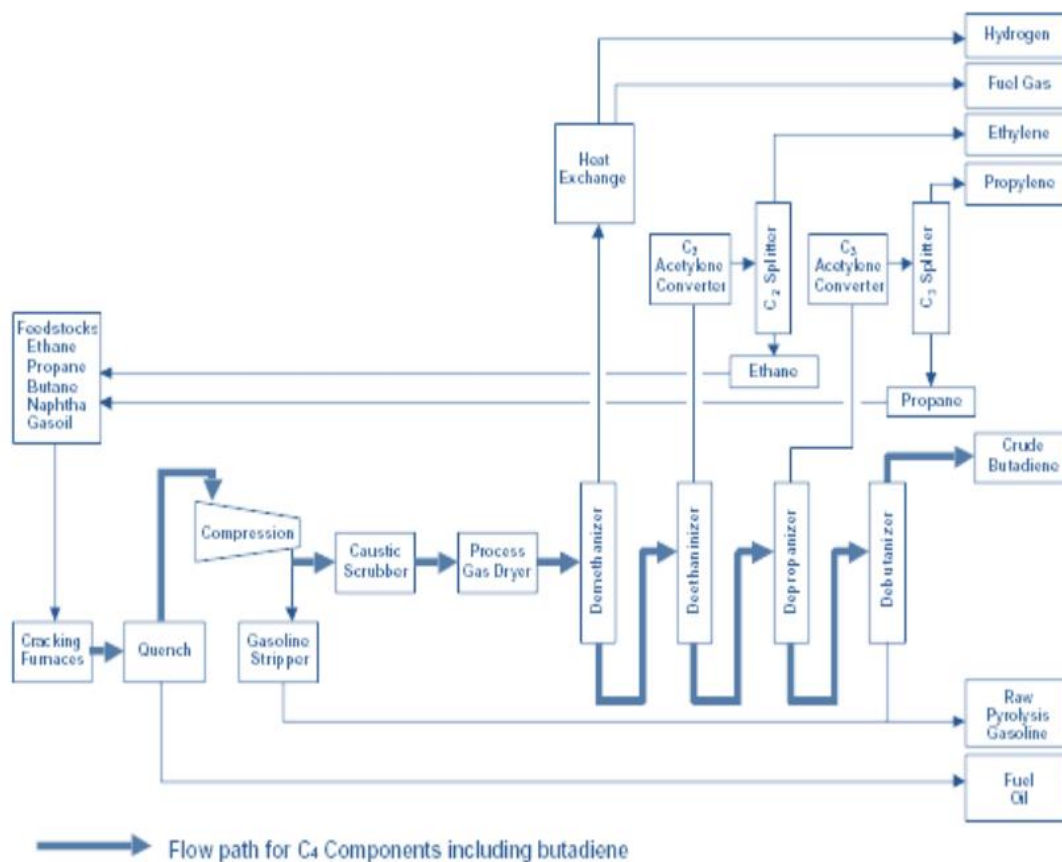
Butadiene is commonly produced by four processes:

- Steam cracking of paraffinic hydrocarbons (as a co-product of ethylene manufacturing);
- Catalytic dehydrogenation of n-butane and n-butene (Houdry process);
- Oxidative dehydrogenation of n-butene (Oxo-D or OX-D process); and
- Ethanol to Butadiene

Steam CRacking: Extraction from C4 hydrocarbons

The steam CRacking process shown in Figure E-1 is the predominant method of butadiene production, accounting for nearly 95% of the world's butadiene supply. In the United States, Western Europe, and Japan, butadiene is produced as a by-product of the steam cracking process used to produce ethylene and other olefins. When mixed with steam and briefly heated to very high temperatures (often over 900°C), aliphatic hydrocarbons give up hydrogen to produce a complex mixture of unsaturated hydrocarbons, including butadiene.

Figure E-1: Block Flow Diagram for a typical olefins production (Steam cracker) plant



Source: Jacobs Consultancy Ltd.

Since the boiling points of the various C₄ components are close to each other, separation of butadiene via simple distillation doesn't currently suffice to adequately separate the components; therefore, extractive distillation (ED) is used. ED is a vapour-liquid process operation that uses a third component, or solvent, to effect a chemical separation. The extractive agent creates or enhances the volatility difference between the components to be separated. The extractive agent and agent-induced less volatile component flow to the bottom of the distillation column, where the extracted component is recovered by a subsequent distillation. The non-extracted species are distilled to the top of the extractive distillation tower.

Butadiene is typically isolated from the other four-carbon hydrocarbons produced in steam cracking by extraction into a polar aprotic solvent such as acetonitrile (ACN), N-methyl-2-pyrrolidone (NMP), furfural, or dimethylformamide (DMF), from which it is then stripped by distillation.

The first plants using furfural as solvent were built in the United States during World War II (the process was developed by Phillips Petroleum). The method introduced by Shell in the early 1950s uses acetonitrile as solvent. It was developed from a one-step procedure involving separate removal of acetylene into a two-step process and is still applied today. Modern plants employ the BASF procedure with N-methylpyrrolidone or the DMF method of Nippon Zeon.

The quantity of butadiene produced depends on the hydrocarbons used as feed. Light feeds, such as ethane, give primarily ethylene when cracked, but heavier feeds like naphtha or virgin gas oil favour the formation of heavier olefins, butadiene, and aromatic hydrocarbons. The pertinent yields from various cracker feedstocks are shown in Table E-1. The data illustrate that ethane and propane produce significantly less butadiene (and other C₄ olefins) than butane, naphtha and gas oil.

Table E-1: Olefins Yield from Various Feedstocks

Feedstock & Olefins	Ethane	Propane	Butane	Naphtha	Gas Oil
Ethylene	76.80%	44.29%	44.33%	30.19%	20.17%
Propylene	2.61%	13.73%	14.89%	15.46%	14.48%
BTD/C4 Olefins	2.61%	3.99%	6.65%	7.67%	7.95%

Source: Jacobs Consultancy Ltd.

Relatively few crackers in the world have all of this flexibility. While some cracker can feed any of these feedstocks, it is much more common to build a cracker designed to operate with only one or two of these feedstocks. In Europe and Asia, most of the crackers are built to feed naphtha and/or gas oil. In the United States, many can feed only natural gas liquids (NGL's - i.e. ethane, propane and normal butane). Feedstock selection is a very important factor in establishing the quantity and quality of co-product production for a given quantity of ethylene production. For the purposes of calculating butadiene production, a factor is used relative to ethylene production. Olefins plants are generally operated to meet ethylene demand; thus, co-products are produced as a function of the ethylene rate. This is expected to remain the case for the foreseeable future and butadiene production will always change with the needs of the ethylene market. Thus, by using a co-product to ethylene ratio, the quantity of the co-product can be calculated.

On-Purpose Butadiene: Dehydrogenation of Butane & Butene

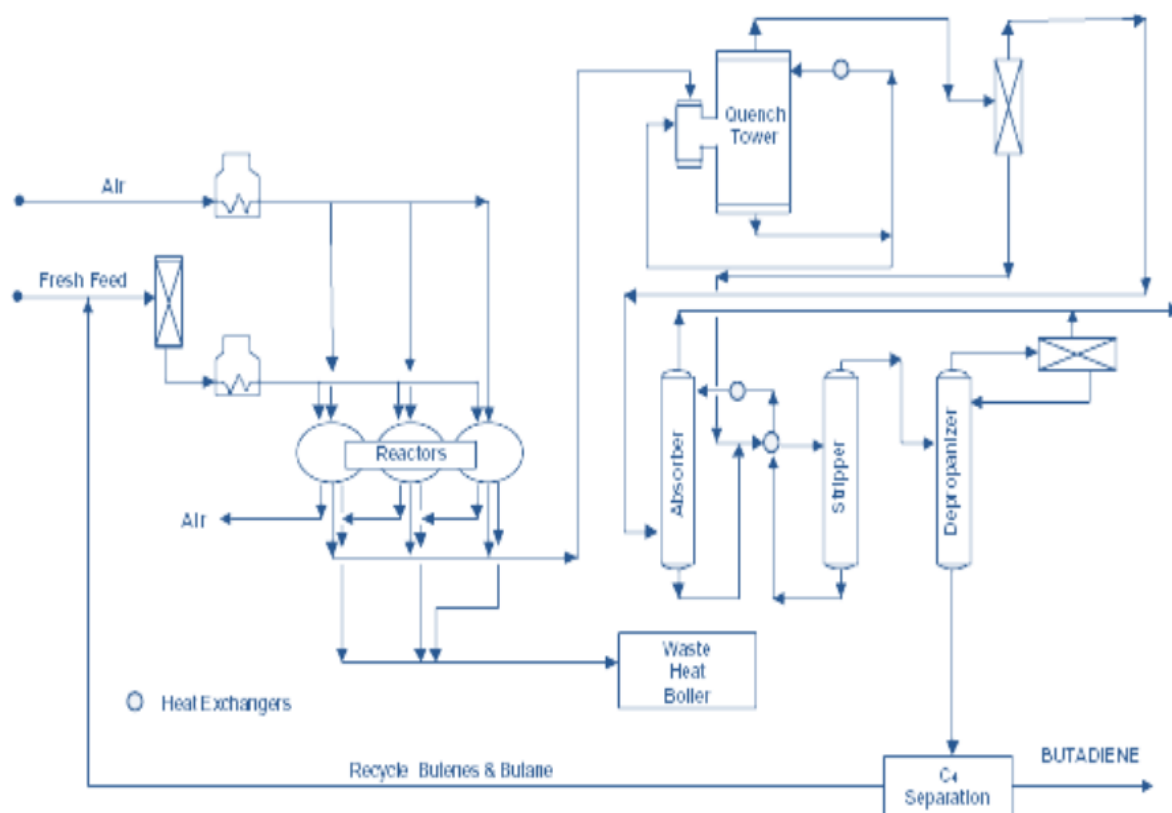
The other source of butadiene is dehydrogenation, often referred to as "on-purpose". There are actually two "on-purpose" systems that have been used to produce refined butadiene in various countries around the world. Though producing butadiene from butane or butylenes is not a new concept, one of the emerging trends in the global butadiene market is the renewed interest in on-purpose production. In the last decade, the on-purpose share of global butadiene production has been in the range of 3.2%.

Dehydrogenation of n-Butane

Butadiene can also be produced by the catalytic dehydrogenation of normal butane. The first such post-war commercial plant, producing 65,000 tons per year of butadiene, began operations in 1957 in Houston, Texas.

Prior to that, in the 1940s the US War Department constructed several much larger plants in Borger, TX, Toledo, OH, and El Segundo, CA to produce synthetic rubber for the war effort as part of the United States Synthetic Rubber Program.

Figure E-2: Block Flow Diagram for a Houdry Catadiene Process (On-Purpose) Plant



Source: Jacobs Consultancy Ltd.

In the former Soviet Union, before the political & economic transition at the start of the 1990s, there was limited access to natural rubber and synthetic rubber feedstocks through imports, and so local resources (NGL) had to be used. Dehydrogenation was the preferred technology to produce synthetic rubber feedstock (butadiene & isoprene) from these streams.

In the FSU butadiene & isoprene are therefore manufactured by the dehydrogenation of paraffins. The processes which have been used for these reactions are versions of the Catadiene (Lummus) and the Yarsintez fluid bed process. The Catadiene process has been installed at Nizhnekamsk for the production of butadiene.

The best known two-step dehydrogenation is the Houdry Catadiene process (Figure E-2), which has been in operation on a commercial scale since 1943. In this adiabatic process, several packed-bed reactors, arranged parallel to each other, are operated alternately. Aluminium oxide mixed with approximately 20% chromium oxide is the catalyst. The n-Butane is subjected to dehydrogenation as such or in a mixture of n-Butenes at 600-700°C and 10-25 kPa. The use of high temperature results in by-products like C₁-C₃ hydrocarbons, hydrogen, and carbon deposits on the catalyst. After 5-15 min of running time, the reactor is switched to regeneration. The heat generated by burning the coke residue during the regeneration phase is stored in the catalyst and in the added inert material and is then reused in the next reaction phase.

The concentration of butadiene at the outlet of the reactor is 15-18%. During the recovery process, which includes absorption of the C₃ & C₄ hydrocarbons, compression, stripping, and separation from unconverted n-butane and n-butenes, the concentration of butadiene is increased to 30-50%. Approximately 550 t of butadiene is obtained from 1000 t of n-butane.

Phillips Petroleum has developed a two-step dehydrogenation process:

- 1) n-Butane is catalytically dehydrogenated to butene at 600°C and 1 bar on $\text{Cr}_2\text{O}_3\text{-Na}_2\text{O-Al}_2\text{O}_3$.
- 2) The n-butenes are separated by extractive distillation with auxiliaries such as acetone, acetonitrile, and furfural.
- 3) The n-butenes are dehydrogenated to butadiene in an isothermal tubular reactor, heated with flue gas to 600°C, at a pressure of 1 bar, with addition of superheated steam on a $\text{Fe}_2\text{O}_3\text{-K}_2\text{O-Al}_2\text{O}_3$ catalyst.
- 4) Butadiene is recovered by extractive distillation with the above-mentioned auxiliaries and purified. The advantages of this method are the longer running time without catalyst regeneration and higher butadiene yields (65% based on butane).

Dehydrogenation of n-Butenes

n-Butenes are formed in the production of standard gasoline by catalytic cracking, in the production of olefins by thermal cracking, and in the dehydrogenation of LPG. Normally, butenes are part of a C4 hydrocarbon mixture. The C4 paraffins can be separated from the C4 olefins by extractive distillation, as routinely employed in the recovery of butadiene. The boiling points of isobutene and n-butene are so close together that they can only be separated by special methods. The gas-phase BASF process employs 40-45% H_2SO_4 to selectively convert iso-butene into tert-butanol. Today, separation is carried out by conversion to methyl tert-butyl ether or to isobutene oligomers.

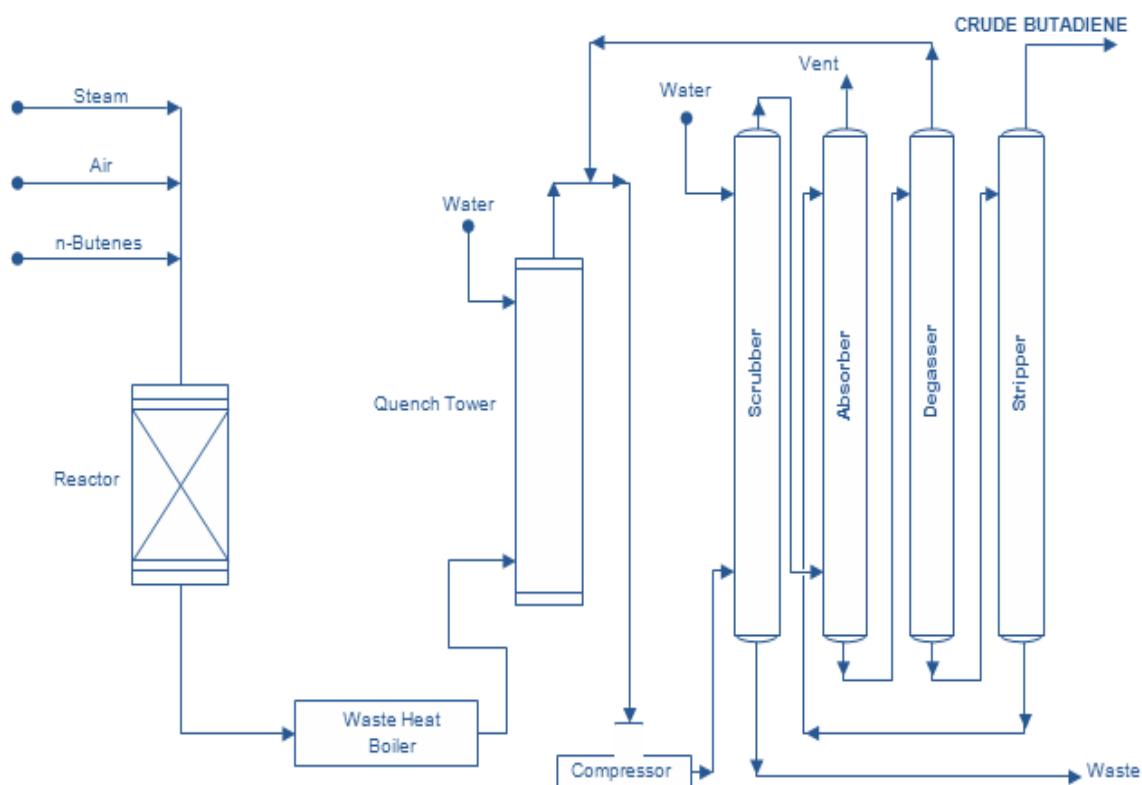
Oxidative Dehydrogenisation of n-Butenes

The conversion and the selectivity of the dehydrogenation of n-butenes to butadiene can be significantly improved by removing the hydrogen from the equilibrium. The addition of oxygen causes the oxidation of hydrogen to water:



The exothermic oxidation of hydrogen partially covers the heat requirements of the endothermic dehydrogenisation reaction and, in addition, the oxygen, together with steam added during the reaction, leads to decreased catalyst coking. Especially productive methods are the Oxo-D process of Petro-Tex and the O-X-D process of Phillips.

Figure E-3: Block Flow Diagram for an Oxo-D Process (On-Purpose) Plant



The Oxo-D process (Figure E-3) was first applied on a large scale in 1965. The advantages of this method are the low consumption of steam and heating energy, high conversion and selectivity per reactor cycle, longer life span of the catalyst, and no necessity for catalyst regeneration. Petro-Tex achieved 65% conversion and a butadiene selectivity of 93% by using a molar steam/butene ratio of 12/1.

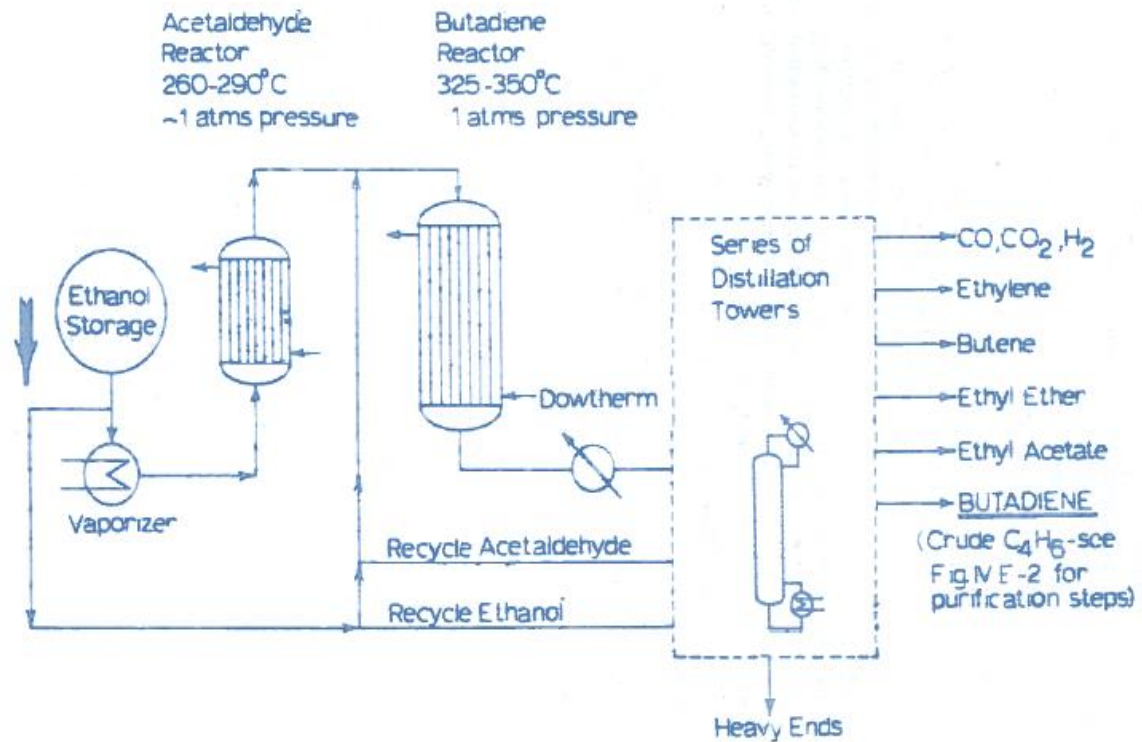
Phillips has operated a plant in Borger (Texas) since 1970 based on the O-X-D process, producing 125 kta of butadiene. Phillips also obtains a high conversion and an 88-92% selectivity of butadiene.

Butadiene from Ethanol

The original on-purpose processes for making butadiene from acetylene by the Aldol or Reppe routes are no longer used on economic grounds. In other parts of the world, including South America, Eastern Europe, China, and India, butadiene is also produced from ethanol as shown in the Figure E-4. While not competitive with steam cracking for producing large volumes of butadiene, lower capital costs make production from ethanol a viable option for smaller-capacity plants.

While this route to butadiene production is consider obsolete in most part of the world today, there are two processes still in use. In the single-step process developed by Sergei Lebedev, ethanol is converted to butadiene, hydrogen, and water at 400– 450 °C over any of a variety of metal oxide catalysts.

Figure E-4: Block Flow Diagram for a Butadiene from Ethanol (On- Purpose) Plant



Source: Jacobs Consultancy Ltd.

This process was the basis for the Soviet Union's synthetic rubber industry during and after World War II, and it remained in limited use in Russia and other parts of Eastern Europe until the end of the 1970s. At the same time this type of manufacture was cancelled in Brazil. Nowadays there is no industrial production of butadiene from ethanol. Lately Laxness has announced a plan to produce butadiene from ethanol. In the other two-step process, developed by the Russian chemist Ivan Ostromislensky, ethanol is oxidized to acetaldehyde, which reacts with additional ethanol over a tantalum-promoted porous silica catalyst at 325 - 350°C to yield butadiene.

This process was also used in the United States to produce government rubber during World War II, though it was not preferred because it is less economical than the butane or butene routes for the large volumes needed. It remains in use today in China and India.

Licensors of Technologies

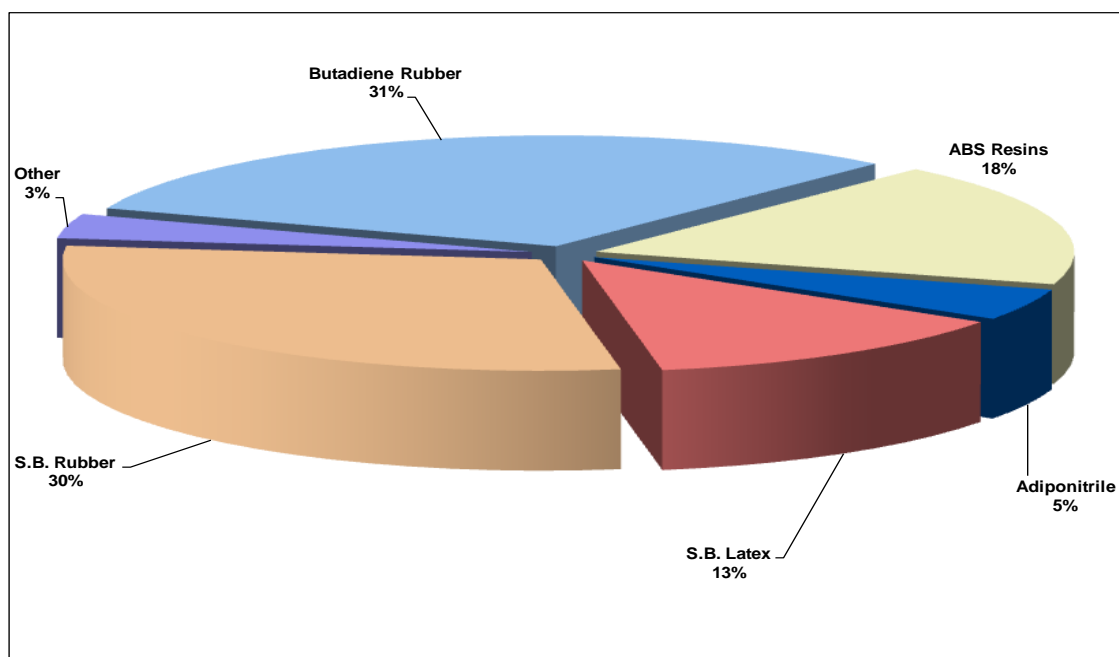
- Extractive distillation :
 - Shell/KBR, BASF/Lurgi, Zeon Chemicals, LyondellBasell, ConocoPhillips, Solutia, Dow, Sinopec, Uhde.
- Dehydrogenation of paraffins :
 - Lummus Technology, Yarsintez
- Dehydrogenation of olefins :
 - TPC Group Inc.

Global Market Overview

The global butadiene industry has witnessed an average demand growth rate of 3.5% in the past 14 years and is estimated to have increased by 1.7% to 10.9 million tons in 2014. Strong upward momentum seen in Asia and other developing countries improved the demand from the trough witnessed in the year 2008-09. However, the demand did witness a dip in 2012 and 2013, with growth rates contracting by 0.9% and 2.2% respectively, as the global economy turned sluggish and demand declined from high growth developing countries like China and India. It must be noted that low automobile market penetration and increasing disposable incomes in the developing regions are said to be driving the demand for butadiene applications. Further demand gains are likely to be fuelled by growth in key original equipment manufacturing (OEM) markets, particularly motor vehicles. In addition, the worldwide motor vehicle demand will grow at a faster pace based on the emerging strength of developing markets, supporting aftermarket demand.

Most butadiene is used in the production of polymers or chemical intermediates which go into the production of polymers. These polymers are used in a wide variety of consumer and industrial products that provide tremendous benefit to society. These polymer products improve functionality and performance of consumer products, improve safety and lower the cost of these products. Butadiene-based products are important components of automobiles, construction materials, appliance parts, computers and telecommunications equipment, clothing, protective clothing, packaging and household articles.

Figure E-5: Butadiene End-use Applications, 2014



Source: Jacobs Consultancy Ltd.

Polybutadiene (PB) along with chloroprene rubber and nitrile rubber (represented as butadiene rubber in the chart above) form the largest end use segment (31%) of butadiene. PB is used as a raw material for tyres, an intermediate in production of acrylonitrile–butadiene–styrene (ABS) resins and as an impact modifier for plastics. ABS resins and adiponitrile are the second-largest use (about 23% combined) of butadiene. However, the largest single end use for butadiene (about 30%) is in the production of styrene–butadiene rubber (SBR). The primary use for SBR is in tyres and tyre products. It is also used in adhesives and sealants, wire and cable coatings and rubber articles, such as shoe soles.

Applications

Table E-2: Butadiene End Uses

Butadiene End Use	World Butadiene Demand (10.9 MMT In 2014) (%)	Downstream Use	Secondary Downstream Use
Styrene–butadiene-rubber (SBR)	30%	Tires Tire products Adhesives Sealants Rubber articles	Shoe soles
Polybutadiene (PB)	26%	Tires ABS resins Impact modifiers	Plastics See ABS below
Styrene–butadiene latex (SBL)	13%	Foam rubber Adhesives Sealants Paper coatings	Carpet backing, cushions, pads, sponges Flooring, tiles, roofing
ACRylonitrile–butadiene–styrene	18%	Automotive parts Telephones Office machines Appliances	Computers, printers, fax machines
Adiponitrile	5%	Nylon resins Nylon fibres	Auto parts, appliance parts, construction materials Carpets, clothing, fabric
Nitrile rubber	4%	Hoses Fuel lines Auto parts Gasket seals Structural adhesives Oil resistant clothing, gloves, footwear Polychloroprene rubber	Gloves, coatings, adhesives, binders
Chloroprene	1%	(neoprene)	Sealants, tires, belts, hoses, faucet washers, footwear
Other uses Styrene–butadiene block copolymers (SBS and SEBS)	3%	Asphalt extenders Lube oil additives Adhesives Auto parts Packaging Medical devices Footwear	

Butadiene End Use	World Butadiene Demand (10.9 MMT In 2014) (%)	Downstream Use	Secondary Downstream Use
		Toys Plastic dinnerware Impact modifiers	
Methyl methacrylate-butadiene-styrene (MMBS)	<1%	Impact modifiers Auto parts Bottles Food packaging	
Chemical intermediates	<1%	1,4-Hexadiene Sulfolane 1,5,9-Cyclodecatriene	EPDM rubber Extraction solvent Nylon fibres and resins

Source: Jacobs Consultancy Ltd.

Currently, crude butadiene is traded globally, with North America and North East Asia being significant importers. Finished butadiene is traded globally, with Canada, Western Europe, Saudi Arabia and Korea being the largest exporters. Mexico, the United States and China are the largest net importers. Global demand for butadiene is expected to grow at about 3.5% per year, with demand growth for synthetic rubber production expected to be around 2%. Demand growth for Northeast Asia (including China) is expected to be higher than the global average; while growth in the United States and Western Europe is expected to be below the global average. Butadiene demand by application is illustrated in Figure E-5 & Table E-2. Butadiene rubber includes polychloroprene rubber, nitrile rubber and polybutadiene rubber.

1,3-Butadiene is used principally as a monomer in the manufacture of a wide range of polymers and copolymers. Polymerization of styrene and 1,3-butadiene yields styrene butadiene rubber (SBR), the largest single use of butadiene; almost 80% of the styrene-butadiene rubber produced is used in tyres and tyre products. Polymerization of 1,3-butadiene produces polybutadiene, almost all of which used for car and bus tyres. Nitrile rubber is produced by copolymerizing 1,3-butadiene and acrylonitrile; it is used in hoses, gaskets, seals, latexes, adhesives and footwear. Acrylonitrile-butadiene-styrene resins are graft tert polymers of polybutadiene on a styrene-acrylonitrile copolymer; they are used in automotive parts, pipes, appliances, business machines and telephones. Styrene-butadiene latexes are suspensions of particles or globules of the elastomer in water and are used in paper coatings and paints and as carpet backing.

Butadiene is also used extensively for various polymerizations for plastics manufacturing. Copolymers with high proportions of styrene have found applications such as stiffening resins for rubber, in water-based and other paints, and in high impact plastic. Butadiene also serves as a starting material for nylon 66 (adiponitrile) and an ingredient in rocket fuel (butadiene-acrylonitrile polymer).

Elastomer Use

Over 70-72% of butadiene use is for rubber and latex (elastomers). The major solid rubbers produced from butadiene include:

- Emulsion styrene butadiene rubber (ESBR)
- Solution SBR (SSBR)
- Polybutadiene rubber (PBR)

- Nitrile rubber (NBR)
- Chloroprene rubber (PCR)

Solid rubbers are used in the production of rubber goods, of which tyres is the dominant use. Other uses include belting, hoses, etc.

ESBR was the first synthetic rubber produced. Production started in the Second World War when the invasion of South East Asia by the Japanese cut off supplies of natural rubber to the Western powers. However following the War, the supply of natural rubber was restored and the commercial interest in synthetic rubbers waned. It was only later in the 1950s and 1960s with the spread of the automobile that synthetic rubber production was again increased since the supply of natural rubber became inadequate to satisfy demand alone.

The original hot emulsion process for ESBR was replaced by the cold emulsion process. More recently the anionic solution process was developed. This yields rubbers with a narrower molecular weight distribution, which are increasingly preferred.

Today both natural rubber and synthetic rubbers have an important role to play in the tyre industry. With tyres becoming more technically defined and the specifications more demanding, the role played by natural rubber and the various synthetic elastomers is differentiated.

ESBR remains today an important elastomer and is still widely used in the treads of tyres. However the increasing sophistication of the tyre industry has led to the use of larger amounts of SSBR in tyre treads and PBR in tyre walls over the last decade. Hence ESBR demand has declined as SSBR and PBR demand increased.

There are two main variants of PBR. The major solid rubber produced is a high cis-1,4 polybutadiene produced by Ziegler Natta polymerisation, originally using cobalt catalysts (today neodymium and titanium based catalysts are more typically employed). This is a broad molecular weight distribution polymer which is used by the tyre industry. A low cis, narrow molecular weight polymer is produced by the anionic polymerisation of butadiene with butyl lithium. This product is not suitable for use in tyres but is used as an impact modifier for polystyrene and accounts for around 20% of PBR demand.

Nitrile rubber and chloroprene rubber are characterised by higher levels of oil resistance compared with SBR and PBR. These therefore tend to be used in seals, hoses, etc., where oil resistance is required. Demand in these end uses is however in long term decline as other non-butadiene derived elastomers are increasingly used (EPDM, butyl rubber, halogenated butyl rubber, silicone elastomers, polyurethane elastomers, and other elastomers).

In addition to solid rubber there is production of rubber latex. The major categories of latex include:

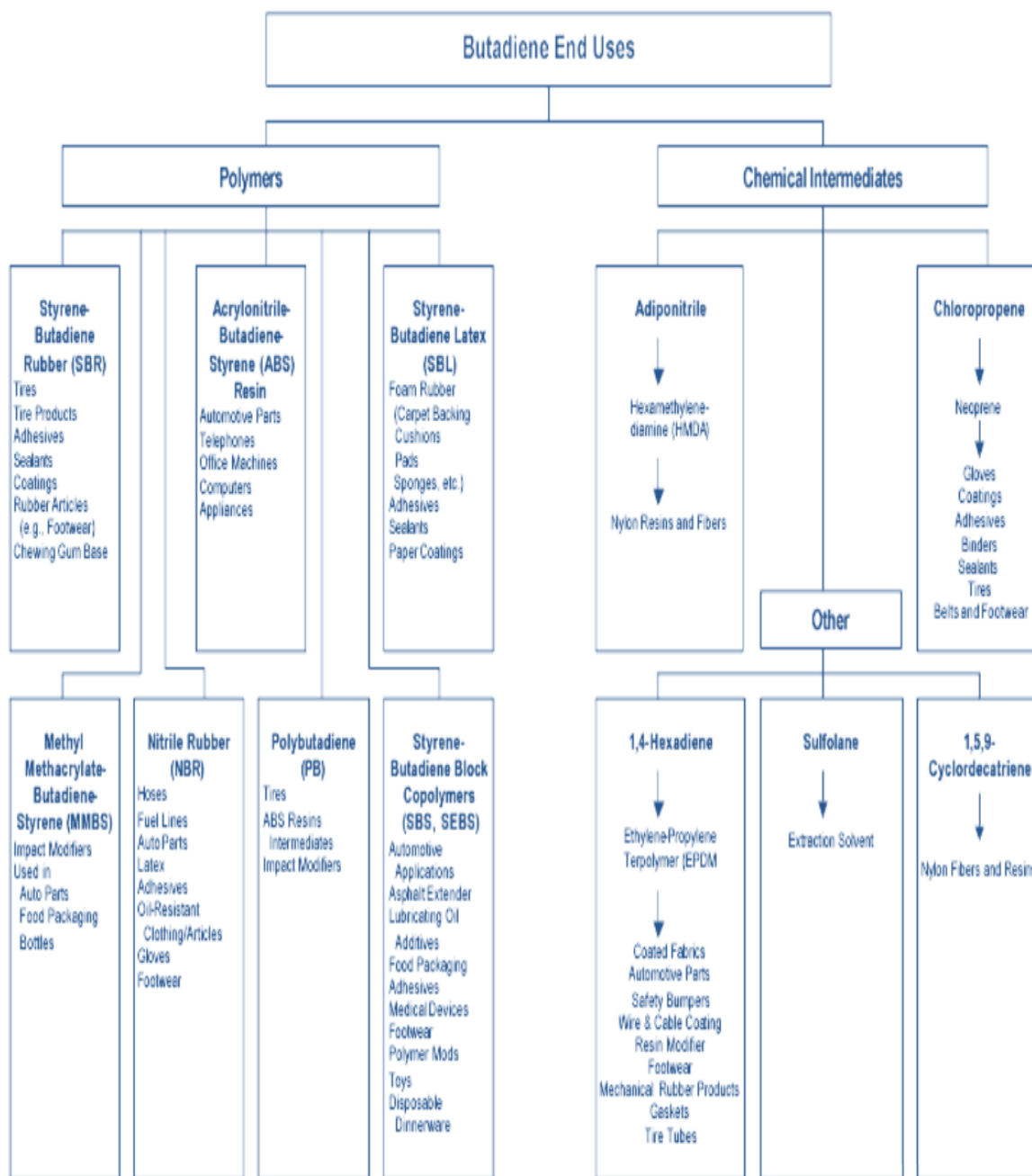
- Styrene butadiene latex (SBL)
- Carboxylated styrene butadiene latex (XSBL)
- Nitrile latex (NBL)
- Others (small amounts of chloroprene latex etc.)

SBL is used in two main applications as carpet underlay and in foam mattresses. Both of these end uses are in long term decline.

Carboxylated latex is used mainly for the coating of paper for glossy magazines, advertising materials etc. This is a growing end use. The other main uses for XSBL are in adhesives.

Nitrile latex is used in the production of hygiene products such as surgical gloves. The use of these has increased with HIV, SARS and other health issues as well as the growth in DNA testing, security screening etc.

Figure E-6: Butadiene End Uses (Polymers & Chemical Intermediates)



Source: Jacobs Consultancy Ltd.

In addition to the above, there is another segment of demand which is not a conventional elastomer. This is the segment of thermoplastic elastomers. Thermoplastic elastomers are a category of materials which can be melted and moulded like a thermoplastic and yet which are elastomeric in nature. Furthermore in contrast to conventional elastomers they do not require to be vulcanised in order to be elastomeric. Hence these are typically linear (or with limited branching) polymers (like thermoplastics) rather than being highly cross-linked gels (the state of vulcanised rubber). In the case of butadiene-based thermoplastic elastomers, they retain the high degree of un-saturation in the polymer backbone which typifies other butadiene-based elastomers.

Butadiene-based thermoplastic elastomers are typically block copolymers combining in a single macromolecule a block of butadiene rubber phase between two blocks of polystyrene; for this reason they are often referred to as SBS thermoplastic elastomers.

SBS is produced by a variant of the solution SBR process whereby the reaction is commenced with styrene only and then once all of the styrene has polymerised it is continued with butadiene. At this point the reaction can either be continued with more styrene or the polymer chains can be coupled to create the SBS block structure. Coupling agents include epoxidised polybutadiene, ethyl acetate or vinyl acetate. SBS is by far the major component of the “others” sector shown in Figure E-5.

The major uses for SBS include lube additives, rubber and plastics uses, and as a bitumen additive.

Non-Elastomer Use

The main non-elastomer uses of butadiene are:

- ABS resins
- Adiponitrile
- Other end uses

ABS is the major engineering resin used in the world today, accounting for 40% of global engineering resin demand. Engineering resins are characterised from commodity resins in being mainly used in long life cycle goods such as electronic devices, cars, durable goods etc. rather than in packaging materials and other disposable items.

The widespread use of ABS can be attributed to the fact that as it can be manufactured at much lower cost than the higher performance engineering resins such as nylon, PMMA, polycarbonate etc. It should be noted that ABS/PC blends (which contain around one third ABS and two thirds polycarbonate) are of growing importance.

ABS is an important polymer in key markets such as electronic and electrical equipment (where ABS/PC blends are increasingly widely used), house hold appliances and automotive applications (an area of increasing demand as metal parts are replaced with plastic compounds).

There is also some relatively small commercial production of methyl methacrylate butadiene styrene polymers (MBS). These resins are mostly used as impact modifiers in blends with other polymers.

The other main use for butadiene in non-elastomer use is in the production of adiponitrile by the Invista process. Adiponitrile is a key raw material in the manufacture of nylon-6,6. The Invista process is unique in using butadiene, with the alternative process starting from acrylonitrile.

Other chemical uses of butadiene cover a wide range of relatively small end uses and include ethylidene norbornene, cyclo-octadiene, butanediol etc.

Butadiene demand is dominated by the production of rubber and latex elastomers, to serve its major market, SBR and polybutadiene rubbers. This accounts for over 70% of global butadiene demand. Thus, the dynamics of the tyre and automobile industries have a major impact on butadiene markets. The severity of the financial crisis on the automotive industry, particularly in North America and Western Europe caused a decline in global butadiene demand. Demand thereafter, improved in 2010-11 on the back of the economic stimulus provided by Governments to sustain growth, but declined in the subsequent years, as the Chinese economy grew sluggish and the Eurozone crisis deepened.

Within its non-elastomers use, ABS resin is the largest application amounting to 18% of total butadiene demand. ABS resins were the fastest growing application with 7.0% p.a. demand growth rate in the period from 2000 till 2014, despite the low demand growth experienced during 2008 and 2009 due to the financial crisis. Other large volume applications of butadiene; styrene butadiene rubber and styrene butadiene latex, have grown around 2.3% p.a. and 2.8% p.a. respectively.

In the long term forecast, the butadiene demand in the ABS application is forecast to stabilize at around 6.0% p.a. as Asia drives demand growth. Demand in the other key applications like butadiene rubber are likely to grow at a slower pace of 1.7% in the long term forecast, while demand for styrene

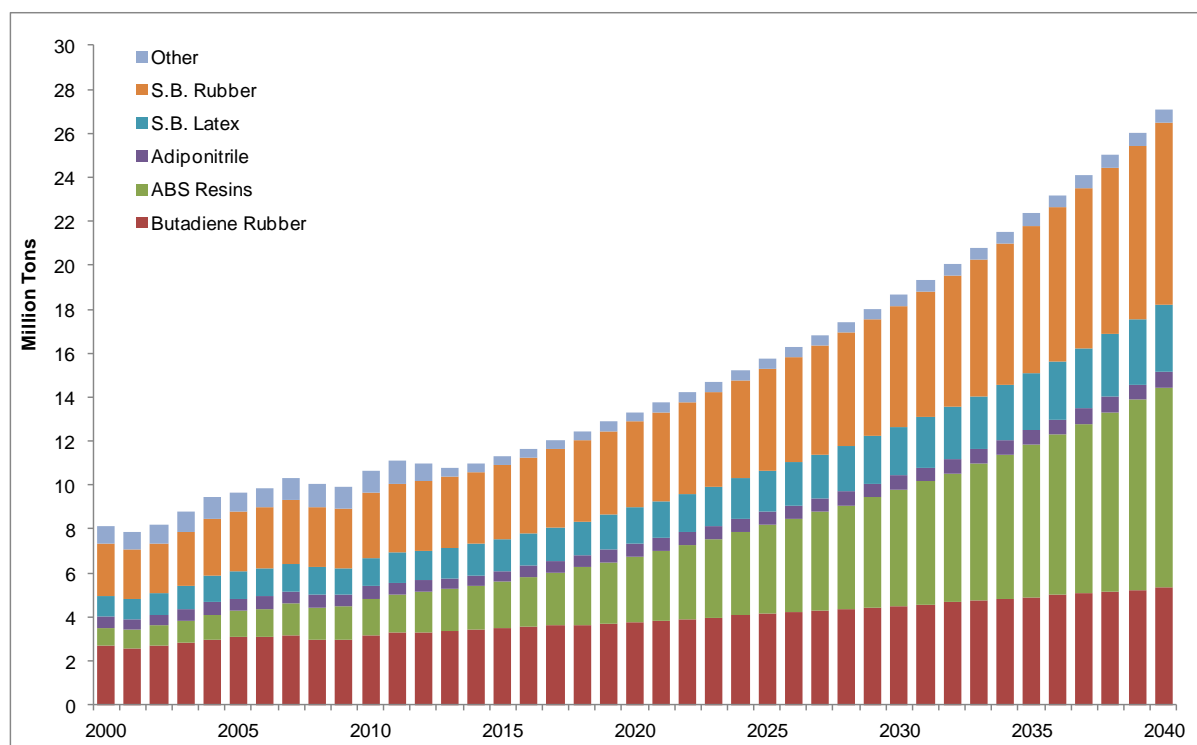
butadiene rubber and styrene butadiene latex are forecast to grow between 3.0-3.5% driven by the growth in the Asian region. Butadiene application in adiponitrile, which is currently about 5.0% of the global demand, is expected to grow at about 1.3% p.a. in the long term forecast.

Global Demand

Global butadiene demand was estimated to be 10.9 million tons in 2014. The global butadiene averaged annual demand growth of 2.2% between 2000 and 2014. However, it should be noted that the market actually grew by about 3.6% p.a. from 2000 till 2007, driven mainly by the Asian derivatives demand, post which the economic meltdown affected the market with the demand declining by -2.8% and -1.4% in 2008 and 2009 respectively. In 2010, the demand bounced back, growing by 7.4% while in 2011 the demand grew by 4.6%. In 2012, demand contracted by 0.9% and further by 2.2% in 2013. However, the demand grew by 1.7% in 2014.

Butadiene demand is dominated by the production of rubber and latex elastomers, to serve its major market, SBR and polybutadiene rubbers. This accounts for over 70% of global butadiene demand. Thus, the dynamics of the tyre and automobile industries have a major impact on butadiene markets. Within its non-elastomers use, ABS resin is the largest application amounting to 18% of total butadiene demand. ABS resins were the fastest growing application with 7.0% p.a. demand growth rate in the period from 2000 till 2014, despite the low demand growth experienced during 2008 and 2009 due to the financial crisis. Other large volume applications of butadiene; styrene butadiene rubber and styrene butadiene latex, have grown around 2.3% p.a. and 2.8% p.a. respectively.

Figure E-7: Butadiene Demand Growth Forecast by Applications

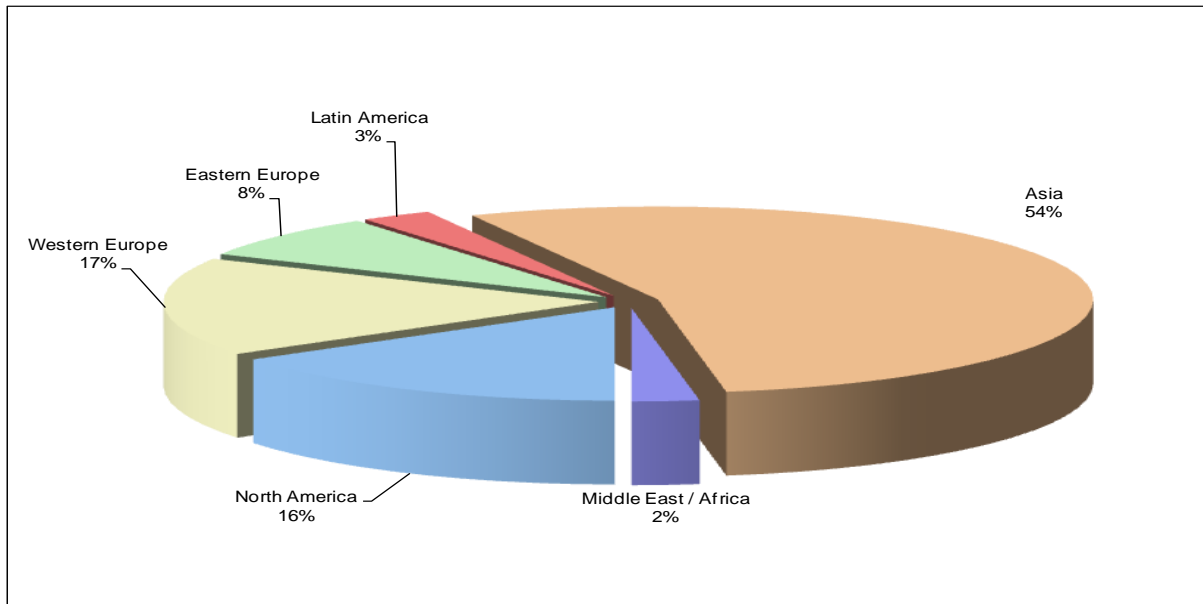


Source: Jacobs Consultancy Ltd.

In the long term forecast, the butadiene demand in the ABS application is forecast to stabilize at around 6.0% p.a. as Asia drives the demand growth. Demand in the other key applications like butadiene rubber are likely to grow at a slower pace of 1.7% in the long term forecast, while demand in styrene butadiene rubber and styrene butadiene latex are forecasted to grow between 3.0-4.0% driven by the growth in the Asian region. Butadiene application in adiponitrile, which is currently about

5.0 % of the global demand, is expected to grow at about 1.3% p.a. in the long term forecast. Figure E-7 depicts the global butadiene demand growth by derivatives.

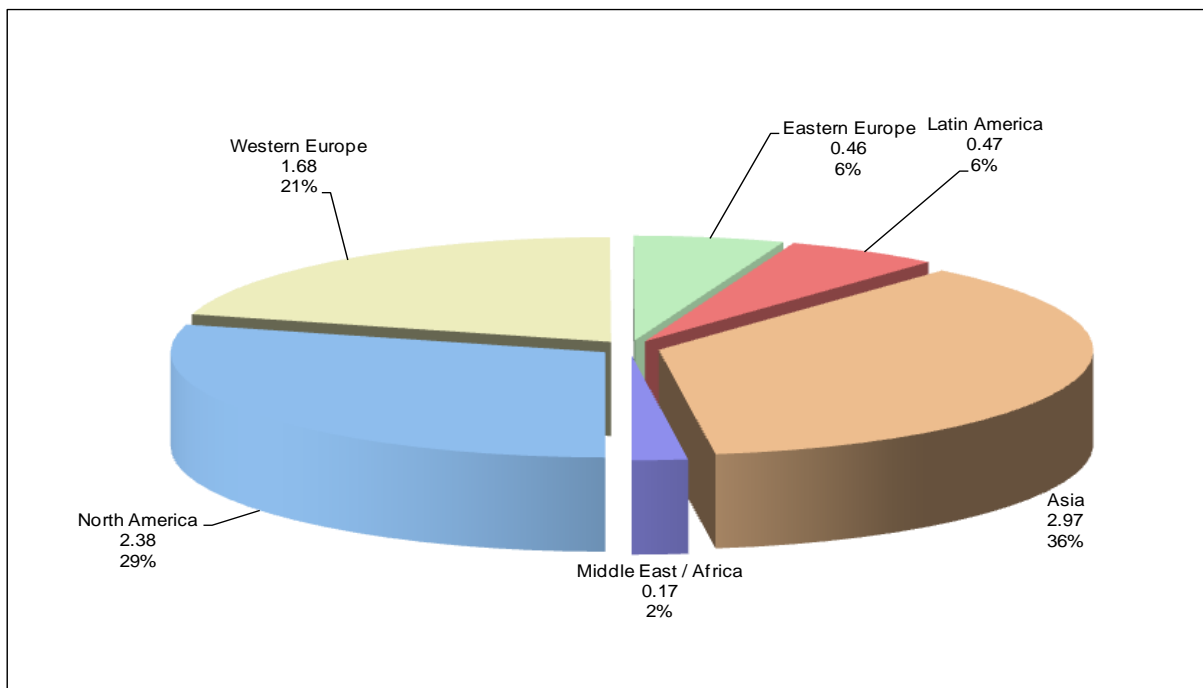
Figure E-8: Butadiene Demand by Region, 2014 (Million Tons)



Source: Jacobs Consultancy Ltd.

Figure E-8 gives the global butadiene demand by region. Share of Asia in the global butadiene demand has grown from about 36% in 2000 to the current values of 54% in 2014, while North America’s share has reduced from 29% in 2000 to about 16% in 2014. Given the strong demand growth in China and other fast developing Asian economies, the regional demand for butadiene in Asia will outstrip the total butadiene demand in the mature economies of West Europe and North America, with Asia’s share moving fast from 36% of global demand in 2000 to around 60% in 2020 and about 75% in 2040. The region of Eastern and Central Europe is likely to maintain its share in the global demand pie between 6-7% over the long term forecast till 2040.

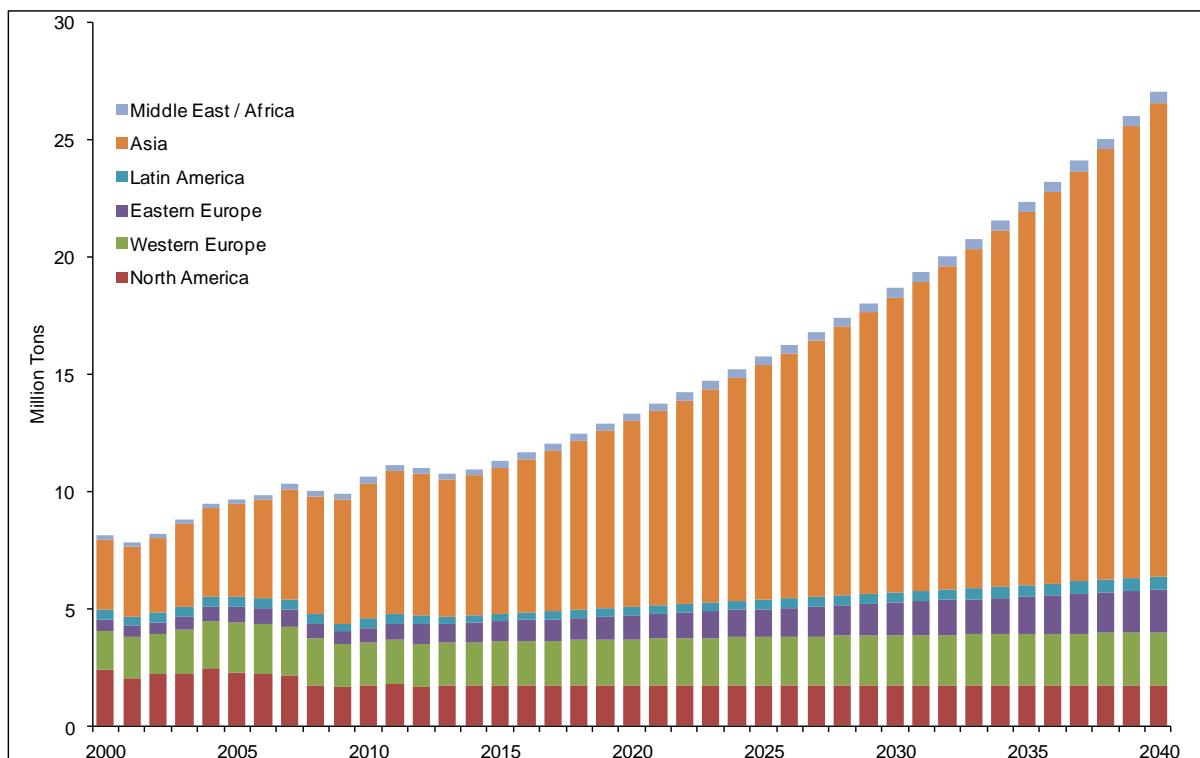
Figure E-9: Butadiene Demand by Region, 2000 (Million Tons)



Source: Jacobs Consultancy Ltd.

Figure E-9 presents an overview of market demand in the major world regions for butadiene in 2000. Historically, demand growth has been dominated by Asia in volume terms, which has seen an average growth in demand of 7% per annum in the period 2000 to 2007, equivalent to an increase in consumption of around 1700 KTA over the period. Butadiene markets slowed down during recession in Asia by growing at a rate of 5%. In 2010 and 2011, the Asian market showed reasonably strong recovery 10.5% and 5.3% respectively. However, with the Chinese economy slowing down in 2012 and 2013, the demand contracted in Asia, by 0.6% and 3.6% respectively. In 2014, the Asian demand for butadiene grew by 2.8%. Growth in the developed markets of Western Europe was much slower as the demand volume increased by only about 430 KTA in total during the same 2000 to 2007 period while North America witnessed a decline in demand by 240 KTA between 2000 and 2007. The economic downturn affected the demand in developed regions with Western European demand declining by -6.2% and -6.9% in 2008 and 2009 respectively; while North American demand declined more drastically by -17.6% and -5.3% in 2008 and 2009 respectively. The North American market recovered in 2010 and 2011 by 4.4% and 4.3% respectively. In 2012, as the global economy declined again, the demand in North America, contracted by 7.5%. In 2013 the demand recovered by 4.0%, but again declined in 2014 by 2.2%. In Western Europe, the demand continued to decline by 2.5% in 2010 and in 2011 demand recovered and improved by 2.3%. The growth was marginal at 0.3% in 2012, while the market contracted again in 2013, by 1.9%. In 2014, the Western European market grew by 3.4%. The Eastern European region witnessed an average increment in butadiene demand of 6.9% between 2000 and 2007 while in 2008 and 2009 the economic downturn resulted in lowering of demand by 11.8% and 14.3% respectively. In 2010, the Eastern European market witnessed strong recovery with demand growing by about 19.9%, while 2011 saw the Eastern European market grow by 9.4%. In 2013 the demand declined marginally by 0.6% while the demand improved in 2014 by 1.7%. The average annual demand growth for Middle East/Africa and Latin American region for the period 2000 to 2014 was 3.5% and -3.3% respectively.

Figure E-10: Butadiene Demand Forecast by Region



Source: Jacobs Consultancy Ltd.

Figure E-10 shows that global butadiene demand is forecast to grow at approximately 3.5% per year through to 2040. Asia is likely to be the highest growth region in the forecasted years with China being the strongest demand market. Asia's strong performance has been due to an increased production of finished goods in electronics, automobile and tyre sectors, which is likely to be the case in the future as well, with demand growth pegged at 4.8% in the long-term forecast till 2040.

Historically (until 2007), Asia was an exporter of butadiene, however Asia is likely to convert into a large importer in the long term forecast. Although global capacity additions between 2014 and 2020 will be primarily in Asia, with approximately 1100 kT worth of butadiene capacity coming on stream by 2020, demand is nevertheless expected to grow at an even faster rate resulting in Asia converting from an exporter to an importer. Additions to butadiene capacity in China alone will account for over 24% of the global total, followed by India and some announcements in Taiwan.

Demand in the North American butadiene market is projected to increase marginally by 0.1% per year during the 2014 to 2040 period. This represents an increment of nearly 50 KTA over the same period. The North American market has historically been an importer of butadiene. On one hand, the region has been experiencing a decline in SBR consumption due to decline in passenger car production as well as imported vehicle tyres. Conversely, the advent of shale revolution has increased availability and use of lighter feedstock for steam cracking, principally ethane, resulting in lower butadiene production as a share of the average North American steam cracker yield. Going forward, with relatively stagnant demand, and projected start-up of on-purpose butadiene plants, seeking to utilise stranded C4s from the shale gas boom, we expect that in the long term the North America region will convert to a net exporter.

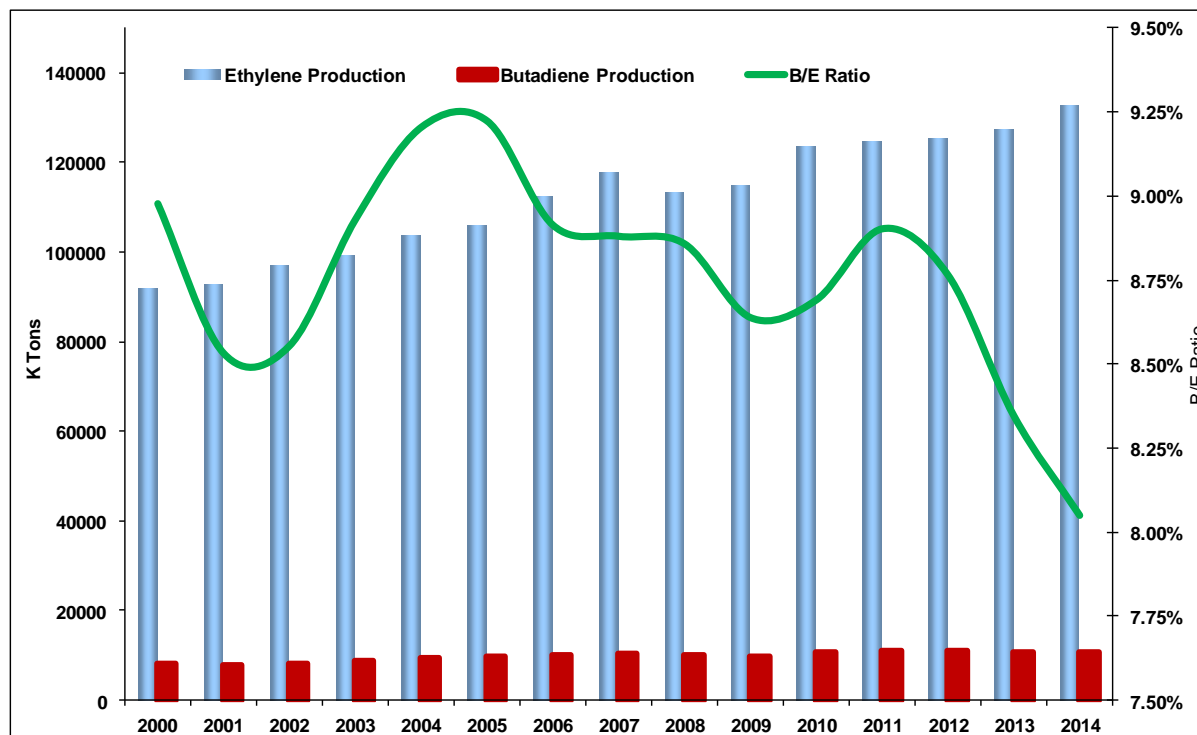
Western European demand is predicted to grow at about 0.6% p.a. in the long-term forecast until 2040, driven mainly by ABS resins, adiponitrile and butadiene rubber products. Historically the region has been a net exporter of butadiene, and the situation is likely to continue in the future as well, as demand stagnates. Despite the fact that supply of butadiene in the region is likely to reduce as ethylene production stagnates with capacities coming up in the Middle East and Asia at competitive levels affecting the overall butadiene production, the region will continue to export small quantities of butadiene owing to lowered demand.

The Central and Eastern European demand growth for butadiene is likely to be about 3.0% p.a. in the long-term forecast until 2040 as tyre production moves from Western Europe to Central and Eastern Europe. While historically the region has been a net exporter of butadiene, albeit small volumes, post 2011 it is likely to turn into a net importer due to tyre industry movement into the region. In the long term, it remains as a net exporter of butadiene.

Global Supply

Prime drivers for chemical production are ethylene and propylene. Historically, businesses were built around the low valued by-products of ethylene production. By-product streams are capturing more value now, but strategic interest remains low. Figure E-11 shows ethylene and butadiene global supply comparison.

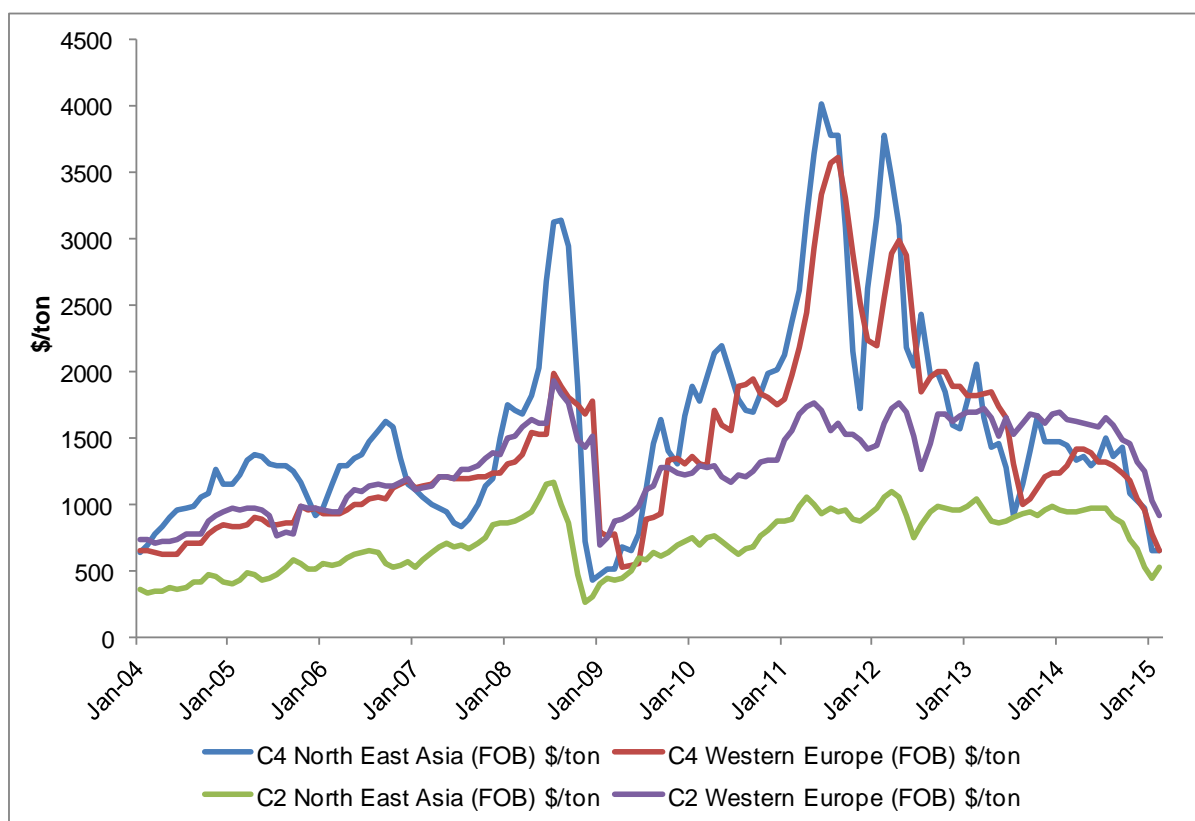
Figure E-11: Ethylene Capacities based on Feed



Source: Jacobs Consultancy Ltd.

The past 14 years have witnessed ethylene capacity growing at an average rate of nearly 3% and operating at an average rate of 86%. Most of the new ethylene capacities have come up in Asia and Middle East. North America, Western Europe, and Japan expect no growth in ethylene capacity. However, most of the ethylene supply has shifted from heavier to lighter feedstock resulting in reduced butadiene production. In US, shale gas driven shift to lighter cracker feeds is also likely to influence the C4 and elastomers business. This reduced supply trend and increased demand from the global automotive sector and other applications mainly from Asia region led to a sharp increase in global butadiene prices in 2012. The prices however declined subsequently as new capacities coming on-stream eased up the supply issues and demand stagnated as seen in Figure E-12.

Figure E-12: Global Butadiene Comparison Prices (\$/ton)

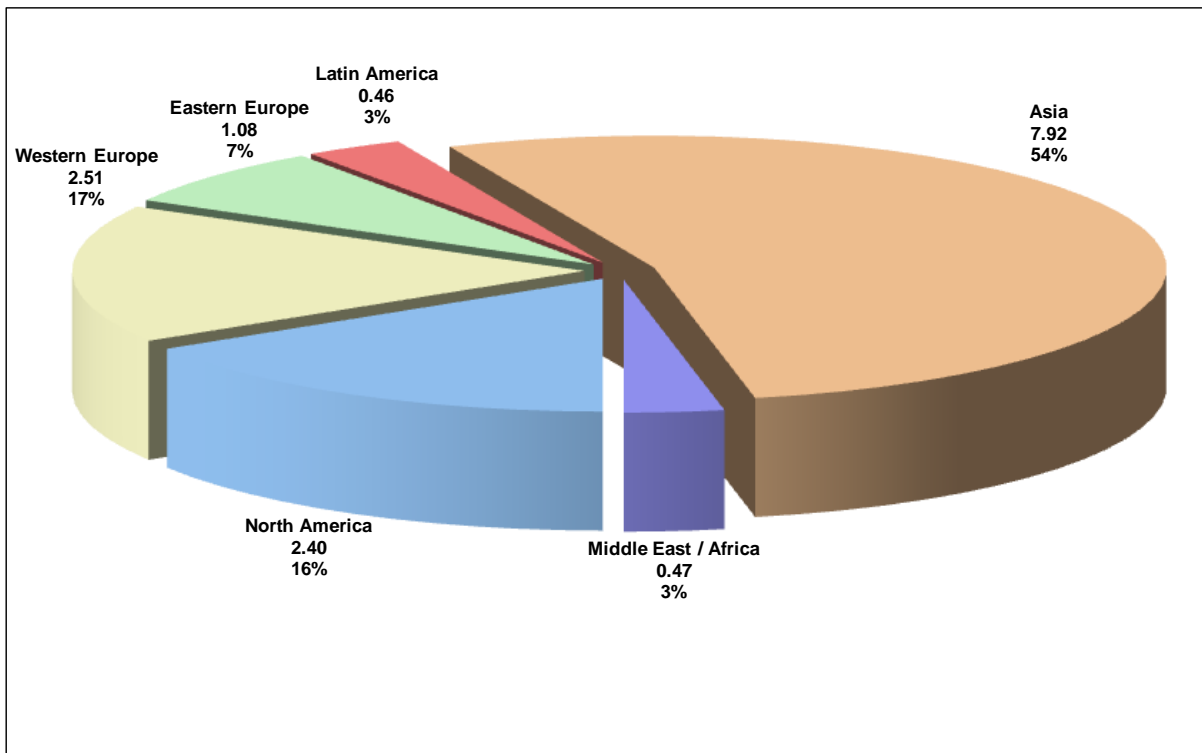


Source: Jacobs Consultancy Ltd.

Considering the present opportunity in C4 and elastomers, major players are opting for butadiene production through vintage and newly developed licensing technology. The main issue to be addressed is the high capital cost for the dehydrogenation of butane or butene and the separation of butadiene. There are clearly opportunities to lower this cost by finding alternative routes, possibly by re-engineering of older and largely abandoned processes, which use ethanol or acetylene as the starting material.

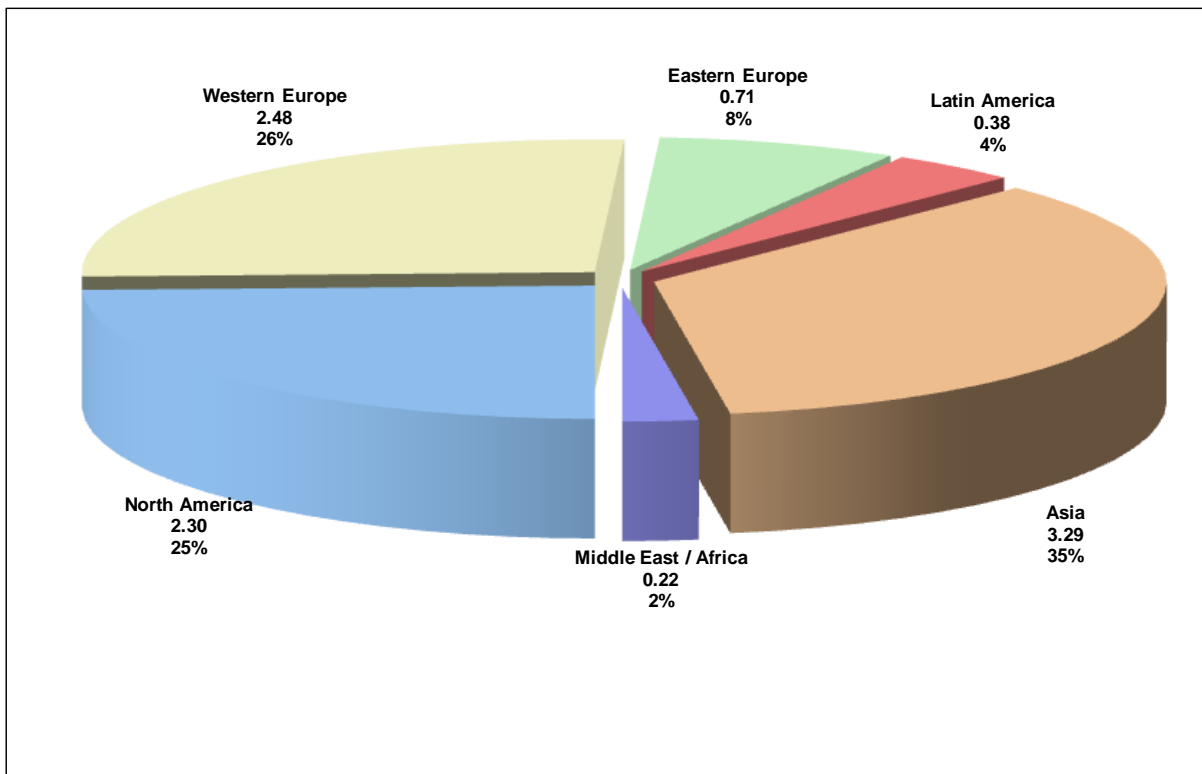
Global butadiene production capacity in 2014 stood at 14.8 million tons from 9.4 million tons in 2000. Nearly 33% of this capacity is located in North America and Western Europe. Asia has the largest single regional share with nearly 54% of global capacity located in the region. Since the year 2000, around 5.4 million tons of new capacity has been added globally, largely in Asia, which witnessed additions of 4.6 million tons.

Figure E-13: World Butadiene Capacity by Region (2014)



Source: Jacobs Consultancy Ltd.

Figure E-14: World Butadiene Capacity by Region (2000)

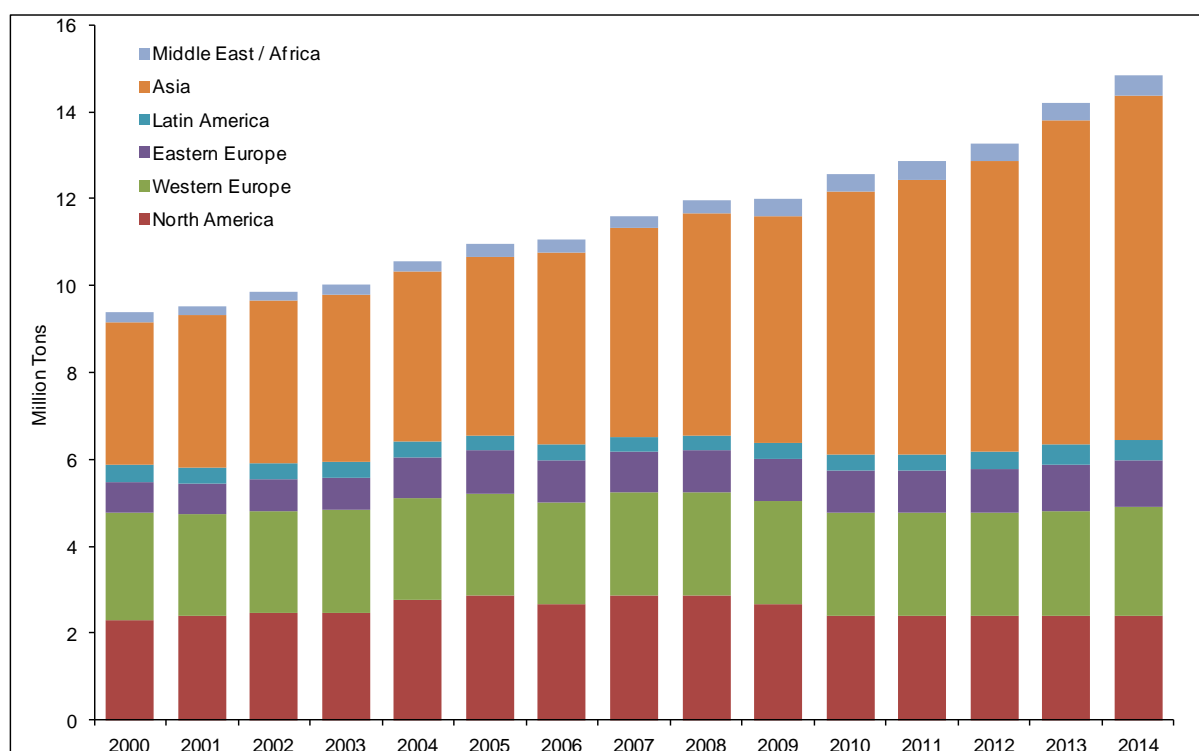


Source: Jacobs Consultancy Ltd.

On a global scale, an average additional 390 kta of new capacity has been installed per annum in the period between 2000 and 2014 representing a growth rate of over 3.2% p.a. Of these additions, about 84% of increments were in Asia, as the installed capacity base grew by over 6.5% every year during the same period. More than a half of the capacity increases in Asia were in China.

North America's butadiene supply position has been eroding over the past several years. Production capacity grew by over 572 kta from 2000 to 2005, post that there were significant closures in capacities that resulted in overall capacity increment of about 100 kta from 2000 to 2014. Closures of steam crackers and the shift towards lighter feedstocks has demoted the US butadiene supply outlook and resulted in a net importer position. A new 270 kta on-purpose butadiene production facility by TPC is likely to come up in the region in 2017.

Figure E-15: Butadiene Capacities by Region, 2000-14 (million tons)



Source: Jacobs Consultancy Ltd.

During 2009 crisis, Europe witnessed closure and consolidation in the region. Between 2000 and 2007, Western Europe saw a decline in butadiene capacity of ~145 KT with no significant addition. However new capacities have recently been announced in the region, including BASF's 155 kta facility at Antwerp, Evonik's 100 kta facility at Antwerp and OMV's 80 kta facility at Burghausen, Germany, all expected to start in 2015. Western Europe's global capacity share has been eroded from 26% in 2000 to 17% in 2014. Despite the new capacity additions, the overall percentage share of Western Europe in global capacity will remain around 16 to 17% as more capacities come up in Asia and Middle East.

Central & Eastern Europe region witnessed an increase of 370 Kt of butadiene capacity between 2000 and 2014. Regional capacity growth consisted mainly of the re-start of previously idled capacity or debottlenecks of existing extraction units. Efforts to consolidate and modernize the existing butadiene and synthetic rubber capacity are advancing but at a slow pace in the region. MOL has announced a 130 kta butadiene facility in Hungary, which is likely to start up in 2016.

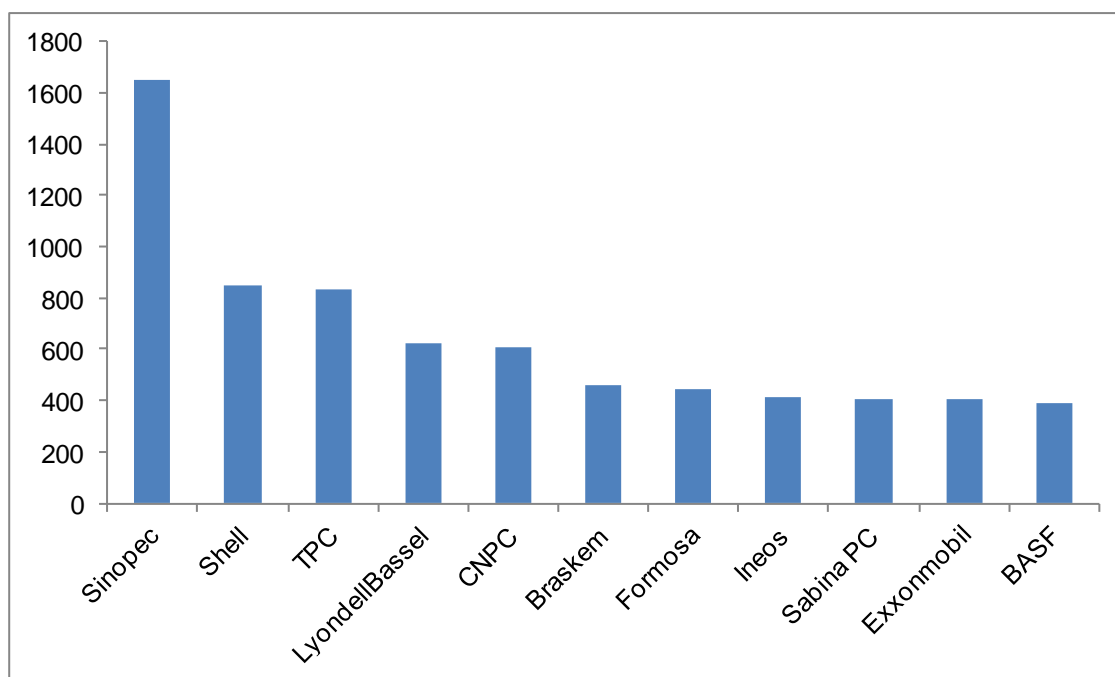
Within the same period, Middle East & Africa region has also seen a significant C4 capacity addition of ~245 Kt. The predominance of ethane and gas cracking that generates limited amounts of crude C4 by-product, combined with high shipping cost for butadiene and obstacles to investment in derivative capacities, have been limiting the pace of capacity expansion in the region.

The prevalence of naphtha cracking in Northeast Asia is reflected in the comparatively high B/E ratio averaging 15% for the last ten years. The start-up of several Chinese extraction units since 2010 has caused a step change in available butadiene capacity and is keeping regional operating rates at low levels in the past few years. New entrants in the Indian subcontinent are set to enter into the petrochemical market with significant C4 extraction capacity. Emerging hub for most of the original equipment manufacturer (OEMs), the Indian subcontinent has potency to support these butadiene capacities.

Industry Structure

The increasing shale gas production has reduced the cost of US ethylene, but has tightened supplies of C3 and C4 olefins. One of the emerging trends in the global butadiene markets is the renewed interest in on-purpose production. To gain the opportunity, industry players are set for the resumption of vintage plants giving a new paradigm to the petrochemical industry.

Figure E-16: Key Butadiene Producers: Global Ranking Based on Shareholding Pattern (2014)



Source: Jacobs Consultancy Ltd.

The main butadiene producers by their global share of production in 2014 are shown in the figure above. Worldwide nearly 80 butadiene producers exist based on their respective shareholding patterns. The top five producers (Sinopec, Shell, TPC Group, LyondellBasell and CNPC), accounted for about 31% of global butadiene capacity in 2014. China Petrochemical Corporation (Sinopec), leads the world's butadiene market, the sole initiator of China Petroleum and Chemical Corporation, is a state-authorized investment vehicle in oil and petrochemical business integrating upstream and downstream assets. Sinopec caters mainly for the Chinese butadiene market, the most favoured market globally. Following Sinopec, Shell ranks second and has a major presence in South East Asia. TPC group ranks 3rd, predominantly leads the US market, which is also the world's largest net importer of butadiene.

Table E-3 gives a listing of various industry structure metrics for the butadiene industry. The concentration ratio is the proportion of the total industry production capacity owned by the eleven largest firms. It is therefore a straightforward measurement of the degree of consolidation. A concentration ratio of 48% is indicative of a low concentration market with a reasonable degree of competition.

The Herfindahl Index (HI) is a measure of the degree of consolidation and the amount of competition in an industry. It is equal to the sum of the squares of the market shares of each firm. The HI can range from 0 to 1 moving from a large number amount of small firms to a single monopolistic producer respectively. HI values between 0.100 and 0.180 are generally considered to indicate a 'moderately concentrated' market and above 0.180 to be a 'concentrated' market. The benefit of the HI over the concentration ratio is that it gives more weight to larger firms.

Table E-3: Global Butadiene Industry Structure Metrics, 2014

Global Production Capacity	14824 KTA
Global Number of Producers	~80
Concentration Ratio C11	48%
Market share of largest producer	11.1%
Herfindahl Index	0.027

Source: Jacobs Consultancy Ltd.

The Herfindahl Index (HI) index for the butadiene industry is 0.027 indicating that the degree of concentration in the market is very low. While the product cannot be stated as highly commoditised, no single producer has a degree of control over the market price. This does also indicate that barriers to market entry are not very high.

Table E-4 gives the market shares of the top seven producers in the butadiene industry globally for 2014. The capacities stated include the individual capacities of the producer as well as any capacity, which they have in joint venture with other companies or with subsidiaries.

Table E-4: Major Butadiene Producers Market Share, 2014

Company	Total Capacity 2014 (KTA)	% Market Share
Sinopec	1,651	11.1%
Shell	852	5.7%
TPC Group	835	5.6%
LyondellBasell	626	4.2%
CNPC	610	4.1%
Others	10,250	69.1%
Grand Total	14,824	100.00%

Source: Jacobs Consultancy Ltd.

As shown in the above Table E-4, globally no butadiene producers have more than 10% market share in the industry except Sinopec. Table E-5 shows the projected increase in regional manufacturing production capacity up to 2019, based on the new projects being planned and under implementation. From 2014 to 2019, around 3.11 million tons of new capacity will be added, mainly in the Asia region, and China in particular. Some marginal capacity increments are likely to occur in Latin America, Western Europe and North America as well as Central & Eastern Europe. Capacity additions are also

likely in Middle East as project developers are increasingly considering heavier steam cracker feed slates, which give rise to butadiene in economically recoverable amounts.

Asia continues to undergo major expansions and is expected to achieve a total installed capacity of over 9 million tons by 2019. About half of these new plants will be in China, providing feedstock to the SBR plants as significant new automotive tyre projects are being planned in the country. The rest of the new capacity is likely to be installed in other developing Asian countries such as India, Thailand, Taiwan, and Singapore.

Table E-5: Major Butadiene Capacity Additions (2014-2019)

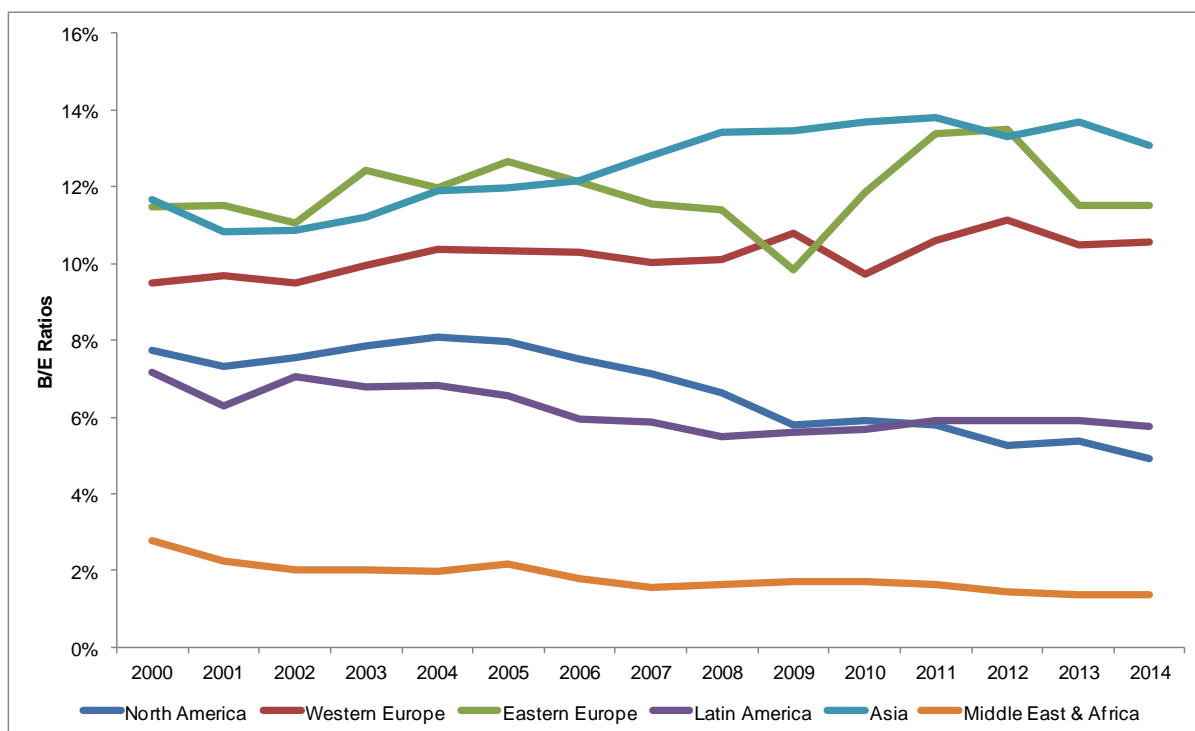
Butadiene		Unit	2014	2015	2016	2017	2018	2019
Total Global Capacity		MMT	14.7	15.5	16.1	16.6	16.7	17.4
Total Global Demand		MMT	11.0	11.3	11.7	12.1	12.5	13.0
Global Operating Rate		%	74%	73%	73%	73%	75%	74%
Net Capacity Additions		MMT		0.8	0.5	0.5	0.1	0.8
Global Demand Growth Rate (%)		%		3.1%	3.2%	3.5%	3.8%	3.4%
Capacity Addition as a percentage of Annual Demand (%)		%		7.2%	4.6%	4.3%	0.7%	5.8%
Country	Company	Location	Type					
Canada	Nova	Corunna	By-Product Extraction	KTA		5		
United States	CP Chem	Cedar Bayou, TX	By-Product Extraction	KTA				30
United States	Dow	Freeport	By-Product Extraction	KTA			38	
United States	Fomosa	Point Comfort	By-Product Extraction	KTA		16		
United States	Oxy	Ingleside, TX	By-Product Extraction	KTA		11		
United States	Sasol	Lake Charles, LA	By-Product Extraction	KTA			30	
United States	TPC Group	Houston, TX	On purpose	KTA			270	
Brazil	Rio de Janeiro Basic Petrochemicals Refinery - (Comperj)	Itaboraí, Rio de Janeiro	By-Product Extraction	KTA			157	
India	OPAL	Dahej, Gujarat	By-Product Extraction	KTA		95		
India	Brahmaputra Cracker and Polymers Ltd - (BCPL)	Assam	By-Product Extraction	KTA				16
China	Jiutai Energy (Zhungeer)	Inner - Mongolia	By-Product Extraction	KTA		60		
China	Sinopec-KPC PC JV	Zhanjiang, Guangdong	By-Product Extraction	KTA			152	
China	Qixiang Tengda Chem.	Zibo, Shandong	On purpose	KTA	150			
China	Shandong Wanda	Dongying, Shandong	On purpose	KTA	150			
China	Zhuhai Zhongguan	Zhuhai, Guangdong	On purpose	KTA		70		
Japan	Asahi Kasei Chemicals Corp	Mizushima	On purpose	KTA		50		
Singapore	PCS	Pulau Ayer Merbau	By-Product Extraction	KTA		100		
Thailand	PTT	Map Ta Phut, Rayong	By-Product Extraction	KTA	75			
Poland	Synthos/Global Bioenergies	Oswiecim	Bio-Derived butadiene	KTA				100
Iran	Kawayan	Assaluyeh	By-Product Extraction	KTA			60	
Algeria	Sonatrach/Total/QP Arzew JV	Arzew	By-Product Extraction	KTA				60
Qatar	Qapco	Ras Laffan	By-Product Extraction	KTA			60	
Saudi Arabia	Sadara Dow Aramco	Al Jubail	By-Product Extraction	KTA		60		
UAE	Chemaweyaast (IPIC/ Borealis)	Taweelah	By-Product Extraction	KTA				30
UAE	Borouge	Ruwias	By-Product Extraction	KTA	60			
Turkey	Petkim		By-Product Extraction	KTA		100		
Egypt	ETHYDCO	Alexandria	By-Product Extraction	KTA		20		
Austria	OMV AG	Schwechat	By-Product Extraction	KTA		15		
Belgium	BASF SE	Antwerp	By-Product Extraction	KTA	155			
Belgium	Evonik	Antwerp	By-Product Extraction	KTA		100		
Germany	OMV AG	Burghausen	By-Product Extraction	KTA		80		

Source: Jacobs Consultancy Ltd.

Supply Limitations

The figure below depicts the B/E ratio of the various regions.

Figure E-17: Butadiene/Ethylene (B/E) Ratios, weight basis



Source: Jacobs Consultancy Ltd.

The US crackers are of vital importance as it has a predominantly mixed feedstock slate for ethylene production. Given the recent availability of NGLs and ethane in the region, the next effect on B/E ratio is likely to be a further reduction. The B/E ratio for the region has gradually lowered from 7.5 in 2000 to almost 4.9 in 2014.

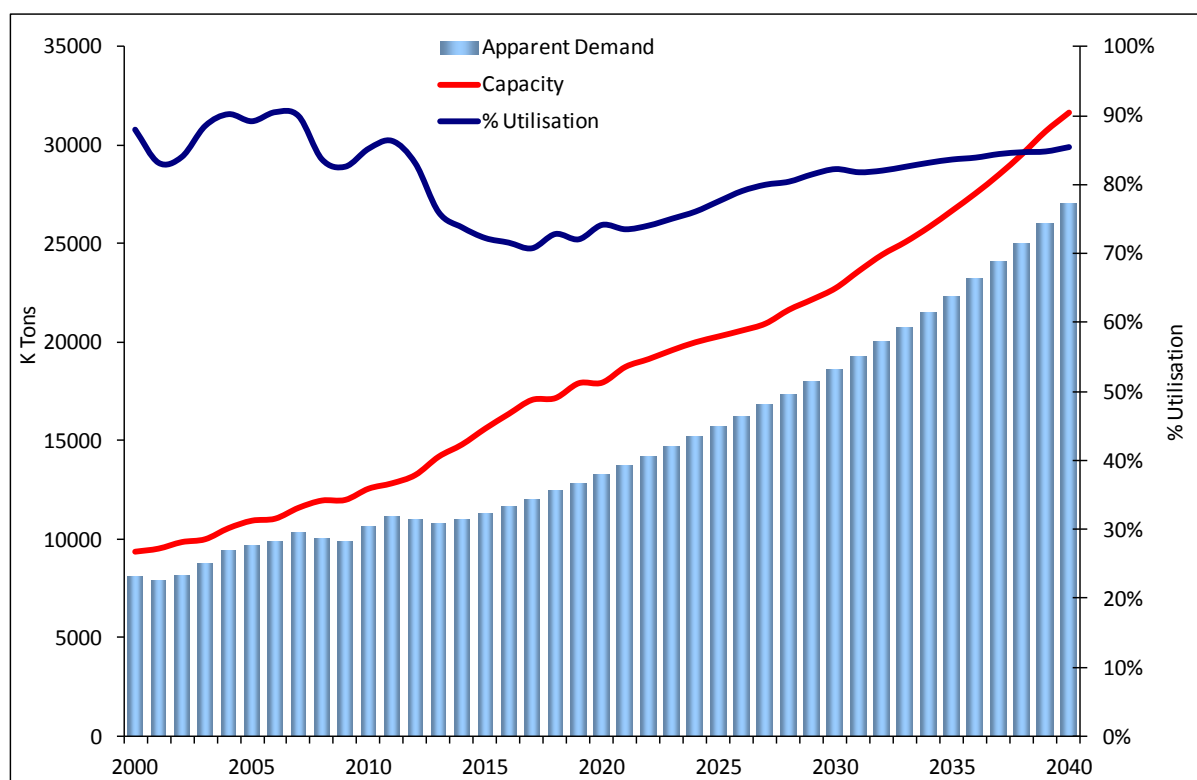
In case of Western Europe, the B/E ratio is much higher as most crackers are naphtha feedstock based. Historically the B/E ratio has averaged about 10.2 since 2000. Similarly for Central & Eastern Europe where most crackers are naphtha based, the B/E ratio has averaged about 11.8 in the past 14 years. In Asia, the B/E ratio for the naphtha crackers in the region is estimated to have averaged to around 12.5 in the period between 2000 and 2014. Currently about 300 kta capacity of on purpose plants are in operation globally, all based in China. By 2020, this is expected to rise to 890 kta, with capacities expected to come on-stream in China and USA.

Butadiene Supply/Demand Balance

Global Outlook

Global butadiene demand was around 10.9 million tons in 2014. This is anticipated to rise to around 13.3 million tons by 2020 and to 27.0 million tons by 2040, representing a long-term growth rate of about 3.5% (Figure E-19). It is anticipated that there will be 14.2 million tons of potential production capacity by 2040, assuming that operating rates will be maintained in the mid-80% range. Production is anticipated to move from North America and Western Europe to the Asian, Central & Eastern Europe and Middle East regions. But due to technology advancement, it is expected that on-purpose butadiene capacity is likely to come in North America, China and South East Asia.

Figure E-18: Global Butadiene Supply and Demand Balance, 2000 – 2040



Source: Jacobs Consultancy Ltd.

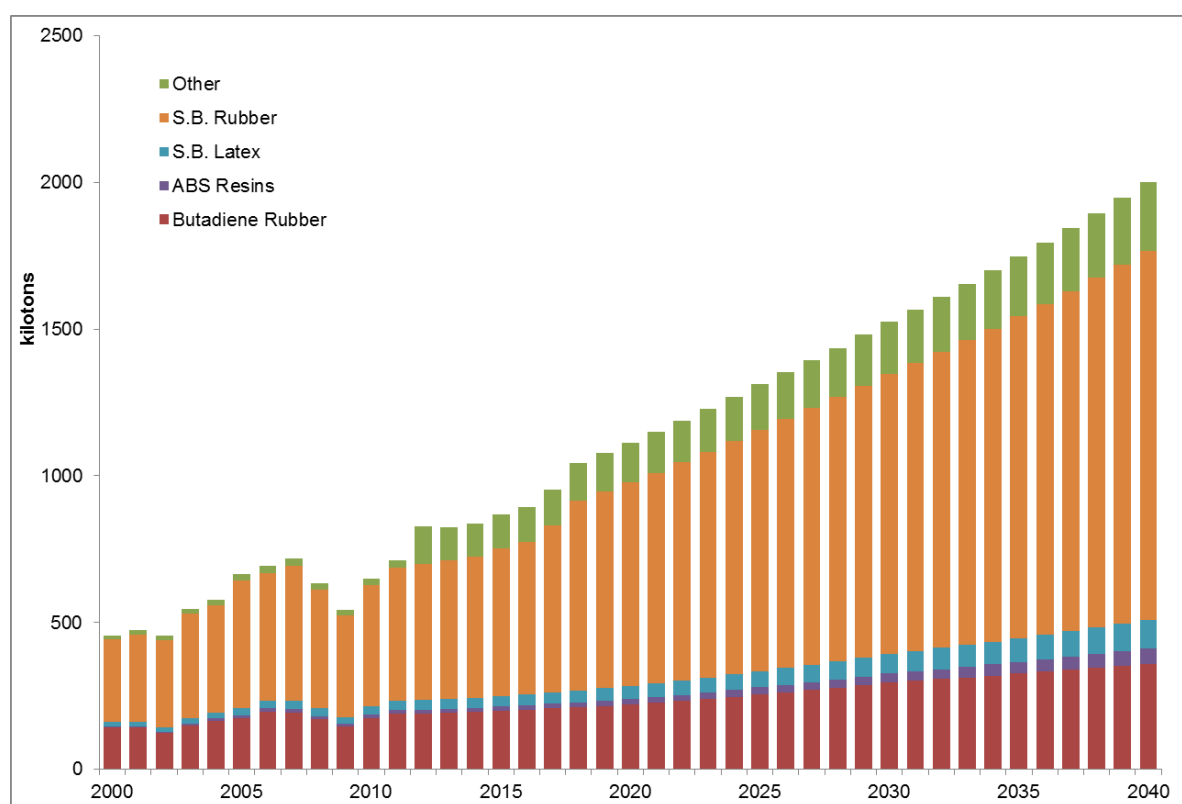
The global operating rate for butadiene capacity is estimated at 73.8% in 2014 due to lighter cracker feedstock slates being used globally especially in North America reducing butadiene production from some existing cracker complexes.

On a regional level while operating rates in North America continue to decline as feed stocks move to lighter slates and development of shale gas in the future, in regions like Asia, Western Europe and Eastern Europe the operating rates are likely to be maintained at mid-80s to low 90s in the long term forecast till 2040 as these regions are likely to continue the use of naphtha as a predominant feedstock. However, it is likely that some feedstock substitution will occur, with a consequent fall in B/E ratio.

Eastern Europe/FSU

Eastern Europe/FSU's average annual demand growth rate for the period 2000 to 2014 was 4.4% p.a. driven mainly by styrene butadiene rubber and polybutadiene demand. The period between 2000 and 2007 saw the market grow by 6.9% on an annual average. However the market was affected by the economic downturn in 2008, with demand declining by 11.8% in 2008 and about 14.3% in 2009. Following the global trend, the demand recovered strongly at a higher rate of 19.9% in 2010 and by a rate of 9.4% in 2011 as the demand from the automotive industry increased the demand for SBR. In 2012, the demand further increased by 16.5% driven by demand from SBR, while in 2013, the demand witnessed a contraction of 0.6%, as demand lowered from the automotive segment. In 2014, the market grew modestly by 1.7% over the previous year's demand. In the long term forecast, the demand in Eastern Europe/FSU is likely to grow by about 3.0% till 2040 driven mainly by butadiene rubber and SBR demand as more automotive companies shift their focus from Western Europe to Eastern Europe/FSU as a manufacturing base.

Figure E-19: Eastern Europe Butadiene Demand Growth Forecast by Derivatives, 2000 – 2040



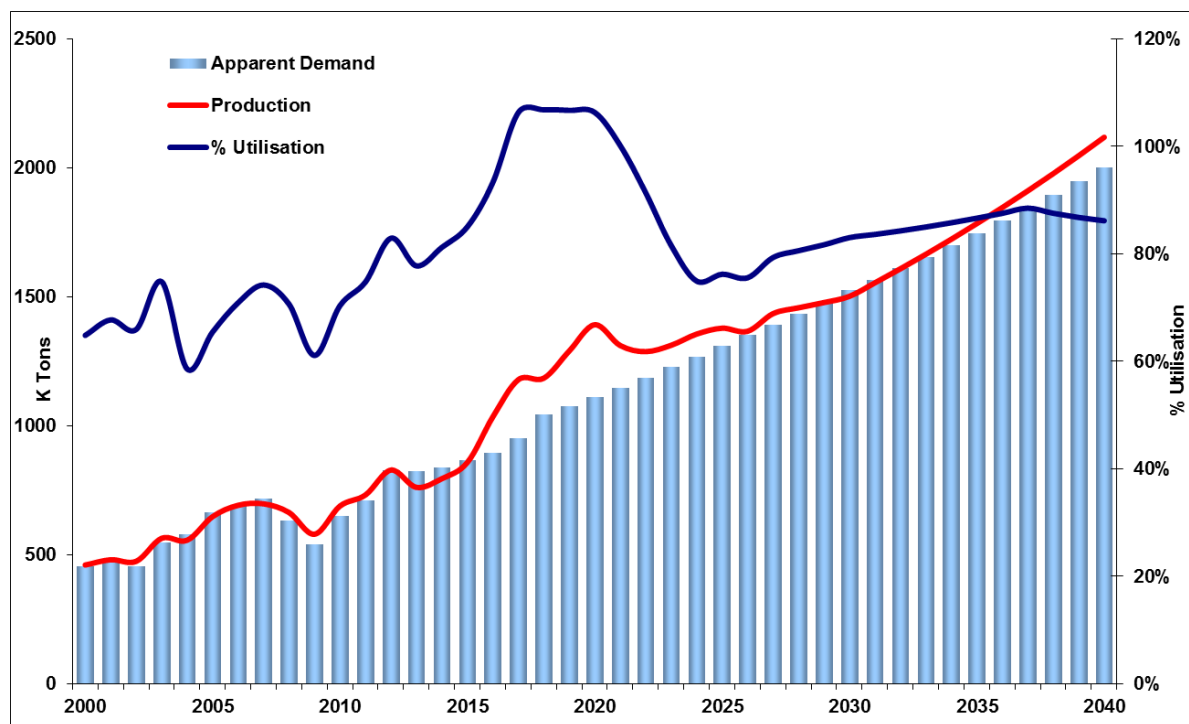
Source: Jacobs Consultancy Ltd.

The utilisation rates in 2014 were about 74% which are likely to be maintained in the mid to high 70s levels till 2019. Nearly 130 kta of new capacity is likely to come on-stream by 2019, via a new plant in Hungary. Another speculative capacity addition may occur in Poland (bio based butadiene), whereas the three Russian projects (all via by-product extraction) appear delayed to at least 2020 and beyond based on their current progress. Rates are likely to be maintained in the higher 70s till 2028 and expected to reach the higher 80s by the end of the forecast period till 2040.

MOL (through its subsidiary TVK) is currently progressing with construction of a 130 kta butadiene extraction plant in Hungary. This plant is expected to come on stream in the second half of 2015, but at least half of the resultant butadiene is ear-marked for a future adjacent SBR plant project that is also in construction phase and is expected to come on-stream in 2017. Other potential new capacities will come from the three 200 kta each Russian projects. These are SIBUR's ZapSibNeftekhim at Tobolsk (West Siberia), CJSC Vostochnaya Neftechimicheskaya (VNHK, part of Rosneft) in the Russian Far East

(Primorsky Oblast) and NKNK’s new unit of same capacity at Tatarstan (Volga Region). All three projects rely on the larger world class steam CRacker projects to be realised, which are not expected on-stream before 2020, with SIBUR being the only entity that has pronounced on the likely on-stream date of 2020. In addition, Synthos / Global Bioenergies JV is also developing a bio-based butadiene plant in Poland, but the project is yet to reach financial close, so its on-stream date is uncertain.

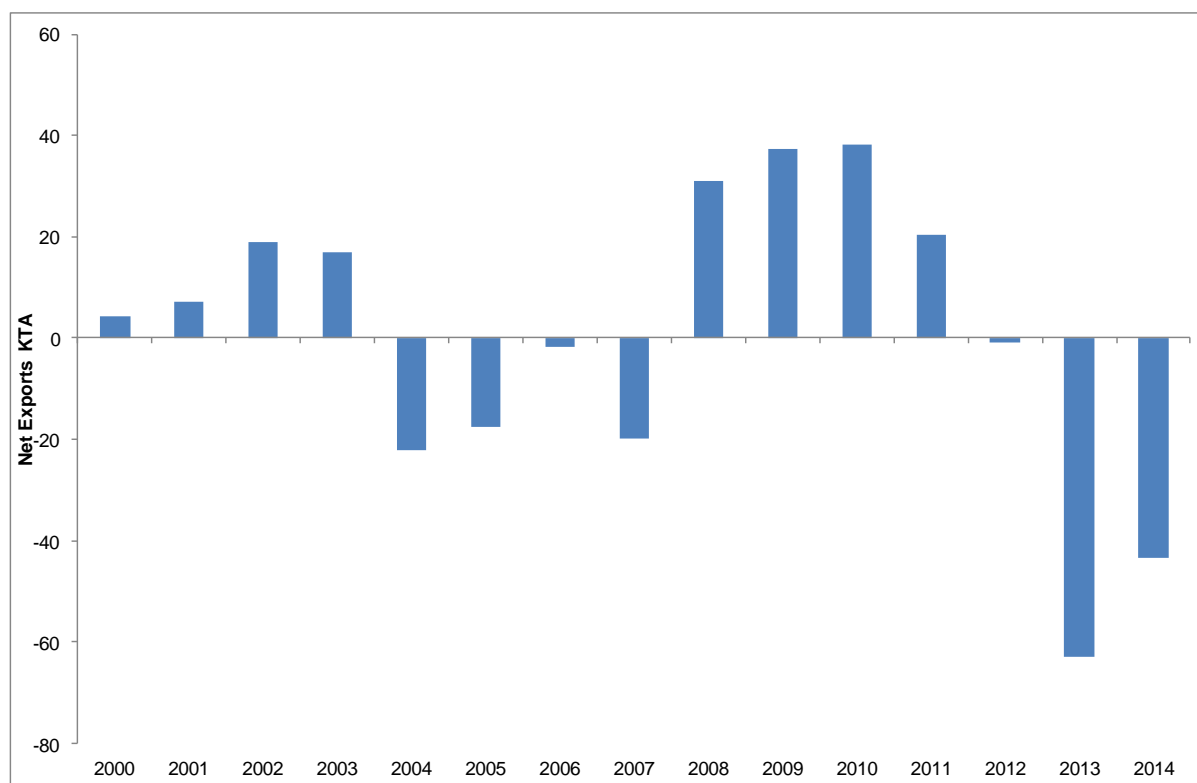
Figure E-20: Eastern Europe/FSU Butadiene Demand Supply Balance



Source: Jacobs Consultancy Ltd.

The region is anticipated to become a net exporter post 2016 when the new Hungary plant comes online, ahead of its sister SBR project. Another driver will be increased butadiene demand from nearby countries of Western Europe, where production is likely to gradually reduce, as WE cracker capacities are likely to stagnate with less butadiene co-produced per tonne of ethylene, due to increasing usage of lighter hydrocarbon feedstocks for the crackers.

Figure E-21: Eastern Europe/FSU Butadiene Net Exports (2000-2014)



Source: Jacobs Consultancy Ltd.

Table E-6: Eastern Europe/FSU Butadiene Demand (2000-2040)

Eastern Europe/FSU Butadiene Demand (KT)										Growth Rates	
Region/Year	2000	2005	2010	2014	2020	2025	2030	2035	2040	2000-2014	2014-2040
Eastern Europe/FSU	456	666	651	838	1014	1196	1391	1593	1825	5.0%	3.4%

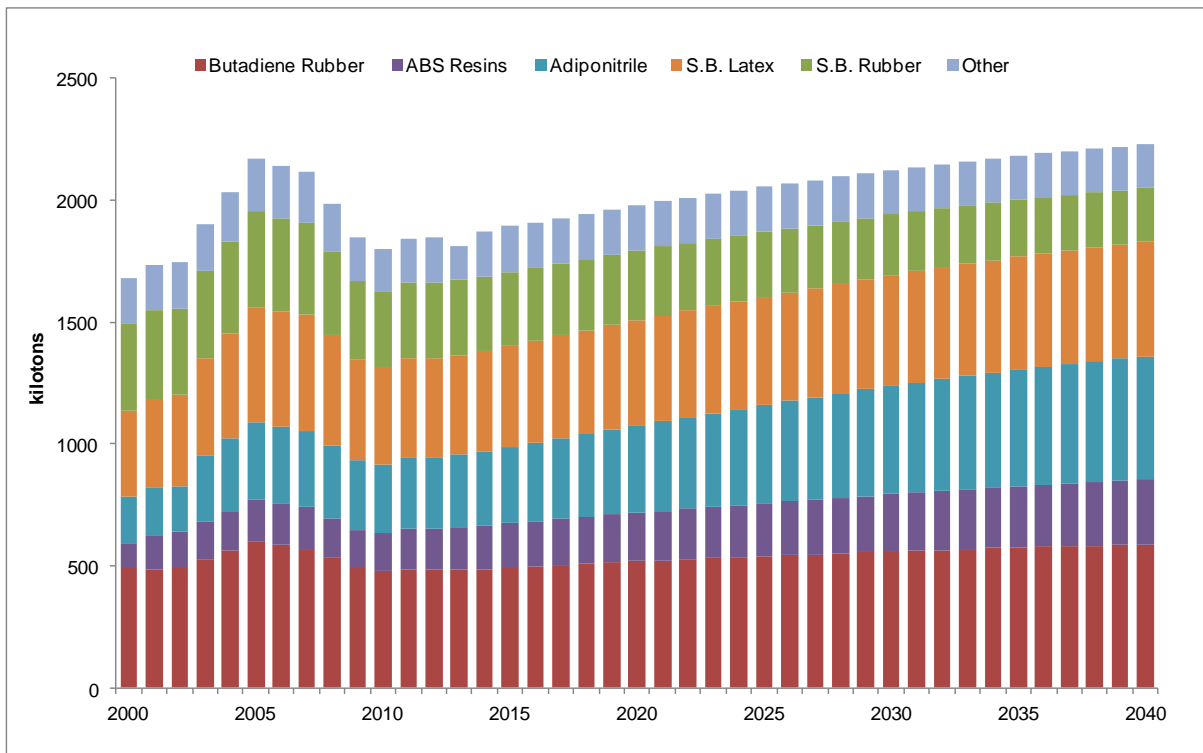
Source: Jacobs Consultancy Ltd.

Western Europe

Western Europe's average annual demand growth rate for the period 2000 to 2014 was 0.77% p.a. It is evident that the decline in demand post the global financial crisis has affected the aggregate growth rate in the region. Prior to the economic downturn, between 2000 and 2007, the demand for butadiene grew by nearly 3.4% on average, driven by ABS resins and adiponitrile demand. However, in 2008 following the economic downturn, butadiene demand declined as derivatives used in the automotive industry and construction industry bore the brunt of the downturn. In 2008 and 2009, the demand declined by 6.2% and 6.9% respectively and it further declined by 2.5% in 2010, while in 2011 market recovered by 2.3%. In 2012, the market grew modestly by 0.3% while contracted again by 1.9% in 2013. The demand grew by 3.4% in 2014 and is expected to grow by 0.67% CAGR till the long term forecast till 2040.

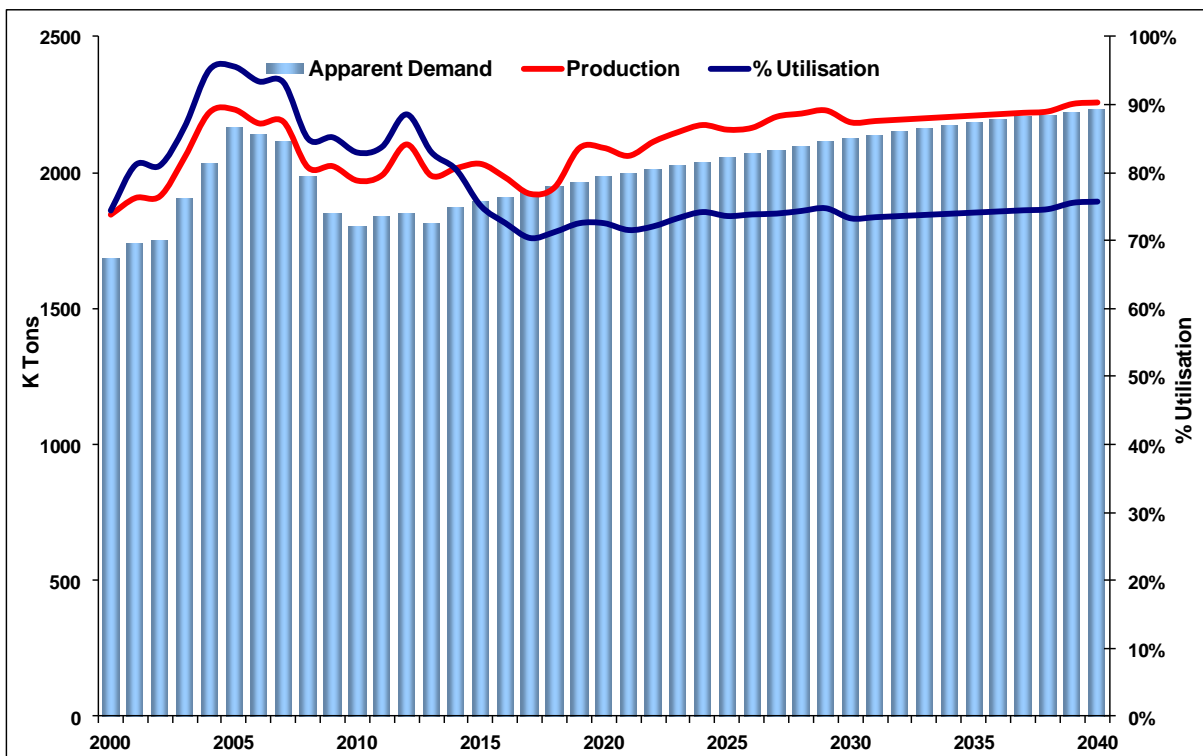
Utilisation rates of 80% in 2014 are expected to lower in the short term forecast as B/E ratio is likely to drop as the region is likely to import cheaper and lighter feedstock from US. New capacities in the range of 220 kta are likely to come up in the region by 2016. On an average, till 2040, utilisation rates are likely to be maintained in the mid to higher 70s. There is also a possibility of shale gas coming into the picture in the next decade. If shale gas production starts in Western Europe, butadiene production is likely to reduce.

Figure E-22: Western Europe Butadiene Demand Growth by Derivatives, 2000 – 2040



Source: Jacobs Consultancy Ltd.

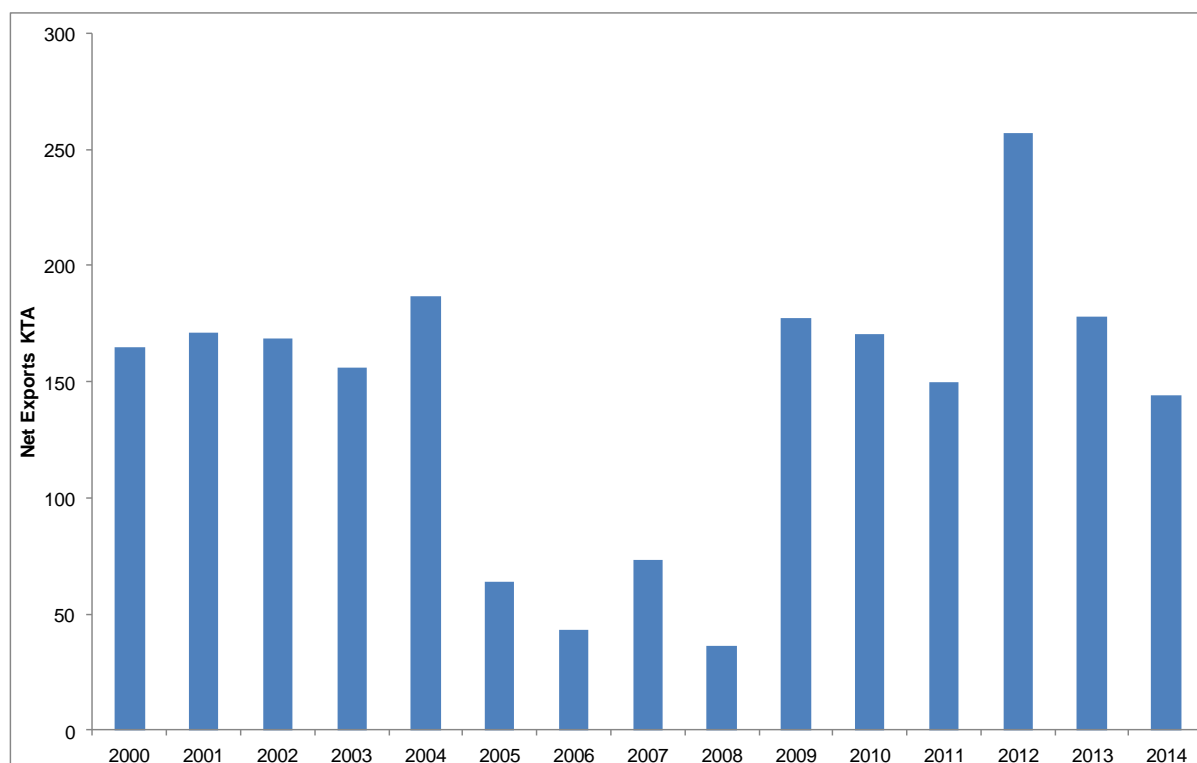
Figure E-23: Western Europe Butadiene Demand Supply Balance, 2000 – 2040



Source: Jacobs Consultancy Ltd.

Historically Western Europe is a major exporter of butadiene to the world. It is expected to follow same trend in the future, with demand almost stagnating in the forecast years.

Figure E-24: Western Europe Butadiene Demand Supply Balance, 2000 – 2014



Source: Jacobs Consultancy Ltd.

Table E-7: Western Europe Butadiene Demand Supply Balance, 2000 – 2040

Western Europe Butadiene Demand (KT)										Growth Rates	
Region/Year	2000	2005	2010	2014	2020	2025	2030	2035	2040	2000-2014	2014-2040
Western Europe	1682	2169	1801	1873	1982	2055	2125	2183	2231	0.77%	0.67%

Source: Jacobs Consultancy Ltd.

Asia

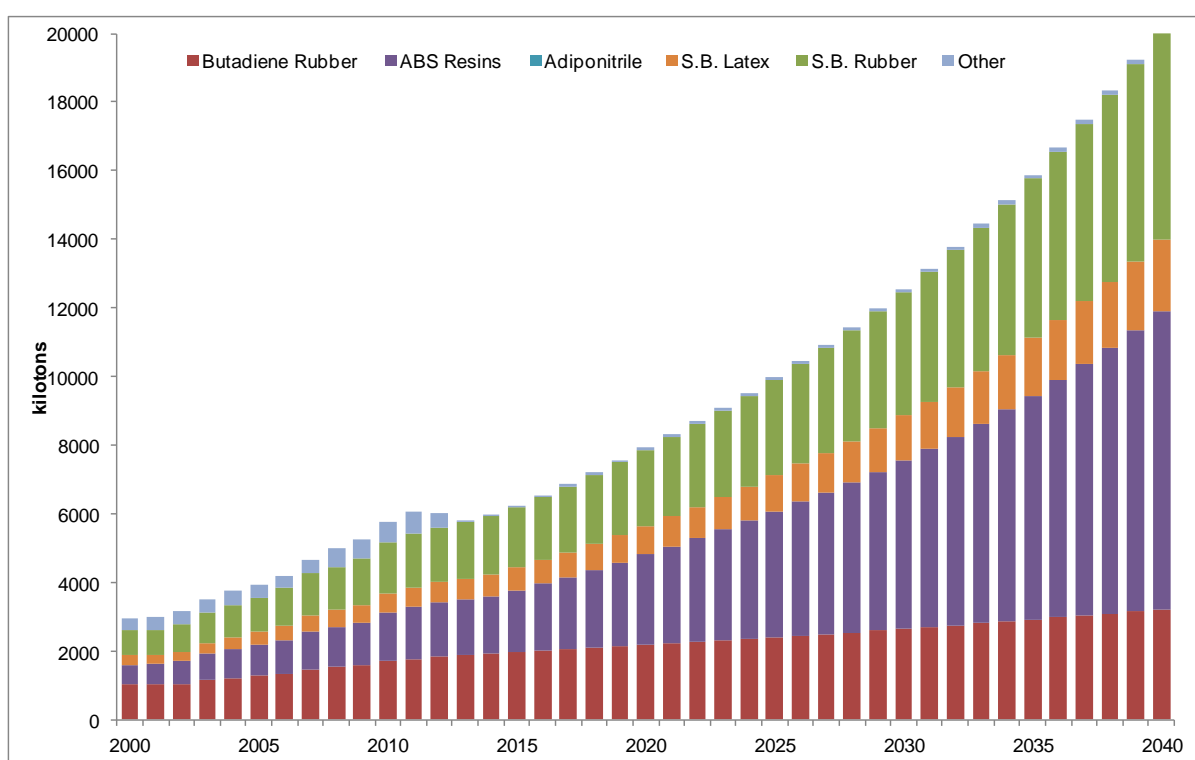
In 2014, Asian demand was about 5.9 Million tons. It contributes about 54% of the global demand. The Asian demand has been growing strongly in the historical years, even showing double digit growth rates in a few years. The demand for butadiene was not very evidently affected during the economic downturn, as the demand grew by 6.8% in 2008 and 4.9% in 2009. The stimulus provided by the Chinese Government as well as higher demand from India resulted in the demand growth rates growing by a further 10.5% in 2010 and 5.3% in 2011. However in 2012 as the Chinese economy grew sluggish and the overall global macroeconomic scenario turned bleak, the demand in the region contracted by 0.6% and a further 3.6% in 2013. Demand recovered by 2.8% in 2014. In the long-term forecast, the demand growth for butadiene in Asia is estimated at nearly 4.8% driven by ABS resins and styrene butadiene rubber as most automotive and other downstream derivative companies look to set up shop in Asia. The expected future capacity additions, largely in China and India, will not be adequate to meet the expected Asian demand growth. This will lead to the region becoming a net importer of butadiene. North East Asia, in particular China, will drive this demand over the 2014 to 2040 period. The Indian subcontinent is predicted to have the highest demand growth rate of 4.7% per year, within the region, over the same period. This is possibly due to the region having a much lower demand base; in 2014 the demand from the Indian subcontinent accounted for 2.0% of the total Asian demand. Investment in cracker complexes in India that will use a heavy feedstock slate is

anticipated to allow butadiene production volumes to increase. India is expected to become the major exporter in Asia.

Utilisation rates declined to mid-70s in the past few years from the highs of mid 90s witnessed at the start of the decade as new capacities came on-stream. In the short term forecast with the start-up of new capacities, including a few on-purpose plants, utilisation rates will remain in the mid-70s. In the long term forecast by 2040, these are expected to rise to mid to higher 80s.

As per our estimates a total of 300 kta of on-purpose capacity is currently operating in China, mainly in the Shandong region. It is anticipated that this capacity will rise to 620 kta in 2015 and will be a total of 890 kta by the end of this decade. Asahi Kasei is developing BB Flex technology, which will produce butadiene from butene. It is expected that they will come up with 50 KTA butadiene plant starting by end 2015, which will be further expanded depending on market conditions. Demand for automobiles is increasing in the region due to growing population base and increasing earning power.

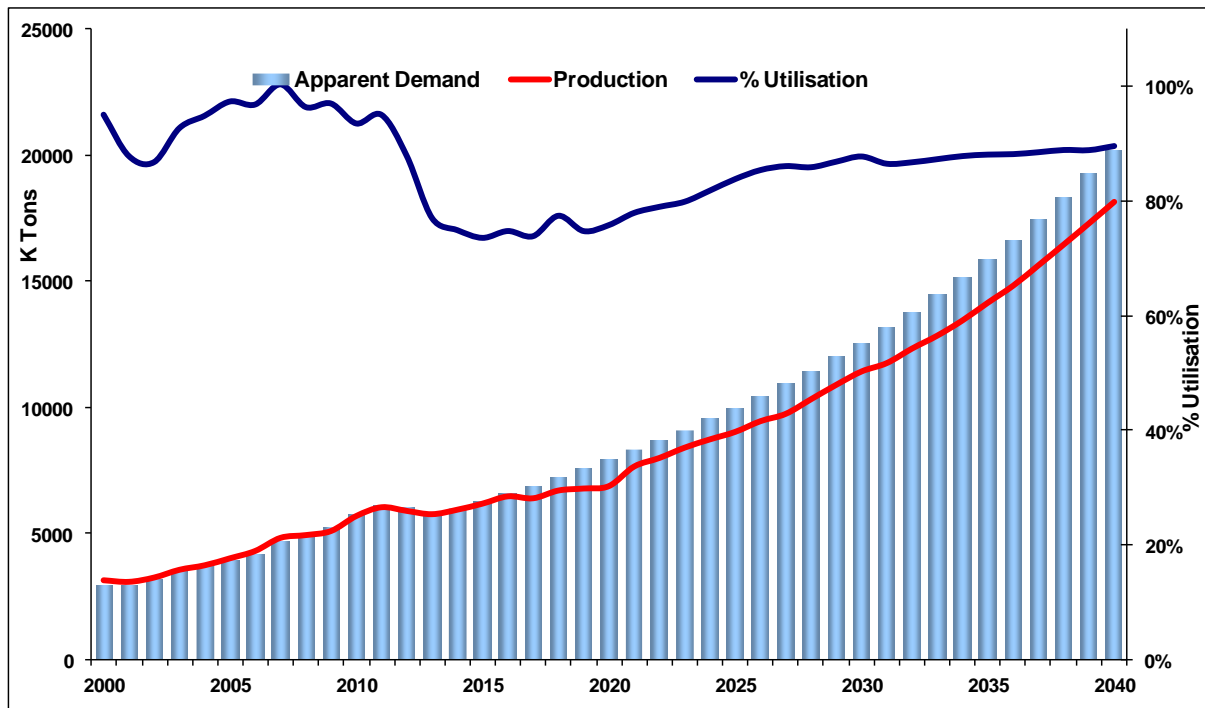
Figure E-25: Asia Butadiene Demand Growth Forecast by Derivatives, 2000 – 2040



Source: Jacobs Consultancy Ltd.

In Asia, demand for butadiene from ABS resins increased by a CAGR of 8.3% from 2000 to 2014. In 2014, the demand from ABS resins was about 28% of the total demand in Asia, which is expected to further increase to 33% by 2020 and reach almost 43% of the total demand for butadiene by 2040. ABS resin is the fastest growing application of butadiene in the Asian region, followed by Latex and Rubber (SBR).

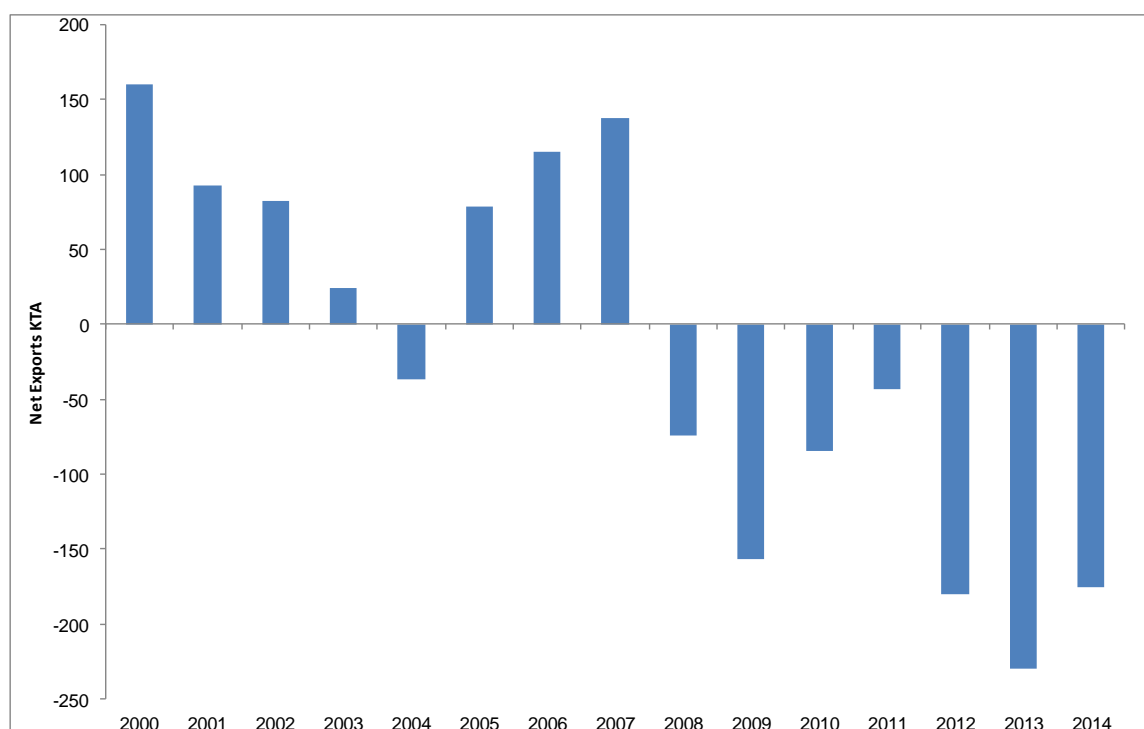
Figure E-26: Asia Butadiene Demand Supply Balance, 2000 – 2040



Source: Jacobs Consultancy Ltd.

Until 2007, Asia was a net exporter of butadiene. Since 2008, it turned into an importer, as demand outstripped and this trend is likely to continue in the coming years. China is a major importer, importing from other countries in Asian region due to increasing demand. In 2013, China imported around 370 KTA of butadiene. China butadiene import increased from 86 KTA in 2000 to 370 KTA in 2014 and is expected to further increase in the coming years, as demand continues to outgrow supply.

Figure E-27: Asia Butadiene Net Exports, 2000 – 2014



Source: Jacobs Consultancy Ltd.

Table E-8: Asia Butadiene Demand, 2000 – 2040

Asia Butadiene Demand (KT)										Growth Rates	
Region/Year	2000	2005	2010	2014	2020	2025	2030	2035	2040	2000-2014	2014-2040
Asia	2973	3927	5769	5978	7946	9983	12559	15887	20193	5.1%	4.8%

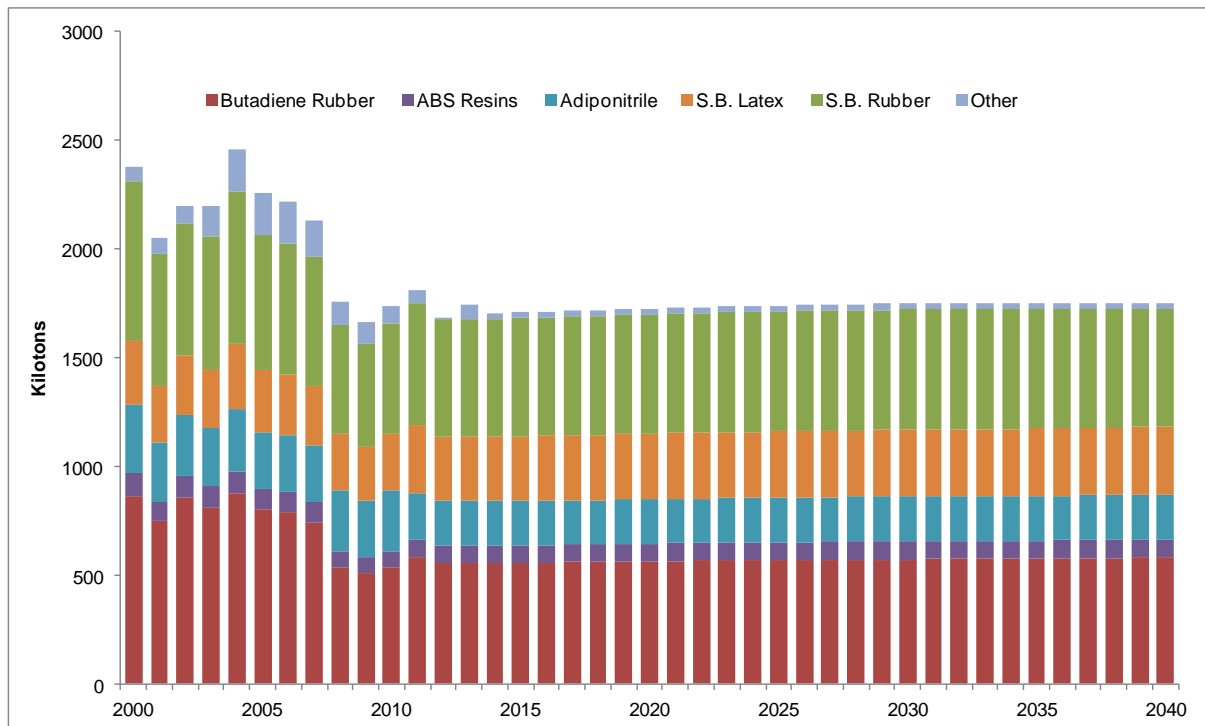
Source: Jacobs Consultancy Ltd.

North America

The overall demand for butadiene in North America, between 2000 and 2014, declined by 2.3% on the back of lowered downstream derivatives demand, the effect of the economic downturn in 2008-09 as well as a decline in the supply as the country moved to lighter feedstocks in its crackers. The global financial crisis dented the market demand severely, as it declined by 17.6% in 2008 and 5.3% in 2009 affecting the aggregate growth rate in the region. Though the demand showed a positive growth rate of 4.4% and 4.3% in 2010 and 2011 respectively, it again contracted in 2012. The demand declined by a further of 2.2% in 2014. The region has been experiencing a decline in SBR consumption due to decline in passenger car production as well as an increase in imported vehicle tyres.

Overall utilisation rates have shown a declining trend in the region, dropping from mid 90s and low 90s at the start of the decade, to about mid-60s. This decline has been due to the lowering of the B/E ratios in the region as the region moved towards lighter feedstocks with the discovery of shale gas. The B/E ratios declined from 7.75 in 2000 to 4.9 in 2014 indicating the usage of lighter feedstocks in the region. In the long term forecast, it is anticipated that utilisation rates will remain in the low to mid 70s.

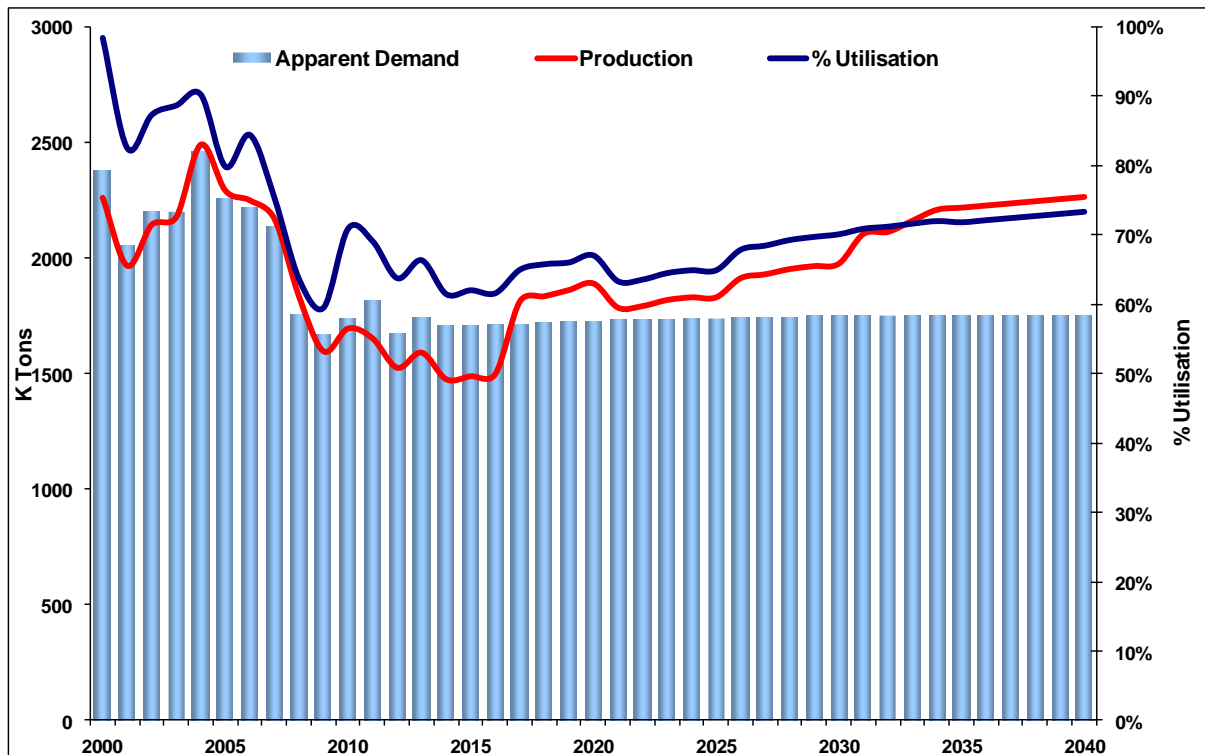
Figure E-28: North America Demand Growth Forecast by Derivatives, 2000 – 2040



Source: Jacobs Consultancy Ltd.

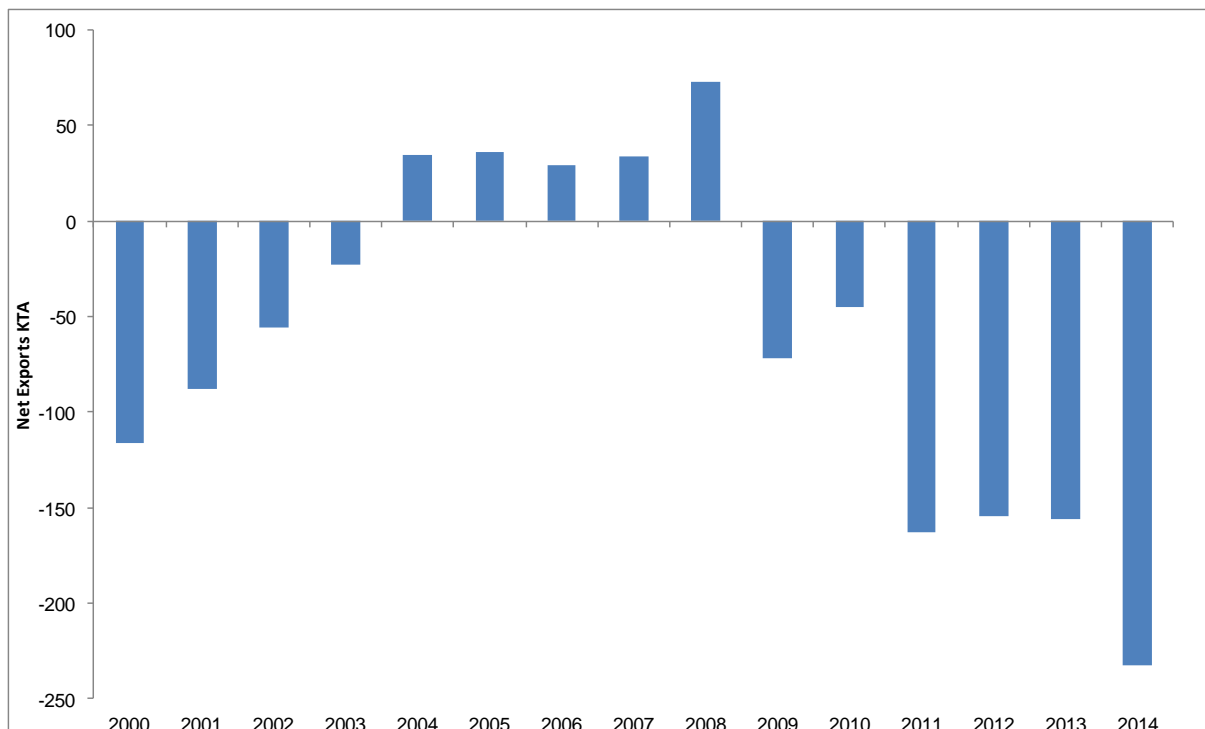
All the new ethylene capacities announced in the region expected to come up in the next 6 to 8 years will be based on the shale gas discoveries utilising lighter feedstocks. As a result the amount of butadiene produced as by-product will be in very small quantities. There is expected to be a drop in the butadiene supply in the future, as a result of which on-purpose plants for butadiene production have been announced. Historically, North America is the biggest importer of butadiene. However with the start-up of TPC's on-purpose butadiene plant as well as stagnant demand, the region will turn net exporter by 2018 and is likely to remain in this status till the end of the forecast period. North American markets are mature and automobile companies are shifting their base from there to other regions, reducing the butadiene demand in coming years.

Figure E-29: North America Butadiene Demand Supply Balance, 2000 – 2040



Source: Jacobs Consultancy Ltd.

Figure E-30: North America, Net Exports, 2000 – 2014



Source: Jacobs Consultancy Ltd.

Table E-9: North America Butadiene Demand, 2000 – 2040

North America Butadiene Demand (KT)										Growth Rates	
Region/Year	2000	2005	2010	2014	2020	2025	2030	2035	2040	2000-2014	2014-2040
North America	2377	2255	1739	1706	1727	1741	1750	1750	1753	-2.3%	0.1%

Source: Jacobs Consultancy Ltd.

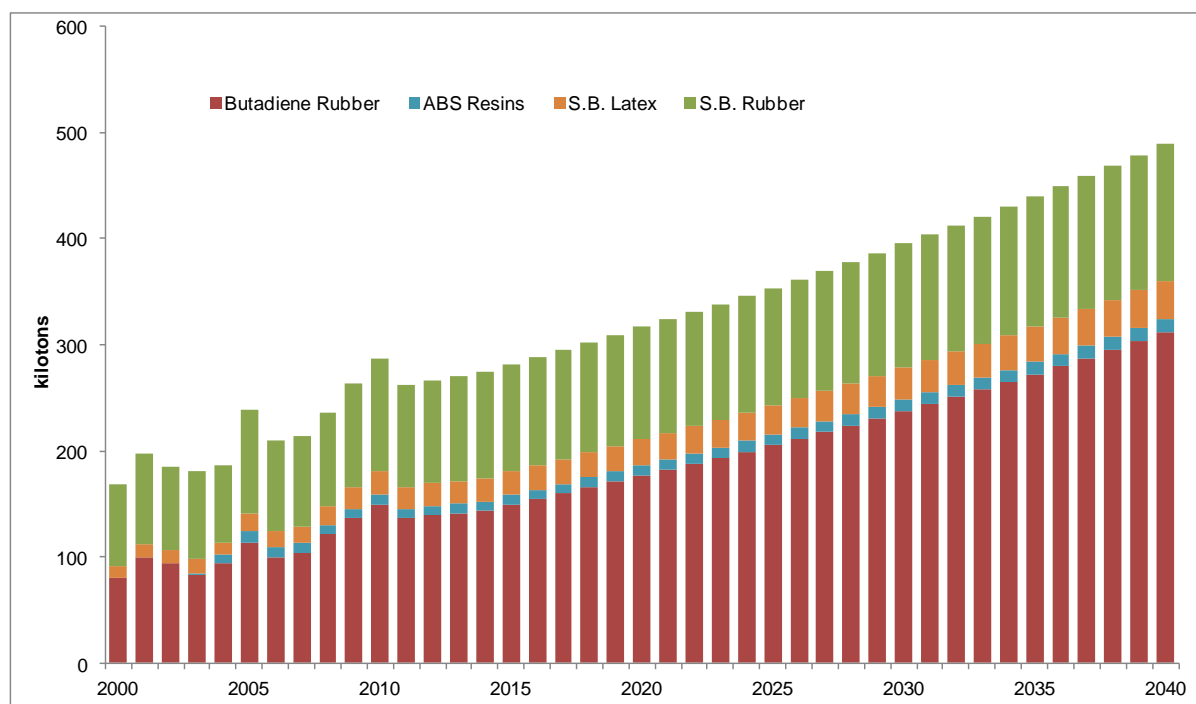
Middle East & Africa

Middle East & Africa’s average annual demand growth rate for butadiene during the period 2000 to 2014 was 3.5% p.a. It is evident that the demand increased in the region in the past 14 years at higher rate from the small base. The regional demand mainly comes from butadiene rubber and SBR applications mainly from the automobile sector as the increasing demand for automobiles in the region, due to increasing population and Governments providing special incentives to develop the downstream industries in the region.

The evolving trend in the region is the development of mixed feed crackers. A mixed-feed cracker will enable the industry to be more flexible to crack the most advantaged feedstock. In the future, the region will develop more mixed feed crackers to become more competitive.

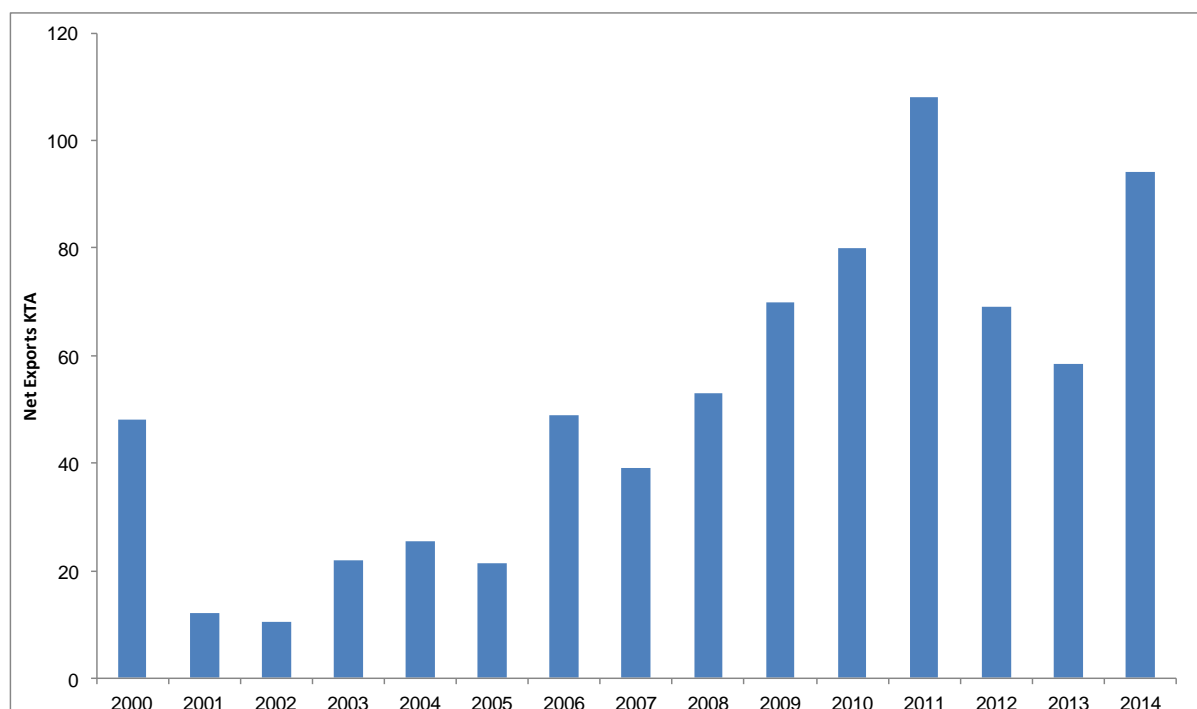
Historically, the region has witnessed high utilisation rates in the high 80s to low 90s. The rates lowered to 79% in 2014. In the long term forecast till 2040, the utilisation rates are likely to stabilise in the level of low to mid 70s, with some speculative capacity to be added via on-purpose butadiene production technology.

Figure E-31: Middle East and Africa Demand Growth Forecast by Derivatives, 2000 – 2040



Source: Jacobs Consultancy Ltd.

Figure E-32: Middle East and Africa, Net Exports, 2000 – 2014



Source: Jacobs Consultancy Ltd.

Historically, Middle East is net exporter and it is likely to maintain its status due to huge capacity expansion in the region.

Table E-10: Middle East and Africa Butadiene Demand, 2000 – 2040

Middle East & Africa Butadiene Demand (KT)										Growth Rates	
Region/Year	2000	2005	2010	2014	2020	2025	2030	2035	2040	2000-2014	2014-2040
Middle East & Africa	169	238	283	274	317	354	395	440	489	3.5%	2.2%

Source: Jacobs Consultancy Ltd.

Outlook

The global butadiene market is undergoing significant changes. New regions are playing key roles, while traditionally dominant markets are experiencing slower growth in both demand and production. The continued emergence of China as a key market will continue to change the trade pattern.

Butadiene markets, especially in Asia, have suffered from tight supplies in recent years. Imports to the region have increased steadily, especially to China. Although capacity additions in Asia during the 2014 to 2020 period will be significant, demand growth is still expected to exceed the capacity growth. Thus, imports to the region are expected to continue to grow, with the North East Asia region becoming the largest net importer of butadiene. Supply will be mostly provided by the rest of Asia, in particular the Indian subcontinent, and the Middle East and Africa – as the region is gradually moving towards heavier feeds.

Changing cracker feed slates will play a part in determining butadiene production levels. In North America the B/E ratio is expected to continue to drop as the use of ethane from shale gas continues thereby reducing butadiene production in the region. Nevertheless, the attractive pricing of LPG may result in an on-purpose butadiene project emerging.

The shift in synthetic rubber production to developing regions of Asia, Eastern Europe/FSU, and Latin America will limit the demand growth in more established market regions of North America and Western Europe.

Butadiene Trade Balance

Globally, butadiene imports were 450 kt in 2014, which is approximately 4.1% of the global demand. Historically, the net exporting regions have been Western Europe, Indian Subcontinent, Middle East & Africa and, to a lesser extent, South East Asia and South America. The net importing regions are North East Asia and North America.

Until 2007, Asia was a net exporter of butadiene, as the region remained relatively self-sufficient due to its large capacity for naphtha cracking. In recent years, imports increased as the supply became tight due to increased butadiene demand. It is expected that new butadiene production capacity in China will help reduce imports into the region for a couple of years, but in the longer term Asia is expected to become the largest butadiene importing region, especially North East Asia. Butadiene extraction capacity and on-purpose butadiene production capacity is being expanded at a faster rate in Asia than anywhere else in the world, but is not adequate to match the growth in demand due to rapidly expanding tyre manufacture and automobile demand across the region.

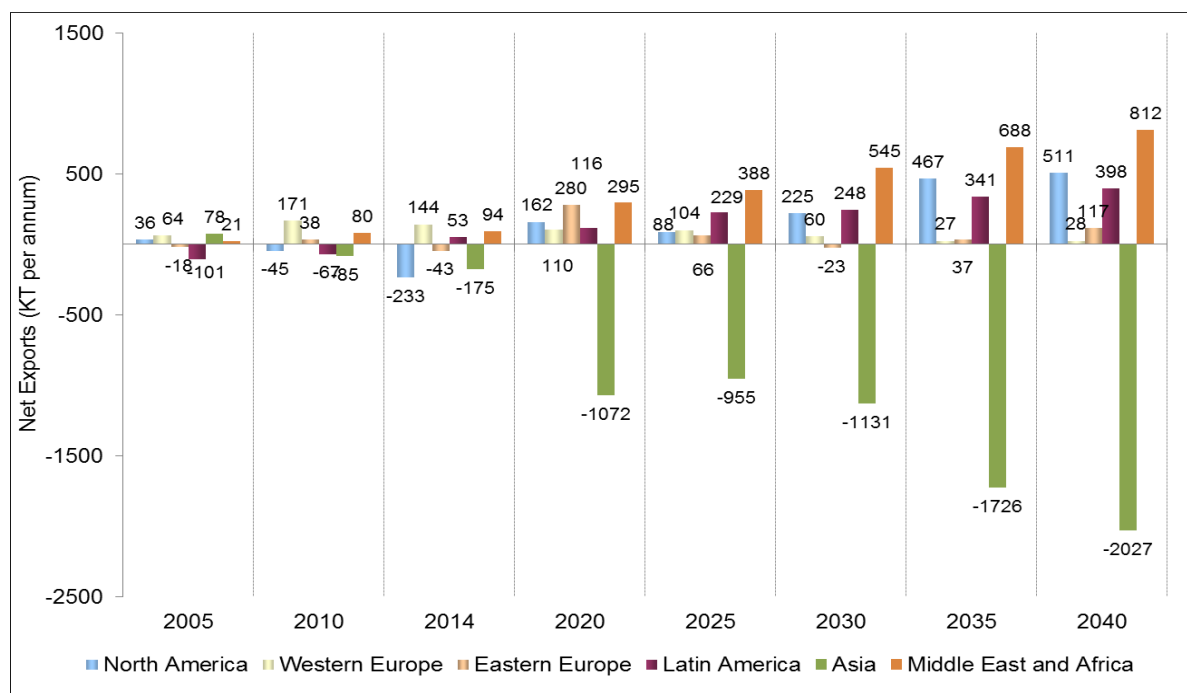
North America is likely to convert to a net exporter in the next few years and will maintain its status as a net exporter of the product, with the start-up of on-purpose capacities and stagnant demand for the product in the forecast years. The region is forecast to produce less butadiene as a by-product of ethylene production due to the use of lighter feedstock in its domestic steam crackers.

Western Europe will remain a small exporter of the product in the long term as butadiene production is expected to reduce as crackers turn to ethane based lighter feed stocks, in line with reducing demand.

In the case of Central & Eastern Europe, post 2016 the region is likely to turn into a net exporter as new butadiene capacity in Russia, Hungary and Poland is likely to produce adequate butadiene to cater to the local demands as well as export to nearby regions.

Figure E-33 below highlights the global trade balance for butadiene and includes the outlook to 2040.

Figure E-33: Butadiene Trade Balance



Source: Jacobs Consultancy Ltd.

Table E-11: Butadiene Trade Balance

Trade Status	2014 Net Exports		2020 Net Exports	
	Region	Volume (KT)	Region	Volume (KT)
Net Importers	Asia	-175	Asia	-1072
	North America	-233	North America (net exporter)	162
	Eastern Europe	-43	Eastern Europe (Net exporter)	280
Net Exporters	Middle East/Africa	94	Middle East/Africa	295
	South America	53	South America	116
	Western Europe	144	Western Europe	110

Source: Jacobs Consultancy Ltd.

Butadiene Target Suppliers

In the Eastern Europe / FSU region, Poland is a consistent net importer of butadiene. Countries such as Russia and Czech Republic, currently net exporters, are likely to maintain this status as new projects are expected to come online by 2017 to meet the local demands as well as cater to export demand. Hence, limited opportunities exist in Eastern Europe/FSU for sourcing butadiene required by Nairit plant. In the case of Western Europe, while demand growth is mature, key countries such as France and Belgium are still likely to experience growth in their butadiene demand and hence can be considered as prospective importers rather than exporters. In Asia, China will remain the largest net importer, paying a premium over European butadiene prices. Thus, other significant Asian markets such as India are likely to route their butadiene to China and hence are unlikely to be cost effective at providing butadiene to Armenia.

Figure E-34: Armenian Land-locked Location



Source: Google Maps

Armenia is a land locked country sharing its border with four countries. It is surrounded by Turkey on the West, Azerbaijan on the East, Georgia on the North and Iran on the South side. **Trade within the country is highly dependent on transit through Georgia by rail and road, as explained below.** Supplies to Georgia generally have to come either via road from Turkey or Russia, or via its western ports. **The rail connection from Russia to Armenia is currently unavailable due to its passing through South Abkhazia, whose government has blocked any rail communications with Georgia.**

Due to political constraints between Armenia and its two neighbour countries, Turkey and Azerbaijan, any trade arrangements with these countries are subject to political risk, although trade with Turkey does occur regularly via neutral intermediaries. While Armenia maintains good relations with Iran, its transport connection is dependent on a single road route. The table below shows the latest net imports and market attractiveness for the project considering various factors like location, new capacities and net imports in 2013. Table E-12 gives an overview of the key target regions to consider.

Table E-12: Butadiene Target suppliers for Nairit and their attractiveness to the project

Region	Country	Net Imports (2013) kt	Long Term Trade Status	Supplier Attractiveness
Eastern Europe/FSU	Russian Federation	11	Net Exporter	<ul style="list-style-type: none"> • Medium/High in future* (forecast) • At present, requires outbidding existing in-country off-takers • Increase in butadiene supply availability is expected after 2020 due to 3 large projects.
	Turkey	0	-	<ul style="list-style-type: none"> • Medium • Likely to be a long term explorer as new capacity comes online (Petkim)

Region	Country	Net Imports (2013) kt	Long Term Trade Status	Supplier Attractiveness
	Austria	-36	Net Exporter	<ul style="list-style-type: none"> • Medium • Large exporter • Land-locked, but Danube is navigable by barge to Black Sea
	Romania	-3.3	Net Exporter	<ul style="list-style-type: none"> • Medium • Access to black sea • No new capacity announced, • Net exporter
	Hungary	0	Net Exporter	<ul style="list-style-type: none"> • Medium • New TVK capacity on-stream from 2015 onwards
	Czech Republic	4	Net Importer	<ul style="list-style-type: none"> • Low • Fluctuates between importer and exporter
	Poland	31.9	Net Importer	<ul style="list-style-type: none"> • Low • If bio-based plant is realized, the trade status of country from will switch to net exporter.
Western Europe	France	246	Net Importer	<ul style="list-style-type: none"> • Low • Major consumer of Dutch and German butadiene
	Belgium	107	Net Importer	<ul style="list-style-type: none"> • Low • Major consumer of Dutch and German butadiene
	Germany	-162	Net Exporter	<ul style="list-style-type: none"> • Medium • Major exporter • Expensive logistics
	Netherland	-348	Net Exporter	<ul style="list-style-type: none"> • Medium • Major exporter • Expensive logistics
USA	USA	233	Net Exporter	<ul style="list-style-type: none"> • Low • Will become a major alternative exporter to compete with Western Europe • Very expensive logistics

Source: Jacobs Consultancy Ltd.

Price Forecasts

Methodology

Introduction

Jacobs Consultancy's price forecasting methodology involves the development of cash production costs at each stage of the production chain from crude oil to downstream product. This cash cost of production, combined with a forecast of return on investment at each stage, gives a forecast of long run marginal costs. This reflects the minimum price over the cycle at which producers will continue to invest in new capacity.

The production process is broken into the following key steps:

- Conversion of crude oil in the refinery into hydrocarbon feeds for the fuels and petrochemical sectors
- The production of olefins (principally ethylene and propylene) and aromatics
- The conversion of olefins and aromatics into petrochemical derivatives.

The cash cost of supply is determined by the full supply chain cost to key world markets, including cash cost of production, freight, SG&A costs and R&D and technical service costs. Cost of supply is forecast according to our estimates of the above factors, and based upon our projections for the prices of each element within the price structure.

The key driver for cost of production for most petrochemicals is the prevailing oil price, as this determines the feedstock cost and thus typically comprises a significant proportion of the full supply chain cost. Our forecasts of crude oil price, on which the price forecasts in this report are based, are discussed later in this section.

In establishing future costs of production, we also take into account the impact of the “experience curve”. This reflects the decline in production costs over time, resulting from improvements in process technology, increasing plant scale and other fixed cost efficiencies. For most refined fuels and petrochemicals, production processes are relatively mature and thus only minor process improvements are anticipated. Thus the major driver of future experience curve effects will be increasing plant scale over the forecast period, with concomitant reductions in specific fixed costs.

The margin achieved by the producing industry is less easy to forecast than production costs, and can vary significantly by industry. Margins are forecast taking into account the following factors:

- Projected supply/demand balance
- Historic margin performance
- Estimated reinvestment cost
- Competitive economics in different world regions
- Substitution effects in downstream markets

Typically, for commodity chemicals markets, the supply/demand situation will have the greatest influence on margins achieved by producers in the short term, with a tight market supporting higher prices. Conversely, when the market is long the bargaining power rests with the buyer, bidding prices down. Longer term, however, margins will be predominantly determined by reinvestment economics for the lead producer.

Other factors can influence margins, however, with some markets consistently achieving better returns than others. One element that impacts the returns achieved by the producers is the industry structure. The most important factor here is the number of players in the producer industry, with a concentrated market structure where pricing is dominated by a few powerful producers tending to support market discipline. For most commodity polymer markets, however, pricing corresponds closely to that determined by free market economics.

The integration of these factors into our long term trend and cycle forecasts is discussed below.

In developing our price forecasts, we use cash flow return (CFR) as a benchmark for assessing the margins achieved by producers. CFR is defined as follows:

$$\text{Cash Flow Return (CFR) \%} = \frac{\text{cash margin, net of freight and selling costs (\$/t)}}{\text{replacement capital cost (\$/t)}}$$

This reflects the instantaneous return on replacement capital in percentage terms and provides a straightforward mechanism for comparing historic and future margins for the producing industry. It should not be confused with IRR (Internal Rate of Return) however, which takes account of cash flow movements through the entire life of a project.

Trend Forecasts

Most fuels and many petrochemical products can be characterised as commodity products, in that they are produced to pre-defined specifications offering suppliers little opportunity to differentiate themselves. Thus there is a single market price which pertains at any particular point of supply. Over the long term, the market would thus be expected to respond to fundamental economics which dictate that the price must be just sufficient to justify investment by a leading producer. If the price were to remain at a higher level for a sustained period, new capacity would be attracted to the market, thus bidding prices down. Conversely, prolonged periods of lower pricing inhibit investment and eventually result in a shortfall in the supply/demand balance, which will cause prices to rise and attract further investment.

This is the basis on which our trend price forecasts are determined, based on our estimation of cash cost of supply, which, combined with a projection of return on investment, gives a forecast of long run marginal cost and thus reflects the minimum price over the cycle at which producers will continue to invest in new capacity.

Cycle Forecasts

Typically, petrochemicals exhibit a strong cyclicity in margins, reflecting primarily the impact of the supply/demand balance. Occasional periods of tight supply and consequent high pricing/margins can promote periods of over-building throughout the industry. The subsequent capacity overhang when these facilities come on-stream initiates a period of over-supply and low pricing, during which producers generally do not initiate substantive new investments. As the market and prices recover, the cycle repeats itself.

Trough or “bottom-of-cycle” pricing levels are generally fairly predictable, with prices trending to the cash cost of the marginal player. The marginal player is defined as the highest cost increment of supply necessary to meet demand. Should prices fall below the cash cost of these producers, some capacity will close, bringing the market closer to a balanced position and eventually initiating a recovery in pricing and margins. Peak level pricing is less predictable and frequently initiated by unplanned outages when the industry is operating at close to full capacity. Prices can rise rapidly—typically to 1.5 to 2 times trend pricing levels, although prices can be even higher than this for short periods.

Historically, the petrochemical cycle has had a period of around seven to eight years. However, economic downturns are frequently initiated by events not directly connected with the petrochemicals industry—the Arab Spring and the Eurozone crisis are examples of recent events that would not have been predicted in a study of this type, yet have had a dramatic influence on economic growth in general and hence on petrochemical demand.

We construct cycle prices based on the trend and bottom of cycle pricing, using an arithmetic construct and allowing for a notional 8-year cycle.

We note however that the Cycle Case has no economic meaning, with only the Trend Case and the Bottom of Cycle Case having any sort of solid basis in economic theory. Hence, Jacobs Consultancy does not advise the use of Cycle Case prices for project planning, or any other long-term view on project viability, but to use the Trend prices for project economic assessment and the Bottom of Cycle prices (for shorter periods) to test project robustness in downturns. The inherent uncertainty in the timing of the cycle means that investment decisions should be based on the Trend Case, which reflects the underlying long-term market fundamentals

Downside Scenario Forecasts

We also model two additional “downside” pricing scenarios which seek to test the robustness of the project opportunity to varying degrees of economic pessimism. We define the following two downside cases as:

- Short-term Downside Prices. This scenario comprises bottom of cycle prices for all products for the first three years of commercial operation with trend prices thereafter. In reality, this would correspond to a prolonged recession coinciding with the first three years of commercial operation. This macroeconomic climate is generally the most adverse for the project.
- Long-term Downside Prices. All product prices are reduced by a relatively small fixed percentage equivalent to 3.0% of its price for the duration of the project. All feedstock prices are unchanged.

Oil Price Basis

The following four oil price scenarios have been considered in this Study:

- Base Oil Case—US\$ 60/bbl (Brent FOB)
- Low Oil Case—US\$ 40/bbl (Brent FOB)
- High Oil Case—US\$ 80/bbl (Brent FOB)
- Very High Oil Case—US\$ 100/bbl (Brent FOB)

These oil price scenarios are constant in money of the day terms for the duration of the economic evaluation.

Butadiene Logistic Costs

We have estimated netback prices for use in the Financial Model for the Project, i.e. appropriate market prices in Western Europe that have had logistics costs added to arrive at a hypothetical price at the gate of the Nairit plant in Yerevan (“ex-gate” prices). These have been estimated on the basis of distance between Yerevan and Western Europe (Rotterdam, Netherlands), allowing for additional premium so as to account for difficult logistical constraints associated with delivery to Yerevan.

Our derived logistical cost is US\$250 per metric ton of butadiene. This logistics cost figure is in 2015 terms and is subject to cost inflation as defined in the Financial Modelling section.

The logistical cost and is based on the following route:

- Supply from North West Europe by semi-pressurised ship to a Georgian port. The most likely candidate for this is the existing Batumi LPG terminal, which already handles around 3 kta of LPG for export. Alternatively, Poti terminal may be considered, which currently only processes liquids.
- Butadiene transport by Rail from Batumi to Yerevan using the existing rail network (e.g. Batumi – Tbilisi – Yerevan connection).

The above has the following cost implications for 2015:

- (i) West European (WE) Price – We forecast a West European Free Delivered (FD) market price for butadiene using the methodology described earlier.
- (ii) Rotterdam – Batumi shipping route is approximately 6 900 km (13 days charter). Based on the average of international shipping freight rate for other well-established routes such as WE – Med or Southern Russia – Med, as well as the monthly charter rates for a 3,500 m³ carrier, the estimated cost for the Rotterdam – Batumi transfer will be around US\$185 per tonne.

- (iii) Georgian Port charges are estimated at US\$25 US per tonne, based on a suitable pro-rata of the existing LPG rates at Batumi LPG export terminal, with an additional US\$10 per ton of butadiene charge premium to incentivise required investment.
- (iv) The rail logistics component, based on the equivalent distance in Russia is around US\$30 per tonne.
- (v) Thus, the butadiene costs (sourced from WE) at the Yerevan facility gates is:

$$\begin{array}{rclclclcl}
 P & = & (i) & + & (ii) & + & (iii) & + & (iv) \\
 P & = & (i) & + & 185 & + & 35 & + & 30 \\
 \mathbf{P} & = & \mathbf{(i)} & + & \mathbf{250} & & & &
 \end{array}$$

The assumption in the above calculation is that the owner of the Batumi LPG terminal, or the Poti port will be willing to undertake the required expansion of its facilities, in return for new business. We estimate that around 7 000 m³ of butadiene storage would be required, which could be achieved in a single tank, which will require an investment of around US\$15 million for the tank, offloading jetty arms, rail loading line and associated piping and metering equipment.

Conversely, the costs may be lowered further if the feasibility of larger vessel receipt in Georgia is confirmed (i.e. sufficient depth at port) or the butadiene shipping vessel is hired on a long term basis.

Should the idea of a new butadiene terminal at Poti prove infeasible due to any factors outside of Armenian government control, an alternative method of butadiene delivery through Georgia is possible, albeit at a higher cost. This would require for butadiene to be transported by rail to Varna, Bulgaria. The rail cars will then be loaded onto a ferry and discharged at existing rail car terminal at Poti, Georgia. From there, they may be further transported to Nairit plant, Yerevan, Armenia, using the existing rail network (Poti – Tbilisi – Yerevan). At present, there are two operational rail ferry lines operating between Varna, Bulgaria and Poti, Georgia, as well as Varna to Batumi, Georgia, both operated by Navigation Maritime Bulgare (Navibulgar).

Overall, this is a more expensive mode of transportation, with the logistical cost estimated in the range of US\$290 – 410 per tonne, depending on the location of the source butadiene in Europe. The high level estimate is as follows in 2015 money:

- (i) West European (WE) Price – We forecast a West European Free Delivered (FD) market price for butadiene using the methodology described earlier.
- (ii) The rail freight costs in Europe are highly dependent on the source of butadiene. For example:
 - Assuming an Austrian location, OMV Schwechat refinery (near Vienna). The rail route to Burgas is some 1,500 km approximately, resulting in an estimated cost of US\$160 per tonne of butadiene.
 - Assuming a Rotterdam location. The rail route to Burgas is some 2,600 km approximately, resulting in an estimated cost of US\$280 per tonne of butadiene.
- (iii) Burgas terminal roll on / transhipment charge for loading of the rail cars is estimated at around US\$25 per tonne.
- (iv) Burgas – Poti / Batumi shipping route charge, 1170 km, based on the typical rail ferry size of 108 rail cars and reported prices for the ferry charter, the freight is estimated at approximately US\$50 per tonne.
- (v) Georgian Port charges for receipt and wheel gauge change are estimated at US\$25 US per tonne.
- (vi) The rail logistics component, based on the equivalent distance in Russia is around US\$30 per tonne.

(vii) Thus, the butadiene costs (sourced from Austria) at the Yerevan facility gates is:

$$\begin{aligned}
 P &= (i) + (ii) + (iii) + (iv) + (v) + (vi) \\
 P &= (i) + 160 + 25 + 50 + 25 + 30 \\
 P &= (i) + 290
 \end{aligned}$$

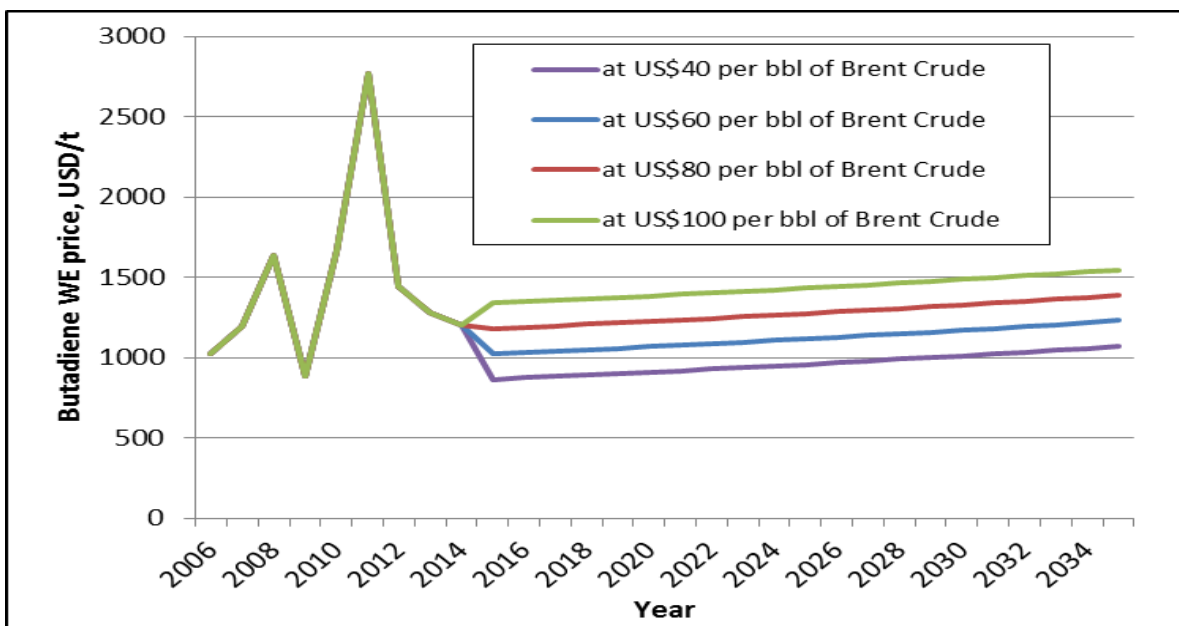
(viii) Conversely, the butadiene costs (sourced from Netherlands) at the Yerevan facility gates is:

$$\begin{aligned}
 P &= (i) + (ii) + (iii) + (iv) + (v) + (vi) \\
 P &= (i) + 280 + 25 + 50 + 25 + 30 \\
 P &= (i) + 410
 \end{aligned}$$

Market Price Forecasts

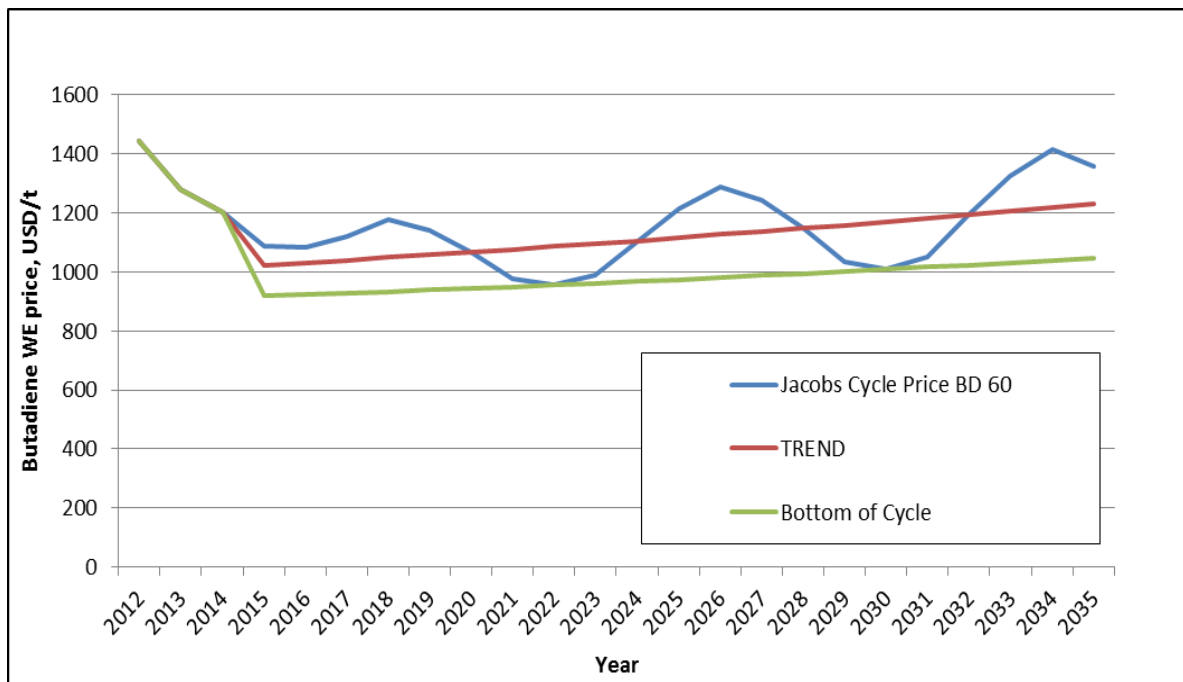
The following figures illustrate our price forecasts for the butadiene raw material and polychloroprene rubber (PCR). The graphs illustrate our price forecasts for Western Europe, oil price scenarios (Base, Low, High and Very High) and pricing scenarios (trend and cycle). All prices indicated are in US\$/MT in money of the day. A full tabulation of the prices is included in the financial model.

Figure E-35: Butadiene Trend Price Forecast



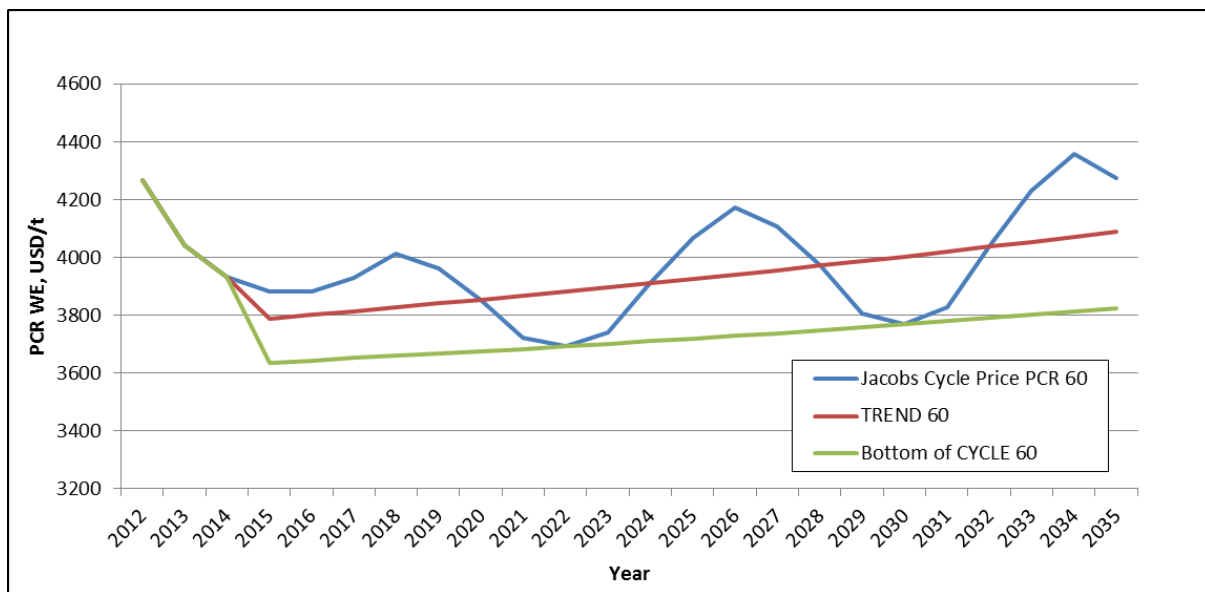
Source: Jacobs Consultancy Ltd.

Figure E-36: Butadiene Base Case trend & cycle price forecast



Source: Jacobs Consultancy Ltd.

Figure E-37: Polychloroprene (PCR) Base Case trend & cycle price forecast



Source: Jacobs Consultancy Ltd.

The above figures show the Jacobs Consultancy price forecasts for butadiene and PCR.

Project Competitiveness

In this section, we examine the competitive position of the Nairit facility against competing producers in Asia, the US and Western Europe. The comparison is based on the full cost of supply (on a delivered cash cost basis). The costs thus include plant variable and fixed costs, product packaging, but exclude delivery to market costs such as freight and tariffs, since these are different for each of the consider target markets.

Basis and Methodology

To assess the relative competitiveness of a number of producers, Jacobs Consultancy has prepared a comparative quantitative analysis based upon our estimates of other producers' delivered cash costs at defined gateways to the target market.

Key Assumptions

The following are the key assumptions for estimating the delivered cash cost:

- **Plant archetypes** – The plants that have been selected for comparison are representative leader plants of the regions in which they are located in terms of capacity, technology, level of vertical integration and other factors. They form a representative picture of the competition for the Project. There are actually only 8 such plants in current operation, excluding Nairit.
- **Alternate Feeds** – We have modelled the cost of production for various alternative configurations for PCR production that may be achieved at Nairit, reflecting that both butadiene and acetylene route processes exist at Nairit. Globally, we have modelled each plant individually, as follows:
 - German and USA plants are based on the butadiene route process, purchasing chlorine and caustic soda from adjacent chlor-alkali units, owned by 3rd parties.
 - Chinese producers, as well as Japanese Omi plant (Denka) are based on the acetylene route process, which is in turn produced from calcium carbide.
 - Japanese Kawasaki (SDK) and Nanyo (Tosoh) plants are based on the butadiene route process, receiving chlorine and caustic soda from adjacent chlor-alkali units, owned by SDK and Tosoh respectively, on a transfer cost of production price basis.
- **Year of analysis** – The year 2015 has been selected for analysis as it corresponds to the most recent year, given that butadiene prices were not overly volatile in the last two years.
- **Feedstock and product pricing basis** – Trend market price forecasts were used for 2015.
- **Transfer pricing** – For vertically integrated plants, intermediate products are assumed to be internally transferred at their cash cost of production.

No capital charges or depreciation are included in this cost of production calculation. This is because the purpose of the cash cost comparison is to demonstrate that in the event of a severe economic downturn there will be an oversupply of capacity and market prices will be set by the Short Run Marginal Cost of supply of the high cost producer. This is either the cash cost, or, in extremis, the variable cost, of the highest cost suppliers to the project's target markets. The aim of our analysis is to demonstrate that in such a scenario the project can continue to operate profitably (though with much reduced profitability) and can maintain its operations.

Our cost models for international producers are based upon public domain information that has been collected over many years. Clearly however, the major factors that significantly differentiate

producers are the technology, feedstock cost, product export logistic costs and economies of scale in production.

Cost Component Estimation

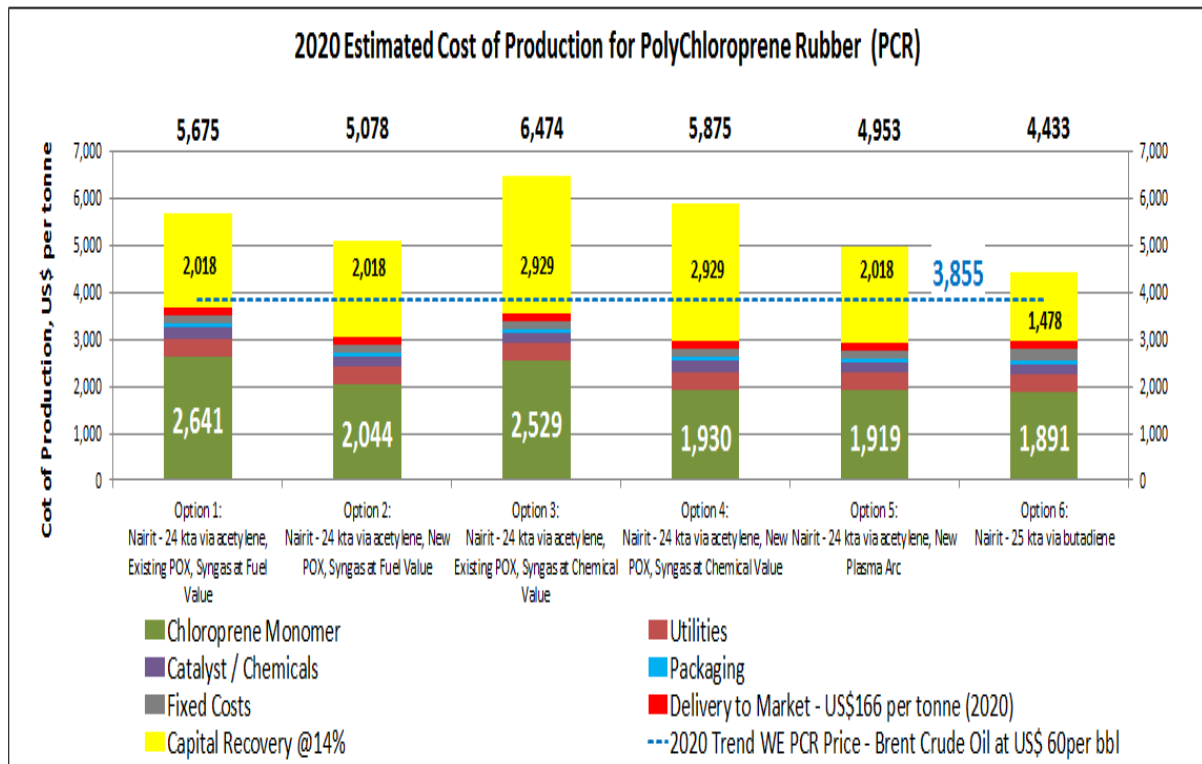
The cash cost of delivering product, calculated on per ton of product basis, are made from a consideration of a large number of parameters, the principal ones being those described below.

- **Feedstock cost** – Estimated as the product of price and requirement per ton of product. Summed for all feeds.
- **Co-product credit** – Estimated as the product of price and co-product yield per ton of product. Summed for all co-products.
- **Utility, catalyst and chemical costs** – Estimated as the requirement of each utility or catalyst per ton of product multiplied by their individual price.
- **Replacement capital cost** – We estimate the replacement capital cost for each plant on the basis of a published reference plant capital cost. We will adjust this reference plant cost for capacity, location, technology, year of EPC and other factors as appropriate. The replacement capital cost is used to estimate a number of fixed costs such as maintenance cost.
- **Fixed costs** – The estimate for the fixed cost of production is based on an estimate of the manpower required to operate the plant from which various other costs are scaled. Thus the starting point is an estimate of the total number of staff directly involved in the operation of the plant multiplied by their individual costs (expressed in US\$ per man-year). We estimate the number of operators, foremen and supervisors. The cost of employees that are engaged in overhead activities such as laboratory work, engineering, HR, IT, business planning and so on are estimated as a proportion of this cost.
- **Maintenance cost** – Estimated as a percentage of replacement capital cost (2.0% of ISBL + OSBL). The figure includes both the labour and material costs for ongoing maintenance as well as the normal periodic turnarounds but not for any plant capacity debottlenecking.
- **SG&A cost**, which represent selling, general, and administrative expenses – as a percentage of product market price (3.0%). This also includes the handling cost incurred for loading and unloading the product at the port.

PCR Competitiveness

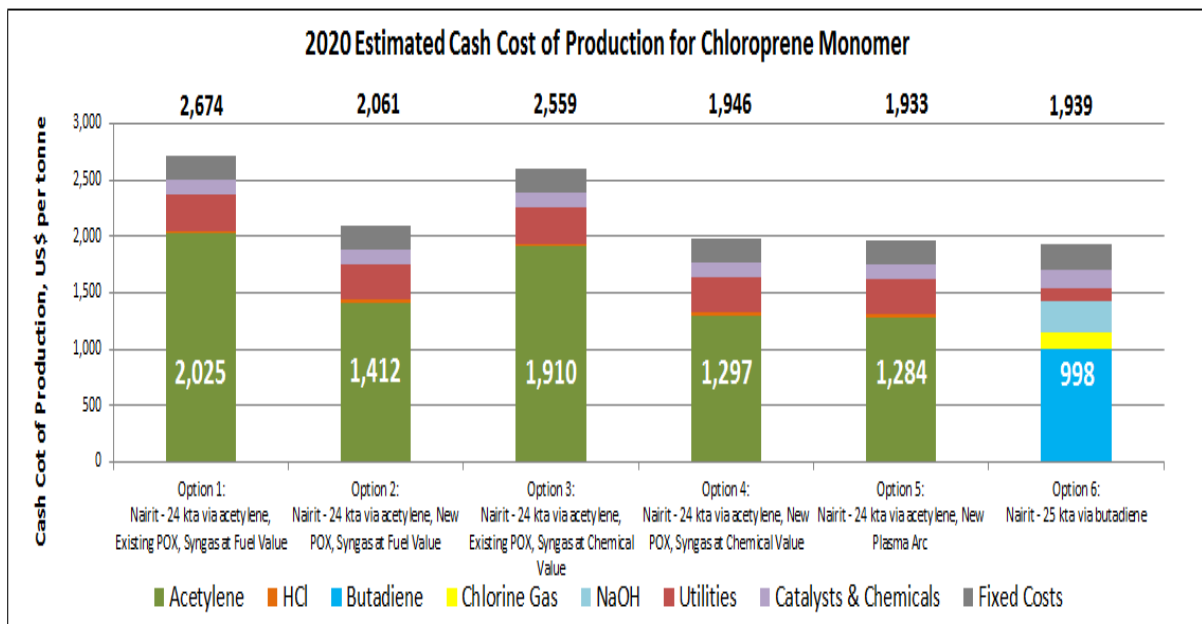
This section discusses the assessment of the competitive position of Nairit's production plant on exports globally against that of other exporters to this market. The Nairit facility has the ability to produce the PCR via either butadiene and/or acetylene, but the butadiene route allows for a more competitive cost of production. The comparison for various acetylene based routes against the butadiene route process is provided below.

Figure E-38: PCR Cost of Production Comparison at Nairit plant gates, CRude at US\$60/bbl



Source: Jacobs Consultancy Ltd.

Figure E-39: CR Monomer Cost of Production Comparison at Nairit plant gates, crude at US\$60/bbl



Source: Jacobs Consultancy Ltd.

For the acetylene route based process, the option of production of acetylene via a new plasma arc process (ISP technology) is marginally more cost effective than that of a new BASF partial oxidation process. The existing partial oxidation unit suffers from a design flaw which has precluded it from achieving its design process performance (i.e. the design 6,500 Nm³ of natural gas per ton of acetylene vs. achieved 8,200 Nm³). The benefits of syngas by-product utilisation for additional chemical production are rather muted, since additional natural gas will be required to generate the necessary

steam, as well as additional return will be required to justify the extra investment into this new chemical unit, plus the operation of this unit will require additional fixed and variable costs, thereby negating any syngas by-product credit to the acetylene price formation. Even assuming a particularly favourable combination of both new POX and syngas utilisation at chemical value, the acetylene based PCR rubber will still be significantly less competitive than that derived via butadiene.

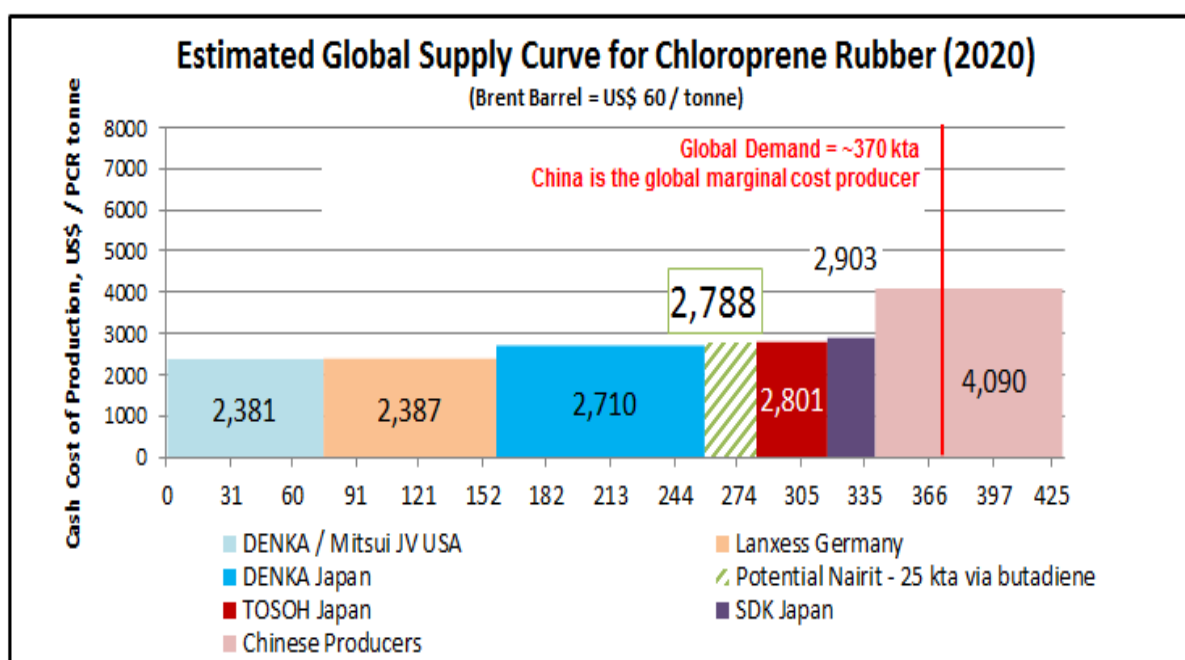
Please note that process options for 12 kta PCR production via acetylene scenario have not been considered here, since these offer even worse cost of production performance than that of 24 kta PCR production via acetylene, as the fixed costs per tonne of acetylene will be much larger, given the negative economy of scale.

The competitiveness of the butadiene based production at Nairit site is assessed against the following producers:

- Denka / Mitsui 75 kta facility in the USA producing the PCR from butadiene feedstock (previously owned by DuPont)
- Lanxess Germany 83 kta in Germany producing the PCR from butadiene feedstock
- Denka Japan 100 kta facility in Japan producing the PCR from acetylene feedstock, which is in turn produced from local calcium carbide.
- Tosoh Japan 34 kta facility in Japan producing the PCR from butadiene feedstock
- SDK Japan 23 kta facility in Japan producing the PCR from butadiene feedstock
- Three Chinese plants
 - SSRGC* (Shanxi Synthetic Rubber Group Company) 30 kta facility in China producing PCR from acetylene feedstock, which is in turn produced from local calcium carbide.
 - SSRGC* (Shanxi Synthetic Rubber Group Company) / Nairit JV 30 kta facility in China producing PCR as above
 - CCC Co. (Chongqing Changshou Chemical Co.) 30 kta facility in China producing PCR as above

The figure and table below provide our assessment of the cash cost competitive position of the PCR production by Nairit when compared to other producers.

Figure E-40: Estimated 2020 PCR Global Supply Curve (at plant gates), CRude at US\$60/bbl



Source: Jacobs Consultancy Ltd.

Table E-13: Estimated Polychloroprene (PCR) Cash Cost of Production at Plant Gates in 2020

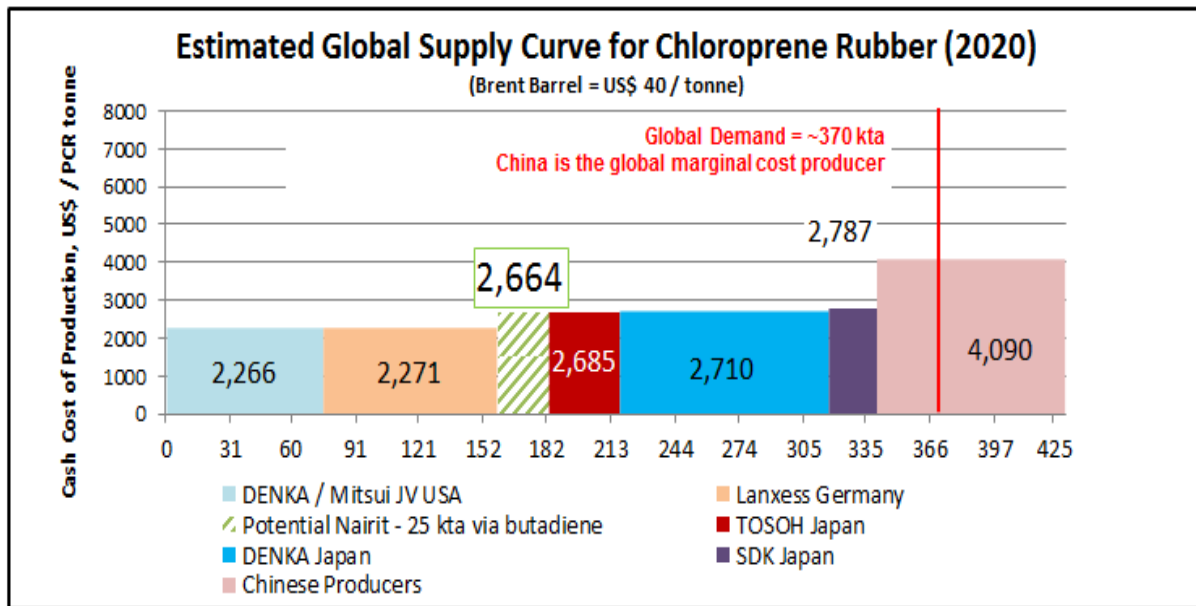
Producer	Capacity kta	Cumulative Capacity kta	Cost of Production US\$/ton
DENKA / Mitsui JV USA	75	75	2,381
Lanxess Germany	83	158	2,387
DENKA Japan	100	258	2,710
Potential Nairit - 25 kta via butadiene	25	283	2,788
TOSOH Japan	34	317	2,801
SDK Japan	23	340	2,903
Chinese producers	90	430	4,090

Note 1: Butadiene trend pricing at US\$60 per barrel of Brent crude Oil

For all cases, a major cost component is the cost of production of the chloroprene monomer, which in turn is mostly influenced by the price of butadiene and acetylene, depending on which process route is used by any given producer. The long term trend acetylene price is driven by either natural gas (Nairit) or calcium carbide prices (Denka Japan, Chinese producers). These in turn are subject to local conditions and general availability. The long term trend butadiene price is driven by the Brent crude oil price.

We have also analysed the effect of varying Brent crude oil price on the PCR supply curve. The results are presented below.

Figure E-41: Estimated 2020 PCR Global Supply Curve (at plant gates), crude at US\$40/bbl



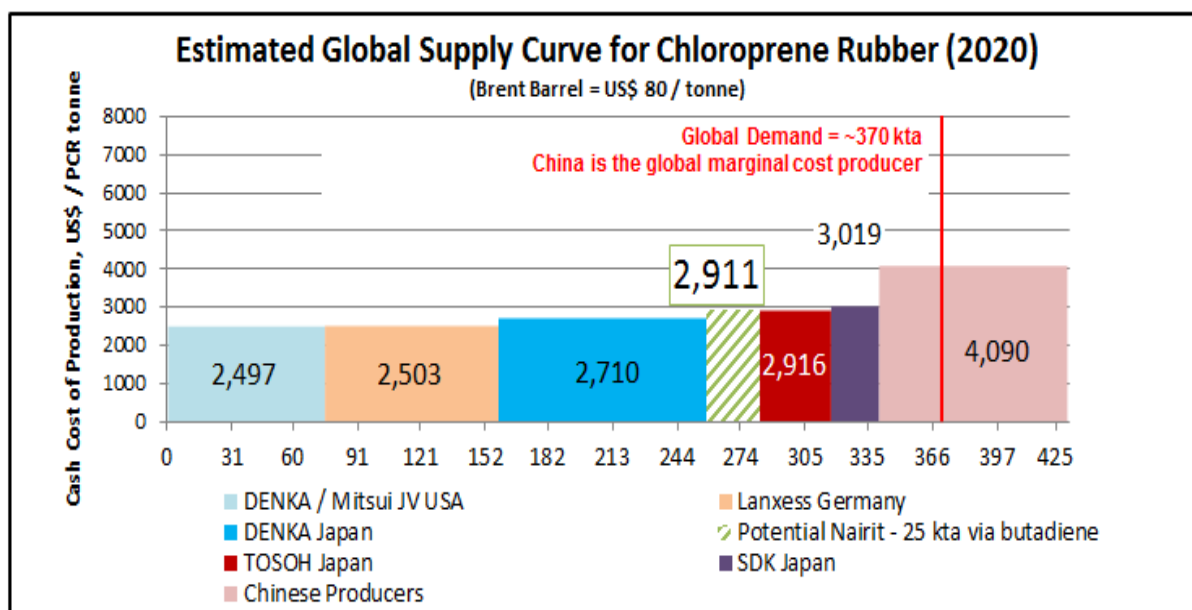
Source: Jacobs Consultancy Ltd.

Table E-14: Estimated Polychloroprene (PCR) Cash Cost of Production at Plant Gates

Producer	Capacity kta	Cumulative Capacity kta	Cost of Production US\$/ton
DENKA / Mitsui JV USA	75	75	2,266
Lanxess Germany	83	158	2,271
Potential Nairit - 25 kta via butadiene	25	183	2,664
TOSOH Japan	34	217	2,685
DENKA Japan	100	317	2,710
SDK Japan	23	340	2,787
Chinese producers	90	430	4,090

Note 1: Butadiene trend pricing at US\$40 per barrel of Brent crude Oil

Figure E-1: Estimated 2020 PCR Global Supply Curve (at plant gates), crude at US\$80/bbl



Source: Jacobs Consultancy Ltd.

Table E-15: Estimated 2020 Polychloroprene (PCR) Cash Cost of Production at Plant Gates

Producer	Capacity kta	Cumulative Capacity kta	Cost of Production US\$/ton
DENKA/Mitsui JV USA	75	75	2,497
Lanxess Germany	83	158	2,503
DENKA Japan	100	258	2,710
Potential Nairit – 25 kta via butadiene	25	283	2,911
TOSOH Japan	34	317	2,916
SDK Japan	23	340	3,019
Chinese producers	90	430	4,090

Note 1: Butadiene trend pricing at US\$80 per barrel of Brent crude Oil

From the figures and tables above, it can be seen that even relatively large variations in the price of Brent Crude Oil do not significantly alter the supply curve, with both USA and German butadiene based plants remaining the most cost efficient by a relatively large margin.

Even though butadiene delivered costs to Nairit plant gate are not necessarily the highest, both high utility (electricity and natural gas for steam) prices, as well as sub-optimal plant performance (relatively high butadiene, chlorine and caustic consumptions per ton of chloroprene monomer) make it difficult for the Nairit plant to compete globally, relegating it to a relatively laggard cost producer position, with only Tosoh 34 kta and SDK 23 kta plant at Kawasaki, as well as the three Chinese plants having a higher cost structure per tonne of PCR produced.

If the above is considered in conjunction with the required return (14%) on the necessary capital investment (US\$264 million) to enable a restart of production at Nairit plant via butadiene process, Nairit will have a higher cost of production than that of Chinese producers at the plant gate, before any additional product delivery costs are considered.

Thus, considering the above cost structure, Nairit's best hope lies in competing with existing Chinese producers who are currently the marginal cost producers. However, the overwhelming majority of Chinese produced PCR is sold to the local Chinese market, which is both tariff protected from foreign imports and requires an additional delivery charge of at least US\$150 per tonne of PCR to freight the product from Armenia to Chinese ports in 2015 money of the day. In summary, in order to be cost competitive Nairit requires a number of conditions to be favourable such as:

- Low crude oil prices
- Allowed entry into Chinese markets
- Reduced project return expectations to mitigate the effect of the capital charge
- Reduced competitor operating rates

Project Financial Modelling

Methodology and Assumptions

General and Financial Assumptions

A Financial Model has been prepared with the following general and financial basis and assumptions:

- All cash flows in nominal (“money of the day”) terms in US dollars
- Corporate tax rate of 20%, no corporate tax holiday
- Depreciation is 20 years straight line methodology
- No bank loan
- Start-up of plant at start of 2019
- 20 years of operations modelled
- Plant terminal value is equal to 400% of year 19 EBITDA
- AMD to USD FX rate was fixed at 415

Inflation Assumptions

A number of inflation assumptions are included in the Financial Model to allow the cost of individual parameters to increase over time. These assumptions are listed below:

- US dollar general rate of inflation 2.0% per year
- Labour cost rate of inflation 2.0% per year
- Long term capital cost inflation 2.0% per year
- Power price increase 2.0% per year
- Logistics cost rate of inflation 2.0% per year.

Utility Prices

Our assumption of natural gas price as well as other utility prices is set out in the table below. We have assumed a price for 2019 that is equal to the highest of Nairit's prices in the forecast years.

Table E-16: Utility Pricing Assumptions.

Utility	Units US\$ per	Nairit Actual (A) & Forecast (F) Prices				Jacobs Consultancy
		2009A	2010A	2012A	2015F	Assumption 2019
N. Gas	'000 Nm ³	199.6	236.1	258.0	277.0	277.0
Power	MW-hr	46.0	59.3	59.4	64.3	69.6
Water	m ³	0.471	0.481	0.464	0.297	0.297

Source: Jacobs Consultancy Ltd.

Note: Both actual prices and forecast prices include VAT

Other utility prices are estimated based upon the above inputs.

Operating Hours and Operating Rate

The Financial Model does not account for shutdown years; instead, it works on an average year of operation, at 8,000 operating hours, with the effect of shutdowns incorporated into the average number of hours of availability.

The operating rate, which is applied to the number of hours available for years 1, 2 and 3+ are 75%, 90%, and 100% respectively. Again, this is a conservative estimate in terms of the ramp-up rate.

Marketing Costs

We understand that a high proportion of the PCR production is to be sold through agents, which will require a supplemental marketing cost. Our assumptions in this regard are as follows:

- Proportion of PCR production marketed by agents: 80% of total production
- Marketing fee on agency sales: 3.0% of product sale price

Labour Costs

The labour costs have been calculated on the basis of an average salary of US\$5,493 per annum. Note that these labour costs include not only the cost of the plant operators but also all support staff (e.g. maintenance) and plant management.

The actual number of employees is based on the man-power estimates and is as follows:

- 436 employees for 12 kta of PCR via acetylene
- 488 employees for 24 kta of PCR via acetylene
- 380 employees for 25 kta of PCR via butadiene

Other Fixed Costs

Maintenance costs were set as 2% of the plant's replacement CAPEX value for a particular year.

Working Capital

The working capital for the integrated project has been allocated as follows:

- 45 days of payables
- 45 days of receivables
- 15 days of product inventory
- 45 days of butadiene at cost (for 25 kta butadiene case only)

Total Installed Cost

Based on the capital cost estimates we presented earlier, we have developed the overall total installed cost estimates for each option as summarised in the table below:

Table E-17: Total Installed Cost Estimate Summary for each scenario

ISBL Cost Estimate (Tyumen, Russia Location)		12 kta PCR (A)	24 kta PCR (A)	25 kta PCR (B)
Year of Estimate	2015			
PCR Capacity	ktpa	12	24	25
ISBL Cost (main process units)		159.8	264.7	131.0
Total ISBL Cost	US\$M	159.8	264.7	131.0
OSBL Cost Estimate		Project	Project	Project
OSBL cost		31.9	51.8	110.6
Total OSBL Cost	US\$M	31.9	51.8	110.6
Other Project Costs				
One Off Land Rental Cost		0.0	0.0	0.0
Development costs (incl FEED, EIA, surveys etc)	1.0% of ISBL+OSBL	0.0	0.0	0.0
PMC	1.0% of ISBL+OSBL	0.0	0.0	0.0
Spare Parts (2 years supply) - for plants only	0.3% of ISBL+OSBL	0.6	0.9	0.7
Financing Charges	0.0% of the loan	0.0	0.0	0.0
Pre Operating Expenses	2.5% of ISBL+OSBL	4.8	7.9	6.0
Insurance	0.5% of ISBL+OSBL	1.0	1.6	1.2
Total Other Project Costs	US\$M	6.3	10.4	8.0
License, Engineering and Technical Service Fees				
License Fees	3.0% of licensed ISBL	0.0	0.0	1.7
Licensors Process Design Packages (PDP)	0.5% of ISBL	0.0	0.0	0.3
Total License, Engineering and Technical Service Fees	US\$M	0.0	0.0	1.9
Capital Cost Summary		12 kta PCR (A)	24 kta PCR (A)	25 kta PCR (B)
ISBL	US\$M	160	265	131
OSBL	US\$M	32	52	111
Other Project Costs	US\$M	6	10	8
License, Engineering and Technical Service Fees	US\$M	0	0	2
Forward Escalation per annum	2.0% US\$M	12	19	15
Total Project Cost	US\$M	210	346	264

Source: Jacobs Consultancy Ltd.

The above estimate assumes no further development costs (e.g. FEED, EIA, surveys), no PMC costs and zero financing charges, as we assume that the plant will be equity financed in absence of any clear project financing plan. We have only allocated a small license fee for the butadiene scenario, payable to the licensor of the new chlor-alkali process unit. However, if any of the acetylene based scenarios were chosen and a new acetylene production unit installed with assistance from the technology

licensors (BASF for partial oxidation or ISP for plasma arc processes), then an additional license fee should be allocated for such cases.

Results

Summary of Modelling Assumptions

To fully appreciate the financial viability of the project, a 'Base Case' scenario is clearly defined by the following input parameters:

- Base Oil Price Scenario at US\$ 60 per bbl of Brent crude Oil and trend feedstock and product pricing;
- Jacobs Consultancy's CAPEX estimates. Note that Base Case does not provide for a CAPEX contingency;
- Operating rate in years 1-20 as indicated in the previous section
- All annual inflation assumptions as indicated in the previous section
- All general and financial assumptions as indicated in the previous section
- No current debt, previously incurred, has been modelled. The asset is assumed to be debt free.

In the following sections, we present the results for each of the following plant configurations:

- 12 kta acetylene based PCR production
- 24 kta acetylene based PCR production
- 25 kta butadiene based PCR production

A flexible Financial Model, provided separately with this report, contains additional input parameters, which can then be used to study a large number of "Sensitivity Cases" to be defined as required by World Bank.

Summary of Modelling Results

Under all of the considered scenarios, the project yields negative project returns. The 25 kta butadiene based scenario results in the least negative results, followed by 12 kta acetylene based scenario, as the project generates less absolute negative monies than a larger 24 kta acetylene based scenario. For the acetylene based cases, the option of using ISP plasma arc process for acetylene generation, yields the least negative results at current prices for natural gas and electricity.

Acetylene Based Production of 12 kta PCR Financial Results

The table below shows our estimates of the financial analysis for the Base Case where 12 kta of PCR is produced based on an acetylene feedstock. The IRR/NPV figures are based on 20 years of cash flow modelling and the payback estimate is a simple, undiscounted measure of the payback period.

Table E-18: 12 kta acetylene PCR Financial Results, existing POx

	Project	Equity	IRR %	NPV \$M		
	Capex \$m	Capex \$m	(20 years)	5%	10%	15%

Project Pre-Tax	210	-	negative	-249	-207	-179
Project After-Tax	210	-	negative	-249	-207	-179
Project After Financing	210	210	negative	-249	-207	-179

Source: Jacobs Consultancy Ltd.

Project returns of the Base Case for 12 kta acetylene PCR production are not attractive for any specific discount rate and yield negative values of NPV and IRR over the entire lifespan of the plant. This is driven by a number of factors:

- High natural gas prices, which also result in high cost of steam to be generated internally.
- High CAPEX investment requirement per tonne of installed PCR production
- Poor process performance of the existing partial oxidation (POx) process used to generate acetylene necessary to produce the chloroprene monomer.
- Poor process performance of the existing chlor-alkali unit, owing to equipment age, resulting in high costs of production of chlorine and caustic soda.
- High electricity prices.

There could be some room for process improvements in order to reduce power consumption or an opportunity to negotiate a better deal for power supply pricing.

The project will not be able to recoup the required investments within the 20 years operational period of the project.

Acetylene Based Production of 24 kta PCR Financial Results

The table below shows our estimates of the financial analysis for the JC case where 24 kta of PCR is produced based on an acetylene feedstock. The IRR/NPV figures are based on 20 years of cash-flow modelling and the payback estimate is a simple, undiscounted measure of the payback period.

Table E-19: 24 kta acetylene PCR Financial Results, existing POx, existing chlor-alkali

	Project	Equity	IRR %	NPV \$M		
	Capex \$m	Capex \$m	(20 years)	5%	10%	15%
Project Pre-Tax	346	-	negative	-390	-328	-287
Project After-Tax	346	-	negative	-390	-328	-287
Project After Financing	346	346	negative	-390	-328	-287

Source: Jacobs Consultancy Ltd.

Table E-20: 24 kta acetylene PCR Financial Results, new BASF POx, existing chlor-alkali

	Project	Equity	IRR %	NPV \$M		
	Capex \$m	Capex \$m	(20 years)	5%	10%	15%
Project Pre-Tax	346	-	negative	-275	-260	-244
Project After-Tax	346	-	negative	-275	-260	-244
Project After Financing	346	346	negative	-275	-260	-244

Source: Jacobs Consultancy Ltd

Table E-21: 24 kta acetylene PCR Financial Results, new ISP Plasma Arc, existing chlor-alkali

	Project	Equity	IRR %	NPV \$M		
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	Capex \$m	Capex \$m	(20 years)	5%	10%	15%
Project Pre-Tax	346	-	negative	-206	-216	-214
Project After-Tax	346	-	negative	-206	-216	-214
Project After Financing	346	346	negative	-206	-216	-214

Source: Jacobs Consultancy Ltd

Project returns of the Base Case for 24 kta acetylene PCR production are not attractive for any specific discount rate and yield negative values of NPV and IRR over the entire lifespan of the plant. Even if a theoretical access to new modern acetylene production technology (BASF partial oxidation or ISP plasma arc) is obtained, the returns are still negative. This is driven by a number of factors:

- High natural gas prices, which also result in high cost of steam to be generated internally.
- High CAPEX investment requirement per tonne of installed PCR production
- Poor process performance of the existing partial oxidation (POx) process used to generate acetylene necessary to produce the chloroprene monomer.
- Poor process performance of the existing chlor-alkali unit, owing to equipment age, resulting in high costs of production of chlorine and caustic soda.
- High electricity prices.

There could be some room for process improvements in order to reduce power consumption or an opportunity to negotiate a better deal for power supply pricing.

The project will not be able to recoup the required investments within the 20 years operational period of the project.

Butadiene Based Production of 25 kta PCR Financial Results

Table below provides our estimates of the financials for the Base Case where 25 kta of PCR is produced based on a butadiene feedstock. The IRR/NPV figures are based on 20 years of cash flow modelling and the payback estimate is a simple, undiscounted measure of the payback period.

Table E-22: 25 butadiene kta PCR Financial Results, new chlor-alkali unit.

	Project	Equity	IRR %	NPV \$M		
	Capex \$m	Capex \$m	(20 years)	5%	10%	15%
Project Pre-Tax	264	-	negative	-193	-186	-178
Project After-Tax	264	-	negative	-193	-186	-178
Project After Financing	264	264	negative	-193	-186	-178

Source: Jacobs Consultancy Ltd

Project returns of the Base Case for 25 kta butadiene PCR production are not attractive for any specific discount rate and yield negative values of NPV and IRR over the entire lifespan of the plant. This is driven by a number of factors:

- High CAPEX investment requirement per tonne of installed PCR production
- Poor process performance of the chloroprene monomer production process.
- High natural gas prices, resulting in high cost of internally generated steam utility.
- High electricity prices.

There could be some room for process improvements in order to reduce power consumption or an opportunity to negotiate a better deal for power supply pricing.

The project will not be able to recoup the required investments within the 20 years operational period of the project.

Section F



SWOT Analysis of the Nairit Chemical Plant

Introduction

In accordance with our technical assignment, Jacobs Consultancy visited the Nairit plant during the last week of February 2015. The purpose of the site visit was to assess the present condition of the assets of CJSC “Nairit Plant” and collect all the necessary information with regards to the examined assets.

The present report contains our SWOT (Strength, Weaknesses, Opportunity, Threats) assessment for the potential restart of chloroprene rubber production on Nairit site.

The above was considered with a view to restarting production under one of the three currently considered production scenarios:

- 12 kta of polychloroprene rubber, via acetylene route
- 24 kta of polychloroprene rubber, via acetylene route
- 25 kta of polychloroprene rubber, via butadiene route

SWOT Analysis

The purpose of conducting this type of detailed analysis for each section of the NAIRIT Polychloroprene rubber (PCR) manufacturing facility is to highlight the key characteristics of the production section that will have a significant effect on the future performance of the whole business. The term SWOT is defined below:

- **STRENGTHS** – describes the characteristics that the facility possesses to contribute to the overall business success. What are the main attributes of the process that provide a means of the business maintaining its competitive advantage?
- **WEAKNESSES** – describes the limitations that the facility possesses that could, if not addressed, result in poor overall business performance (many of these limitations maybe inherent in the facility and will need to be fully understood). Is there an action plan in place to attempt to overcome these weaknesses?
- **OPPORTUNITIES** – describes the particular opportunities that could be derived from that particular section of the facility to enhance the business performance. This analysis is usually applied to factors external to the business but we have combined this with internal features.
- **THREATS** – describes the external elements in the environment (political, social, environmental etc.) that could cause difficulties to the business to operate successfully. We have adapted this concept to also describe factors that may have a negative effect on the whole facility operation.

Summary

Based on market, technical and financial analysis described as well as the SWOT analysis contained within this report, none of the proposed scenarios are at present particularly attractive, with 25 kta production via the butadiene route being the most favourable of the 3 options considered.

The summary of the key issues is as follows:

- For all considered cases, the plant equipment is very old, and has largely reached the end of its useful life.
- Natural gas supply is very expensive and affects the two scenarios for production via acetylene disproportionately more, as gas is used as the main process feedstock.
- The butadiene route is exposed to butadiene logistics, which are thought of as challenging and are at present not clearly defined. However, our analysis shows that delivery of butadiene to site is feasible, albeit with a significant logistical cost.
- Product logistics are less challenging, but still rely on access to a port in a 3rd country, with Georgian ports being the most likely candidates. This results in significant costs for delivery of the product to customers.
- Substantial capital investment required to restart operations under any of these scenarios.
- Both 24 kta via acetylene route and 25 kta via butadiene route benefit from greater economy of scale, but in turn are more exposed to global markets, and as such are more threatened by fluctuation in global demand for polychloroprene rubber, as well as the behaviour of other major producers.
- Both acetylene route scenarios are inherently more complex and more dangerous than the butadiene route scenario. This contributes to the lower overall cost of production via the butadiene route.

- Nairit's product will be sold on the international market, allowing for major foreign currency import to Armenia.
- As a sole chemicals processing plant in Armenia, this facility has high strategic value, enabling a downstream enterprise park to be set up in the adjacent industrial park or within selected areas of the Nairit site.

12 kta of polychloroprene rubber, via acetylene route

Strengths

The major strengths of this option are listed below:

1. Lowest capital investment option.
2. Natural gas feed stock provides some measure of raw material independence; although the price is fixed by an external organisation.
3. Relatively small impact on the global PCR market should allow for high utilisation of installed capacity, as its products may be sold into nearby Former Soviet Union and Middle East countries without entering into a pricing war with its major competitor in these markets (Lanxess, Germany).
4. The integrated full chain of production units is available on site, resulting in transfer pricing for all key intermediate chemicals necessary for polychloroprene rubber production (i.e. chlorine, HCl, acetylene, chloroprene monomer, caustic soda).
5. Some of the existing plant equipment may be reused, either to re-enter operation or as spare parts to support the new investment.
6. Considerable operations experience on the site for the process unit operations.
7. Local own brine supply of adequate quality for the existing Chlor-Alkali units.
8. High speed response to the maintenance operation with the ability of the site personnel to fabricate new parts for the equipment (e.g. copper electrodes for Chlor-Alkali electrolyzers, simple vessels, piping).
9. A more efficient addition of chlorine to produce the chloroprene monomer (in comparison to the butadiene route) results in a lower capacity requirement for the chlor-alkali unit (which is the main electric power consumer on site).
10. The site has its own pilot polymerisation unit which allows it to maintain high quality control over the product, resulting in less wastage and the ability to producer on-spec products.
11. The PCR produced by the Nairit facility in the past was of good quality and had a good reputation in the market place. The Nairit PCR products are known globally and Nairit has been active in the PCR market for many years, prior to the shut-down of operations in 2010.
12. Many of the Nairit PCR products manufactured at the site have been approved in critical applications where there is a significant barrier to entry for the competition (i.e. automotive applications, cables etc).
13. Nairit's product will be sold on the international market, allowing for major foreign currency import to Armenia.
14. As the sole chemicals processing plant in Armenia, this facility has high strategic value, enabling a downstream enterprise park to be set up in the adjacent industrial park or within selected areas of the Nairit site.

15. Secure supply of electrical power from the local utility provider from a natural gas power station.

Weaknesses

The major weaknesses of this option are listed below:

1. Lowest cost efficiency of production of the three options, due to small scale (increased capital investment per tonne of production capacity installed, increased operations and maintenance costs).
2. The existing acetylene production unit is (A) is in a very poor condition (B) has a design fault resulting in excessive natural gas consumption. The net effect is that the existing unit is both inefficient and unsafe to operate, requiring licensor involvement to correct the design fault and substantial capital investment to restore the unit.
3. The price of natural gas supply is outside Nairit's control and currently is set at prohibitively high levels.
4. The price of electric power supply is outside Nairit's control and currently is set at prohibitively high levels.
5. The existing equipment and surrounding infrastructure is in very poor condition with significant evidence of major deterioration of the mechanical integrity of the facility.
6. As the facility has historically relied on the 'make it in-house' approach has perpetuated its reliance on out-dated technology and impeded technological progress and improved operational efficiency.
7. The lack of capital investment has resulted in the obsolescence of the facility and has impeded the facility from adopting more modern technology both in terms of operational efficiency and overall health and safety.
8. Reliance on outdated manual operation has resulted in the facility being operated with excessive manual intervention and thus having low operability and efficiency. In the event of operations being resumed, substantial culture change and operator training will be necessary.
9. The continued use of diaphragm cell technology for Chlor-Alkali operations, where asbestos is used in the construction of the diaphragm results in lower efficiency, additional capital costs and HSE concerns.
10. The spent asbestos from the cells has to be disposed of in accordance with modern health and safety practice and results in a higher operational cost.
11. Unsuitable HSE performance; gas detectors are not installed, flares are heavily corroded, no environmental monitoring instruments seen.
12. Higher amounts of chlorinated waste by-products (than obtained via butadiene route) which need to be safely incinerated to avoid dioxin formation and its subsequent release to atmosphere.
13. A new Air Separation Unit is required, resulting in additional capital investment.
14. It is likely that in times of crisis or reduced power generation capacity that the Nairit production site will not be a priority customer for the power company, risking supply disruption.
15. Failure to address the excessive staffing of the plant will result in loss of margin for the PCR & revenue for the project.

Opportunities

The major opportunities of this option are listed below:

1. Potential for relatively quick implementation, given large scale of spare surviving equipment
2. A reduction in natural gas pricing will substantially improve process economics.
3. Additional small tonnage specialty chemicals production from associated by-products may help to further marginally increase the profitability of operations.
4. The routing of syngas (by-product of acetylene production) for additional steam generation will allow reduced natural gas consumption on site. This option is perceived as more beneficial than routing the syngas for additional chemical production, since less capital investment is required (i.e. new dual fuel steam boiler vs. an additional chemical production unit, its associated infrastructure, plus new natural gas steam boiler).
5. Potential introduction of new acetylene production technology (either new design from BASF for the partial oxidation of natural gas or ISP plasma arc) will lead to substantial process operation improvement.
6. A switch to a new (membrane) chlor-alkali production technology, as well as a new Air Separation Unit, will allow reduced overall electricity consumption of the site, and thereby the cost of production, albeit at the expense of larger capital investment.
7. Polychloroprene is typically exported in rather small 25 kg bags, leading to relatively high packaging costs. Introduction of a price incentive to recover the bags from clients at a reduced price may go towards improving the overall cost of production. Options towards shipping in bigger bags / containers should also be explored.
8. There are opportunities to expand the present production to the original name plate of the process over the early years of operation at an acceptable capital investment cost.
9. The use of target marketing of the PCR product into the higher value sectors of the market could bring improved returns to Nairit. Focus efforts to develop the Nairit sales force rather than agents.
10. Nairit has a polymerisation pilot plant on the site which can be used for new product development into some of the high value sectors. This is a valuable asset not available to many of the competition.
11. The development of an enterprise park on the Nairit site (with the support of the government) could bring additional value to Nairit as small enterprises could be set up to process the PCR into final products.
12. There is ample room to improve the process efficiency and asset management of the site in order to increase the overall economic efficiency of the presently considered investment.
13. Large amount of redundant processing equipment will be an additional source of revenue during the clearing of the site.

Threats

The major threats of this option are listed below:

1. Higher cost of production scenario than that of production via butadiene route. This will hamper the ability of Nairit to compete with other producers and excessively expose it to market demand fluctuations, as its large cost of production will threaten the overall profitability of operations.

2. The need to recoup the capital costs associated with the reconstruction of the plant to enable process operations, places a very large burden on the cost of production structure of Nairit.
3. The Nairit processing plant could be priced out of the market by other producers increasing production in countries with access to cheaper raw materials and easier transport routes to major markets.
4. Exposed to natural gas pricing mechanisms, which are outside Nairit's control.
5. Exposed to electric power pricing mechanisms, which are outside Nairit's control.
6. The project is insufficiently defined at present to give confidence in its speedy implementation and cost control (i.e. the overall project definition is lacking, there are no provisions for how the project will be financed, there are no construction contractors currently lined up to execute the work, there are no process licensors other than Nairit itself that can guarantee the process performance).
7. The overall process route is inherently more hazardous than chloroprene monomer production via butadiene. On 14 May 2009, an explosion occurred in the hydro-chlorination section of this chloroprene monomer production unit, resulting in four fatalities and injuries to other personnel.
8. Improvement to the cost of production of acetylene intermediate is a key step towards lowering the overall cost of production of PCR product. In order to achieve this, it will be necessary to involve an acetylene technology holder / licensor. However, access to modern technology may not be possible if either BASF or ISP consider the Nairit project to be a competitive threat, or of little interest.
9. Failure to adequately address the poor condition of the site and to clear the derelict and/or decommissioned process equipment could result in environmental damage & loss of production. Any contamination events that are left unchecked could cause significant business disruption.

24 kta of polychloroprene rubber, via acetylene route

Strengths

The major strengths of this option are listed below:

1. Same strengths as those listed for 12 kta of polychloroprene rubber, via acetylene route under items 2, 4 – 15.
2. More cost efficient mode of production, when compared to analogous 12 kta scenario, due to larger scale (increased capital investment per tonne of production capacity installed, increased operations and maintenance costs).

Weaknesses

The major weaknesses of this option are listed below:

1. Same weaknesses as those listed for 12 kta of polychloroprene rubber, via acetylene route under items 2 – 15.
2. Highest capital investment option.

Opportunities

The major opportunities of this option are listed below:

1. Same opportunities as those listed for 12 kta of polychloroprene rubber, via acetylene route under items 2 – 14.

Threats

The major threats of this option are listed below:

1. Same threats as those listed for 12 kta of polychloroprene rubber, via acetylene route under items 1 – 9.
2. Higher cost of production scenario than that of 25 kta of polychloroprene rubber via butadiene. This will hamper the ability of Nairit to compete with other producers and excessively expose it to market demand fluctuations, as its large cost of production will threaten the overall profitability of operations.
3. While this option benefits from greater economy of scale, compared to 12 kta via acetylene route, it is in turn more exposed to global markets, and as such is more threatened by fluctuation in global demand for polychloroprene rubber, as well as the behaviour of other major producers.

25 kta of polychloroprene rubber, via butadiene route

Strengths

The major strengths of this option are listed below:

1. Same strengths as those listed for 12 kta of polychloroprene rubber, via acetylene route under items 4 – 6, 8, 10 – 15.
2. Lowest cost of production option, which maximises Nairit's ability to compete with other polychloroprene rubber producers.
3. While the quality of local brine supply is such that it will need further purification to make it suitable for a new membrane Chlor-Alkali production unit, this is not overly costly, and results in cheaper cost of brine feedstock than that enjoyed by competitors that have to buy solar or vapour salt on the market for the chlor-alkali unit operations.
4. A simpler and less hazardous production route compared to the two production options via acetylene route.
5. No asbestos material handling required (i.e. new membrane chlor-alkali unit).
6. Less exposed to natural gas prices than either of the two production options via acetylene route.
7. Not exposed to 3rd party licensor risk (i.e. no need for acetylene production).
8. No need to find a suitable syngas utilisation option.
9. Exotic materials of construction used for the original chloroprene production unit (from butadiene) afford greater confidence in equipment still having useful operation life in it and thus available for re-use.
10. Less chlorinated waste by-products, resulting in a more environmentally friendly operation.
11. No need for new air separation unit.

Weaknesses

The major weaknesses of this option are listed below:

1. Same weaknesses as those listed for 12 kta of polychloroprene rubber, via acetylene route under items 3 – 8, 11, 14, 15.
2. Exposed to butadiene supply logistical challenges, as there is no butadiene production in Armenia. Thus, a significant part (if not all) of butadiene imports must proceed through a port in a 3rd country with rail or road connection to Armenia. This will most likely be either the Georgian port of Poti or Batumi. Neither of these ports has adequate import facilities at present.
3. Requires rail infrastructure investment on site to receive butadiene rail shipments as delivered after transshipment in the 3rd party port (i.e. Batumi or Poti).
4. Higher capital investment required than that for the option of 12 kta of polychloroprene rubber, via acetylene route.
5. Still relatively high cost of production when compared to main competitor (Lanxess, Germany) supplying customers in Europe or Former Soviet Union countries.

Opportunities

The major opportunities of this option are listed below:

1. Same opportunities as those listed for 12 kta of polychloroprene rubber, via acetylene route under items 7 – 13.
2. A reduction in natural gas and/or electricity pricing will improve process economics, albeit to a lower degree than it does for the two options via acetylene route.
3. Opportunistic / spot delivery of butadiene from Iran (Tabriz) may be feasible and allow diversifying from the difficult logistic supply route for butadiene from Europe or elsewhere.

Threats

The major threats of this option are listed below:

1. Same threats as those listed for 12 kta of polychloroprene rubber, via acetylene route under items 2 – 6, 9 .
2. Subject to stability and pricing of butadiene supply route (e.g. political stability and good will in Georgia).
3. While this option benefits from greater economy of scale, compared to 12 kta via acetylene route, it is in turn more exposed to global markets, and as such is more threatened by fluctuation in global demand for polychloroprene rubber, as well as the behaviour of other major producers.