Benzene Production from Pygas (Extractive Distillation Process)

Report
Benzene E11A
Cost Analysis

United States

INTRATEC

BENZENE PRODUCTION FROM PYGAS (EXTRACTIVE DISTILLATION PROCESS)
REPORT BENZENE E11A

Analysis developed by Intratec

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ABSTRACT

This report presents a cost analysis of Benzene production from pyrolysis gasoline (pygas). The process examined is a typical extractive distillation process. First, pygas is fractionated into 3 hydrocarbon cuts. A C5s stream and a heavies stream are generated as by-products. The remaining C6s fraction is then fed to an extractive distillation system, using N-formylmorpholine (NFM) as solvent, to recover benzene.

The report examines one-time costs associated with the construction of a plant and the continuing costs associated with the daily operation of such a plant. The analysis assumes a United States-based plant with a capacity of 250 kt of Benzene per year and includes:

* Capital Investment, broken down by:

  - Total fixed capital required, divided in process unit (ISBL); infrastructure (OSBL), contingency and owner's cost

  - Working capital and costs incurred during industrial plant commissioning and start-up

* Operating cost, broken down by:

  - Variable operating costs (raw materials, utilities)

  - Fixed operating costs (maintenance, operating charges, plant overhead, local taxes and insurance)

  - Depreciation

* Raw materials consumption, products generation and labor requirements

* Process block flow diagram and description of industrial site installations (process unit and infrastructure)

This report was developed based essentially on the following reference(s):

"Benzene", Ullmann's Encyclopedia of Industrial Chemistry, 7th edition

Keywords: BTX, Aromatics, Hydrotreatment, Diprolene, Distapex, Lurgi, ED

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ABOUT THIS REPORT

Study Objective

This report presents the economics of Benzene production from pyrolysis gasoline (pygas). The process examined is a typical extractive distillation process.

The primary objective of this study is to explain the cost structure of the aforementioned process, encompassing capital investment and operating cost figures.

The process design and economics in this report are based on an industrial facility with a capacity of 250,000 metric ton of Benzene per year, a nominal capacity that is globally competitive.

In addition, the economic assessment, developed for the period Q2 2017, assumes the construction of a United States-based industrial facility that includes the infrastructure typically required for such a project.

Report Overview

This report is structured into eight main parts which follow a logical sequence. Each of these parts is described below.

By way of introduction, the first part – the current chapter – briefly explains the report itself, its structure and objective. Readers are encouraged to spend a few minutes reading this chapter, so as to make the most of the study.

In the second part, *About Benzene*, the reader will learn the basics of Benzene itself. This chapter also covers its applications and major industrial process pathways.

The third part, *Process Overview*, presents basic aspects of the process studied: products generated, process inputs, and physico-chemistry highlights.

The fourth part, *Industrial Site*, describes an industrial plant based on the process under analysis, in terms of the process unit and infrastructure required. This technical analysis underlies the entire study.

The fifth part, *Capital Investment*, presents all capital costs associated with the process examined, from design and erection of an industrial site to plant startup.

Operating Costs of the process are examined in the sixth part. Ongoing costs related to the operation of a unit based on the process are studied, including operating fixed costs, operating variable costs and depreciation.

The seventh part, *Product Value*, targets to estimate the gate cost of the plant final product, by adding corporate overhead costs and a parcel that will guarantee an expected Return On Capital Employed (ROCE). It provides an idea of the minimum price at which the product may be sold, and how competitive it is.

The eighth part, *Process Economics Summary*, summarizes all economic figures presented throughout the report.

Finally, to address any questions or concerns about the methodologies and procedures adopted in the development of this report, the reader is referred to the eighth part, *Analysis Methodology*.

How to Use this Report?

The main purpose of this Report is to assist readers in a preliminary economic evaluation of the industrial process approached. It is a valuable **support tool** for a myriad of activities and studies, such as screening and assessment of investment options, preliminary evaluation of the economic potential of emerging industrial processes, rough assessment of the economic feasibility of industrial ventures, cost estimates double-checking, preliminary budget approval, research planning, and so on.

Readers must always bear in mind the nature of this report and the resulting limitations on how to properly use it. Limitations that apply to both technical data and economic assessment presented in this study are explained below.

Technical Data

The preliminary design of the process, presented in the part *Industrial Site*, is based on fast techniques that rely on reduced design efforts. The goal of such preliminary design is exclusively to represent the process in sufficient detail for supporting capital and operating costs estimation within the accuracy expected: class 4 budgetary estimates. Therefore the technical data presented must not be confused with an actual conceptual process design, and must not be used as such.

Economic Assessment

The economic assessment presented in this report (parts *Capital Investment, Operating Cost, Product Value Analysis and Process Economic Summary*), developed for the period 2017 Q2, assumes the construction of a United States-based industrial facility. This means that capital and operating costs estimates presented are based on several general assumptions (e.g. average market figures for raw materials, chemicals and utilities prices, labor costs, taxes and duties), believed to suitably portray local conditions for the period of analysis informed, on a country-level basis.

Accordingly, the economic assessment provided in this report is not meant to fit any specific industrial venture, which would involve a wealth of specific data and assumptions not herein considered.

EXECUTIVE SUMMARY

About Benzene

Benzene (a.k.a. Benzol) is an organic compound, in the aromatic hydrocarbon class. More specifically, it is the simplest of these compounds, comprising of one single aromatic ring. Benzene is a colorless, volatile, flammable liquid, insoluble in water, but soluble in most organic compounds. It is hardly found in its free form in nature, appearing only as traces in crude oil and coal. It was first isolated in 1825, with production starting in 1849 and growing rapidly in the 1950s, with the rising demand for polymers. Benzene is an extremely important chemical compound, being used as a versatile building block for a great variety of organic compounds, primarily aromatic ones.

Being a flammable, volatile, and toxic material, Benzene must be handled, stored and transported according to strict regulations. It may be stored in steel drums or tanks.

Benzene is shipped by rail tank cars, trucks, barges, and tankers. Because of the flammability, toxicity, and volatility of benzene, transfers from one vessel to another are conducted in closed systems. Metal tanks and storage containers should be grounded during transfers. Smaller quantities of benzene are routinely shipped in steel or glass containers.

Benzene is used in the production of pharmaceuticals; specialty chemicals; plastics; resins; dyes; pesticides and other organic compounds. It is also employed as motor fuel component and solvent, although it has been replaced by less toxic materials.

Benzene Production Process

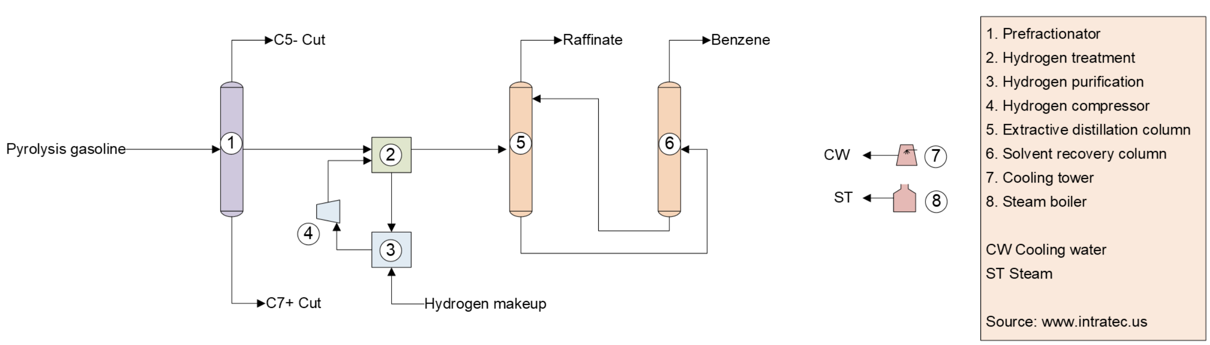
The present analysis approaches Benzene production from pyrolysis gasoline (pygas).

The process under analysis comprises two major sections: (1) Benzene Purification; and (2) Hydrogen Purification.

Benzene Purification. First, the pyrolysis gasoline, a hydrocarbons stream with carbon chains ranging from C5 to C12, is separated into three hydrocarbons cut. Both the light and heavy cuts are sold to nearby facilities. The intermediate cut, containing C6 hydrocarbons, is then fed with hydrogen to a pretreatment reactor. There, diolefinic material in the pyrolysis gasoline is hydrotreated in the presence of catalysts (cobalt molybdate on alumina). The diolefins in the pyrolysis gasoline feed are converted to olefins, which are then saturated. Also, thiophene and other sulfur compounds in the pyrolysis gasoline are converted to H2S. The regenerated aromatic stream is subjected to a extractive distillation. In the extractive distillation process, N-formylmorpholine (NFM) is mixed with the feed stream in order to alter the vapour pressure of the components to be separated. The solvent lowers the vapour pressure of benzene in the feed stream more than the other non-aromatic hydrocarbons. Given the shift in the vapour pressures, benzene is recovered alongside with the solvent fed to column. The rich-benzene solvent is fed to a stripping column to recover the solvent, through the column's bottom, and benzene, through the column's top.

Hydrogen Purification. Hydrogen stream is fed to the bottom of a multi-stage absorber column. The absorption is conducted in a counter-current flow. The purpose is to remove residual hydrocarbons from the hydrogen-rich feed stream, avoiding the build-up of impurities in the process. The washed hydrogen-rich gas is compressed and heated, before being directed to pretreatment reactor.

Process Schematic Diagram



Economic Analysis

The next table provides a summary of all capital, operating and non-operating costs related to the process described in the report, based on a □ mt/y plant. Also, it presents some remarks about the key aspects surrounding the economic analysis performed.

Economic Analysis Summary

BASIS: UNITED STATES, Q3 2021 (IC INDEX: 189.7)

PLANT CAPACITY & OPERATION		CAPITAL INVESTMENT SUMMARY	MM USD
Nominal capacity (mt/y)	□	Fixed capital	□□□
Operating rate (h/y)	□	Working capital	□□□
Actual production (mt/y)	□	Additional capital	□□□
		TOTAL CAPITAL INVESTMENT	□□□

DESCRIPTION	QUANTITY PER MT	PRICE	<FILE	MM USD/YR	%
□□□□□□□□□□□□□□□□	□ □□□	□□□□□□ □□□□□□□	□	□□□	□
□□□□□□□□□□□□□□□□	□ □□□	□□□□□□ □□□□□□□	□	□□□	□
Net raw materials cost			□	□□□	□□□
Net utilities cost			□	□□□	□□□
OPERATING VARIABLE COSTS			□	□□□	□□□
OPERATING FIXED COSTS			□	□□□	□□□
OPERATING CASH COST			□	□□□	□□□
Depreciation	□˜ for ISBL & Owner's cost / □˜ for OSBL		□	□□□	□□□
TOTAL OPERATING COST			□	□□□	□□□
Corporate Overhead			□	□□□	
PRODUCT VALUE			□		

The above table shows the impact of variable costs in the operating costs - it represents approximately □% of the total operating cost.

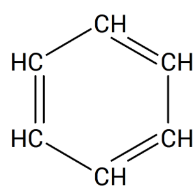
Regarding the capital investment it is worth mentioning that, in order to fulfill the infrastructure requirements assumed in the present analysis, OSBL investment represents about □% of the plant cost.

ABOUT BENZENE

Introduction

Benzene (a.k.a. Benzol) is an organic compound, in the aromatic hydrocarbon class. More specifically, it is the simplest of these compounds, comprising of one single aromatic ring. Benzene is a colorless, volatile, flammable liquid, insoluble in water, but soluble in most organic compounds. It is hardly found in its free form in nature, appearing only as traces in crude oil and coal. It was first isolated in 1825, with production starting in 1849 and growing rapidly in the 1950s, with the rising demand for polymers. Benzene is an extremely important chemical compound, being used as a versatile building block for a great variety of organic compounds, primarily aromatic ones.

The structure of Benzene is presented below:



Benzene

Nowadays, benzene, toluene and xylene – the so-called BTX aromatics – are primarily produced from petroleum. In this context, Benzene is produced on commercial scale mainly by reforming and separation, thermal or catalytic dealkylation of toluene, and disproportionation. Benzene is also produced from pyrolysis gasoline, derived in turn from steam cracking of olefins.

Alternatively, Benzene may be recovered from light oils, obtained from the carbonization or coking of coal.

Being a flammable, volatile, and toxic material, Benzene must be handled, stored and transported according to strict regulations. It may be stored in steel drums or tanks.

Benzene is shipped by rail tank cars, trucks, barges, and tankers. Because of the flammability, toxicity, and volatility of benzene, transfers from one vessel to another are conducted in closed systems. Metal tanks and storage containers should be grounded during transfers. Smaller quantities of benzene are routinely shipped in steel or glass containers.

Commercial Forms & Applications

The uses and applications of Benzene may vary according to the product grade. The main forms of Benzene are:

Benzene is used in the production of pharmaceuticals; specialty chemicals; plastics; resins; dyes; pesticides and other organic compounds. It is also employed as motor fuel component and solvent, although it has been replaced by less toxic materials.

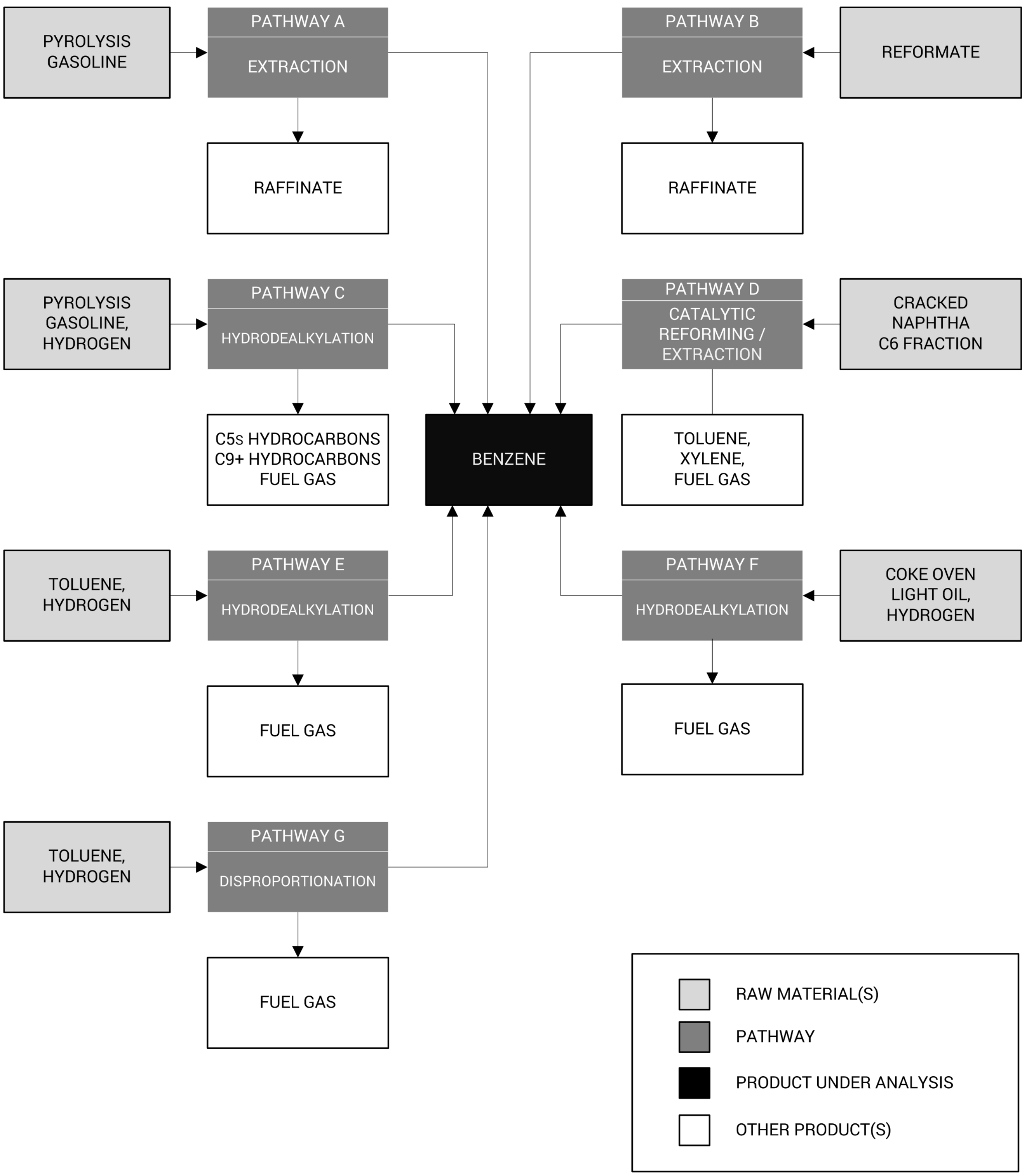
Benzene can be used in the manufacture of other products, including: ethylbenzene; cumene; cyclohexane; nitrobenzene; and resorcinol.

The main uses of Benzene are in the production of ethylbenzene, cumene, and cyclohexane. All such chemicals are important intermediates, employed respectively for the production of styrene (monomer of several polymeric and copolymeric products), phenol and acetone (used in phenolic resins) and adipic acid (raw material for nylons).

Benzene Pathways

Until the 1930s, commercial Benzene was primarily produced from coal; more specifically, it was recovered by extraction and distillation of byproduct gas and aromatic liquid from the pyrolysis of coal. Since then, as new catalytic processes were developed, petroleum became the main source for this chemical and related aromatics. Different pathways for Benzene production are presented below.

Benzene Pathways Diagram



PROCESS OVERVIEW

This chapter presents technical aspects of the process under analysis.

More specifically, the current chapter describes the outputs generated, the process inputs, and highlights about the physico-chemistry related to this process.

Product(s) Generated

The main product obtained in the process under analysis is high purity Benzene (99.7 wt% or higher). In addition, a residual fuel gas and two hydrocarbon streams are also produced in this process, these by-product streams are described below.

* Crude C5s

This by-product is obtained from the prefractionation of the pyrolysis gasoline feed. It contains most of the C5 hydrocarbons that were present in the process feed stream. This stream is exported to the nearby petrochemical complex.

* Raffinate

This by-product is obtained from the top of the extractive distillation column, it contains mostly C6 non-aromatic hydrocarbons. This stream is exported to the nearby petrochemical complex. There it is usually used as feedstock for steam crackers.

* Crude C7+

This by-product stream contains heavier hydrocarbons ranging from C7 to C12, with a considerable concentration of aromatics. This stream is the bottom product of the prefractionation of the pyrolysis gasoline feed. This stream is exported to the nearby petrochemical complex. There it is usually added to the gasoline blending pool.

Process Inputs

Raw Material(s)

* Pyrolysis Gasoline

The pyrolysis gasoline, also known as pygas, contains hydrocarbons ranging from C5 to C12. It is frequently added to gasoline blends because of its high octane content. As it also contains aromatics, it may be used as feed to separation processes for aromatic compounds generation.

For this analysis, it was considered the following concentration of BTX: 38 wt% of Benzene, 21 wt% of toluene and 14 wt% of xylenes.

* Hydrogen

Hydrogen (H_2) is an important chemical feedstock, mainly applied in the manufacture of ammonia and methanol, and for hydroprocessing operations in petroleum refineries. H2 is produced on a commercial scale primarily from steam reforming and partial oxidation of natural gas, coal, coke, or residue, and electrolysis of water.

In this analysis, it is assumed that the reformer grade hydrogen, with a purity of 90 mol%, is supplied to the process by the nearby petrochemical complex at 30 bar. The main impurities in the hydrogen stream generated in the process are methane and acetylene.

* Catalysts and chemicals

This topic refers to several chemicals that are used in minor amounts in several process unit operations in this process.

The hydrogenation in the pretreatment step makes use of a proprietary sulfided-nickel cobalt molybdate catalyst.

This process makes use of a solvent in order to facilitate the recovery of benzene. The solvent used is N-formyl-morpholine (NFM). It is used in a closed circle, however due to inherit inefficiencies in its recovery, a small make-up stream must be continuously supplied to the process to account for solvent losses.

The costs associated with the acquisition of these and other minor chemicals are taken into account under this item.

Utilities

The utilities consumed in the process are cooling water, steam and electricity.

Technology Maturity Assessment

The process technology under study was categorized according to its maturity. The technical maturity, while a measure of performance, reliability, and operating experience associated with the technology being assessed, serves as an important input in the definition of assumptions that have a relevant impact on process economics (e.g. process contingency, project contingency, costs related to start-up inefficiencies and R&D, etc).

The process technology maturity is defined by Intratec team through a method adapted from the so-called Technology Readiness Level (TRL) method, developed by NASA and nowadays used in a broad range of sectors/industries. There are nine TRLs, which describe the maturity of a technology, from basic technology reasearch to system test, launch and operations.

Originally intended to supporting decision-making over research and development activity, the nine technology readiness levels were divided into five major classes to portray the maturity level of chemical process technologies, from ‘concept’ to ‘established technology’. The table in the next page describes such five classes according to which Intratec team classifies technologies being studied, as well as the TRLs included within each class.

Process Technology Maturity Scale

TECHNOLOGY STATUS	DESCRIPTION	SCALE	TRL
Established (Outdated)	* Existing plants being shut down * No longer adopted in new plants * Obsolete technology	Commercial (at least 1 plant)	-
Established (In Use)	* 2+ commercial plants * Proven technology (successful operations)	Commercial (2+ plants)	9
Emerging	* 1 commercial plant * Basic data for commercial plant * Performance validation * Demonstration plant * Prototype near or at planned operational system	Commercial (1 plant) Demonstration	7-8
Embryonic	* Pilot-scale demonstration * Engineering-scale models / prototypes * Basic data for scale-up * "Proof-of-Concept" validation * Bench-scale demonstration * Lab-scale technology definition * Process modeling * Analytical studies * Active R&D	Pilot Bench Lab	4-6 2-3
Conceptual	* Unproven idea/proposal * No analysis or testing * Paper concept/studies	Concept Idea	1

Highlights & Remarks

INDUSTRIAL SITE

This chapter presents all installations that comprise an industrial site for Benzene production from pyrolysis gasoline (pygas). The process examined is a typical extractive distillation process.

Introduction

The information presented in this chapter is based on commonly utilized concepts related to the type of installations found within a typical industrial site. These concepts include:

* Process unit. Also known as inside battery units, these installations comprise all main units of the site required to modify the input stream and obtain the target output. These units are located Inside the Battery Limits (ISBL).

* Infrastructure. Also known as outside battery units or offsite facilities, these installations do not directly enter into the modification of the process input stream. They are support buildings, auxiliary units used for providing and distributing utilities and storage facilities. These units are located Outside the Battery Limits (OSBL).

In order to make a better distinction between these types of installation, a diagram is presented in the next page. It provides an insightful overview of the industrial site as whole and helps to clarify how raw materials and utilities are supplied to the process unit. In addition, it shows how any products or utilities generated in the process are discharged from the process unit.

Industrial Site Configuration

Process Unit

The process unit is the core of an industrial site. Comprising the site's battery limits (ISBL), it may be complex and involve several pieces of equipment. In this context, the most didactic approach to present a process unit is through the use of a block flow diagram. Visual information is, in fact, the clearest way to present a chemical process and is least likely to be misinterpreted.

In general, these diagrams consist of a series of blocks, representing unit operations or groups of equipment, connected by input and output streams. In fact, there are no strict standards according to which such diagrams are made.

To facilitate the presentation of the process unit under analysis, Intratec developed a block flow diagram according to some standards.

The process areas represented (in light blue) correspond to a "functional unit". Basically, a "functional unit" is a significant step in the process in which a particular physico-chemical operation (i.e., distillation, reaction, evaporation) occurs. According to this definition, a given functional unit is not associated with a single piece of equipment, but rather with a group of equipment and ancillaries required to perform a particular operation.

Blocks representing process areas also show key technical parameters related to these areas, including: highest operating temperature and pressure, representative material of construction, and other parameters.

As to the process streams represented, there is an indication of their phase when leaving/entering a block. Also, such streams provide a global material balance of the process, normalized by the mass flow rate of the product considered in the analysis. In other words, the number near each stream represents the ratio between its mass flow rate and the output flow rate of the product under analysis.

It is worth noting that areas having no significant impact on the economics of the process may not be included in the diagram. Similarly, some streams may also not be represented. Nevertheless, the diagram presented is still extremely useful in providing readers with an overall understanding of the process studied.

For more information on how the process examined was divided into functional units, the reader is referred to the section on *Process Unit* in the "Analysis Methodology" chapter.

Site Infrastructure

Infrastructure requirements comprise the offsite facilities, or the units located Outside the Battery Limits (OSBL). The OSBL usually have a significant impact on the capital cost estimates associated with any new industry venture. This impact is largely dictated by, among other things: specific conditions where the industrial site will be erected; the level of integration the new site will have with nearby facilities or industrial complexes; and assurance and promptness in the supply of chemicals.

Process Unit Description

The functional units related to the process under analysis are described based on the above explanation. On the next page, a block flow diagram illustrates the functional units examined.

Block Flow Diagram - Manufacturing Process

The process under analysis is briefly described below. For clarity, the description was divided according to the process areas indicated in the diagram.

For a more detailed diagram presenting pieces of equipment and more process streams, reader is referred to the Process Flow Diagram & Equipment List, available in the 'Advanced Analysis' (Appendix E).

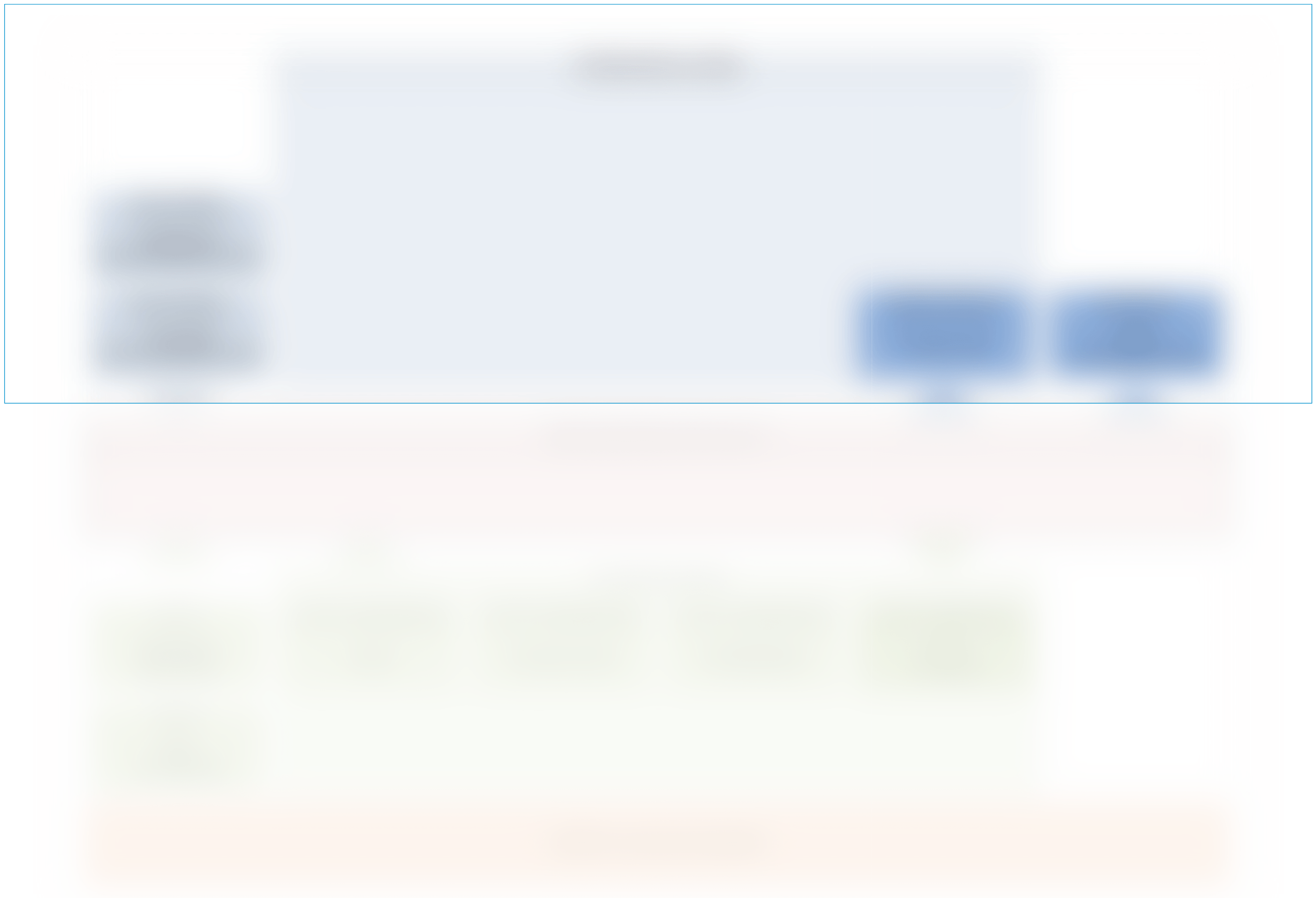
It is important to mention that some aspects of the process examined are either industrial secrets, not published in patents, or have changed and were not reported in the literature at the time this report was developed. That being the case, the design herein presented is partially based on Intratec process synthesis knowledge such that there may be some differences between the industrial process actually employed and the process described in this study. Nevertheless, the design presented suitably represents the technology examined in sufficient detail to estimate the economics of the technology within the degree of accuracy expected from conceptual evaluations.

Site Infrastructure Description

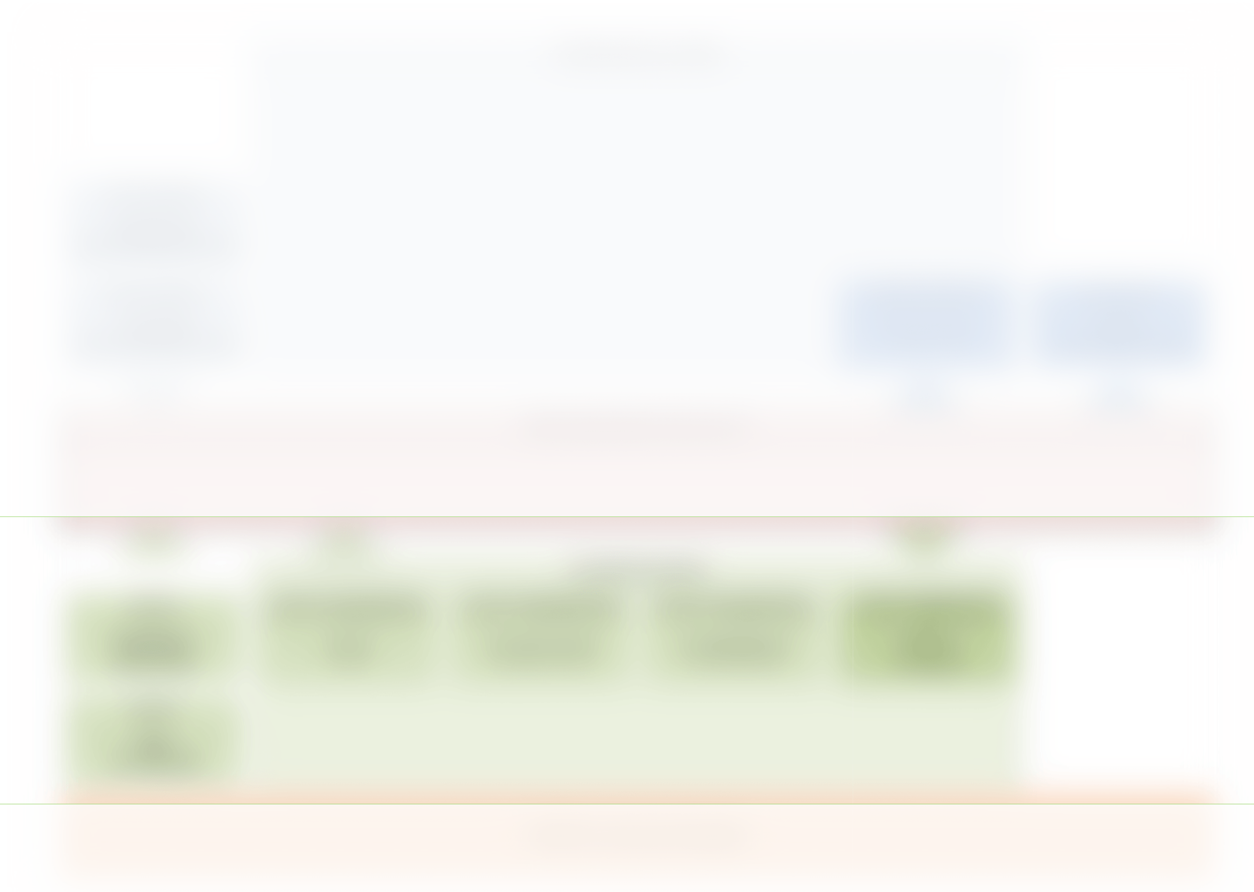
The infrastructure requirements of the industrial site examined are defined based on the following assumptions:

Finally, offsite facilities were divided into areas according to their type/function. These areas are listed in the following pages, as well as the major equipment, systems and facilities included in each of them.

* Area 90 - Storage Installations



* Area 91 - Utilities Facilities



* Area 92 - Support & Auxiliary Buildings

Key Process Input and Output Figures

In accordance with the block flow diagram and the global material balance previously presented, the following tables show key process indicators of the technology examined in this report. These indicators reflect the raw material consumption and the products generation rates per metric ton of Benzene.

Raw Materials Consumption

RAW MATERIAL	QUANTITY PER MT OF PRODUCT	UNIT
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

It should be noted that estimation of raw material requirements in the conceptual design phase is usually reasonably accurate but tends to be somewhat understated compared to real operations. Losses from vessel vents, unscheduled equipment, inerting systems, physical property inaccuracies, startup, shutdown and other process operations not typically addressed in this phase may increase raw materials

For detailed figures regarding utilities consumption, reader is referred to the the 'Extended Analysis' found in Appendix D.

Labor Requirements

The following table presents the number of operators per shift required to run the equipment of the process examined, as well as the personnel per shift required to directly supervise the operating labor.

Labor Requirements

PERSONNEL	WORKERS PER SHIFT
Operators	[illegible]
Supervisors	[illegible]

CAPITAL INVESTMENT

This chapter details all capital costs associated with Benzene production from pyrolysis gasoline (pygas), from design to industrial plant startup.

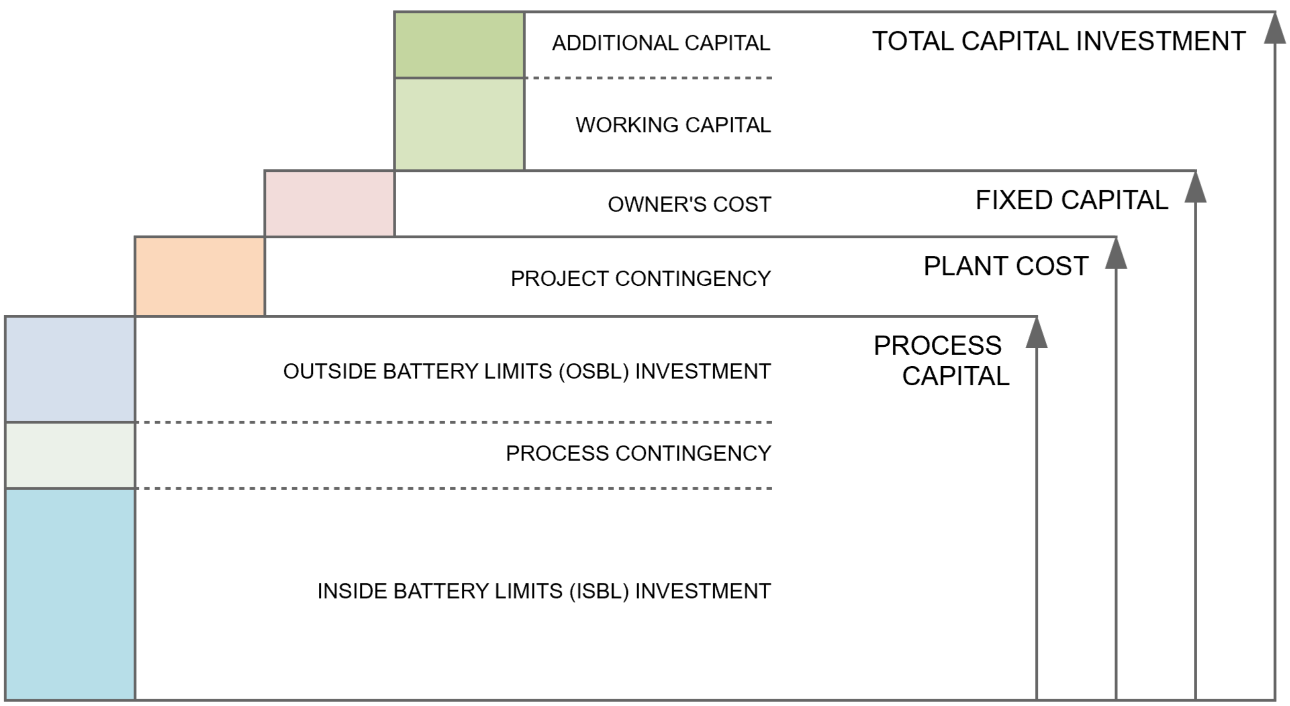
The costs that comprise the total capital investment are grouped under three main headings:

* Fixed capital. Depreciable capital invested in erecting the industrial plant and making it operational

* Working capital. Funds for getting the plant into operation, and meeting subsequent obligations

* Additional capital requirements. Costs incurred during industrial plant start-up

The graph below illustrates the composition of total capital investment.



The estimates included in this chapter are based on the following assumptions:

* Plant nominal capacity: **250,000 metric ton** of Benzene per year

* Industrial plant location: **United States**

* Construction on a cleared, level site

* Period of analysis: 2021 Q3

* IC Index-United States at the period of analysis: 189.7

The IC Index stands for Intratec Chemical Plant Construction Index, an indicator published monthly by Intratec to scale capital costs from one time period to another. It reconciles price trends of key components of chemical plant construction (e.g. labor, material, energy), providing historical and forecast data for readers.

Fixed Capital

Also referred to as "capital expenditures" (CAPEX), fixed capital constitutes the fraction of the capital investment which is depreciable. It includes Plant Cost and the Owner's Cost, further detailed below.

Plant Cost

The plant cost is related to the erection of the industrial site itself. It includes Total Process Capital (TPC) and Project Contingency, as described below.

Total Process Capital encompasses the investment required for the construction of: (1) process areas previously presented in the "Process Block Flow Diagram" (ISBL investment); (2) a process contingency reflecting technical uncertainties associated with limited design data, which may incur capital cost increases (e.g., additional equipment not included in the preliminary design); and (3) the site infrastructure (OSBL Investment), also previously discussed.

Project Contingency, in turn, is included to cover the costs that may arise as the project evolves. Such costs include: project errors or incomplete specifications, labor costs changes, strikes, problems caused by weather; inflation, etc.

The chart below summarizes all items that make up the plant cost.

Plant Cost Summary (USD Million)

Breakdowns for both ISBL and OSBL investments are provided in the 'Advanced Analysis' (Appendix E).

Plant Cost Estimate Accuracy Range (USD Million)

COMPONENT	ESTIMATE	LOWER LIMIT	UPPER LIMIT	%
Inside battery limits (ISBL)	[illegible]	[illegible]	[illegible]	[illegible]
Process contingency ([illegible] of ISBL)	[illegible]	[illegible]	[illegible]	[illegible]
Outside battery limits (OSBL)	[illegible]	[illegible]	[illegible]	[illegible]
Total process capital (TPC)	[illegible]	[illegible]	[illegible]	[illegible]
Project contingency ([illegible] of TPC)	[illegible]	[illegible]	[illegible]	[illegible]
PLANT COST	[illegible]	[illegible]	[illegible]	[illegible]

The above table presents the lower and upper limits for the plant cost figures, according to the accuracy range expected from conceptual evaluations presented in this report. The presented range is associated with a confidence level of 90%. In other words, a 90% confidence level means that, for every 100 times the project is actually implemented, the plant cost required will fall into the range predicted with our estimates 90 times.

Owner's Cost

Besides the plant cost, there are other costs that the owner must account for, such as:

* Initial catalyst load in reactors (if relevant)

* Purchase of technology through paid-up royalties or licenses

* Miscellaneous costs (pre-feasibility/environmental studies, regulatory and permits, long distance pipelines, etc.)

The aforementioned costs are included as owner's cost.

The table below presents a breakdown of the owner's cost. Unless otherwise indicated, all figures presented are in US million dollars (MM USD).

Owner's Cost Summary

COMPONENT	ASSUMPTION	MM USD	%
Prepaid royalties	[illegible] of plant cost	[illegible]	[illegible]
Miscellaneous costs	[illegible] of plant cost	[illegible]	[illegible]
OWNER'S COST		[illegible]	[illegible]

For more information about the components of owner's cost, the reader is referred to section *Capital Investment Estimating* in the "Analysis Methodology" chapter.

Fixed Capital Summary

The table below summarizes the fixed capital components discussed thus far.

Fixed Capital Summary

COMPONENT	MM USD	%
Plant cost	[illegible]	[illegible]
Owner's cost	[illegible]	[illegible]
TOTAL FIXED CAPITAL	[illegible]	[illegible]

Working Capital

For the purposes of this study, working capital is defined as the funds, in addition to the fixed capital, that a company must contribute to a project. Those funds must be adequate to bringing the plant into operation and meeting subsequent obligations.

Working capital includes: raw materials inventory, products inventory, in-process inventory, supplies and stores, accounts receivable and accounts payable.

The table below presents a breakdown of working capital. Unless otherwise indicated, all figures presented are in US million dollars (MM USD).

Working Capital Breakdown

COMPONENT	ASSUMPTION	MM USD	%
Accounts receivable	[illegible] day(s) of total operating cost + corporate overhead	[illegible]	
Accounts payable	[illegible] day(s) of operating cash cost + corporate overhead	[illegible]	
Net accounts receivable		[illegible]	[illegible]
Raw materials inventory	[illegible] day(s) of raw materials costs	[illegible]	[illegible]
Products inventory	[illegible] day(s) of total operating cost + corporate overhead	[illegible]	[illegible]
In-process inventory	[illegible] day(s) of operating cash cost + corporate overhead	[illegible]	[illegible]
Supplies and stores	[illegible] of annual operating labor and maintenance costs	[illegible]	[illegible]
Cash on hand	[illegible] day(s) of operating cash cost + corporate overhead	[illegible]	[illegible]
TOTAL WORKING CAPITAL		[illegible]	[illegible]

Additional Capital Requirements

Several expenses are incurred during commissioning and start-up of an industrial site. These expenses may be related to:

* Employee training
* Initial commercialization costs
* Operating inefficiencies and unscheduled plant modifications (equipment, piping, instruments, etc.)

In addition, expenses with land acquisition and site development must also be accounted for. Such additional costs are not addressed in most studies, but can become a significant expenditure. In the current analysis, these costs are represented by additional capital requirements.

The table below presents a breakdown of additional capital investment. Unless otherwise indicated, all figures presented are in US million dollars (MM USD).

Additional Capital Requirements Breakdown

COMPONENT	ASSUMPTION	MM USD	%
Operator training	day(s) of operating + supervision labor costs		
Start-up inefficiencies	˜ of annual operating cash cost + corporate overhead		
Unscheduled plant	˜ of plant cost		
Start-up costs			
Land & site development	˜ of plant cost		
TOTAL ADDITIONAL CAPITAL			

Total Capital Investment

The chart below summarizes all major capital costs discussed thus far, from the design and erection of an industrial site to plant startup.

Capital Investment Summary (USD Million)

For more information about how the capital costs were estimated, the reader is referred to section on *Capital Investment Estimating* in the “Analysis Methodology” chapter.

OPERATING COSTS

This chapter details all ongoing costs required for Benzene production from pyrolysis gasoline (pygas). Also referred as operational expenditures (OPEX), these encompass costs associated with the plant operation and depreciation. In the current analysis, the operating cost was grouped under three main headings:

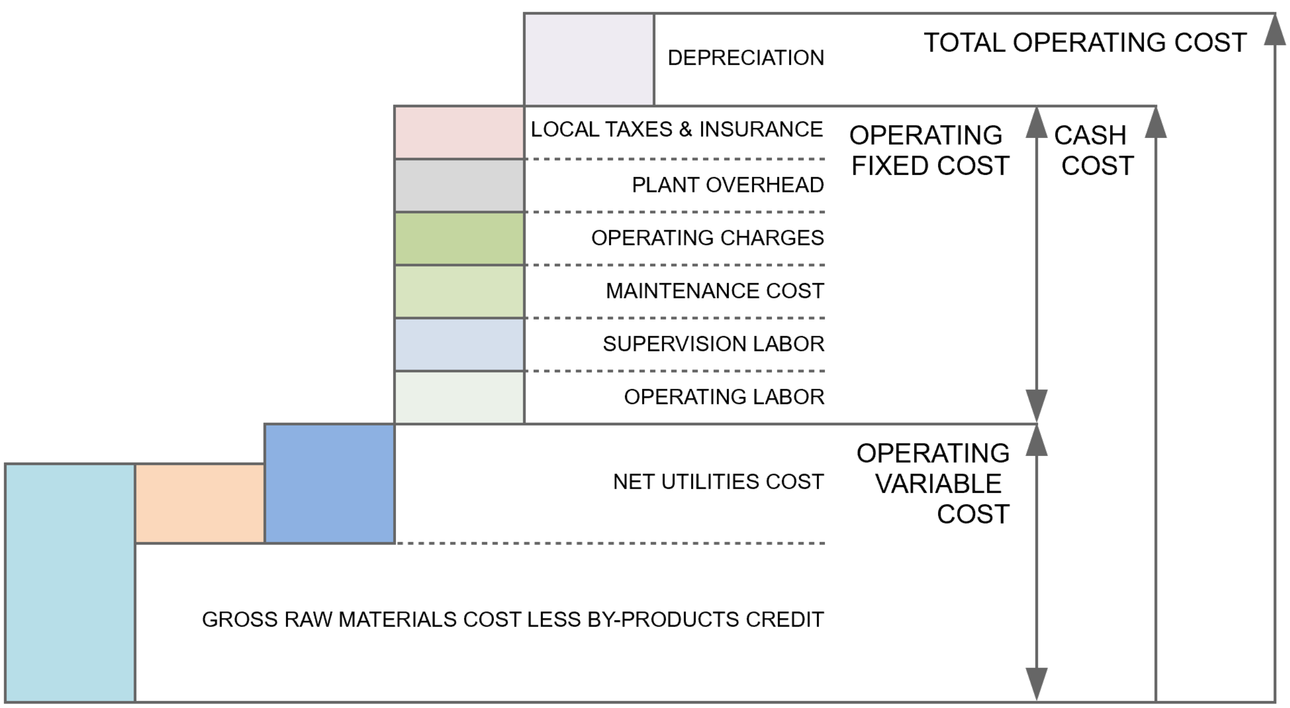
* Operating variable costs. Costs directly proportional to the actual operating rate of the industrial site (i.e. raw materials and utilities consumption)

* Operating fixed costs. Operating costs directly tied to the plant capacity, but which do not change with the operating level (i.e., operating labor, supervision labor, maintenance costs, plant overhead)

* Depreciation. Refers to the decrease in value of industrial assets with passage of time

It should be kept in mind that the sum of operating fixed costs and operating variable costs is referred as "cash cost". The sum of cash cost with depreciation, in turn, is referred to as "total operating cost".

The graph below illustrates the composition of total operating cost.



The estimates included in this chapter are based on the following assumptions:

* Industrial plant location: **United States**
* Period of analysis: 2021 Q3
* Plant nominal capacity: **250,000 metric ton** of Benzene per year
* Plant operating rate (hours per year):

Operating Variable Costs

Variable costs change in direct proportion to changes in the operating level. Such costs include raw materials and utilities (i.e., steam, electricity, fuel, and refrigeration).

In this study, the operating variable costs are considered to be negligible in comparison to the magnitude of the fixed costs. Those costs correspond to the cost of purchasing the minor chemicals and generating minor utilities required.

Operating Variable Costs Breakdown

COMPONENT	QUANTITY PER MT	PRICE	<FILE	MM USD/YR	%
□□□□□□□□□□□□□□□	□ □□□	□□□□□□ □□□□□□□	□	□□□	□□□
□□□□□□□□□□□□□□□	□ □□□	□□□□□□ □□□□□□□	□	□□□	□□□
Net raw materials cost			□	□□□	□□□
Net utilities cost			□	□□□	□□□
OPERATING VARIABLE COSTS			□	□□□	□□□

All costs presented in this table are derived from unit consumptions, detailed in the previous chapter, and pricing information.

Operating Fixed Costs

Operating fixed costs are the costs primarily related to the capacity of an industrial site, but which do not change with operating rate. Such costs include maintenance costs, operating charges, plant overhead, local taxes and insurance.

The table below presents a breakdown of operating fixed costs.

Operating Fixed Costs Breakdown

COMPONENT	ASSUMPTION	<FILE	MM USD/YR	%
Operating labor	□ operators/shift ;	□	□□□	□□□
Supervision	□ supervisors/shift ;	□	□□□	□□□
Maintenance cost	□□□˜ of plant cost per year	□	□□□	□□□
Operating charges	□˜ of operating labor costs	□	□□□	□□□
Plant overhead	□˜ of operating labor and maintenance	□	□□□	□□□
Property taxes and insurance	□□□˜ of fixed capital per year	□	□□□	□□□
OPERATING FIXED COSTS		□	□□□	□□□

Depreciation

Depreciation refers to the decrease in value of industrial assets with passage of time, primarily because of wear and tear. While not a true operating cost, depreciation is considered to be a operating expense for accounting purposes – it allows the recovery of the cost of an asset over a time period.

In this study, the depreciation unit cost corresponds to □ <File Missing>/metric ton of Benzene produced. This calculation was based on the straight-line method and a project economic life of 10 years for both the core production unit (ISBL assets) and owner's assets, and 20 years for the site infrastructure (OSBL assets).

Total Operating Cost

The table below summarizes all operating cost components discussed thus far.

Operating Cost Summary

COMPONENT	<FILE	MM USD/YR	%
Operating variable costs	□	□□□	□□□
Operating fixed costs	□	□□□	□□□
Operating cash cost	□	□□□	□□□
Depreciation	□	□□□	□□□
TOTAL OPERATING COST	□	□□□	□□□

The chart below presents a graphical representation of the operating cost breakdown.

Operating Cost Breakdown (<File Missing>/mt)

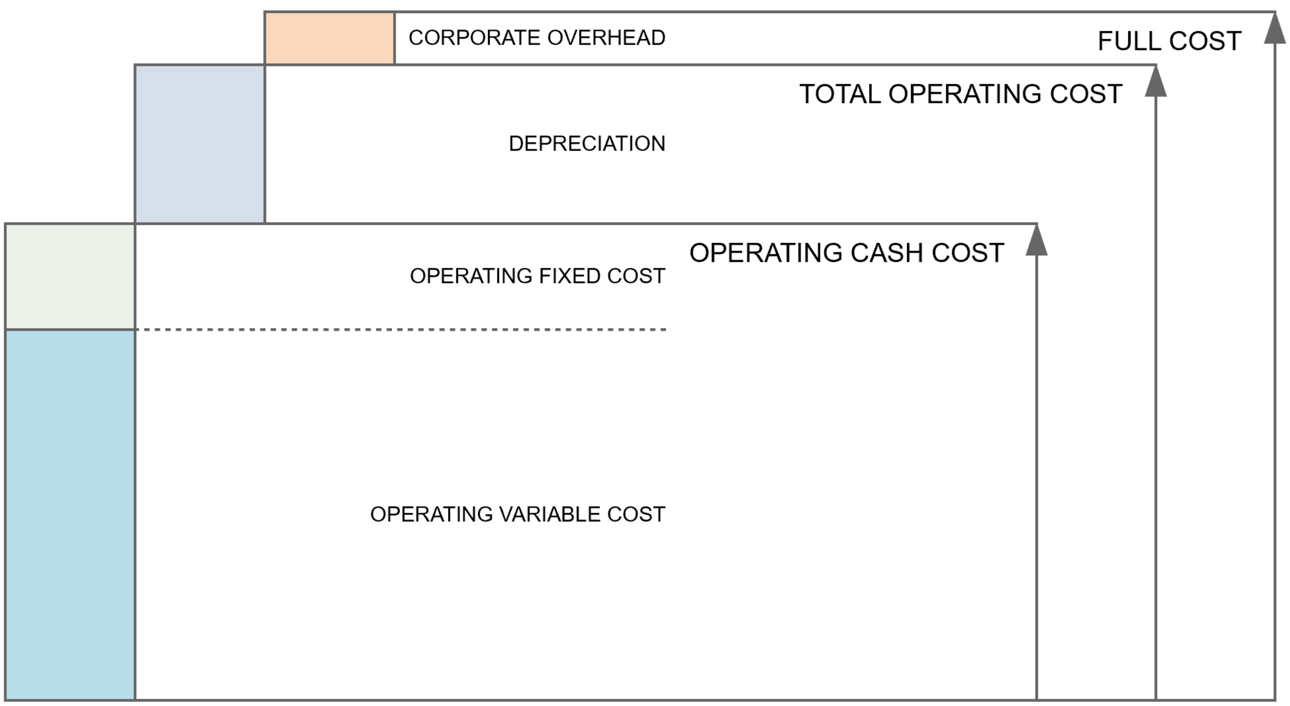
For more information about how the operating cost components were estimated, the reader is referred to the section on *Operating Cost Estimating* in the “Analysis Methodology” chapter.

PRODUCT VALUE ANALYSIS

Heretofore, the capital cost and operating cost related to the process examined were described. In order to provide a more consistent economic analysis of the process examined, all such costs are combined in a single item: “Full Cost”.

“Full Cost” is a term commonly used wherein all costs associated with a process are combined. More specifically, it includes the operating cost (operating variable costs, operating fixed costs, and depreciation), as well as corporate overhead costs.

The graph below illustrates the composition of the "Total Cost".



Corporate Overhead

Corporate overhead is associated with costs incurred by a company's head office such as general administrative costs, information technology, research & development activities and marketing.

The table below presents a breakdown of corporate overhead costs.

Corporate Overhead Costs Breakdown

COMPONENT	ASSUMPTION	<FILE	MM USD/YR	%
Administration costs	□□ of operating labor and maintenance costs	□	□□□	□□□
Information & technology	□□ of fixed capital	□	□□□	□
Marketing & advertising	□□ of operating cash cost at full capacity	□	□□□	□
Research & development	□□ of operating cash cost at full capacity	□	□□□	□□□
CORPORATE OVERHEAD		□	□□□	□

Return on Capital Employed (ROCE)

The ROCE is included to pay the investment made to manufacture target product. This component is based on the expected return on capital employed typically aimed by chemical companies.

This "Expected ROCE Amount" component is, in fact, a measure of the cost of investment required to construct the plant, in terms of US dollars per amount of product.

Most chemical companies aim to achieve a ROCE percentage ranging from 5% to 25% for the construction of a new plant. In this context, the Intratec team usually assumes an expected ROCE percentage in the range of 7% to 25%, depending on the type of product manufactured and the readiness of the technology employed (early-stage industrial processes inherently involve a larger amount of risk and cost uncertainty). For this specific process a ROCE percentage of 0% was assumed.

This results in an increment of 0 <FILE MISSING>/mt in the product value.

PROCESS ECONOMICS SUMMARY

This chapter provides a summary of all capital, operating and non-operating costs related to the process described so far. Also, it presents some remarks about the key aspects surrounding the economic analysis

Product Value Composition

The chart below shows the impact of each cost component on the product value.

Product Value Composition (<File Missing>/mt)

It is important to emphasize that product value should not be confused with product price. The product value should be seen as a minimum price for which the product could be sold, so as the plant owner can get the expected ROCE according to the assumptions on which the economic analysis was based.

In other words, the product value is a variable calculated based on the costs associated with the manufacture of a product, which is something different from the actual product price seen in the market.

Economic Datasheet

The table on the next page condenses the analysis developed in this report.

Benzene Production from Pygas (Extractive Distillation Process) - Economic Datasheet

BASIS: UNITED STATES, 2021 Q3

PLANT CAPACITY & OPERATION		CAPITAL INVESTMENT SUMMARY	MM USD
Nominal capacity (mt/y)	[illegible]	Fixed capital	[illegible]
Operating rate (h/y)	[illegible]	Working capital	[illegible]
Actual production (mt/y)	[illegible]	Additional capital	[illegible]
		TOTAL CAPITAL INVESTMENT	[illegible]

DESCRIPTION	QUANTITY PER MT	PRICE	<FILE	MM USD/YR	%
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Net raw materials cost			[illegible]	[illegible]	
Net utilities cost			[illegible]	[illegible]	
Operating labor	[illegible] oper./shift		[illegible]	[illegible]	
Supervision	[illegible] sup./shift		[illegible]	[illegible]	
Maintenance cost	[illegible]˜ of plant cost per year		[illegible]	[illegible]	
Operating charges	[illegible]˜ of operating labor costs		[illegible]	[illegible]	
Plant overhead	[illegible]˜ of operating labor and maintenance		[illegible]	[illegible]	
Property taxes and insurance	[illegible]˜ of fixed capital per year		[illegible]	[illegible]	
OPERATING FIXED COSTS			[illegible]	[illegible]	
OPERATING CASH COST			[illegible]	[illegible]	
Depreciation			[illegible]	[illegible]	
TOTAL OPERATING COST			[illegible]	[illegible]	
Corporate Overhead			[illegible]	[illegible]	
PRODUCT VALUE			[illegible]		

Economic Remarks

The "Return On Capital Employed" (ROCE) percentage usually ranges from 5% to 25% for the construction of a new plant. A ROCE of 7% is more commonly expected for established industrial processes in the basic chemicals sector, while higher percentages are expected for less mature industrial processes or in more risky sectors, such pharmaceuticals or consumer products.

It should be noted that the risk taken into account in this analysis is limited to the technical risks associated with the process uncertainties or inherent risks associated with the venture's industry sector. Other venture risks, such as business environment, raw materials and product prices variations, change in government policy, shall be evaluated case by case, and are not taken into account here, since this is a general analysis.

It is also important to mention that product value must not be confused with product price. While the product value is calculated based on operating cost and expected ROCE, the product price is the actual value practiced in market transactions.

For more information about ROCE calculation, the reader is referred to the Product Value Estimating section of the chapter "Analysis Methodology".

For further clarification about the pricing assumptions used in this analysis, the reader is referred to the *Operating Cost Estimating* section, also in the chapter "Analysis Methodology".

REFERENCES

ANALYSIS METHODOLOGY

Introduction

Intratec distilled its expertise, gained from more than a decade of supporting companies worldwide in the analysis of chemical markets and process economics, and developed a consistent report development methodology.

The methodology ensures a holistic, coherent and consistent techno-economic evaluation, guiding the development of a report that allows readers to fully understand a specific chemical process technology.

In addition to being based on a common methodology, all Intratec reports that approach industrial processes have a common structure, i.e., indexes, tables and charts share similar standards. This ensures that Intratec's readers know upfront what they will get and, more than that, will be able to compare technologies addressed in different reports.

Our methodology is continuously tested and proven by the many chemical and oil corporations, R&D centers, EPC companies, financial institutions and government agencies that rely on our reports.

The methodology used in the development of this report is illustrated in the diagram presented on the next page.

Bibliographical Research

The report is based on a comprehensive bibliographical research, entirely focused on the industrial process to be examined. Our research encompasses patents, encyclopedias, text books, technical papers and non-confidential information disclosed by licensors, duly reviewed by the Intratec team.

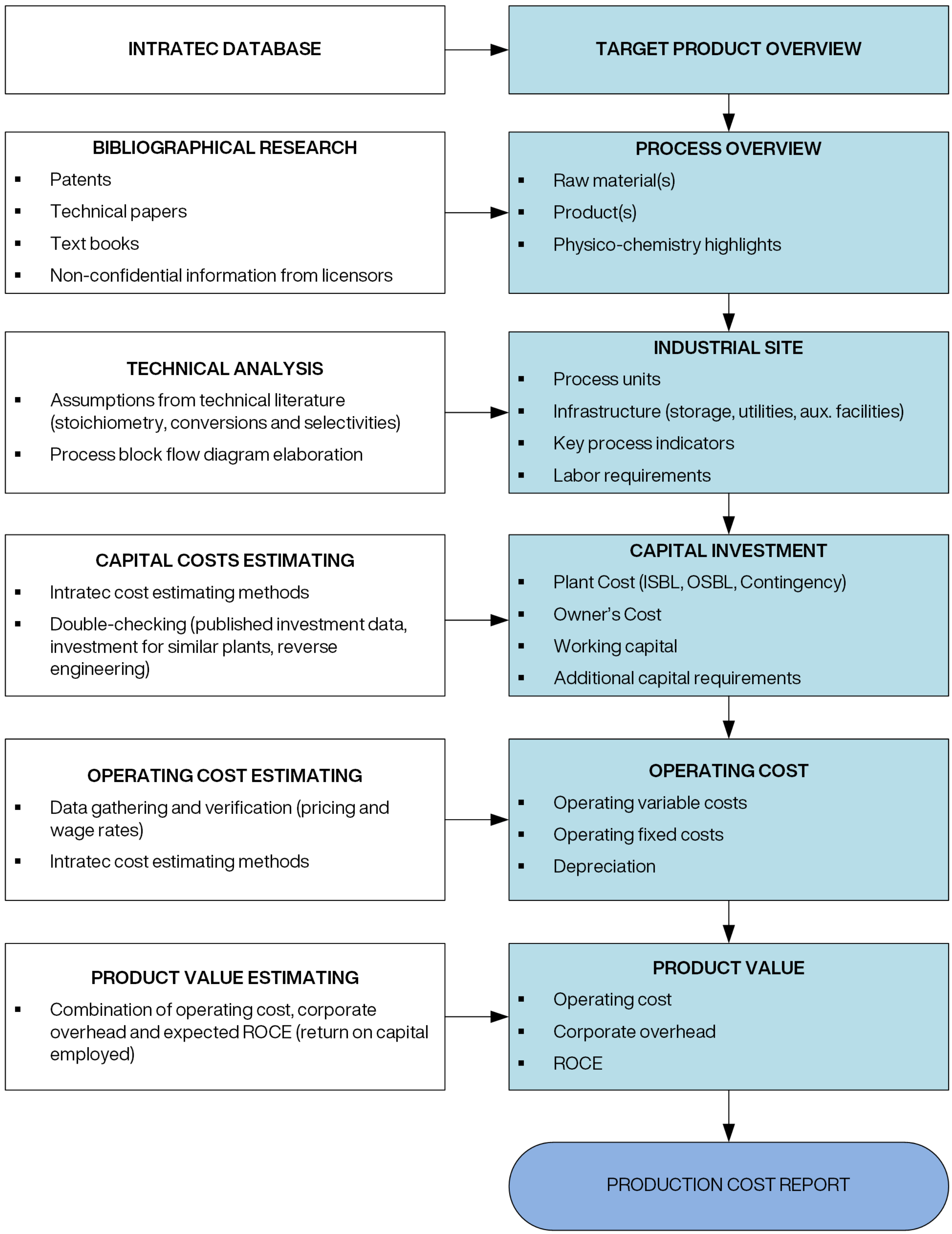
The main goal of this research is to provide a solid understanding of the process examined, which in fact underlies the entire study. During this research, Intratec team identifies the maturity of the process under analysis. Basically, established processes are mature industrial processes, i.e., several plants employing these processes have been constructed worldwide, while new industrial processes are those that have only been employed in a few plants constructed around the world. Finally, early-stage industrial processes are the processes still under development; currently, either no plants have employed such technologies or the designs of the processes themselves have yet to be completed.

Process Overview

The Intratec team's first goal is to understand the chemical, biological and/or physical transformations occurring in the target process, as well as reactants required and products formation.

Thus, initially, bibliographical research focuses on stoichiometry, conversions, yields and/or selectivity of processes' main reactions or biological processes, while also addressing the occurrence of side reactions and relevant information about catalyst employed.

Production Cost Report Development Methodology



Regarding raw materials, the Intratec team identifies minimum quality requirements (e.g. minimum purity, maximum presence of specific contaminants), as well as typical industrial sources. For products, the Intratec team gathers information regarding possible uses and applications, as well as the usual specifications necessary to ensure their suitability for those applications.

Technology Maturity Assessment

As part of Intratec's report development methodology, the process technology under study is categorized according to its maturity at the moment the report is being developed. The technical maturity serves as a measure of performance, reliability, durability, and operating experience associated with the technology being assessed. Such assessment is crucial in the development of each Intratec report, since important parameters explained later on, which actually impact on process economics (e.g. process contingency, project contingency, costs related to start-up inefficiencies and R&D, etc), are defined based on it.

The process technology maturity is defined by Intratec team through a method adapted from the so-called Technology Readiness Level (TRL) method, developed by NASA and nowadays used in a broad range of sectors/industries. Originally intended to supporting decision-making over research and development activity, technology readiness levels were modified by Intratec team to portray, on a scale with five divisions, the maturity level of chemical process technologies, from 'concept' to 'established technology'.

Examining an Industrial Site

At this point, the Intratec team examines how an industrial site based on the process under analysis would be, in terms of process units and infrastructure required.

In this step, Intratec team defines a preliminary design of the process under analysis, based on fast techniques for process and capital cost estimation, which rely on reduced design efforts. The main goal is to represent the technology examined in sufficient detail to estimate the economics of the technology within the degree of accuracy expected from conceptual evaluations.

It is important to highlight that some specific technical data are not taken into account neither in the preliminary design defined nor in the economic estimates further calculated. In fact, Intratec Reports are meant to be tools to assist the preliminary economic evaluation of emerging or consolidated industrial processes for producing chemicals, and must NOT be viewed as process design packages, design basis or front end engineering design (FEED) packages.

Process Unit

The Intratec team compiles all knowledge acquired around the process into a process block flow diagram, showing major process areas and main process streams, accompanied by a process description. The process areas correspond to what Intratec defines as "functional units". Basically, a "functional unit" is a significant step in the process in which a particular physico-chemical operation (i.e., distillation, reaction, evaporation, etc.) occurs. According to this definition, a given functional unit is not associated with a single piece of equipment, but rather with a group of equipment and ancillaries required to perform a particular operation.

Such division in process areas not only facilitates process understanding, but also serves as the basis for further economic analysis development.

While outlining process block flow diagram, the Intratec team also maps key technical parameters related to each process area portrayed, including: highest operating temperature and pressure, representative material of construction of equipment, and other parameters. These parameters serve as inputs for the cost estimating methods used by Intratec, further described in this methodology.

Site Infrastructure

The Intratec team also examines the industrial site in terms of the infrastructure (OSBL facilities) required. More specifically, this analysis identifies installations that are required but do not directly enter into the manufacture of a product (e.g., storage, utilities supply, auxiliary and administrative buildings).

The first step in identifying the required infrastructure is to define the level of integration the industrial site under analysis will have with nearby facilities or industrial complexes. Integration levels primarily impact storage requirements – e.g., a plant that is not integrated needs storage for all raw materials and products, while a plant that is fully integrated with nearby complexes does not need such installations.

The Intratec team assumes a level of integration based on what is most typical for the type of industrial plant examined. So, based on the process analysis previously developed and on how integrated the industrial site will be, the Intratec team defines the OSBL facilities requirements.

Defining Site Requirements

* Key Process Inputs & Outputs

At this point, the main processing steps have been identified and global material balance calculations are performed. This preliminary global material balance leads to the identification of key process indicators, which reflect raw material consumption, utilities consumption rates and products generation rates per amount of the main product manufactured.

It is worth mentioning that estimation of raw materials and utilities requirements in the conceptual design phase is generally reasonably accurate but tends to be somewhat understated compared to real operations. Losses from vessel vents, unscheduled equipment, inerting systems, physical property inaccuracies, startup, shutdown and other process operations not typically addressed in conceptual design may increase raw materials consumption.

* Labor

Operating labor is associated with the number of operators per shift actually required to run the equipment, while supervision labor is the personnel per shift required to directly supervise the operating labor.

The number of operators and supervisors estimated is based on the type and number of functional units included in the process examined.

Also, it is important to mention that in addition to the operating and supervision labor considered, chemical plants also require other types of labor, not included as an operating cost item. Examples of such labor are: maintenance labor, outsourced labor, technical assistance to operation, plant engineers, restaurant, purchasing, employee relations department, etc.

Capital Investment Estimating

The costs that comprise the capital investment are grouped under three main headings: fixed capital; working capital; and additional capital requirements.

Before estimating such capital investment figures, the Intratec team defines plant nominal capacity according to the process under analysis, considering that the plant should be competitive on a global scale.

Once this assumption has been made, the Intratec team begins the actual estimation of the capital investment figures as follows.

Plant Cost

The Plant Cost, together with the Owner's Cost (described further), composes the fixed capital, which is related to the erection of the industrial site itself. It constitutes the fraction of the capital investment which is depreciable.

The Plant Cost comprises the costs directly, or indirectly, associated with the construction of the plant itself. It can be broken down in many ways according to specific goals. In the present report, two different breakdowns are available. They are described below.

* Plant Cost Summarized Breakdown

The summarized plant cost breakdown presented includes (1) Inside Battery Limits (ISBL) Investment, (2) Process Contingency, (3) Outside Battery Limits (OSBL) Investment and (4) Project Contingency, estimated as follows.

(1) Inside Battery Limits (ISBL) Investment

The ISBL investment is the fraction of the fixed capital associated with the construction of all process areas (functional units) portrayed in the process block flow diagram.

Initially, to calculate ISBL investment, the Intratec team approaches each process area individually. The construction cost of a given area is estimated based on the respective process parameters detailed in the block flow diagram (flow rates, pressure and temperature conditions, materials of construction, complexity), through the use of specific preliminary cost estimation models.

It is worth noting that the Intratec cost models were founded on a number of established cost estimating methods, based on mathematical and statistical processing of an extensive volume of actual cost data of well-known industrial processes and functional units. In fact, such a massive refining of established methods has led to robust cost models, continuously tested and proven for more than a decade by major global companies that rely on Intratec's cost estimates of industrial processes.

So, from the process parameters identified, the output of Intratec cost models is the construction cost for each functional unit, including all costs associated with the erection of those units: direct material and labor costs, as well as indirect costs, such as construction overheads, including: payroll burdens, field supervision, equipment rentals, tools, field office expenses, temporary facilities, etc.

In the case of nonstandard functional unit, additional research is conducted and the construction cost is estimated from the use of specialized engineering design software or through quotations provided by equipment suppliers.

Finally, the sum of all construction cost figures, associated with the functional units examined, leads to the total ISBL investment figure.

NOTE: a detailed assessment of the ISBL investment, showing the share of each functional unit inside battery limits in the total ISBL investment, is presented in Appendix E, available exclusively in the "Advanced" version of the report.

(2) Process Contingency

Process contingency is utilized in an effort to lessen the impact of absent technical information or the uncertainty of that which is obtained. That being the case, the reliability of the information gathered, its amount and the inherent complexity of the process are significant to its evaluation. Errors that occur may be related to:

a. Addition and integration of new process steps

b. Uncertainty in process parameters, such as severity of operating conditions and quantity of recycles

c. Estimation of cost through scaling factors

d. Off-the-shelf equipment

Hence, process contingency is a function of the readiness of the technology and the availability of information about this technology. This value typically falls between 5% and 30% of ISBL investment and is estimated according to the table below.

It is important to highlight that different assumptions may be adopted in particular analyses due to specific conditions of the process or the context approached in the economic analysis.

Process Contingency Factor Estimation Methodology

TECHNOLOGY READINESS	INFORMATION		
	Low	Average	High
Established (Outdated)	15%	10%	5%
Established (In Use)	15%	10%	5%
Emerging	18%	15%	
Embryonic	22%		
Conceptual	26%		

It is worth noting that the amount of information about less mature processes is small in comparison to established processes, mainly because of the inherent uncertainties surrounding its development. Therefore, it is not coherent to define a process contingency value for technologies in the conceptual or embryonic phases when information availability is different from low, because this situation does not occur.

(3) Outside Battery Limits (OSBL) Investment

The OSBL investment is the fraction of the plant cost associated with the construction of all infrastructure (storage, utilities, auxiliary units and buildings) required.

The Intratec team employs cost estimation models similar to those previously described for estimating ISBL investment, i.e., by approaching the components of each process area individually.

The cost of a given functional unit or building associated with plant infrastructure is estimated based on a preliminary design of OSBL equipment, facility or building, according to the process requirements. As with ISBL functional units, this preliminary design information serves as an input to Intratec's cost estimation models, with which Intratec team calculates the fixed capital for each OSBL functional unit. The fixed costs include all costs associated with the erection of those units. The sum of all construction cost figures, associated with the functional units examined, leads to the total area investment figure. Finally, the sum of the investment figures for all areas associated with plant infrastructure give the final OSBL investment.

NOTE: a detailed assessment of the OSBL investment, showing the share of each functional unit outside battery limits in the total OSBL investment, is presented in Appendix E, available exclusively in the 'Advanced' version of the report.

(4) Project Contingency

Project Contingency is included to cover the costs which may arise as the project evolves, related to: project errors or incomplete specifications, labor costs changes, strikes, problems caused by weather; inflation, etc.

Project contingency is largely dependent on the plant complexity and technology maturity, identified during initial research. The following table shows how project contingency varies according to such aspects.

Project Contingency Factor Estimation Methodology

TECHNOLOGY READINESS	DEGREE OF COMPLEXITY		
	Low	Average	High
Established (Outdated)	15%	20%	25%
Established (In Use)	15%	20%	25%
Emerging	20%	25%	30%
Embryonic	25%	30%	35%
Conceptual	30%	35%	40%

* Plant Cost Breakdown per Discipline

For a better understanding of the total plant cost previously calculated, the construction costs for all functional units (process areas, storage, utilities, auxiliary units and buildings) are rearranged into a different cost breakdown: direct process costs, indirect process costs and project contingency. This alternative breakdown is commonly adopted for the assessment of construction costs, in a range of industries.

Fundamentally, the direct process costs are the total installed equipment cost (from purchase to installation, including the required installation bulks). They include bare equipment, equipment setting, piping civil, steel, instrumentation & control, electrical, insulation, painting, as described below:

* Bare Equipment. This is the cost associated with the purchase of process equipment

* Equipment Setting. Those are costs related to the labor cost for setting the purchased equipment in place.

* Piping. The costs related to piping include materials, such as valves, fittings, pipe and supports used in the erection of the piping used directly in the process (for raw materials, intermediate-products, finished-products, steam, water, air, as well as any other process piping). The labor for piping erection and installation is also covered in this topic.

* Civil. This topic covers costs associated with material and labor required for equipment foundations and civil work related to any building required in the industrial site.

* Steel. Costs associated with material and labor required for equipment platforms erection, as well as any supports needed during equipment installation.

* Instrumentation & Control. Those costs relate to instruments, controllers and industrial networks material, and labor required to install it.

* Electrical. The costs related to electrical system cover power wiring, instrument wiring, lighting, as well as transformation and service.

* Insulation. Costs related to any labor or material required to insulate process equipment, either for process needs or for operators safety.

* Painting. Those costs are related to labor and material required to paint and/or coat equipment according to process requirements.

The indirect costs account for field indirects, engineering costs, overhead, and contract fees, as described below:

* Engineering & Procurement. Engineering expenses include process and project engineers involved in process and construction design, as well as associated overhead. Development of computer-based drawings and cost engineering are also costs included in this topic. Procurement costs are those related to the purchase team, associated home office and overhead, and accounting professionals.

* Construction Material & Indirects. Those costs relate to field temporary buildings and their operation, construction tools, rentals, home office personnel located at the construction site, construction payroll, burdens and benefits.

* General & Administrative Overheads. General and administrative costs are associated with construction management and general costs incurred during construction, such as construction supervision, taxes and insurance, internal and licensed software, communications and travel & living.

* Contract Fee. Expenses related to contract fees for engineering, equipment purchase and construction work.

NOTE: The Plant Construction Cost Breakdown per Discipline as described above, including direct costs, indirect costs and project contingency, is presented in Appendix E, available exclusively in the 'Advanced' version of the report. This analysis includes a direct costs breakdown (bare equipment, equipment setting, piping civil, steel, instrumentation & control, electrical, insulation, and painting) and an indirect costs breakdown (engineering & procurement, construction material & indirects, general & administrative overheads and contract fee).

Owner's Cost

The Owner's Cost is defined as those expenses that, despite not being associated with the construction of the plant itself, are required to make the plant operational. The Owner's Cost comprises the (1) initial charge of chemicals & catalysts (if required), (2) Prepaid Royalties and (3) Miscellaneous Costs, estimated as follows.

(1) Initial Charge of Chemicals & Catalyst

This cost may occur if the process requires an inventory of a specific chemical and/or catalyst that will last more than a year and represents a significant expense. In this case, it should not be included in the working capital (described further), which, in turn, corresponds to the funds used in its day-to-day operation.

(2) Prepaid Royalties

Royalty charges on portions of the plant are usually levied for proprietary processes. A value ranging from 0.5 to 1% of the plant cost is generally used.

(3) Miscellaneous Costs

A value ranging from 5% to 10% of the plant cost is generally used to account for:

a. Preliminary planning studies, HAZOP studies and environmental reviews

b. Legal costs, rights of way, permits and fees

c. Long distance pipelines, transport equipment and plant vehicles

d. Initial stock of maintenance

e. Owner's engineering (staff paid by owner to evaluate the work of the company in charge of plant construction)

f. Owner's contingency

* Fixed Capital Estimates Validation

Depending on the availability of information about the process examined, the Intratec team utilizes three different methods to double-check fixed capital estimates:

(1) Published investment data, related to the construction of industrial plants of that process worldwide (adjusted in time, location and capacity); and/or

(2) Fixed capital of similar plants (adjusted in time, location and capacity); and/or

(3) Reverse engineering methods, i.e., the fixed capital is calculated based on the known profitability of the process examined.

Fixed Capital Estimate Accuracy

The accuracy range for a fixed capital cost estimate is mainly influenced by:

* Reliability and amount of the information available

* Examined technology readiness

* Degree of extension of the study

As previously explained, the estimate within this analysis is based on the preliminary design of functional units which, in turn, relies on a process scheme. The greatest essential uncertainty lies in the basic conception of this process scheme. The level of uncertainty varies broadly among published information and from steps of a process in a given research. In some instances, sufficient information may not be available to support rigorous estimation, thus, only basic design methods are warranted.

The maturity of the examined technology, in turn, also plays an important role in the fixed capital estimates. Processes that are still on a conceptual stage require an extra level of caution.

In addition, the extension of the analysis helps enormously to reduce uncertainties and improve the accuracy of the cost estimation. Detailed studies are crucial to achieving more precise estimates.

Finally, the accuracy range for the fixed capital estimate obtained according to the methods hereby presented is -15% to -40% on the low side and +25% to +70% on the high side, depending on the readiness of the technology under analysis and the amount of information available, in accordance with the table on next page.

The absence of factors for emerging, embryonic and conceptual technologies when there is high availability of information is explained by the inherent nature of such processes, which, while in the development / scale up phases, present a lot of uncertainties. Therefore, the amount and reliability of the information about such processes is not comparable to established technologies in operation for several years.

The non-uniform spread of accuracy ranges (+50 to – 30 %, rather than ±40%, e.g.) is justified by the fact that a lack of available information usually results in underestimating rather than overestimating project costs.

Fixed Capital Estimate Accuracy Range

TECHNOLOGY READINESS	INFORMATION		
	Low	Average	High
Established (Outdated)	-25% / 40%	-20% / 30%	-15% / 25%
Established (In Use)	-25% / 40%	-20% / 30%	-15% / 25%
Emerging	-30% / 50%	-25% / 40%	
Embryonic	-35% / 60%		
Conceptual	-40% / 70%		

Working Capital

For the purposes of this report, working capital is defined as the funds, in addition to the fixed capital, that a company must contribute to a project. Those funds must be adequate to getting the plant into operation and meeting subsequent obligations.

The initial amount of working capital is regarded as an investment item. The Intratec team uses the following items/assumptions for working capital estimation:

* Accounts receivable. Products shipped to but not paid for by the customer; represents the extended credit given to customers. It is estimated as a certain period – in days – of total operating cost (including depreciation and excluding by-product credits, if any) plus corporate overhead.

* Accounts payable. A credit for accounts payable such as feedstock, chemicals, and packaging materials received but not paid to suppliers. It is estimated as a certain period – in days – of operating cash cost (excluding by-product credits, if any) plus corporate overhead.

* Product inventory. Products in storage tanks. The total amount depends on sales flow for each plant, which is directly related to plant conditions of integration to the manufacturing of the product's derivatives. It is estimated as a certain period – in days – of total operating cost (including depreciation and excluding by-product credits, if any) plus corporate overhead.

* Raw material inventory. Raw materials in storage tanks. The total amount depends on raw material availability, which is directly related to plant conditions of integration to raw material manufacturing (estimated as a certain period – in days – of raw material delivered costs).

* In-process inventory. Material contained in pipelines and vessels, except for the material inside the storage tanks, assumed to be 1 day of cash cost (excluding by-product credits, if any) plus corporate overhead.

* Supplies and stores. Parts inventory and minor spare equipment (estimated as a percentage of operating labor and supervision and maintenance cost).

* Cash on hand. An adequate amount of cash on hand to give plant management the necessary flexibility to cover unexpected expenses. It is estimated as a certain period – in days – of cash cost (excluding by-product credits, if any) plus corporate overhead.

Additional Capital Requirements

There are certain one-time expenses related to bringing a process on stream. From a time standpoint, a variable undefined period exists between the nominal end of construction and the correct operation of the plant (e.g.production of quality product in the quantity required). This period is commonly referred to as start-up.

During the start-up period, expenses are incurred for operator and maintenance employee training, temporary construction, auxiliary services, testing and adjustment of equipment, piping, and instruments, etc. Intratec's method of estimating start-up expenses may consist of the following components:

* Labor training. Represents costs of plant crew training for plant start-up, estimated as a certain number of days of total plant labor costs (operators, supervisors, maintenance personnel and laboratory labor).

* Commercialization costs. Commercialization costs are those associated with marketing the product and include developing a market plan, establishing a distribution network and devising a customer support strategy. Those costs are dependent on how integrated the plant is with consumer facilities and on the maturity of the product – how established and well-known it is. These costs range from 0.5% to 5% of annual cash cost (excluding by-product credits, if any).

* Start-up inefficiency. Takes into account those operating runs when operation cannot be maintained or there are false starts. Start-up inefficiency varies according to the process maturity: 1% for established processes and up to 5% for less mature technologies, based on annual cash cost (excluding by-product credits, if any).

* Unscheduled plant modifications. A key fault that can occur during the start-up of the plant is the risk that the product(s) may not meet market specifications. Then, equipment modifications or additions may be required.

* Land & Site Development. Site preparation, including roads and walkways, parking, railroad sidings, lighting, fencing, sanitary and storm sewers, and communications.

Operating Cost Estimating

Pricing & Wage Rates Definition

In order to calculate fixed and variable operating costs, the Intratec team collects average transaction prices of raw materials and average operators' wage rates in the region examined in the study.

The prices are based on trade statistics issued by official government agencies, over the time period considered. Pricing information is checked to verify consistency, but issues like differences in product qualities, discounts related to volumes, or contractual negotiations are not considered.

However, for some chemicals, there are no trade statistics (e.g., intermediate chemicals that are not traded because of transportation issues, but are usually generated and consumed onsite). In those cases, the Intratec team assumes a transfer price that considers all the costs related to the manufacturing of that product plus an amount to pay the investment made to manufacture it.

The operators' wage rates are based on data published by official government agencies.

Operating Variable Cost

Variable costs change in direct proportion to changes in the operating rate. Examples of common variable costs include raw materials and utilities.

The Intratec team calculates the operating variable costs of the plant under analysis from previously identified process input and output figures and historical pricing data, as follows:

Operating Variable Costs = Net Raw Material Costs + Net Utilities Costs

* Net Raw Materials Costs

"Net raw material costs" are the difference between raw materials costs and credits from by-products generation, as expressed in the formula below.

Net Raw Material Costs = Raw Material Costs – By-product Credits

The raw materials costs, in turn, are estimated by multiplying process' consumption figures by the respective raw material prices in the region considered. The formula below illustrates the raw materials costs calculation:

*Raw Material Costs = Sum (Raw Material Price * Raw Material Consumption)*

By-products credits were estimated in a similar way, based on process' input and output figures and pricing data.

* Net Utilities Cost

In this report, the utilities cost component encompasses costs related to a plant's consumption of steam, electricity, fuel, and refrigeration. These utilities requirements, in turn, are estimated through correlations internally developed by the Intratec team that were refined from a well-established method reported in technical literature by Mardsen et al. related to chemical process industries. (See "References" chapter)

Through the use of these correlations, utilities consumption figures can be quickly estimated with basic information, related to chemical properties of components involved in the process and parameters presented in the block flow diagram. Such parameters include: number of functional units; type of each functional unit according to its energy consumption (i.e., if it involves phase changes, endothermic or exothermic reactions, negligible use of energy, if it is a nonstandard functional unit, etc.); flow rates; heats of reactions involved in the process; molecular weight and approximate boiling points of the components.

Operating Fixed Cost

Operating fixed costs are all the costs related to the plant operation that are not proportional to the plant operating rate. They are estimated as the sum of the following items:

* Operating labor. This item accounts for the total costs of plant operators actually required to run the equipment. This cost includes wages, burdens and benefits. The annual operator cost is obtained according to the formula: number of operators per shift x number of shifts per day x operator hourly wage rate x hours worked per week x weeks per year.

* Supervision. Accounts for the costs of field supervision labor, including wages, burdens and benefits. The annual supervision cost is obtained according to the formula: number of supervisors per shift x number of shifts per day x supervisor hourly wage rate x hours worked per week x weeks per year.

NOTE: a detailed assessment of utilities consumption, presented per utility (e.g., steam, cooling water, electricity.) is presented in Appendix D, available exclusively in versions 'Extended' and 'Advanced' of the report.

* Maintenance cost. This item accounts for the costs related both to the labor and material costs related to the maintenance of the plant. It is calculated as a percentage of the fixed capital, ranging between from 1 to 4% of TFC per year. This figure is primarily based on the type of equipment employed (intimately associated with the kind of fluid handled in the plant) and the industry sector. The percentages assumed are based on average industry values and are defined according to the following table.

Maintenance Cost Estimation Methodology

FLUIDS HANDLED	INDUSTRY SECTOR			
	Basic	Specialty	Consumer Product	Pharmaceutical
Solids	2%	3%	4%	2%
Gas-Liquid-Solids	1.5%	2.5%	3.5%	1.5%
Gas-Liquid	1%	2%	3%	1%

* Operating charges. This category includes operating supplies (i.e., consumable items such as charts, lubricants, test chemicals, etc.); packaging; laboratory supplies and laboratory labor. It is calculated as a percentage of the total labor cost (item operating labor + item supervision).

* Plant overhead. This item comprises all other non-maintenance (labor and materials) and non-operating site labor costs for services associated with the manufacture of the product, including: outsourced labor; technical assistance to operation; plant engineers; restaurant; recreation; purchasing; employee relations department; and janitorial. It is calculated as a percentage of the sum of total labor and maintenance costs.

* Property taxes and insurance. This cost is associated with the local property taxes charged by governments on commercial land or buildings as well as the cost of insurance to cover third party liabilities and potential plant damages. It is calculated as a percentage of the fixed capital per year.

Depreciation

Depreciation refers to the decrease in value of industrial assets with the passage of time, primarily due to wear and tear. While not a true operating cost, depreciation is considered to be a operating expense for accounting purposes – it allows the recovery of the cost of an asset over a time period.

In this report, depreciation is calculated based on the straight-line method, according to which the cost of an asset is uniformly distributed over its lifetime. A 10-year lifetime is assumed for the main production unit (ISBL units) and assets derived from owner's costs, while the site infrastructure (OSBL facilities) is assumed to have a total life-time of 20 years. Therefore, depreciation adopted for ISBL facilties and owner's costs is 10% of respective capital investment per year, and, for OSBL assets, 5% of respective capital investment per year.

Product Value Estimating

Heretofore, capital investment and operating cost of the process examined were estimated. If the examined process targets to produce a chemical, the next step in the methodology is the development of a more consistent analysis, encompassing all costs estimated so far, and aiming to estimate the value of this target product generated.

In this context, all costs estimated are combined in a single item: the “Product Value”. More specifically, the product value results from the sum of operating costs (i.e., operating variable costs, operating fixed costs, and depreciation) with corporate overhead, and a return on capital employed (ROCE), a parcel which reflects the capital investment. The formula below expresses the product value calculation.

Product Value = Operating Variable Costs + Operating Fixed Costs + Depreciation + Corporate Overhead + Expected ROCE Amount

where all components are expressed in US dollars per amount of product.

The corporate overhead and the ROCE are estimated as follows.

Corporate Overhead

Corporate overhead represents costs incurred by a company’s head office not directly related to the process operation and is estimated as the sum of the following items:

* Administration costs. This item comprises the executive and administrative activities. It includes salaries and wages for administrators, accountants, secretaries, legal costs, communications, office maintenance and other costs associated with the company’s head office. It is calculated as a percentage of the sum of total labor and maintenance costs.

* Information technology. Information technology (IT) expenses refers to the total cost related to information processing (e.g. computer software, hardware, personnel, data communications, miscellaneous). The total IT expense is estimated as 1.4% of the fixed capital per year.

* Marketing & advertising. This is related to the costs associated with the sales (sales personnel, advertising, technical sales service) of the products manufactured in the plant. This cost is calculated as a percentage of the operating cash cost (excluding by-product credits, if any), considering the plant operating at full capacity. The costs associated with marketing and advertising is intimately related to the industry sector (basic chemicals, specialties, pharmaceuticals or consumer products).

Marketing & Advertising Cost Estimation Methodology

	INDUSTRY SECTOR			
	Basic	Specialty	Consumer Product	Pharmaceutical
Assumption	.8%	1.6%	6%	5%

* Research & development. This is associated with the research activities related to the process and products. It includes salaries and wages for personnel and funds for machinery, equipment, materials and supplies related to the research and development activities. This cost is calculated as a percentage of the operating cash cost (excluding by-product credits, if any), considering the plant operating at full capacity and will vary according to the process maturity and the industry sector.

Research & Development Cost Estimation Methodology

TECHNOLOGY READINESS	INDUSTRY SECTOR			
	Basic	Specialty	Consumer Product	Pharmaceutical
Established	2%	3%	2%	12%
Under Development	3%	5%	2.5%	17%

The above factor values are based on industry average values according to the plant industry segment and employed technology readiness. Different assumptions may be adopted in particular analyses due to specific conditions of the process or the context approached in the economic analysis.

Return on Capital Employed (ROCE)

The expected ROCE amount is a component which reflects the capital costs of a given process into its product value. This component is based on the expected return on capital employed typically aimed by chemical companies. It is calculated by multiplying capital costs by the expected ROCE percentage, divided by the total amount of product manufactured:

*Expected ROCE Amount = Capital Costs * Expected ROCE Percentage / Product Annual Production*

This "Expected ROCE Amount" component is, in fact, a measure of the cost of investment required to construct the plant, in terms of US dollars per amount of product.

Most chemical companies aim to achieve a ROCE percentage ranging from 5% to 25% for the construction of a new plant. In this context, the Intratec team assumes an expected ROCE percentage of 7% for established industrial processes in the basic chemicals sector.

In contrast, a 25% expected ROCE is assumed for early-stage industrial processes in the pharmaceuticals business, as such processes inherently involve a larger amount of risk and cost uncertainty. It should be noted that the risk taken into account here is limited to the technical risk associated with the process uncertainties. Other venture risks were not considered, such as business environment, product market changes, increased competition, raw materials and product prices variations, change in government policy, etc.

The ROCE assumptions, according to the industry sector and technology readiness, are presented in the following table.

Expected ROCE Factor Estimation Methodology

TECHNOLOGY READINESS	INDUSTRY SECTOR			
	Basic	Specialty	Consumer Product	Pharmaceutical
Established	7%	12%	15%	20%
Under Development	10%	15%	18%	25%

Technologies under development are those that are not yet established on commercial scale, i.e., a technology that is either on a conceptual, embryonic or emerging phase.

The above percentages are based on industry average values according to the plant industry segment and employed technology readiness. Different assumptions may be adopted in particular analyses due to specific conditions of the process or the context approached in the economic analysis.

Finally, it is also important to mention that product value must not be confused with product price. While the product value is calculated based on operating cost, corporate overhead and expected ROCE, the product price is the actual value practiced in market transactions.

Estimates Limitation

The cost estimates presented refer to a process technology based on a standardized design practice, typical of major chemical companies. The specific design standards employed can have a significant impact on capital and operating costs. In this context, cost estimates calculated by Intratec team naturally have limitations.

In fact, the accuracy range for operating cost estimated in the present study is -10% to -20% on the low side and +10% to +20% on the high side, depending on the maturity level of the process examined. The presented accuracy considers a confidence level of 90%, which is consistent with the type of conceptual evaluation that this study aims to provide.

Also, it is to be noted that the basis for capital and operating costs estimation is that the plant is considered to be built in a clear field with a typical large single-line capacity, unless explicitly stated otherwise. In comparing the cost estimates presented with actual plant costs and/or contractor's estimate, the following must be considered:

* Minor differences or details (many times, unnoticed) between similar processes can noticeably affect cost.

* The omission of process areas in the design considered may invalidate comparisons with the estimated cost presented.

* Industrial plants may be overdesigned for particular objectives and situations.

* Rapid fluctuation of equipment or construction costs may invalidate cost estimate.

* Market price fluctuations may invalidate operating cost estimate.

* Equipment vendors or engineering companies may provide goods or services below profit margins during economic downturns.

* Specific locations may impose higher taxes and fees, which can impact costs considerably.

Furthermore, no matter how much time and effort are devoted to accurately estimating costs, errors may occur due to the aforementioned factors, as well as cost and labor changes, construction problems, weather-related issues, strikes, or other unforeseen situations. This is partially considered in the project contingency. Finally, it must be said that an estimated project cost is not an exact number, but is rather a projection of the probable cost.

APPENDIX A – ABOUT INTRATEC

Our Business

In operation since 2002, Intratec is a leading provider of data & analysis focused on commodities, energy and production processes. In a nutshell, we produce independent, readily accessible data and analyses, so that our customers can focus on what they do best and take better decisions.

We serve our valued customers from all over the world through our website, an e-commerce where they easily learn about our offerings – reports and online databases – and promptly order what they need.

Our portfolio of reports and databases provide key information surrounding commodities and energy, such as prices, trends and forecasts, as well as cost structures of production processes. Our expertise spans the fields of petrochemicals; plastics & polymers; inorganic chemicals; fertilizers & food; renewables & recyclables; oil, gas & derivatives; metals & mining; specialty chemicals and energy & utilities.

With well-designed offerings, we serve a diverse group of customers, from Fortune 500 companies and local manufacturers to biotech startups and consultants. Our studies and data have been used in multiple ways, such as:

* To evaluate transaction prices in international markets

* To identify monthly/yearly price trends

* To assess procurement planning performance

* To obtain estimates of capital and operating costs of industrial plants

* To learn about the economic potential of R&D breakthroughs

* To screen and assess industrial investment options

Production Cost Reports

Intratec offers more than 900 up-to-date reports examining production costs of chemicals and utilities. Our portfolio covers +300 chemicals and utilities, including basic chemicals and inorganics, plastics, fibers and rubbers, green chemicals and biofuels, fertilizers, specialties and more.

In short, each report examines the economics of one specific production process, presenting key information such as raw materials consumption, capital investment and operating costs. Intratec Reports may be acquired individually or through one of our subscription plans.

Find below the chemicals covered in Intratec reports. For a more complete and updated list, reader is encouraged to visit our online store at https://www.intratec.us/production-cost-reports-store.

3-Hydroxypropionic Acid
Acetone
Acetylene
Acetyls
Acrylic Acid and Derivatives
Acrylic/Maleic Copolymer
Acrylonitrile
Adipic Acid
Aldehydes
Alkylbenzenes
Amino Acids
Ammonia
Aniline
Biodiesel
Bisphenol A
BTX
Butadiene and C4's
C6's
Caprolactam
Carbon Monoxide
Chlorine and Derivatives
Chloroprene
Citric Acid
Cosmetics
Cumene
Detergents
Dicyclopentadiene
Diesel
Dimethyl Carbonate (DMC)
Dimethyl Terephthalate
Diols
Diphenyl Carbonate
Dyes & Pigments
Electricity
Epichlorohydrin
Ethanol
Ethylene
Ethylene Oxide
Fertilizers
Fibers
Fire Retardants
Food Additives
Furans and Derivatives
Glycerol
Glycols
Hydrogen
Hydrogen Cyanide
Hydrogen Peroxide
Industrial Gases
Insecticides
Isocyanates
Isophthalic Acid
Isoprene
Lactic Acid
Linear Alpha Olefins
Methacrylic Acid & Derivatives
Methanol
MTBE
Nitric Acid
Nitro Aromatics
Nylon
Oxalic Acid
Oxo Alcohols
Pentaerythritol
PET
Pharmaceuticals
Phenol
Phosgene
Phthalic Anhydride
Polyacrylate
Polyacrylonitrile
Polyalphaolefins
Polycarbonates
Polyesters
Polyethers
Polyethylenes
Polylactic Acid (PLA)
Polypropylene
Polyurethanes
Propanol and Isopropanol
Propylene
Propylene Oxide
PVC
Reformate
Resins
Silanes
Silicones
Siloxanes
Sodium Hydroxide
Speciality Polymers
Styrenics
Succinic Acid
Sulfuric Acid
Synhetic Rubbers
Synthesis Gas
Vitamins
Terephthalic Acid
Trimethylolpropane
Urea
Vinyls

APPENDIX B – TERMS & CONDITIONS

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APPENDIX D - EXTENDED ANALYSIS

CONTENTS

UTILITIES CONSUMPTION BREAKDOWN

Utilities Consumption Figures

Find below the key utilities consumption indicators of the technology examined in the report. These indicators reflect the net utilities consumption rates per unit of product manufactured.

Net Utility Consumption Rates (per mt of Benzene)

UTILITY	NET CONSUMPTION RATES
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

It should be noted that estimation of utility requirements in the conceptual design phase is usually fairly accurate but tends to be somewhat low compared to real operations. Losses from vessel vents, unscheduled equipment, inerting systems, physical property inaccuracies, startup, shutdown and other process operations not typically addressed in this phase may increase utilities consumption.

Impact of Utilities on Operating Cost

The table below summarizes utility costs share in total operating cost.

Utilities Share in Total Operating Cost

COMPONENT	%
Net utilities	□□□
Net raw material costs	□□□
Operating fixed costs	□□□
Operating cash costs	□□□
Depreciation	□□□
TOTAL OPERATING COST	□□□

The following chart indicates the utilities with the greatest impact on the economics of the process.

Cost Contribution of Each Utility

ECONOMIC ANALYSIS FOR DIFFERENT CAPACITIES

Introduction

This analysis presents the impact of a plant capacity change on the economic analysis presented in this report. Additional capacity scenarios were analyzed using the same methodology and compared with the base case presented in the report.

The analysis is divided into two parts: (1) a capital investment comparison, examining fixed investment, working capital and additional capital requirements; and (2) an operating costs & product value Comparison.

Capital Investment Comparison

The economic analysis presented in this report was reproduced for a range of plant capacities, in such a way as to estimate a curve representing the ways in which capital investment varies with the plant nominal output. This curve is presented in the chart below.

Capital Investment (USD Million) Versus Plant Capacity

From the range depicted above, the minimum, the mid-range and the maximum capacities are compared in details on the next page. The following table presents detailed capital cost figures to better portray how the economy of scale impacts the process under analysis.

Capital Investment Analysis for Different Capacities (MM USD)

BASIS: UNITED STATES, Q3 2021 (IC INDEX:189.7)	SMALLER PLANT	BASE	LARGER PLANT
Capacity (mt/y)	□	□	□
Inside battery limits (ISBL)	□□□	□□□	□□□
Process contingency (□˜ of ISBL)	□□□	□□□	□□□
Outside battery limits (OSBL)	□□□	□□□	□□□
Total process capital (TPC)	□□□	□□□	□□□
Project contingency (□˜ of TPC)	□□□	□□□	□□□
PLANT COST	□□□	□□□	□□□
Owner's cost	□□□	□□□	□□□
FIXED CAPITAL	□□□	□□□	□□□
Working capital	□□□	□□□	□□□
Additional capital	□□□	□□□	□□□
TOTAL CAPITAL INVESTMENT	□□□	□□□	□□□

Operating Cost & Product Value Comparison

The operating costs and the product value were also estimated for a range of plant capacities, resulting in the chart below. A summary of the datasheet presented in the section "Process Economics Summary" is reproduced on the next page, and also includes the two additional scenarios evaluated in this analysis.

Operating Cost (USD/mt) Versus Plant Capacity

Operating Cost & Product Value Analysis for Different Capacities (<File Missing>/mt)

BASIS: UNITED STATES, Q3 2021 (IC INDEX:189.7)			
	SMALLER PLANT	BASE	LARGER PLANT
Capacity (mt/y)	[illegible]	[illegible]	[illegible]
Operating rate (h/y)	[illegible]	[illegible]	[illegible]
Annual production (mt/y)	[illegible]	[illegible]	[illegible]
OPERATING COSTS			
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
Net raw materials cost	[illegible]	[illegible]	[illegible]
Net utilities cost	[illegible]	[illegible]	[illegible]
OPERATING VARIABLE COSTS	[illegible]	[illegible]	[illegible]
Operating labor	[illegible]	[illegible]	[illegible]
Supervision	[illegible]	[illegible]	[illegible]
Maintenance cost	[illegible]	[illegible]	[illegible]
Operating charges	[illegible]	[illegible]	[illegible]
Plant overhead	[illegible]	[illegible]	[illegible]
Property taxes and insurance	[illegible]	[illegible]	[illegible]
OPERATING FIXED COSTS	[illegible]	[illegible]	[illegible]
OPERATING CASH COST	[illegible]	[illegible]	[illegible]
Depreciation	[illegible]	[illegible]	[illegible]
TOTAL OPERATING COST	[illegible]	[illegible]	[illegible]
Corporate Overhead	[illegible]	[illegible]	[illegible]
ROCE	[illegible]	[illegible]	[illegible]
PRODUCT VALUE	[illegible]	[illegible]	[illegible]

PROJECT IMPLEMENTATION & CONSTRUCTION SCHEDULE

The primary objective of this analysis is to present a preliminary project implementation schedule, encompassing the period from the decision to invest to the start of commercial production.

This is divided in five major steps:

(1) Basic Engineering;

(2) Detailed Engineering;

(3) Procurement;

(4) Construction; and

(5) Start-up.

The duration of each project phase is detailed in the table below:

Project Phases Schedule

	PHASE START	DURATION
	Months After Project Start	Months
Basic engineering	□	□
Detailed engineering	□	□
Procurement	□	□
Construction	□	□
Commissioning & start-up	□	□

Since the project phases overlap, the total project duration is not equal to the sum of each phase duration. The Engineering, Procurement & Construction (EPC) period - from the basic engineering start until the end of construction - is about 0 months. The total project duration, also including commissioning and start-up, is approximately 0 months.

The bar chart below illustrates the project implementation and construction schedule and clarifies the overlaps among the distinct project phases.

Implementation & Construction Schedule

MATERIALS & UTILITIES PRICING DATA

Analysis Pricing Basis

The economic analysis presented within this report is based on the prices seen in the table below.

Materials & Utilities Prices (United States, Q3'21)

DESCRIPTION	PRICE	UNIT	REMARK
Raw Materials			
□□□□□□□□□□□□□□□□	□□□□□□□	□□□□□□□□	
□□□□□□□□□□□□□□□□	□□□□□□□	□□□□□□□□	
Utilities			
□□□□□□□□□□□□□□□□	□□□□□□□	□□□□□□□□	
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Historical Prices

The charts on the following pages depict how the costs of some materials have evolved during the last three years.

APPENDIX E - ADVANCED ANALYSIS

CONTENTS

PROCESS UNIT (ISBL) CONSTRUCTION COST BY FUNCTIONAL UNIT

In accordance with all the assumptions previously presented, a cost estimate was developed for each functional unit inside battery limits (ISBL). The following table shows the share of each functional unit.

Process Unit (ISBL) Construction Cost by Functional Unit

DESCRIPTION	%
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
PROCESS UNIT (ISBL) CONSTRUCTION COST	100.0

On the next page, the pie charts present an illustration of the construction cost breakdown.

Process Unit (ISBL) Construction Cost by Functional Unit

INFRASTRUCTURE CONSTRUCTION COST BY PIECE OF EQUIPMENT

Introduction

This analysis provides a more detailed explanation of the fixed capital associated with the process described in the report. More specifically, it is focused on the investment required for erecting the site surrounding infrastructure, also referred to as Outside Battery Limits (OSBL), comprising support buildings, auxiliary units used for providing and distributing utilities and storage facilities.

In accordance with the configuration previously presented, a cost estimate was developed for each facility outside battery limits. The following pie chart shows OSBL investment broken down into each area.

Site Infrastructure (OSBL) Construction Cost by Area

The investment estimated for each area is further detailed in the next chapters

Construction Cost: Area 90 - Storage Installations

This chapter details the cost estimate associated with Area 90 - Storage Installations. The components included in the estimate are detailed in the table below.

Area 90 - Storage Installations: Scope Description

COMPONENT	DESCRIPTION
□□□□□□□□□□□	□□□
□□□□□□□□□□□	□□□
□□□□□□□□□□□	□□□
□□□□□□□□□□□	□□□

The pie chart below illustrates how each component impacts the construction cost estimate for this area.

Storage Installations Construction Cost per Piece of Equipment

The cost of each component was based on the following assumptions:

Construction Cost: Area 91 - Utilities Facilities

This chapter details the cost estimate associated with Area 91 - Utilities Facilities. The components included in the estimate are detailed in the table below.

Area 91 - Utilities Facilities: Scope Description

COMPONENT	DESCRIPTION
□□□□□□□□□□□	□□□
□□□□□□□□□□□	□□□
□□□□□□□□□□□	□□□
□□□□□□□□□□□	□□□
□□□□□□□□□□□	□□□

The pie chart below illustrates how each component impacts the construction cost estimate for this area.

Utilities Facilities Construction Cost per Piece of Equipment

The percentage associated with the remaining facilities is divided as follows:

The cost of each component was based on the following assumptions:

Construction Cost: Area 92 - Support & Auxiliary Buildings

This chapter details the cost estimate associated with Area 92 - Support & Auxiliary Buildings. The components included in the estimate are detailed in the table below.

Area 92 - Support & Auxiliary Buildings: Scope Description

COMPONENT	DESCRIPTION
□□□□□□□□□□□	□□□
□□□□□□□□□□□	□□□
□□□□□□□□□□□	□□□
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□□□□□□□□□□□	□□□

The pie chart below illustrates how each component impacts the construction cost estimate for this area.

Support & Auxiliary Buildings Construction Cost per Piece of Equipment

The percentage associated with the remaining facilities is divided as follows:

The cost of each component was based on the following assumptions:

Site Infrastructure Cost Summary

Site Infrastructure (OSBL) Construction Cost by Piece of Equipment

COMPONENT	% OF TOTAL
□□□□□□□□□□□	□□□
□□□□□□□□□□□	□□□
□□□□□□□□□□□	□□□
□□□□□□□□□□□	□□□
Area 90 - Storage Installations	□
□□□□□□□□□□□	□□□
□□□□□□□□□□□	□□□
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□□□□□□□□□□□	□□□
Area 91 - Utilities Facilities	□
□□□□□□□□□□□	□□□
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□□□□□□□□□□□	□□□
Area 92 - Support & Auxiliary Buildings	□
SITE INFRASTRUCTURE CONSTRUCTION COST	□□□

PLANT COST BREAKDOWN PER DISCIPLINE

Introduction

The primary objective of this analysis is to provide an alternative perspective on the Plant Construction Cost. This analysis presents the Plant Construction Cost divided in three categories: (1) direct costs (all material and labor costs associated with the process equipment); (2) indirect costs (defined by the American Association of Cost Engineers (AACE) Standard Terminology as those "costs which do not become a final part of the installation but which are required for the orderly completion of the installation"); and (3) contingency.

It is important to highlight that the breakdown presented within this analysis refers exclusively to the Plant Cost figure included in the report. Other fixed capital components, such as Owner's Cost, are not included in this breakdown.

The chart below presents the plant cost divided in each category described above.

Plant Construction Cost Summary

The two charts in the next page detail the composition of direct field costs and indirect costs, respectively.

Direct Costs Breakdown

Fundamentally, the direct process costs are the total installed equipment cost (from purchase to installation, including the required installation bulks). They include the following disciplines: bare equipment, equipment setting, piping civil, steel, instrumentation & control, electrical, insulation, painting.

Accordingly, the chart below presents the direct costs broken down by aforementioned discipline.

Direct Construction Costs by Discipline

Indirect Costs Breakdown

The indirect costs account for field indirects, engineering costs, overhead, and contract fees.

Accordingly, the chart below presents the plant cost broken down by direct process costs, indirect costs and project contingency.

Indirect Costs Summary

Plant Cost Breakdown Summary

The next table presents the detailed plant cost breakdown, based on the direct and indirect costs approach. Two alternative views are presented in the table:

(1) % of BEQ. Each component is presented as a percentage of the bare equipment (BEQ) cost;

(2) % of Total. Each component is presented as a percentage of total plant cost.

Plant Construction Cost by Discipline

COMPONENT	% OF BEQ	% OF TOTAL
Bare equipment (BEQ)	□□□	□□□
Equipment setting	□□□	□□□
Piping	□□□	□□□
Civil	□□□	□□□
Steel	□□□	□□□
Instrumentation & control	□□□	□□□
Electrical	□□□	□□□
Insulation	□□□	□□□
Painting	□□□	□□□
Direct costs	□□□	□□□
Engineering & procurement	□□□	□□□
Construction material & indirects	□□□	□□□
General & administrative overheads	□□□	□□□
Contract fee	□□□	□□□
Indirect costs	□□□	□□□
Total process capital (TPC)	□□□	□
Project contingency (□˜ of TPC)	□□□	□□□
TOTAL PLANT COST	□□□	□

The absolute cost of the plant is presented in the 'Plant Cost Summary' chart (chapter *Capital Investment*). It is worth noting that the process contingency presented in the aforementioned table is included within each component listed in the table above.

For further information about the components included in the plant cost breakdown, reader is referred to the chapter “Methodology”.

PROCESS FLOW DIAGRAMS & EQUIPMENT LIST

This chapter comprises a schematic representation of relevant operations of the process examined in the report. It indicates process operations, main process streams, main pieces of equipment and utilities consumed.

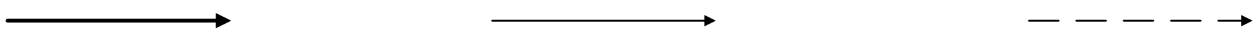
Please find below the standards adopted in the development of the Process Flow Diagrams.

Equipment Tags

X-1001

- Equipment Number Inside Area
- Area Number
- Equipment Type:
  C – Column | E – Heat Exchanger | F – Furnace | K – Compressor | P – Pump |
  R – Reactor | S – Special | T – Tank | V – Vessel

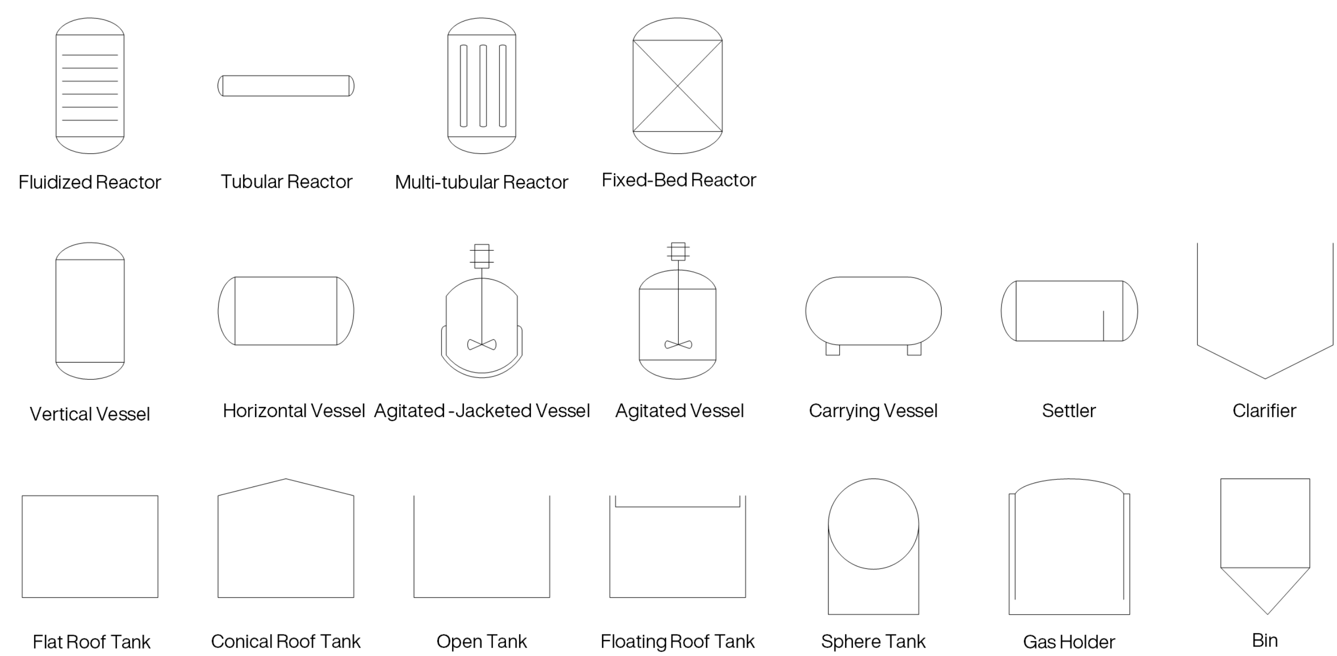
Streams



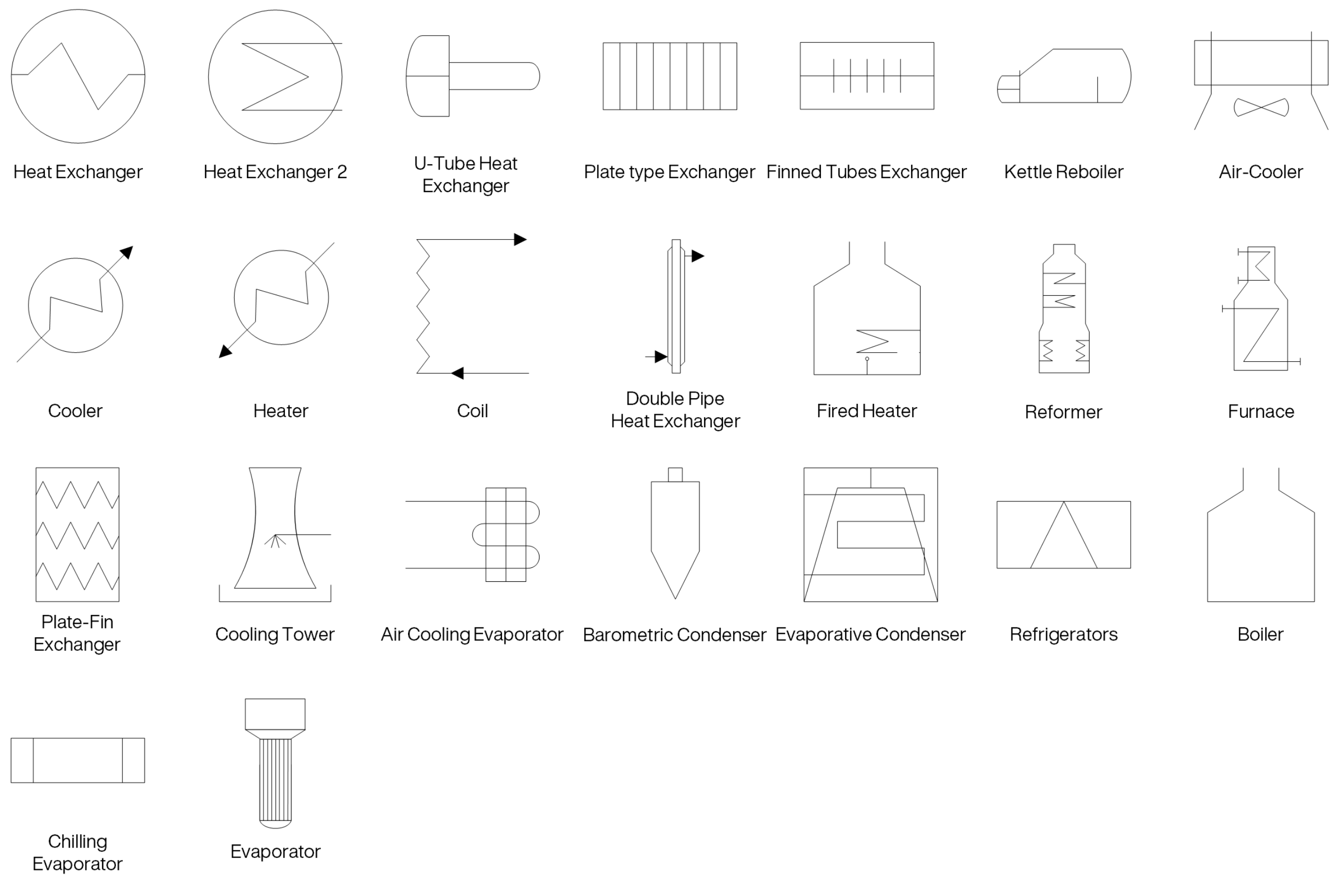
Main process stream | Secondary process stream or Utility stream | Energy stream or Computer signal

Equipment Symbols

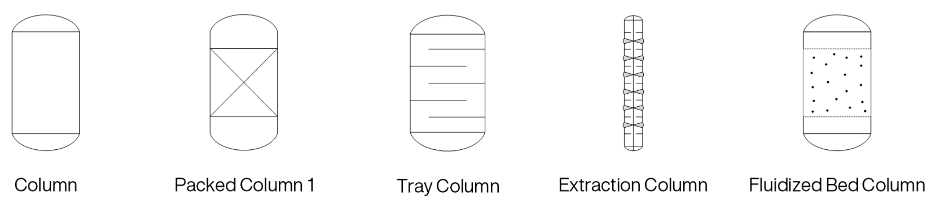
Reactors & Vessels



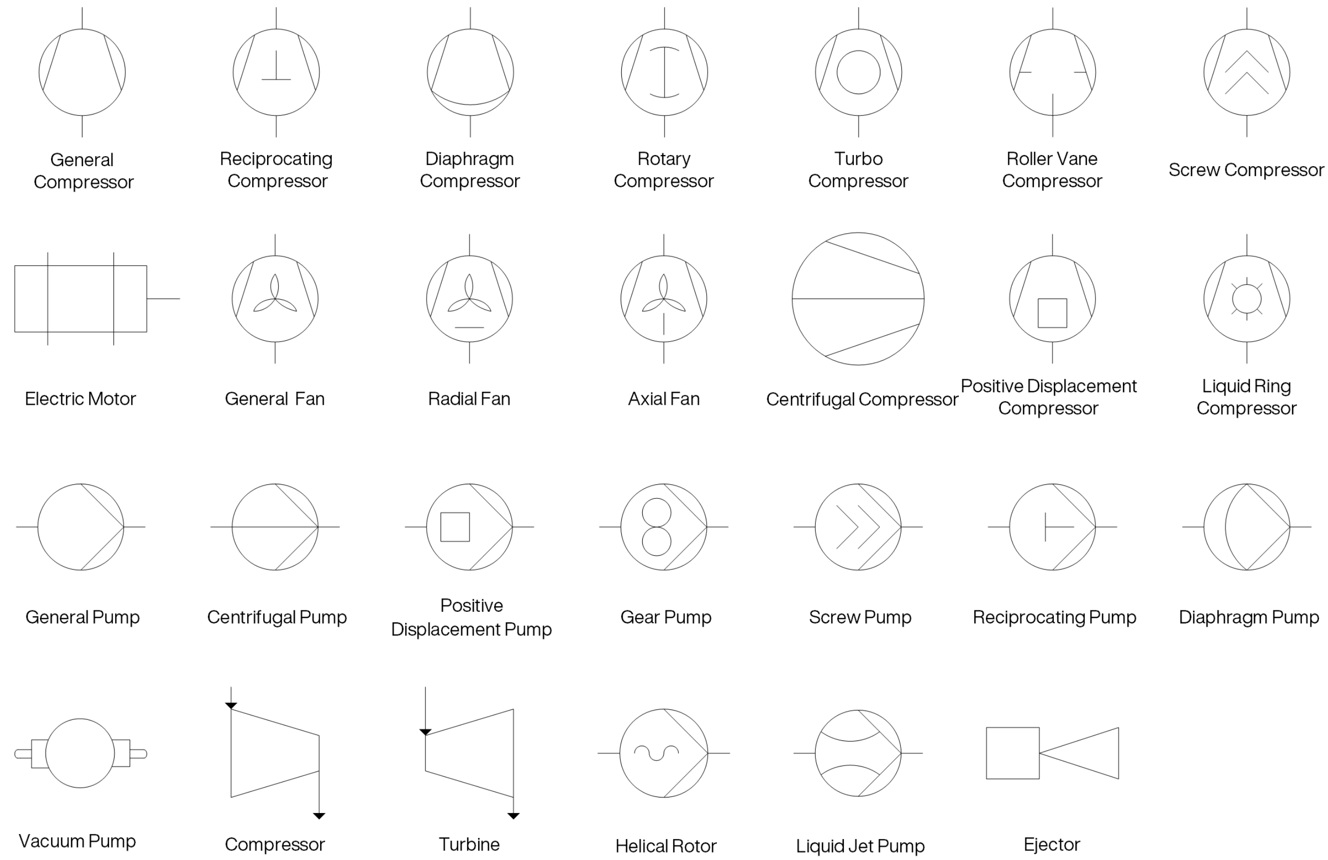
Heat Exchangers



Columns



Compressors & Pumps



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PROCESS FLOW DIAGRAM

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