Acrylic Acid Production from Glycerol - Cost Analysis

Acrylic Acid E21A
ABSTRACT

This report presents a cost analysis of Ester-Grade Acrylic Acid (EAA) production from crude glycerol. The two-step process examined is similar to Arkema process. In this process, crude glycerol (at 85 wt% purity) obtained as by-product of biodiesel plants, is used as the main raw material. After purification, glycerol is dehydrated to acrolein and subsequently oxidized. The final product obtained is EAA, which is used in the production of acrylic esters.

This report examines one-time costs associated with the construction of a United States-based plant and the continuing costs associated with the daily operation of such a plant. More specifically, it discusses:

* 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 costs, 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):

US Patent 2010/0168471 A1, issued to Arkema in 2010

Keywords: Glicerin, Dehydration, Oxidation, Unsaturated Carboxylic Acid, Propenoic Acid
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OPTIONAL ANALYSES & DATA

Intratec offers optional analyses that provide extra information and data about the process approached in this report. Some of them are listed below:

* Capital Investment Details
  - Plant Construction Cost Breakdown per Discipline
  - Site Infrastructure Cost Breakdown per Pieces of Equipment
  - Economic Analysis for Different Capacities
  - Project & Construction Implementation Schedule

* Operating Cost Details
  - Utilities Consumption Breakdown

* Economics for Another Plant Location (defined by client)
  - Economic Analysis in a Country of Choice

* Technical Details
  - Process Flow Diagrams & Equipment List

Access [www.intratec.us/analysis/acrylic-acid-e21a](http://www.intratec.us/analysis/acrylic-acid-e21a) and find the full list of available optional analyses, as well as respective descriptions, samples and pricing.
ABOUT THIS REPORT

Study Objective

This report presents the economics of Ester-Grade Acrylic Acid (EAA) production from crude glycerol. The two-step process examined is similar to Arkema 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 _______ per year, a nominal capacity that is globally competitive.

In addition, the economic assessment, developed for the period _______, 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 Acrylic Acid*, the reader will learn the basics of Acrylic Acid itself. This chapter also covers its applications and major production 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*.
ABOUT ACRYLIC ACID

Description

Acrylic Acid (also known as Prop-2-enoic Acid and Acroleic Acid) is a moderately strong carboxylic acid, primarily used to prepare emulsion and solution polymers.

On a commercial scale, Acrylic Acid is primarily produced from the oxidation of propylene and/or propane derived from oil or natural gas, which are nonrenewable fossil carbon-based starting materials. Over the past years, research efforts have been made towards manufacturing Acrylic Acid from naturally renewable starting materials. In fact, alternative Acrylic Acid routes have emerged, using the following starting materials: lactic acid or 3-hydroxypropionic acid (3-HP) (both obtained by fermentation of glucose or molasses originating from the biomass); or glycerol byproduct from biofuels production, based on methanolysis of vegetable oils.

Acrylic Acid is produced in two main grades:

* Ester-Grade (Technical-Grade) Acrylic Acid: approx. 94% purity
* Glacial (Polymer-Grade) Acrylic Acid: generally >99.6% purity

Corrosive to many metals, Acrylic Acid must be stored in glass, stainless steel, aluminum, or polyethylene-lined equipment. The chemical is stabilized with minimum amounts of inhibitors, frequently phenothiazine, hydroquinone, or hydroquinone monomethyl ether (MEHQ).

Applications

Acrylic Acid is directly used in the production of an acrylic acid polymer or, after esterification with alcohols, in the production of the polymer of the corresponding ester. These acrylate esters are in turn widely used in a range of applications. The main end-uses of acrylic esters are presented below:

* Surface coatings
* Textiles
* Acrylic fibers
* Adhesives
Ester-Grade Acrylic Acid Production Pathways Diagram

There are several pathways for Acrylic Acid production. This acid may be produced by gas-phase propylene oxidation, hydrolysis of acrylonitrile, vapor-phase condensations of acetic acid or esters with formaldehyde, liquid-phase oxidation of acrolein, sugar fermentation followed by dehydration, among others. The most common routes are the ones based on propylene oxidation. Different pathways for Acrylic Acid production are presented below.
PROCESS OVERVIEW

This chapter presents technical aspects of the Ester-Grade Acrylic Acid (EAA) production from crude glycerol. More specifically, the current chapter describes the raw materials consumed, the products generated and highlights about the physico-chemistry related to this process.

Product(s) Generated

Process Inputs
Highlights & Remarks

The reaction in a dehydrogenation reaction between two alkenes, in which the double bonds are converted into single bonds, is called dehydrogenation. In order to achieve complete dehydrogenation, a mixture of ethylene and propylene is fed to a reactor in the presence of a hydrogen catalyst. The reaction is represented as follows:

\[ 	ext{C}_2	ext{H}_4 + 	ext{C}_3	ext{H}_6 \rightarrow 2	ext{C}_2	ext{H}_6 \]

The reaction can also be represented as:

\[ 	ext{H}_2 + 	ext{C}_2	ext{H}_4 \rightarrow 	ext{C}_2	ext{H}_6 \]

Note: This reaction also occurs in a dehydrogenation reaction where ethane is converted into ethene. The reaction is represented as:

\[ 	ext{C}_2	ext{H}_6 \rightarrow 	ext{C}_2	ext{H}_4 + 	ext{H}_2 \]

The superheated stream is fed to a fixed bed catalytic reactor, in which ethylene and 2-butene react to produce propylene. Side reactions also occur.

The reactor exit stream consists of a mixture of propylene, unconverted ethylene and butenes, butane, and some C9 components from side reactions. This stream is sent to area 18.

The reaction in the dehydrogenation reactor can also be represented as:

\[ 	ext{C}_2	ext{H}_4 + 	ext{C}_3	ext{H}_6 \rightarrow 2	ext{C}_2	ext{H}_6 \]

The reaction can also be represented as:

\[ 	ext{H}_2 + 	ext{C}_2	ext{H}_4 \rightarrow 	ext{C}_2	ext{H}_6 \]

The superheated stream is fed to a fixed bed catalytic reactor, in which ethylene and 2-butene react to produce propylene. Side reactions also occur.

The reactor exit stream consists of a mixture of propylene, unconverted ethylene and butenes, butane, and some C9 components from side reactions. This stream is sent to area 18.
INDUSTRIAL SITE

This chapter presents all installations that comprise an industrial site for Ester-Grade Acrylic Acid (EAA) production from crude glycerol. The two-step process examined is similar to Arkema process.

The present study was mainly based on:

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:

* Production units. Also known as inside battery units, these installations comprise all main processing units of the site necessary to the manufacturing of products. 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 manufacturing of a product. 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.
Acrylic Acid Production Industrial Site
Production Units

Production units form the core of an industrial site. Comprising the site's battery limits (ISBL), such units may be numerous, complex and involve several pieces of equipment. In this context, the most didactic approach to presenting all production units of a site 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 production units under analysis, Intratec developed a block flow diagram according to some standards.

The process areas represented (in light blue) correspond to what is defined as a “functional unit”. Basically, a “functional unit” is a significant step in the production 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 and “feeling” 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 Production Units 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 Units Description

The process units related to the process under analysis are described based on the above explanation. On the next page, a block flow diagram illustrates the production units examined.
Acrylic Acid Production Facility
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 supplemental analysis *Process Flow Diagram & Equipment List - Acrylic Acid E21A*, which is available as an optional analysis of this report at Intratec website.

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.
In the offshore C fermentation, part of this mixture is recycled to area 17 and what remains is purged to avoid the build-up of butane and C8 hydrocarbons in the process. This Heats purge is sold on land to other nearby facilities.

2. Area 16 - Propylene Intermediate Tank

The HD propylene product from depropanizer column is stored in an intermediate tank before being sent to the offshore storage.
Site Infrastructure Description

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

- Industrial site level of integration. The site is partially integrated, meaning that it is integrated with a nearby petrochemical complex that supplies raw materials (ethylene and styrene) to the site through pipelines.
- Raw materials storage. As raw materials are locally provided, the industrial site does not have storage facilities for raw materials.
- Product storage. The site has storage facilities for the products manufactured.
- Utilities facilities. The process examined is not integrated with the industrial complex in terms of utilities supply. All necessary installations are constructed to supply utilities required by the process.
- Support & auxiliary facilities. The industrial site has its own administrative buildings and auxiliary facilities.

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.
The scope of this area includes:

1. Tanks providing a total storage capacity of 20 days for PC propylene product.
This area includes:

1. Cooling water systems, including cooling towers and circulation pumps.
2. Steam generation, boiler feed water treatment systems and supply pumps.
3. Refrigeration system, including heat exchangers, flash vessels, circulation pumps and compressors.

* Area 10 - Support & Auxiliary Buildings
Auxiliary buildings and support facilities are comprised of:

1. Central control room
2. Maintenance shops and stores
3. Laboratories and warehouses
4. Administration and offices
5. Change house and cafeterias
6. Gate house and parking lot
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 unit of product generated.

Raw Materials Consumption

<table>
<thead>
<tr>
<th>RAW MATERIAL</th>
<th>CONSUMPTION PER OF PRODUCT</th>
<th>UNIT</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
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</tbody>
</table>

Products Generation

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>GENERATION PER OF PRODUCT</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

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 consumption.

For detailed figures regarding utilities consumption, reader is referred to the supplemental analysis *Utilities Breakdown - Acrylic Acid E21A*. This optional feature is available at Intratec website.

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.

<table>
<thead>
<tr>
<th>PERSONNEL REQUIRED</th>
<th>WORKERS PER SHIFT</th>
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</tbody>
</table>
CAPITAL INVESTMENT

This chapter details all capital costs associated with Ester-Grade Acrylic Acid (EAA) production from crude glycerol, from design and erection of an industrial site to 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 required 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: ____________________ of Acrylic Acid per year

* Industrial plant location: United States

* Construction on a cleared, level site

* Period of analysis: __________

* IC Index at the period of analysis: __________

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. This index reconciles the price trends of fundamental components of chemical plant construction such as labor, material and energy, providing meaningful historical and forecast data for readers.
In the next pages capital costs are described in further detail, and calculated estimates are presented. For more information on the methods used for estimating costs, the reader is referred to the “Analysis Methodology” chapter.

**Fixed Capital**

Also referred 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.

**Plant Cost Summary (USD Million)**

```text

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost (USD Million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPC</td>
<td></td>
</tr>
<tr>
<td>Contingency</td>
<td></td>
</tr>
<tr>
<td>Plant Cost</td>
<td></td>
</tr>
<tr>
<td>Owner's Cost</td>
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</tbody>
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For OSBL cost details, see the analysis *Site Infrastructure Cost Breakdown per Pieces of Equipment* - *Acrylic Acid E21A*.

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**Plant Cost Estimate Accuracy (USD Million)**

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>ESTIMATE</th>
<th>LOWER LIMIT</th>
<th>UPPER LIMIT</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside battery limits (ISBL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process contingency (of ISBL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outside battery limits (OSBL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total process capital (TPC)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project contingency (of TPC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PLANT COST</strong></td>
<td></td>
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</tbody>
</table>

The above table presents the upper and lower 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 not negligible)
* 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**

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>ASSUMPTION</th>
<th>MM USD</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial catalyst load</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prepaid royalties</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miscellaneous costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>OWNER’S COST</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>MM USD</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Owner's cost</td>
<td></td>
<td>100.00</td>
</tr>
<tr>
<td><strong>TOTAL FIXED CAPITAL</strong></td>
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</tbody>
</table>

**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 (USD Million)**

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>ASSUMPTION</th>
<th>MM USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accounts receivable</td>
<td>day(s) of total production cost*</td>
<td></td>
</tr>
<tr>
<td>Accounts payable</td>
<td>day(s) of operating cash cost* + corporate overhead</td>
<td></td>
</tr>
</tbody>
</table>

**Net accounts receivable**

- Raw materials inventory: day(s) of raw materials costs
- Products inventory: day(s) of total production cost*
- In-process inventory: day(s) of operating cash cost* + corporate overhead
- Supplies and stores: of annual operating labor and maintenance costs
- Cash on hand: day(s) of operating cash cost* + corporate overhead

| **TOTAL WORKING CAPITAL** | |

(*) Excluding by-product credits
**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 (USD Million)

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>ASSUMPTION</th>
<th>MM USD</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operator training</td>
<td>day(s) of all labor costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercialization costs</td>
<td>of annual operating cash cost* + corporate overhead</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start-up inefficiencies</td>
<td>of annual operating cash cost* + corporate overhead</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unscheduled plant modifications</td>
<td>of plant cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Start-up costs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land &amp; site development</td>
<td>of plant cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL ADDITIONAL CAPITAL</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(*) Excluding by-product credits
Total Capital Investment Summary

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 Ester-Grade Acrylic Acid (EAA) production from crude glycerol. Also referred as operational expenditures (OPEX), these encompass costs associated with the plant operation and depreciation, selling of products, and contribution to corporate functions (e.g., administration and R&D activities). 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:

* Plant nominal capacity: ___________________ of Acrylic Acid per year

* Plant operating rate: __________ hours per year

The plant operating rate assumed leads to an annual output of ______________ of Acrylic Acid. It is important to mention that this rate does not represent any technology limitation; rather, it is an assumption based on usual industrial operating rates.

In the next pages the operating cost items are described in further detail, and estimates calculated are presented. For more information on the methods employed to estimate the costs presented, the reader is referred to the "Analysis Methodology" chapter.
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).

The next table displays the operating variable costs.

Operating Variable Costs Breakdown

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>QUANTITY PER MT</th>
<th>PRICE</th>
<th>USD/MT</th>
<th>MM USD/YR</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross raw materials cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>By-product credits</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net raw materials cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net utilities cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>ASSUMPTION</th>
<th>USD/MT</th>
<th>MM USD/YR</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating labor</td>
<td>operators/shift ; USD/oper./h</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supervision</td>
<td>supervisors/shift ; USD/sup./h</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>of plant cost per year</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating charges</td>
<td>of operating labor costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant overhead</td>
<td>of operating labor and maintenance costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Property taxes and insurance</td>
<td>of fixed capital per year</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MANUFACTURING 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 an operating expense for accounting purposes – it allows the recovery of the cost of an asset over a time period.

In this study, the depreciation is USD ______ per ______ of Acrylic Acid produced. This calculation was based on the straight-line method and a project economic life of 10 years.

Total Operating Cost

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

Operating Cost Summary

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>USD/MT</th>
<th>MM USD/YR</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating variable costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating fixed costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating cash cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depreciation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL OPERATING COST</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The chart below presents a graphical representation of the operating cost breakdown.

Operating Costs per Unit of Acrylic Acid (USD)

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: “Product Value”.

“Product value” is a term commonly used wherein all costs associated with the manufacture of a product are combined. More specifically, it includes the operating cost (operating variable costs, operating fixed costs, and depreciation), as well as corporate overhead costs and an expected Return on Capital Employed (ROCE).

Product value should not be confused with product price. While product value, as previously mentioned, is calculated based on the costs associated with the manufacture of a product, product price is the actual value as seen in the market. 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.

The graph below illustrates the composition of the product value.
Corporate Overhead

Corporate overhead is associated with costs incurred by a company’s head office such as general administrative costs, research and development activities, market and product distribution.

The table below presents a breakdown of corporate overhead costs.

Corporate Overhead Costs Breakdown

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>ASSUMPTION</th>
<th>USD/MT</th>
<th>MM USD/YR</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administration costs</td>
<td>of operating labor and maintenance costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market &amp; distribution</td>
<td>of operating cash cost at full capacity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research &amp; development</td>
<td>of operating cash cost at full capacity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CORPORATE OVERHEAD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(∗) Excluding by-product credits

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 10% to 30% for the construction of a new plant. In this context, the Intratec team usually assumes an expected ROCE percentage in the range of 10% (for established industrial processes) to 30% (for early-stage industrial processes, which inherently involve a larger amount of risk and cost uncertainty). For this specific process a ROCE percentage of _ ______ was assumed.

This results in an increment of _ ______ USD/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 performed.

Product Value Composition

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

Product Value Composition (USD/unit produced)

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 price 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.
### Plant Capacity & Operation

<table>
<thead>
<tr>
<th>Nominal capacity</th>
<th>Fixed capital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating rate</td>
<td>Working capital</td>
</tr>
<tr>
<td>Annual production</td>
<td>Additional capital</td>
</tr>
</tbody>
</table>

### Operating Variable Costs

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity Per MT</th>
<th>Price</th>
<th>USD/MT</th>
<th>MM USD/yr</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supervision</td>
<td>sup./shift</td>
<td>USD/sup./h</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating charges</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant overhead</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prop. taxes and insur.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Operating Fixed Costs

<table>
<thead>
<tr>
<th>Description</th>
<th>% of Fixed Capital per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depreciation</td>
<td></td>
</tr>
</tbody>
</table>

### Operating Cash Cost

<table>
<thead>
<tr>
<th>Description</th>
<th>% of Fixed Capital per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administration costs</td>
<td></td>
</tr>
<tr>
<td>Marketing &amp; distribution</td>
<td></td>
</tr>
<tr>
<td>Research &amp; development</td>
<td></td>
</tr>
</tbody>
</table>

### Total Operating Cost

<table>
<thead>
<tr>
<th>Description</th>
<th>% of Fixed Capital per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administration costs</td>
<td></td>
</tr>
<tr>
<td>Marketing &amp; distribution</td>
<td></td>
</tr>
<tr>
<td>Research &amp; development</td>
<td></td>
</tr>
</tbody>
</table>

### Corporate Overhead

<table>
<thead>
<tr>
<th>Description</th>
<th>% of Total Capital Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROCE</td>
<td></td>
</tr>
</tbody>
</table>

### Product Value

(*) Excluding by-product credits
Economic Remarks

Due to the presence of unconverted ethylene, propylene refrigeration is used to achieve the low temperature required in the top condenser of the column. The deethylenizer column overhead, consisting mainly of unconverted ethylene, is recycled back to area 12. A small vent stream is purged to avoid the build-up of light paraffins, impurities in the process. This vent stream is used as feed to other nearby facilities.

Reflux 14 consists of a deethylenizer column, which separates unreacted ethylene for reuse in the reaction.

Due to the presence of unconverted ethylene, propylene refrigeration is used to achieve the low temperature required in the top condenser of the column. The deethylenizer column overhead, consisting mainly of unconverted ethylene, is recycled back to area 12. A small vent stream is purged to avoid the build-up of light paraffins, impurities in the process. This vent stream is used as feed to other nearby facilities.

The superheated stream is fed to a fixed bed catalytic reactor, in which ethylene and 2 butenes react to produce propylene. Side reactions also occur.

The reactor exit stream consists of a mixture of propylene, unconverted ethylene and butenes, butenes, and some C8 components from side reactions. This stream is sent to area 18.
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.

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.
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 and products generation rates per amount of the main product manufactured.

It is worth mentioning that estimation of raw material 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.

Fixed Capital

The fixed capital is related to the erection of the industrial site itself. Also referred as “capital expenditures” (CAPEX), the fixed capital constitutes the fraction of the capital investment which is depreciable.

It is composed of Plant Cost and Owner’s Cost, described below.

* Plant Cost

The Plant Cost comprises the costs directly, or indirectly, associated with the construction of the plant itself. It includes (1) Inside Battery Limits (ISBL) Investment, (2) Process Contingency, (3) Outside Battery Limits (OSBL) Investment and (4) Project Contingency, estimated as follows.
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 fixed capital 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 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 fixed capital 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 capital cost is estimated from the use of specialized engineering design software or through quotations provided by equipment suppliers.

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

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 maturity of the technology and the reliability of the information gathered for the analysis. This value typically falls between 5% and 20% of ISBL investment.

Outside Battery Limits (OSBL) Investment

The OSBL investment is the fraction of the fixed capital 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 OSBL investment, i.e., initially, a preliminary design of OSBL equipment is defined based on the process requirements. This preliminary design information serves as an input to Intratec’s cost estimation models.
Owner’s Cost

In this study, the Owner’s Cost is defined as those expenses that, despite not being associated with the construction of the plant itself, should be included in the Fixed Capital (the depreciable capital), as they 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 is only accounted for 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 is a depreciable expense and 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:

- Preliminary planning studies, HAZOP studies and environmental reviews
- Legal costs, rights of way, permits and fees
- Long distance pipelines, transport equipment and plant vehicles
- Initial stock of maintenance
- Owner’s engineering (staff paid by owner to evaluate the work of the company in charge of plant construction)
- Owner’s contingency

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.

<table>
<thead>
<tr>
<th>PROCESS MATURITY</th>
<th>PLANT COMPLEXITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Simple</td>
</tr>
<tr>
<td>Established Industrial Processes</td>
<td>15%</td>
</tr>
<tr>
<td>New Industrial Processes</td>
<td>20%</td>
</tr>
<tr>
<td>Early-Stage Industrial Processes</td>
<td>25%</td>
</tr>
</tbody>
</table>

* Owner’s Cost

In this study, the Owner’s Cost is defined as those expenses that, despite not being associated with the construction of the plant itself, should be included in the Fixed Capital (the depreciable capital), as they 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.

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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:

- Preliminary planning studies, HAZOP studies and environmental reviews
- Legal costs, rights of way, permits and fees
- Long distance pipelines, transport equipment and plant vehicles
- Initial stock of maintenance
- Owner’s engineering (staff paid by owner to evaluate the work of the company in charge of plant construction)
- Owner’s contingency
* Fixed Capital 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 the fixed capital cost estimate obtained according to the methods hereby presented is -15% to -35% on the low side and +25% to +60% on the high side. This accuracy range is mainly influenced by:

* Reliability and amount of the information available

* Examined technology maturity

* Degree of extension of the study

As previously explained, the fixed capital is estimated 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. Early-stage processes 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 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.

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) plus corporate overhead.

* 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: 5% for early-stage processes, 2% for new processes, and 1% for established processes, based on annual cash cost (excluding by-product credits, if any) plus corporate overhead.

* 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.
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:

\[
\text{Operating Variable Costs} = \text{Net Raw Material Costs} + \text{Net Utilities Costs}
\]

* 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.

\[
\text{Net Raw Material Costs} = \text{Raw Material Costs} - \text{By-product Credits}
\]

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:

\[
\text{Raw Material Costs} = \sum (\text{Raw Material Price} \times \text{Raw Material Consumption})
\]

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)
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.

* 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 5% of TFC per year. This figure is primarily based on the type of equipment employed and the maturity of the process.

* 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. The Intratec team assumes a depreciation of 10 % of the fixed capital per
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.

\[
\text{Product Value} = \text{Operating Variable Costs} + \text{Operating Fixed Costs} + \text{Depreciation} + \text{Corporate Overhead} + \text{Expected ROCE Amount}
\]

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.

* Marketing & distribution. This is related to the costs associated with the distribution and 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, which varies according to the process maturity and the level of integration with product consumers.

* 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.

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:

\[
\text{Expected ROCE Amount} = \frac{\text{Capital Costs} \times \text{Expected ROCE Percentage}}{\text{Product Annual Production}}
\]

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 10% to 30% for the construction of a new plant. In this context, the Intratec team assumes an expected ROCE percentage of 10% for established industrial processes.

In contrast, a 30% expected ROCE is assumed for early-stage industrial processes, 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.

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. 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.
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