Independent Statistics & Analysis
U.S. Energy Information Administration

Engineering Economic Analysis Guide: Liquid Fuels Technologies

December 2015

Independent Statistics & Analysis
www.eia.gov

U.S. Department of Energy
Washington, DC 20585

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Introduction

The mission of the U.S. Energy Information Administration (EIA) is to provide independent energy information to the public, the government, and other energy stakeholders. This information includes the operating status of surveyed facilities, and both short-term and long-term projections. The EIA Office of Energy Analysis (OEA) produces the Annual Energy Outlook (AEO) and International Energy Outlook (IEO), which include estimated deployment rates for a variety of technologies across a range of future market conditions. The better EIA understands how a technology may penetrate the market under different scenarios, the better EIA can model and project technology deployment over 30-year horizons. Conducting engineering economic analyses enables EIA to consistently represent energy technologies in its models and energy reports.

Engineering economic analysis – detailed examination of plant and market conditions required for investment in a technology with consideration of technology characteristics, plant project costs, plant operational costs and revenues, non-economic factors, and plant location.

The long-term projections include non-petroleum fuels that are not yet in common use as fuel-grade products for blending with traditional petroleum products, and alternative feedstocks for the traditional petroleum refinery. The EIA/OEA Office of Petroleum, Natural Gas, and Biofuels Analysis (PNGBA) is responsible for analyzing these renewable and emerging liquid fuel technologies and developing reasonable technical and economic assumptions to inform the models that project the penetration of these technologies (Table 1).

Table 1. Liquid fuel technologies recently analyzed by EIA for its long-term outlooks

Biochemical	Thermochemical catalytic	Thermochemical Fischer-Tropsch
Corn ethanol	Methyl ester biodiesel	Gas-to-Liquids (GTL)
Advanced grain ethanol	Non-ester renewable diesel	Coal-to-Liquids (CTL)
Cellulosic ethanol	Pyrolysis	Biomass-to-Liquids (BTL)
Biobutanol		

Source: U.S. Energy Information Administration, Office of Energy Analysis

Conventional technologies in new market conditions are also analyzed such as the use of condensate splitters, condensate stabilizers, and atmospheric distillation units for processing light tight oil.[1]

Assessing technology maturity

EIA's objective in modeling technologies is to estimate the technical, regulatory, and market conditions that induce successful deployment of a technology. This includes modeling both emerging technologies and existing commercial technologies that currently lack significant market presence. EIA focuses its

[1] U.S. Energy Information Administration, *Technical Options for Processing Additional Light Tight Oil Volumes within the United States, 2015*, http://www.eia.gov/analysis/studies/petroleum/lto/pdf/lightightoil.pdf.

analysis on advanced technologies that have a Technology Readiness Level (TRL)[2] of 7 or higher (see Appendix A for glossary of all terms used in this report and Appendix B for TRL, specifically). TRL 7 technologies have been demonstrated in a relevant environment and the final design is virtually complete. The technology has overcome the two "death valleys" on the path towards commercialization – technological and commercialization.[3] EIA also analyzes existing technologies that currently are deployed in limited quantities in either domestic or foreign markets.

Technologies are developed because they have at least one advantage over conventional technologies. The technology might be less expensive, perform more efficiently, generate fewer pollutants, etc. Certain technology attributes and requirements may be mandated by regulation or be location-dependent. For inclusion, technologies are assessed on a case-by-case basis to ensure that immature but potentially impactful technologies are not excluded in EIA's long-term energy analysis and modeling.

Technologies at TRL 7 and higher are best suited for analysis because they have the required level of maturity and sufficient data to enable EIA to perform an engineering economic analysis (see Appendix B for initial assessment of technologies). Technologies that are less mature are also analyzed by EIA to examine and model long-range energy scenarios where currently less mature technologies may deploy at a future time. However, these technology deployment estimates have much higher uncertainties. It is also necessary to gather information about the market, including how both the market and the advanced technology are likely to evolve over time (e.g., demand, competition, prices, learning, regulations, and taxes). Data sources must also be identified for both the technology and market.

Defining engineering economic analysis

In engineering economic analysis, multiple analyses are required – technology, project design, project capital costs, operation and maintenance (O&M) costs, and operational cash flows. These analyses are strongly interrelated and each requires a variety of analytical skills and tools. This requirement for a broad set of skills for a comprehensive engineering economic analysis lends itself to a team approach that includes experienced chemical engineers, project managers, project financial managers, and energy market analysts.

This analysis is also useful when examining existing technology expansions into new markets. In his book, *The 7 Habits of Highly Effective People*,[4] Steven R. Covey felt that "Begin with the End in Mind" was sufficiently important to promote it as habit number 2. In terms of engineering economic analysis, this habit means focusing on the questions to be answered.

The fundamental question about both advanced and existing technologies for new markets is:

Under which market conditions will the technology deploy?

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[2] U.S. Department of Energy, *Technology Readiness Assessment Guide*, Table 1, Technology Readiness levels, accessed November 10 2015, http://www2.lbl.gov/dir/assets/docs/TRL%20guide.pdf.

[3] Jesse Jenkins and Sara Mansur, *Bridging the Clean Energy Valleys of Death*, Breakthrough Institute (November 2011), p. 3, http://thebreakthrough.org/blog/Valleys_of_Death.pdf.

[4] Stephen Covey, *The 7 Habits of Highly Effective People*, Simon & Schuster (November 2013), p. 102.

This guide is intended to assist the analyst in answering this and other questions (see Appendix C).

Before EIA can answer this question, analysts must estimate the most likely plant design, capital costs, fixed and variable O&M costs, plant performance, and product prices over the lifetime of the plant. To obtain the most accurate project cost estimate, the cost analysis should be completed at the highest granularity permitted by time and resource constraints. Capital cost breakdown analysis is detailed in Appendix D. This knowledge permits EIA to conduct a breakeven analysis under a variety of market conditions and analyze deployment sensitivities to product prices, feedstock costs, environmental and social externalities, and other fluctuating or uncertain parameters.

Reporting analytical results

Good communication is an essential component of engineering economic analysis. The analyst should first develop the report outline, including clearly identifying the most important technology deployment issues. The reader should understand the main advantages and disadvantages of the technology and the critical factors (i.e., technology, market, regulatory, environmental, and social) that impact the investment decisions. The results report should include a separate section informing modelers how to represent the technology, with the required model inputs for the technology in tabular form. Deployment sensitivities should be discussed to illustrate the likelihood and timing of deployment under commonly considered scenarios.

Characteristics of a good analysis report:

- Main takeaways are presented first (e.g., optimized sizing, overnight cost, breakeven requirements, cost breakdown, etc.)
- Assumptions are clearly defined (e.g., technology performance and improvement rates, projected market and regulatory conditions, recovery cycles)
- Consistent use of terminology and analysis methods (e.g., overnight capital cost, net present value, return on investment, total project cost, levelized cost, capital recovery factor, utilization rate, hurdle rate, weighted average cost of capital, risk adjusted discount rate)
- Best methods are used for presenting the results (graphs, charts, diagrams, and tables)
- Level-of-certainty of findings is described
- Sensitivities are rank-ordered (e.g., technology advancements, market conditions, regulatory conditions, location, product prices, fuel and feedstock costs)
- Recommendations are made (e.g., future analysis, monitoring, need for data/information to improve analysis, potential publications)

EIA intends to standardize analysis reports (Appendix E) in both format and content, with future reports revised based on feedback from the readers. Standardization saves the reader time and makes it easier to compare reports. It is the responsibility of the analyst to create a report that is easy to understand and clearly illustrates how the technology could deploy under a variety of realistic market scenarios.

Choosing a project cost estimating method

Depending on the availability of technology, market, and financial data, the analysis method is selected to produce the best estimate of project costs and deployment rates under potential market conditions.

Table 2. Estimating project costs by category and method

Category/Method	Accuracy (%)	Requirements
Full design analysis		
Detailed	+/- 5 %	Detailed drawings and specifications, found mainly in contract bids
Unit cost	+/- 10% to 20%	Detailed costs of similar existing projects
Selective design analysis		
Percent of delivered equipment	+/- 20% to 30%	Detailed analysis of delivered-equipment costs before scaling based on type of plant
Lang factors	+/- 30% to 40%	Plant cost based on equipment cost; accuracy improved with discrete factors for different equipment
Comparative		
Power factor	+/- 30% to 40%	Similar plants with known costs
Investment cost per unit of capacity	+/- 30% to 40%	Cost indexes for time adjustments and scaling methods for size differences
Turnover ratio	+/- 50%	A rule-of-thumb industry-specific ratio of sales to fixed-capital investment

Source: Based on Max Peters, Klaus Timmerhaus, and Ronald West, Plant Design and Economics for Chemical Engineers, McGraw-Hill (2003), p. 249.

The method selected for estimating project capital costs is also based on the amount of time and resources devoted to the analysis. A variety of cost estimating methods exists that can be grouped into three basic categories (Table 2).

Full design analysis – These are the most complex and accurate methods and require detailed information on the chemical processes, project design and cost components, financial terms and conditions, O&M costs, and market demand and prices. Risk analysis is also part of both methods (detailed and unit cost) and is done at the same level of detail used for estimating project costs. This category requires the most time and resources to complete and may not be possible due to data availability and reporting schedules.

The *detailed analysis* method is normally reserved for supporting contract bid requests and is best done by experienced contractors working in the industry. Cost estimates for this method may be available without the underlying details from engineering firms that specialize in plant design for the selected technologies. This method is the most costly and should be done only for potentially highly market-impacting technologies (i.e., “game changers”).

The *unit cost* method can be accomplished in-house, provided that project design details are available. The plant design can be estimated using mass-balance calculations of the plant processes and chemical process simulation software packages such as CHEMCAD® to estimate the required processing equipment and piping. This method should include an optimization-of-design step to ensure that the design modelled, and therefore project cost, is closest to the deployed configuration.

Selective design analysis – These methods combine aspects of the comparative and full design analysis methods by conducting detailed analysis of only the critical plant components having the largest impact on total project cost accuracy. If cost ratios between the delivered equipment and the balance-of-plant items are available and the delivered equipment is well-defined with documented costs, then the overnight capital cost can be quickly estimated using the *percentage of delivered equipment* method.

If the cost ratios are not available but the delivered equipment costs are, *Lang factors* can be used based on the plant type (solid, solid-fluid, and fluid) to estimate the capital investment. [5] Lang identified three process plant types based on output: solid processing, solid-fluid processing, and fluid processing. Solid refers to materials that do not flow and thus require augering, blowing, or non-pumping methods for transport within the plant (used in coal briquetting, food processing). Solid-fluid refers to feedstocks that are solids, such as stover, intermediates that are either solid or fluid (liquid or gas) and fluid products (used in solvent extraction with byproduct, plastics). Fluid refers to liquid or gas feedstock, intermediates, and products (used in petroleum distillation, petrochemicals).

The accuracy of the Lang factors method are improved if the plant can be deconstructed into its solid, solid-fluid, and fluid sections and corresponding Lang factors applied to the individual section's equipment costs. Estimating capital costs based on purchased equipment has reduced accuracy but can be done quickly and may be sufficient to answer technology deployment questions.

The Lang factors method is used frequently to obtain order-of-magnitude cost estimates of both direct and indirect costs and is based on multiplying factors by purchased equipment cost (Table 3). For many direct and indirect costs, the Lang factors vary slightly between processing plant type. However, others can be quite different. For example, the cost for piping for fluid processing plants is significantly larger than the cost for plants processing more solid materials.

Comparative – These are the simplest methods of analysis and consist of estimating capital costs using known costs and performance of existing plants that use comparable technology and making best judgment adjustments (sizing and modifications) based on technology, operation, and market differences. Plant energy use, product sales, and <u>cost-per-unit-of-capacity</u> factors are based on similar plants and assume a linear relationship of these parameters to capital costs. The existing plants used for comparison should be comparable in size and type. <u>Power factors</u> are similar to Lang factors but applied at the higher process or product level. The <u>turnover ratio</u> refers to how fast project capital in "turned-

[5] Hans J. Lang, "Simplified Approach to Preliminary Cost Estimates," *Chemical Engineering*, No. 55 (June 1948), p. 112.

over" through product sales. For the chemical industry, the ratio has ranged historical between 1.0 and 1.5.[6]

Table 3. Estimating capital costs using Lang factors

	Fraction of delivered equipment		
Cost type	**Solid processing plant**	**Solid-fluid processing plant**	**Fluid processing plant**
Direct costs			
Purchased equipment	1.00	1.00	1.00
Delivery, percent of purchased equipment	0.10	0.10	0.10
Purchased equipment installation	0.45	0.39	0.47
Instrumentation and controls	0.18	0.26	0.36
Piping	0.16	0.31	0.68
Electrical	0.10	0.10	0.11
Buildings	0.25	0.29	0.18
Yard improvement	0.15	0.12	0.10
Service facilities	0.40	0.55	0.70
Indirect costs			
Engineering and supervision	0.33	0.32	0.33
Construction expenses	0.39	0.34	0.41
Legal expenses	0.04	0.04	0.04
Contractor's fees	0.17	0.19	0.22
Contingency	0.35	0.37	0.44
Working capital	0.70	0.75	0.89

Source: Based on Hans J. Lang, "Simplified Approach to Preliminary Cost Estimates," Chemical Engineering, No. 55 (June 1948), p. 112.

Results from these methods are highly uncertain (often greater than 50%) and are used primarily as a first-round assessment of technologies that are potentially competitive. The high uncertainty of these methods are unlikely to properly support modeling the technology in a market model because the return on investment uncertainty can easily preclude a "Go"/ "No Go" decision on the project (i.e., there will be a large uncertainty regarding whether the return on investment exceeds the minimum acceptable rate of return, MARR).

Since it is the simplest and fastest method, the comparative method is used first. If the findings are sufficient for the customer's needs, the analysis can end. If not, a more detailed analysis is performed, provided data is available. All three analysis categories use a modular approach where technology, finance, and market costs are initially assessed separately to make it easier to conduct sensitivity and scenario analyses and estimate breakeven and return-on-investment values.

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[6] The Boston Consulting Group, *How 20 Years Have Transformed the Chemical Industry*, Exhibit 13, accessed November 10, 2015, https://www.bcgperspectives.com/content/articles/process_industries_value_creation_strategy_how_20_years_have_transformed_chemical_industry/?chapter=5.

Estimating project capital costs

A project is a temporary undertaking with a start, a finish, and a one-time cost. Estimating the initial project capital costs includes all the activities required to build or retrofit a fully operational plant producing liquid fuels or electricity from technologies. Details on estimating capital costs of the project components can be found in Appendix D.

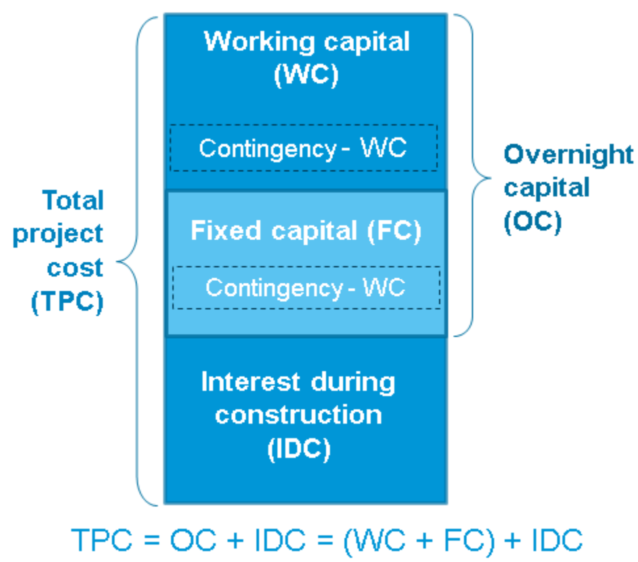
Overnight capital cost

In order to understand how both *plant design* and *project financing* impact the overall competitiveness of the technology, their cost effects need to be isolated. This is done by estimating the project capital cost responsive to plant design (no time element), known as Overnight Capital (OC).

Overnight Capital (OC) = cost of the project with no interest incurred during construction

The OC consists of the cost to build the plant – fixed capital (FC) – plus working capital (WC) required for plant operations (Figure 1). The OC does not include the cost associated with financing the plant's construction. The OC is essentially the cost to acquire a fully operational plant if it could be built overnight (i.e., no interest generated).

Figure 1. Project cost terminology



Estimating the OC enables comparison of technology options and testing sensitivities to feedstock costs, product prices, and other market conditions such as access to global markets and potential changes in federal regulations.

The FC portion of the OC consists of the costs for preliminary design, full design, long lead-time purchases, land acquisition and improvements, plant construction and configuration, initial plant startup, and any other activities needed to establish the new plant capability. Land purchases are normally excluded from the FC because land is not a depreciating asset and can be sold at the end of the plant's lifetime for approximately the time-adjusted purchase price.

WC is required at plant start-up to cover initial plant operation costs because revenue streams from product sales are usually delayed at least one full billing cycle (typically 30 days) from plant start-up.

FC and WC contingencies cover unidentified costs that can occur during construction and initial operations. Larger contingencies are made for higher risk projects like first-of-a-kind technologies.

Total project cost

Both FC and WC depend on the plant design and account for most of the total project cost. The capital costs associated with financing the project depend on the construction period, financial position of the company, project risk, and financial markets. These project financing costs can be significant, especially for projects with lengthy construction periods.

During plant construction, capital is used and its cost depends on the source – equity (the company's capital) or debt (loaned capital). The cost of equity is the expected return on equity (ROE) and is based on a company's expected returns to capital, while the cost of debt is the interest rate on the construction loan. The accrued interest, known as the interest during construction (IDC), depends on the financing strategy, interest rate, construction period, and construction draw schedule.

The cost of equity and debt during construction can be treated discretely or combined into a single value for determining the cost of capital during construction. These two rates can be combined into an effective cost of capital, known as the weighted average cost of capital (WACC) and is determined by the cost of equity, cost of debt, debt-to-equity ratio, construction period, and loan draw schedule. A similar WACC can be determined for operations to calculate discount cash flows over the life of the plant. Companies often set a minimum acceptable rate of return (MARR) prior to project analysis to ensure that only highly profitable projects are considered for financing (i.e., hurdle rate). However, EIA recognizes that multiple companies involved in assessing a build decision could have different revealed MARR, and it is the minimum of these that is of interest when considering an industry response to market conditions.

For riskier investments, the WACC can be adjusted upward to account for expected higher loan rates. A company's internal rate of return (IRR) can be used as the ROE for a project that has the same risk as the company's current investments. In determining the net present value of a risky project such as first-of-a-kind technology deployments, a risk premium is often added to get a risk-adjusted discount rate (RADR). These terms (ROE, WACC, MARR, IRR, and RADR) are commonly used in describing the expected plant performance thresholds to attract project financing. EIA will document these rates to provide additional clarity to the analysis.

Combined, the OC and IDC constitute the total project cost (TPC), a one-time cost. During plant operations, both fixed and variable recurring costs occur to produce revenue-generating products. To analyze both one-time costs and recurring costs, either the one-time costs must be amortized over the lifetime of the plant or the present value of the costs over the lifetime of the plant must be calculated. Amortizing the one-time project costs requires setting the plant lifetime and an effective interest rate (e.g., RADR) over the plant lifetime to compute an annuity conversion factor known as the capital recovery factor (CRF).[7]

[7] See Breakeven analysis section in Market demand and prices section.

Although not part of the capital cost, operations and maintenance (O&M) cost estimates are needed to calculate the WC. Project capital costs do not include the recurring costs associated with the operation, routine maintenance of the plant, major overhauls, and plant closure (see *Estimating O&M costs* section).

Project capital costs are a major cost component of a plant and occur prior to plant operations. As such, these costs have a significant impact on the competitiveness of the plant and require an accurate estimate to correctly model market penetration of the technology. For example, length of construction uncertainties lead to uncertainties in the IDC and total project cost.

Many factors impact project costs such as plant location, labor costs, material costs (e.g., steel prices), and access to capital. By estimating costs at the lowest component level possible, cost estimate accuracies are improved and cost sensitivities and contingencies are better quantified. Whether the plant is built on a site with existing infrastructure (brownfield) or without (greenfield) also matters because the project cost can be significantly lower at brownfield sites where supporting infrastructure costs[8] are mostly reduced or eliminated. Direct plant processing costs[9] (e.g., new distillation towers and reformers) will be required for either case.

Health, safety, and environmental plant requirements also impact projects costs during both plant construction and operations. To obtain the mandatory siting, construction, and operating licenses, these requirements will be explicitly addressed in the design plans.

Accounting for contingencies ensures that there is sufficient financing available to complete the project and begin operations. Project cost overruns can occur due to a variety of causes such as weather, equipment delays and failures, accidents, cost escalations, unrealized plant performance, labor issues, and permit violations that result in work stoppage and additional fees/fines. If the project and operations also involve currency conversion, additional contingency is usually required. These known and unknown risks are accounted for by increasing the WC and FC contingencies based on historical experience and expected project difficulties. Historical cost overruns for similar projects can be used as a starting point for setting the contingencies as a percentage of the WC and FC or as fixed amounts. FC contingency amounts not spent during construction can be released at the end of construction or used for WC contingency.

In addition to estimating risks, first-of-a-kind plants may have overly optimistic assumptions that result in significantly underestimating capital costs. To compensate for this tendency, capital cost estimates can be increased by some percentage based on historical overruns of similar first-of-a-kind plants. As additional plants are built, optimism-adjusted cost estimates are replaced with estimates based on actual project costs. Learning effects also appear in future project cost reductions as construction lessons are learned, processes refined, and experience gained by construction firms.

Cost estimating requires that any cost data used is properly time-adjusted to account for the effect of inflation/deflation and cost changes that occur for specific materials, equipment, and labor skills. Also,

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[8] Sometimes referred to as outside battery limits (OSBL) costs.
[9] Sometimes referred to as inside battery limits (ISBL) costs.

cost data should include the causes of cost overruns to assess whether learning will significantly reduce the likelihood of repeating the same mistakes on future projects. EIA uses the Chemical Engineering's Plant Cost Index[10] unless otherwise noted to adjust plant OC costs to common-year values.

International cost estimates

Estimating the cost to build a plant outside the United States can be challenging because cost data may be difficult to find or expensive to purchase. One option for cost estimating international projects is to complete a cost estimate for the same plant in the United States and then make cost adjustments based on cost differentials between the U.S. and the other country. More granular location cost factors yield potentially more accurate project cost estimates because differentials will likely vary between capital cost categories (labor rates, equipment, building materials, and overhead). Project capital costs are not the only costs affected by plant location. O&M cost categories will also have varying location cost factors and should be analyzed with similar granularity. Companies with experience building plants in the country of interest can be a good source of information for developing factors. International cost factors are used similarly as the U.S. locational cost factors used by EIA in estimating capital and operating costs.[11]

As a second option, countries with similar geographic, economic, and infrastructure conditions may be used as a proxy country for estimating location cost factors. Using granular location cost factors requires that the U.S. cost estimate be deconstructed into comparable categories.

Financing international projects involves estimating the country-dependent risk to capital. Risk premiums are added to account for the risks associated with project failure, plant profitability, geopolitical and market considerations. For international projects, the analysis should include a standardized set of risk premiums to reflect the additional perceived risk to capital.

For some countries, foreign investors may require such a high risk premium that a plant would not be profitable and would only be built with government financing. In those cases, the analysis is no longer purely technical and economic. A socio-political analysis would be necessary to identify the conditions that would trigger government actions to build an uneconomical plant. For example, if a government provides a guaranteed rate of return, the risk premium might be reduced to zero or near zero and the resulting project cost reduction may make the project profitable.

[10] Chemical Engineering, *Chemical Engineering's Plant Cost Index*, http://www.chemengonline.com/pci-home.

[11] U.S. Energy Information Administration, *Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants*, Table 4, Regional cost adjustments for technologies modeled by NEMS by Electric Market Module (EMM) region, April 2013, http://www.eia.gov/forecasts/capitalcost/pdf/updated_capcost.pdf.

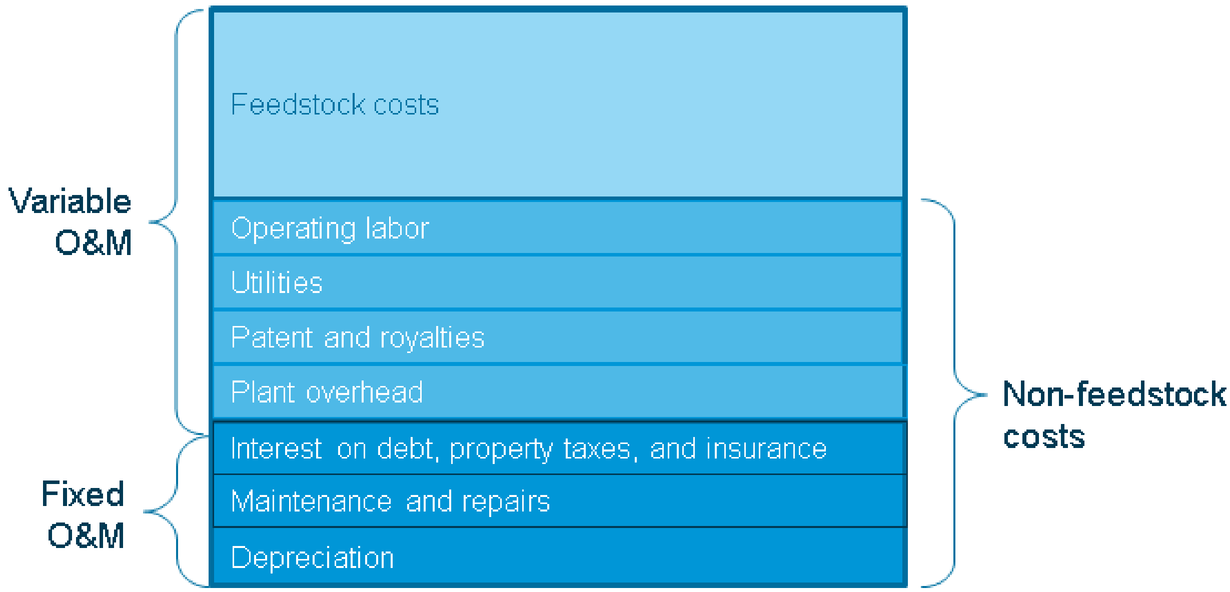
Estimating O&M costs

All expenses directly connected with operating and maintaining the process equipment are included in the O&M costs. These expenses are commonly deconstructed into two major components:

- Feedstock costs
- Non-feedstock costs

The non-feedstock costs are further itemized into fixed and variable costs (Figure 2). Most O&M costs are incurred when the plant is operating. Yet a processing plant does not always operate at its full-load production rate or nameplate capacity due to planned maintenance, equipment or process failure, accident, strike, natural disaster, or regulatory violation.

Figure 2. O&M cost categories



Any one of these events may cause a plant shutdown or a ramping down of production to a safe limit. This drop in production capacity can be calculated using a utilization factor defined as:

Utilization factor = realized production rate / design full-load production rate

The design utilization factor indicates the frequency and duration of planned and unplanned maintenance resulting in reduced operations. For a new technology during the first year of operations, it is not uncommon for production to be as low as 50% of the nameplate capacity. Unforeseen issues can occur during commissioning and start-up operations that can require extensive redesign and rework before full operation can be restored.

Many references exist for estimating O&M costs in terms of percent of total product cost, fixed capital cost, and operating labor. Table 4 is an example of relative O&M cost percentages based on *Plant Design and Economics for Chemical Engineers*, a common reference for cost engineers.

Table 4. Summary of O&M costs

	Percent share of		
O&M costs[1]	**Total product cost**	**Fixed capital cost**	**Operating labor**
Variable production costs	**~ 66%**		
Raw materials	10-80%		
Operating labor	10-20%		
Direct supervisory and clerical labor			10-20%
Utilities	10-20%		
Maintenance and repairs		2-10%	
Operating supplies		0.5 -1%	
Laboratory charges			10-20%
Patents and royalties	0-6%		
Fixed charges	**10-20%**		
Depreciation		depends on calculation method	
Local Taxes		1-4%	
Insurance		0.4 -1%	
Rent[2]		< 10%	
Financing (interest)		0-10%	
Plant overhead costs3	**5-15%**		**50-70%**
General expenses	**15-25%**		
Administrative costs[4]	2-5%		~ 20%
Distribution and marketing costs[5]	2-20%		
Research and development costs	~ 5%		

Notes:

[1] Total product cost = manufacturing cost + general expense.
Manufacturing cost = Variable production costs + fixed charges + plant overhead costs.

[2] Rent is assumed to be 8-12% of value of rented land and buildings, roughly < 10% of total fixed capital costs.

[3] Plant overhead costs include general plant upkeep and overhead, payroll overhead, packaging, medical services, safety and protection, restaurants, recreation, salvage, laboratories, and storage facilities.

[4] Administrative costs executive salaries, clerical wages, computer support, legal fees, office supplies, and communications.

[5] Distribution and marketing costs include costs for sales offices, salespeople, shipping and advertising.

Source: Based on Max Peters, Klaus Timmerhaus, and Ronald West, *Plant Design and Economics for Chemical Engineers*, McGraw-Hill Publication (2003).

Feedstock costs

Feedstock is the material that is directly consumed in producing the liquid fuels and constitutes a major operating cost. In addition to natural gas, coal, and biomass, feedstock includes the chemical reactants, constituents, and additives needed in production. In EIA analysis, the cost of utilities such as steam, water, and oxygen is not included in the feedstock cost even if they are used in the chemical reaction. Materials necessary to carry out process operation but do not become part of the final product, such as catalyst and solvents, are considered non-feedstock O&M costs.

When the plant is not operating, feedstock is not used, and the plant is not producing liquid fuels. The cost of feedstock is adjusted using the utilization factor to account for the realized capacity. The feedstock cost is given by:

Feedstock cost = Feedstock required for design capacity * feedstock price * utilization factor

When feedstock prices are not readily available as model parameters, quotes from suppliers are the preferred source. When neither of these prices is available, published prices in third-party trade journals can be used. For a preliminary cost analysis, market prices are often used, such as prices for commercial chemicals published in the ICIS,[12] Chemical and Engineering News,[13] and IHS Chemical Week.[14] Chemical prices are normally quoted on an FOB (free-on-board) basis, which do not include the cost to ship to the plant. Transportation charges are included in raw material costs when available; they may be estimated as 10% of the feedstock cost, but that percentage depends heavily on the location of both the plant and feedstock suppliers.

The amount of feedstock required per unit time or per unit of product is determined from process material balances. One of the most important steps of the design process is to calculate accurate material balances for the processes. The mass balance method is used to estimate the rate of feedstock required to yield key products at a desired output rate. Alternatively, conversion efficiency from past experience can be used to estimate the required feedstock rates.

For process units with energy-related products, the performance of the plant is often measured as energy conversion efficiency, defined as:

Energy conversion efficiency = Energy content of products / Energy content of feedstock

[12] ICIS at http://www.icis.com/chemicals/channel-info-chemicals-a-z/.
[13] Chemical and Engineering News at http://cen.acs.org/index.html.
[14] IHS Chemical Week at http://www.chemweek.com/home/.

Energy conversion efficiency provides a measure of technology performance for both power plants and plants producing liquid fuels. For non-energy conversion plants, efficiency is measured as energy intensity.

> **Feedstock energy intensity** – the feedstock energy required to produce a unit of product (MMBtu per barrel of product) or a unit of product value (MMBtu per dollar of product). Energy intensity is used in place of energy conversion efficiency for computing feedstock costs when the plant product is not fuel or energy (e.g., chemical plants).

Ultimately, plant efficiency is a measure of the conversion of costs to revenue, which is a function of plant performance (utilization rate and conversion efficiency), capital costs, fixed and variable plant costs, products produced, and market prices.

Non-feedstock costs: fixed O&M

Fixed O&M costs are expenses that are independent of the production rate.

Interest on debt, property taxes, and insurance

Expenditures for depreciation, property taxes, insurance, financing (interest on debt), and rent are classified as fixed charges. These charges with the exception of financing and depreciation tend to change due to inflation or market conditions. Since depreciation is on a schedule established by the business income tax regulations of the government where the plant is located, it may differ from year to year, but it is not affected by inflation. The amortized debt repayment includes principal and interest. Only the interest amount is part of the fixed O&M cost. The principal portion of the debt payment is accounted for as part of fixed capital costs. The cost of debt financing usually ends before the lifetime of the plant and may be accelerated based on net profits during the repayment period and the terms of the loan.

Other fixed charges that are independent of the production rate are salaries of the administrative and supervisory staff. A certain amount of direct supervisory and clerical assistance is always required for a manufacturing operation. The cost of supervisory and administrative labor is approximately equivalent to 15% of the operating labor for a plant operating at design capacity (i.e., a utilization factor of 1.0). This cost is often included as part of the variable non-feedstock costs for plant.

Maintenance and repairs

The annual cost of equipment maintenance and repairs normally ranges from 2% to 20% of the equipment cost. The maintenance charges for plant buildings are more predictable, ranging between 3% and 4% of the building cost. In process industries, total plant cost for maintenance and repairs can range from 2% to 10% of the fixed capital investment, with 7% being a commonly used value. More detail on the major maintenance and repair items improves the accuracy of this cost estimate. If the plant design uses mostly standard industrial equipment and processes, detailed costs are available through professional journals, trade publications, or directly from the equipment manufacturers.

Depreciation

All equipment eventually wears out at the end of its serviceable lifetime. Its performance decreases over time due to wear and tear, corrosion, or weather. At the end of its useful life, equipment needs replacement. Depreciation represents the amount charged as manufacturing expenses that represent the loss of capital due to aging of plant equipment. Under U.S. tax law, the rate at which depreciation may be charged is defined by the Internal Revenue Service (IRS) using several depreciation estimation methods.[15]

There are a few IRS-approved depreciation methods available with the most commonly used being the Modified Accelerated Cost Recovery System (MACRS), which changes the amount of depreciation charged every year. For a preliminary analysis it is acceptable to use a constant annual depreciation rate for a fixed period (class life or recovery period). Class life is defined by the IRS based on classification of industrial property and the recovery period is the number of years that a company depreciates an asset such as plant equipment.

Two methods are available to depreciate property under MACRS the General Depreciation System (GDS) and the Alternative Depreciation System (ADS). These methods e stablish the recovery periods for the properties (Table 5). GDS has three depreciation methods (200% declining balance, 150% declining balance, and straight line). The ADS option only has the straight line method.

Table 5. Depreciation estimation methods

Property	Refinery	Chemical manufacturing
Asset class designation number	**13.3**	**28**
Class life	16 yr	9.5 yr
GDS recovery period	10 yr	5 yr
ADS recovery period	16 yr	9.5 yr

Source: Based on U.S. Internal Revenue Service publication 946

A company selects a method that maximizes its profits, and consistently applies a single method to all technologies being assessed. Straight line is the simplest method and evenly distributes the depreciation over the class life of the property.

[15] U.S. IRS publication 946, "How to depreciate property," http://www.irs.gov/pub/irs-pdf/p946.pdf, defines the methods for depreciating property based on the type of property and how it is used.

Salvage, scrap, and land value

It is common practice to recover the capital investment used to build the plant using depreciation, which functionally occurs over the plant life. In theory, depreciation recovers the entire capital cost by the end of plant life, and value of the plant at that time will be zero. In reality, at the end of plant life, the plant may often have operational capacity value known as the salvage value.

The term salvage value implies that the plant can be of further service. If the plant is not useful, it can often be sold for its material value (e.g., scrap steel). Income obtainable from this type of disposal is known as scrap value.

Salvage value – the estimated value of the plant at the end of its designed plant life

Scrap value – the estimated value of the plant components at the end of its designed plant life

Because plant lifetimes are normally 25 years or longer and the risk-adjusted weighted cost of capital (used to discount the future value of assets) exceeds 15%, the net present value of both the salvage value and scrap value are less than 3% of the total project cost and thus has little impact on the net present value of the investment. The realized scrap value may even be negative due to restoration and environmental cleanup costs when the plant is closed. Thus, it is not uncommon for companies to set the net present value of both savage value and scrap value to zero. The plant asset value can also be estimated for any year earlier than the plant lifetime. This is done to assess plant ownership options, including plant sale or refinancing before the end of the plant's life.

For an engineering economic analysis, purchased land is not included as a capital cost. It is not depreciated and is considered sold at the end of the life of the plant for no gain.

Non-feedstock costs: variable O&M costs

Variable O&M costs include expenses directly associated with production, e.g., direct operating labor, utilities, maintenance and repairs, operating supplies, royalties, catalyst, and solvents. These costs are incurred only when the plant is operating or under maintenance.

Operating labor

Operating labor is divided into skilled and unskilled labor. The hourly wages for operating labor in different industries at various locations can be obtained from the U.S. Bureau of Labor.[16] For chemical processes, operating labor typically ranges between 10% and 20% of total product cost.

In a preliminary cost analysis, the quantity of operating labor can often be estimated either from company experience or from published information on similar processes. If flow sheets and drawings of the process are available, operating labor may be estimated since the number, type, and arrangement of equipment are known. Labor rates are adjusted if limited availability of skilled labor causes rates to increase significantly. Plants built in foreign countries face different labor costs or often use imported workers.

[16] U.S. Bureau of Labor, *Monthly Labor Review,* http://www.dol.gov/dol/topic/statistics/publications.htm.

Utilities

The cost of utilities such as steam, electricity, process and cooling water, compressed air, natural gas, fuel oil, refrigeration and waste treatment varies depending on the process and amount needed during process operation. The cost depends on location and source of the utility. Required utilities are established by the flow sheet conditions; their amount can be estimated in preliminary cost analysis from available information. The more accurate estimate is obtained using the material and energy balances and available values from quotes or market prices.

Patent and royalties

Some process technologies are owned by others and it is necessary to pay for patent rights or royalties. These charges are based on the amount of material produced. If the company involved in the operation obtained the original patent, a certain amount of the total expense involved in the development and procurement of the patent rights is borne by the plant as an operating expense. These costs are usually amortized over the legally-protected life of the patent. A rough approximation of 0% to 6% of the total product cost is used to estimate these charges.

Non-feedstock costs: plant overhead costs

These costs are not directly related to production. Many expenses are incurred for the efficient functioning of the plant. These include administrative costs, distribution, and marketing costs, and research and development costs. These costs can range between 50% and 70% of the total expenses for operating labor, supervision, and maintenance.

Market demand and prices

Revenue and O&M costs are key factors to plant profitability. Revenue comes from the sale of products and byproducts produced by the plant. In conducting an economic analysis of a process, a utilization factor of 50% for the first year of operation is used because initial production rates are low and the length of the start-up is uncertain. After the first year, an allowance of 10-20% downtime is typically given for maintenance each year, equivalent to 36-73 days based on 24 hours/day, 365 days/year of continuous plant operation. The maximum utilization rate is affected by feedstock types, process complexity and stress, and design choices. The unit production cost is calculated by dividing the annual production cost (amortized capital cost, ACC) plus operations and maintenance cost (O&M) by the annual production. This production cost is also the minimum product price needed for the plant to breakeven.

Estimating product prices is best derived from a market study. For established products, price information is available from EIA and independent sources such as ICIS *Chemical Market Reporter*[17] and *Oil and Gas Journal*.[18] Plant location must be considered when determining market demand, prices, and the cost of transporting the products to market.

Product prices respond to changes in the levels of supply and demand. Product prices and the production rate of the plant over its lifetime determine revenue. Fixed and variable plant costs and the production rate of the plant over its lifetime determine costs. Estimated net cash flows determine the profitability of the plant and estimating prices, costs, and production are equally critical in estimating how a technology may deploy and compete in the market. Many of these factors are considered in EIA's modelled results.

Due to market interactions, markets are seldom in equilibrium. This means price pressures exist and cause prices to be in constant flux. Price and cost profiles used to estimate the market over the lifetime of the plant must be consistent and represent the most likely market trends. The evolution of markets and potential market disruptions are fully considered when analyzing a technology as future markets may differ considerably from existing markets in regards to the technology. EIA models energy technologies under different future market scenarios, such as high and low oil price cases, to gain insights into deployment sensitivities of competing technologies.

Market demand and prices are dependent on several factors such as the production of competing products, seasonal conditions, and government-imposed taxes and subsidies. In most cases, market trends are analyzed based on the most common commodity such as the price of crude oil for fuels and petrochemicals or the price of corn for biofuels and biochemicals.

[17] ICIS *Chemical Market Reporter* at http://www.icis.com/about/price-reports/
[18] *Oil and Gas Journal* at http://www.ogj.com/index.html

Breakeven analysis

A breakeven analysis examines the conditions when costs equal revenues either in a specific year or over the entire lifetime of the plant. Since breakeven analysis can be performed under a variety of assumptions, the breakeven analysis effort should be tailored to answer specific profitability questions. Variations in the analysis are related to markets and plant parameters that affect cash flows. A top-down breakeven analysis is provided in Appendix F.

The fundamental equations for a breakeven analysis are:

Gross profit = Total revenue – Total cost

Total cost = Amortized capital cost + O&M costs

Amortized capital cost = TPC (as a net present value) * Capital recovery factor (CFR)

CRF = $[i(1+i)^n]/[(1+i)^n-1]$, where i = fixed interest rate, n = fixed number of years

Breakeven analysis can be done by calculating the net present value of both revenues and costs over the lifetime of the plant and computing a set of parametric values such as product prices and feedstock prices that result in the net present value of revenues equaling the net present value of costs (i.e., $NPV_{REVENUES} = NPV_{COSTS}$). The resulting curve is the breakeven curve for the plant under the assumptions and a set of parametric values.

For two independent variables such as product prices (converted to crude oil) and feedstock prices (natural gas, coal, or biomass), the resulting curve is two-dimensional. On one side of the curve, the plant makes a net profit, and on the other side of the curve, the plant makes a net loss. Understanding the breakeven conditions and the sensitivity of the curve to assumptions is critical to understanding if and when a technology will penetrate the market.

The following parameters are needed to conduct a breakeven analysis:

- Return on equity
- Construction period
- Plant life (physical life)
- Salvage value at end of plant life
- Equity-to-debt ratio
- Loan terms
- Costs (TPC and O&M)
- Product Prices
- Utilization rate
- Tax rate
- Depreciation schedules

The final breakeven analysis is prepared on an after-tax basis when estimating deployment rates because that is the true measure of breakeven for a corporation. Intermediate breakeven analysis can be assessed on a before-tax basis for comparing technologies when assessing the effect of specific federal and local incentives.

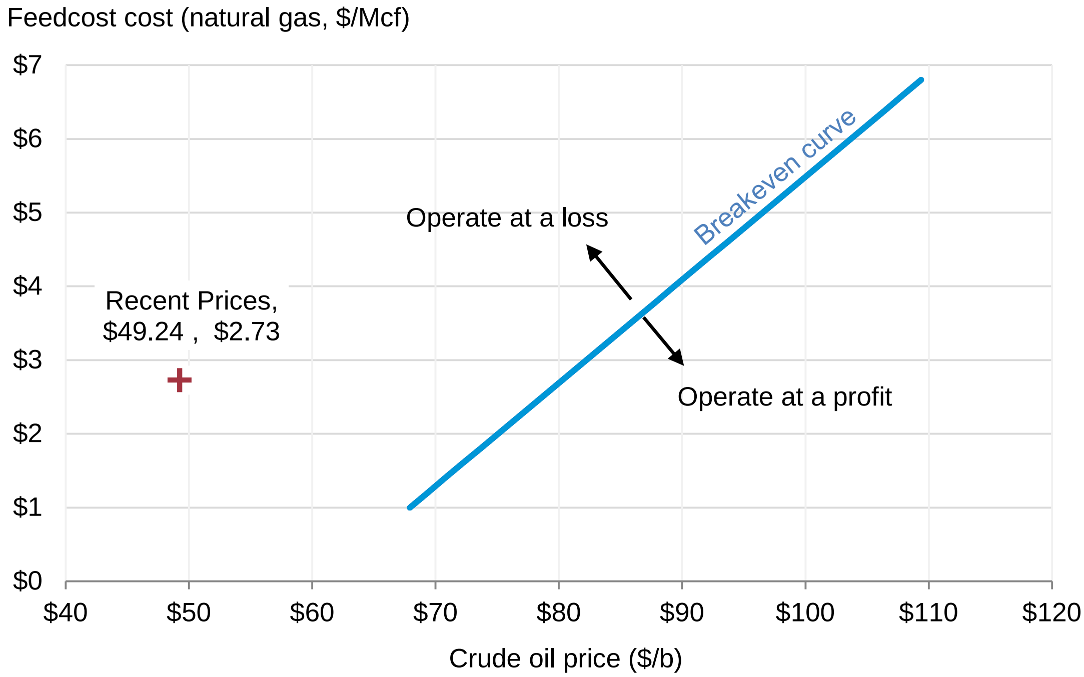
Breakeven price of the key product

A chemical production facility normally uses more than one feedstock and produces more than one product. For breakeven analysis, the key product can be used to estimate the breakeven price by calculating the following:

- Amortized capital cost using interest rate and expected plant life
- Amortized salvage value using interest rate and expected plant life
- Fixed operating expenses
- Variable operating expenses using the utilization factor

To create a breakeven curve, the gross profit equation is set to zero (i.e., Revenue = Expenses) and all the variables are fixed except for one expense and one revenue variable. As shown in the example graph (Figure 3), the feedstock cost (natural gas) is selected as the dependent variable and the crude oil price is selected as the independent variable. Feedstock costs are then calculated for a range of crude oil prices that produce zero profits. These cost and price pairs lie along the breakeven curve. Above the breakeven curve, the project operates at a loss (Revenues < Expenses) and below the curve, the project operates at a profit (Revenues > Expenses) for the assumptions used in the calculation. This breakeven curve can be done for other revenue-expense variable combinations to examine other sensitivities of the project. If three non-fixed variables (two independent and one dependent) are used in a similar manner, a 3-D break-even surface can be generated.

Figure 3. Breakeven curve example



Source: U.S. Energy Information Administration, illustrative example of a breakeven curve.

A breakeven price ($ per production unit) is determined by dividing expenses by production to get the minimum product price needed to cover expenses.

Care should be taken in selecting which variables to fix as feedstock, product, and by-product prices usually vary with crude oil prices for petrochemical feedstock and products. A linear relationship can be developed using different crude oil prices and the gross profit equation can be reduced to avoid this multi-variable dependency issue.

Comparative analysis

When different technologies yield the same product, a comparative analysis is used to understand to competitiveness of a technology. In such situations, the following comparative analysis process can be used:

- Estimate the capital costs and operating costs for plant using competing technologies
- Calculate the net present value for all projects
- Select only projects that are profitable
- Estimate the marginal ROE differences between the competing technologies

Technologies with the largest risk-adjusted[19] net present value or ROE are more likely to be deployed on a purely economic basis. However, other non-economic factors should also be examined such as socio-political priorities to ensure that less competitive technologies are properly modelled. Technologies with similar rates of return, within the uncertainties of the data and assumptions, are treated as equally competitive to avoid faulty deployment conclusions. All technology differences (e.g., CO_2 emission rates) should be monetized and included in the analysis for each scenario examined.

Sensitivity analysis

Sensitivity analysis is performed to understand how sensitive a plant's profitability is to changes in the parameters that drive costs and revenues (Table 6). This analysis focuses on plant and market parameters that create the largest impacts or the largest uncertainties on plant profit. Historical ranges can be used (when available) to develop a set of breakeven sensitivity curves in order to examine only realistic future world conditions.

Table 6. Sensitivity analysis parameters

	Plant parameters	Market parameters
	Utilization rate	Product prices
Revenue	Product slate	
	Fixed capital	Cost of capital
Cost	Conversion efficiency	Feedstock prices

Based on estimated plant parameter uncertainties or historical market parameter fluctuations, sets of breakeven curves can be developed for each parameter to illustrate the required product price for a given feedstock price. Since feedstock prices and product prices are the dimensions of the breakeven plot, they are not used as the sensitivity analysis parameter.

At a minimum, utilization factor, fixed capital, and cost of capital effects are examined. Other parameters, including indirect and more detailed parameters, can also be examined to answer a specific question or if a parameter is highly uncertain or represent a unique characteristic for the plant (e.g., skilled labor shortage).

Market penetration analysis

If a technology is expected to be profitable in future markets, the next step in the analysis is to estimate when the deployment occurs (first plant), at what rate (deployment curve), and to what extent (maximum market penetration). What drives the deployment rate and maximum market penetration is the technology's competitiveness with other technologies that produce the same or substitution products.

The standard deployment curve is a sigmoid function or "S" curve, where the deployment rate grows to a maximum rate and then decreases as the technology approaches its maximum market share. The shape of the deployment curve depends on the evolution of market forces (technology pull and push)

[19] Note: see page 8 on costing project risk.

that attract capital investments. Positive market forces will initially be small due to such factors as high technology risk. As the technology cost and performance in the market is demonstrated, positive market force can grow to a maximum resulting in a maximum deployment rate. As the technology approaches its market share limit, positive market forces will shrink, slowing the deployment. Market forces can also become negative over time due to competition and other changing market conditions, causing a reduction in the number of replacement plants. Each subsequent build decision will be based on risk-adjusted competitiveness, availability of capital, and future market expectations. A technology must not only be profitable, it must be the better choice and have access to financing.

Maximum market share depends on a variety of market limits that develop naturally or are created through government intervention. Upstream and downstream limits, cost and price shifts, market shifts, disruptive technologies and policies are just some of the market forces that are considered when developing the deployment curve for an emerging technology in a particular location.

Appendix A. Glossary

For this guide, the following definitions have been used.

Amortized capital cost (ACC) – the annualized cost or annuity value of the Total Project Cost (TPC), based on project life and a fixed annual interest rate (i.e., ACC = TPC * CRF). See the definition of Capital Recovery Factor (CRF) for the CRF formula.

Annual production costs – the annual amortized capital and O&M (fixed and variable) costs.

Breakeven price – the product price that results in expenses equaling revenues at a point in time during the physical life of the plant.

Capital recovery factor (CRF) – converts a net present value into an annuity value using a fixed interest rate (i) and number of payments (N) ($CRF = [i(1+i)^N] / [(1+i)^N - 1]$).

Class life – the number of years over which a property is depreciated for tax purposes, where tax regulations define the classification (i.e., class life) of property.

Contingency – the additional amount of capital added to the capital cost estimate to cover known risks that may occur during construction (fixed capital contingency) or operations (working capital contingency); amounts are based on historical project data.

Cost of capital – the effective rate of return for the capital (both equity and debt) used in for the project.

Depreciation – a systematic reduction or decrease in the value of a fixed asset with the passage of time.

Efficiency – a measure of how well feedstocks are converted into products. For fuel plants, it can be represented as an energy content ratio of fuel products to feedstocks (i.e., $MMBtu_{products}/MMBtu_{feedstocks}$).

Expenses – the fixed and variable costs incurred during plant operations to earn revenue, including asset depreciation.

Feedstock – the basic materials (a.k.a. raw materials) processed into products.

Fixed capital cost (FC) – the one-time capital cost to build the plant.

Inside battery limits (ISBL) – the area inside a process plant that contains the primary units. The term is used to identify project costs that are incurred for both greenfield and brownfield projects.

Interest during construction (IDC) – the total interest that accrues on the construction loan up to the first amortized loan payment.

Lang factors – Three ratio factors (F_{LANG}) - 3.10 for solid, 3.63 for solid-fluid, and 4.74 for fluid process plants – developed by Hans J. Lang to estimate the total installed cost (TOT) for a project using delivered equipment cost of the major technical components [$TOT = F_{LANG}$ * Cost (delivered equipment)].

Minimum acceptable rate of return (MARR) – the lowest acceptable rate of return for a project to be considered for approval (a.k.a. hurdle rate, expected rate of return).

Net present value (NPV) – the time-adjusted current value of all revenues and costs projected to occur over the construction period and operating life of the plant.

Non-feedstock costs – the cost category that includes all O&M costs except the cost of feedstocks.

Operations and maintenance costs (fixed) – the O&M costs that occur during the life of the plant that are independent of plant operations.

Operations and maintenance costs (variable) – the O&M costs that occur during the life of the plant that are determined by the level and mode of plant operations.

Outside battery limits (OSBL) – the areas in a process plant outside the primary process units' boundary, e.g., utilities, tankage, etc. (i.e., part of the facility that is not in the ISBL). The term is used to identify project costs that may not be incurred for a brownfield project because the equipment may already exist at the facility.

Overhead cost – insurance, taxes, contingency, field and office expense, temporary construction facilities, and contractor fee.

Overnight cost (OC) – the one-time capital cost as if no interest were incurred during project construction. It is equal to Fixed Capital (FC) plus Working Capital (WC) costs.

Owners' costs – project costs paid by the owner for purchasing or leasing the land, operating cost, etc.

Plant life – the number of years the plant is designed to operate.

Profit – revenues less costs.

Return on investment (ROI) – the net annual rate of return of an investment amount over the investment period.

Return on equity (ROE) – the annual expected rate of return on a company's equity. It is used in estimating the cost of capital.

Revenue – A computed value equal to the summation of the unit product price times the amount of product sold for all units sold (Revenue = Σ_j(Unit Product Price)$_j$*(Number of Units Sold)$_j$).

Risk-adjusted discount rate (RADR) – the computed discount rate of the project that includes all risk premiums.

Salvage value – the estimated value of the plant at the end of its designed plant life.

Scrap value – the estimated value of the plant components at the end of its designed plant life.

Technology readiness level (TRL) – a classification of the maturity of a technology using a standardized classification method.

Total installed cost (TOT) – The cost estimate typically provided by a contractor to build the plant (delivered equipment cost, material and labor costs for site improvements, foundations, steel, buildings, piping, electrical, controls, both design and construction costs, and overhead costs). Generally excludes owners' costs.

Total project cost (TPC) – the one-time cost to build an operational plant. It is equal to the fixed capital (FC) plus working capital (WC) plus interest during construction (IDC) costs.

Turnkey or turnkey project– a project constructed at a fixed cost and sold as a completed product.

Unit production cost – cost to product a unit of product (annual production costs ÷ annual production).

Utilization factor – the ratio of the actual annual operating hours to the total hours in a year. The factor is used in conjunction with the nameplate capacity of the plant to estimate such financial and performance metrics as annual production and variable O&M costs.

Weighted average cost of capital (WACC) – the effective cost of capital for a project based on the opportunity cost of capital or expected rate of return, debt financing rate, and debt financing ratio.

Working capital (WC) – the capital required to operate the plant at full-planned capacity.

Appendix B. Initial assessment of technology

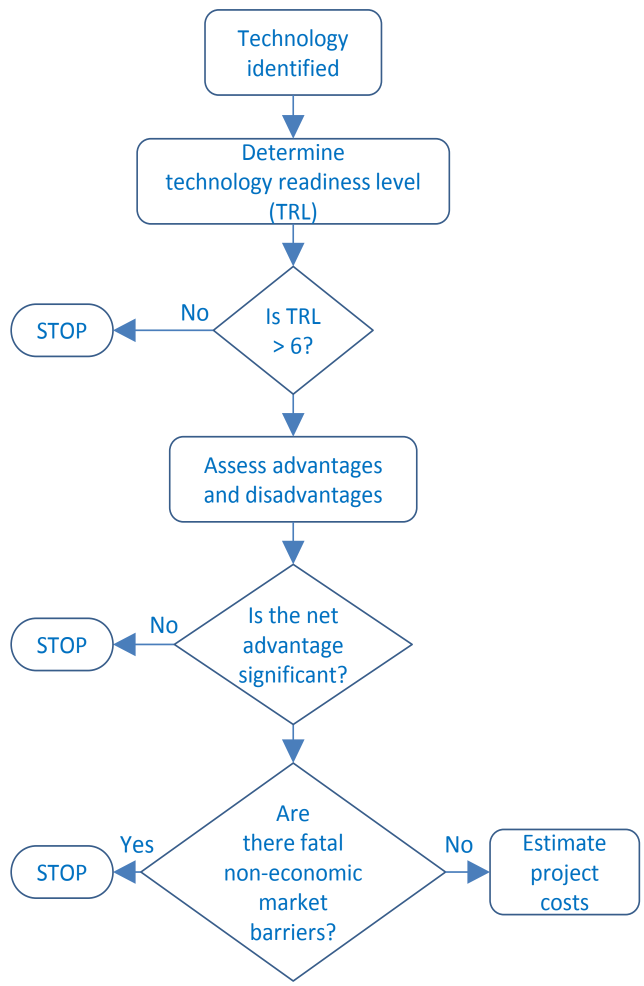
An initial assessment of the technology readiness, including its competitive advantages and disadvantages, is first completed to avoid conducting a lengthy engineering economic analysis of a fatally-flawed advanced technology (Figure B-1).

Existing technologies competing directly with a new alternate technology must be understood, including estimating their future improvements in lowering costs and improving performance. Existing technologies have advantages that create non-economic barriers to new technology market entry, such as established infrastructure, suppliers, partnerships with local communities, and long-term customers and contracts. If the advanced technology can be owned or licensed by existing companies, the market barriers may be lowered or eliminated, allowing the advanced or alternate technology to compete on a purely economic basis.

Emerging technologies must also be analyzed for sustainability to understand the impacts the technology will have on the environment and the feedstock resources. For example, bio-based technologies must operate within the natural carbon and nitrogen cycles and other feedstock limitations.

Technology readiness levels (TRL) were developed by NASA in the 1970s to classify the maturity of spacecraft design. The U.S. Air Force adopted and modified the TRL approach in the 1990s for classifying technology for weapon systems. Since then, the TRL approach has been adopted by many industries and governments (including the Department of Energy, DOE) to assess and compare the state of maturity of relevant technologies.

Figure B-1. Initial technology assessment steps



Note: A "STOP" indicates that the technology assessment should be customized to account for significant technology uncertainties or deployment barriers

Table B–1 provides summary explanations of the nine TRLs used by DOE is classifying energy-related technologies.[20]

Table B-1. Technology readiness levels (TRL) explained

TRL	TRL definition	Short description
9	Actual system operated over a full range of expected mission conditions	The technology is in final form and operated under the full range of operating mission conditions.
8	Actual system completed and qualified through test and demonstration	The technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development.
7	Full-scale, similar (prototypical) system demonstrated in relevant environment	This represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Final design is virtually complete.
6	Engineering / pilot-scale, similar (prototypical) system validation in relevant environment	Engineering-scale models or prototypes are tested in a relevant environment. The major difference between TRL 5 and 6 is the step up from laboratory scale to engineering scale and the determination of scaling factors that will enable system design.
5	Laboratory scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to the final application in almost all respects. The tested system is almost prototypical.
4	Component and/or system validation in laboratory environment	The basic technological components are integrated to establish that the pieces will work together. This is relatively low fidelity compared with the eventual system. TRL 4-6 represent the bridge from scientific research to engineering.
3	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development (R&D) is initiated, including analytical studies and laboratory-scale studies to physically validate the analytical predictions of separate elements of the technology. At TRL 3, the work has moved beyond the paper phase to experimental work, but there is no attempt to integrate the components into a complete system.
2	Technology concept and/or application formulated	Once basic principles are observed, practical applications can be invented. The step up from TRL 1 to TRL 2 moves the ideas from pure to applied research. Experimental work is designed to corroborate the basic scientific observations made during TRL 1.
1	Basic principles observed and reported	This is the lowest level of technology readiness. Scientific research begins to be translated into applied R&D. Examples might include paper studies of a technology's basic properties or experimental work that consists mainly of observations of the physical world.

[20] Shortened version of TRL descriptions found in DOE G413.3-4A, Technology Readiness Assessment Guide (2011), http://www2.lbl.gov/dir/assets/docs/TRL%20guide.pdf.

Appendix C. Fundamental questions

The analysis answers fundamental questions about when a technology becomes sufficiently competitive to deploy under different market scenarios and provides EIA modelers with parametric inputs. By separating technology analysis, project analysis, and O&M analysis, the causal relationships and sensitivities can be better isolated and modeled. Questions focus on the technology, project costs, O&M costs, and financing.

Technology analysis

- What is the **readiness of the technology** (i.e., TRL)?
- What are the **performance characteristics** of the technology?
- What are the other existing and near future **competing technologies**?
- Which **technology risk** still exists?
- How do risks compare among competing technologies and this technology?
- How will this **technology advance** over time in terms of cost, performance and risk?
- How will this technology advance compared to competing technologies?
- How **sensitive** are the performance and cost of this technology to market and regulatory changes?
- What are the **optimized configurations** under likely market conditions?
- What are the likely **learning rate(s)** for technology improvements?

Project cost estimating

- What are the **cost components** and their estimated costs?
- What are the **uncertainties and sensitivities** of the costs?
- What are the **project risks** and likely cost of those risks?
- What is the estimated **overnight cost** of the project under the most likely configurations?
- What is the project **duration**?
- What is the **contingency** in terms of both time and cost?
- How **optimistic** are the available cost estimates?
- What is the most likely **method of financing** the project (debt/equity/financial sources)?
- What is the relationship between **project costs and external factors** (energy prices, labor rates, etc.)?
- How is **total project cost** typically defined by the industry and financial partners?
- What is the likely **learning rate(s)** for building new plants?

O&M analysis

- What are the **fixed and variable O&M** costs?
- What is the expected **utilization** rate?
- What are the **major overhaul** costs and frequency?
- What is the expected **lifetime and savage** value?
- What are the **end-of-life** costs?
- What are the expected **fuel and feedstock** requirements?
- What are the expected **products** and **output rates**?
- What are the expected product **prices** over the lifetime?
- What are the expected **costs** over the lifetime?
- What are the **sensitivities to net cash flow** (breakeven analysis, stress test)?
- What are the expected **learning rate(s)** for plant operations?

Financial analysis

- What are the possible **sources of financing** for the project (debt/equity/financial sources)?
- What is the **hurdle rate** or minimally acceptable rate of return (**MARR**) required by the industry to consider the deployment of this technology?
- What are the primary **risk issues** and **mitigation costs**?
- What is the **risk-adjusted discount rate** (RADR) for the technology in the most likely markets?
- Which **market conditions** are necessary and sufficient for the technology to be deployed at different rates (price, demand, growth, competition, regulations, global/national/industry economic growths, lending rates, risk perceptions, alternative investment opportunities)?
- What are the rate-of-return **sensitivities**?

Appendix D. Capital cost breakdown

The most important aspect of an accurate cost estimate is to identify all the cost components. The simplest of approaches identifies inputs, outputs, and describes the major atributes of the technology itself. Most of the methods of estimating capital costs require at least some level of detail about the plant equipment, including cost. Cost uncertainties are also needed to develop cost ranges.

Once the plant design is determined in terms of plant configuration and component sizing (to produce a "balanced" design where the plant is optimized for normal operating conditions), a cost component list can be created and cost estimates made for each component using the best available information. The cost component list includes both cost ranges and references to illustrate the uncertainties of the cost values, enable future cost updates, and create transparency in the project cost estimate. A preferred way to show cost ranges is by giving the high, low, and most likely values. The most likely value is not the mean of the high and low values. It is the most probable component cost based on available data. Historical cost ranges are used to establish the high and low values. Contingency is also included.

Fixed capital costs (FC) are all the costs, direct and indirect, associated with establishing an operational plant. FC does not include the initial materials such as feedstock, consumable catalysts, and fuel. Those costs are part of the working capital (WC).

FC components for any technology project are grouped as follows:

- **Civil and structural costs:** allowance for site preparation, drainage, installation of underground utilities, structural steel supply, and construction of buildings on the site
- **Mechanical equipment supply and installation:** major equipment, including but not limited to, boilers, flue gas desulfurization scrubbers, cooling towers, steam turbine generators, condensers, combustion turbines, and other auxiliary equipment
- **Piping:** pipes, fittings, valves, pipe controllers and sensors, pipe hangers and supports, pipe insulation, other pipe support equipment, and the cost of installation[21]
- **Electrical and instrumentation/control:** electrical transformers, switchgear, motor control centers, switchyards, distributed control systems, and other electrical utilities
- **Project indirect costs**: engineering, distributable labor and materials, craft labor overtime and incentives, scaffolding costs, construction management start up and commissioning, and fees for contingency
- **Owners' costs:** development costs, preliminary feasibility and engineering studies, environmental studies and permitting, legal fees, insurance costs, and property taxes during construction

The most significant errors in capital investment estimates are often due to the omission of equipment, services, or auxiliary facilities rather than to gross errors in cost estimating. The estimate accuracy is

- [21] In a liquid fuel production plant, piping can be the single largest cost item.

limited by the accuracy of the largest cost items. Predesign cost estimates require much less detail than firm definitive or detailed estimates and are important for comparing alternative designs and/or making “go”/”no-go” decisions.

Although larger contingency factors are used to compensate for insufficient data, they do not improve the accuracy of the estimates. For EIA’s needs, cost estimates are used to inform market models and it is important that comparative technologies have similar levels of detail to produce estimates of similar accuracy and minimize the risk of generating faulty model conclusions.

Fixed capital cost

Civil and structural costs

Before the plant can be erected, the site must be prepared to provide the support infrastructure needed to operate the plant. Materials, supplies, people, energy, and information need to move in and out of the plant. There are safety, security, and environmental requirements for the plant facilities and systems. Site development involves surveying the site locations, preparing the areas for construction, and installing fundamental support structures. Following site development, foundations and auxiliary facilities can be built.

Site preparation

Costs for fencing, grading, roads, sidewalks, railroad sidings, landscaping, and concrete platforms for equipment installation are all considered in site preparation. The costs for these items in most chemical plants are typically 10% to 20% of the purchased equipment cost or 2-5% of the FC. A more detailed estimate can be made by using known site preparation costs for existing plants of similar type (e.g., refineries, chemical plants) and scaling at the most detailed level posible.

Foundation and auxiliary facilities

Following site development work, the equipment foundations and auxiliary facilities can be built. The cost of buildings including services consists of expenses for labor, material, and supplies involved in the erection of all buildings connected with the plant. Costs for plumbing, heating, lighting, ventilation, and similar building services are included. These costs typically range from 45% to 70% of the purchased equipment cost. Using known building costs from similar industrial plants can provide sufficient cost accuracy because these buildings are fairly similar in construction and systems. If unique building requirements exist for a new technology, a more detailed cost estimate should be completed to isolate the unique cost drivers.

Depending on whether the project is an expansion of an existing plant (brownfield) or a new plant (greenfield), civil and structural costs can vary greatly because most, if not all, of the support infrastructure may already be in place for a plant expansion project. Two terms, inside battery limits (ISBL) and outside battery limits (OSBL) have been used historically to distinguish the main processing area (ISBL) from the supporting infrastructure that is located apart from the processing units (OSBL). These terms are still used in some models such as the Liquid Fuels Market Model (LFMM) within EIA’s National Energy Modeling System (NEMS) to address cost differences between greenfield and brownfield projects.

Mechanical equipment supply and installation

FC estimates are mostly based on the cost of equipment purchased. The installation cost can be either estimated as a percentage of the total equipment cost or calculated separately for each major piece of equipment and then summed for a total installation cost for the project. The total installation cost includes both labor and materials required to install the purchased equipment. Estimating purchased equipment costs requires reliable sources for equipment prices. Price indices are required to adjust equipment prices for capacity and methods are needed for estimating auxiliary process equipment. The equipment types are normally divided into three categories:

- **Processing equipment** enable chemical transformation of materials and include reaction vessels and the associated suppport equipment to chemically process the feedstock and transport the materials to and from the vessels.
- **Raw materials handling equipment** moves and mechanically prepares the materials for use by the processing equpment. Raw materials may require cleaning, filtering, neutralizing, grinding, preheating, and other preparations prior to processing.
- **FInsished products handling and storage equipment** cover all post-processing steps to make to products ready for sale such as cooling, filtering, sorting, collecting, packaging, staging for shipment, and storing.

Although, the most accurate method for determining process equipment costs is to obtain firm bids from fabricators or suppliers, bid information may be treated as proprietary by a company or industrial trade organization and unavailable to EIA. However, fabricators and suppliers may provide estimates that approximate the bid price. As estimates, the provided costs should be cross-checked with other sources. For example, ChemStations produces annually updated cost estimates for major plant equipment as part of its CHEMCAD® software licensing agreement[22] and McGraw Hill has an online equipment cost estimator tool.[23]

An advanced technology plant will likely have both unique leading-edge equipment and conventional equipment found throughout the liquids fuel industry. Reliable prices for leading-edge equipment may be difficult to find, requiring comparative estimates. Conventional equipment prices can be obtained directly or through engineering design firms that have access to historical price data. All these approaches require a plant equipment list or plant design.

The next most accurate method for estimating FC is to conduct a full mass and energy balance calculation for all plant processes. A complete mass and energy balance is sufficient to estimate the equipment (capacities and specifications) needed to make cost estimates. During the plant design phase, the capacity and specifications of the equipment needed for a chemical process are derived using fixed equipment parameters or calculations using material and energy balances. Simulating the chemical processes at specified operating temperatures and pressures determines the chemical kinetics, reaction velocity, and chemicals, both used and produced in the reactor. With this information, reactor

[22] ChemStations, http://www.chemstations.com/Why_ChemCAD/, accessed on November 10, 2015.
[23] McGrawHill, http://www.mhhe.com/engcs/chemical/peters/data/ce.html, accessed on November 10, 2015.

material, pressure rating, size, and heat duty are calculated. It is these parameters that determine the equipment requirements and costs.

Another method for estimating FC is to compare the project to similar existing projects and apply scaling techniques to exisiting project equipment costs as needed. Engineering design firms with extensive process plant databases can be contracted to provide equipment costs estimate ranges based on a detailed equipment list or provide a full plant cost estimate based on a detailed plant design.

In-house cost estimating of equipment can be done using scaling of known equipment costs. Scaling includes cost adjustments for differences in equipment sizing (i.e., capacity) and specifications, vintages, cost inflators, and location effects. If cost data is not available for a particular size or capacity, the cost estimate is adjusted for capacity by using the standard six-tenths factor rule.

Six-tenths rule = $\text{Cost (A)} / \text{Cost (B)} = [\text{Size (A)}/\text{Size (B)}]^{\text{index}}$

where A is the required equipment, B is the same equipment of a different size and known cost, and the index is a value between 0.3 to 1.2 that depends on the equipment type (Table D-1). In most cases, the index is between 0.4 and 0.8, where 0.6 is used a the default value for non-indexed equipment. Detailed cost-scaling tables can be found in most chemical engineering handbooks. For refinery facilities, EIA assumes a cost scale factor of 0.8.[24]

Table D-1. Typical cost-scaling indices for equipment cost as function of capacity

Equipment category	Min. size	Max. size	Units	Index
Blender	50	250	ft3	0.49
Blower (centrifugal)	1,000	10,000	ft3/min	0.59
Compressor (reciprocating) 150 psi discharge pressure	10	400	ft3/min	0.69
Evaporator	100	10,000	ft2	0.54
Pump (centrifugal)	10,000	100,000	pm-psi	0.33
Reactor Stainless Steel 300 psi pressure rating	100	1,000	gal	0.56
Tray, Bubble Cap Carbon Steel	3	10	feet	1.2
Shell and Tube Heat Exchanger (floating head)	100	10,000	ft2	0.6

Source: See, for example, L.B. Evans, A. Mulet, A.B. Corripio, and K.S. Chretien, “Costs of pressure vessels, storage tanks, centrifugal pumps, motors, distillation and absorption towers,” Modern Cost Engineering II, Chemical Engineering Magazine, McGraw-Hill, New York (1984), pp. 140-146, 177-183; and Frederick T. Moore, “Economies of Scale: Some Statistical Evidence,” Quarterly Journal of Economics (May 1959), pp. 232-245

[24] U.S. Energy Information Administration, *Technical Options for Processing Additional Light Tight Oil Volumes within the United States,* April 2015, p.6, https://www.eia.gov/analysis/studies/petroleum/lto/.

If the required capacity is greater than the maximum size specified, costs can be aggregated from multiple pieces of equipment or obtained through by direct quotes from the manufacturer.

Piping

The cost of piping includes pipe, labor, valves, fittings, insulation, painting, supports, and hangers required to erect the piping systems required for the process. This covers piping required for feed handling, intermediate product, finished product, all utilities, and other operations. The process piping can be as much as 80% of the purchased equipment cost or 25% of the FC. As a result, the most precise cost estimating method available should be used.

Piping cost estimation methods (in increasing order of precision) include:

- Order-of-magnitude estimate
- Preparing a small-scale model of the process and then calculating the piping required for a full-size plant
- Using a detailed piping and instrument diagram and isometric diagram to estimate required piping
- Using computer-aided design software (e.g., Autocad) to design piping systems

Order-of-magnitude factors can be found in many chemical engineering handbooks (Table D-2).

Table D-2. Estimated cost of piping

	Percent of purchased equipment			
Type of process plant	**Material**	**Labor**	**Total**	**Percent of fixed-capital equipment**
Solid	9	7	16	4
Solid-Fluid	17	14	31	7
Fluid	38	30	68	13

Note: Solid refers to materials that do not flow and thus require augering, blowing, or non-pumping methods for transport within the plant; Solid-Fluid refers to feedstocks that are solids, such as stover, intermediates that are either solid or fluid (liquid or gas), and fluid products ; and Fluid refers to liquid or gas feedstock, intermediates, and products.

Source: Max Peters, Klaus Timmerhaus, and Ronald West, Plant Design and Economics for Chemical Engineers, McGraw-Hill (2003), p. 245.

Electrical, instrumentation, and control

These costs are usually range between 4% and 10% of the total installed plant cost with a median value of 7.5%. The methods available for estimates are:

- **Factored estimate** as a percent of installed plant for specific type of plant, if based on actual data, gives reasonable results and is adequate for an initial analysis. This method is the quickest way to estimate electrical, instrumentation, and control costs.

- **Detailed estimates** require detailed drawings and materials pricing from suppliers' catalogs. The labor hours are estimated from data provided by most handbooks. For the United States, the National Electrical Contractors Association[25] publishes an excellent manual of electrical costs.
- **Unit pricing** gives a quick and accurate estimation based on accumulated data from many jobs on various types of plants. Each unit cost contains all costs involved in the installation of that unit. For stand-alone motors (i.e., not part of a purchased equipment), the installed costs include the starter, conduit, wire, and a proportionate share of panelboard and busbars.

Project indirect costs

Project indirect costs are also known as nonmanufacturing fixed-capital investments. These costs mainly cover construction design and engineering including internal or licensed software, computer-based drawings, purchasing, accounting, construction and cost engineering, travel, communications, warehousing, temporary structures, support facilities, and home office expenses plus overhead.

Other indirect plant costs are construction tools and rentals, home office personnel located at the construction site, construction payroll, travel and living expenses, taxes and insurance, and any other construction overheads.

For the typical chemical plant, these indirect cost range from 8% to 10% of the FC. Costs can be estimated using known indirect costs from previous projects of similar size and complexity. For first-of-a-kind projects, the cost percentage may be higher to resolve unique technology issues such as special designs for major overhauls or large equipment replacement operations.

Owners' costs

Owners' costs are primarily related to preliminary project work and project-support activities, and costs related to liabilities and laws. These include project development and feasibility studies, legal costs, project insurance, approvals, permits, licenses, and property taxes paid during construction.

During the planning stage, the owner is required to apply for approval to establish the project, a permit to build, and a license to operate the plant.

There and many types of permits[26] with a long list of direct and associated costs, including developing and submitting the permits and all required supporting documents; attending and presenting at review meetings and hearings with state, federal, and local governments; updating/resubmitting applications; providing additionally requested documents; and associated costs related to preliminary feasibility and engineering studies, environmental studies, legal fees, and initial project management.

A technology license, a waste disposal license, and an operating license must also be secured prior to start-up. The costs associated with preparing the license application and the licensing fees are usually well-known but are location-specific and are based on the technology and the complexity of the project.

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[25] National Electrical Contractors Association at http://www.necanet.org/neca-store/publications

[26] Permit types include Basic business operations, Zoning and land use, Air pollution operations, and Hazardous waste treatment, storage, and disposal facility (TSDF).

While the costs for permitting and licensing are relatively small (less than 3% of the total project cost), obtaining the permits and licenses can take months to years to complete and can impact the schedules for site preparation, construction, and plant start-up and, therefore, indirectly drive up the cost of the project.

Adjusting for location is an important consideration when estimating all project costs. Labor costs, supporting infrastructure, regulations and taxes, and transportation costs can vary greatly between locations and must be included in estimating all FC components. Location adjustment factors are available from various sources such as the *Richardson's International Construction Factors, Location Cost Manual*.[27]

Working capital

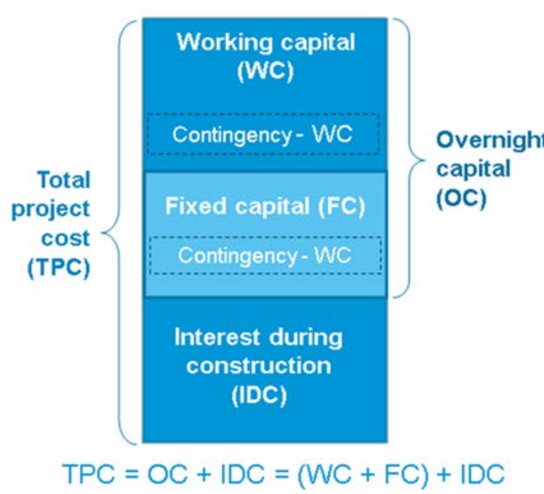
Working capital (WC) consists of

- Raw materials and supplies required for plant start-up
- Operating expenses prior to receipt of revenues such as salaries and wages
- Other miscellaneous expenses and contingency

In chemical plants, WC has typically ranged between 10% and 20% of the TPC. This percentage can increase to as much as 50% if the feedstock is seasonal in nature (e.g., corn stover for cellulosic biofuel). The WC can be calculated by estimating the operating expenses for 30 days at full planned operation levels. Most projects also include a WC contingency ranging from 20% to 100% to account for unknown operating expenses and payment interruptions. The contingency percentage is derived from estimating the perceived operational risks (plant performance, feedstock prices, and payments). Debt financing of a project may require higher WC contingency as financial institutions tend to be more risk averse and rate risks higher than industry.

Since revenues are normally received 30 days after products are delivered, the cost of both raw materials (i.e., feedstock) and required supplies for 30 days of full operations are normally funded by the WC. Operational wages and other expenses for this initial period of plant operation are also funded through the WC. The cash kept on hand for known-unknown operating expenses and taxes payable, both corporate and property, are also part of the WC. Because corporate taxes are normally paid quarterly, the WC includes estimated corporate taxes for a 90-day period of operations (Figure D-1). Property taxes are usually paid annually, semi-annually, or quarterly and the WC will usually include some portion of

Figure D-1. Working capital components



[27] *Richardson's International Construction Factors, Location Cost Manual*, http://www.icoste.org/Book_Reviews/CFM-Info.pdf.

property taxes.

Location impacts on WC include distances to and reliability of feedstock supplies, local labor rates, and supporting local infrastructure. Location can also impact the final plant design because location-related risks must be mitigated and this is best done through integrated design solutions.

Health, safety, and environmental costs

Over the years, the requirements for the occupational health, safety, and environmental functions in the plant have increased substantially. There is no general guideline for estimating these costs for the process industry. Most project planners include these costs as part of an integrated plant or process unit design. Pollution prevention and pollution minimization techniques should be part of the design strategy. In process plants, the heat recovery section normally has devices to capture sulfur emissions. The wastewater treatment section includes the costs associated with building a wastewater pond or purification of the wastewater discharged to environment.

All existing government regulations in effect that impact plant profitability are considered in the plant design and analysis. Proposed and potential future government regulations that could increase plant costs can be considered. EIA typically does not include the effects of proposed regulations in its reference case projections, but often does consider alternate cases where alternate laws or regulations are in effect.

Cost of project financing and cost of capital

Projects are financed through two means:

- **Equity** financing is provided by the owners or shareholders of the company. The cost of equity capital is measured as the return on equity (ROE).
- **Debt** is acquired from financial institutions to pay for the construction. The debt plus accrued interest is normally repaid over the loan repayment period or tenor and is usually described as amortized capital using the interest rate of the loan. Usually debt financing occurs as a single construction loan that accrues interest during construction based on the draw schedule. Once the plant becomes operational, the loan is usually converted to an amortized loan at a lower rate. This higher rate during construction acts as an extra incentive for the project to be completed quickly. Different sources of debt financing may exist for a project at different rates and terms. The higher the project risk, the fewer the sources because each has a different level of maximum risk it will finance. If project risk can be reduced (e.g., loan guarantees), more options will exist for financing at more favorable terms.

The debt/equity financing ratio varies depending on several factors such as plant capacity and project risks, the credit-worthiness of the plant owners, the source of the financing, and prevailing financial market conditions. It is not uncommon in engineering economic analysis to set equity equal to debt (i.e., 50/50) for the purpose of calculating project financing cost terms such as the accrued interest during construction (IDC) and weighted acceptable cost of capital (WACC). The appropriate industry debt/equity financing ratio is used if known. A consistent risk-based method should be used in estimating financing conditions to permit technology comparisons.

Interest during construction (IDC)

The interest that accrues during the construction period can be a significant project cost. Companies carefully plan their construction schedules and all the activities and purchases that impact the construction schedule to minimize the construction period and accrued interest. A construction loan can have a higher interest rate than the amortized loan interest rate. The accrued interest is based on when the construction loan monies are actually drawn. Construction draw schedules are developed and approved prior to construction but can be delayed or accelerated based on the terms of the construction loan. Since construction can take years to complete with multiple draws, equity may be used to fund the lower-cost initial phases of the project with construction loan draws taken during the latter and higher-cost major construction phases. Any delays during major construction will likely add to both the direct and indirect costs of the project including additional accrued interest.

Analysis of how interest rates affect competitiveness occurs only after a technology project appears competitive. High, low, and expected interest rates can be examined to understand the effect on IDC and the importance of government assistance such as federal loan guarantees and incentives from state and local governments.

If plants are purchased through a “turnkey” or similar contract, the accruing interest will not be transparent because the contractor’s construction loan interest is imbedded in the turnkey price and must be inferred using the construction period, an estimated loan rate, and an estimated draw schedule.

Learning, scaling and optimism

Learning

As the same technology is repeatedly deployed, the cost of building additional plants or units declines due to a reduction in errors or lessons learned from earlier projects. This concept of estimating the rate of learning was first used in industry in the 1920s and 1930s and published in 1936 by T.P. Wright in estimating cost reductions that would occur in repetitive airplane assemblies.28 Since then, many industries have used this learning concept to estimate future costs of repetitive processes. Learning is useful if the plants under consideration have an identical or nearly identical configuration. This has been observed in the electric power industry where plant configurations are fairly consistent. Although, different byproducts may be produced, the primary objective of that industry is to produce a single product – electricity. By contrast, most process industry plants have a variety of configurations and produce a number of outputs and byproducts. EIA energy models incorporate learning, which impacts deployments rate estimates. The learning rate is the cost reduction percentage expected when the cumulative production is *doubled*.

[28] T. P. Wright, “Factors Affecting the Cost of Airplanes,” *Journal of the Aeronautical Sciences* (February 1936).

$$C_N = C_1 N^{-b}$$

N = cumulative number of units built
C_N = cost to build the N^{th} unit
C_1 = cost to build the first-of-its-kind unit

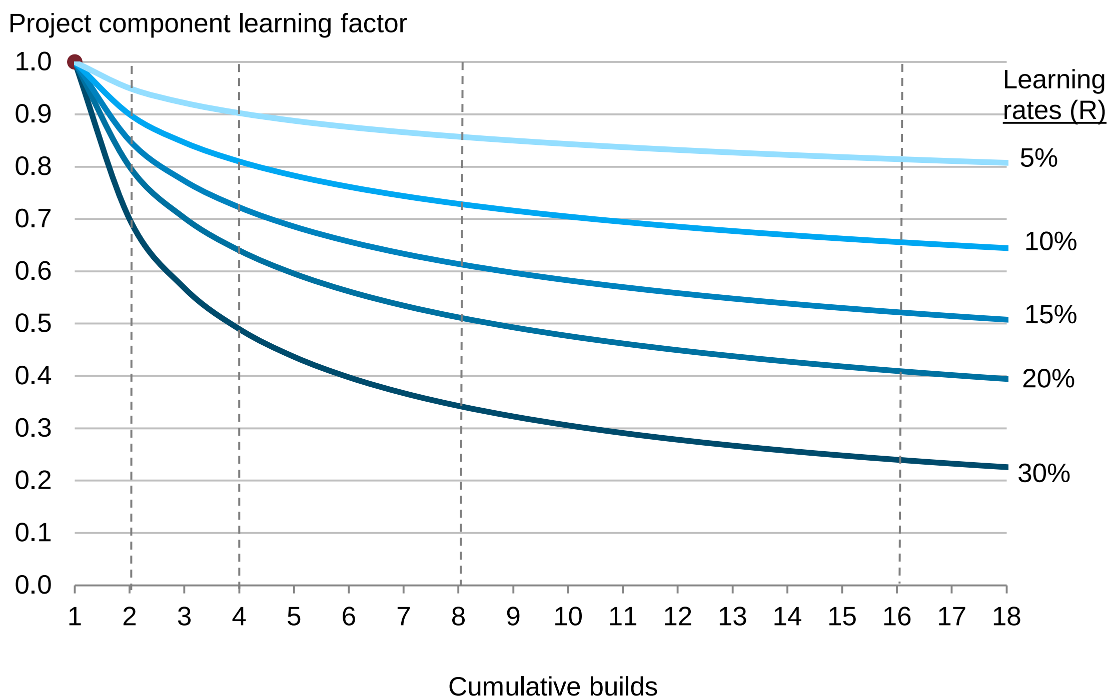
b = index of learning
R is the learning rate
2^{-b} is defined as the progress ratio

$$R = (1 - 2^{-b})$$

$$b = -\log(1-R) / \log(2)$$

Because plant components are at different levels of maturity, learning rates are estimated at the component level rather than at the plant level. Different learning rates will result in different estimates of project component costs for future builds (Figure D-2). Because a significant portion of the plant may be fully mature, learning rates for the entire plant cost will be much smaller than for the aggregated individual technology components.

Figure D -2. Learning curves at various rates



Notes: Learning curves are for illustration purposes only.
Cumulative doubling indicated by vertical dashed lines at 2, 4, 8, and 16 cumulative builds.

Source: EIA-generated learning factor (N-b) curves, part of the learning rate equation (CN = C1N-b).

Learning rates are calculated based on historical data. The frequency with which this cost reduction pattern is found in practice sometimes leads to an incorrect impression that the learning curve can be arbitrarily applied to technology projects. Learning rates must be properly documented to minimize the tendency for overestimating the learning effect.[29]

Scaling

Scaling has been described in detail for estimating equipment costs when actual costs from bids, catalogs, or cost guides are not available. In some cases, scaling is used to estimate the cost of the entire project. Scaling is applicable to equipment costs, but cannot be extended to an entire project unless:

- The actual cost of multiple projects with identical configuration(s) is available, and cost data is sufficiently consistent to generate cost curves useful for estimating equipment costs
- Projects consist of few pieces of equipment that perform identical functions (e.g., refinery units)
- FC and WC do not depend on utilization factors
- FC is independent of capacity utilization of the plant

Other factors affecting FC parameters used in EIA's technology assessment are:

- Technology – normally identified by process technology name
- Capacity – expressed as barrels/stream day (b/sd)
- Overnight cost – expressed in total dollars or dollars per unit production rate (dollars per barrel per stream day, $/b/sd)
- Contingency factor – used to adjust the cost for unknown factors not considered in the assessment

Optimism

Optimism refers to taking an optimistic viewpoint about first-of-a-kind project risks that are unknown. This viewpoint tends to underestimate project costs for new technologies and can be accounted for by scaling up the TPC by an optimistic factor. Subsequent plant builds will need less optimism adjustments because actual project costs are available.

Both learning and optimism are considered when estimating plant builds for new technologies.

[29] EIA develops learning rates at the component level based on the level of experience with the design component. See U.S Energy Information Administration, *Assumptions to the Annual Energy Outlook 2015*, p 166, http://www.eia.gov/forecasts/aeo/assumptions/pdf/0554(2015).pdf.

Appendix E. Reporting analysis results

The deliverable from an engineering economic analysis is a clear results report that provides the reader with a full understanding of the technology, how it is likely to be deployed, and how it can compete in the market. Since the results are used for different purposes, the report contains sections that can stand alone for each type of reader. The modeler needs to know the assumptions and parametric values required to properly represent the technology and can correlate the analysis to the scenarios that are modelled (e.g., high resource case, high price case). The technical executive needs a summary that highlights the advantages and disadvantages of the technology in the market and the sensitivities of the technology to market and regulatory conditions. The general public needs an easy-to-follow explanation of the technology and why it is likely or unlikely to penetrate the market. The report does not merely list the analytical results. It illustrates critical thinking (i.e., the relationships and interactions between the technology and the market).

The report uses the EIA format with EIA formatted figures and tables and correct footnoting and referencing. As a minimum, the report includes the following sections:

- Executive summary
- Technology description
- Project design and costs
- O&M costs and market conditions
- Sensitivities
- Modeling assumptions
- Detailed summary and recommendations
- References

Depending on the complexity of the technology and market dynamics, additional sections can be prepared.

Executive summary provides a short description of the technology, its current deployment in the United States and globally, its current and potential competitiveness, and the main findings of the analysis. The main findings are likely to be the deployment sensitivities and how prices, regulations, and market access impact deployment rates. The summary is typically one or two pages in length, with no more than one or two graphics that illustrate the main take-aways. The summary must be able to stand on its own merit and answer two questions regarding cost to produce and cost sensitivities.

Technology description clearly explains the main advantages and disadvantages of the technology and what control its market competitiveness. Advantages/disadvantages are highly dependent on market and regulatory conditions. The technology description should be framed in the context of the existing technologies with which it competes, including future expectations.

Project design and costs are presented in this section along with industrialization options for technology deployment. Winning design options and estimation methods are explained. Project costs include a discussion of any unique design features that impact the costs. Assumptions used in estimating costs are described and tables are used to itemize costs for the most likely plant configurations. Use of engineering tools such as CHEMCAD® is described.

O&M costs and market conditions explain how the plant is operated to generate maximum profits. Detailed O&M costs, including feedstock and product price profiles, are presented as graphs to clearly display expected trends over the plant lifetime. Uncertainties in costs and prices are discussed, including the assumptions related to uncertainty limits. Net present value (NPV) and return on investment (ROI) values are provided under the set of assumptions analyzed. Breakeven curves are presented and discussed to point out the relative profit drivers. Existing costs, prices, and competition profit margins are shown to illustrate how competitive the technology is under current and potential future conditions.

Sensitivities identify and illustrate the profit sensitivities to plant operations, market costs and prices, and other market conditions. Breakeven price curves are used to illustrate the magnitude of the dominant profit drivers. Sensitivities are described in terms of current and most likely future conditions.

Modeling assumptions are written in coordination with the modelers to ensure that analysis results are transferrable to the models. This section serves as a reference document for modelers attempting to represent technologies. Assumptions and parameters are tabulated to show how values and technology characteristics are determined and describe any underlying assumptions that could impact the competitiveness of the technology.

Detailed summary and recommendations is a section for general readers that details the technology and technical characteristics that drive competitiveness in select market scenarios. Future analysis and associated data requirements are included to address any analysis issues. This section answers technology, project, and market questions.

References used in the analysis are listed to indicate how and where the references were used. If possible, hyperlinks and the date last accessed are included. By listing all the sources for data and information, the reader has a better understanding of the level of effort to complete and replicate the analysis.

Appendix F. Top-down technology analysis example

This appendix presents one of the technology assessment processes used by EIA in analyzing Gas-to-Liquid (GTL) Fischer-Tropsch technologies. The Fischer-Tropsch process refers to using carbon monoxide and hydrogen to produce hydrocarbons.

The first step in a top-down estimate is to collect the data required to estimate the base overnight capital cost. From publically available sources, EIA prepared Table F-1, which compares key parameters across five GTL plants that are operational or under construction worldwide. Note that the overnight capital costs have all been converted to 2014 U.S. dollars.

Table F-1. Comparative data from existing GTL plants

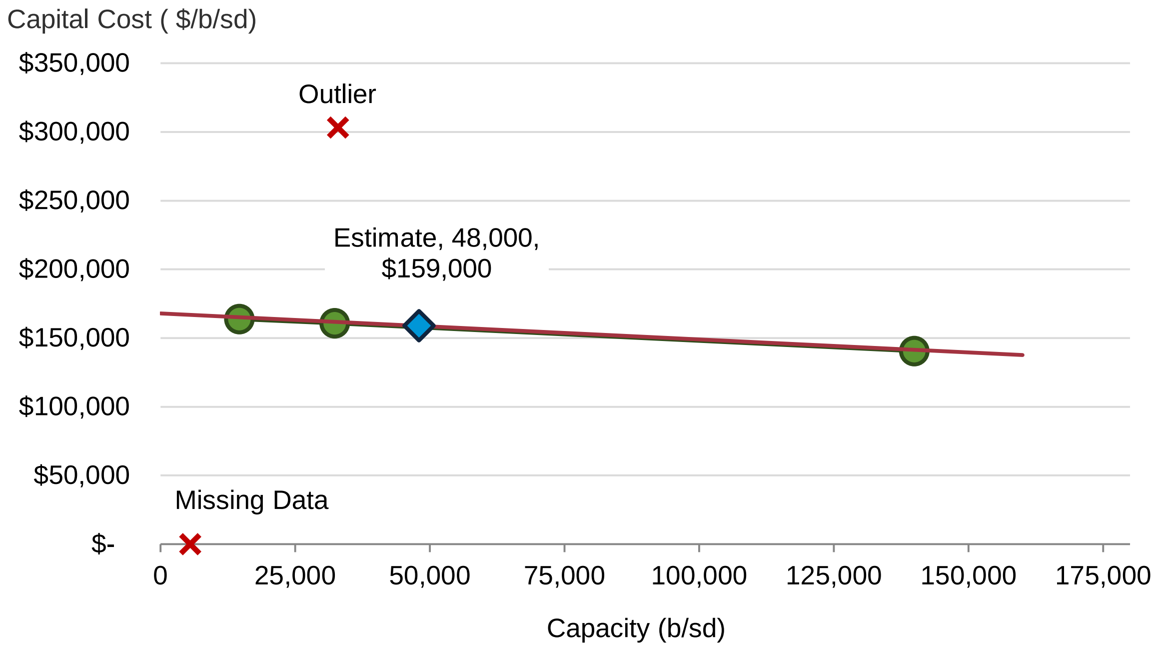
Plant operator and location	Capacity b/sd	Operational year	Capital in operational yr million US$	CPI multiplier	Base overnight cost 2014$/b/sd
Shell, Bintulu, Malaysia	14,700	1993	1,500	1.60	163,000
Sasol, Sasolburg, So. Africa	5,600	1994		1.55	
Sasol / Chevron, Oryx, Qatar	32,400	2006	4,500	1.15	159,000
Shell, Pearl, Qatar	140,000	2011	19,000	1.03	140,000
Chevron, Escravos, Nigeria	33,000	2014	10,000	1.00	309,000

Sources: http://www.shell.com.my/products-services/solutions-for-businesses/smds/process-technology.html; http://www.sasol.com/innovation/gas-liquids/overview; http://www.shell.com/global/aboutshell/major-projects-2/pearl/overview.html; http://www.chevron.com/deliveringenergy/gastoliquids/; http://www.nytimes.com/2012/12/18/business/energy-environment/sasol-betting-big-on-gas-to-liquid-plant-in-us.html?_r=0; http://www.meed.com/supplements/2013/gas-to-liquids/oryx-gtl-runs-close-to-capacity/3186983.article.

Two projects were eliminated from the estimation (Sasol, South Africa project is missing cost data and Escravos, Nigeria project is a cost outlier). The resulting order-of-magnitude estimate has an average capacity of 60,000 b/sd with an overnight capital cost of $157,000/b/sd. Because additional information was available indicating the likely capacity was 48,000 b/sd, the estimate was further adjusted to 48,000 b/sd with an overnight capital cost of $159,000/b/sd (Figure F-1).

Existing project cost data is consistent with economy-of-scale effects with the larger plant having a lower unit cost. The data suggests that overnight capital costs are reduced approximately $190/b/sd for each 1,000 b/sd increase in plant size. If additional information was available about why the outliner was costing so much more to build, an isolation of the additional cost drivers might be possible and an adjusted outliner cost included in the estimate.

Figure F-1. Overnight capital cost estimate (top-down approach) – GTL example



Sources: http://www.shell.com.my/products-services/solutions-for-businesses/smds/process-technology.html; http://www.sasol.com/innovation/gas-liquids/overview; http://www.shell.com/global/aboutshell/major-projects-2/pearl/overview.html; http://www.chevron.com/deliveringenergy/gastoliquids/; http://www.nytimes.com/2012/12/18/business/energy-environment/sasol-betting-big-on-gas-to-liquid-plant-in-us.html?_r=0; http://www.meed.com/supplements/2013/gas-to-liquids/oryx-gtl-runs-close-to-capacity/3186983.article.

Estimation of feedstock cost

The amount of feedstock consumed and products produced using these technologies are required for the estimation.[30] The Oryx GTL plant uses 9,250 standard cubic feet of gas per barrel of liquid fuel produced (scf/bbl); whereas Pearl GTL uses 11,400 scf/bbl. For a generic GTL plant, 10,000 scf/bbl is used. The feedstock cost depends on how many days the facility is operational. In an order-of-magnitude estimate, production includes the down time for the plant. Using the heating value of natural gas as 1,024 Btu/scf and the heating value of liquid products as 139,000 Btu/gallon, the overall efficiency of the plant is approximately 57%, which is similar to values reported in literature.

Amortized capital cost

At an overnight cost of $159,000/b/sd, an interest rate of 12% for all periods (construction and plant lifetime), a 25-year plant life, and a 4-year construction period with 4 equal draws, $53,800/b/sd of

[30] Olga Clebova, “Gas to Liquids: Historical Development and Future Prospects”, NG-80, Oxford Institute for Energy Studies, 2013; Leidos, “Liquid Fuels Technology Assessments – Non-Petroleum Refinery Processes.” study commissioned by EIA, 2015; Gerald N Choi, Sheldon Kramer and Samuel S Tam. “Design and economics of a Fischer-Tropsch plant for converting natural gas to liquid transportation fuels,” Argonne National Laboratory, 2002; Chul-Jin Lee, Youngsub Lim, Ho Soo Kim, and Chonghun Han, “Optimal Gas-To-Liquid Product Selection from Natural Gas under Uncertain Price Scenarios,” *Industrial and Engineering Chemistry Research*, 2009.

interest is accrued during construction for a capital cost of $212,800/b/sd and an amortized capital cost of $27,100/b/sd for 25 years. The resulting CRF is 0.1275.

Estimation of O&M costs

Estimated O&M costs vary considerably; the costs are equivalent to 20-70% of total capital costs. An average value of 45% is used for this estimate, for illustration purposes only. Since a capacity factor of 85% is used, this cost is adjusted for the average time the plant is operating during a year (310 stream days).

O&M Cost = ($27,100/b/sd * 45%) ÷ (365 days/year * 85%) = $39.30/b

Revenue and feedstock costs

A 48,000 b/sd capacity plant operating 310 stream days can consume 149 Bcf of natural gas and produce 14.9 million barrels of liquid fuels in a given year.

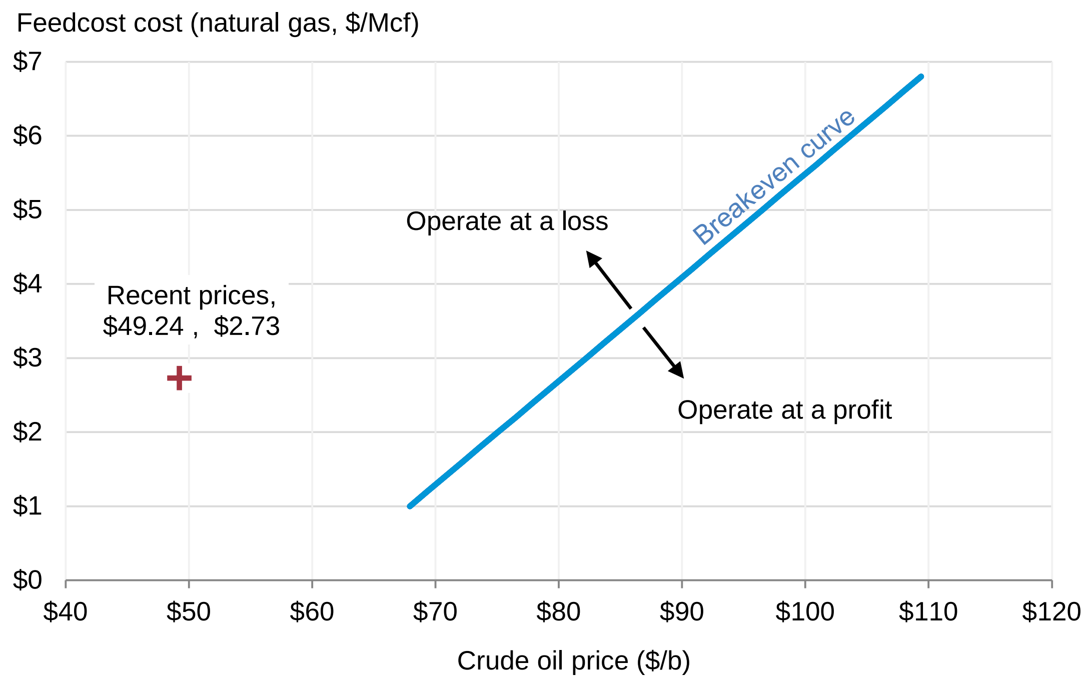
Diesel is considered the key product from a GTL plant and revenue is based on the diesel price. From an analysis of recent monthly average wholesale prices, diesel prices are directly dependent on crude oil prices. The approximate relationship between the two prices is

Diesel price ($/gal) = 0.5 + 0.025 * Crude oil price ($/b)[31]

If cash flows (revenues and expenses) are estimated for a range of feedstock costs and product prices, a breakeven analysis can be done to illustrate the market conditions (feedstock costs and product prices pairs) where profits are zero. The curve is generated by setting the costs equal to the revenue and solving for the product price given the feedstock cost. These breakeven conditions can be plotted in a nomogram along with current costs and prices point to illustrate the competitiveness of the technology on a purely economic basis (Figure F-2). Above the curve, the plant is operating at a loss and below the curve, a profit. Since top-down estimates have large uncertainties, only conditions (costs and prices) far from the breakeven curve on the nomogram should be considered indicative of technology profitability. For conditions close to the curve, a more detailed analysis should be done.

[31] Calculated from EIA monthly wholesale price series over January 2014 – August 2015 for No. 2 diesel for resale, http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMA_EPD2D_PWG_NUS_DPG&f=M, and refiner acquisition cost for composite crude, http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=R0000____3&f=M.

Figure F-2. Breakeven analysis – GTL example



Source: U.S. Energy Information Administration, illustrative example of a breakeven curve.