Plant economics

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Capital

To build and run a chemical/industrial plant it is necessary to have an appropriate capital.

This capital can be allocated by the company that decides to build the plant, borrowed from banks or collected by a trust of investors.

Individual entries for the capital needed to build and startup the plant are:

FCI: Fixed Capital Investment

WC: Working Capital

TCI = **FCI** + **WC**: Total Capital Investment

Fixed capital investment

The fixed capital investment, **FCI**, can be further split into:

MFCI: Manufacturing Fixed Capital Investment (direct costs)

NMFCI: Non-Manufacturing Fixed Capital Investment (indirect costs)

The following relation holds:

FCI = **MFCI** + **NMFCI**

The FCI is the capital required to purchase and install the equipment and components needed to turn key the plant.

MFCI: site preparation, equipment, instrumentation, piping, insulation, foundations, …

NMFCI: land, offices, laboratories, locker rooms, canteen, bar, auxiliary buildings, loading and unloading areas, waste storage, …

Working capital

Working Capital, **WC**, is the amount invested in:

- Raw materials;
- Semi-finished products;
- Finished products;
- Drawn invoices not yet paid;
- Invoices to be issued;
- Available cash to purchase raw materials, pay wages, pay bills, interests, … ;
- Taxes.

Usually, the raw materials are stored in sufficient quantity to satisfy the production activity for at least **one month**.

In case of final seasonal products, the storage of raw materials and finished products must ensure the operation over longer periods (*i.e.* a few months).

Cost indexes

A **cost index**, is a number that indicates the value of a piece of equipment or a plant at a given time, compared to that of the same unit or plant at a reference time.

$$\text{Present cost} = \text{Original cost}\left(\frac{\text{present cost index}}{\text{original cost index}}\right)$$

Cost indexes are used to perform an **estimate** of the actual cost of a process unit if the cost of the same unit, referred to a past period, is known.

It is generally *not recommended* to use cost indexes when the time interval is longer than 10 years.

The cost index can also be used to **extrapolate** the present value of a process unit or a whole plant in the near future (for instance at the expected time of purchase compared to the design time).

Cost indexes

The most commonly used cost indexes in the process industry are:

Marshall & Swift (M&S): *All industries* and *Process Industry* (base 100 in 1926)

Nelson-Farrar: *Refinery construction index* (base 100 in 1946)

Chemical Engineering (CEPCI): *Plant cost index* (base 100 in 1959)

Vatavuk (VAPCCI): *Air pollution Control* (base 100 in 1994)

Cost indexes

	Marshall and Swift Equipment Cost Index		Nelson-Farrar Refinery (inflation) index	Chemical Engineering Plant Cost Index (CEPCI)
Year	All Industries	Process Industry		
1995	1027.5	1029.0	1392.1	381.1
1996	1039.2	1048.5	1418.9	381.7
1997	1056.8	1063.7	1449.2	386.5
1998	1061.9	1077.1	1477.6	389.5
1999	1068.3	1081.9	1497.2	390.6
2000	1089.0	1097.7	1542.7	394.1
2001	1093.9	1106.9	1579.7	394.3
2002	1104.2	1116.9	1642.2	395.6
2003	1123.6		1710.4	402.0
2004	1178.5		1833.6	444.2
2005	1244.5		1918.8	468.2
2006	1302.3		2008.1	499.6
2007	1373.3		2251.4	525.4
2008	1449.3		n.a.	575.4
2009	1468.6		2217.7	521.9
2010	1457.4		2337.6	550.8
2011			2435.6	585.7
2012				584.6

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Capital investment

The capital investment includes the money needed to buy, install, and operate a plant.

In general, to get an order of magnitude of the **capital investment** required to build and run a plant we look at the following table which expresses the costs as a **percentage of the FCI**:

Component	Range of FCI, %
Direct costs	
Purchased equipment	15-40
Purchased equipment installation	6-14
Instrumentation and controls (installed)	2-12
Piping (installed)	4-17
Electrical systems (installed)	2-10
Buildings (including services)	2-18
Yard improvements	2-5
Service facilities (installed)	8-30
Land	1-2
Indirect costs	
Engineering and supervision	4-20
Construction expenses	4-17
Legal expenses	1-3
Contractor's fee	2-6
Contingency	5-15

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Capital investment

Here follows an example where we assume that the purchase cost of the equipment is equal to **€ 1 million**. After having selected a percentage of the FCI for each item, we normalize and obtain:

Components	Selected % of FCI	Normalized % of FCI	Estimated cost
Purchased equipment	25	22.9%	1,000,000
Purchased equipment installation	9	8.3%	360,000
Instrumentation and controls (installed)	10	9.2%	400,000
Piping (installed)	8	7.3%	320,000
Electrical systems (installed)	5	4.6%	200,000
Buildings (including services)	5	4.6%	200,000
Yard improvements	2	1.8%	80,000
Service facilities (installed)	15	13.8%	600,000
Engineering and supervision	8	7.3%	320,000
Construction expenses	10	9.2%	400,000
Legal expenses	2	1.8%	80,000
Contractor's fee	2	1.8%	80,000
Contingency	8	7.3%	320,000
	109	**100.0%**	**4,360,000**

It must be emphasized that **the uncertainty of this assessment is ±30%**.

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Equipment cost

To evaluate the cost of a process unit with given *potential* S_b, knowing the cost of a similar process unit with *potential* S_a in absence of further information, one can use the so-called **0.6 power law**:

$$\text{Cost of equipment } b = \text{Cost of equipment } a \left(\frac{S_b}{S_a} \right)^{0.6}$$

Often we take as ***potential*** S_i the **capacity** of the equipment.

N.B.: this equation plotted on a bi-logarithmic diagram is a straight line whose slope is 0.6.

Equipment cost

It is possible to replace the generic coefficient 0.6 with a specific value α related to the equipment typology:

Apparecchiatura	Dimensioni	Esponente α
Soffiante centrifuga	0.5-4.7 m3/s	0.59
Cristallizzatore batch sotto vuoto	15-200 m3	0.37
Compressore, singolo stadio	0.05-0.5 m3/s	0.79
Essiccatore sotto vuoto	1-10 m2	0.76
Essiccatore atmosferico	1-10 m2	0.40
Ventilatore centrifugo	0.5-5 m3/s	0.44
Ventilatore centrifugo	10-35 m3/s	1.17
Scambiatore di calore shell & tube testa flottante	10-40 m2	0.60
Scambiatore di calore shell & tube testa fissa	10-40 m2	0.44
Ribollitore kettle con camicia	1-3 m3	0.27
Motore a sicurezza intrinseca	4-15 kW	0.69
Motore a sicurezza intrinseca	15-150 kW	0.99
Reattore acciaio inossidabile	0.4-4 m3	0.56
Serbatoio a testa piana acciaio al carbonio	0.4-40 m3	0.57
Colonna di distillazione acciaio al carbonio	500-1.E6 kg	0.62
Piatto a campanelle	1-3 m	1.20
Piatto forato acciaio al carbonio	1-3 m	0.86

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Equipment cost

By introducing the size factor and the time factor, it is possible to determine the actual cost of a piece of equipment compared to another one whose date of quotation/purchase is known:

$$\text{Cost of equipment } b = \text{Cost of equipment } a \left(\frac{S_b}{S_a}\right)^{\alpha} \frac{C.I._b}{C.I._a}$$

In some situations it is also possible to adjust the economic evaluation by introducing suitable correction factors for the **operating pressure** and the **material of construction**:

$$\text{Cost of equipment } b = \text{Cost of equipment } a \left(\frac{S_b}{S_a}\right)^{\alpha} \frac{C.I._b}{C.I._a} \left(\frac{P_b}{P_a}\right)^{\beta} \left(\frac{M_b}{M_a}\right)^{\gamma}$$

Installation cost

The installation cost of a process unit takes into account: labor, foundations, supports, platform, erection.

The following table shows the **installation costs** as a percentage of the **purchase costs** of several process units:

Apparecchiatura	Costo di installazione %
Separatori centrifughi	20-60
Compressori	30-60
Essiccatori	25-60
Evaporatori	25-90
Filtri	65-80
Scambiatori di calore	30-60
Cristallizzatori	30-60
Serbatoi metallici	30-60
Miscelatori	20-40
Pompe	25-60
Colonne di distillazione	60-90
Cristallizzatori sotto vuoto	40-70

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Shipping expenses

The purchase cost of equipment is often quoted as **f.o.b.** or **free on board**. This means that the equipment, when shipped by sea, is transported from the manufacturer to the harbor wharf and then loaded on the ship. From then on it is up to the buyer to transport it up to the production site.

During the planning activity, in order to estimate the shipping cost of the equipment, we can consider it being approximately equal to 10% of the total equipment cost.

Other terms related to purchase and shipping are:

c.i.f.: Cost Insurance Freight (*i.e.* equipment cost + insurance + shipping)

f.a.s.: Free Along Side (in sea transportation, the manufacturer has no further responsibilities once the equipment has been unloaded on the wharf of the harbor)

f.o.t.: Free On Truck (in land transportation, the manufacturer has no further responsibilities once the equipment is loaded on the truck)

Instrumentation and control

By the term instrumentation and control we include the cost of equipment, installation, labor, the control system (DCS), any specific software for advanced control, optimization, supervision, operators training (OTS), …

The instrumentation and control cost can be in the range of **8-50% of the TDEC** (Total Delivered Equipment Cost). For chemical plants a value of 26% represents a suitable initial estimation.

Piping

The piping cost includes: pipes, valves, column packing, insulation materials, supports, silencers, manpower.

Lines: steam, water, air, sewer, …

In general, we can reach **80% of the TDEC** (Total Delivered Equipment Cost) which is equivalent to **20% of the FCI** (Fixed Capital Investment).

Power systems

The power system is mainly divided into:

1. Power lines
2. Lighting
3. Transformers and service systems
4. Instrumentation and control lines

Generally we can reach **15-30% of the TDEC** (Total Delivered Equipment Cost) equivalent to **4-8% of the FCI** (Fixed Capital Investment).

Buildings

The building costs include: storage area of raw materials and products, design + construction + manpower, hydraulic works, heating, cooling, lighting, auxiliary services.

Usually it can be reached **40-60% of the TDEC** (Total Delivered Equipment Cost) equivalent to **10-18% of the FCI** (Fixed Capital Investment) for a new plant built at a new production site.

Soil preparation

The cost includes: fence, leveling the ground, roads, links, loading and unloading are for freight trains, reducing environmental impact.

Generally we can reach **10-20% of the TDEC** (Total Delivered Equipment Cost) equivalent to **2-5% of the FCI** (Fixed Capital Investment).

Service equipment

By "service equipment" we mean the supply of steam, water, electricity, compressed air, fuel, waste storage and disposal, fire protection systems, shops, bars, dining hall, recreation room.

Usually we may reach **30-80% of the TDEC** (Total Delivered Equipment Cost) equivalent to **8-20% of the FCI** (Fixed Capital Investment).

HSE, health, safety, and environment

The importance of HSE, health, safety and environment, is increasing.

One of the most important economic terms is that related to the reduction of pollutants.

The associated costs with these items are often relevant.

At the same time, there are no guidelines to quantify spending on safety, health, and environment and relate them to TDEC and FCI.

Soil

The cost of soil, geological prospects, and property taxes depends on the area where the plant will be erected.

Sometimes the government facilitates the erection of industrial plants in some specific areas of the territory.

A rough estimate shows approximately **4-8% of the TDEC** (Total Delivered Equipment Cost) equivalent to **1-2% of the FCI** (Fixed Capital Investment).

Engineering and supervision

The engineering costs include the basic and detailed design, the use of internal or licensed by third parties software, CAD drawings, purchasing activities, accounting, cost analysis, travels, communications, …

Engineering costs account for about **30% of the TDEC** (Total Delivered Equipment Cost) equivalent to **8% of the FCI** (Fixed Capital Investment).

Legal fees

The legal costs are largely related to the contracts to be signed to purchase the soil, equipment and construction. Other important items are related to the management of business activities with government agencies (also referred to safety and environment).

An estimate of legal costs is about **1-3% of the FCI** (Fixed Capital Investment).

Construction and erection

These costs refer to the expenditures occurring during the erection of the plant, up to its startup.

They also include those temporary but necessary works for the erection of the plant: buy or rent the necessary tools for the excavation and construction, workers accommodation, *travel and living*, taxes, insurance, …

An estimate of this cost amounts to about **8-10% of the FCI** (Fixed Capital Investment).

Contractor's fees

Under this item we include the remuneration of the engineering company responsible for the design of the plant.

An estimate of this cost is about **2-8% of the TDEC** (Total Delivered Equipment Cost) equivalent to **1.5-6% of the FCI** (Fixed Capital Investment).

Contingencies

The **contingencies** heading includes the unforeseen events and the aspects that cannot be fully determined or known *a priori*.

Possible unforeseen events are: floods, storms, hurricanes, avalanches, landslides, earthquakes, lightning, sudden prices changes (*e.g.*, the price of crude oil in recent years), minor changes to the design specifications, errors in the performed estimates.

An estimate of this cost is **5-15% of the FCI** (Fixed Capital Investment).

1. Assessment of the capital investment

As shown in the example of page L8-8, one of the methods to obtain an estimate of the **capital investment** required for the construction of a new industrial plant is to bring the individual costs aforementioned to a percentage of the **TDEC** (**Total Delivered Equipment Cost**).

By doing so, we get the **TCI** (**Total Capital Investment**) by adding the percentages of the items/headings mentioned in the previous slides:

$$TCI = TDEC\left(1 + \sum_{i=1}^{N.ITEMS} f_i\right)$$

2. Assessment of the revenues

In general, the **revenues** are estimated on a yearly basis.

We need to know the amounts of products made in one year and the unit cost of each product (primary or secondary).

$$\text{Annual incomes } [€/\text{y}] = \sum_{i=1}^{NP} \left(\text{quantity of sold product, kg/y}\right)_i \left(\text{selling price, €/kg}\right)_i$$

It is worth observing that respect to a theoretical total amount of 8760 h/y, a plant generally runs for 90% of that value (*i.e.* about 8000 h/y).

3. Assessment of the total product costs

The third term of an economic analysis is the sum of the costs related to plant operation, product sales, payback of the invested capital, administration, management, research and development.

These items form the term: **Total Product Cost**.

We can outline two contributions to this term: **Manufacturing Costs** and **General Expenses**.

3. Assessment of the total product costs

Raw materials
Operating labor
Operating supervision
Utilities
- Electricity
- Fuel
- Refrigeration
- Steam
- Waste treatment and disposal
- Water, process
- Water, cooling

Maintenance and repairs
Operating supplies
Laboratory charges
Royalties (if not on lump-sum basis)
Catalysts and solvents

Subtotal A: Variable production costs

Depreciation
Taxes (property)
Financing (interest)
Insurance
Rent

Subtotal B: Fixed charges

Medical
Safety and protection
General plant overhead
Payroll overhead
Packaging
Restaurant
Recreation
Salvage
Control laboratories
Plant superintendance
Storage facilities

Subtotal C: Plant overhead costs

Manufacturing costs:
A + B + C

Executive salaries
Clerical wages
Engineering
Legal costs
Office maintenance
Communications

Subtotal D: Administrative expenses

Sales offices
Sales personnel expences
Shipping
Advertising
Technical sales service

Subtotal E: Distribution and marketing expenses

Research & Development

Subtotal F

General expenses:
D + E + F

TOTAL PRODUCT COST:
A + B + C + D + E + F

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Depreciation

The **depreciation** term refers to either the **decrease in value of assets** (*e.g.*, equipment) or the **allocation of costs of assets to periods** when those assets are used/work.

Equipment, buildings, and other machines require an initial investment to purchase them. This investment must be paid back and this is done by accounting for the depreciation as a production cost.

At the same time, the depreciation percentage of equipment is quite important for the assessment of the income tax. Each piece of equipment has a specific depreciation time. The depreciation percentage follows the rules established by the nation where the plant is erected. The simplest hypothesis consists in assigning a fixed percentage equal to the inverse of the depreciation period. More generally, there are different depreciation percentages for every working year.

Depreciation

The depreciation rate is often higher during the initial years and then decreases in the last years of the allowed depreciation period. The sum of every single annual depreciation percentage must be equal to 100%.

The use of a higher depreciation rate in the first years helps the company get the income tax reduced.

By doing so, the financial balance on the plant is improved/facilitated during the initial years when the company is expected to get some returns from the significant investments on construction, erection, and startup of the plant.

Gross profit, net profit, cash flow

The **gross profit**, g_j, for the year j is equal to the revenues from the sales, s_j, minus the total cost of production, c_j:

$$g_j = s_j - c_j$$

If we consider the depreciation, d_j, the **gross profit** becomes:

$$G_j = s_j - c_j - d_j$$

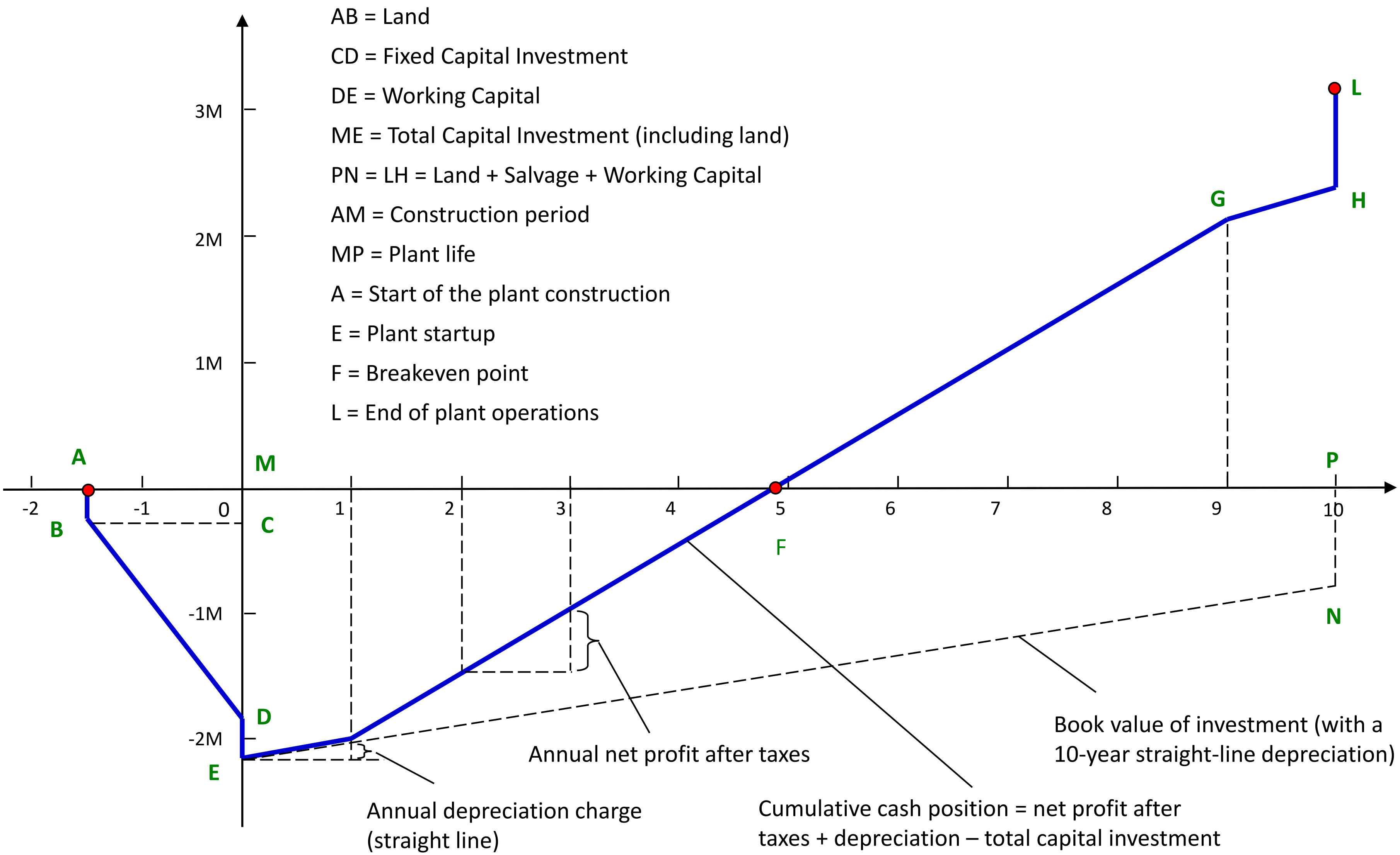
The **net profit**, N_{pj}, is equal to the gross profit once the taxation on revenues has been accounted for by means of a percentage Φ:

$$N_{pj} = G_j \left(1 - \Phi\right)$$

The **cash flow**, A_j, resulting from the operation of the plant is equal to:

$$A_j = N_{pj} + d_j$$

Cumulative cash flow



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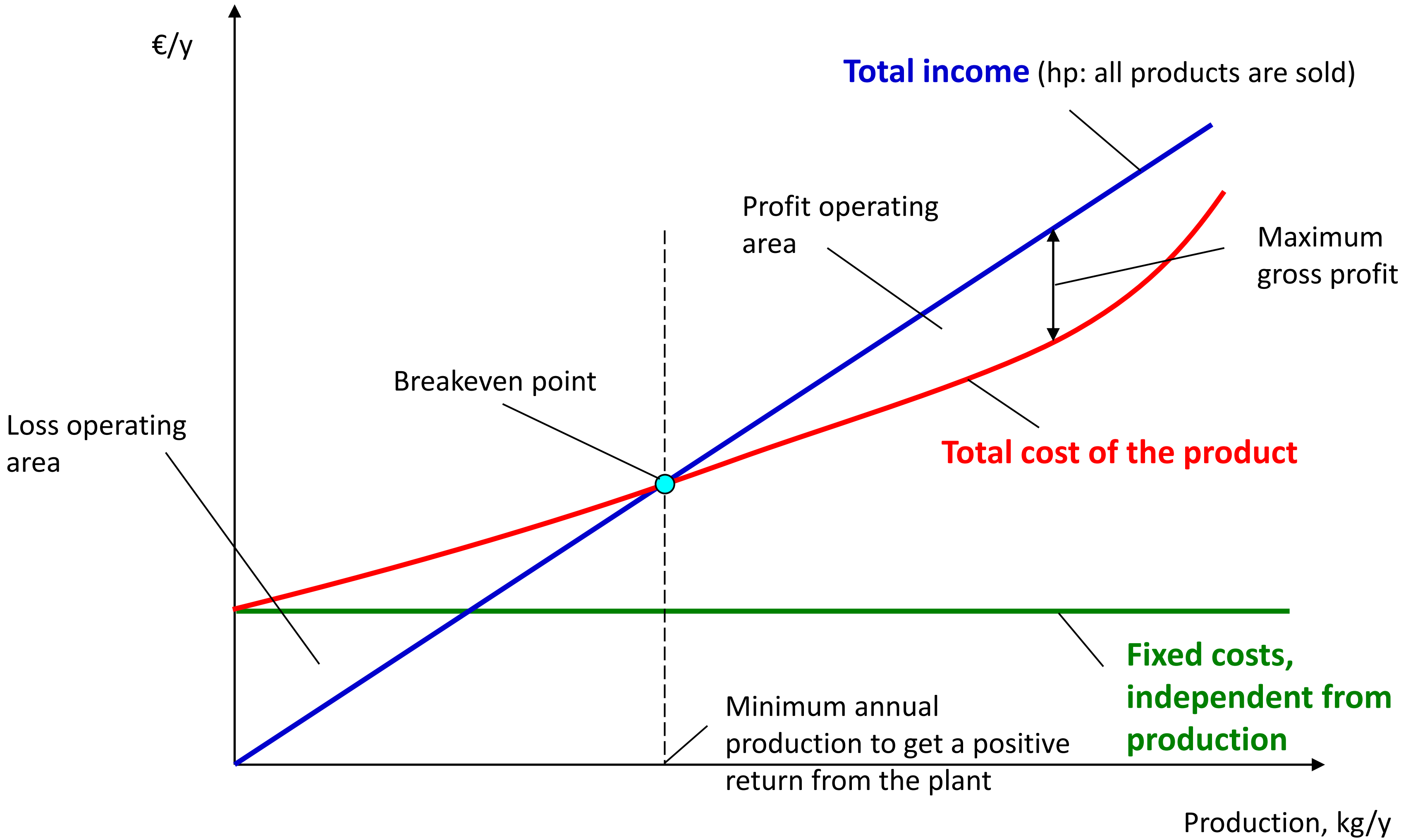
Break-even point of a chemical plant



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- Peters, M.S., K.D. Timmerhaus, R.E. West, Plant Design and Economics for Chemical Engineers, Mc Graw Hill, 2003.

- Oil&Gas Journal, 2014 – www.ogj.com