WASTE2ROAD

Techno-economic assessment of conceptual processes and life cycle costing

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Biomass liquefaction modelling online webinar, 20 April 2021

www.process-design-center.com

process development, integration, and optimization

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 818120.

Breda, The Netherlands

Purpose of TEA and LCC

- TEA
  - Evaluate the technical feasibility
  - Estimate the economic feasibility
  - Perform cost sensitivity studies
  - Drive the process design and modeling to minimal capital and/or operating cost
- LCC
  - Evaluate the project in term of total (life cycle cost), instead of total initial cost
  - Include environmental aspects

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TEA & LCC Methodology

Understanding the basic principles

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Type and accuracy of cost estimates

Estimate class	Level of project definition	End usage	Methodology	Expected accuracy range	Preparation effort
Class 5	0% - 2%	Concept screening	Capacity factored, parametric models, judgment, or analogy	-50 to +100%	1
Class 4	1% - 15%	Study or feasibility	Equipment factored or parametric models	-30 to +50%	2 – 4
Class 3	10% - 40%	Budget, authorization or control	Semi-detailed unit cost with assembly level line items	-20 to +30%	3 – 10
Class 2	30% - 70%	Control or Bid/Tender	Detailed unit cost	-15 to +20%	4 – 20
Class 1	50% - 100%	Check Estimate or Bid/Tender	Detailed unit cost with detailed take-off	-10 to +15%	5 – 100

Source, e.g:
Skills & Knowledge of Cost Engineering, S.J. Amos (Ed.), AACE International, 2004

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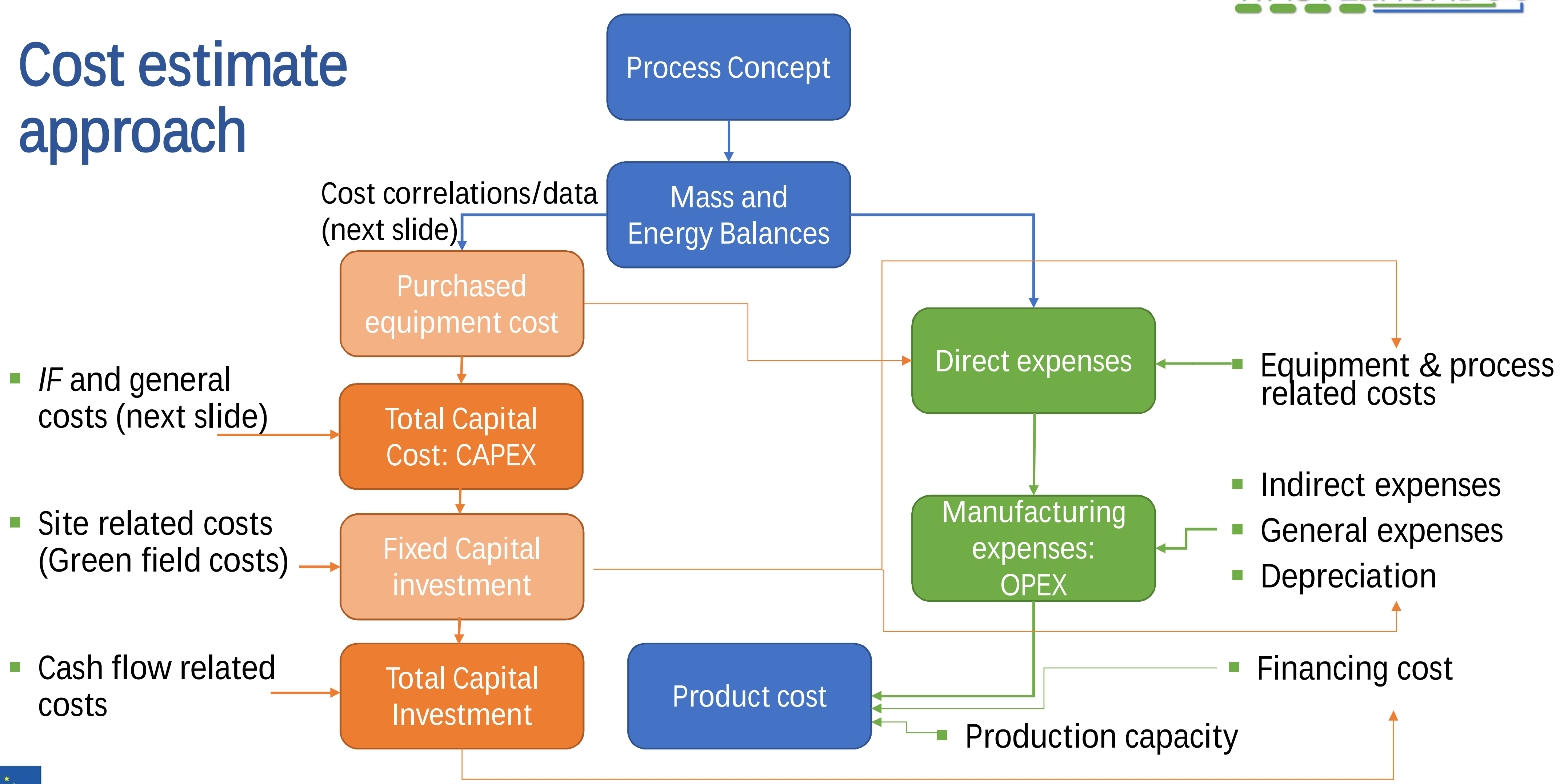
Cost estimate approach



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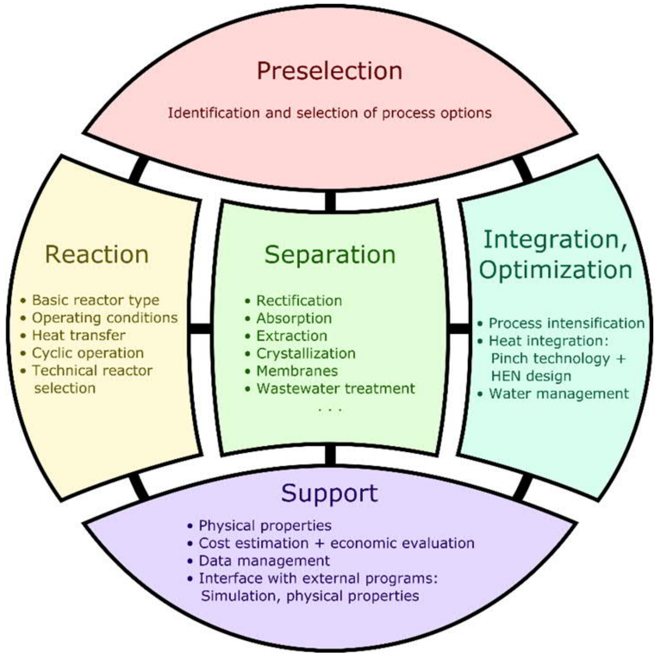
Sources of cost correlations/data for Purchased equipment cost

- Books / public literature
- Published cost tables of cost engineering associations
  - e.g. Dutch Association of Chemical Engineers
- Vendor quotations
- In-house cost correlations based on previous projects
- Software, e.g.
  - AspenONE Economic evaluator
  - PROSYN®
    - Unique knowledge-based system applied by PDC
    - Structured and systematic method to Conceptual Process Design (CPD), Techno-Economic Analysis (TEA) and Process Integration



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TEA methodology for Total Capital Cost: CAPEX from Purchased equipment cost

- CAPEX estimate based on a sized equipment list
  - Estimation of equipment cost from parametric models or quotations
  - Typically only main pieces of equipment considered
  - General facilities (OSBL/off-sites) included by factored approach

$$CAPEX = (1 + F_{contingencies})\left((1 + F_{unlisted})\sum_i (PEC_i \cdot IF_i) + \text{OSBL} + \text{site improvement} + \text{fees/engineering}\right)$$

Allowance for contingencies, typically 10-30%

Allowance for unlisted minor equipment (pumps, vacuum units, reflux drums etc), dependent on detail of study, e.g. 15%

Purchased equipment cost

Installation factor (typically range 2 - 5, equipment dependent)

Additional costs for outside battery limit equipment (e.g. storage, unitilities), site improvement, fees and engineering

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Capital cost calculation – important aspects

- Economy of scale:
  - CAPEX ~ capacity^n ($n < 1$)
  - Typical plant n = 0.6 – 0.7, but higher values for
    - Specific equipment, e.g. high-pressure vessels
    - Stacked equipment, like parallel membrane units (n = ~0.9)
    - When internal cost (absorbents, catalyst, equipment internals) dominate

Scale

$C_{new} = C_{base} * (A_{new}/A_{base})^n$

C = unit cost
A = capacity
n = scaling exponent

- Cost date
  - Correct from the cost date of the model/quote to the project date
  - E.g. Chemical Engineering Plant Cost Index (CEPCI)

Time value

$C_{new} = C_{base} * (CEPCI_{new}/CEPCI_{base})$

C = unit cost
$CEPCI_{new}$ = current year index value
$CEPCI_{old}$ = reference year index value

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Economic analysis parameters to express feasibility

- Key assumptions for economic analysis
- Production cost ($/t or $/L)
- DCFROR (discounted cash flow rate of return analysis) and determine the
  - NPV (Net present value)
  - IRR (internal rate of return)
  - MSP (Minimum selling price, the SP for NPV = 0 $)
- May also be company dependent or based on the client's preference
- Cash flow diagram

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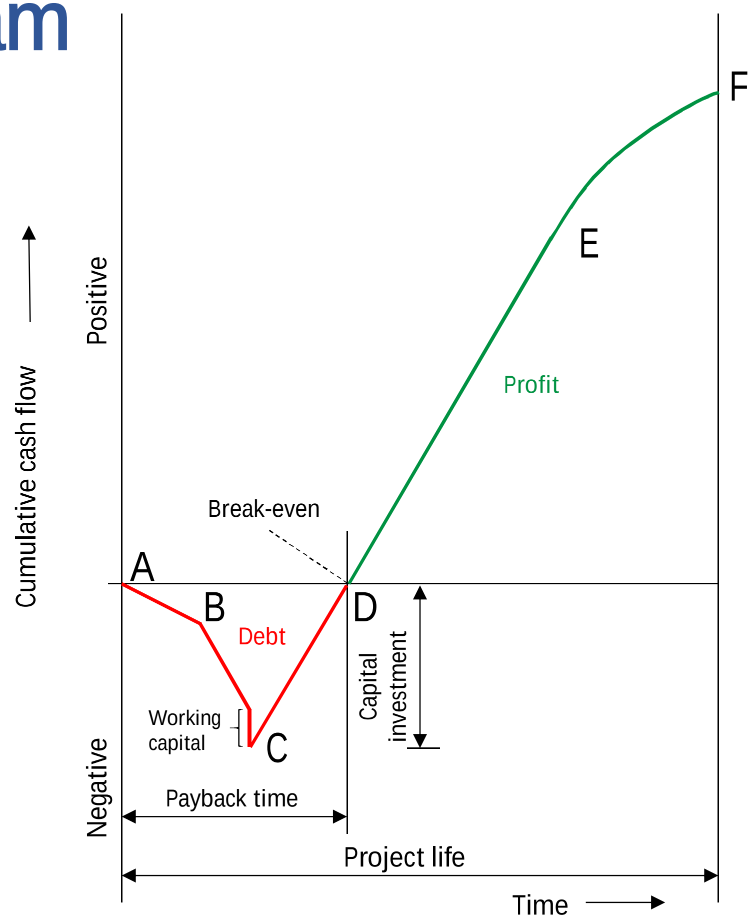
Cashflow diagram



Project cash-flow diagram

A-B Investment to design the plant

B-C Capital needed to build the plant

C-D Plant comes on stream and generates income from sales. At point D the cumulative cash flow returns to zero and the investment is paid off

D-E Cumulative cash flow is positive, the project is earning a return on investment

E-F Towards the end of the project life the rate of cash flow tends to fall off (increase in operating cost and/or falling sales volume/price)

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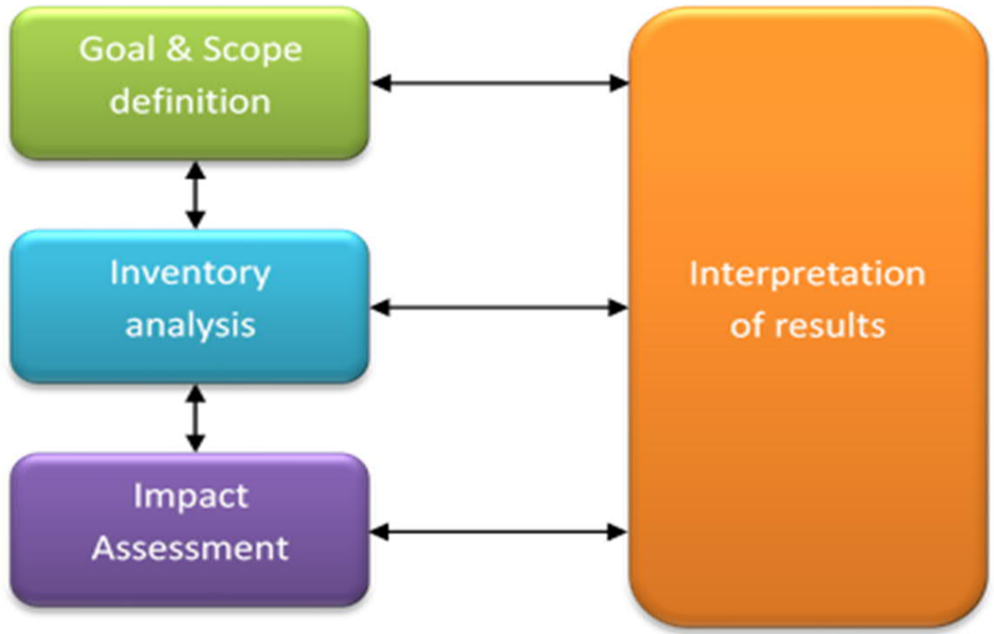
Life cycle costing - LCC

- No formal LCC methodology exist
- Based on environmental life cycle assessment (ISO 14040 & ISO 14044 guidelines)
- Differences between a LCA and LCC:
  - Items to be included in the inventory
- Different life phases
  - Production phase
  - Use phase
  - End-of-life phase
  - Environmental externalities & external costs



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LCC– Impact assessment EXAMPLE

	LCC Phase	Cost category	Unit	VC1 - example	VC2 - example
A&B	Production and Use phase	Capital and Operating costs	MM €/yr	€ 159.80	€ 317.6
C	End-of-life phase	Decommissioning	MM €/yr	€ 0.0	€ 1.86
D	Externalities	Green carbon tracking savings	MM €/yr	(€ 2.5)	(€ 0.08)
E		CO_2 carbon tax on non-biogenic emissions	MM €/yr	€ 0.05	€ 0.10
F	Total LCC cost (B + C + F + E)		MM €/yr	€ 157.35	€ 319.48
G	Total gasoline equivalent units produced		MM t/yr	220	282
H	Specific LCC cost		€/t	0.71	1.13
	Market cost or KPI value		€/t	0.9	0.9
	Margin achieved		€/t	0.18	(0.23)

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Practical examples and tips

Techno-economic assessment

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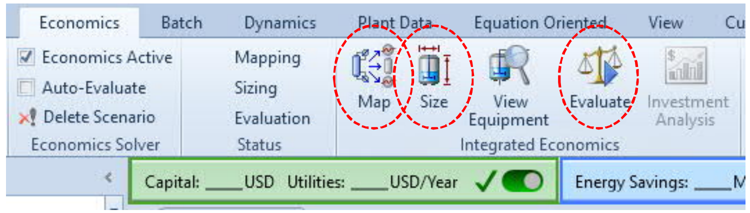
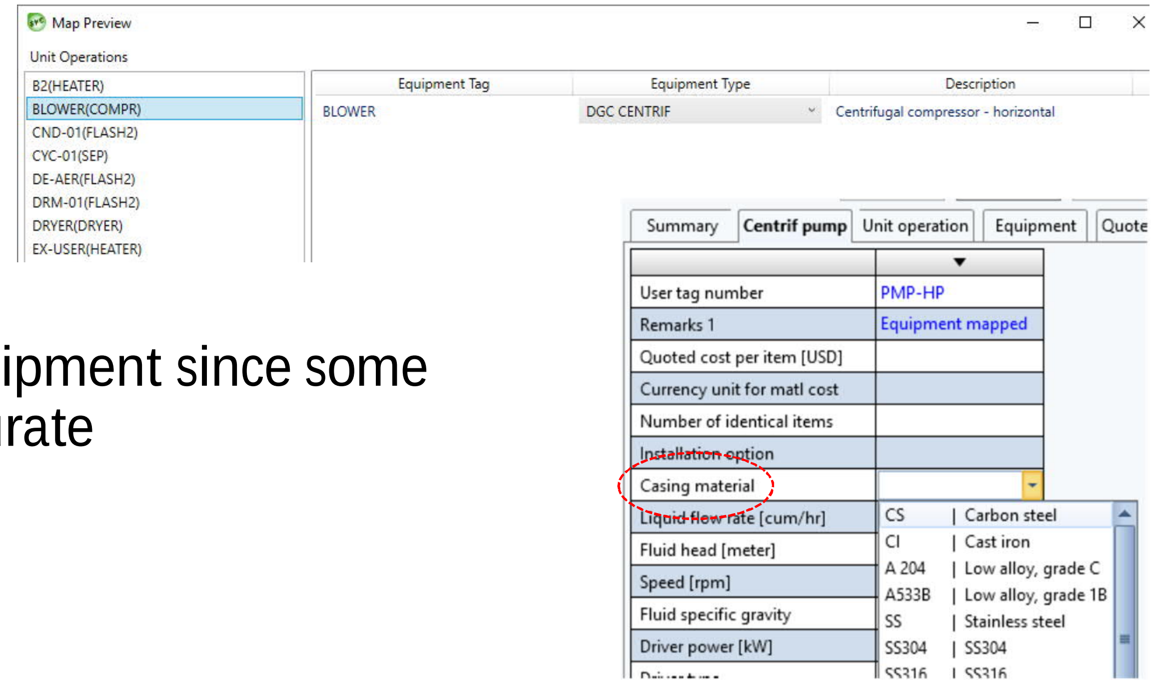
Tips: Aspen Process Economic Analyzer



- Used in many research articles
- How to use it:
  - Map equipment
  - Size
  - Evaluate & Analyze
  - Adjust for material of construction
- Always 'sanity-check' each unit of equipment since some equipment unit costs may not be accurate



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Example: Capital and Operation cost calculation

- From literature on fast pyrolysis
  - Corn stover to bio-oil and upgrading
  - Compared hydrogen production on-site versus purchased hydrogen
  - Provided economic analysis result as fuel product value ($/gallon of gasoline equivalent) and $/L

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Techno-economic analysis of biomass fast pyrolysis to transportation fuels

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ABSTRACT

This techno-economic study examines fast pyrolysis of corn stover to bio-oil with subsequent upgrading of the bio-oil to naphtha and diesel range fuels. Two 2000 dry tonne per day scenarios are developed: the first scenario separates a fraction of the bio-oil to generate hydrogen on-site for fuel upgrading, while the second scenario relies on merchant hydrogen.

The modeling effort resulted in liquid fuel production rates of 134 and 220 million liters per year for the hydrogen production and purchase scenarios, respectively. Capital costs for these plants are $287 and $200 million. Fuel product value estimates are $3.09 and $2.11 per gallon of gasoline equivalent ($0.82 and $0.56 per liter). While calculated costs of this biofuel are competitive with other kinds of alternative fuels, further research is required to better determine the effect of feedstock properties and process conditions on the ultimate yield of liquid fuel from bio-oil. Pioneer plant analysis estimates capital costs to be $911 and $585 million for construction of a first-of-a-kind fast pyrolysis and upgrading biorefinery with product values of $6.55 and $3.41 per gge ($1.73 and $0.90 per liter).

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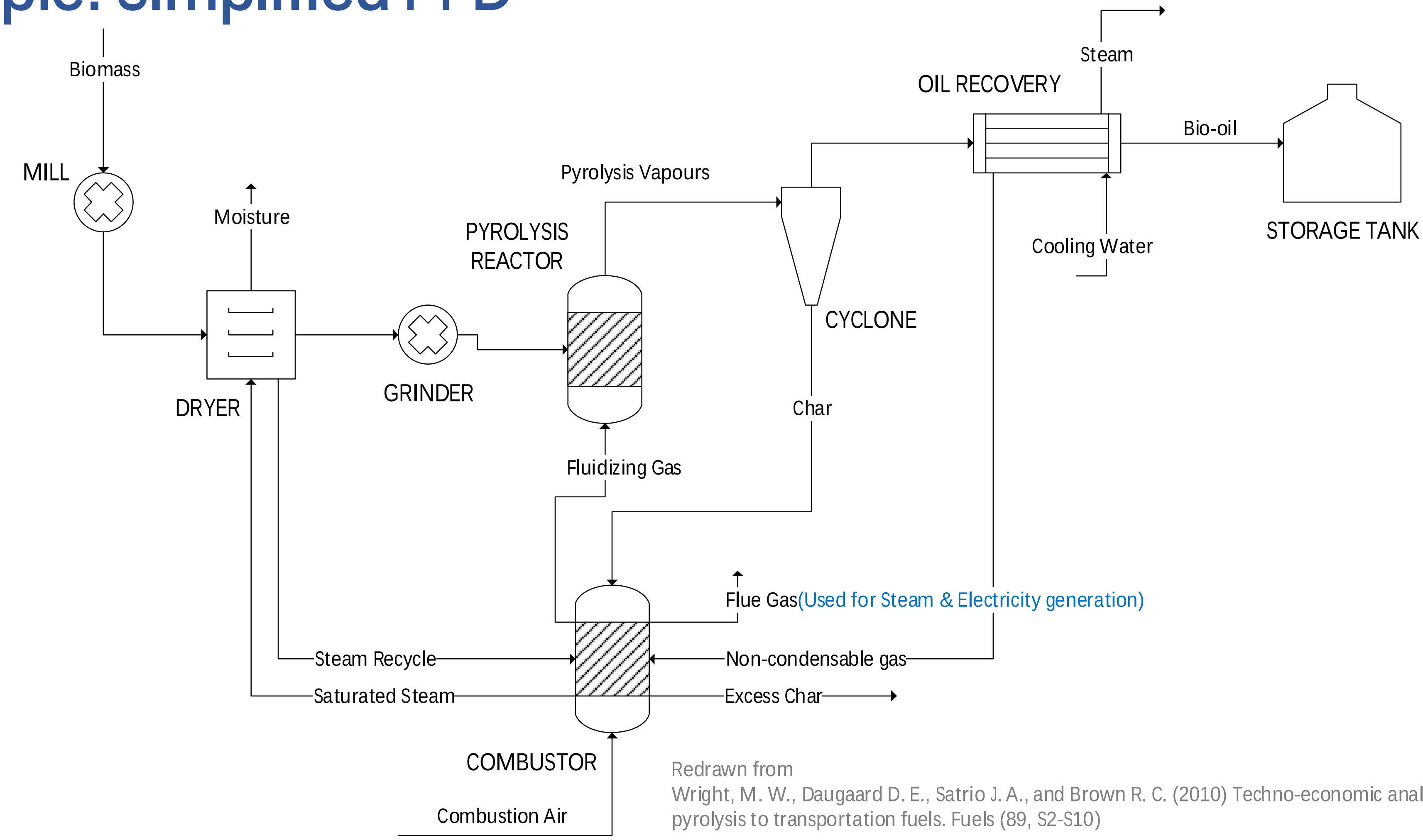
Example: Simplified PFD



Redrawn from
Wright, M. W., Daugaard D. E., Satrio J. A., and Brown R. C. (2010) Techno-economic analysis of biomass fast pyrolysis to transportation fuels. Fuels (89, S2-S10)

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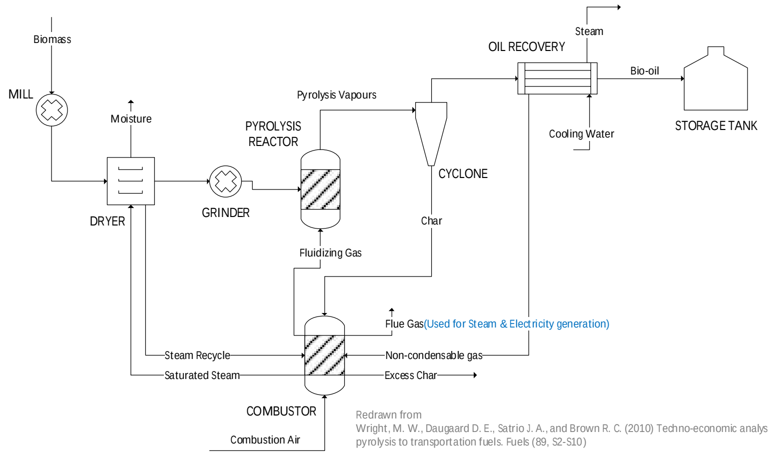
Example: Mechanical equipment list (PEC)

EQUIPMENT NAME	SIMULATION UNIT (Aspen Plus)	COMMENTS	SIZING & COSTING APPROACH
MILL	May or may not modelled	Study used a literature reference for the grinder screen size and energy requirement of hammer mill, which can be used to size equipment	Based on energy reg. specific for biomass, particle size and moisture content required.
STEAM DRYER	Dryer	How the feed stream was defined will determine accuracy of heating duty required	Size based on energy duty
GRINDER	May or may not modelled	-	Based on energy reg. specific for biomass, particle size and moisture content required.
PYROLYSIS REACTOR	RSTOIC Reactor	Depends on data available	Size based on volumetric feed rate As first estimate, cyclone could be used together with rules of thumb, followed by literature values if available
COMBUSTOR	RSTOIC Reactor	Combustion reactions (stream data is again important for heat balance)	Biomass boiler and furnace
	Blower (Compressor unit)		Air Blower
	Heat exchangers		check if included in boiler and furnace cost
	Flash drum		check if included in boiler and furnace cost
CYCLONE	SEP Block	Could use Aspen's cyclone if solids stream class was used	Size based on volumetric feed rate
OIL RECOVERY	Flash drum	Process Vessel	Size based on volumetric feed rate and residence time, cost based on vessel dimensions
STORAGE TANK	Optional to include	Residence time is important, 'batch process'	Size based on volumetric feed rate and residence time required, cost based on vessel dimensions

KEY
Aspen Plus/Rules of thumb
Literature values
Vendor quote



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Total installed cost = Purchased equipment cost * installation factor

$$\sum_i (PEC_i \cdot IF_i)$$

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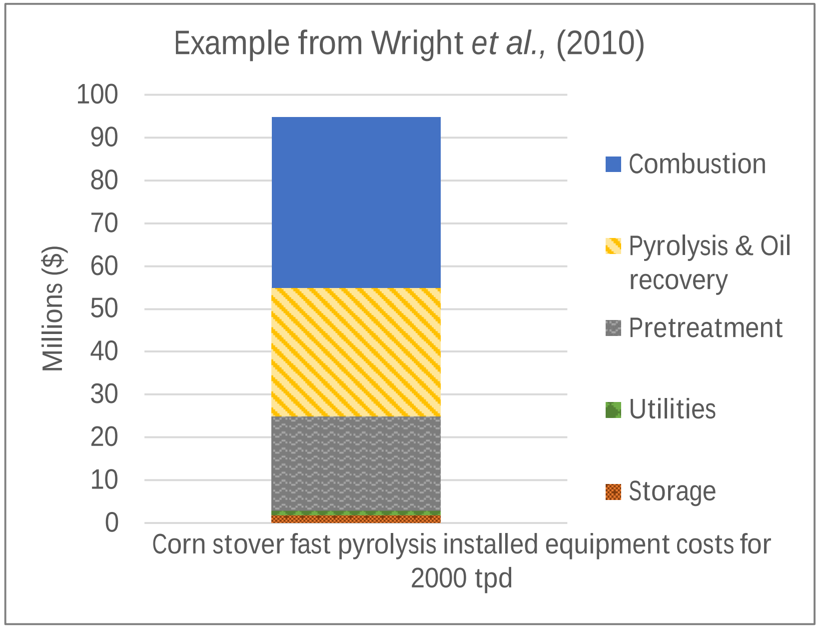
Example: Capital cost calculation

Capital cost calculation	% (TBC)	million ($)
Total mechanical equipment		
Total installed cost	a	103.0
	% of a	
Contingency	15%	15.5
Engineering fee	3%	3.1
Total capital cost (CAPEX)	b	121.5
	% of b	-
Land cost	3%	3.6
Site development	5%	6.1
Auxiliary buildings	4%	4.9
Off-site facilities	50%	60.8
Total grass roots capital (FCI)	c	196.9
	% of c	-
Start-up expenses	2%	3.9
Working capital	20%	39.4
Total capital investment		240.2 $



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Example: OPEX calculation

	Direct costs	%	Method	Million $
A	Raw materials and Consumables			15.50
B	Waste disposal			4.70
C	Utilities			5.00
D	By-products			(1.00)
E	Operating Labor			5.40
F	Supervisory and clerical labor	20%	of E, operating labor	1.08
G	Maintenance and repairs	6%	of grass roots capital	11.81
H	Operating supplies	15%	of G, maintenance	1.77
J	Patents and Royalties	3%	Grass roots capital	5.91
L	Total Direct costs		Sum of A to J	50.17
Indirect Costs				
M	Overhead, packaging and storage	60%	of (E+F+G)	10.98
N	Local taxes	2%	of grass roots capital	3.94
O	Insurance	1%	of grass roots capital	1,97
P	Total indirect costs		(M + N + O)	16.88
General Expenses				
Q	Administrative costs	25%	of M, Overheads	2.74
R	Distribution and selling	1%	of (L-J+P+Q+U)/0.91	0.91
S	Research and Development	5%	of (L-J+P+Q+U)/0.91	4.57
T	Total general expenses			8.23
U	Depreciation	10%	of (grass roots capital – land cost)	19.33
V	Financing	10%	of grass roots capital	19.69
X	Total operating costs (OPEX)		L+P+T+U+V	114.13

Grass roots capital cost is 196.9 million $ and land cost is 3.6 million $. From the study, the total operating costs were 109 million $, but has increased since the capital costs were corrected for time value.

Values A – E are approximate values for this example.

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In conclusion

- A techno-economic analysis can be used to determine the capital and operational costs, accurate to a certain range depending on the engineering effort spent
- Depending on the purpose of the study, the TEA results can be expressed using various economic parameters (production cost, IRR, NPV etc.)
- LCC can assist to take additional factors into consideration, e.g.:
  - Environmental factors, End-of-life costs

➢ LCC is useful for comparing different scenarios to determine the 'best' overall process scenario or value chain

➢ For an environmental focused LCC, the economic and environmental performance can be combined for more 'balanced' results

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Thank you for your attention!

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TEA of modelled process concepts

	Development of process concept	Validation of technical feasibility	Assessment of economic feasibility
Tasks	▪ Conceptual design ▪ Selection of unit operations	▪ Process modelling ▪ Experimental test (lab/pilot/demo)	▪ Capital cost estimation ▪ Operational cost estimation
Outcome	▪ Process concept ▪ Equipment selection and preliminary design	▪ M&E balance ▪ Equipment list with basic dimensions, operating & performance data	▪ CAPEX ▪ OPEX ▪ Total production cost, payback time, NPV, IRR, EBITDA, etc.

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Type and accuracy of cost estimates

General project data	CLASS 5	CLASS 4	CLASS 3	CLASS 2	CLASS 1
Project scope description	General	Preliminary	Defined	Defined	Defined
Plant production capacity	Assumed	Preliminary	Defined	Defined	Defined
Plant location	General	Approximate	Specific	Specific	Specific
Soils and hydrology	None	Preliminary	Defined	Defined	Defined
Integrated project plan	None	Preliminary	Defined	Defined	Defined
Project master schedule	None	Preliminary	Defined	Defined	Defined
Escalation strategy	None	Preliminary	Defined	Defined	Defined
Work breakdown structure	None	Preliminary	Defined	Defined	Defined
Project code of accounts	None	Preliminary	Defined	Defined	Defined
Contracting strategy	Assumed	Assumed	Preliminary	Defined	Defined
Engineering deliverables					
Block Flow Diagrams	S/P	P/C	C	C	C
Plot Plans		S	P/C	C	C
Process Flow Diagrams (PFDs)		S/P	P/C	C	C
Utility Flow Diagrams (UFDs)		S/P	P/C	C	C
Piping & Instrument Diagrams (P&IDs)		S	P/C	C	C
Heat & Material Balance		S	P/C	C	C
Process Equipment List		S/P	P/C	C	C
Utility Equipment List		S/P	P/C	C	C
Electrical One-Line Drawings		S/P	P/C	C	C
Specifications & Datasheets		S	P/C	C	C
General Equipment Arrangement Drawings		S	P/C	C	C
Spare Parts Listings			S/P	P	C
Mechanical Discipline Drawings			S	P	P/C
Electrical Discipline Drawings			S	P	P/C
Instrumentation/Control system Discipline Drawings			S	P	P/C
Civil/Structural/Site Discipline Drawings			S	P	P/C

Source, e.g:
Skills & Knowledge of Cost Engineering, S.J. Amos (Ed.), AACE International, 2004

N = None
S = Started
P = Preliminary
C = Complete

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Cost correlations for mechanical equipment cost

- Often in parametric form: equipment cost is function of key geometric or capacity related parameters like:
  - Volume
  - Area
  - Diameter
  - Height
  - Flowrate (mass, volumetric, molar)
  - Duty
- Check what is included in the cost correlation
  - Other equipment, e.g. Does an agitator or pump include the driver/electric motor?
  - Local installation
- (Short-cut) equipment design needed, based on
  - Mass / heat balance
  - Process simulations
  - Basic calculations
- Typical values / assumptions needed for
  - Heat transfer coefficients
  - Temperature of utilities (ΔT used for heat transfer)
  - Specific power input (e.g. for mixing)
  - (Bulk) densities
  - Efficiencies (HETP, tray efficiency, etc.)
  - Materials of construction
- Output
  - Parameters for parametric cost correlations

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Total Capital Investment

- Sum of installed equipment (Ce)
- General cost
  - Contingencies
  - Fees
- Site related cost (green field)
  - Land cost and site development
  - Auxiliary buildings
  - Auxiliary or off-site facilities
- Cash flow related cost
  - Startup expenses
  - Working capital

Total capital costs

Fixed capital Investment ($Cf = fL * Ce$)

fL = the "Lang factor", which depends on the type of process.
fL = 3.1 for predominantly solids processing plant
fL = 4.7 for predominantly fluids processing plant
fL = 3.6 for a mixed fluids-solids processing plant

Total capital investment

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