PDC®

Process
Design Center

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Techno-economic analysis

Essential guide in sustainable process development

Hank Vleeming

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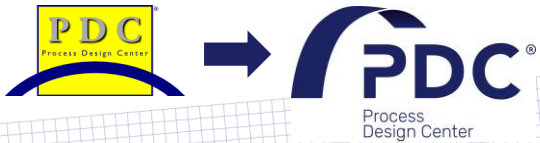
Process Design Center

- Our mission is to help create a better process industry with lower carbon footprint and more sustainable operations.
- We do this using disruptive PROSYN® technology, proving able to generate capital and operating cost savings of up to 50%!
- Our key expertise includes conceptual process design, process integration and optimization, and techno-economic analysis
- Currently more than half of our turnover is in biobased and circular process development
- We are in the process of a change of logo/identity



7726 kton of CO_2 savings

34 years in business

>1000 third-party reviews

210 million euros of R&D projects

75% doctorate degree holders

Techno-economic analysis

Essential guide in sustainable process development

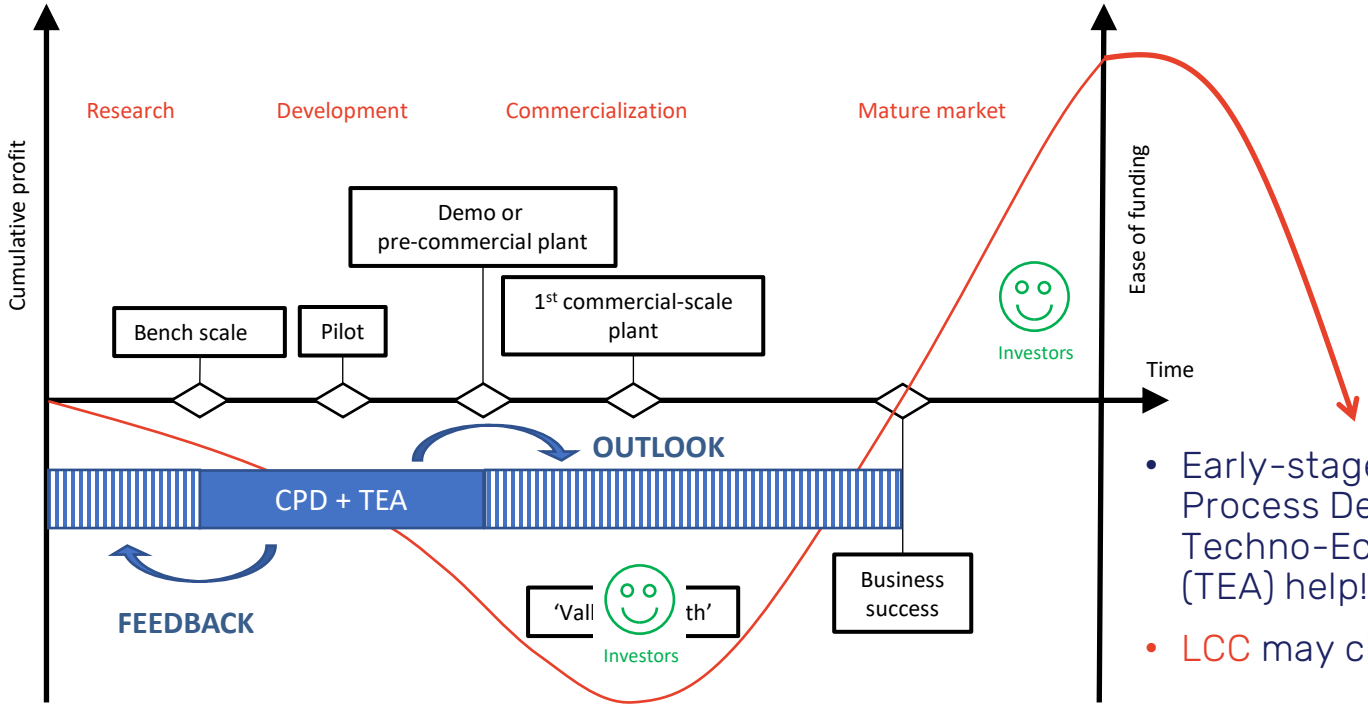
*Quote from **Martin Atkins**, former Chief Scientist at **BP** in China and Chief Technologist at **Petronas** in Malaysia and currently CEO of **Green Lizard Technologies** and CTO **Poseidon Plastics** in the UK:*

"… Working early with PDC at conceptual and TEA study has taken considerable amount of time off the path to commercialization. In some cases the work with PDC has led us to stop projects early and prevent the team going down dead ends"

TEA – Boring or exiting?

- Traditional thinking … “boring”
  - Work for cost engineers
  - Performed at the end to proof economic viability
  - No real relevance for sustainability
- PDC thinking … “exiting”
  - Work for conceptual process engineers
  - Performed early-stage to create an industrial outlook and steer the design towards techno-economic viability
  - Sustainability can be valued

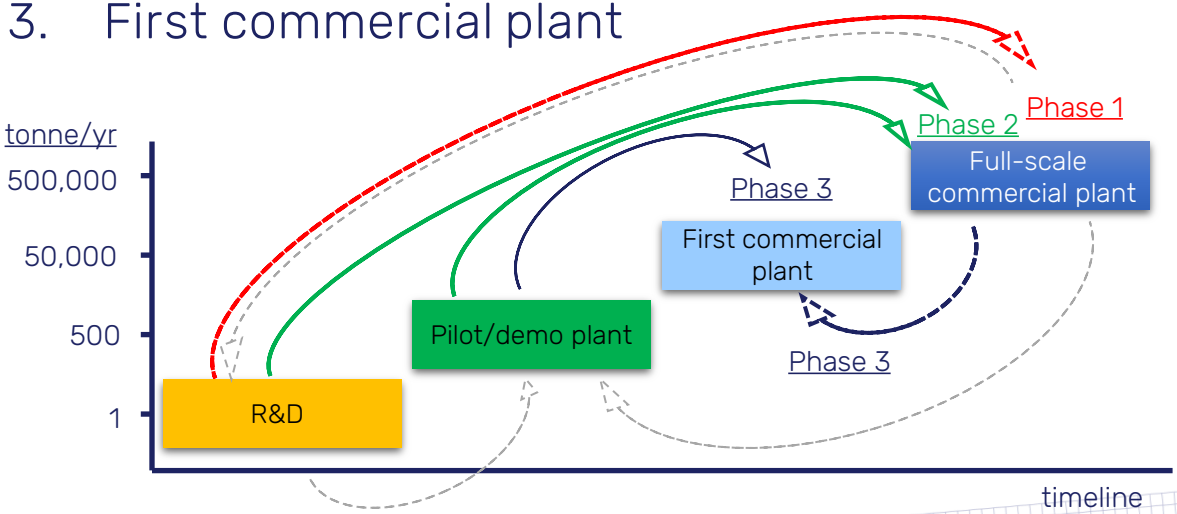
Crossing the valley of death



- Early-stage Conceptual Process Design (CPD) and Techno-Economic Analysis (TEA) help!
- LCC may change the game

TEA along the TRL – example Avantium

1. Large-scale industrial outlook based on early R&D
2. Update using R&D and pilot/demo plant results
3. First commercial plant



TEA elements

- Capital cost (CAPEX) → Fixed cost of production (FCOP)
- Operating cost (OPEX) → Variable cost of production (VCOP)
- Manufacturing cost → Cash cost of production (CCOP)

$$CCOP = FCOP + VCOP$$

VCOP = Sum of all variable cost minus byproduct revenues

FCOP = Sum of all the fixed cost of production

TEA elements

- Economic performance
  - Gross profit = Main product revenues – CCOP
  - Net profit = Gross profit – taxes
  - Profitability indices (PBT, ROI, IRR, EBITDA, …)
- Total cost of production (TCOP)

$$TCOP = CCOP + ACC$$

ACC = Annual Capital Charge (depreciation, interest)

CCOP = Cash Cost of Production

CAPEX estimate

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

Typically values:

First-of-its-kind design	+30%
Existing design	+20%
Low risk project	+10%

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

Purchased equipment cost

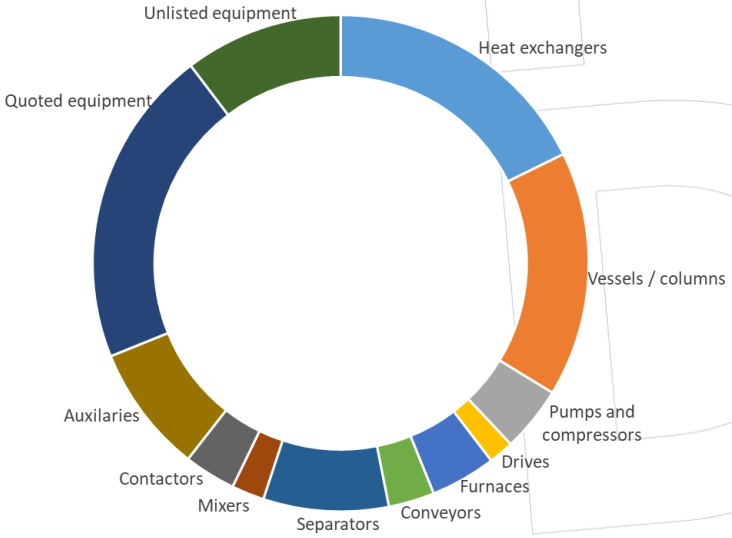
Installation factor (typically 2-5)

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

CAPEX estimate

EXAMPLE

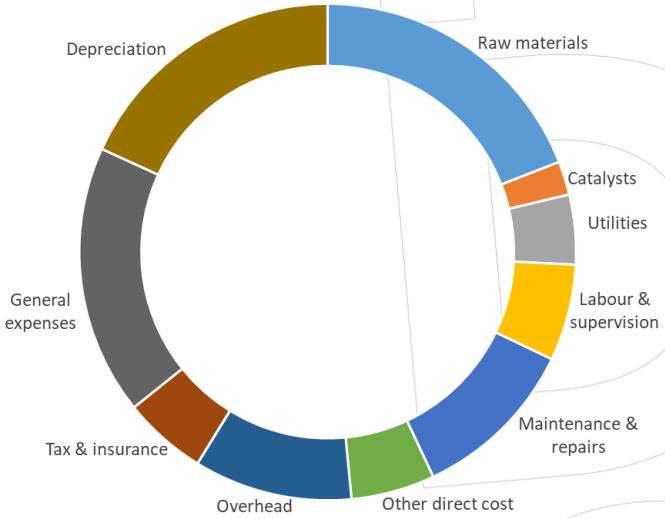
Capital cost calculation					
Heat exchangers		€	5,000,000		
Vessels / columns		€	4,500,000		
Pumps and compressors		€	1,200,000		
Drives		€	461,445		
Furnaces		€	1,200,000		
Conveyors		€	845,000		
Separators		€	2,300,000		
Mixers		€	600,000		
Contactors		€	950,000		
Auxilaries		€	2,350,000		
Quoted equipment		€	5,850,000		
Unlisted equipment	15%	€	2,910,967		
Total bare module cost				**€**	**28,167,412**
Contingency	30%	€	8,450,224		
Fee	6%	€	1,690,045		
Total module capital cost				**€**	**38,307,680**
Land cost	3%	€	948,026		
site development	5%	€	1,580,043		
auxilary buildings	4%	€	1,264,035		
off-site facilities	25%	€	7,900,216		
Fixed capital investment (FCI)				**€**	**50,000,000**
startup expenses	2%	€	1,000,000		
working capital	15%	€	7,500,000		
Total capital investment (TCI)				**€**	**58,500,000**



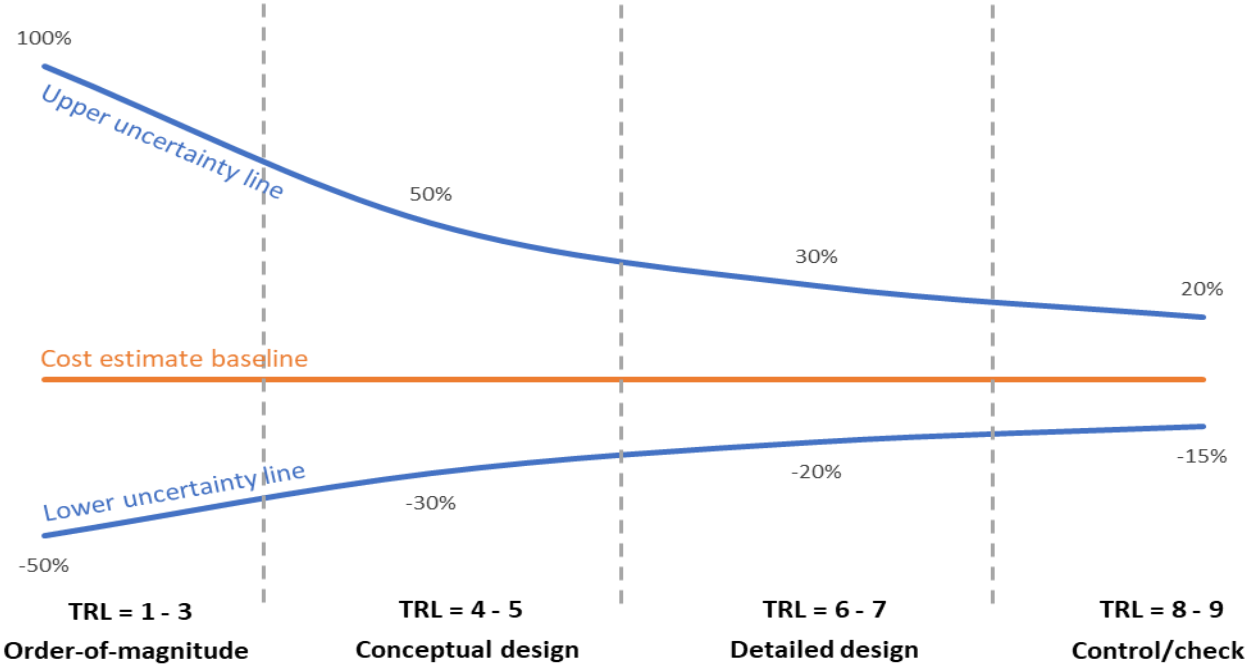
OPEX estimate

Manufacturing expenses (annual)					
Direct					
	Raw materials		€	5,250,000	
	Catalysts		€	600,000	
	Operating labour		€	1,502,890	
	Supervisory and clerical labour	15% of operating labour	€	225,434	
	Utilities		€	1,250,000	
	Maintenance and repairs	6% of grass roots capital	€	3,000,000	
	Operating supplies	15% of maintenance	€	450,000	
	Laboratory charges	15% of operating labour	€	225,434	
	Patents and royalties	3% of manufacturing expenses excl. financing	€	825,000	
SUM					€ 13,328,757
Indirect					
	Overhead, packaging, and storage	60% of labour, supervision, maintenance	€	2,836,994	
	Local taxes	2% of grass roots capital	€	1,000,000	
	Insurance	1% of grass roots capital	€	500,000	
SUM					€ 4,336,994
General expenses					
	Administrative costs	25% of overhead	€	709,249	
	Distributing and selling	10% of manufacturing expenses excl. financing	€	2,750,000	
	Research and development	5% of manufacturing expenses excl. financing	€	1,375,000	
SUM					€ 4,834,249
Depreciation					
	Depreciation	10% of grass roots capital	€	5,000,000	
SUM					€ 5,000,000
Financing					
	Financing	0% of total capital investment	€	-	
SUM					€ -
	Co-products and waste streams		€	-7,500,000	
Total			**€**	**20,000,000**	
Plant capacity				20	kton/year
Total cost of production (TCOP)			**€**	**1,000**	**€/ton**

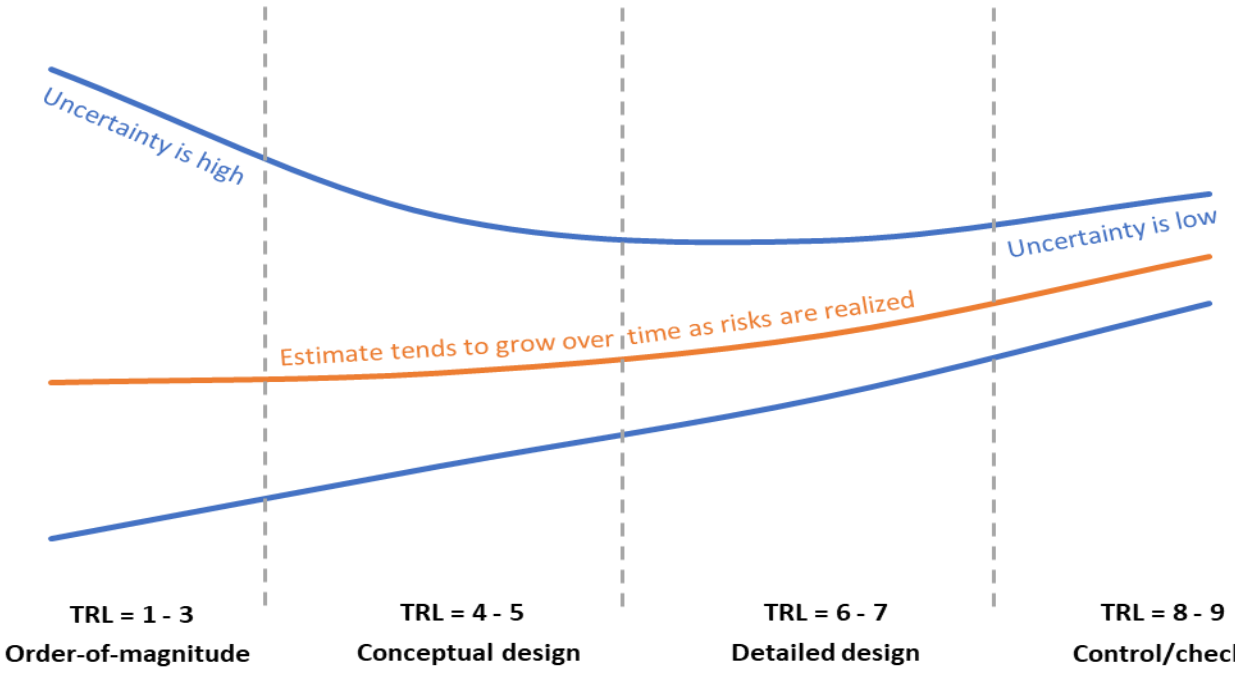
EXAMPLE



TEA along the TRL - accuracy



Cost estimate over TRL



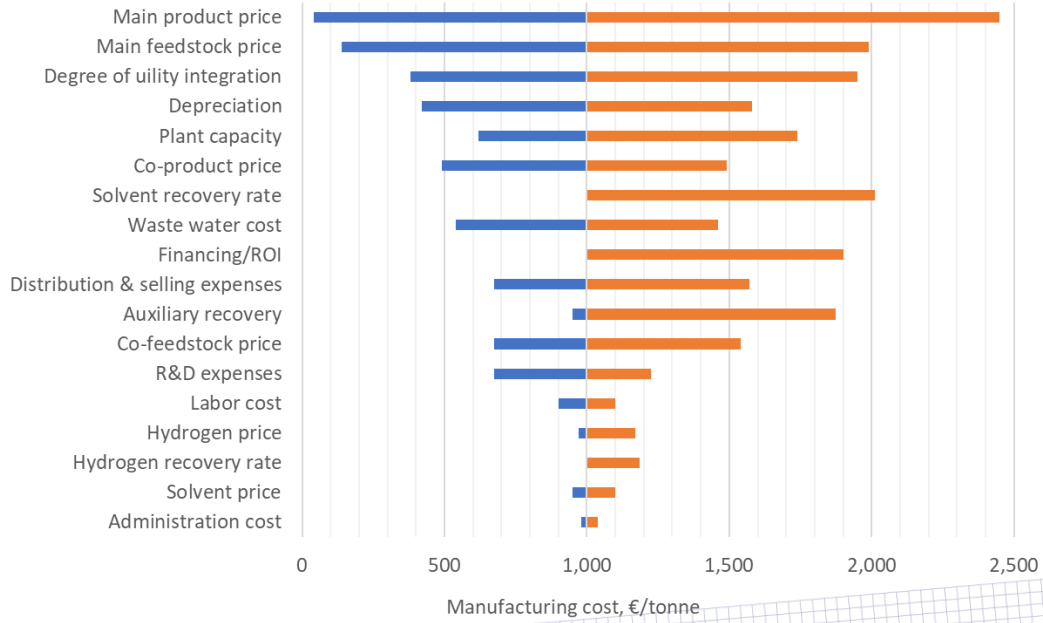
- Inclusion of LCC may change the estimate (over time)

How to deal with uncertainty?

- Add higher contingency
  - E.g. if one technology is at higher TRL than another
  - But promising new developments are penalized compared to state-of-the-art
- Alternative is "n^{th} plant approach"
  - Assume technology is proven in (n-1) plant with n>10
  - Adopt expected future improvements in R&D
  - But… be aware that results are uncertain

How to deal with uncertainties?

- Visualise uncertainties in a sensitivity analysis



← Tornado diagram

EXAMPLE

How to deal with uncertainties?

- Waste feedstock price variations due to
  - Availability
  - Quality
  - Region
  - Demand
  - Legislation/regulation
- Could also be adopted as an opportunity to optimize economics, e.g.
  - Select the optimal location (country)
  - Adopt multi-feedstock technology (e.g. combination of feedstocks in W2R)
  - Secure price by long-term offtake agreements

Life cycle aspects in TEA - history

- As early as the 90s we worked with large corporates on new designs, implementing cost for GHG emissions
- Expand system boundary, e.g include waste (water) treatment (Shell SMPO, biorefinery)
- LCC promises a step beyond this

Life cycle aspects in TEA - Dilemmas

- Monetizing social or environmental effects is difficult
  - Who suffers?
  - What is the cost impact?
  - Who pays for the effects?
- Examples
  - Emission of toxic compounds
  - Introduction or extinction of species
  - Ford Pinto, 1970



“Thank you for your attention”

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"More than efficiency..."