

Cost modelling - a tool for sustainable innovation

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Acknowledgements to Dr. Steven Hancock,

Co-founder at InCA Technology



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Learning objectives of this lecture

Cost assessment

How to paint a cost based picture of an innovation as part of how novel technology could be assessed financially

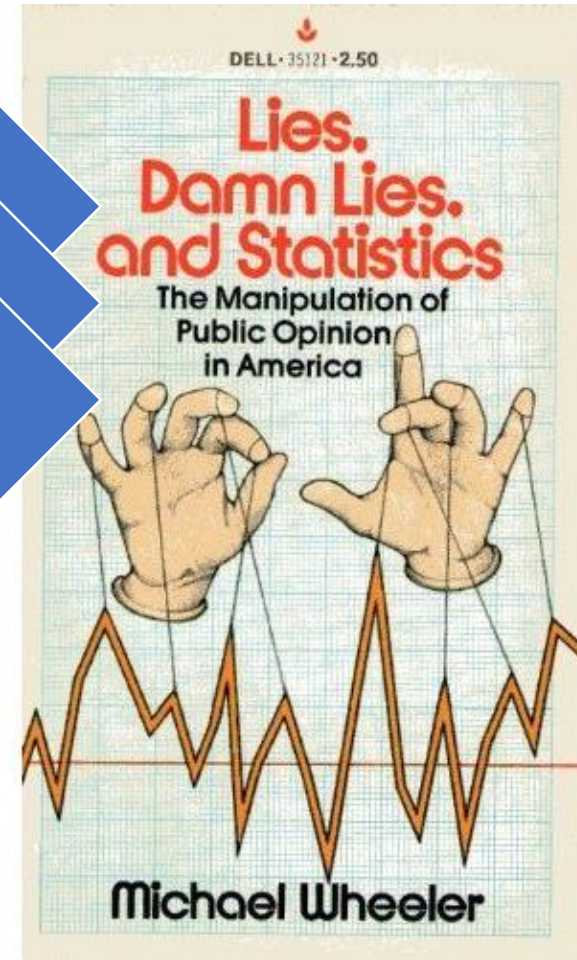
Build solid models

How to build solid and useful models to aid in assessing innovation and alternative strategies

Equip

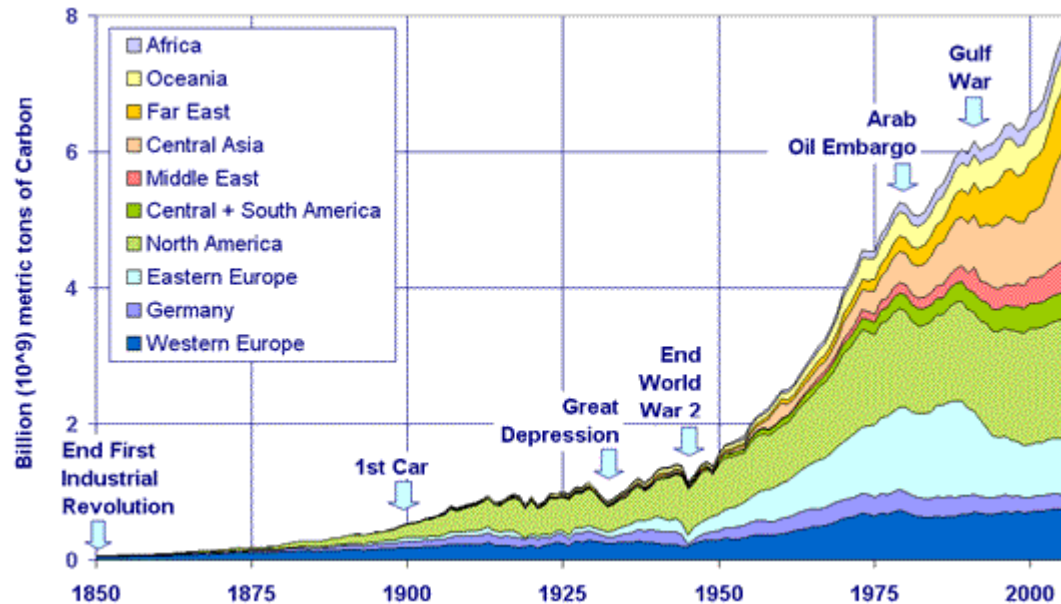
Language and skills to apply within organizations (universities to start-ups and large corporations)

Show costing tool



CO₂ technological and sociological factors

- Social evolution
- Technological evolution
- Vehicles are much more efficient today but this is offset by our driving more km

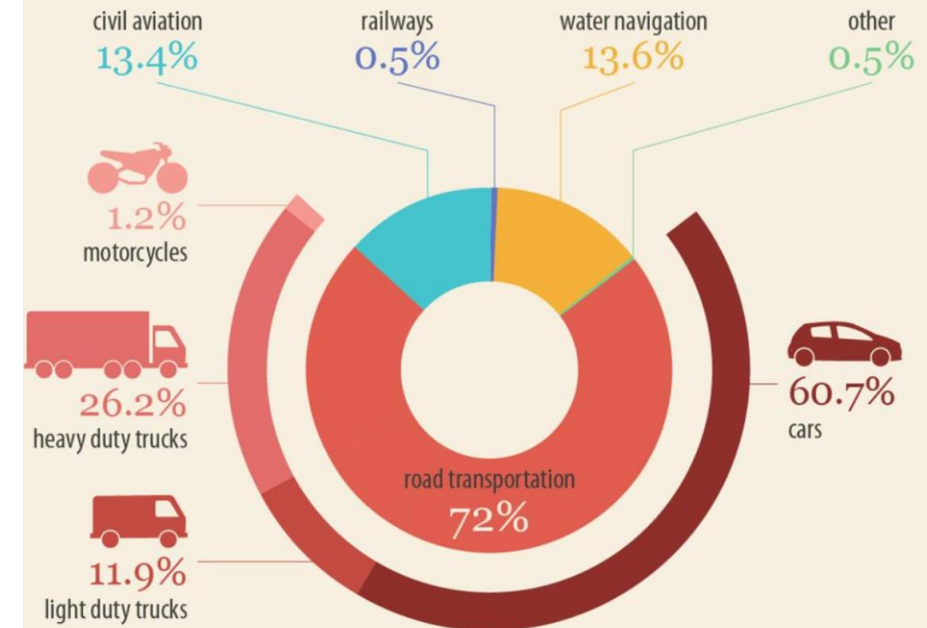


<https://qph.fs.quoracdn.net/main-qimg-434b21caa94121cf2d1f22e75a9dba1>



TRANSPORT CO₂ EMISSIONS IN THE EU

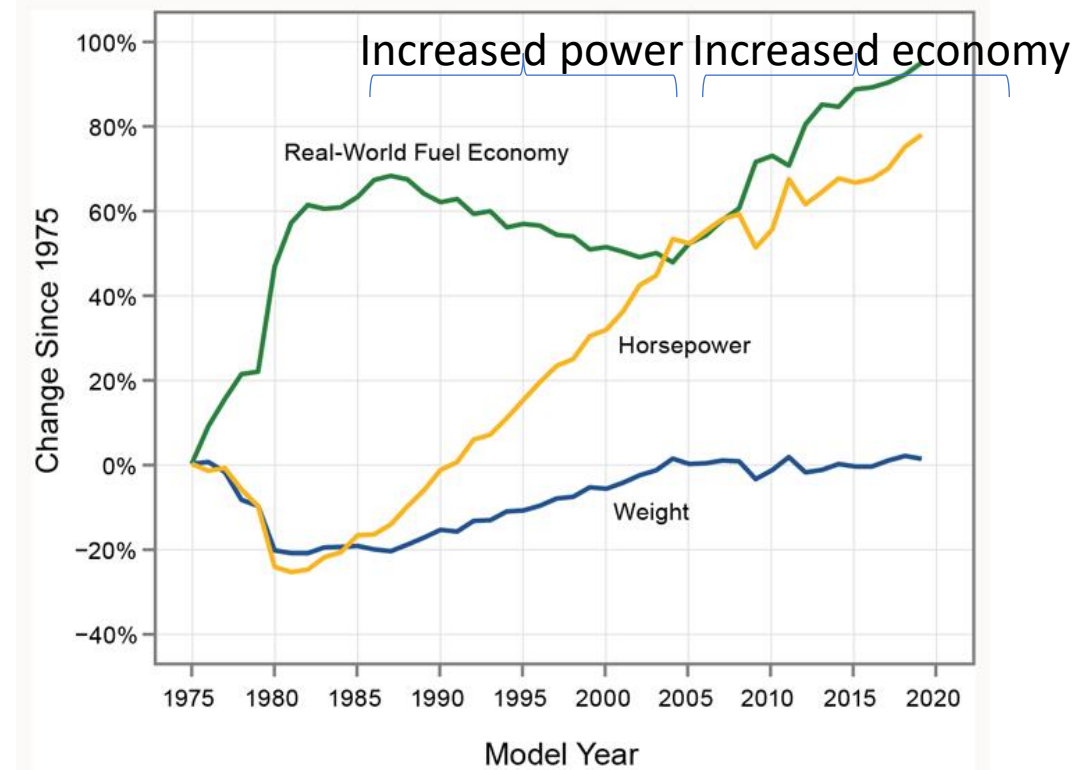
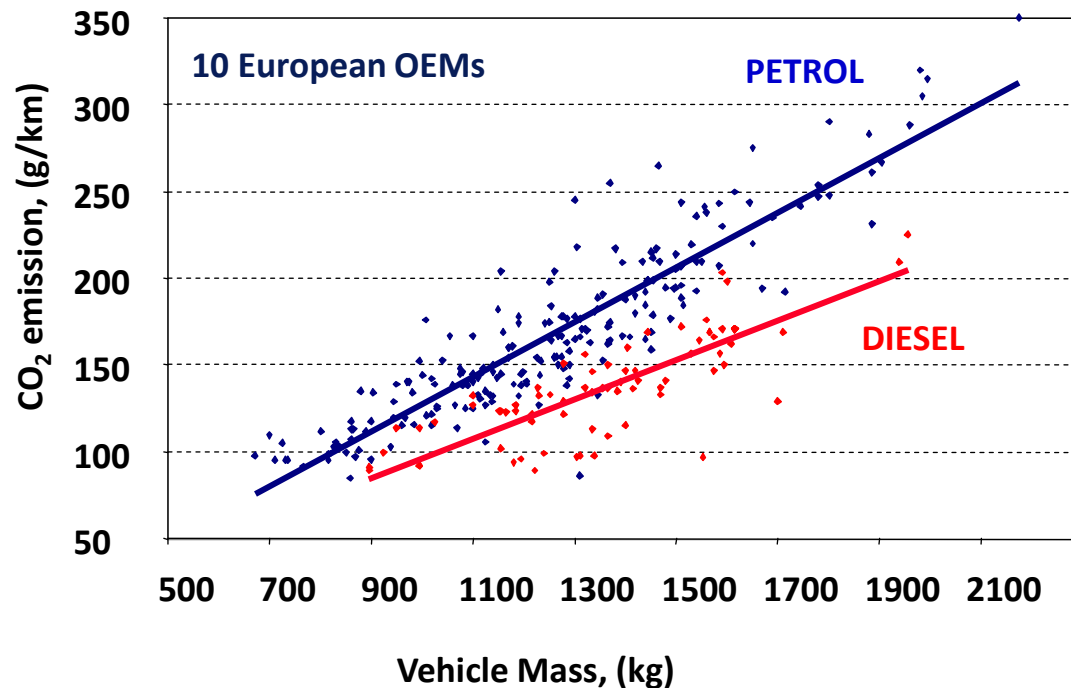
Emissions breakdown by transport mode (2016)



<https://www.europarl.europa.eu/news/en/headlines/society/20190313STO31218/co2-emissions-from-cars-facts-and-figures-infographics>

Weight, time, and vehicle emissions

- OEMs need to reduce CO₂ and hence vehicle weight (to meet customer demands & emerging legislation)
- OEMs need robust solutions and available & equipped supply chains
- OEMs “Materials Blind”: need full package

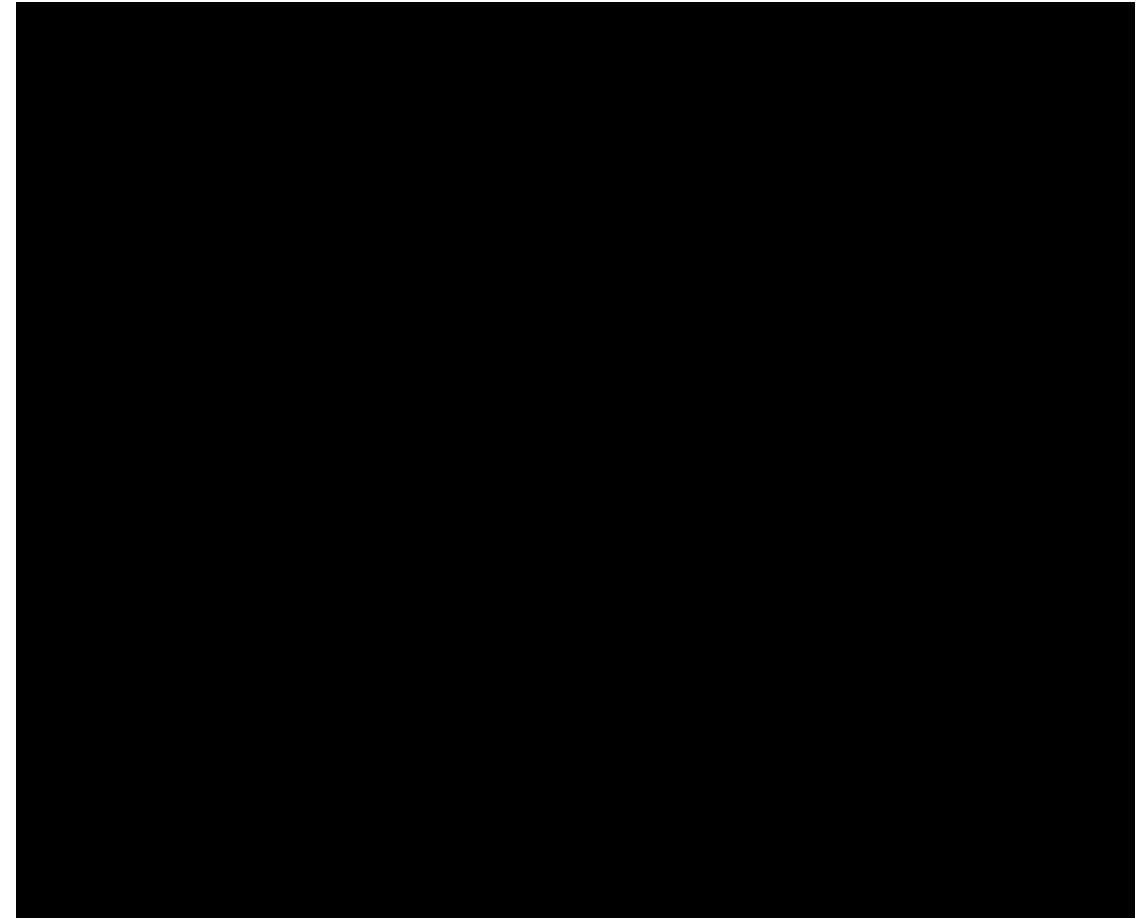
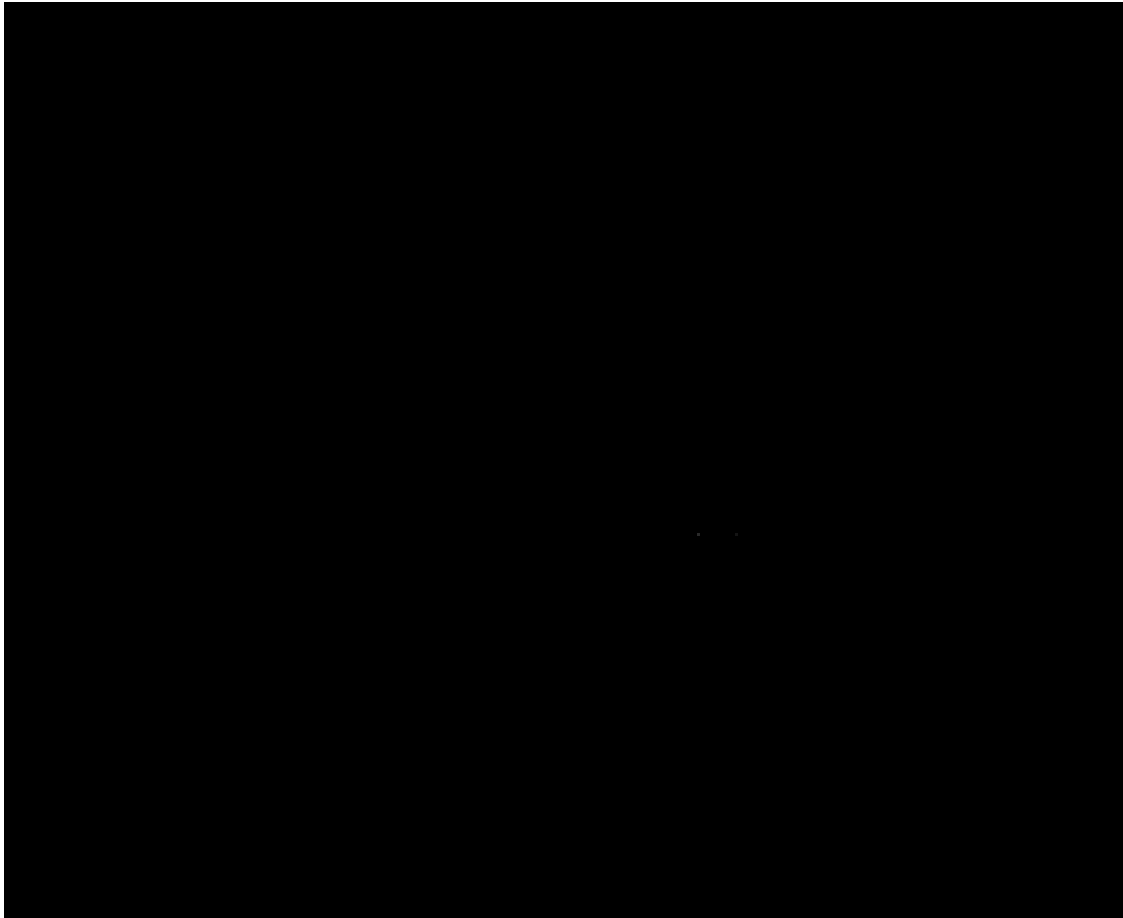


<https://www.epa.gov/automotive-trends/highlights-automotive-trends-report#Highlight5>

Overview

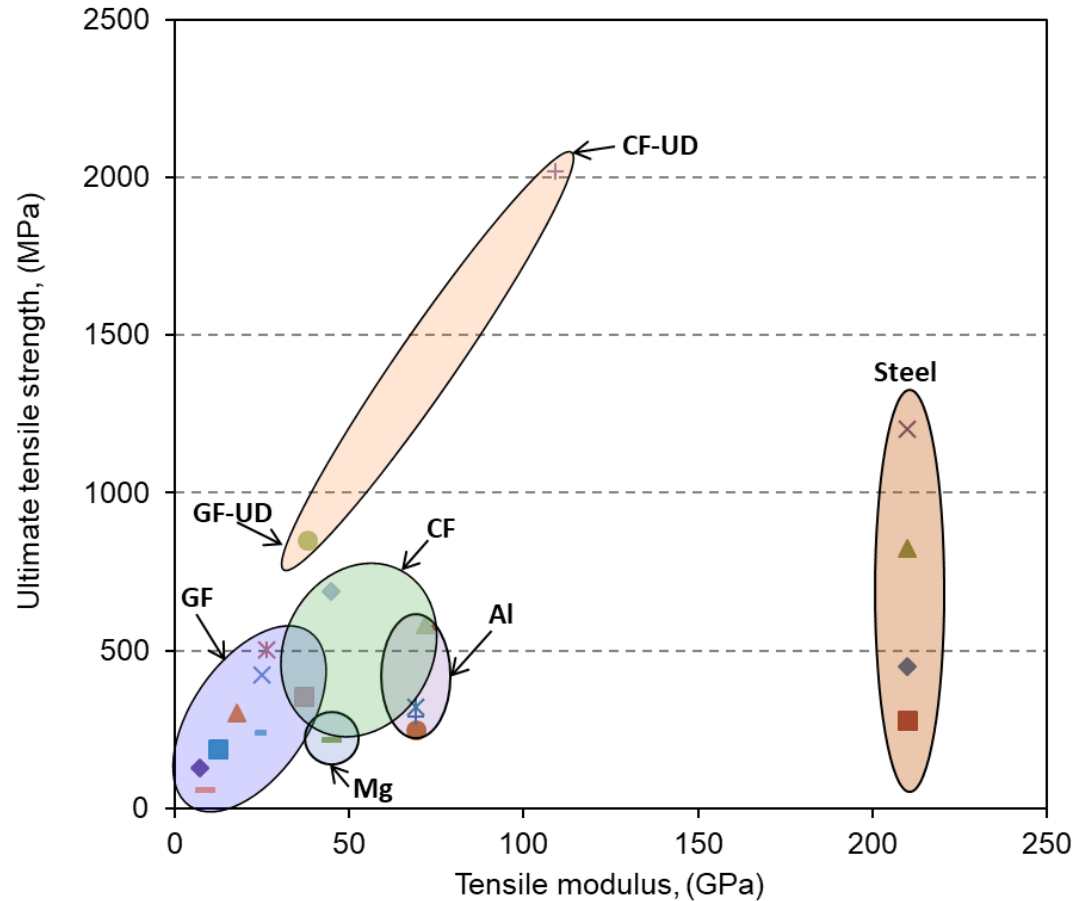
- Cost modelling approaches
 - Technical cost modelling deep dive
 - Cost modelling and technology strategy
 - Cost modelling and sustainability
 - Wrap up
 - A simple cost tool
-
- *Annex 1: Cost tool arithmetic*
 - *Annex 2: Historical cost data*
 - *Annex 3: Financial definitions for engineers*

Modelling the cost of a manufacturing and assembly process?

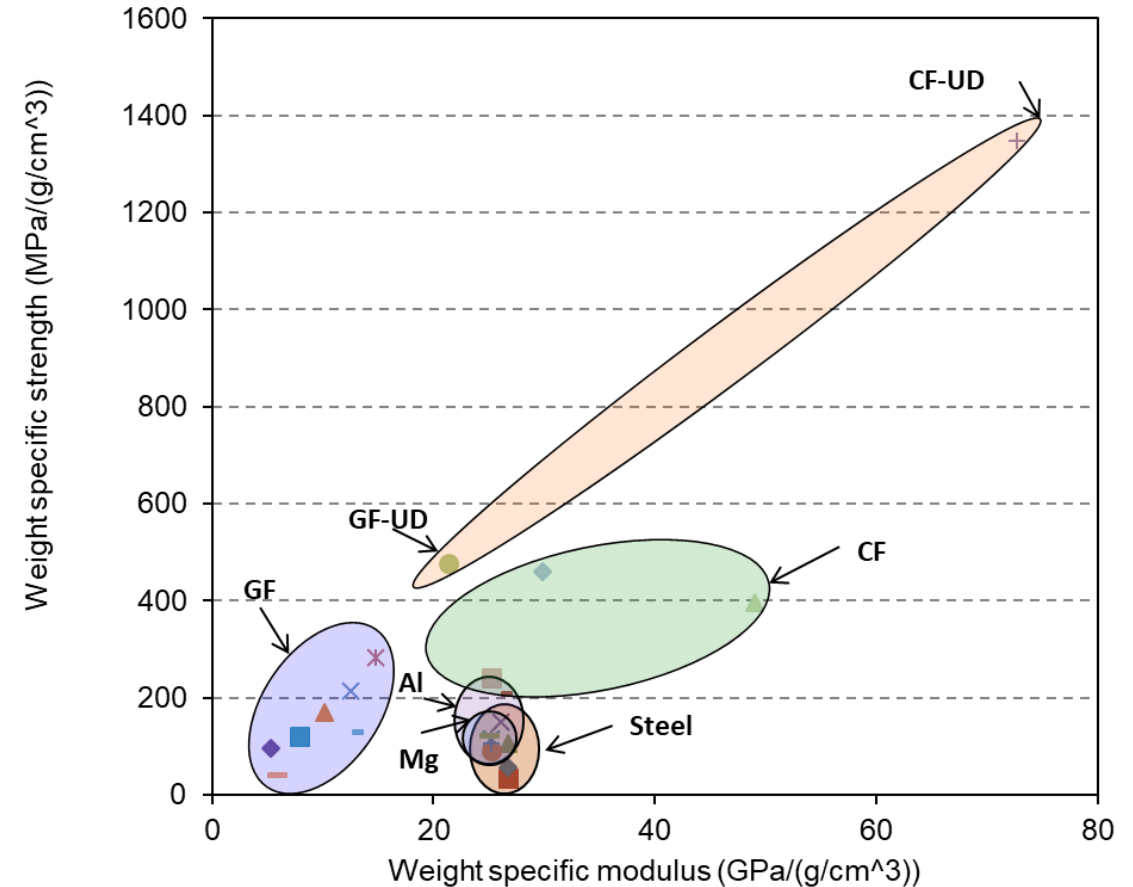


How can we understand the cost picture (investments and resulting part & assembly costs?)

Comparison of properties: strength and modulus

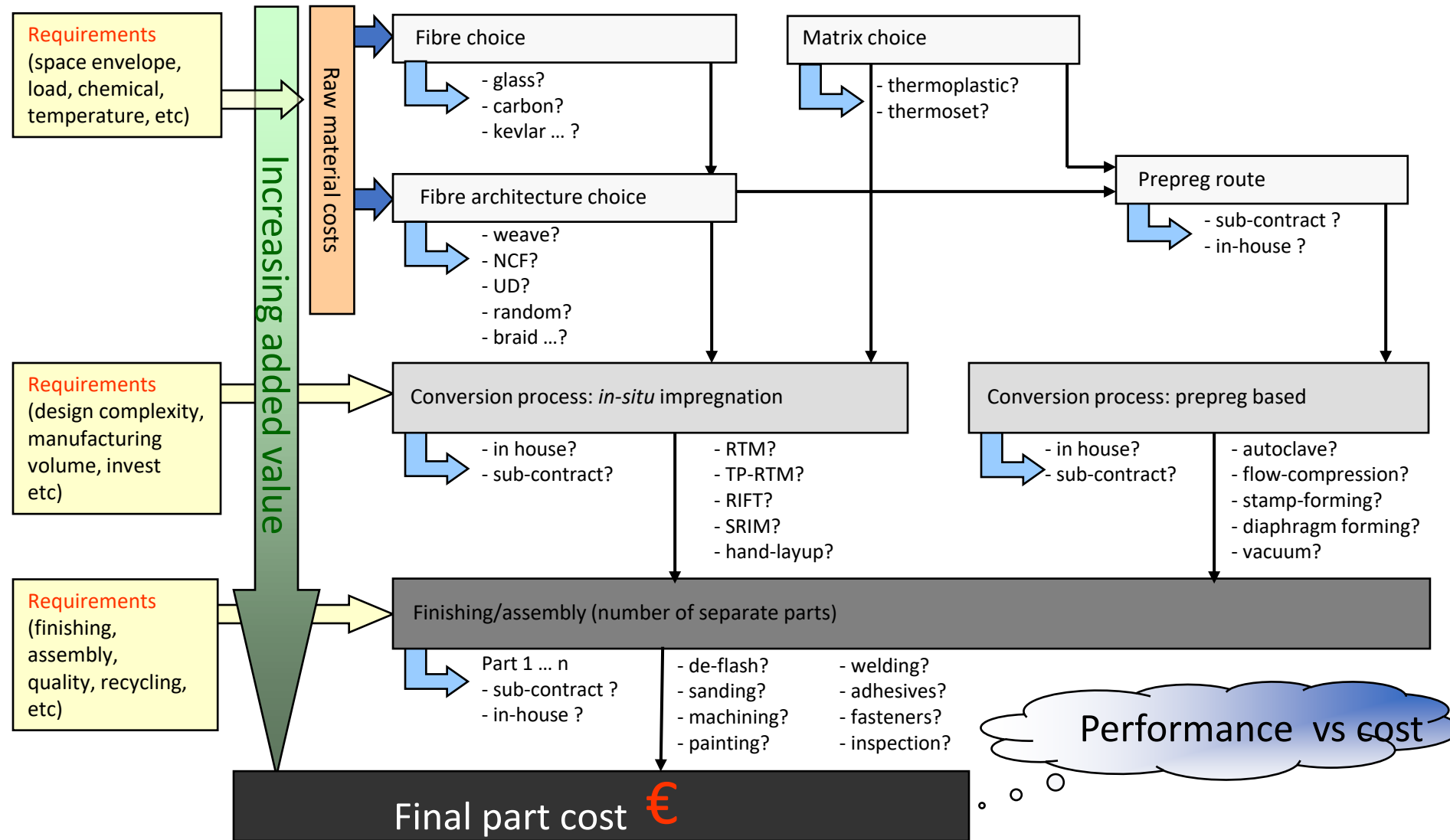


- Steel is a very stiff material
- Other metals and plastics do replace steel while meeting stiffness needs by modifying the design (cross sections, ribbing etc)



- When density is included, steel, Al and Mg have similar weight specific stiffness.
- GF offers increased weight specific strength (crash)
- CF offers increased weight specific modulus and strength
- The most effective material is UD carbon fiber PA tape.

Using composite materials? ... a decision map!



What can cost modelling help you with

Start-up

- Assess viability of your idea
- Work out cost of your product
- How the cost develops as you scale up the concept with time
- As supply chain evolves

Engineer in industry

- e.g. composites engineer
- Screening material and process options from existing qualified suppliers

Industry initiatives

- New product/known market
- New product/new market
- Quantified value proposition, VOC,
- Financials: anticipated margin, CAPEX versus time, NPV & ROI

Corporate R&D strategy

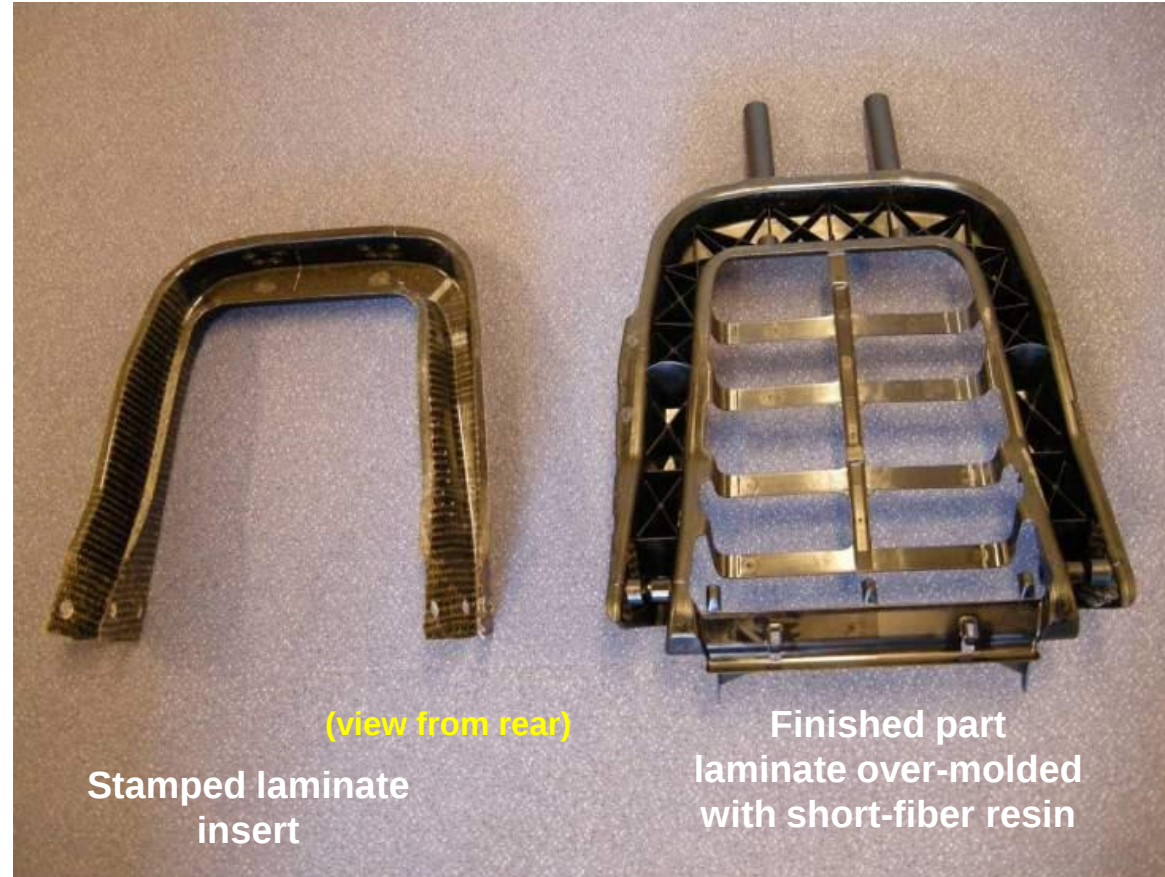
- Cost projections with market penetration models and needed CAPEX build
- Give comparative NPV and ROI predictions versus other investment candidates

Questions

- What questions would you need to ask to work out how much these parts cost to make?



- Weight save
???% vs. steel
- Systems cost reduction
???%



Example of new approach:
- design freedom & functional integration



Which variables need to go into a cost model?

① Start presenting to display the poll results on this slide.

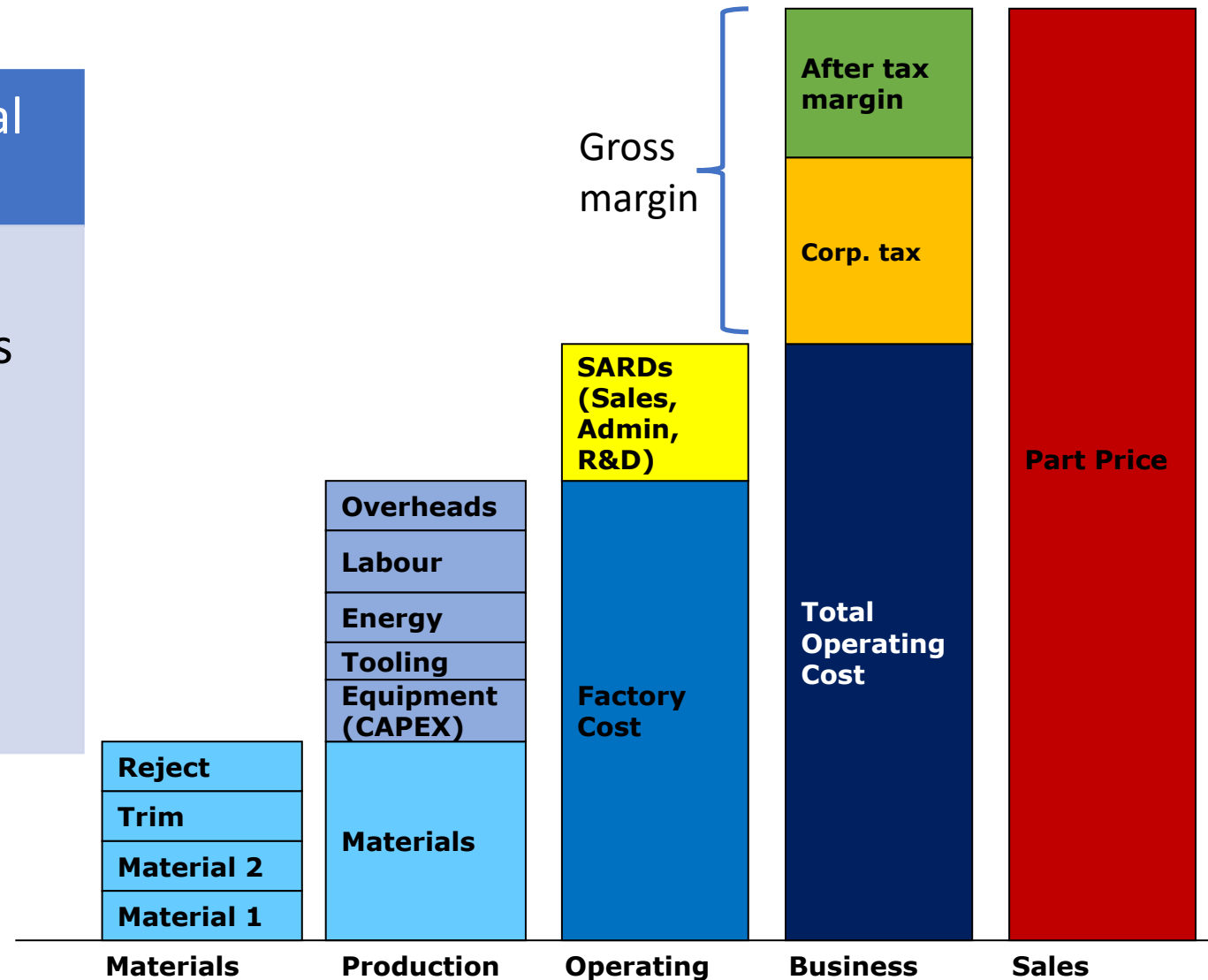
Elements and uses of a cost model

Give cost position

- Independent of market
- Materials
- Staffing
- Production/CAPEX
- SARDs
- Finance / interest

Business financial /venture

- Gross margin
- Anticipated sales growth and pricing
- CAPEX/OPEX vs. time
- NPV / ROI



Gross margin approaches

- Value in use pricing
 - Examine the benefits of your product to the customer to meet their needs in monetary terms (quantified)
 - Compare with in-kind and non-in-kind incumbents
 - Probe willingness to pay
 - Margin is built upon product specific value proposition
- Cost plus
 - Apply a fixed gross margin e.g. 40% to the total operating cost
 - Commodity approach
 - When lacking a strongly defined value proposition
 - Weak understanding of customer needs / poor customer intimacy
 - Lack of product differentiation

NetPositive

- Don't forget the circular lecture ...
- NetPositive approaches
- Internal cost of carbon
- Negative externalities
- Stakeholder vs. shareholder
- Regenerative approaches
- Collaboration in supply chain
- Leverage margin to build stronger business and be restorative
- Optimization to multiple KPIs
 - Cost & CAPEX / OPEX are some of many ...

Cost modelling approaches

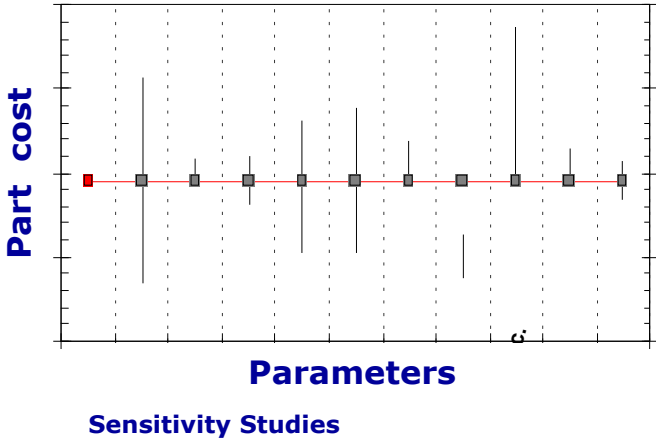
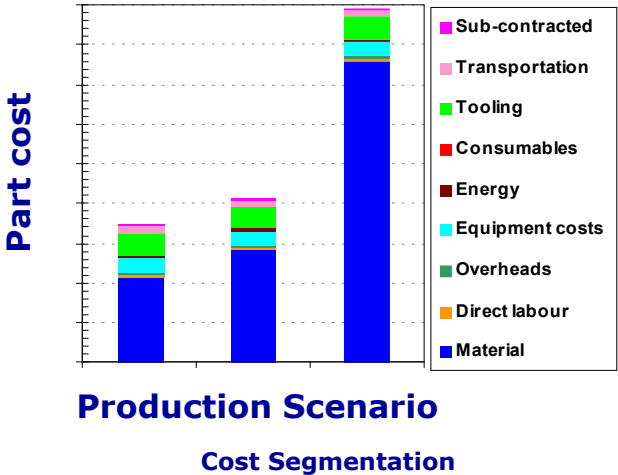
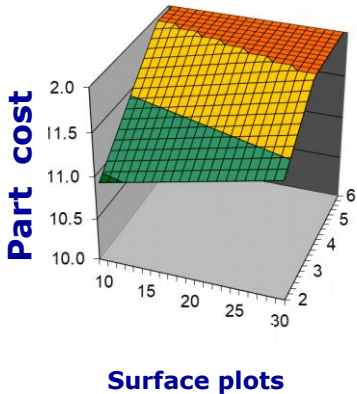
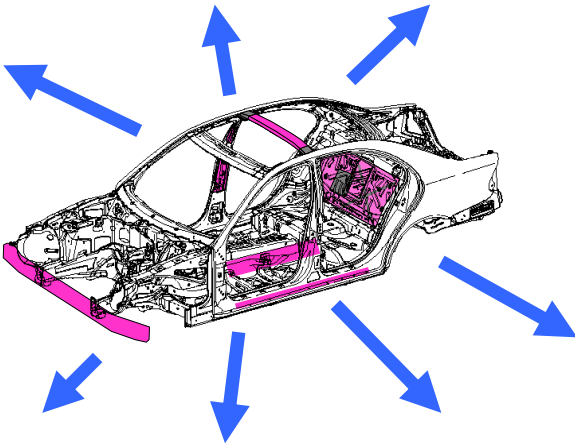
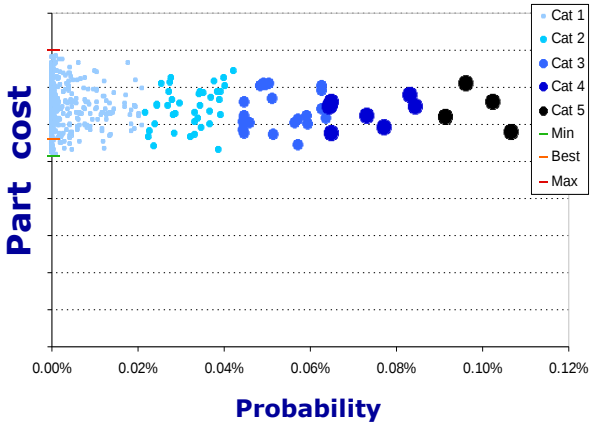
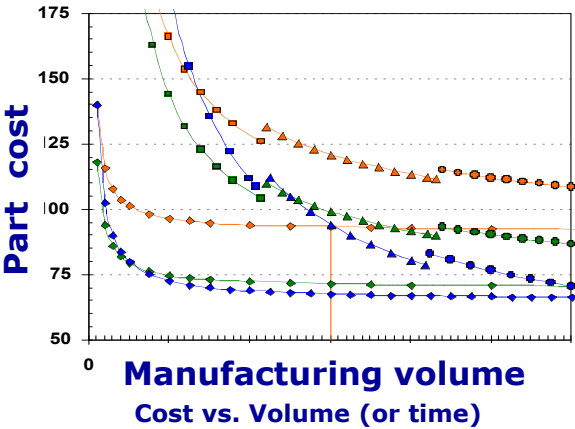
Activity based costing

- Attributes direct and overhead costs to products and services based on the underlying activities that generate the costs
- Based upon historical data
- Can go to plant and clock process
- Of limited use when new processes are considered

Technical cost modelling

- Related to ABC
- Uses engineering, technical and economics characteristics associated with each manufacturing activity to evaluate its cost
- Where detailed overhead costs not available, volume based approximations are applied (ratio of direct to indirect labor)

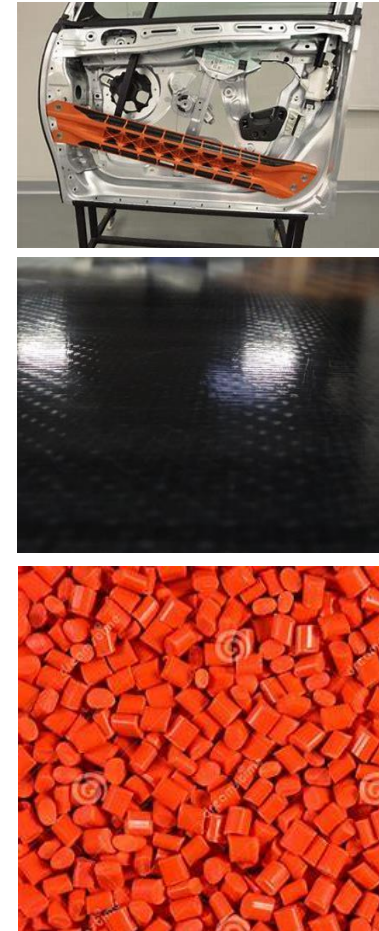
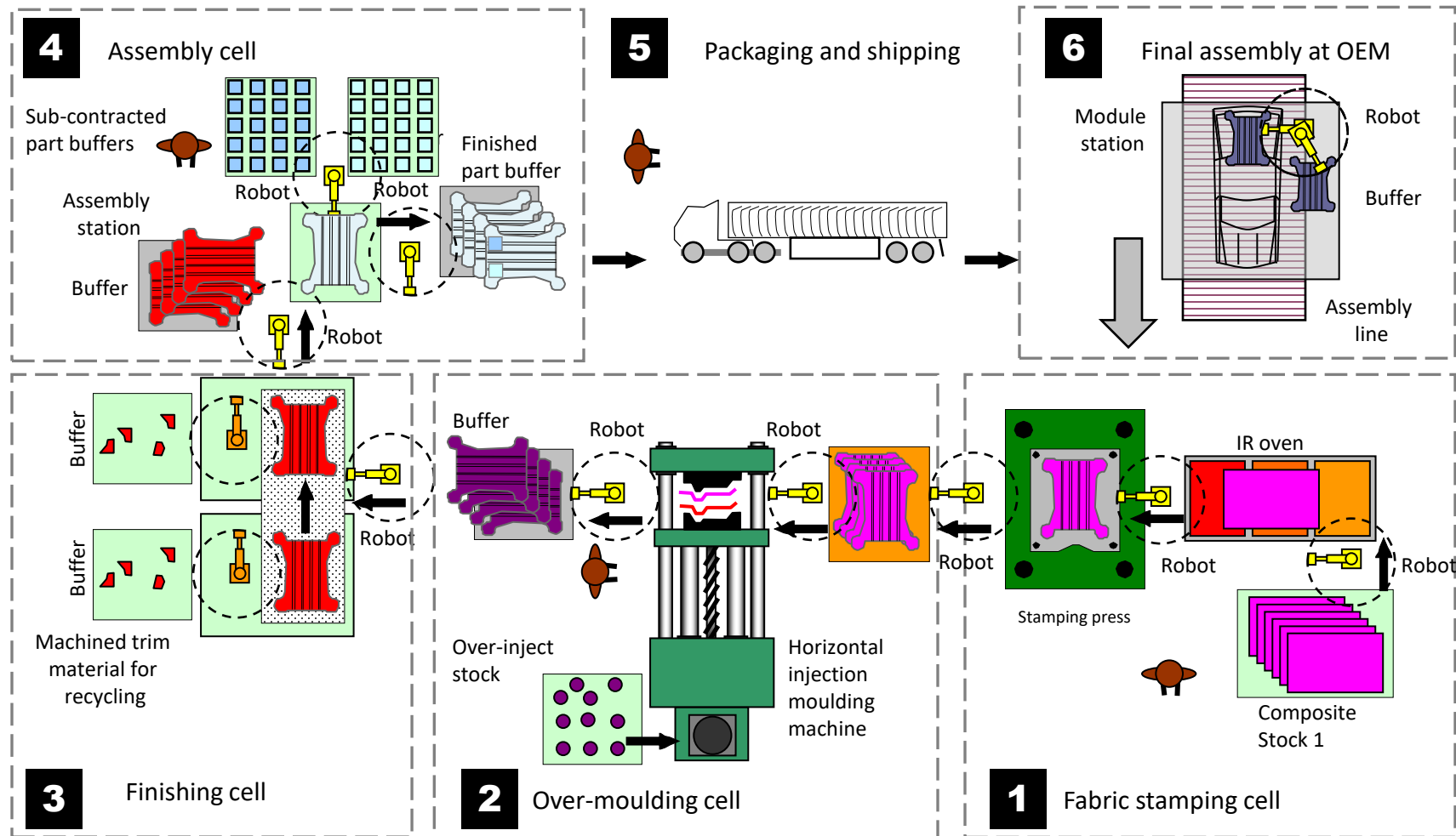
Examples of cost model output



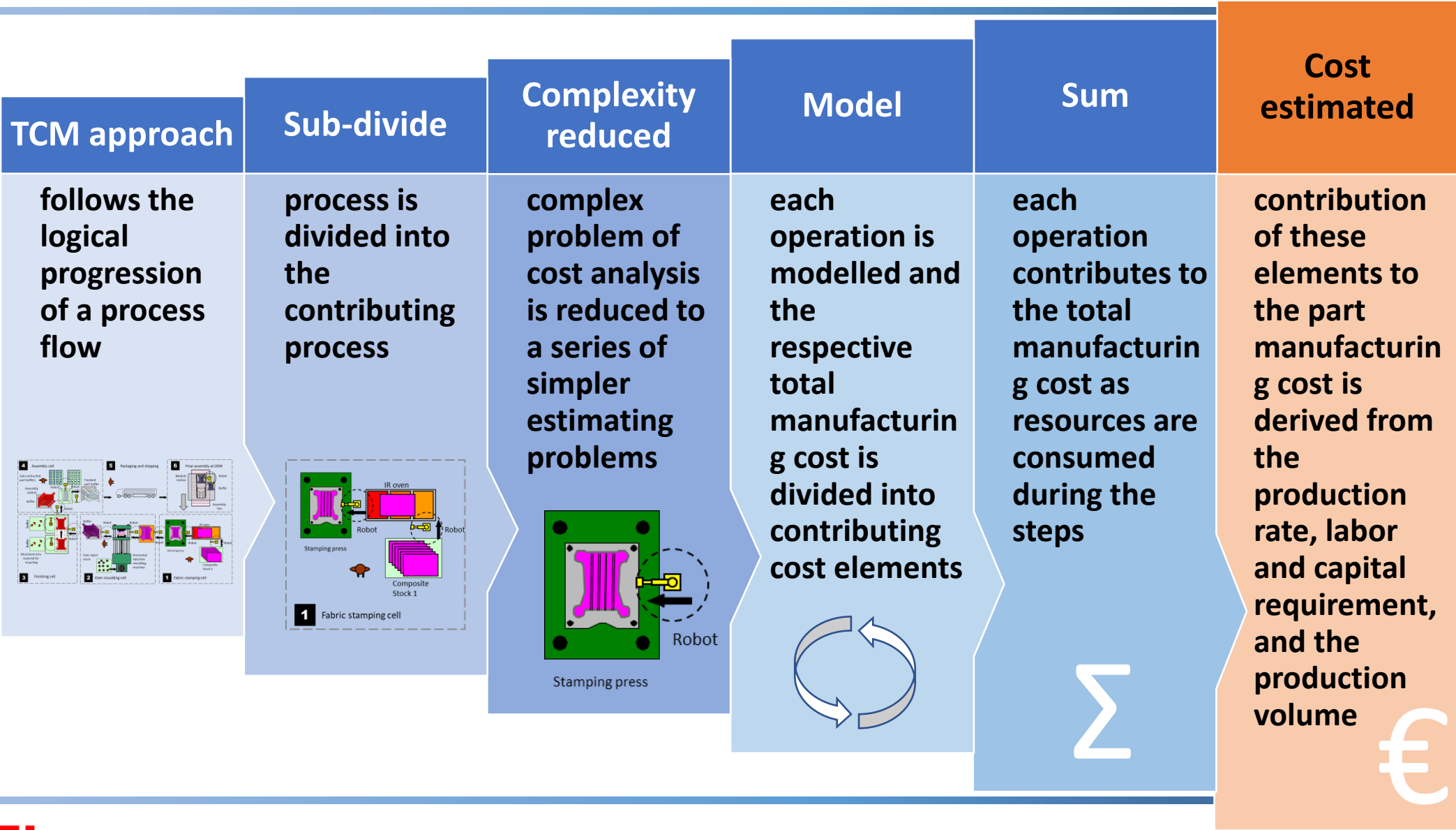
Overview

- Cost modelling approaches
- **Technical cost modelling deep dive**
- Cost modelling and technology strategy
- Cost modelling and sustainability
- Wrap up
- A simple cost tool

Example of a conceptual manufacturing plant

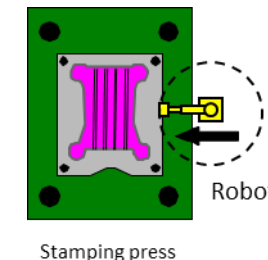
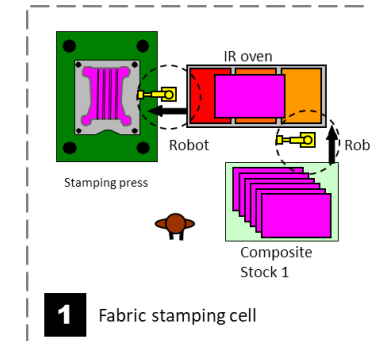
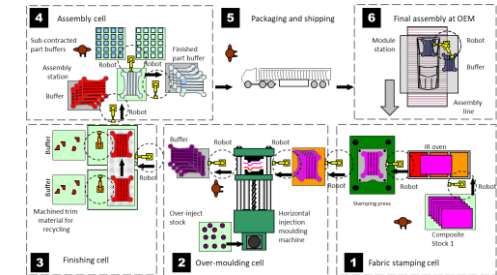
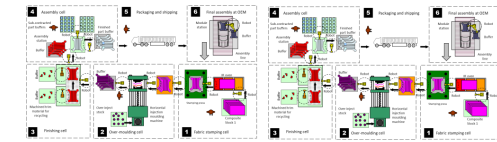


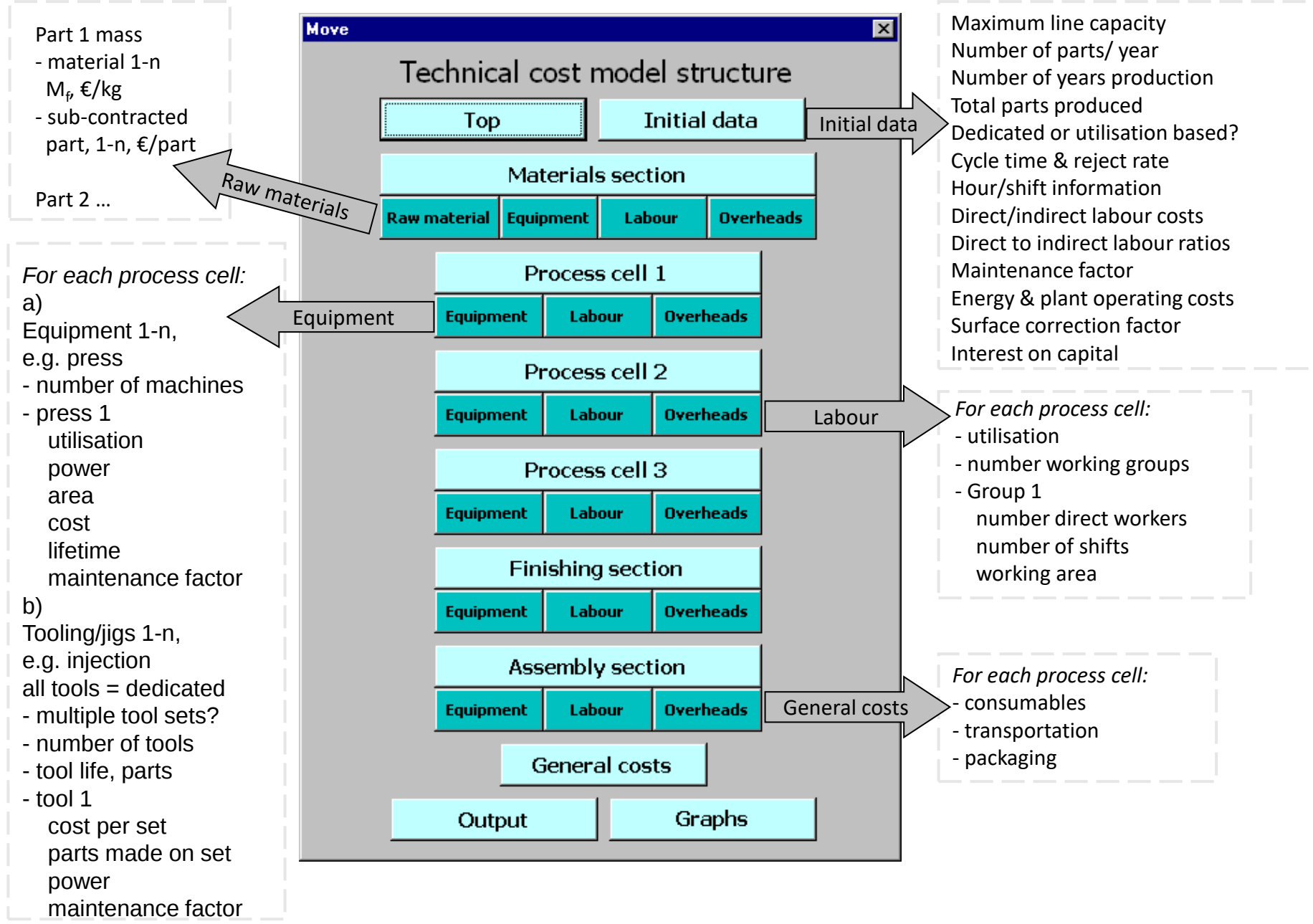
Technical cost modelling approach



Elements

- Plant
 - Overall manufacturing system, could be composed of multiple lines
- Line
 - The equipment needed to produce one part,
 - e.g. the two cells of a stamping press and an injection cell
- Cell
 - Key grouping of equipment that performs an integral linked operation within a line, e.g. an oven, robot, and stamping press
- Machine
 - A piece of equipment within a cell, e.g. a hydraulic press





Importance of data quality

Rigorous scientific exercise

Using experiments

FEA simulations / virtualization to aid data generation

Include the physics

Quotations: Building relationships with future suppliers

Regression models

Known to those skilled in the art

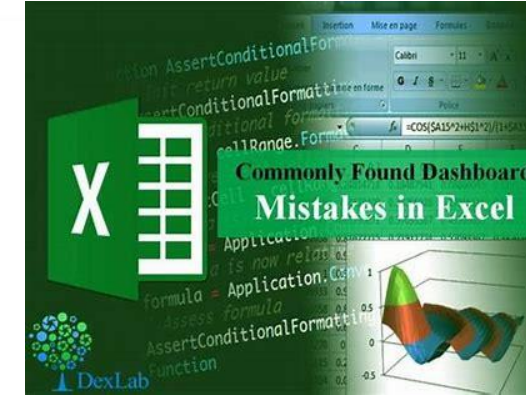
Consultants

Sensitivity analysis

“Garbage in, garbage out”



Your analysis is as good as your data.



Garbage in, garbage out.
Data preparation is the most important step.
Incorrect or insufficient data equals
bad business decisions



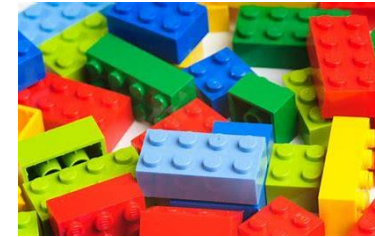
Chuck Robida
Chief Scientist, Experian
@ExperianDA

#DataTalk
ex.pn/datatalk

Overheads / general input data

- Your overall assumptions for the factory where the part will be made
- Can change by cell (to simulate different internal costs or a supply chain with each cell as a factory)

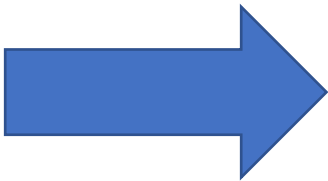
General input data	
Number of years production, [yrs]	4
Production period, [days/yr]	220
Hours/shift, [hrs]	7.3
Combined indirect & direct wage [€/hr]	52
Ratio indirect/direct labor	0.75
Unit energy cost, [€/kWhr]	0.18
Plant operating cost, [€/(m2/yr)]	140
Surface correction factor, [multiplier]	4.25
Interest on capital, [%]	0.06
3 shift: machine life, [yrs]	7
1 & 2 shift: machine life, [yrs]	7
Maintenance factor (% purchase), [€/yr]	0.07
Consumables/direct person, [€/hr]	0.5



An overhead view of a mold room in the new Lego factory in Nyíregyháza, Hungary. 672 newly purchased mold machines are installed at this location
<https://lego-tenthings.weebly.com/legos--manufacturing.html>

Labor costs by country

- Pay excl. social costs
 - EU average = €30/hr
 - Germany = €40/hr



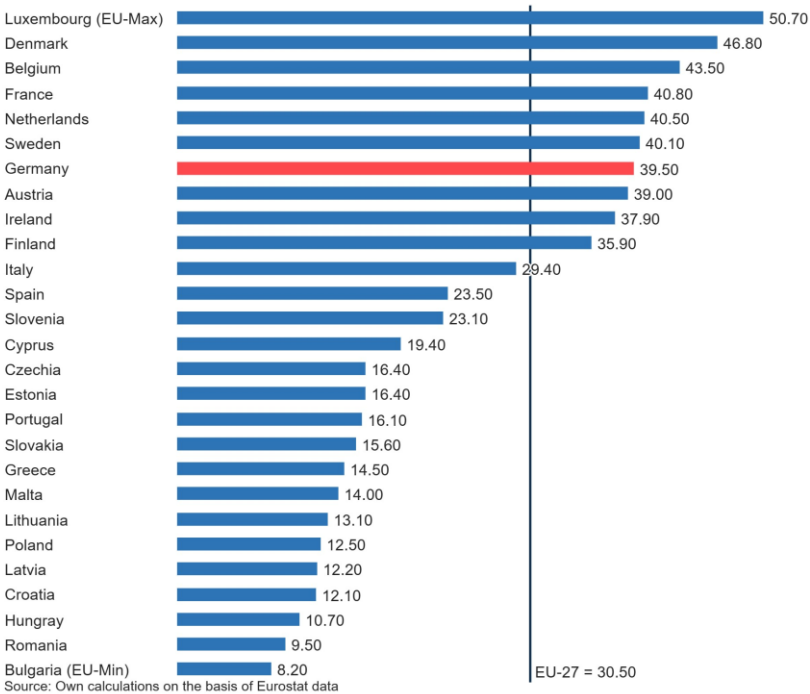
- Social security tax rate

- Average EU social overhead is 20%
- Direct labor cost in model is hence $40 \times 1.2 = \text{€}48 \text{ /hr}$
- Indirect labor cost in model **€56 /hr**
CHE

[Mercedes-Benz Group Technical Lead Salaries in Germany | Glassdoor](#)

Labour costs comparison across EU countries per hour worked, 2022

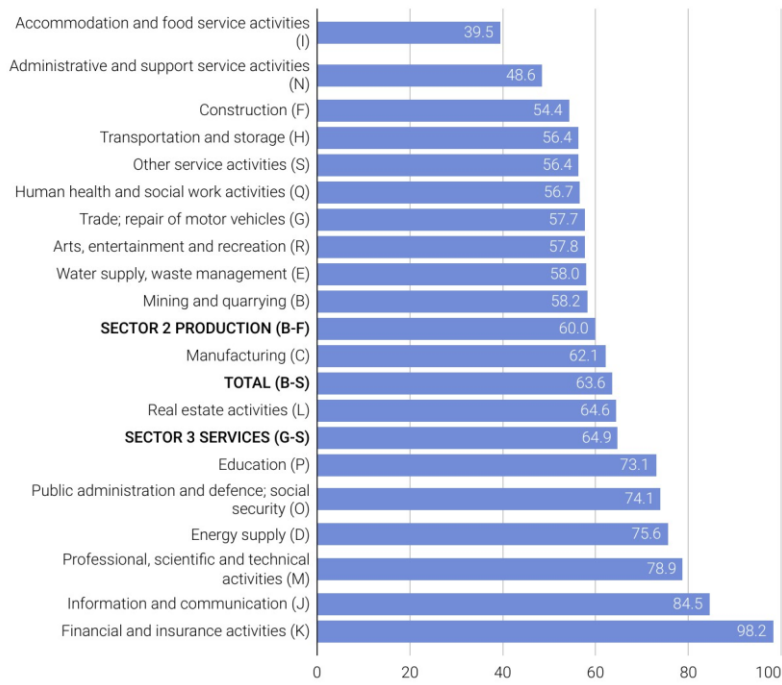
Industry, construction and services (except public administration, defense, compulsory social security), euros



© Statistisches Bundesamt (Destatis), 2023

Hourly labour cost by economic section, 2020

Switzerland (private and public sectors), including apprentices, in Swiss francs



Source: FSO - Labour cost structural statistics

© FSO 2023

Country	SST Rate 2022	Population (2022)
France	40,00	65,273,511
Czech Republic (Czechia)	33,80	10,708,981
Sweden	31,42	10,099,265
Italy	30,00	60,461,826
Russia	30,00	145,934,462
Spain	29,90	46,754,778
Belgium	25,00	11,589,623
Portugal	23,75	10,196,709
Netherlands	23,59	17,134,872
Greece	22,54	10,423,054
Poland	22,14	37,846,611
Ukraine	22,00	43,733,762
Austria	21,38	9,006,398
Finland	20,66	5,540,720
Germany	19,98	83,426,789
Bulgaria	19,02	6,948,445
Hungary	17,00	9,660,351
Luxembourg	15,17	625,978
Norway	14,10	5,421,241
United Kingdom	13,80	67,886,011
Ireland	11,05	4,937,786
Canada	7,66	37,742,154
United States	7,65	331,002,651
Denmark	7,65	5,792,202
Switzerland	6,40	8,654,622
Iceland	6,10	341,243
Romania	2,25	19,237,691
Lithuania	1,77	2,722,289

One hour worked cost an average of 39.50 euros in 2022 - German Federal Statistical Office (destatis.de)

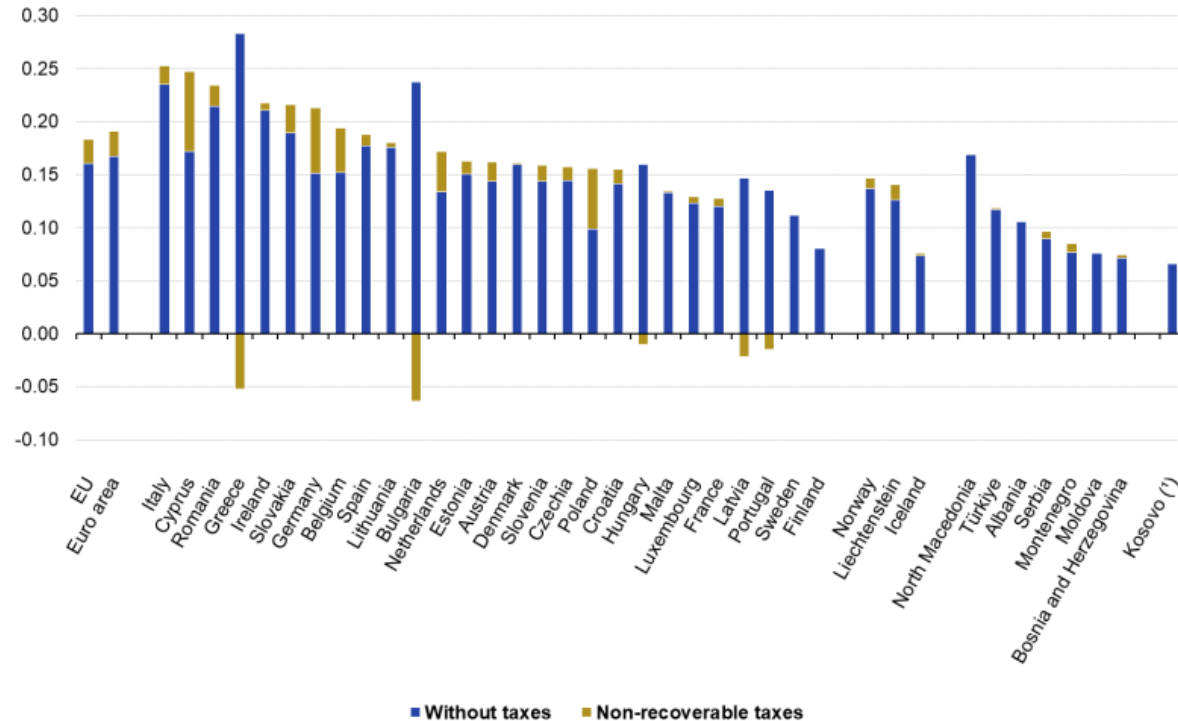
[Labour costs | Federal Statistical Office \(admin.ch\)](#)

[Social Security Tax Rates for Employers in Europe 2022 \(eurodev.com\)](#)

Electricity costs, non-household consumers

- EU average price 1st half of 2023 = €0.18 per kWh

Electricity prices for non-household consumers, first half 2023
(euro per kWh)



(*) This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo Declaration of Independence.

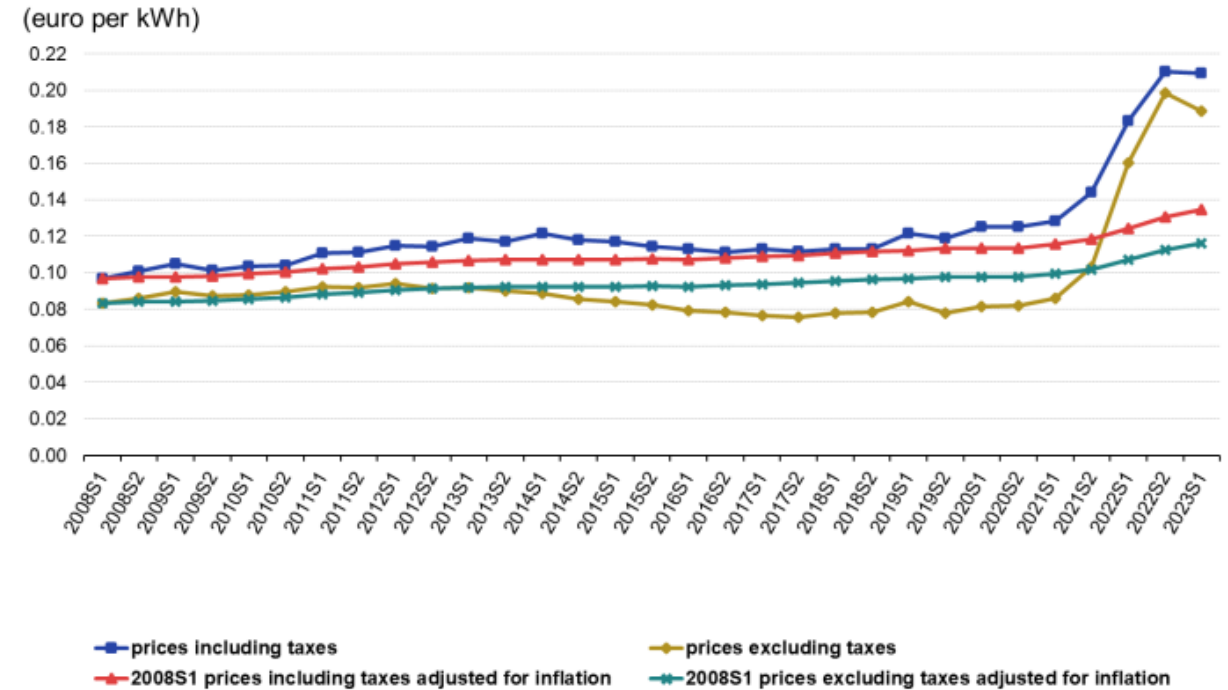
Source: Eurostat (online data codes: nrg_pc_205)

[File:Electricity prices for non-household consumers, first half 2023 \(euro per kWh\) 23-10-2023.png - Statistics Explained \(europa.eu\)](#)

eurostat

- Pricing trend vs. time (VUCA world)

Development of electricity prices for non-household consumers, EU, 2008-2023
(euro per kWh)

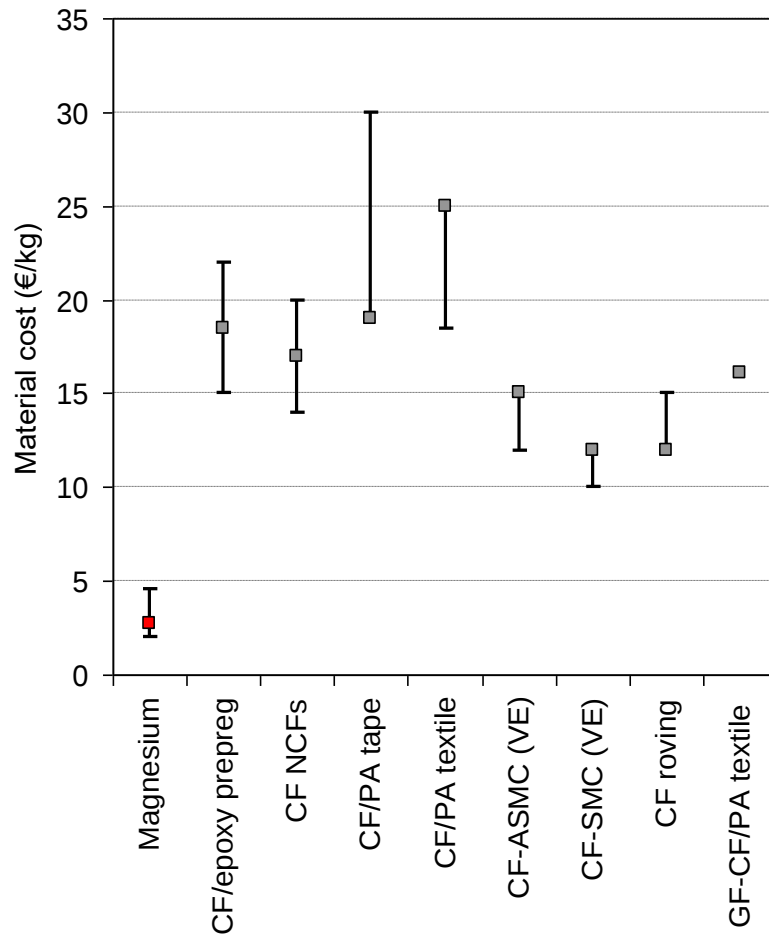


Source: Eurostat (online data codes: nrg_pc_205)

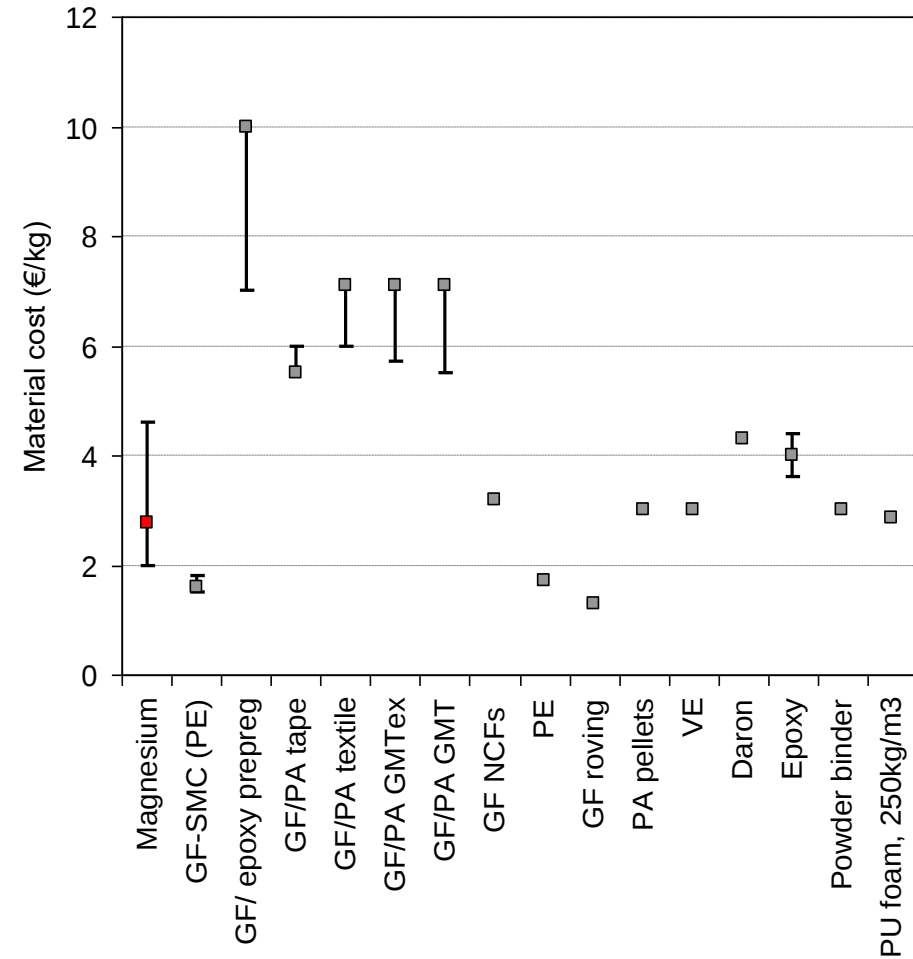
eurostat

[Electricity price statistics - Statistics Explained \(europa.eu\)](#)

Material cost assumptions (historical data ...)



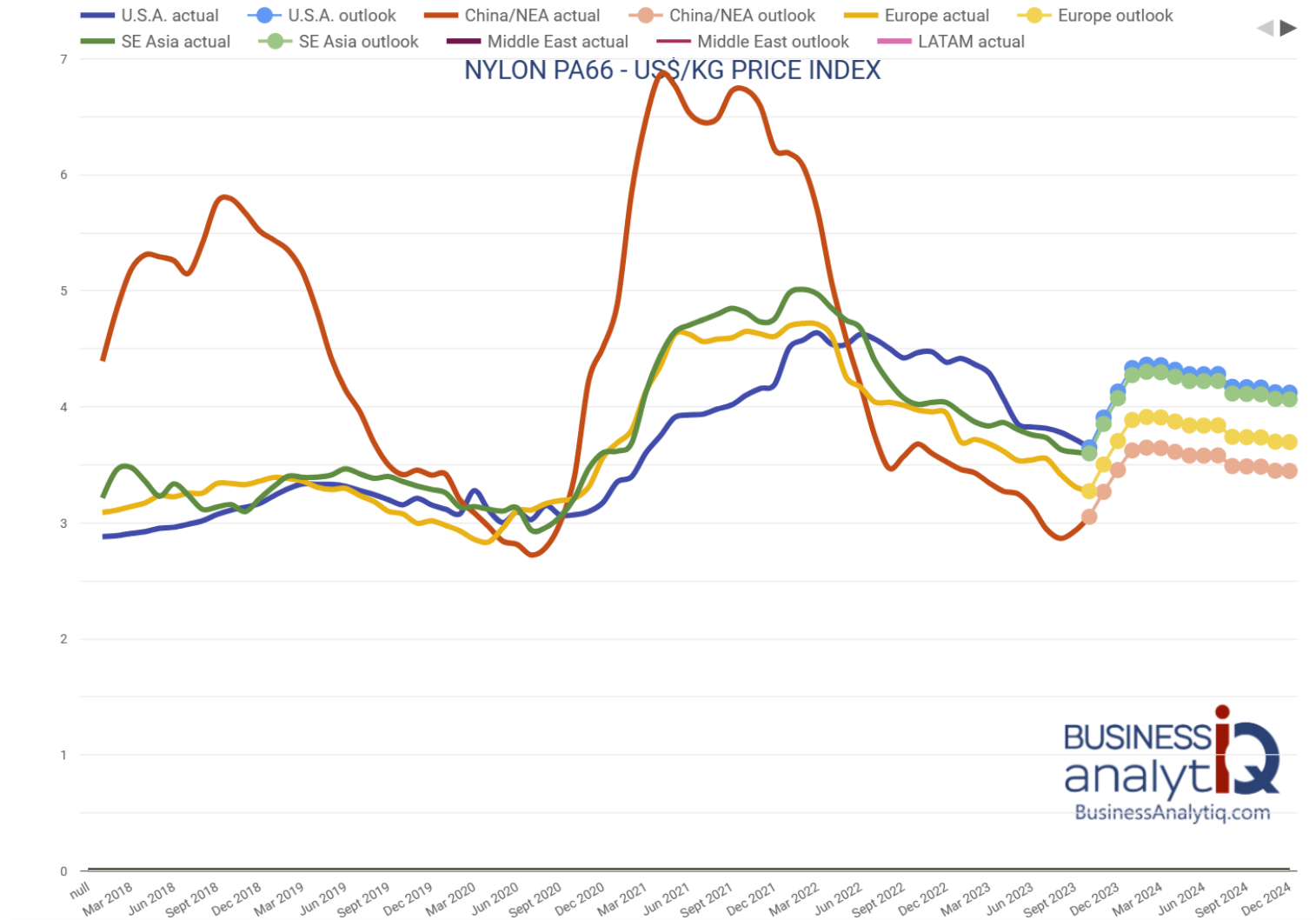
Carbon fiber-based



Glass fiber-based

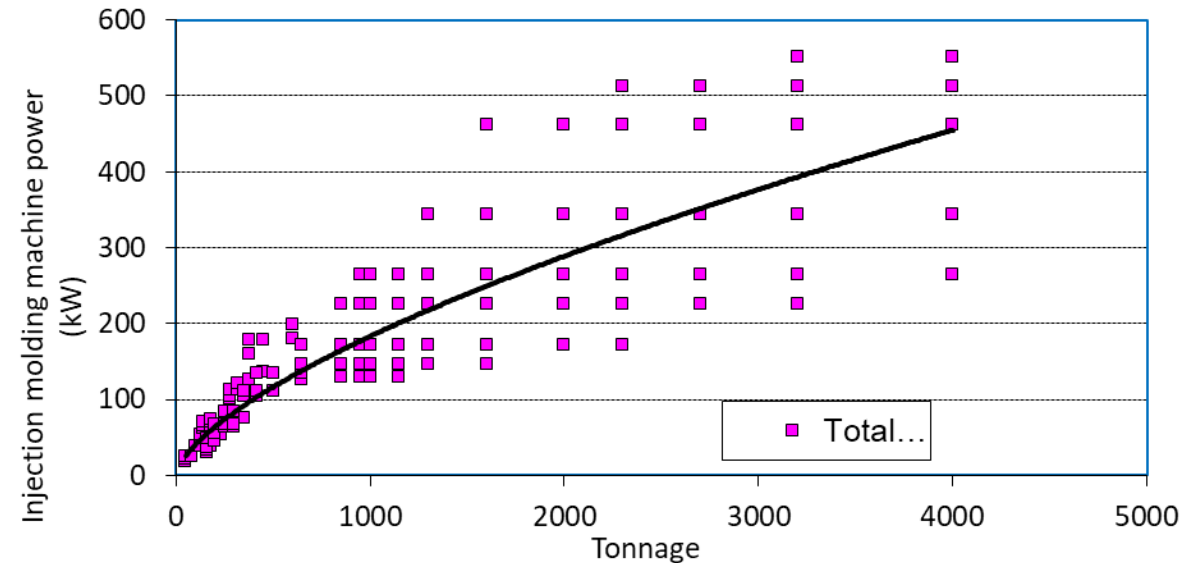
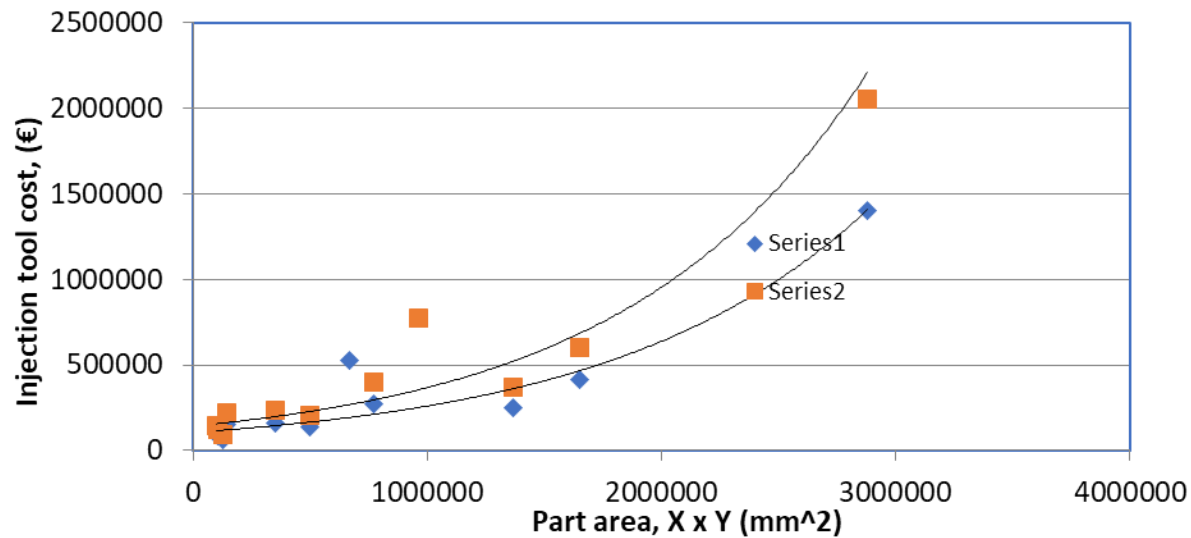
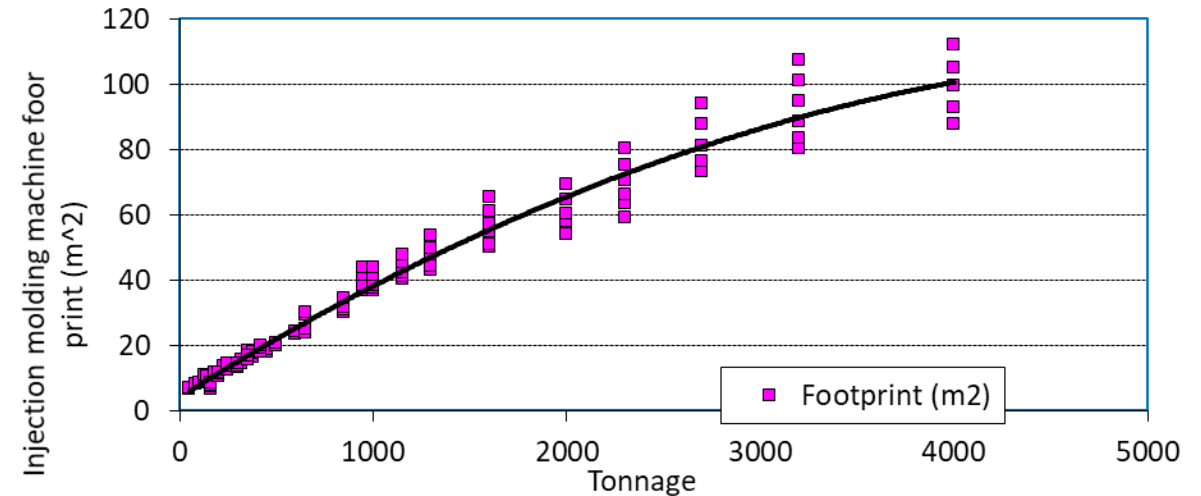
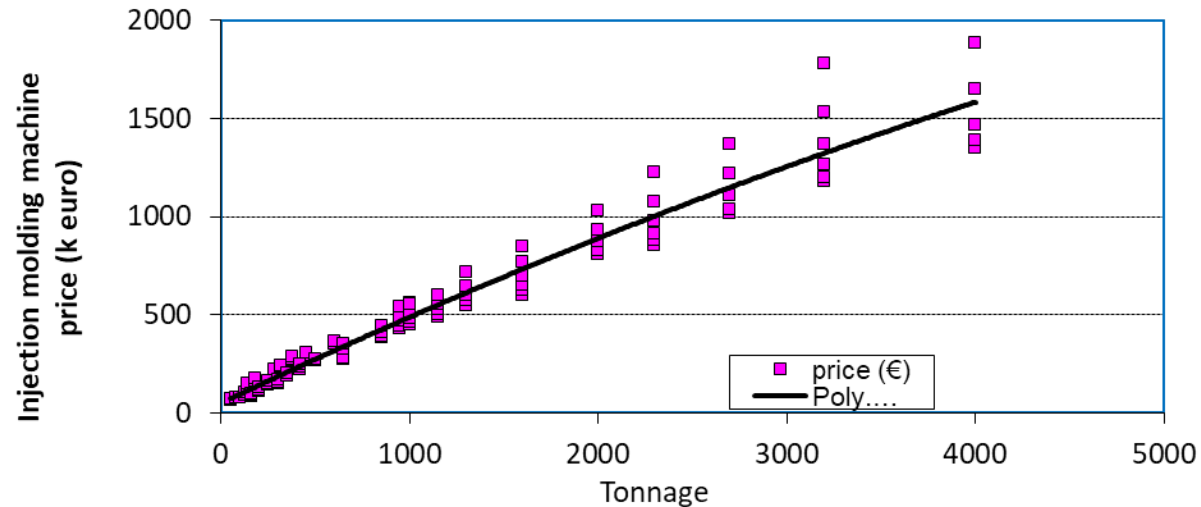
Historical PA66 pricing

- Material cost varies with market conditions, oil price, geo-political tensions, extreme weather events, supply and demand, business strategy M&A



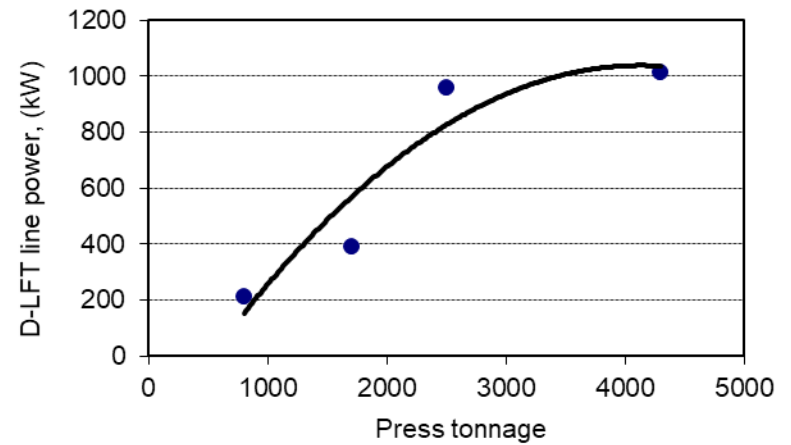
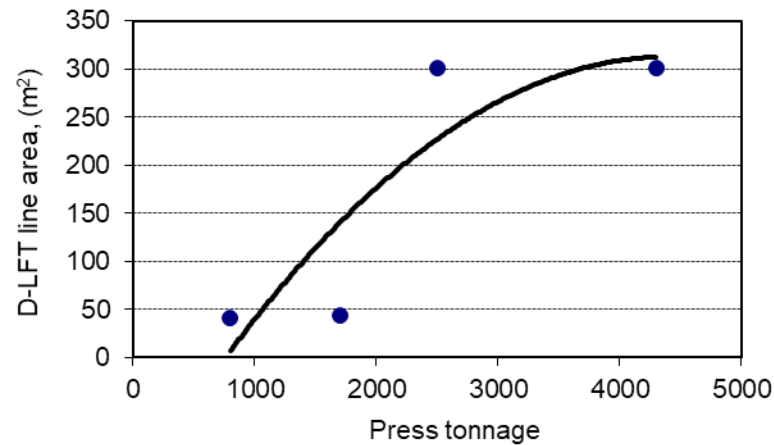
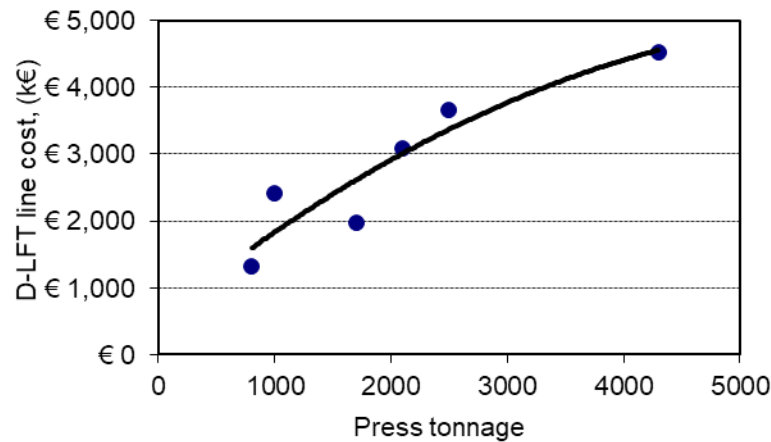
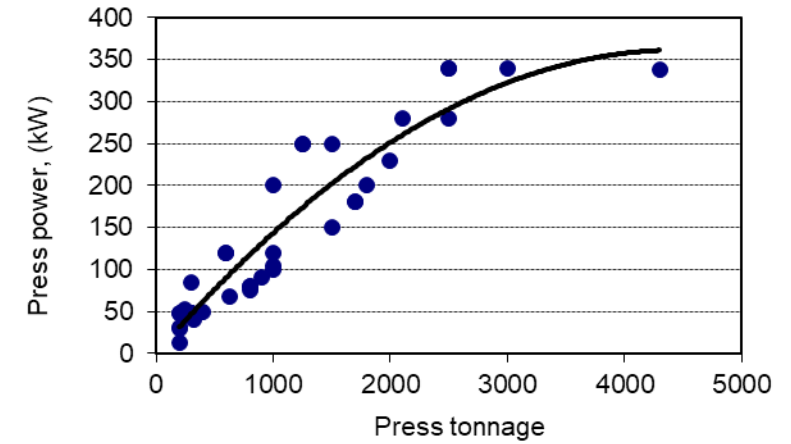
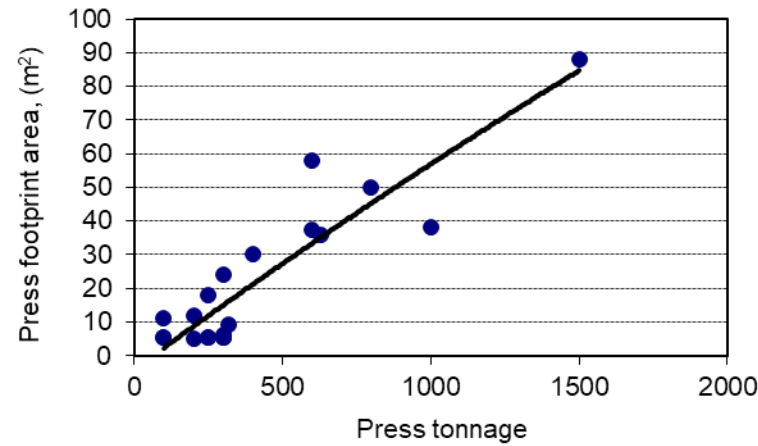
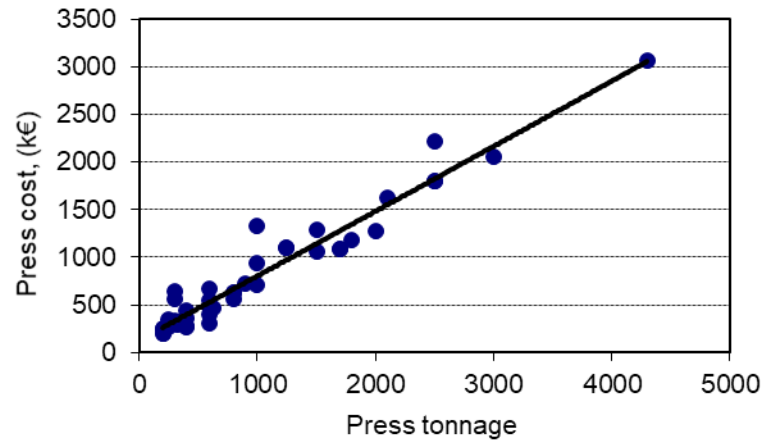
[PA66 \(Nylon 66\) price index - businessanalytiq](#)

Input data for injection molding



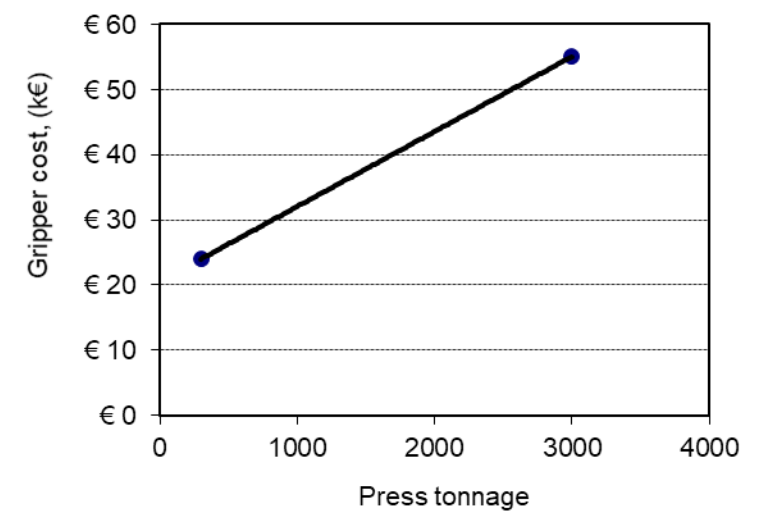
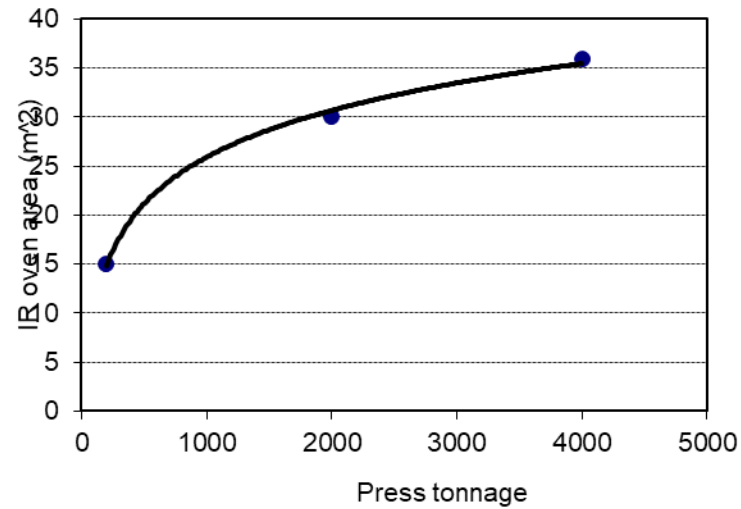
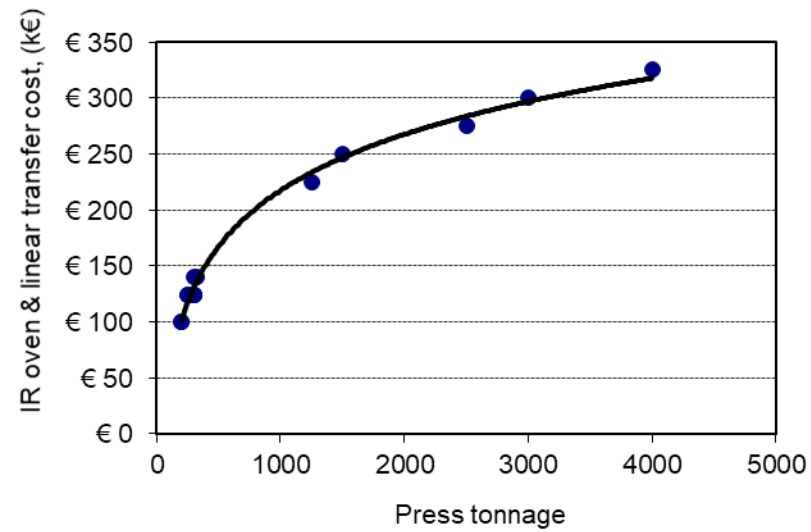
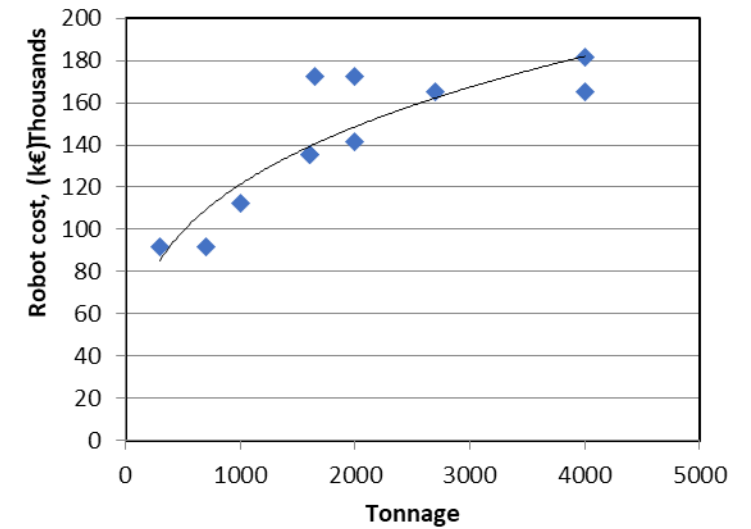
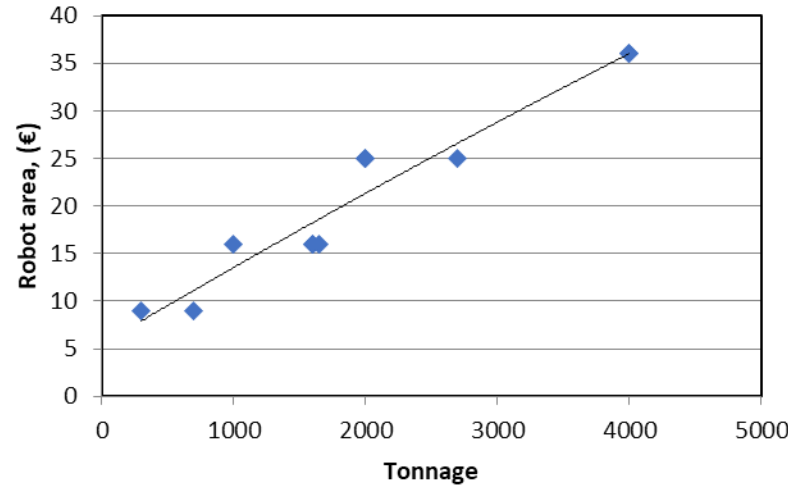
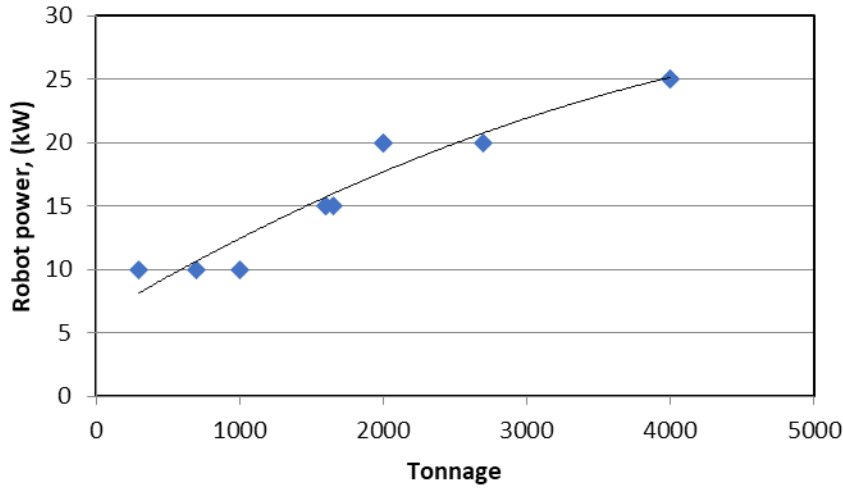
Cycle time approx. 7s/mm thickness, plus 5 sec allowance/part
AND robotic transfer (fast is 7s one side, up to 14s)

Input data for press molding (HP-RTM, D-LFT, TPC)



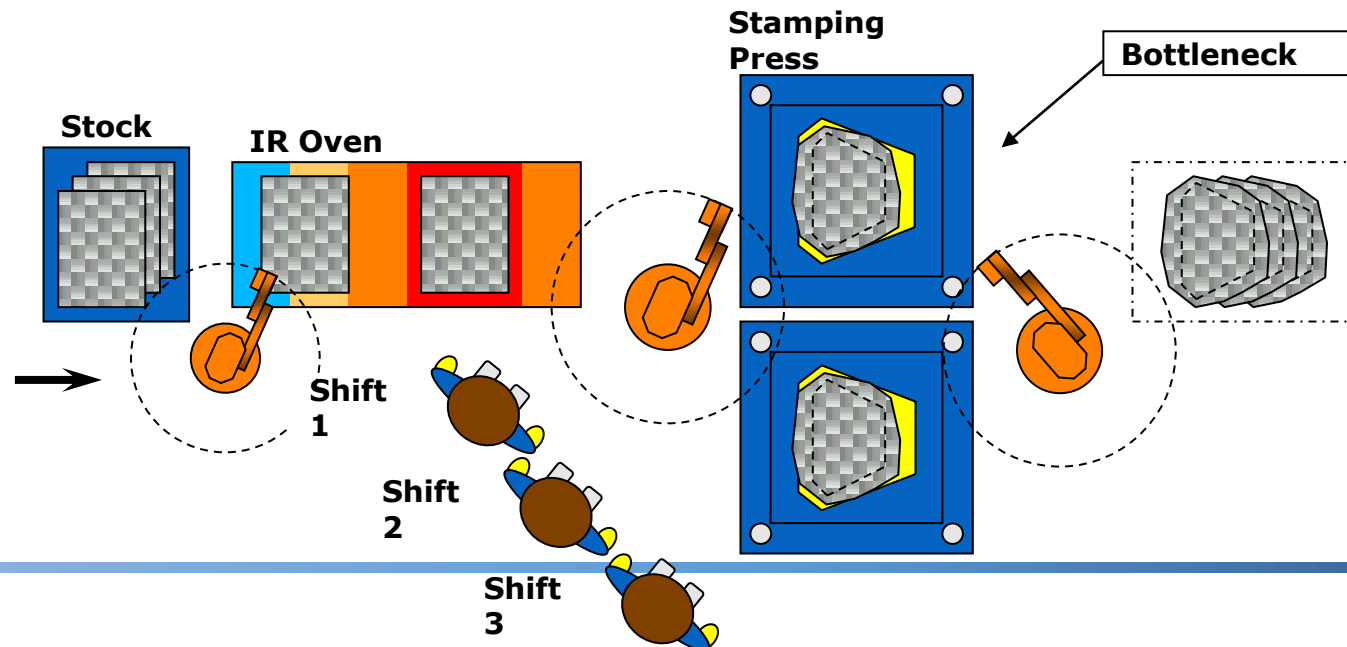
press tonnage rule
50-60 k euro per 1000kN press force

Automation, ovens



To meet desired manufacturing volume

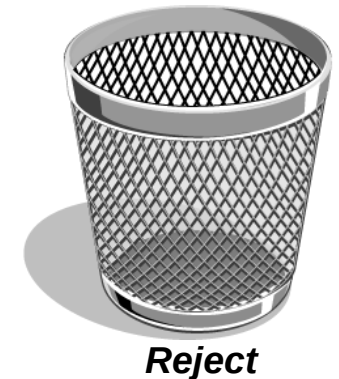
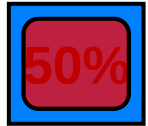
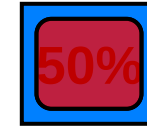
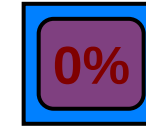
- Multiplication to meet Target Production Volume
 - If production capacity of the specified setup is lower than the target volume required, labour, activities and tooling must be added in parallel as follows:
 - **First** - add extra shifts until maximum number per day
 - **Second** - add machines or entire cells in parallel



- Manufacturing line not necessarily the same at low and high volume,
- Need to use different plant diagrams and assemble the cost curve

Inclusion of reject and trim in the process flow

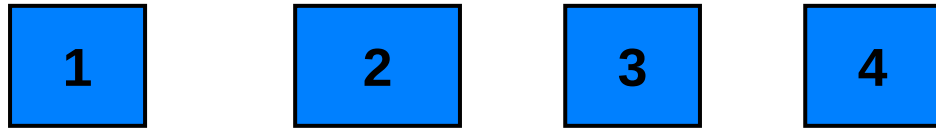
- Trim – needed for a good part
 - Increases the required material mass IN and hence part cost (does not affect machine utilization)
- Reject – (bad part) increases the required production rate
 - Cumulative over cells and machines
 - Need to buy more material and machine time
 - Affects plant utilization downstream of the rejects
 - Rework possible
- **Avoid Trim and Reject!**



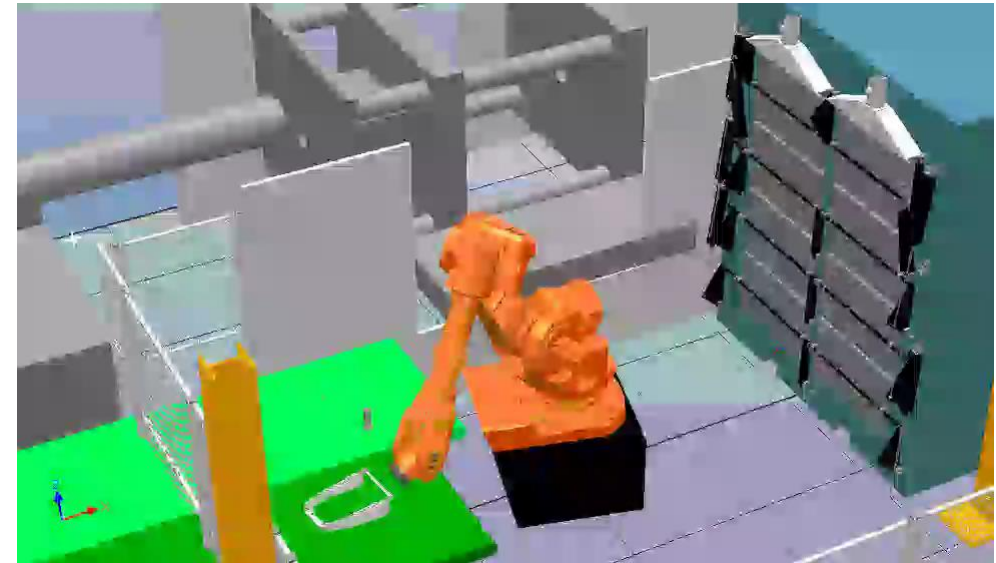
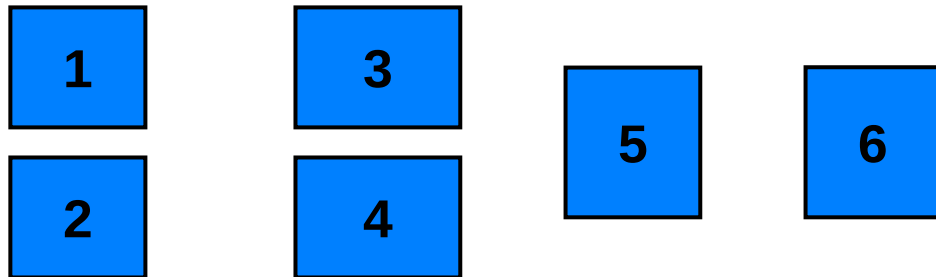
Process Flow - Series & Parallel

- Steady State

- Series



- Parallel Converging (assembly)



Segregation of cost elements

CAPEX

- **Capital expenditures** (CapEx)
- Funds used by a company to acquire, upgrade, and maintain physical assets such as property, plants, buildings, technology, or equipment
- CapEx is often used to undertake new projects or investments by a company
- **CAWC**
 - cost associated with capital (installation), sometimes $\text{CAPEX} + \text{CAWC} = 1.5 \text{ to } 2.5 \times \text{CAPEX}$

OPEX

- **Operating expenditure**
- Ongoing expenses inherent to operation of the asset
- Includes items like electricity, salaries, R&D, travel, SG&A (selling, general and administrative expense)

Segregation of cost elements

Fixed costs

- Typically a one-time capital expenditure
- Capital investments that are necessary for the manufacturing facility
- Fixed costs per piece vary according to the production volume
- As volume increases, fixed costs are reduced because the investment can be amortised over more parts
- e.g. machine, tooling, maintenance, cost of capital, and building costs

Variable costs

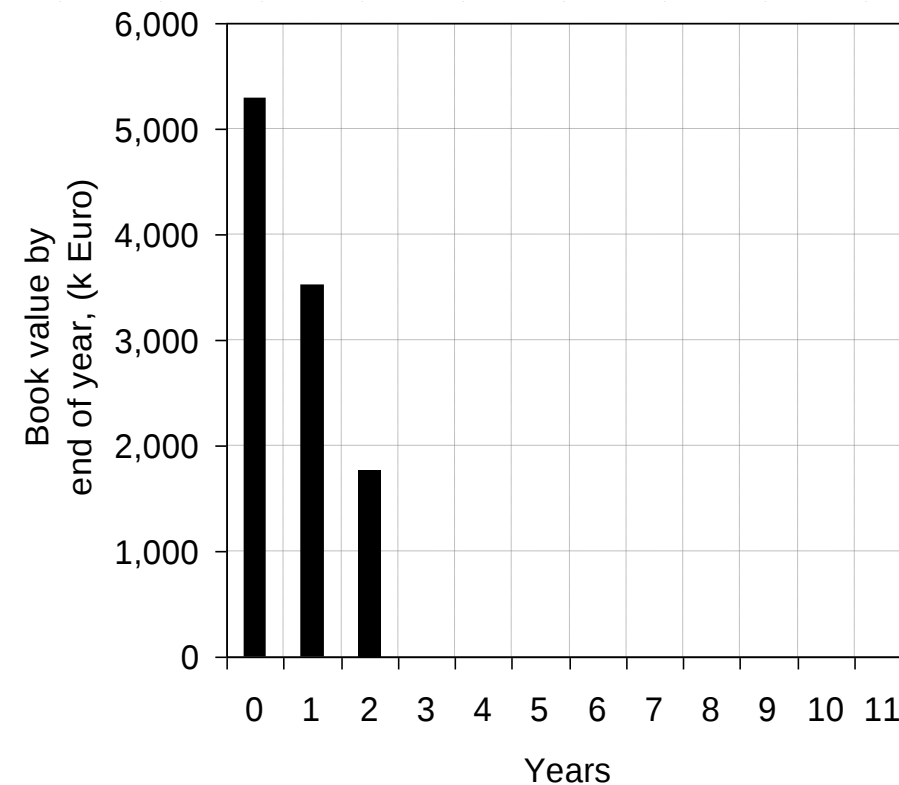
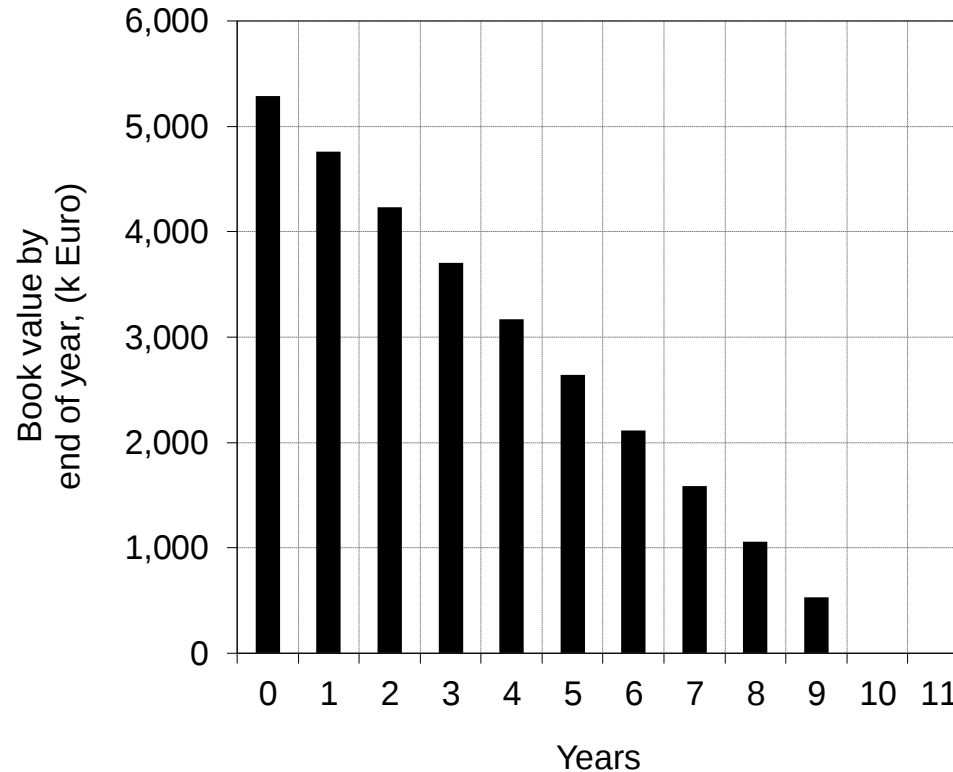
- Independent of the manufacturing volume within a given time frame
- e.g. raw material cost, labour, energy, and sub-contracted costs
- Can push fixed costs towards variable costs by contract or toll manufacturing (don't own asset)

Depreciation of fixed capital *(heavy process equipment)*

(3 shift pattern = 7 year plant life)
(2 shift pattern = 10 years plant life)

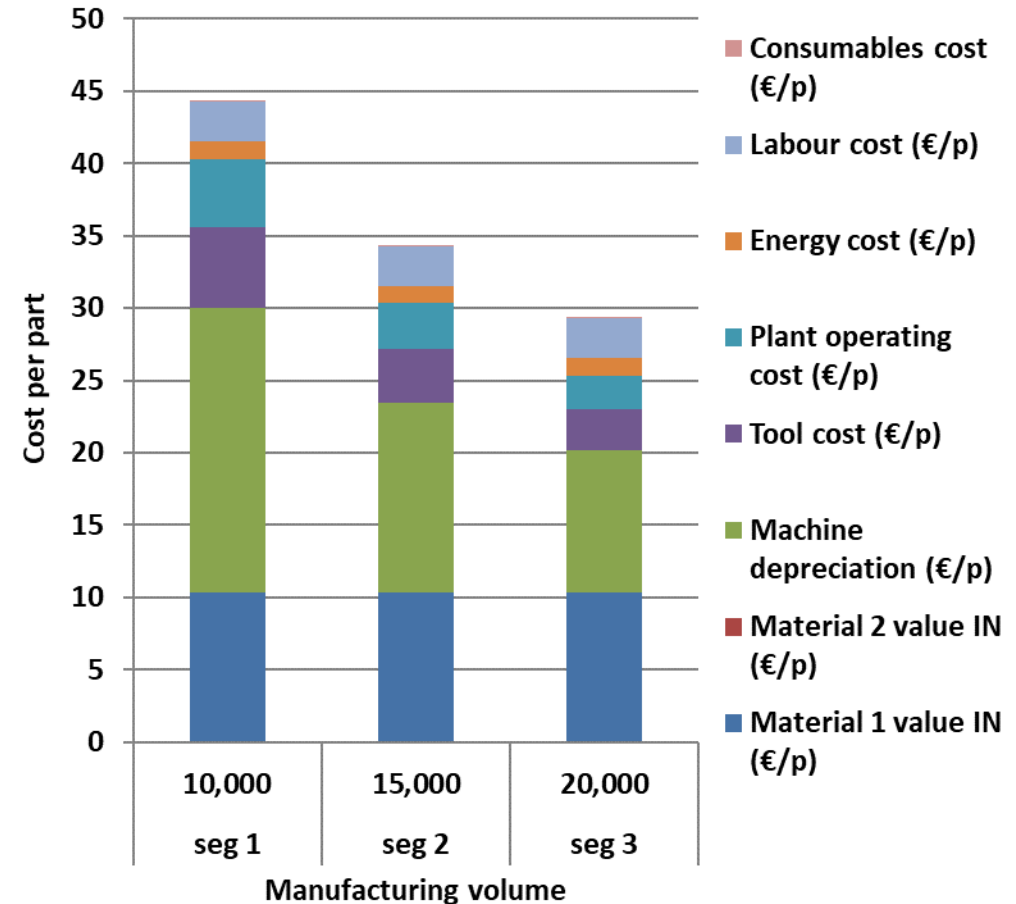
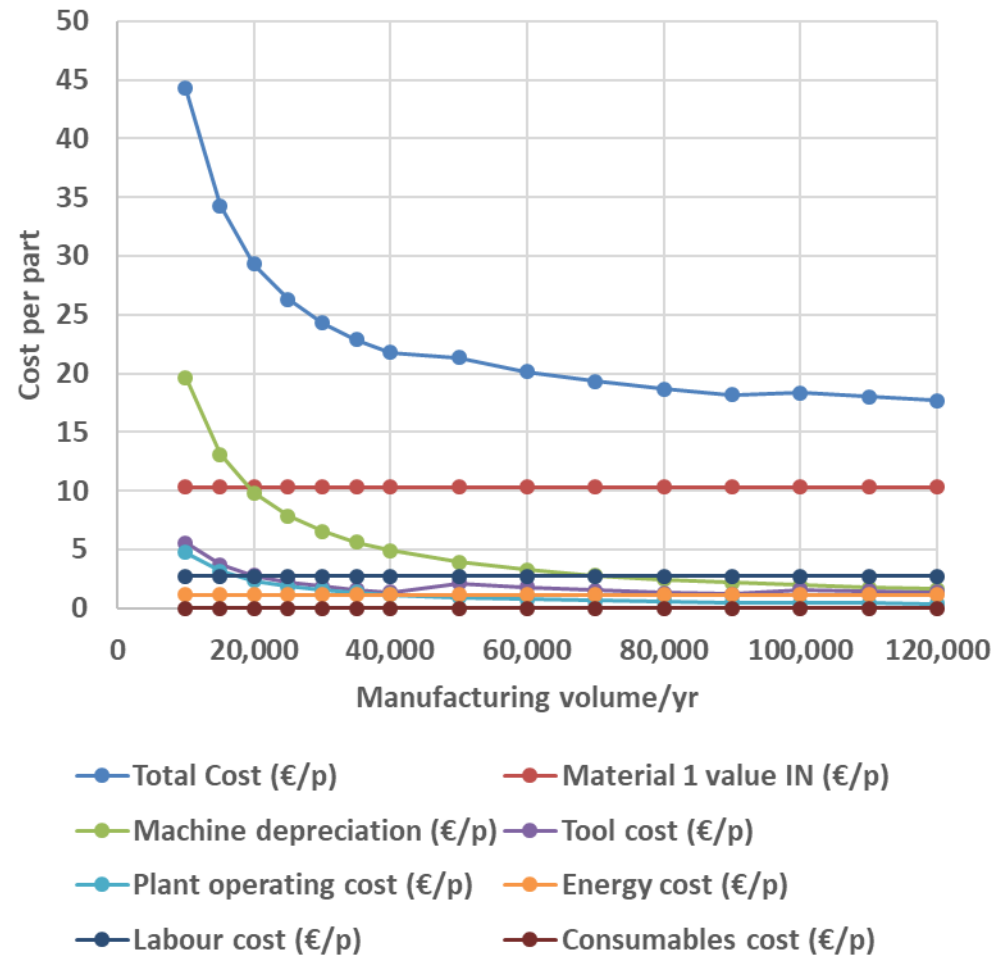
3 years depreciation
(dedicated line assumption)

Linear depreciation



Tooling cost is always dedicated to the part (cost/number parts), e.g. steel IM tool = €1,000k

Example of fixed and variable costs from simple tool



Dedicated plant

Amortization of plant costs

- Amortization of plant costs can be approached in two manners

Dedicated

- Whole line dedicated to one product
- All of the fixed plant costs are amortised over the number of parts produced for the total years of production
- Cost against volume graphs can be generated simply by assuming that the full plant costs are spread over the parts produced
- Strongly increasing costs at lower volumes

Utilized

- Multiple products
- Only a fraction of either a line capacity or a plant would be assigned to one product while the remaining capacity would be sold to a second client
- Fixed plant costs are amortised as a fraction of utilisation and the number of shifts and years that the plant is used
- Effectively giving a charge rate per minute for a manufacturing line



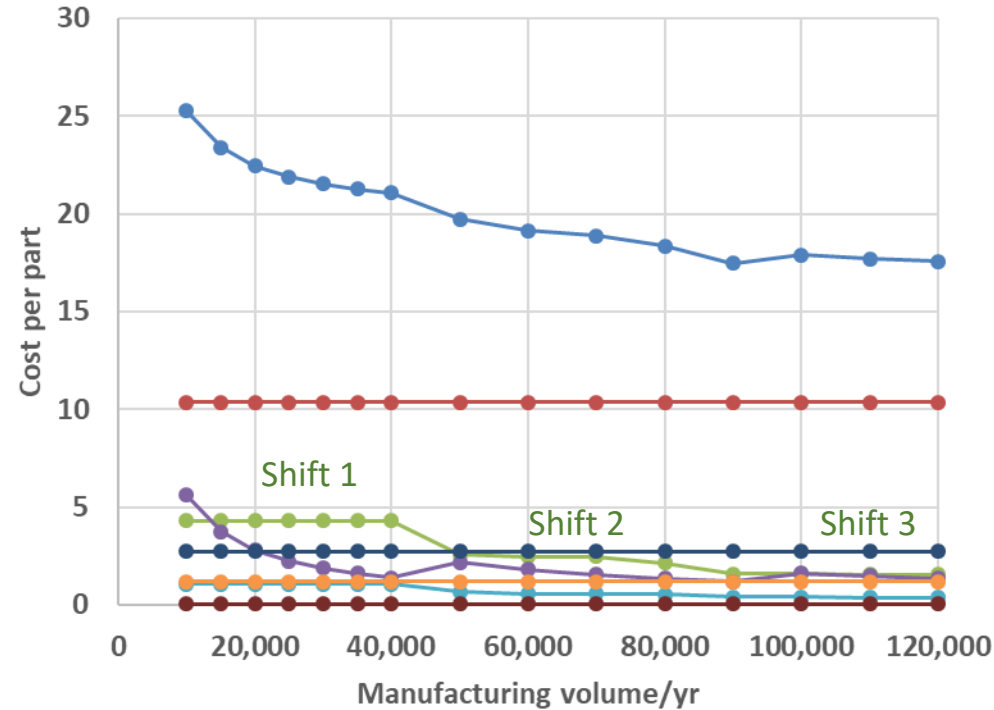
Dedicated



Utilized

Utilized vs. dedicated: fixed and variable costs

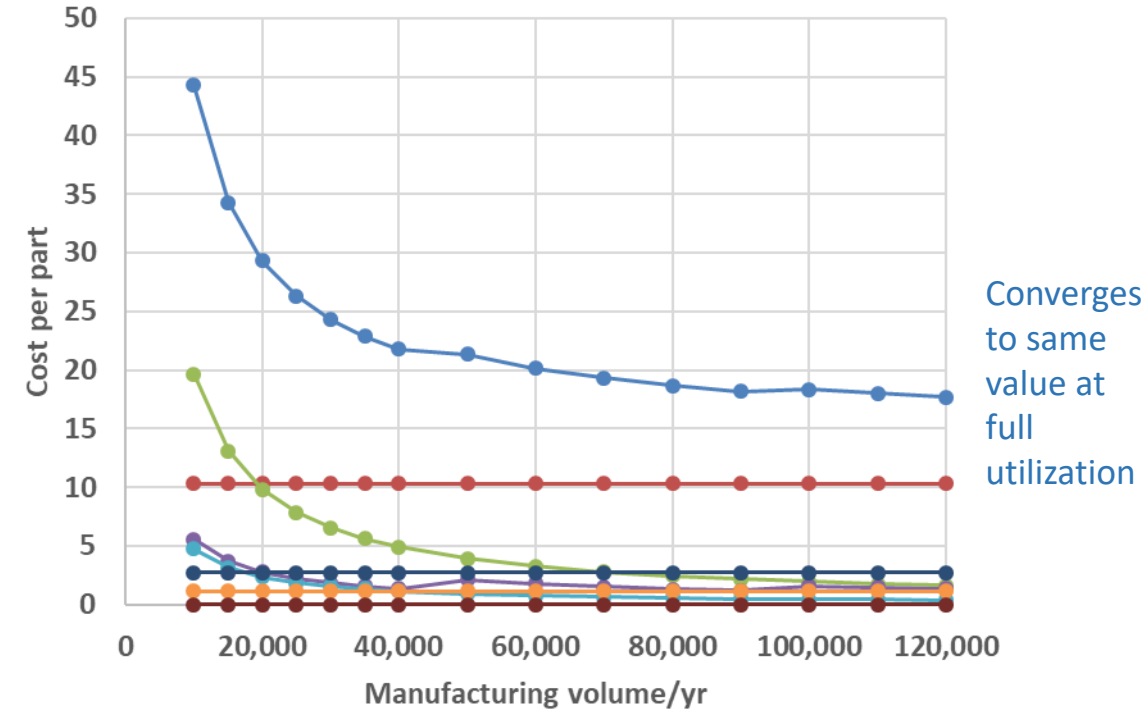
Remaining capacity paid for by different product or client



- Total Cost (€/p)
 - Machine depreciation (€/p)
 - Plant operating cost (€/p)
 - Labour cost (€/p)
 - Material 1 value IN (€/p)
 - Tool cost (€/p)
 - Energy cost (€/p)
 - Consumables cost (€/p)
- Tooling here is part specific, so dedicated

Utilized plant

ALL capacity paid for by ONE product or client



- Total Cost (€/p)
- Machine depreciation (€/p)
- Plant operating cost (€/p)
- Labour cost (€/p)
- Material 1 value IN (€/p)
- Tool cost (€/p)
- Energy cost (€/p)
- Consumables cost (€/p)

Dedicated plant

Cell utilization and technology maturity

Established technology

Utilization based
Open booking
accounting within
automotive standard
practice

Assume that any
remaining capacity is
used by

- **a different product**
- **a different client**

Novel technology

Dedicated equipment for a cell
or for a full line

Where the investment is highly
part specific

Where the OEM requires
exclusivity, or risk

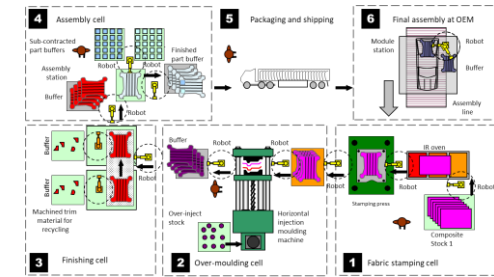
For the first applications, the
risk of empty capacity or the
lack of plant flexibility may
require the plant to be costed
as dedicated

Low volumes

Dedicated
plant can
really
penalize
novel
technology
at low
volumes

Cell grouping (and assumptions) within a plant

- Cells can be modelled as:
 - A) Dedicated (amortization over number of parts made)
 - B) Utilization based (amortization over full capacity, cost per minute)

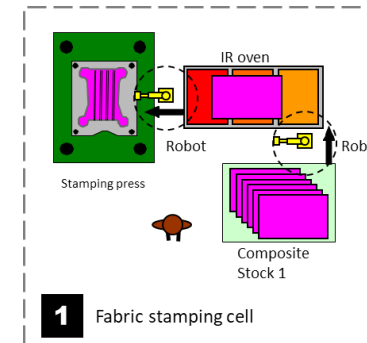


Adjusted

- Based upon cycle time in each cell
- There will be a bottle neck cell in any process
- A slower cell reduces a faster cell's maximum utilization
- Adjust cell cycle time and % utilization to bottle neck

Independent

- A slower cell does not impact a faster cell's maximum utilization
- (as the faster cell's extra capacity is assumed to be used by a different product)
- Complex case: This enables simulation of multiple suppliers working together



Part mass as a key driver in a cost model

Part mass (bill of materials)

- Often high contribution to overall cost
- Sensitive parameter
- Prototype tooling and physical testing are costly

Virtual prototyping

- Virtual prototyping 1st step
- CAD and FEA to give part mass to estimate cost and derive business case
- Digital twin

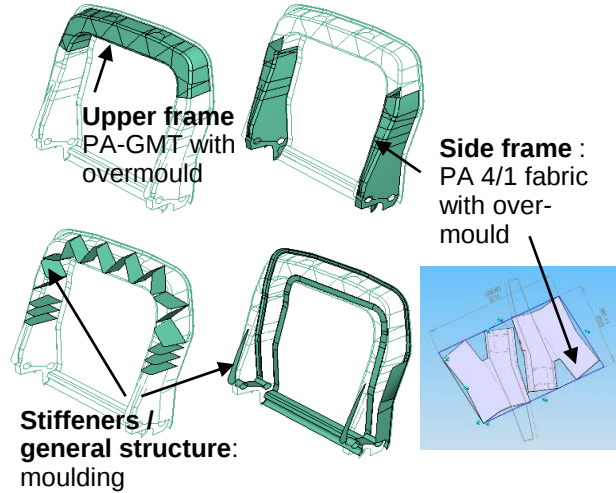
When comparing an incumbent e.g. Steel design

- Check which CTQs (e.g. deflection under load) need to be matched
- Some are a consequence of
 - Manufacturing route (material flow in tool)
 - Material formability
 - Fatigue ...
- To avoid over-design of novel technology (wall thickness)

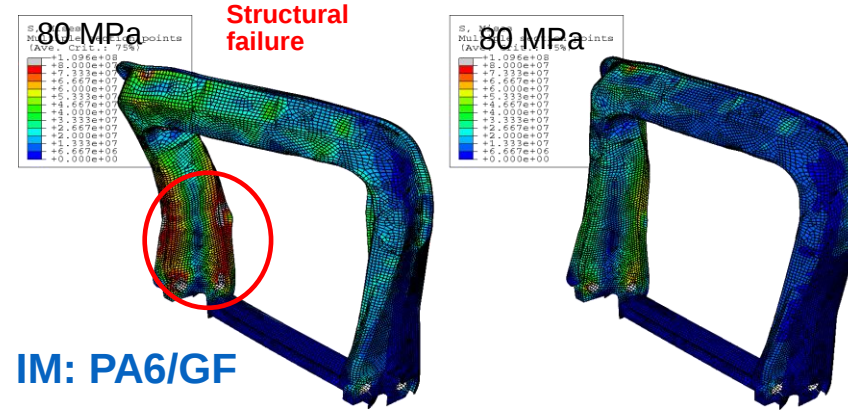
Application case study – Front seat structure



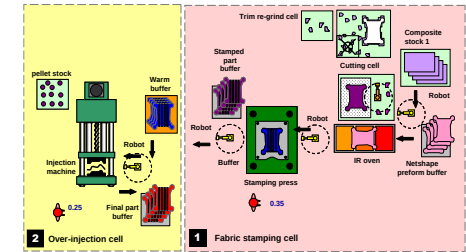
Load case:
5 kN in upper corner at 80°C



Stress (deformation 5x)

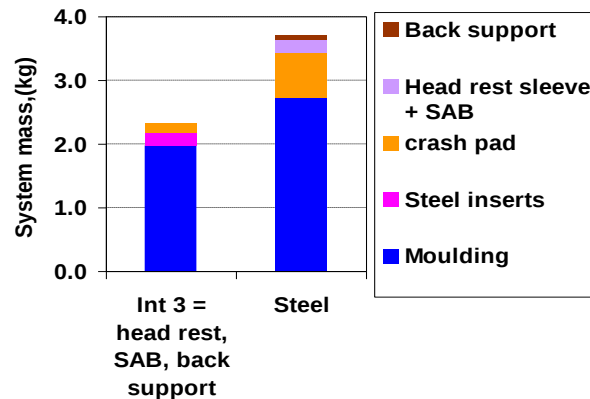


**PA6 GF
+ GMT
+ fabric**

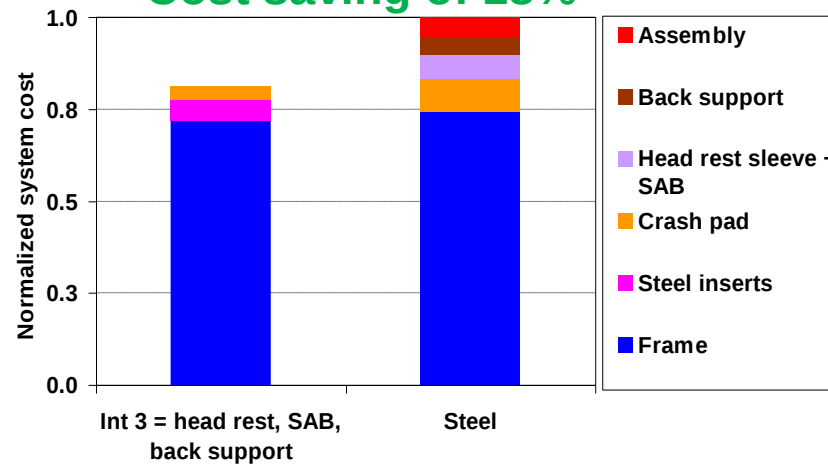


**Manufacturing plant
60s cycle time, 240k/yr**

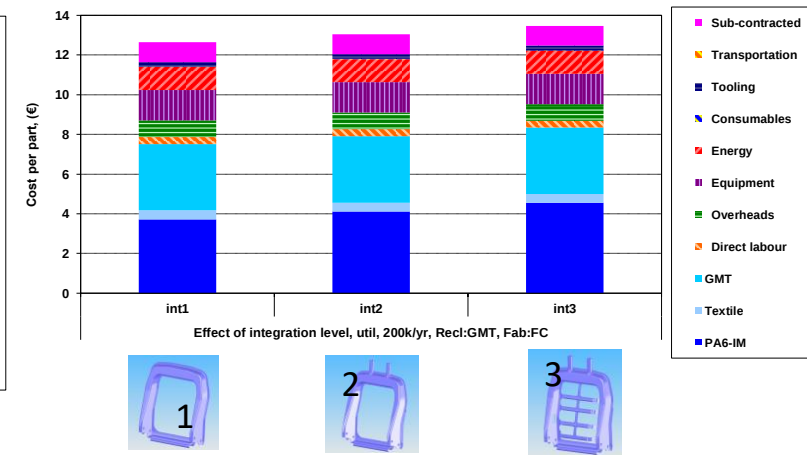
Weight saving of 37%



Cost saving of 18%



Dominance of material costs



**m1 eigen-freq.
plain to IPPC
(80°C)
= 58 to 72 Hz**

Process flow simulation

Process flow simulation

- % error for each step
- correction of an error
- operators needed to run cells vs error %
- scrap handling
- buffer sizes
- simulation over longer time periods
- increased accuracy of cost prediction

Dynamic model

- make preform
- transfer
- buffer
- transfer
- injection
- remove component

Static model

- make preform
- transfer
- inject

Buffer:

- maximum capacity
- number of parts at start
- failure probability
- recovery time after failure
- number of parts rejected by failure

Process machine:

- cycle time
- failure probability
- recovery time after failure
- number of parts rejected by failure

Single transfer:

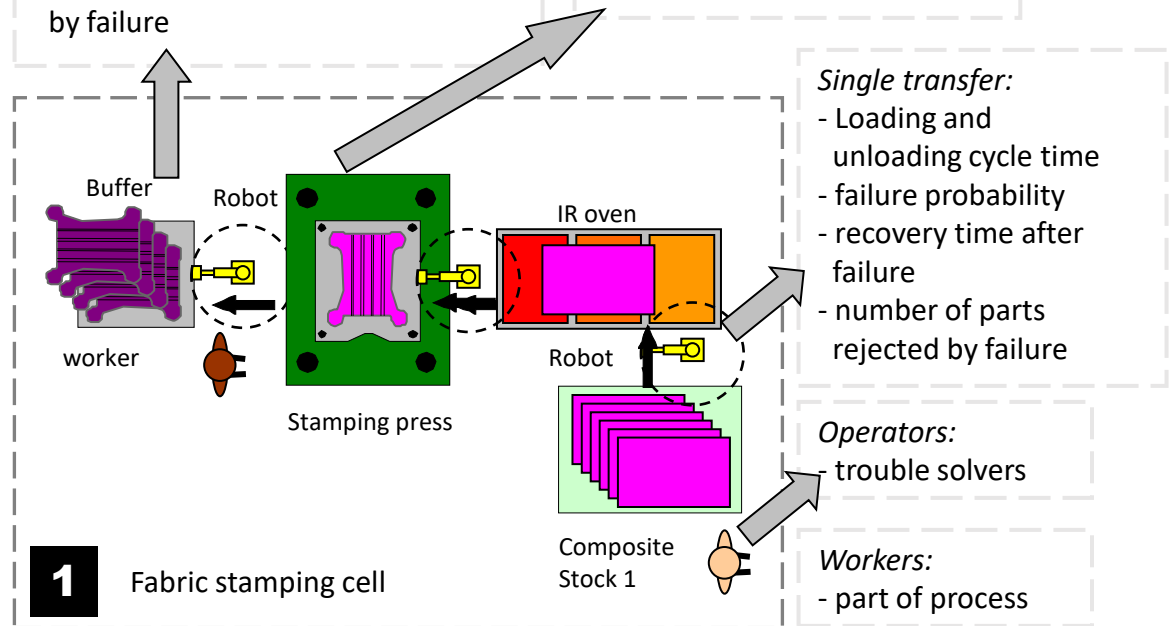
- Loading and unloading cycle time
- failure probability
- recovery time after failure
- number of parts rejected by failure

Operators:

- trouble solvers

Workers:

- part of process



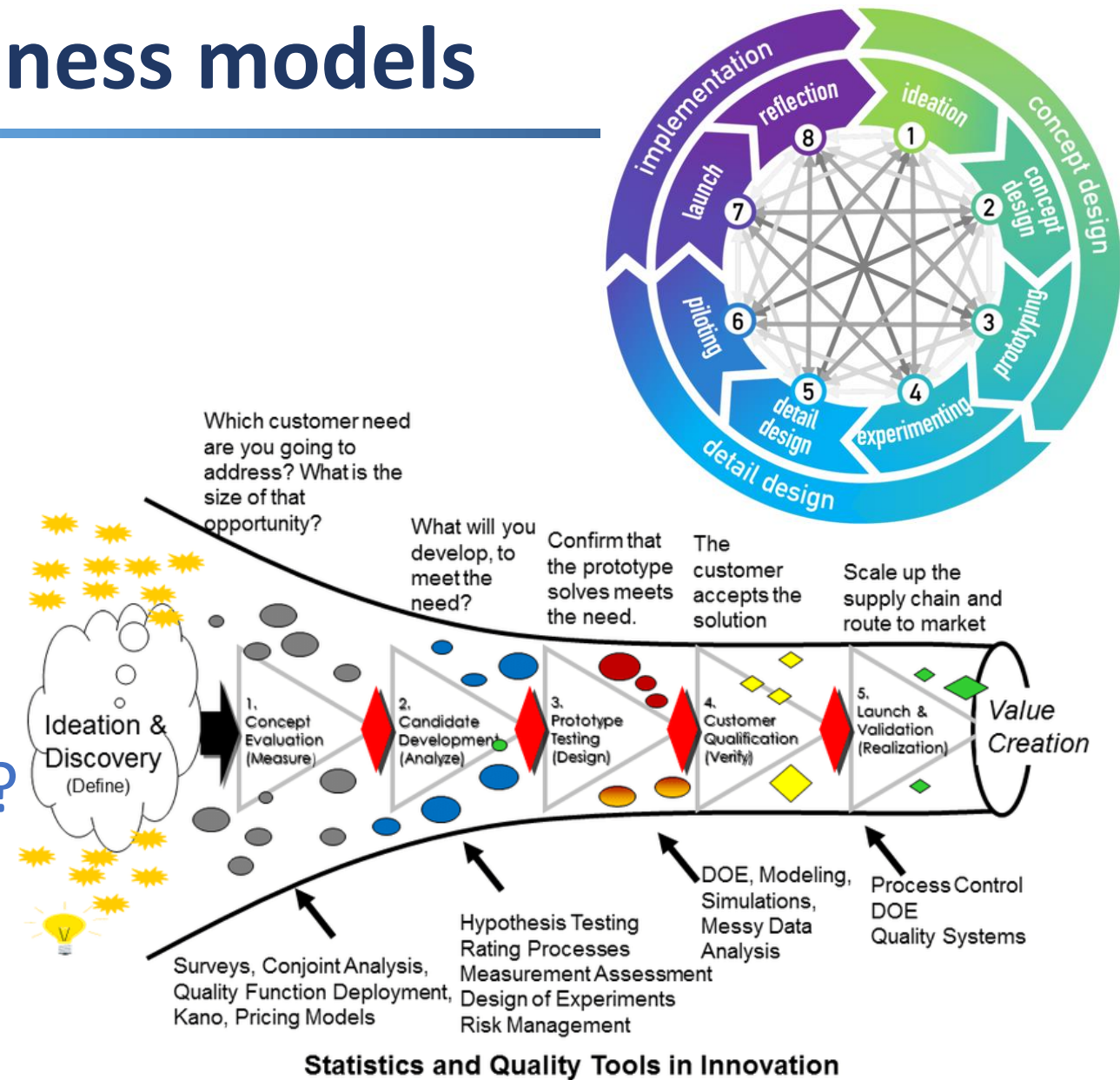
BREAK

Overview

- Cost modelling approaches
- Technical cost modelling deep dive
- **Cost modelling and technology strategy**
- Cost modelling and sustainability
- Wrap up
- A simple cost tool

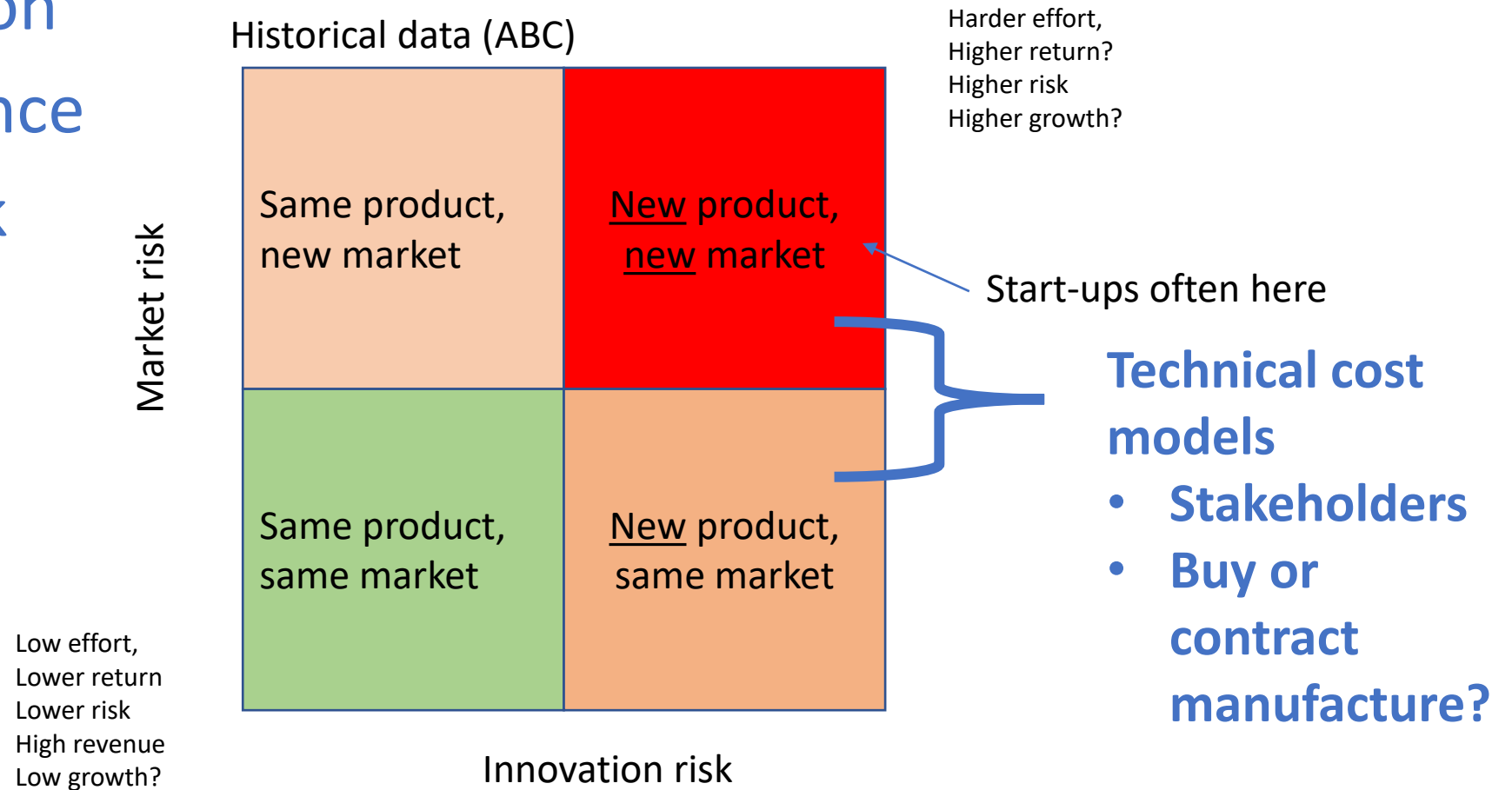
Cost, investment, and business models

- Strategy through the process
- Speaking business language
- Understanding cost, CAPEX, customers, markets
- Will your idea make money?
- At what risk?
- What do your customers think?
- Is it sustainable?

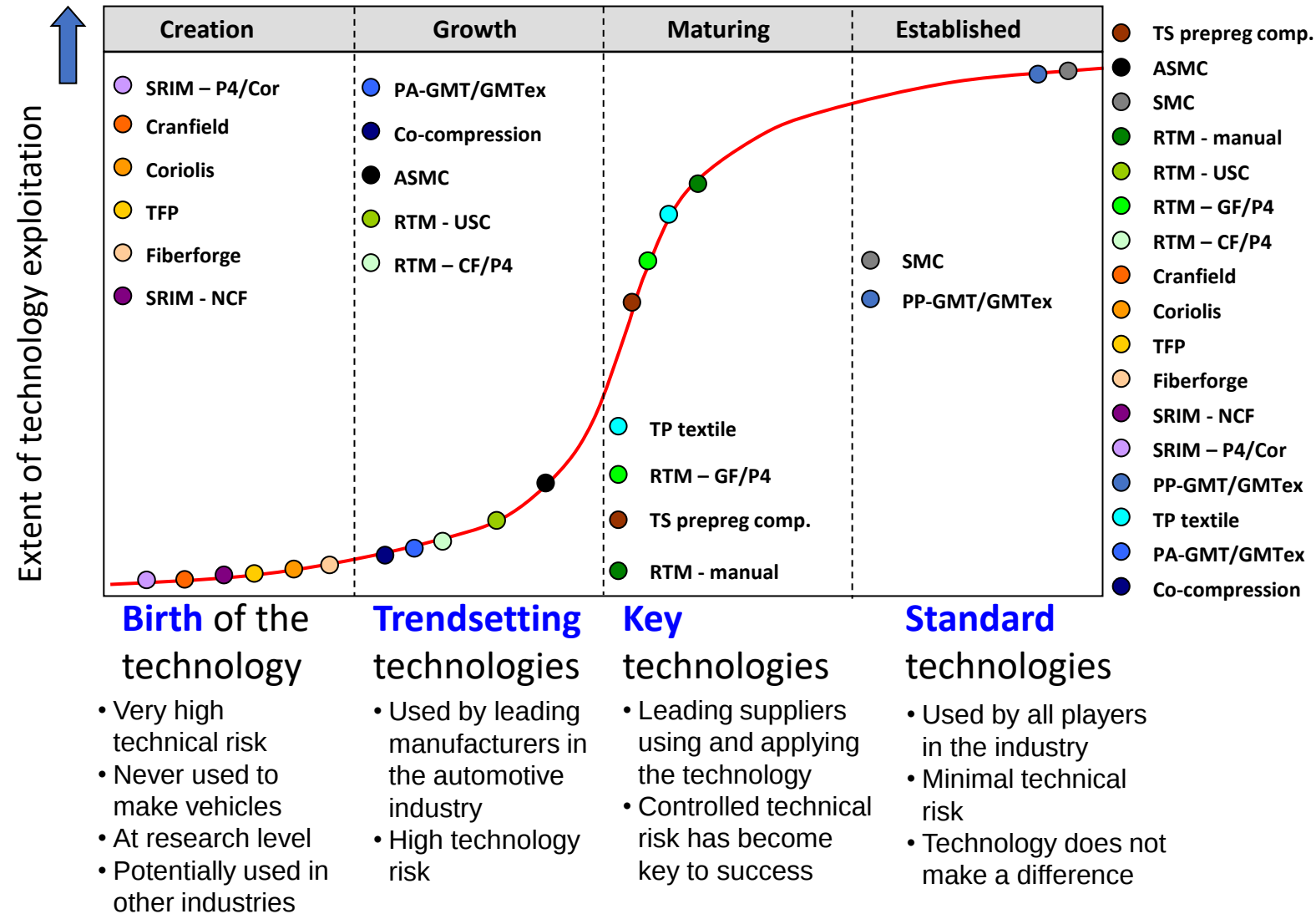


Innovation and risk

- Knowing the effect of your idea on the company and its markets
- Value proposition
- Cost, performance
- Investment, risk



Risk assessment: cost models do not eliminate Risk!



- Where is your idea vs. established processes?
- e.g. steel stamping
- Might be comparing birth phase to standard technologies

Definition of a Value Proposition



The compelling promise and desired set of product deliverables and experiences that an offering makes to a defined target audience that outweighs its total perceived cost while being differentiated from available alternatives and supported by reasons to believe.

Source: Mohan Sawhney
Kellogg School of Management

- Specific to: i) customer and ii) an application (not a material or process)
- **Quantified benefits (\$ basis)**
- Needs to be compelling enough for upfront engineering investment
- In automotive light-weighting
 - Functional performance
 - System mass and cost

Costing in-kind and non-in-kind incumbents

Proposal



- Non-in-kind incumbent
(steel stamping)



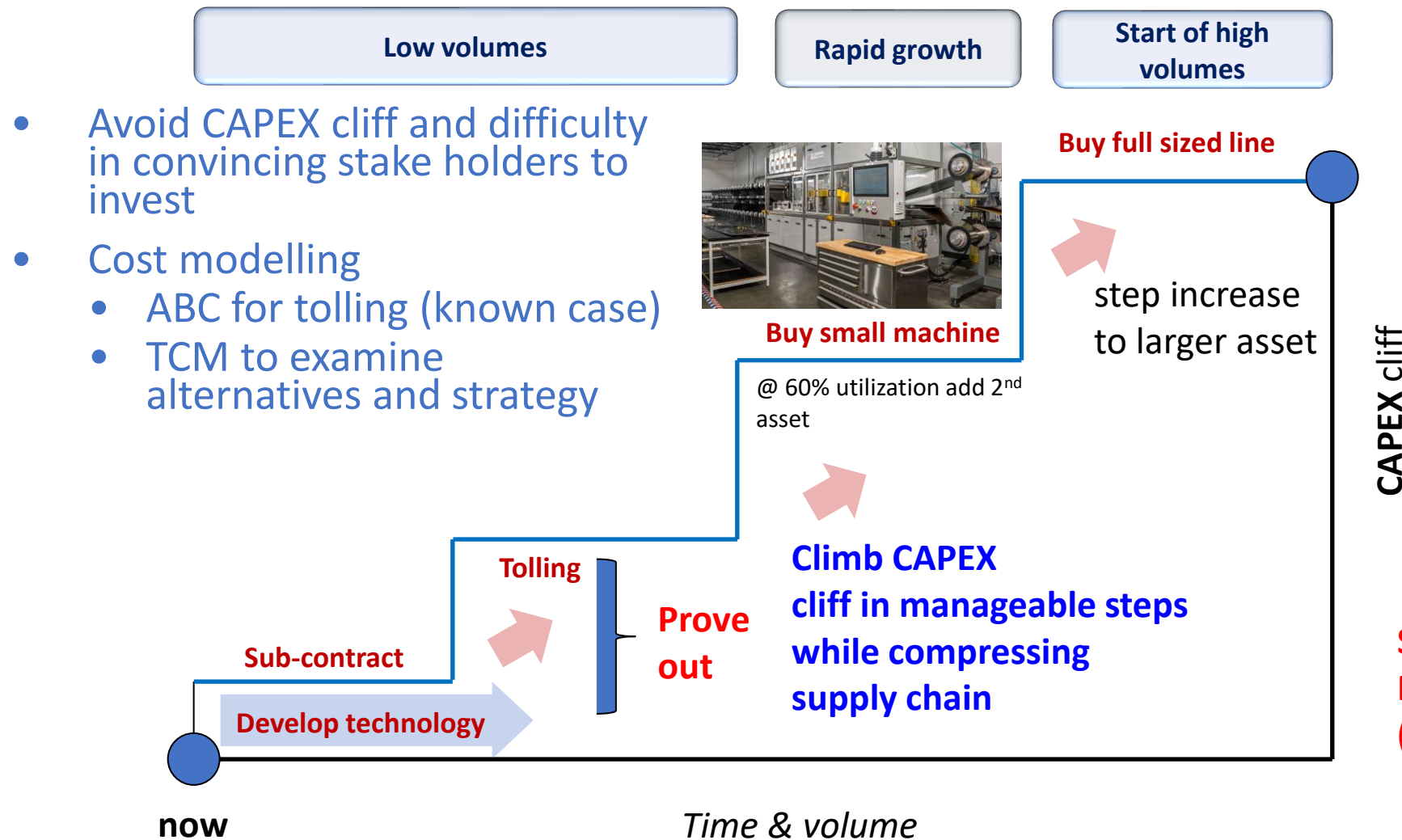
- In-kind incumbent
(another composite process)



OEM approaches to costing targets

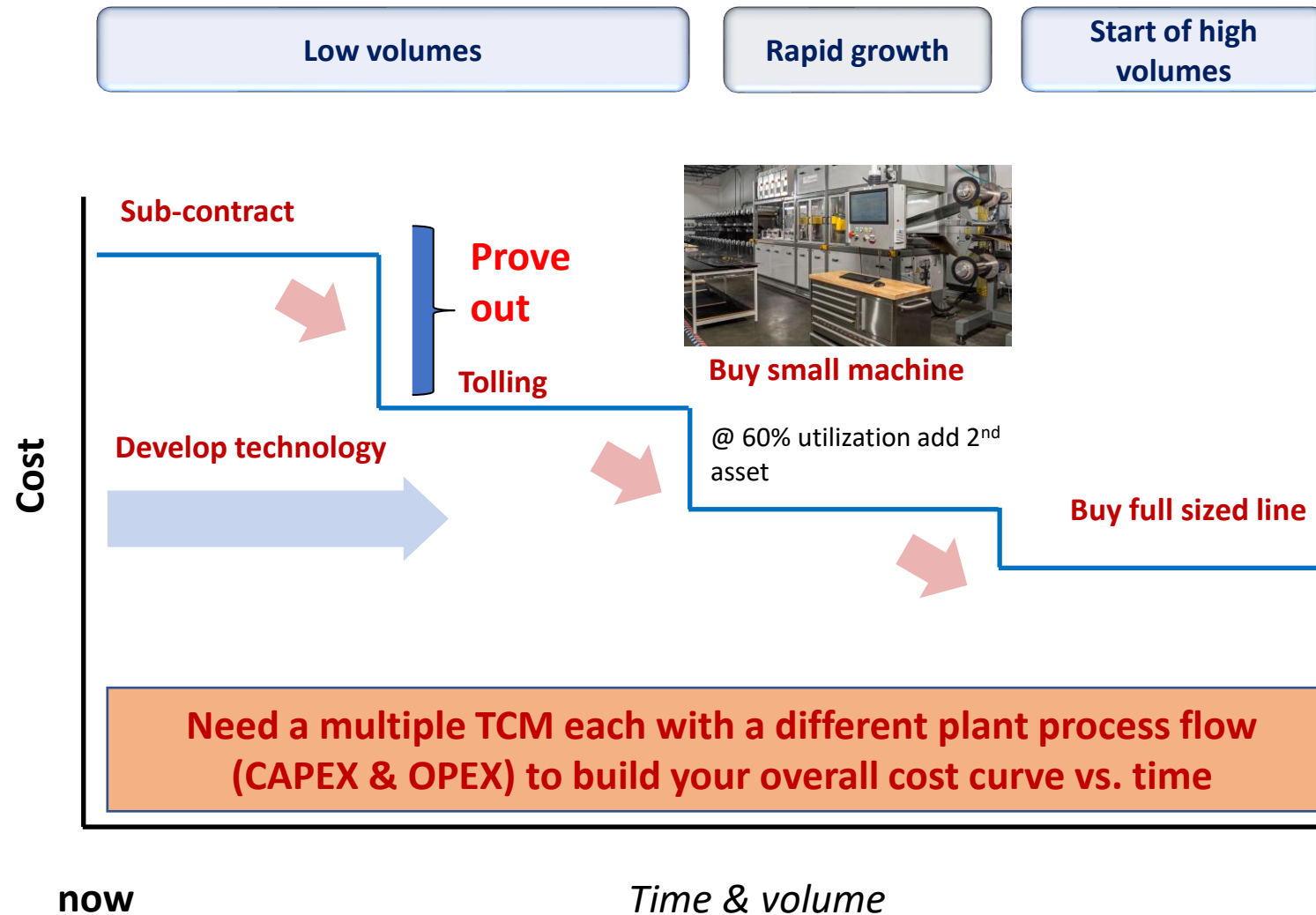
- Use buy in price (need to know manufacturing volume & if / how tooling is amortized)
 - Use internal COM data, which may or may not include plant / tooling amortization
 - May give a cost “target”, which may or may not be the same as the real price or cost
-
- OEM contact person, if not a costing person, may not understand the basis of the number they supply to us

Strategy to minimize CAPEX exposure (risk)



- Don't forget open innovation ...
 - M&A of SME to bring in capacity, capability, immediate revenue vs. high internal development costs and delayed time to market
- SAME PRODUCT vs. time (customer's eyes)**

Cost versus time



- CAPEX scaled stepwise
- Reduce financial exposure
- Test market
- Reduce risk
- Compress supply chain
- Final cost 4x lower

How to model increasing production volumes

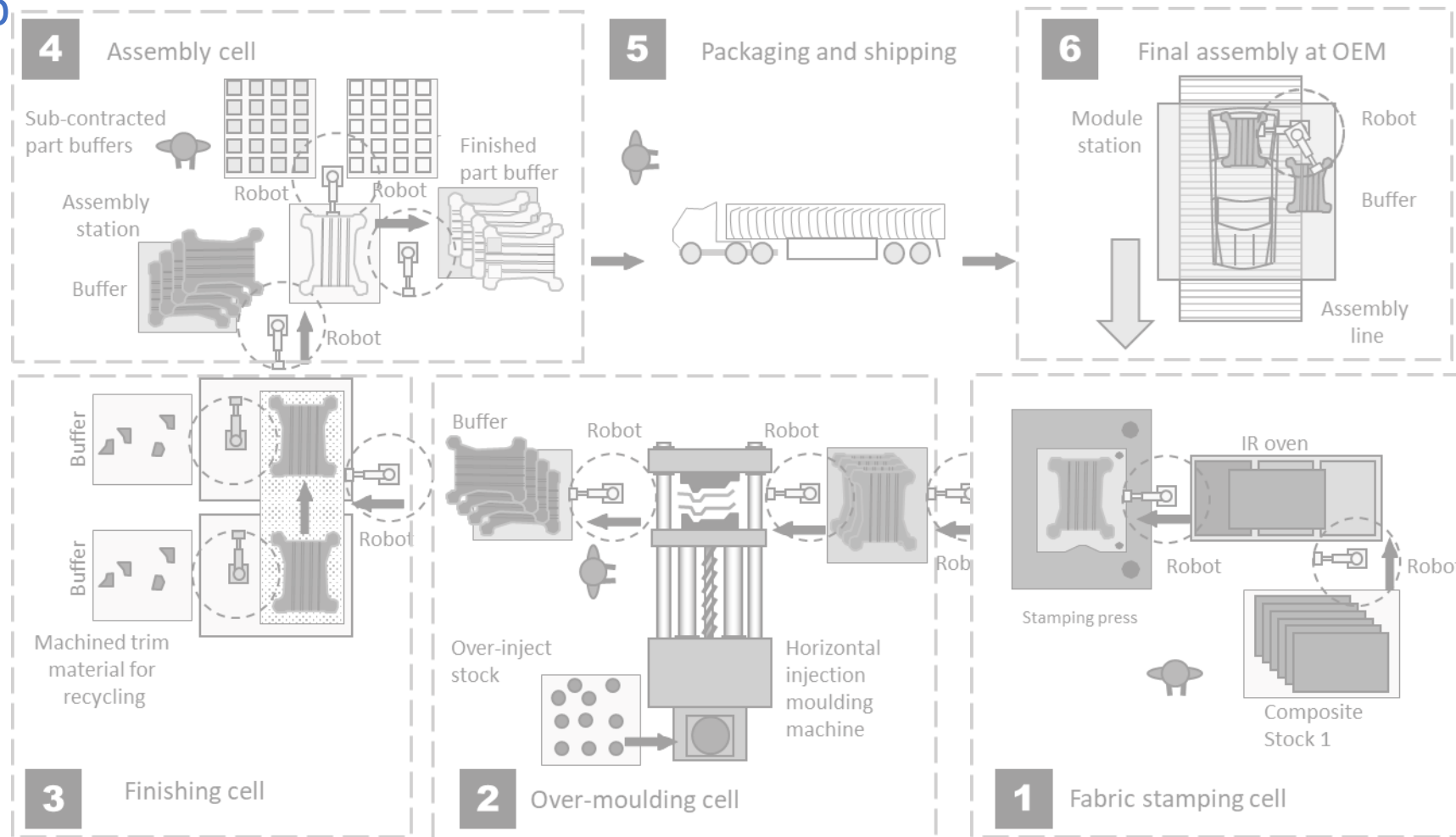
- Need to define:
 - Plant A: lower volumes
 - Add extra shifts
 - Lower CAPEX, lower risk at low volumes, potentially higher costs
 - Plant B: medium volumes
 - Extra shifts added but need to duplicate a machine in bottleneck cell
 - Plant C: high volumes
 - Add parallel cells, higher through-put machines, doubling of tool sets
 - Higher CAPEX, higher risk at low volumes, lower costs at higher volumes

This mean building up a master curve from the three models

If you use option C for low volumes your CAPEX will be very high and under utilized (especially dedicated) physical assets are highly unattractive.

How to model increasing production volumes

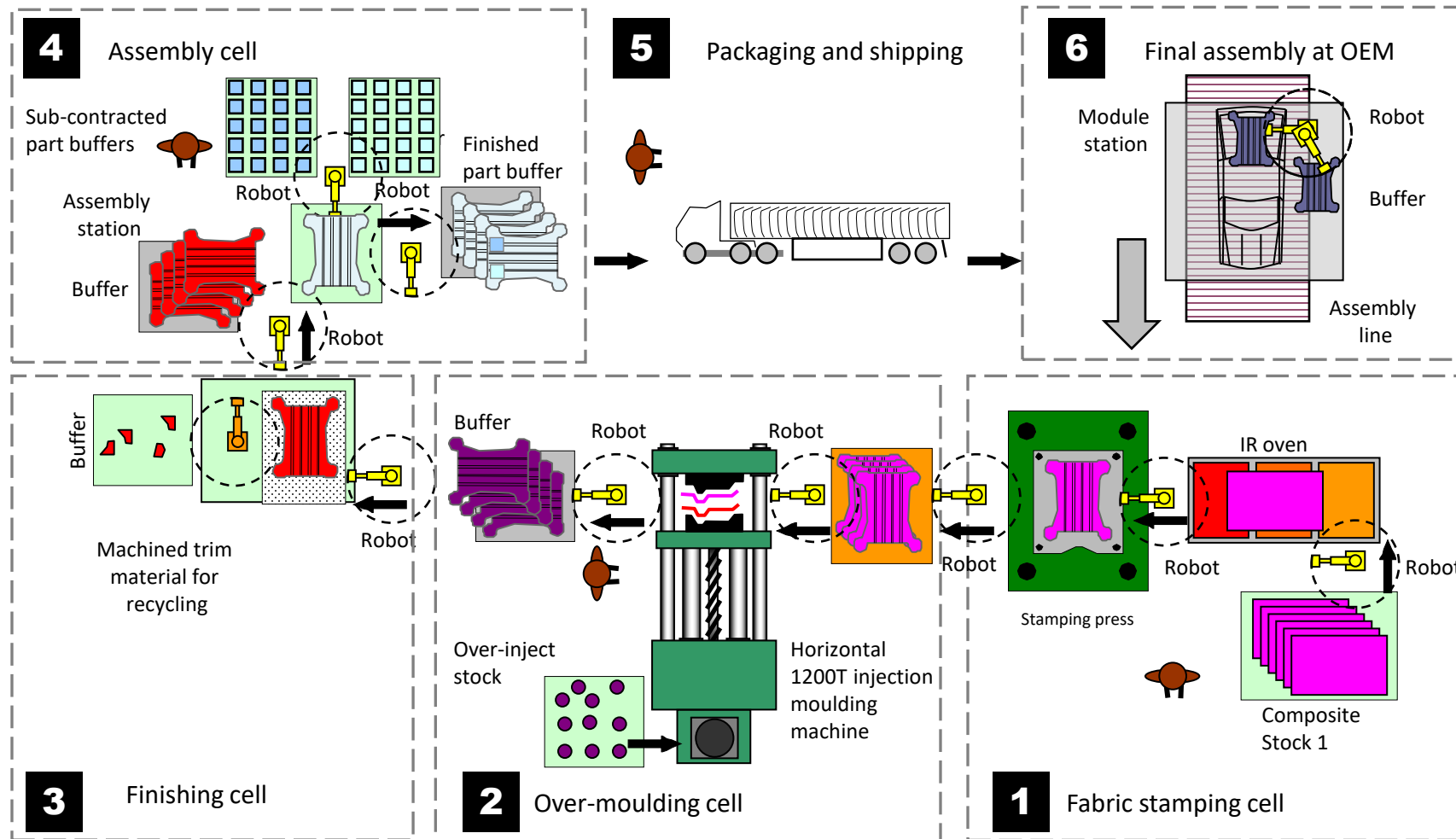
- Start-up



Toll manufacturing / contract manufacturing: only invest in the most unique areas (or not at all)

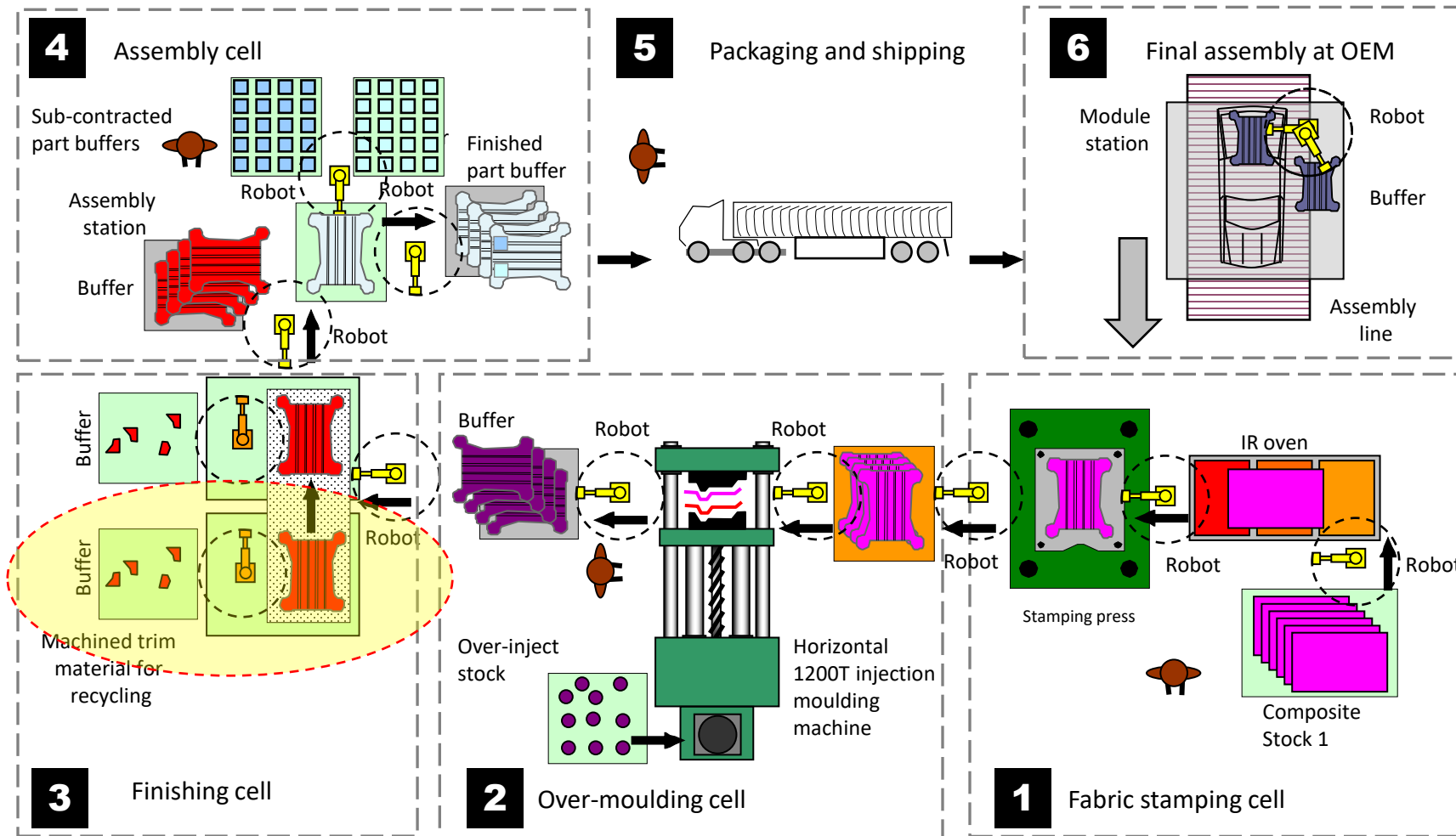
How to model increasing production volumes

- Low volume



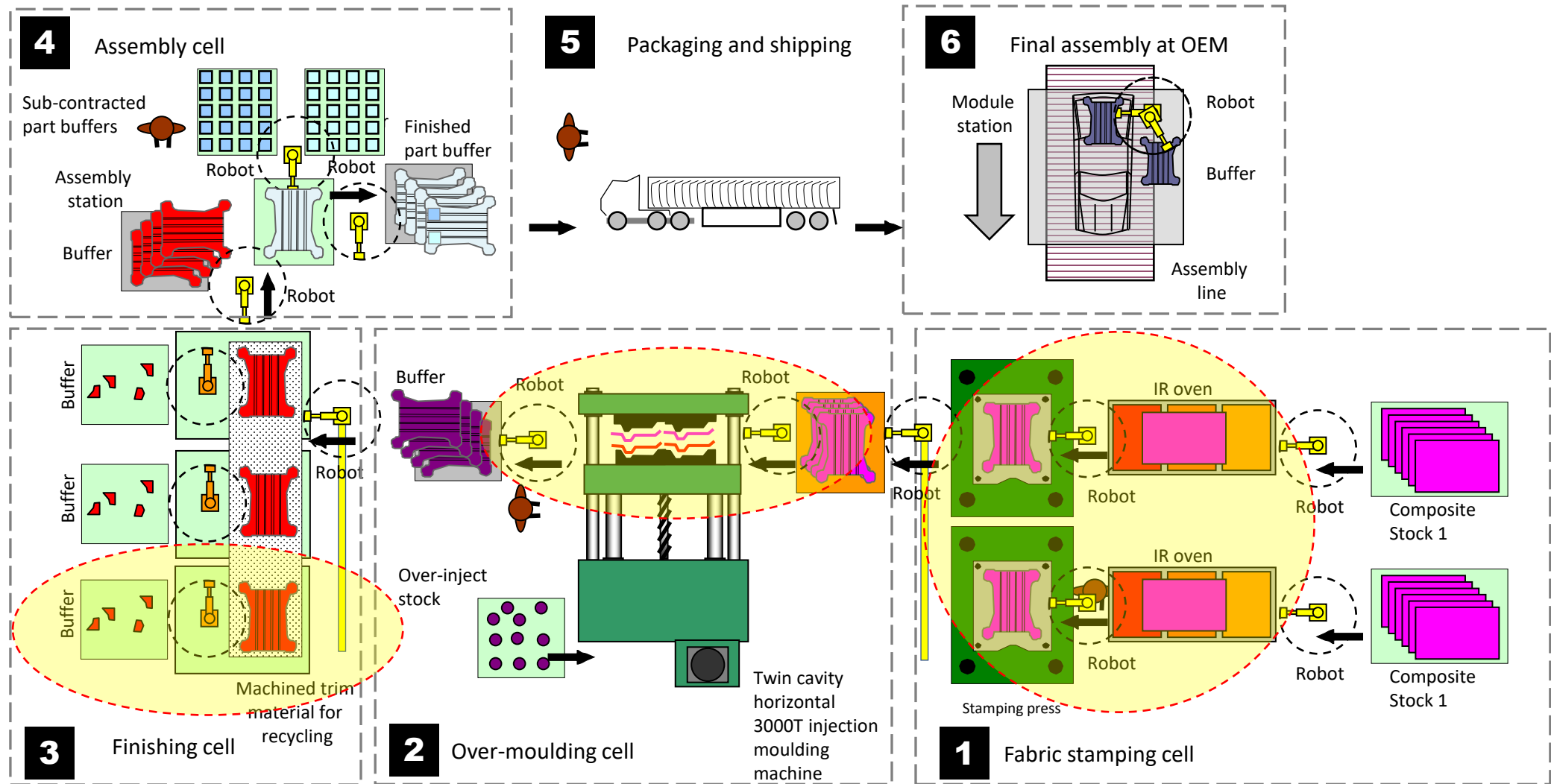
How to model increasing production volumes

- Medium



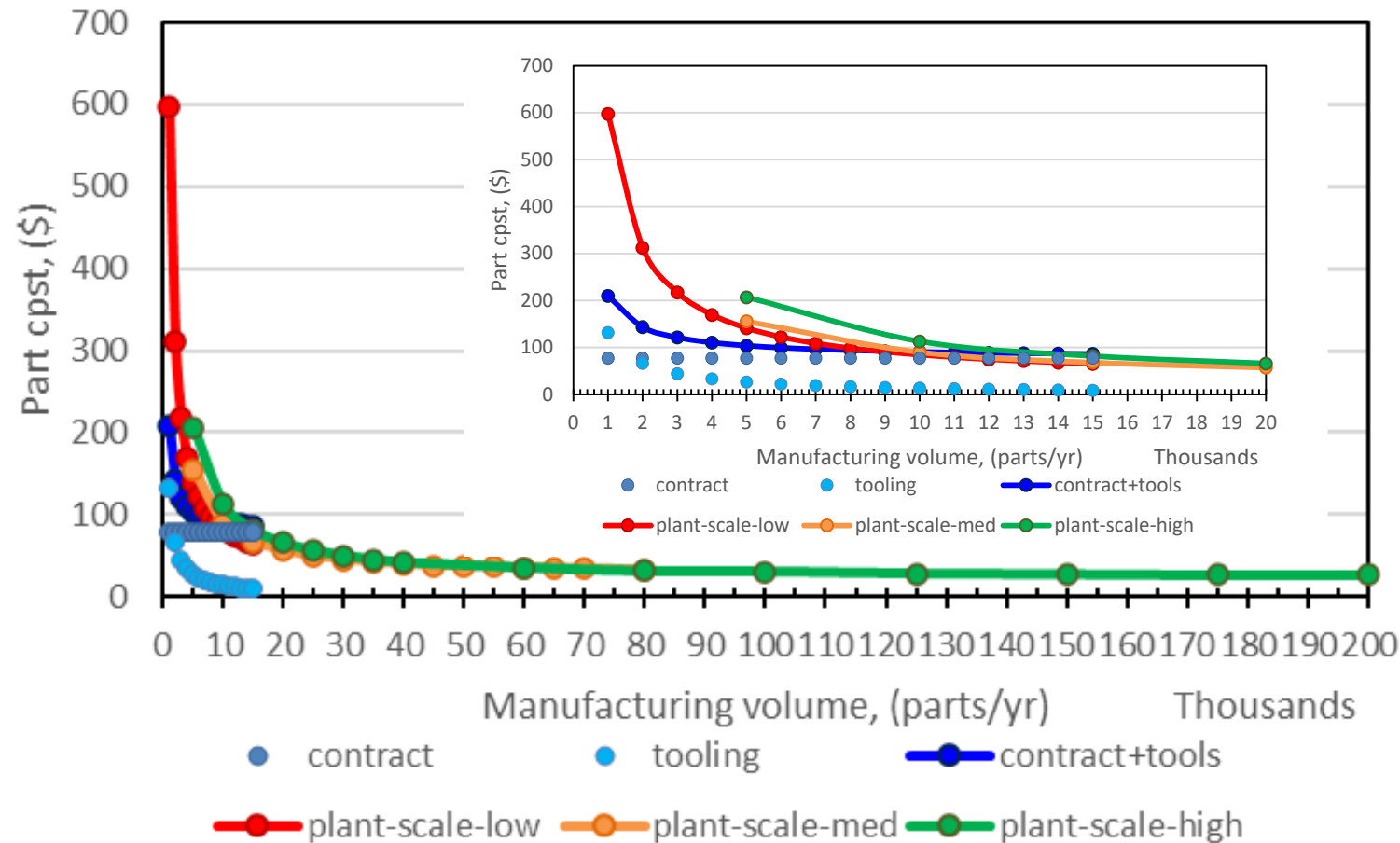
How to model increasing production volumes

- High

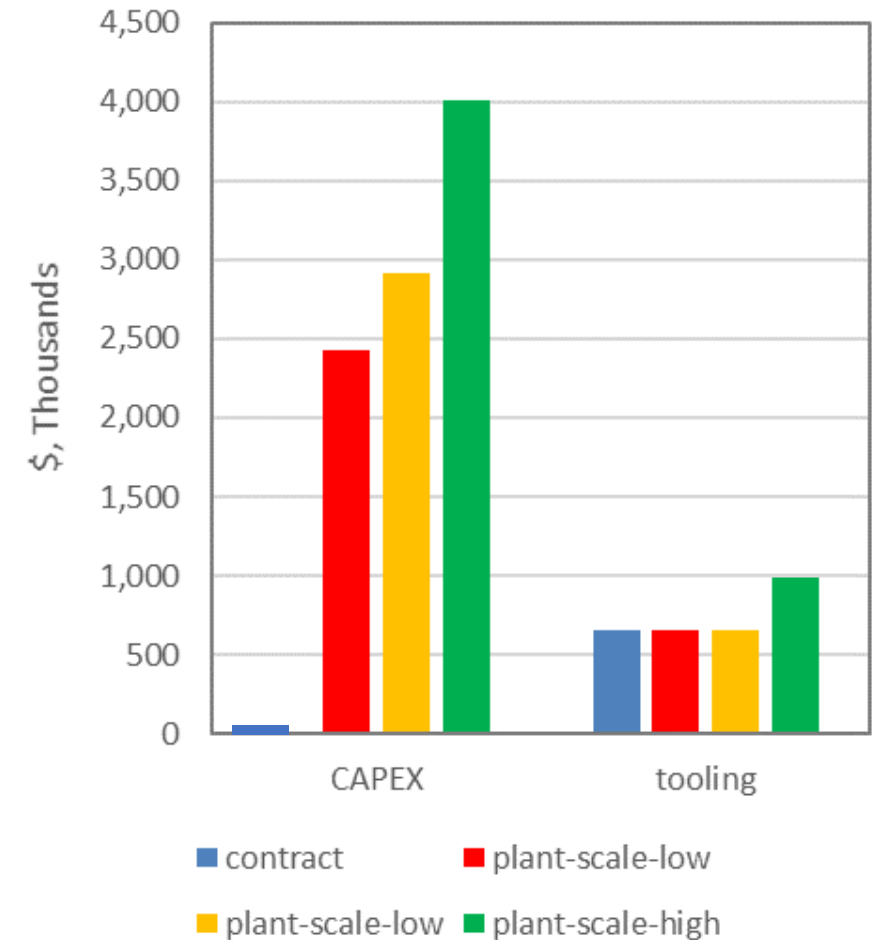


Master curve (from dedicated cells)

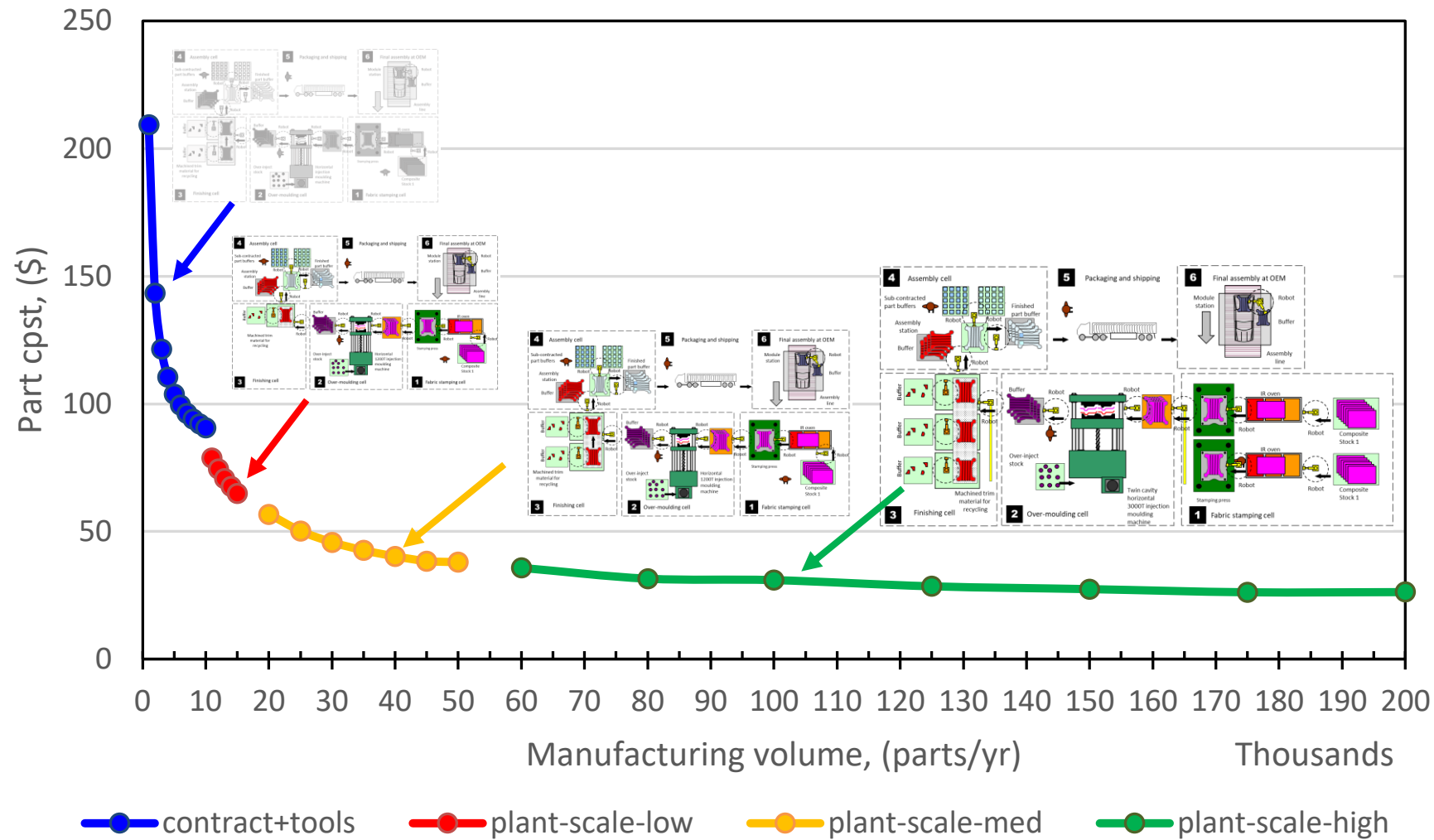
- Cost



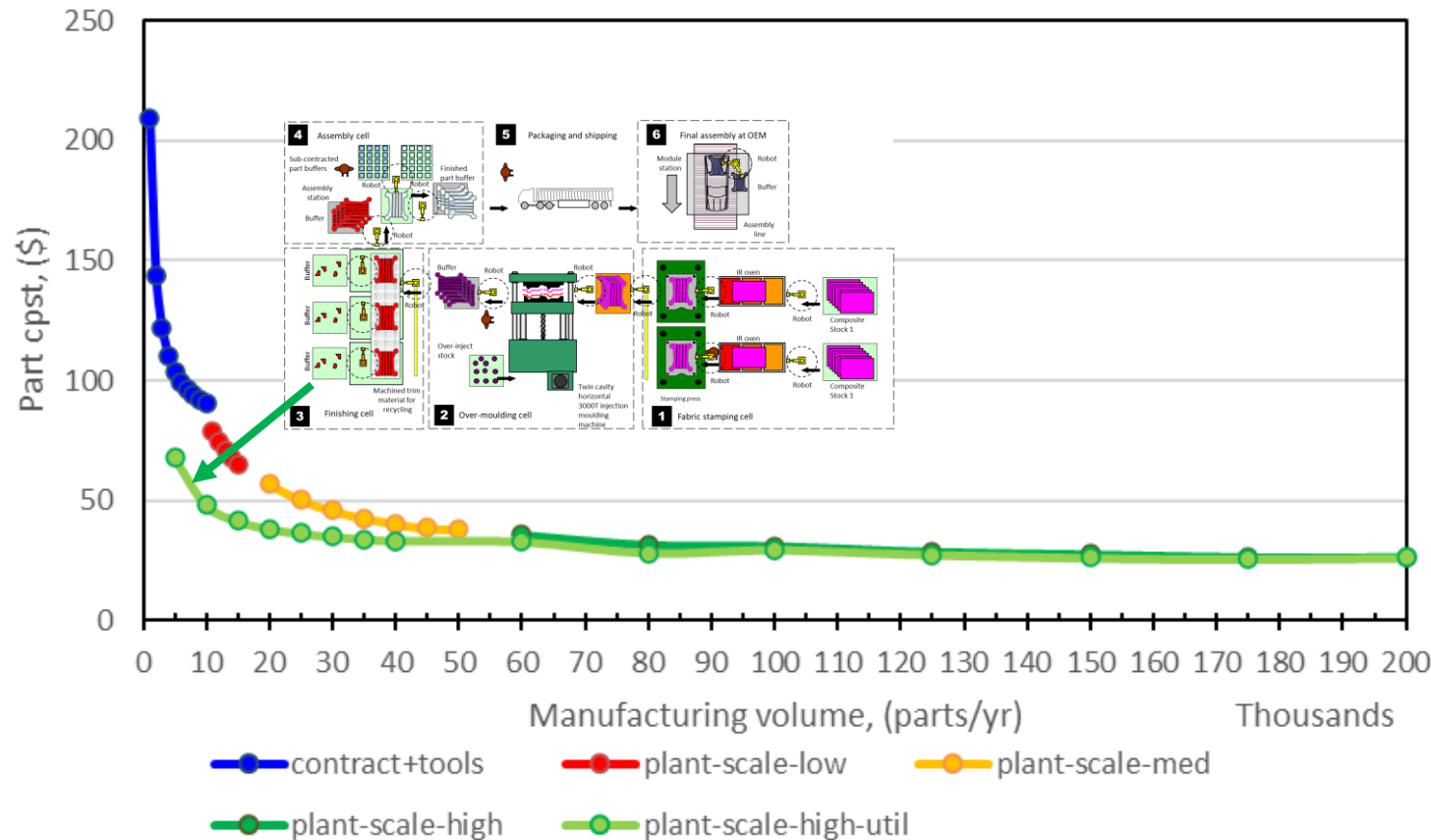
- CAPEX



Master curve (from dedicated cells)



High volume utilized



Need to model NPV / IRR / ROI / disc. Payback period etc USING cost model data to make true master curve

- Caution using the “best-case” fully utilized model at low volume
- Don’t invest in ultimate case if your plant cannot have e.g. >60% utilization
- Stepwise scale up (case-by-case)
- CAPEX is key to attractive business financials (NPV)
- Cost models do not show breakeven / cross overs with business financial modeling but are key to build good business models

Overview

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Implementation of light weight materials

Selection factors (steel vs. Al vs. TPC vs. XYZ)

Weight saving

Cost position

CAPEX intensity
(OEMs / Tiers /
Material suppliers)

LCA (one of many
important issues to
understand and
position)

Engineering
investment
Acceptable risk

Trusted design and
modeling tools

Design space
needed / functional
integration

Transition from a
linear to a circular
economic model



Good financials
NPV, ROI, GM

Robust
manufacturing:
equipped and able
supply chain

Stable materials
supply (multi-
source)

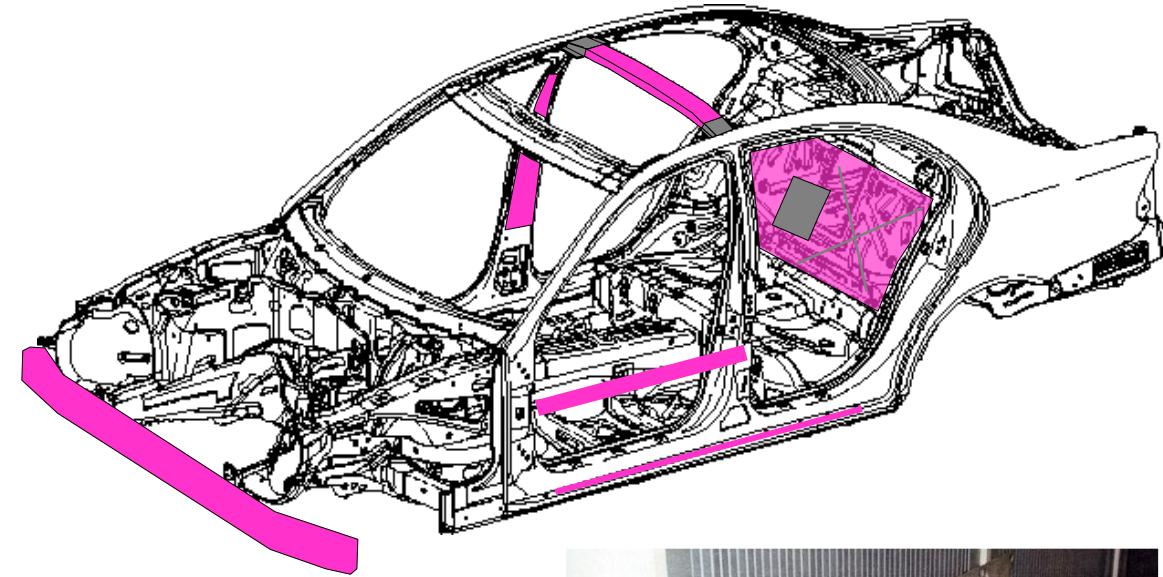
NetPositive
companies

Curved structural panel: Cost, LCA, LCC case study

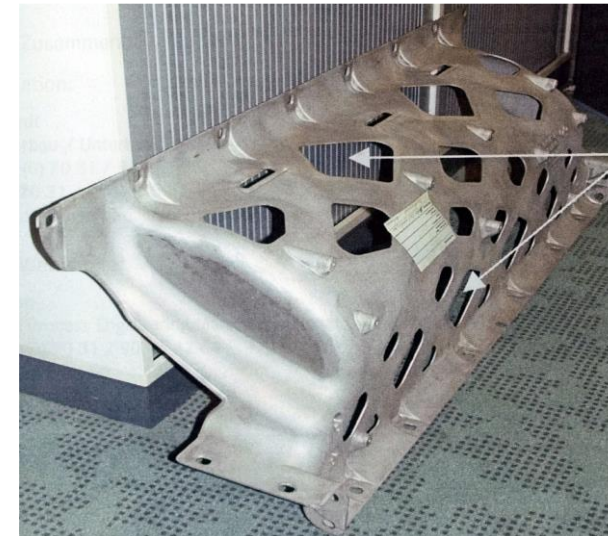
Functional unit:

Curved structural panel

- typical of BIW, rear bulkhead
 - does not need to pass through E-coat process (but could)
 - temperature capability if needed
 - magnesium benchmark
 - detailed sensitivity studies
-
- Rear Structural Bulkhead
 - Steel 5.8kg
 - Magnesium 2.2kg
 - SMC 2.5kg
 - GF/PA GMT 2.4kg
 - GF NCF/HP-RTM 2.3kg
 - CF NCF/HP-RTM 1.8kg (1.2kg)

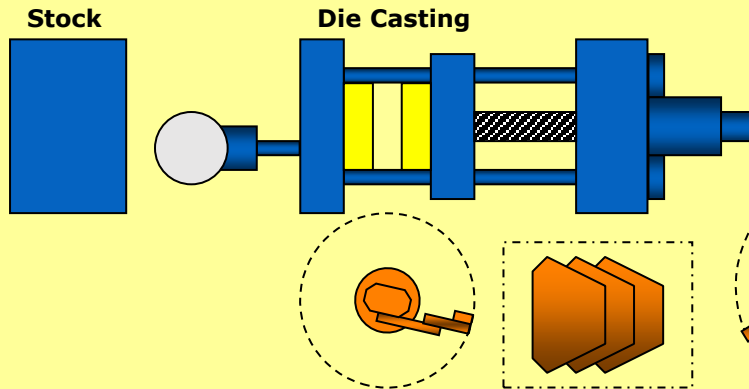


Aluminum?



Magnesium Die Casting

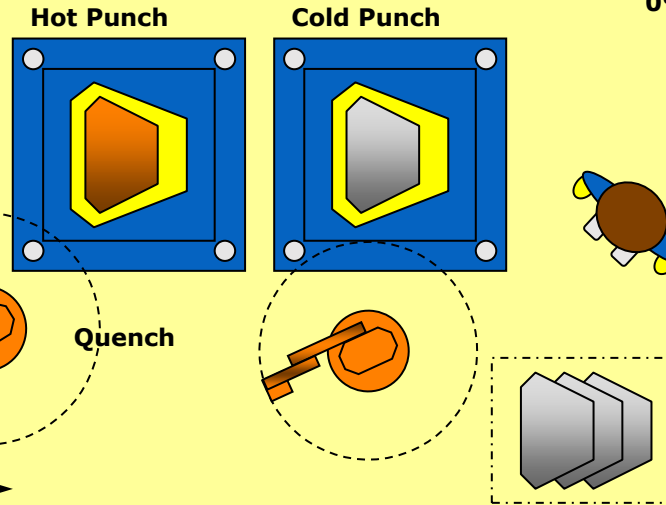
Cell1: Die Casting (110s)



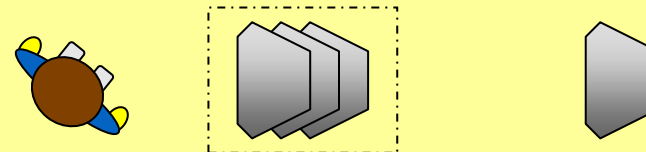
Labour: 0.25, Scrap: 0%, Reject: 2%

Cell 2: Punching (90s)

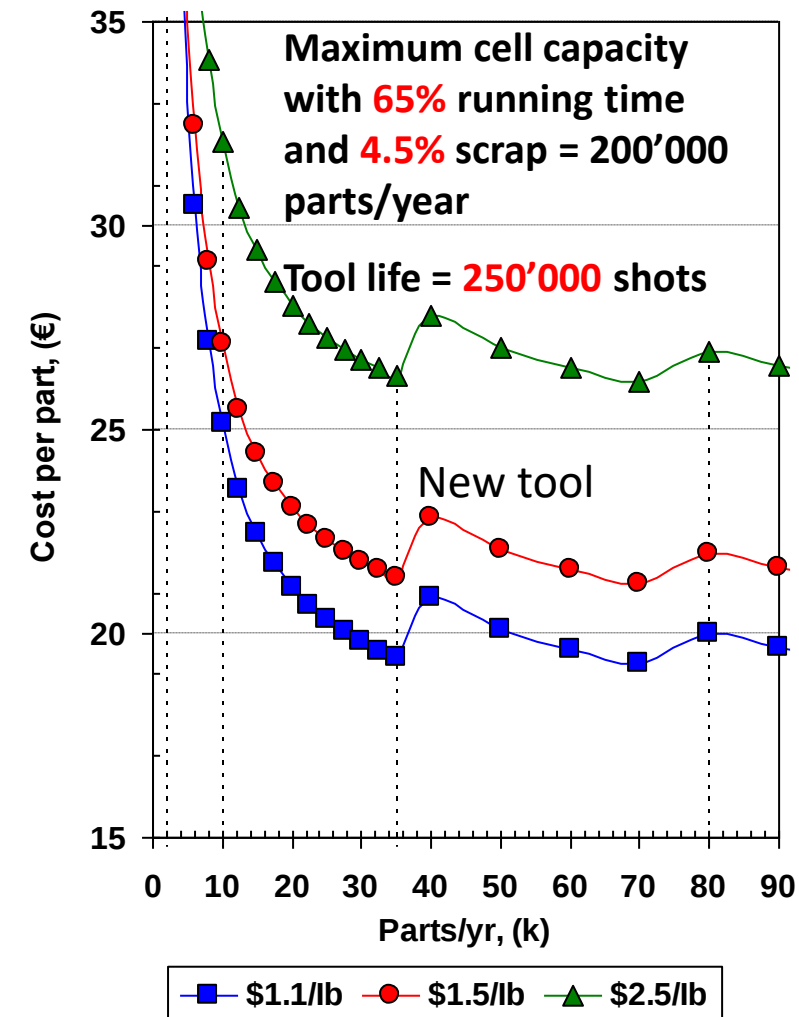
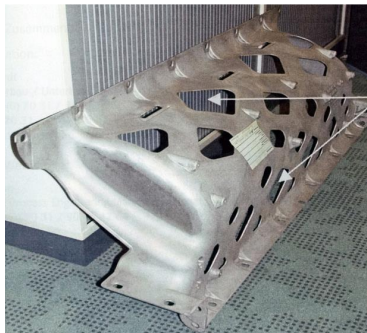
Labour: 0.25,
Scrap: 25%, Reject: 0%



Cell 3: Machining (60s)

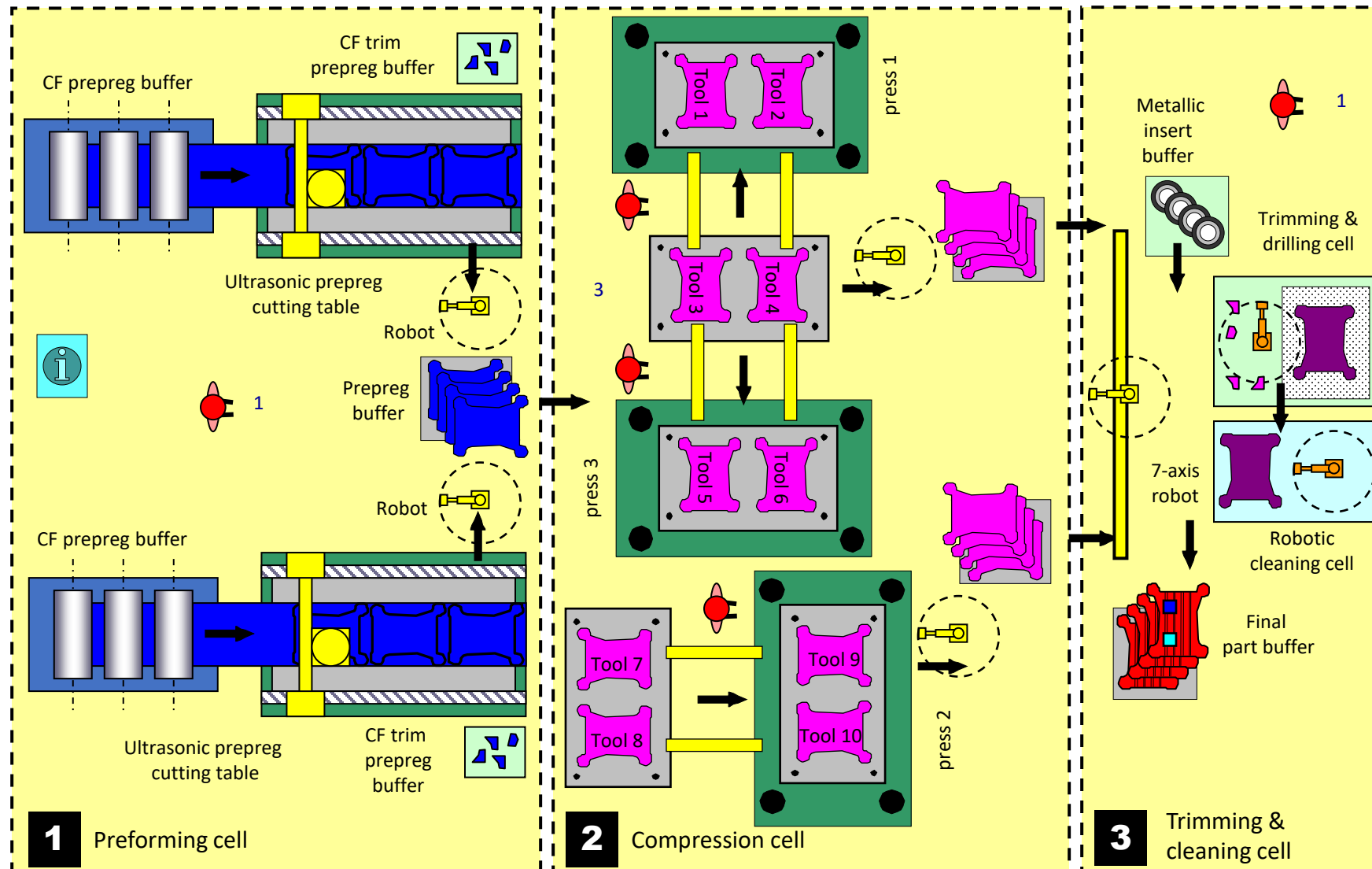


Labour: 1, Scrap: 5%, Reject: 0%



CF/epoxy prepreg compression (1 example)

- Cure time reduced over 15 years from 10 min to 1min30s
- Today less plant and CAPEX needed (reaction kinetics)
- Now used in BMW 7 series



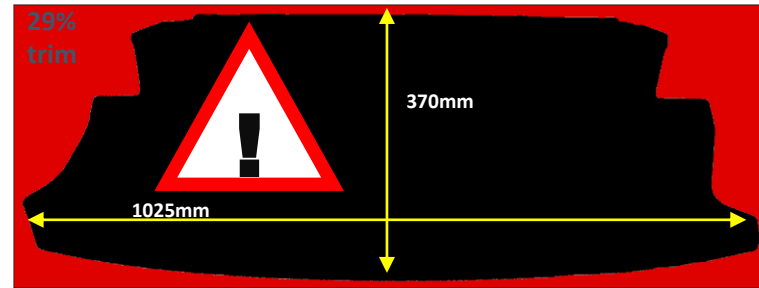
Key issue
was high
amount of
carbon
fiber trim

State of the art – reduce trim fractions

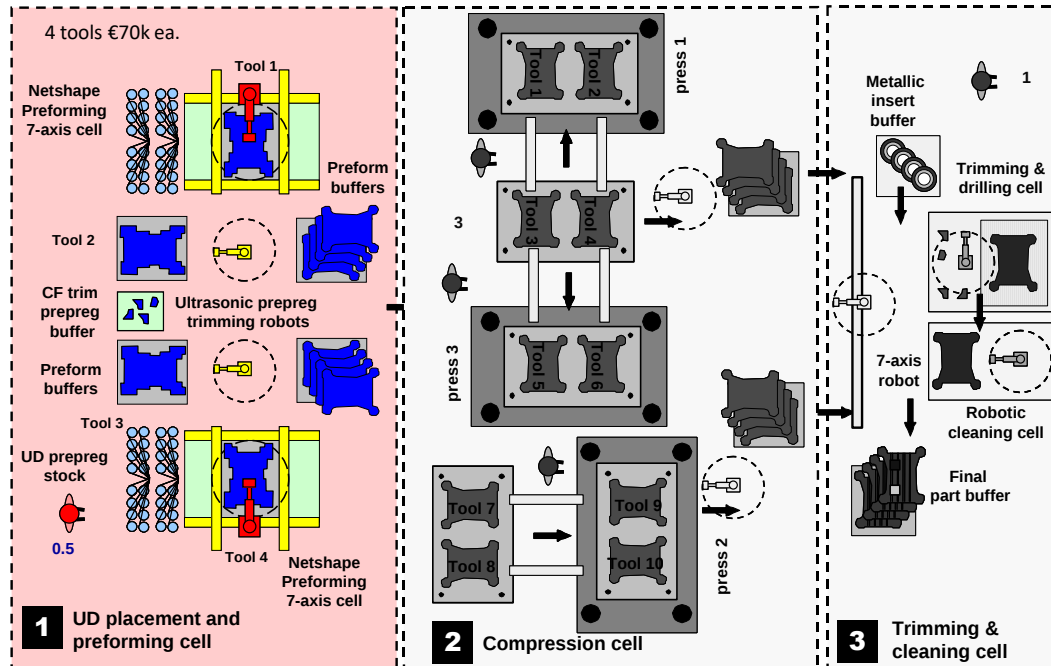
- 6 axis robot & external 7 axis
- up to 30 yarns placed simultaneously
- machine cost = €700k, €1M with 7th axis
- UD CF/epoxy prepreg
- trim = 5% (bulkhead) / reject rate = 2%

- cell maximum capacity

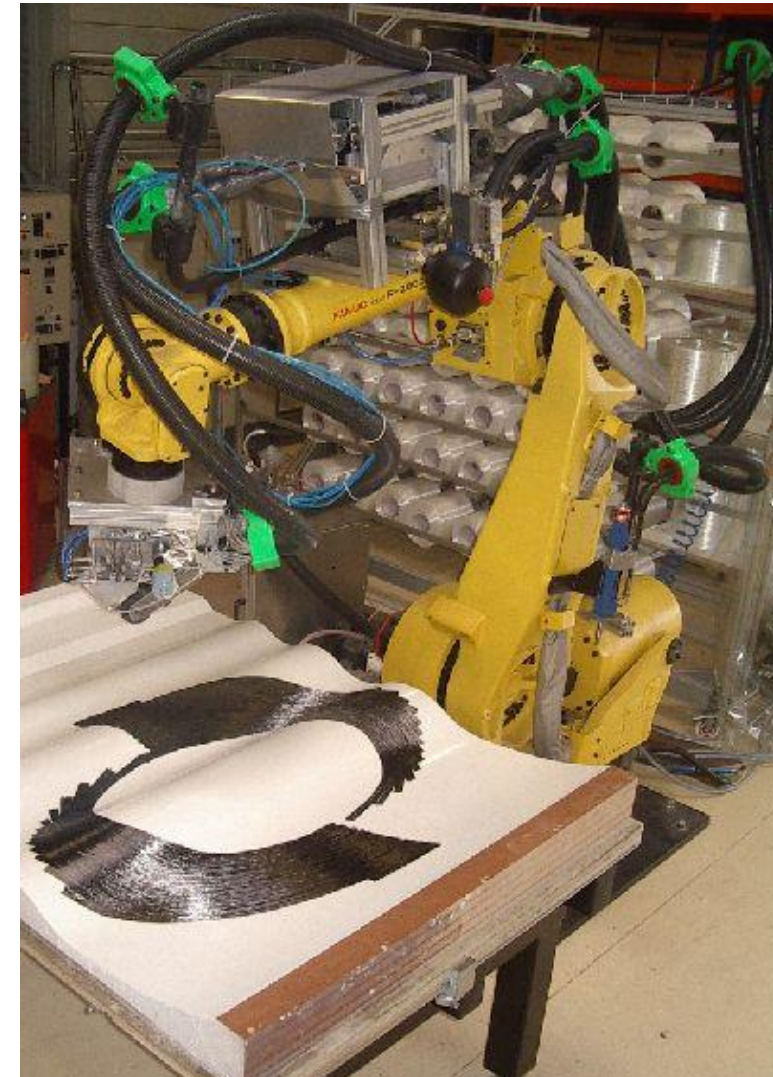
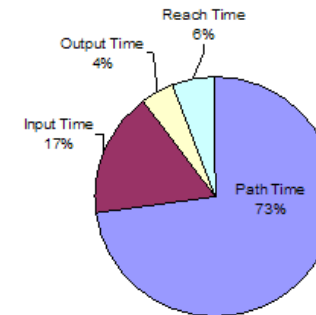
• 1 shift = 22k/yr, 2 shift = 45k/yr, 3 shift = 68k/yr



Key area to address in composite manufacturing process development

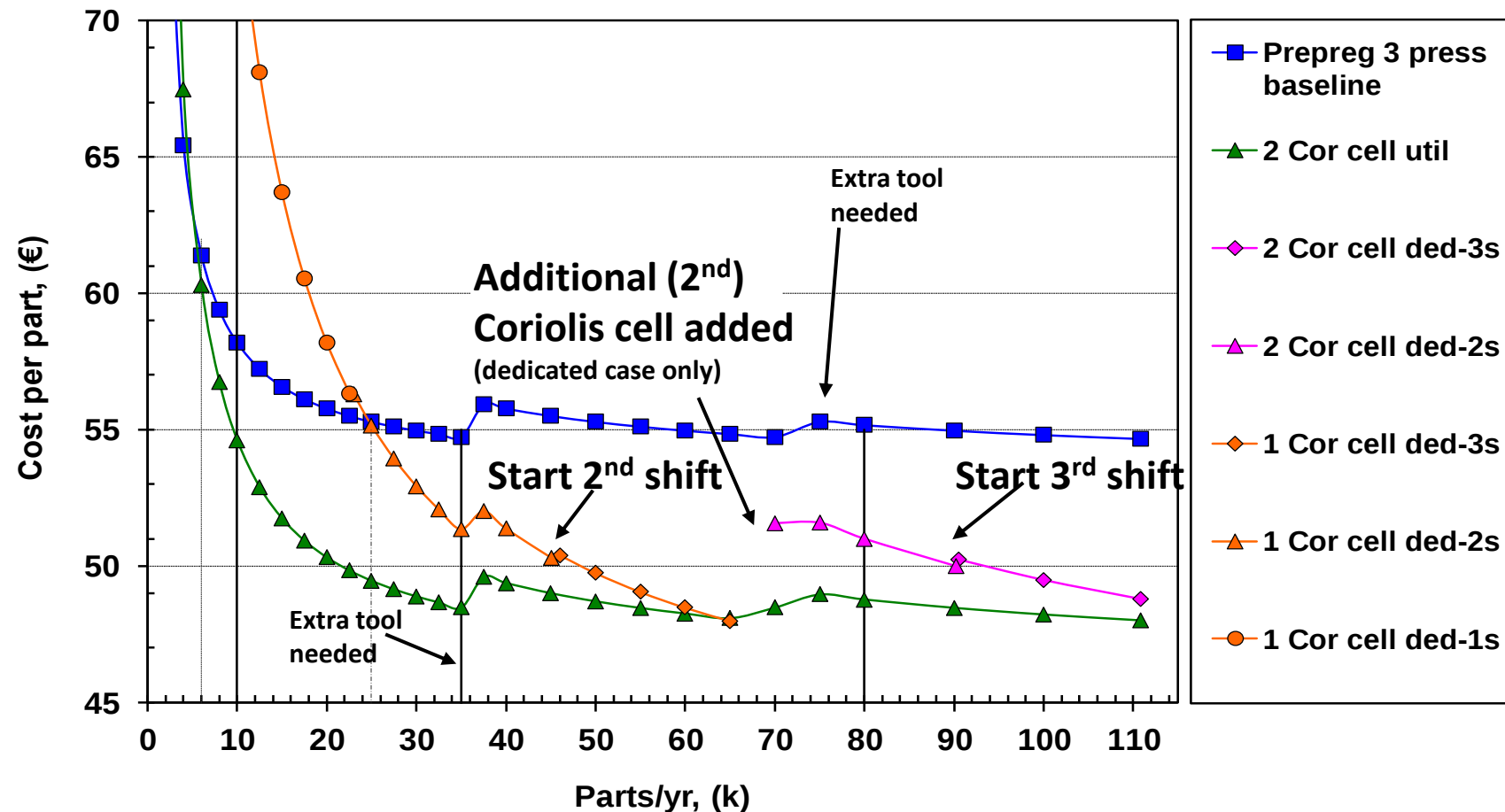


CORIOLIS
composites



<https://www.compositesworld.com/articles/automated-preforming-the-numbers-and-landscape>

CF/epoxy prepreg compression – netshape approach

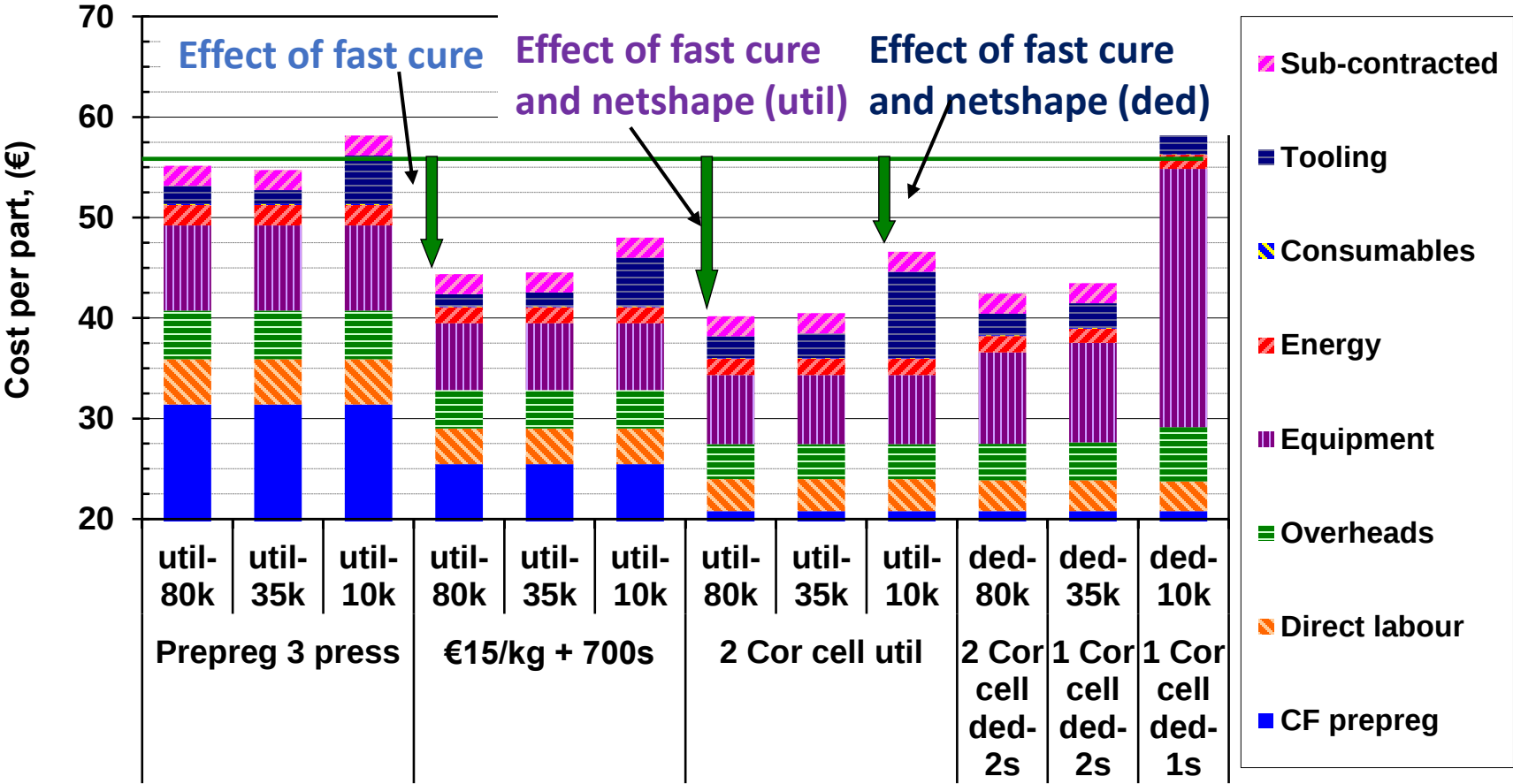


Changing plant diagram (1 cell to 2 cells) in this chart for dedicated cell approach

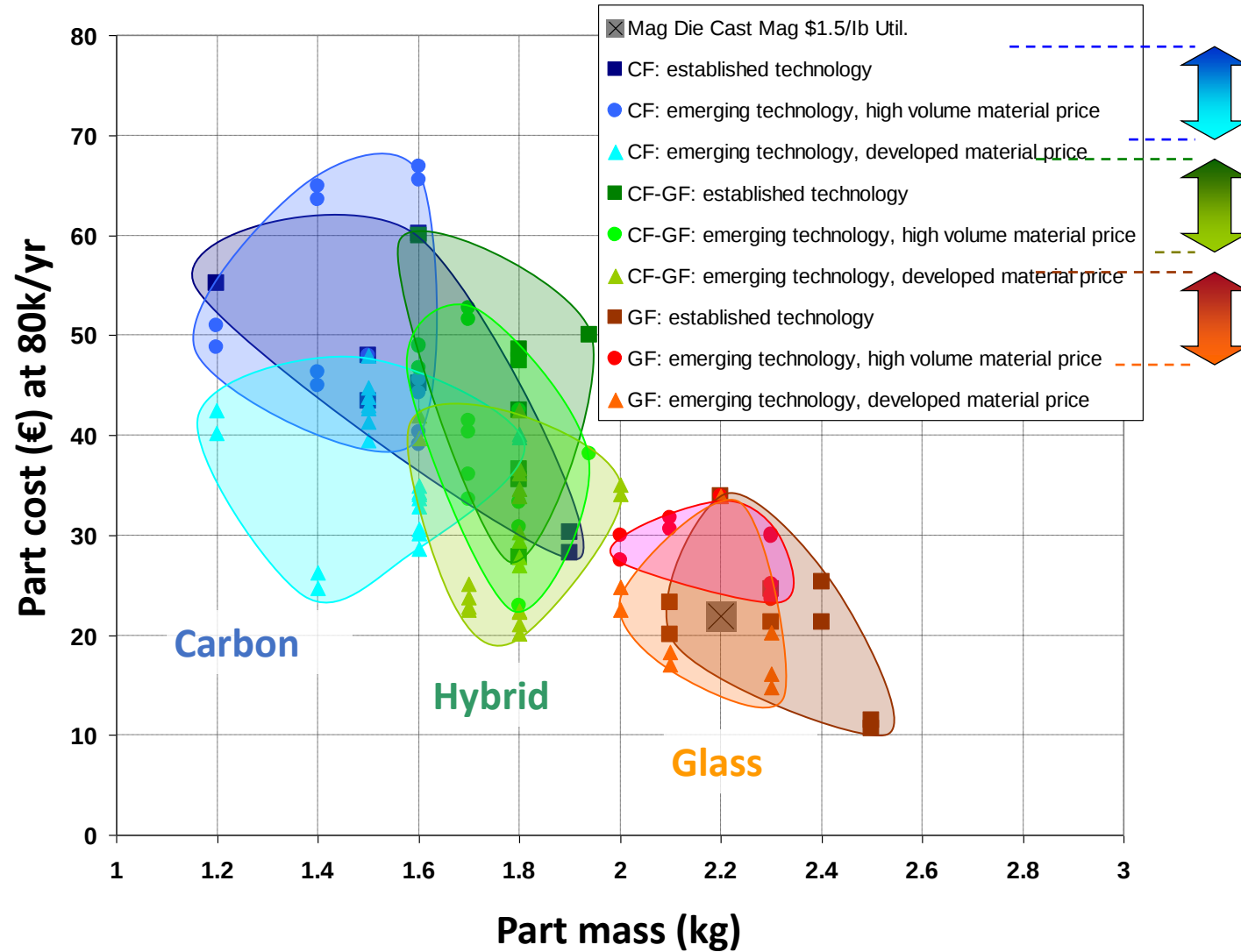
CF prepreg compression –netshape & fast cure

Hypothetical assumption: cure cycle reduced from 900s to 700s (compared also for textile approach)

COMBINED with Coriolis system and prepreg cost reduction from €18.5/kg to €15/kg

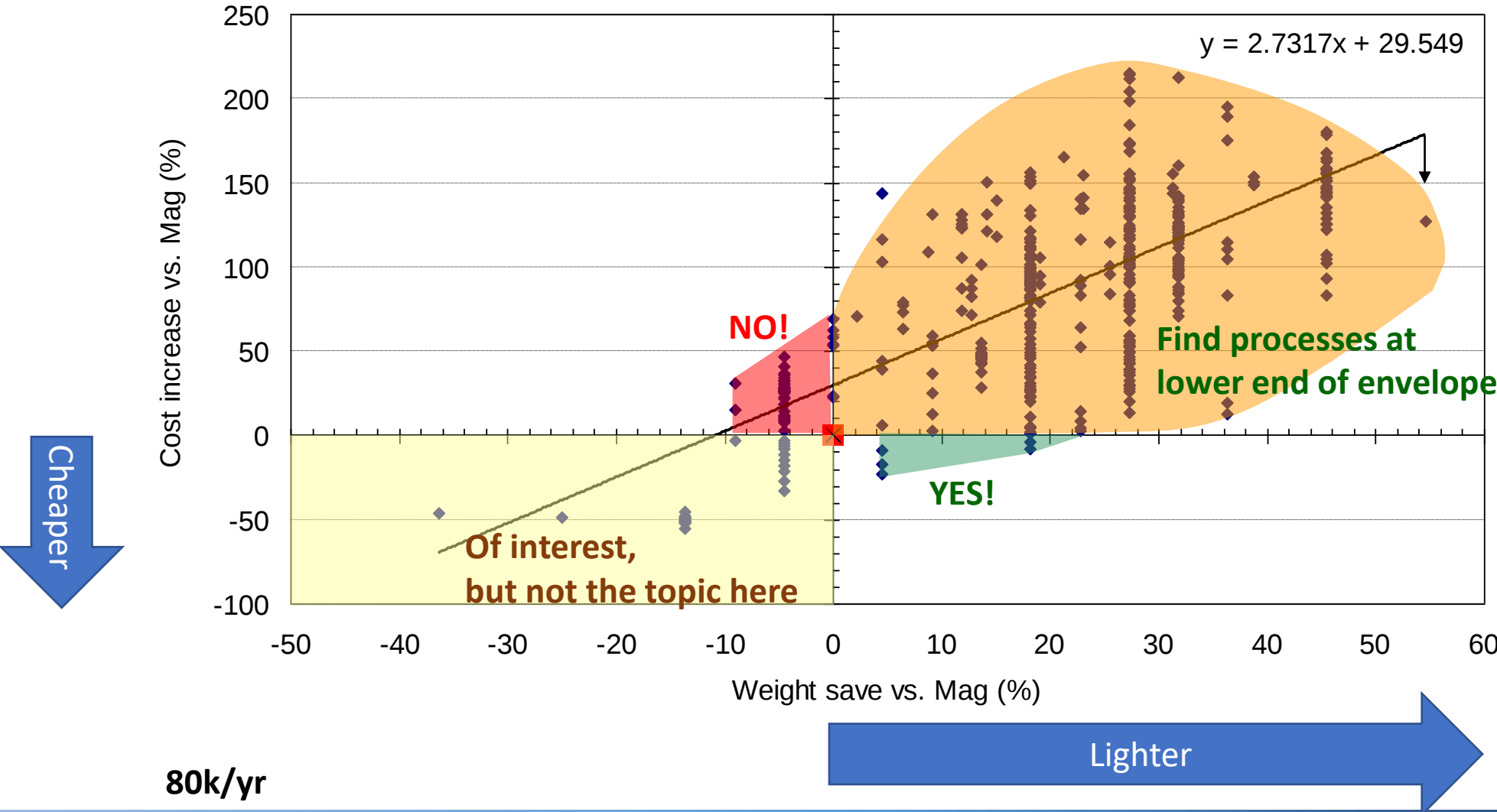


Cost vs. mass map – selected case

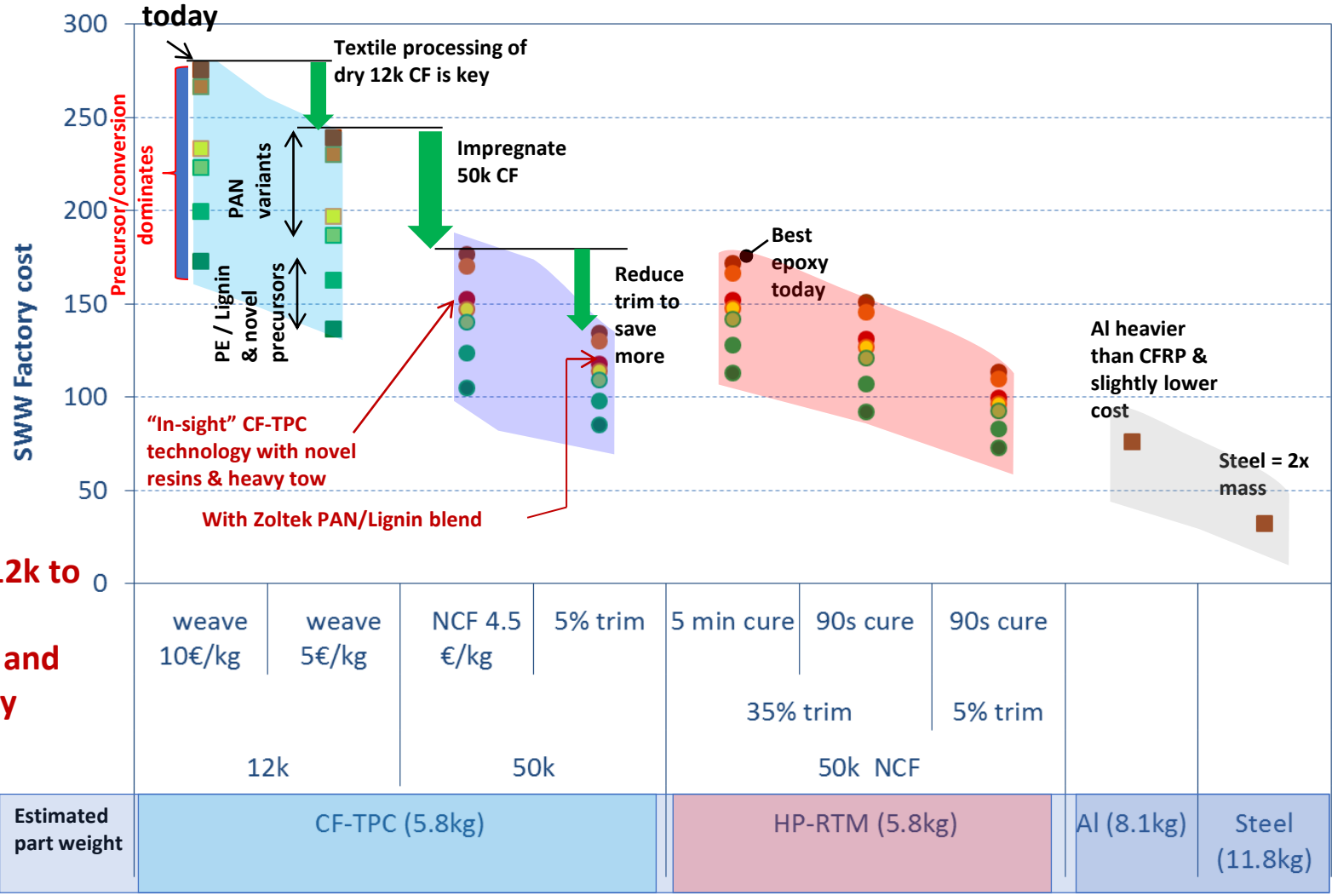


80k/yr

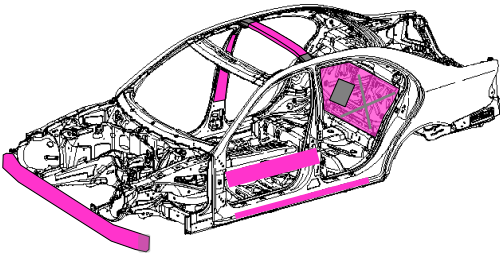
Cost increase vs. weight saving



Reducing cost of automotive structures



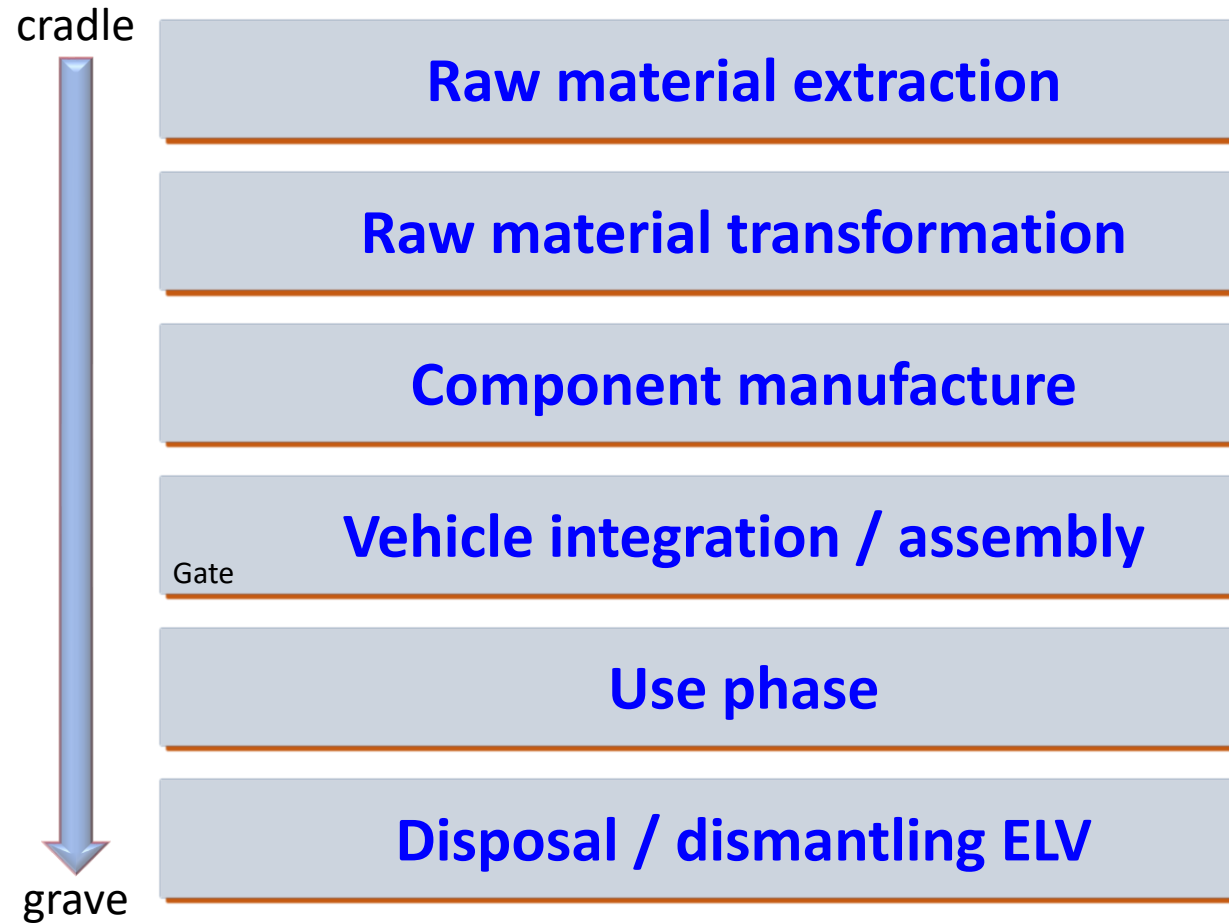
- Transition from 12k to 50k tow
- Enabled by resin and textile technology
- Reduce trim



Future developments will place both TS and TP composites at cost parity with Al at lower weight

LCA system boundaries: define scope

Life Cycle Phases

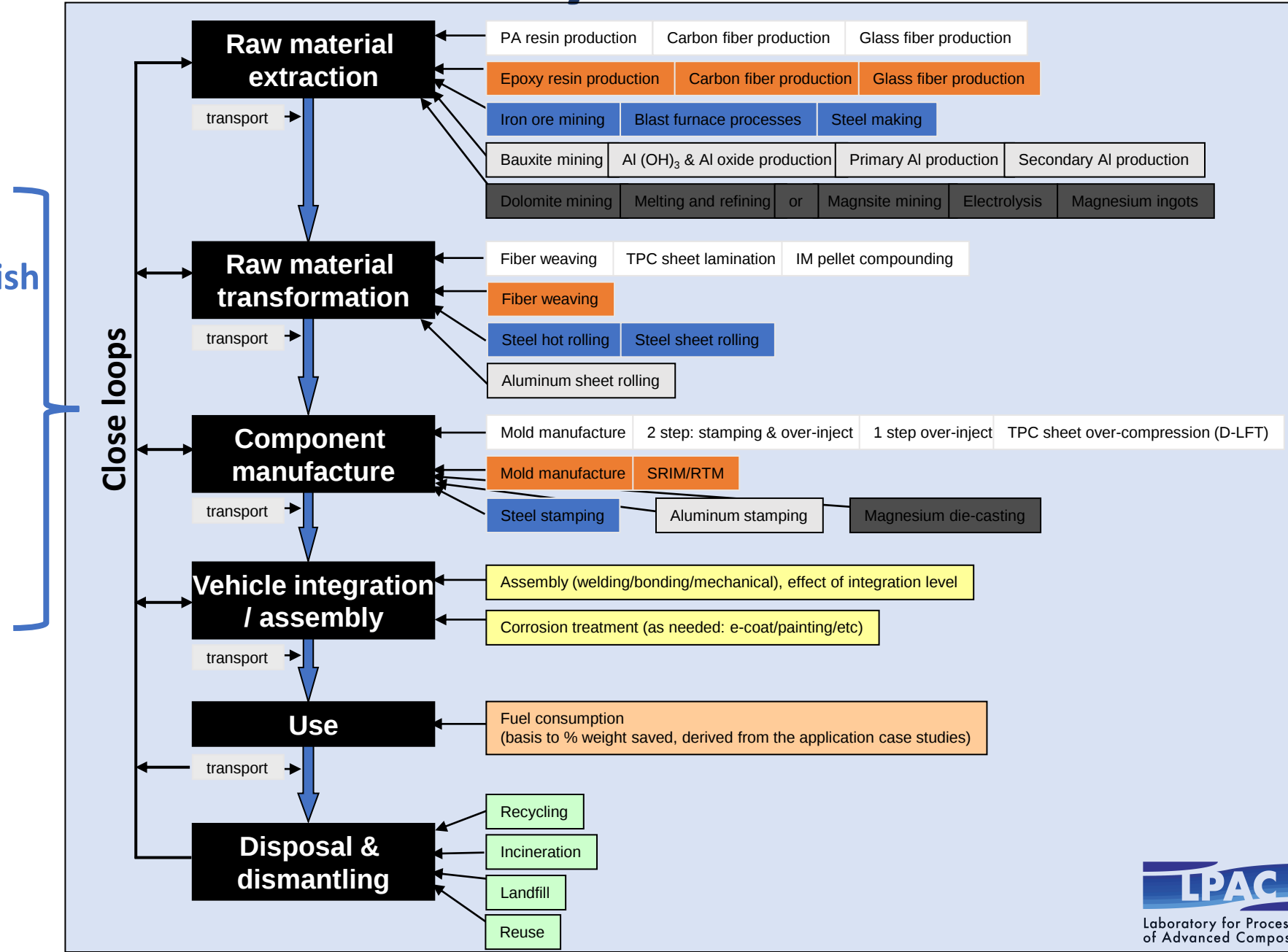


Full system analysis to examine multiple interests and see complete effect

We need to move from a linear to circular economic model

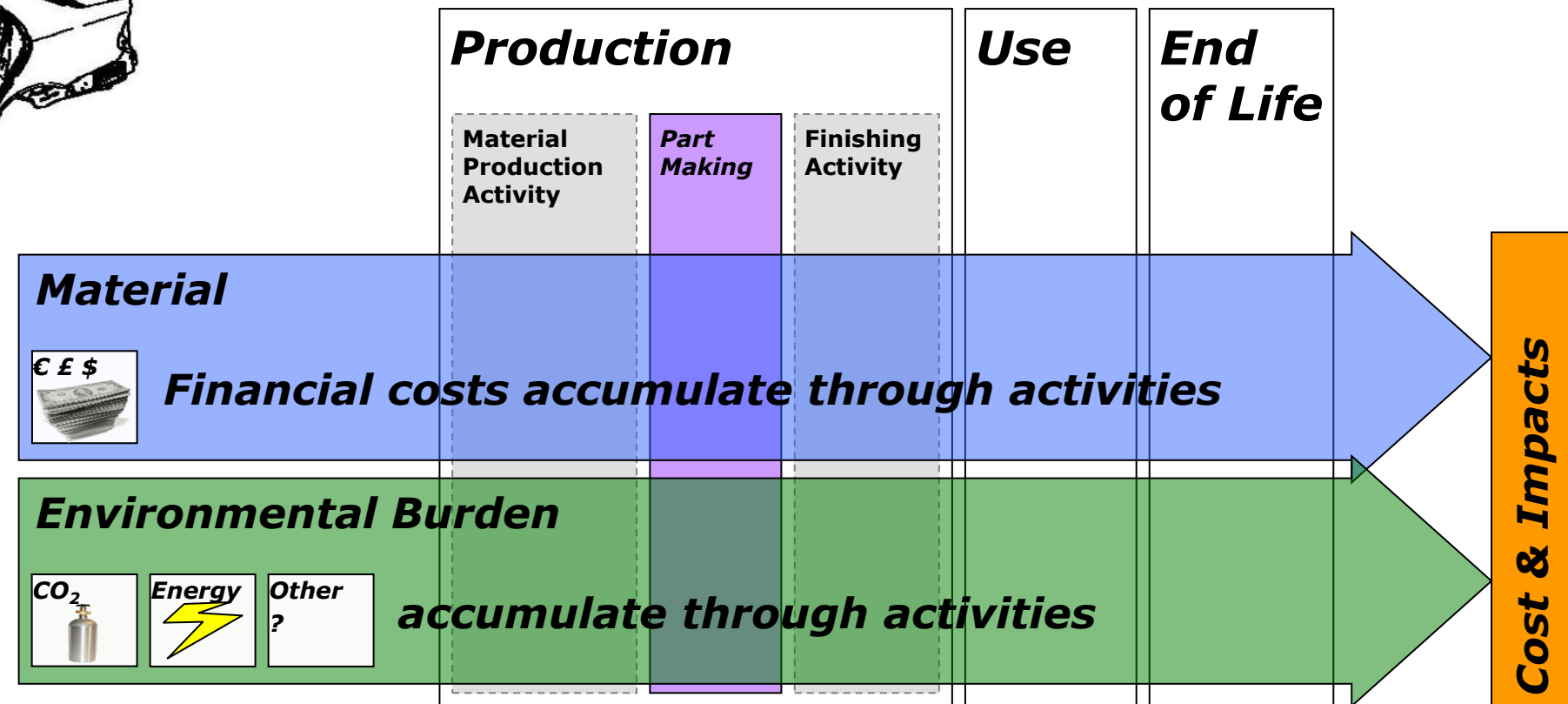
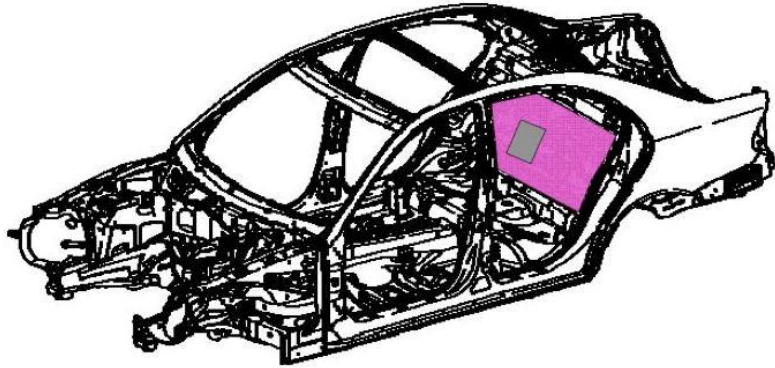
Example of multi-material LCA system boundaries

- Reuse / Redistribute
- Remanufacture / Refurbish
- Recirculate materials
- Maintain / Prolong
- Regenerate
- Share
- Recycling

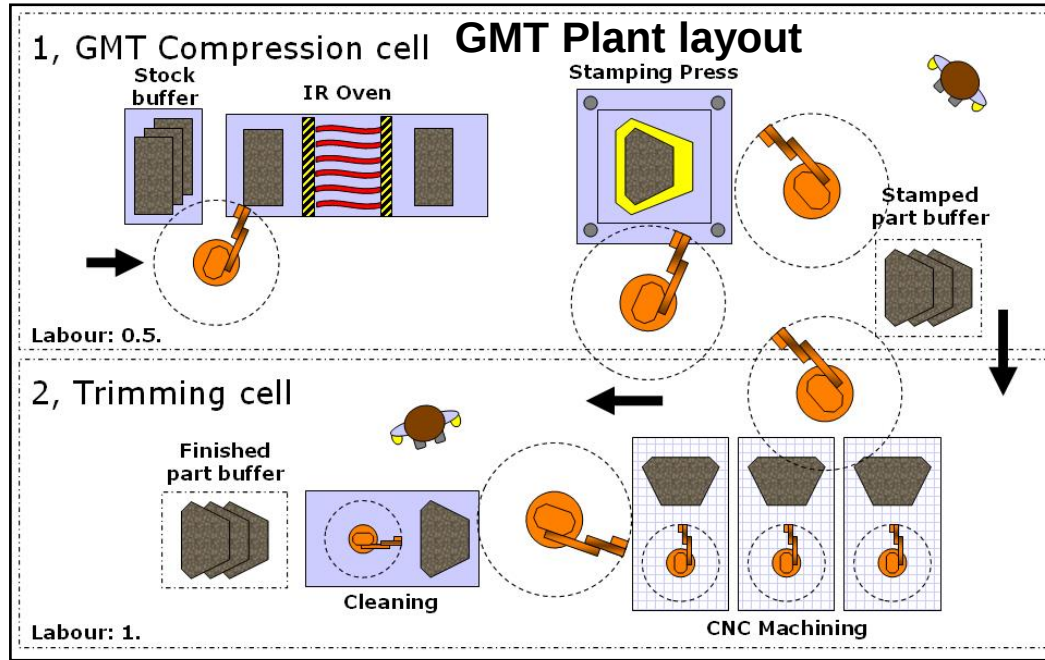


Coupled cost modelling, LCA, and LCC

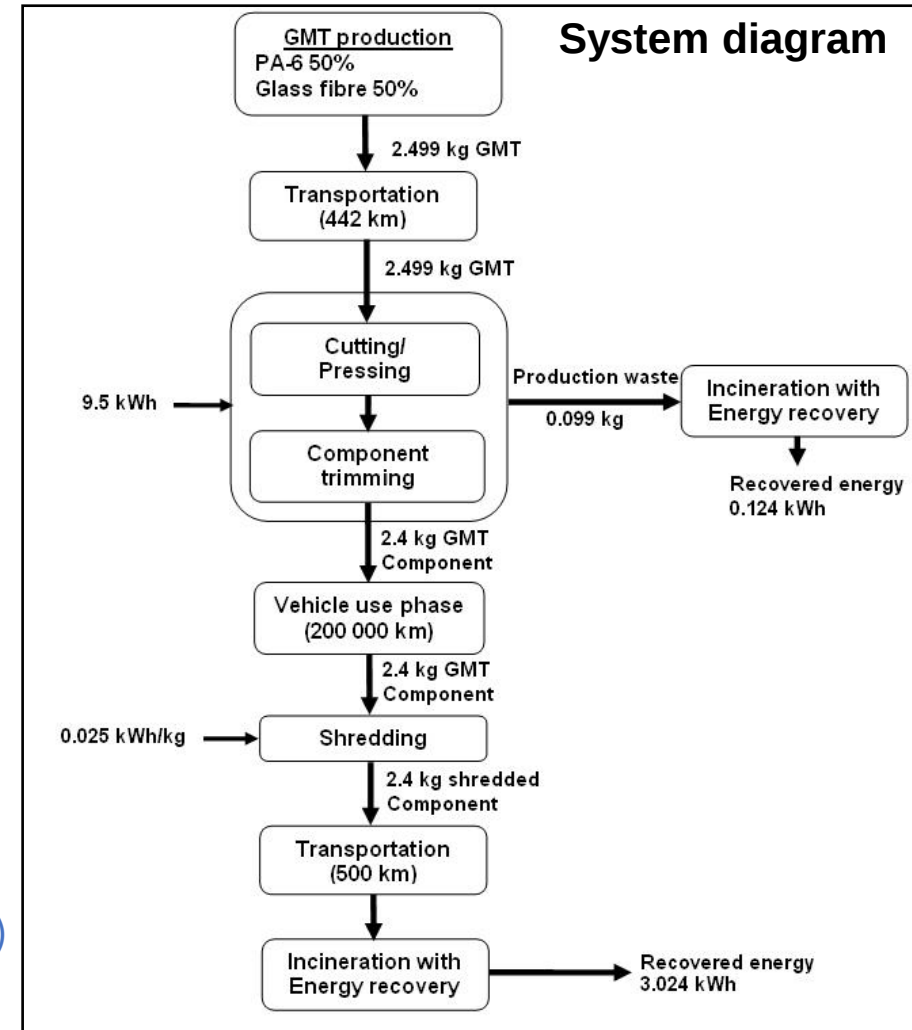
- Costs & burdens of each phase are considered
- Accumulated info used for economic and environmental assessment



Case study method



- Technical cost model (LPAC)
- Simapro used, with Impact 2002:
 - Human health Disability Adjusted Life Years (DALY)
 - Ecosystem quality Potentially disappeared fraction (PDF)
 - Climate change CO₂ (kg)
 - Resources MJ



P4 process and SRIM

A key step made – but needs combining with aligned materials



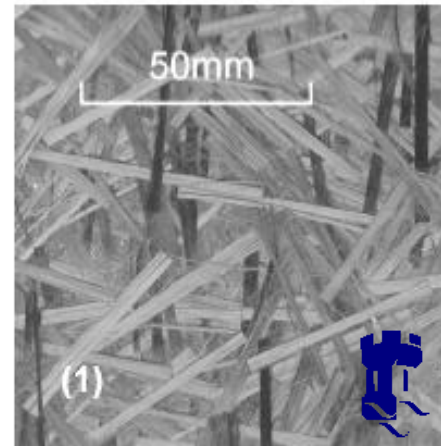
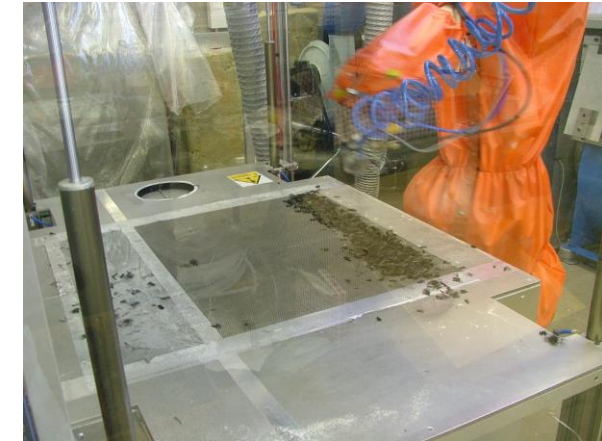
- 2 preforming stations
- preform mass 3.1kg
 - quick tool changes (~10 min)
 - 7-axis robot
 - net-shape preform
 - complex shape capability
 - direct process from roving
 - low scrap (< 3%)
 - high output (4 kg/min)



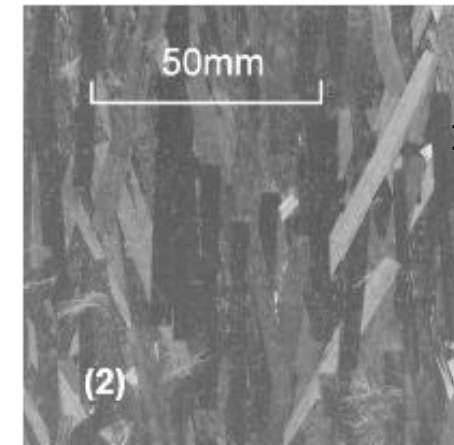
Vanquish with P4 applications



CARBON FIBER P4



random



aligned

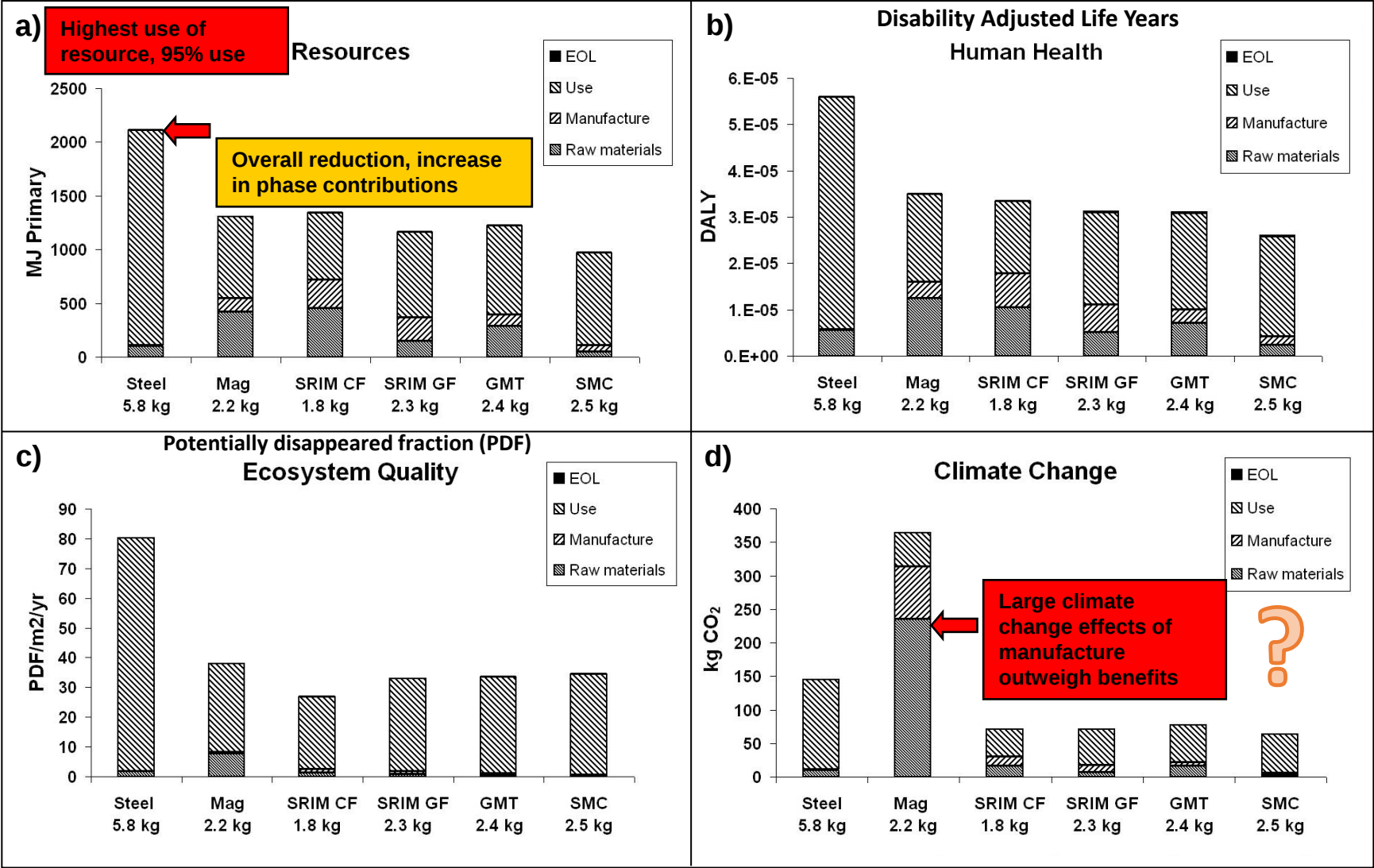
SRIM
160s to 520s cycle
time per tool
depending
on chemistry

Random CF (recycled/recovered grades)
Use primary CF as an aligned material

Life cycle assessment results

Recovered steel

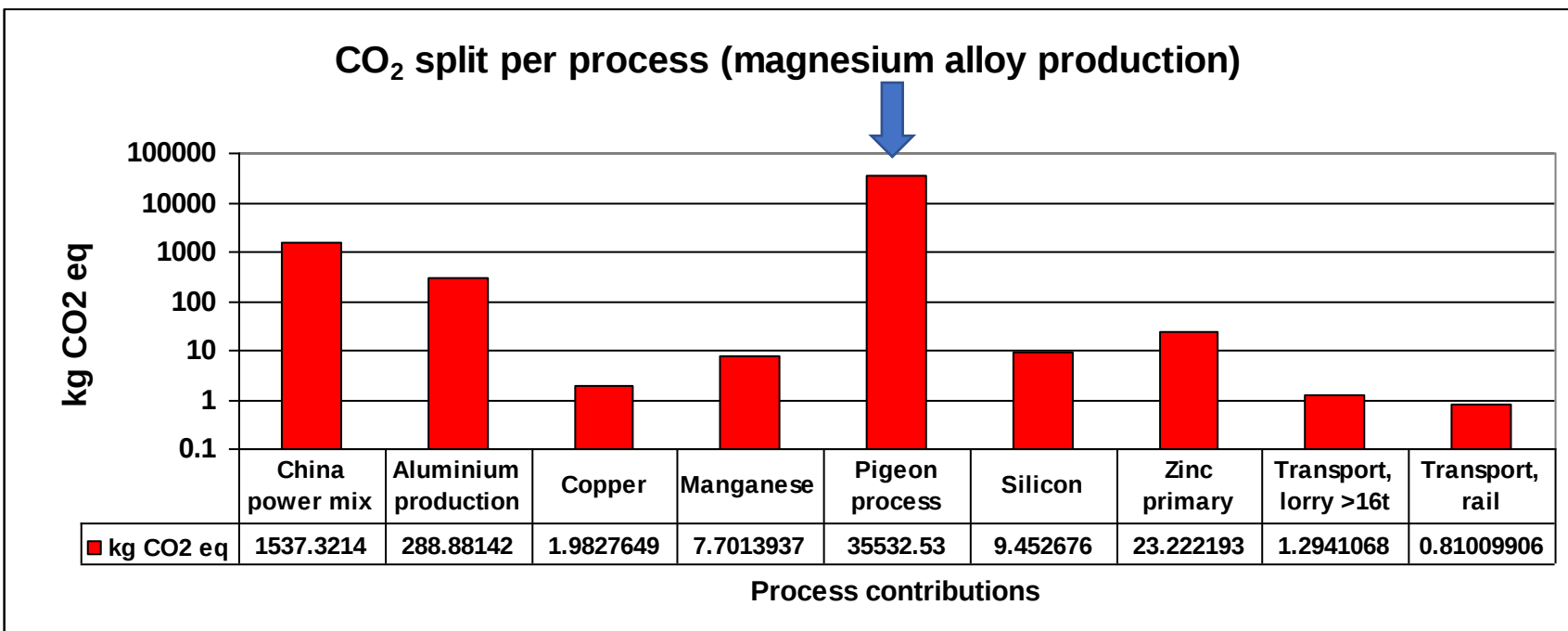
Potential Disappeared Fraction of Species



DALYs measure the gap between an ideal situation in which everyone lives to the standard life expectancy in perfect health and the actual situation

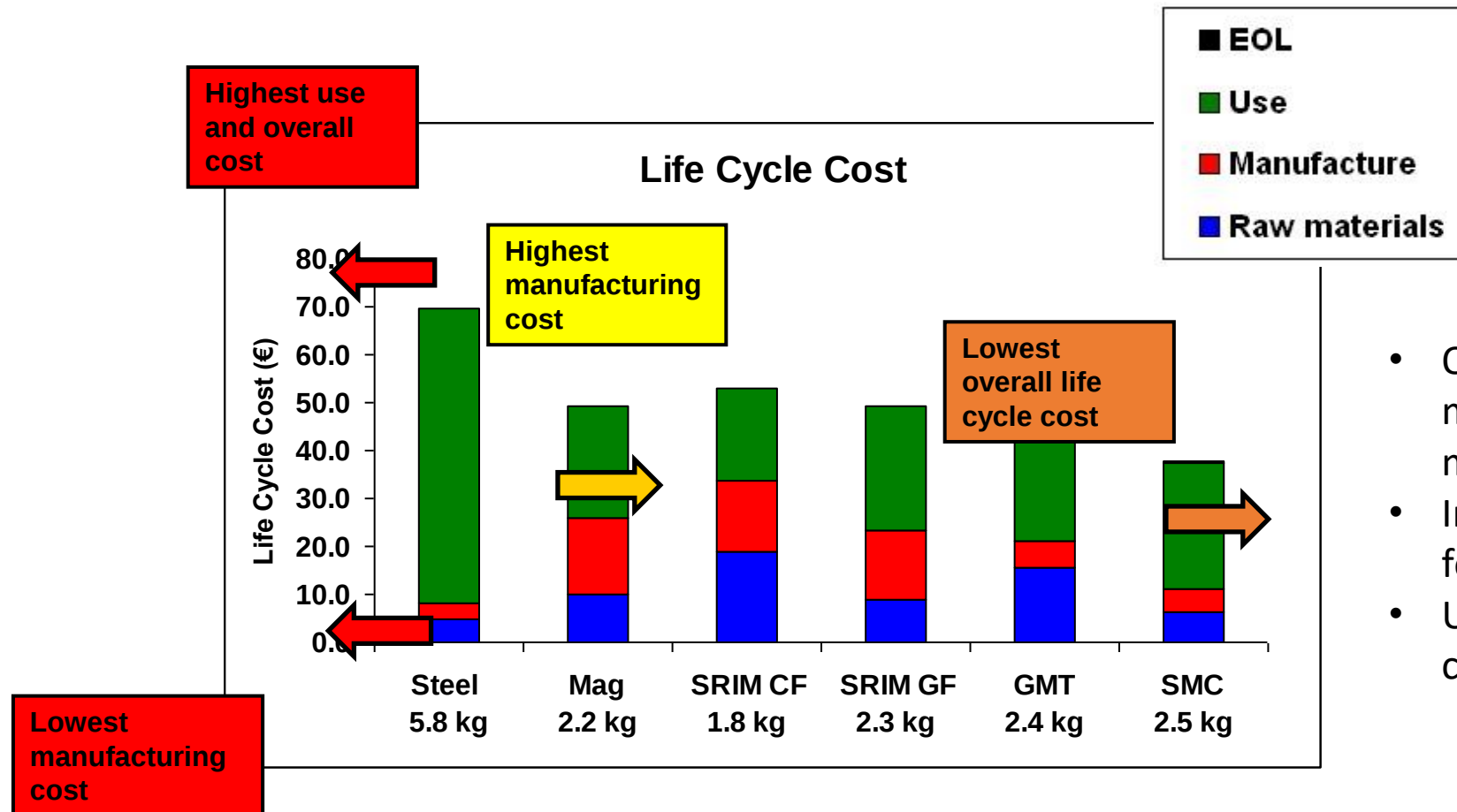
Magnesium production: needs sensitivity study

- Molten Mg & alloys volatile, oxidize explosively in air, require surface protection in casting processes
- Industrial adoption of Sulfur Hexafluoride (SF6) in protective gas mixtures to reduce formation of impurities and improve quality to give cleaner, non-toxic atmospheric workplace
- SF6 applied in low concentrations, but is most potent greenhouse gas defined under Kyoto Protocol
 - estimated atmospheric lifetime of 3,200 years, a 100-year global warming potential of 23,900 relative to CO₂ (Norsko Hydro, 1998)



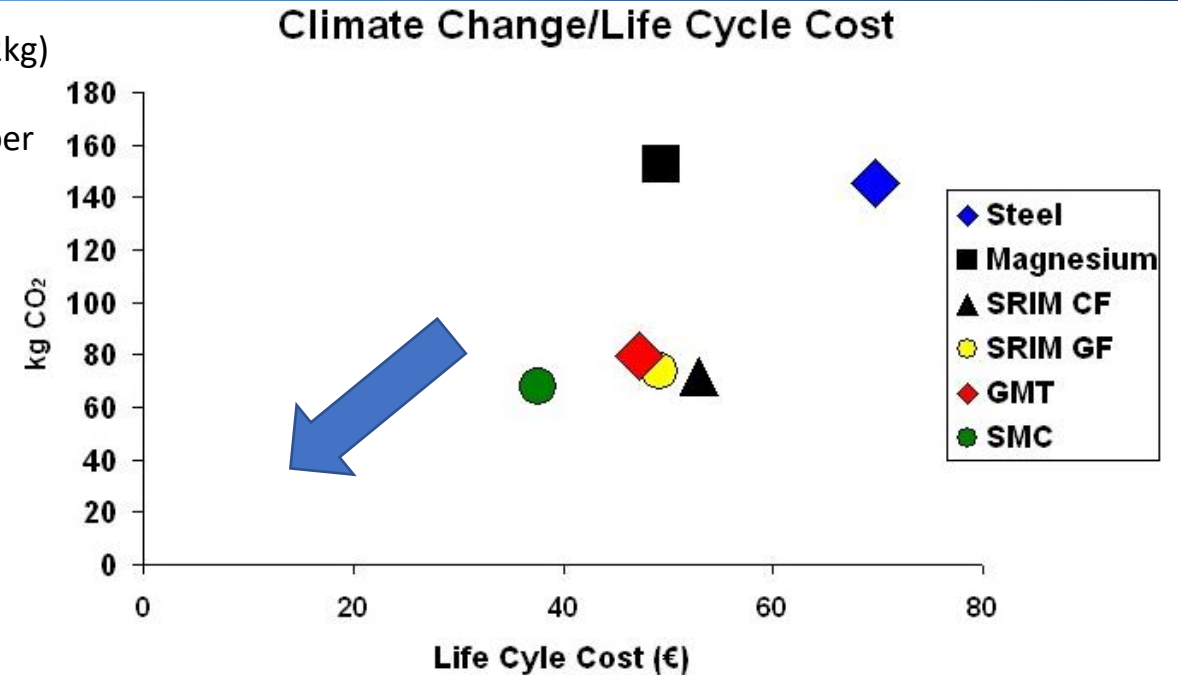
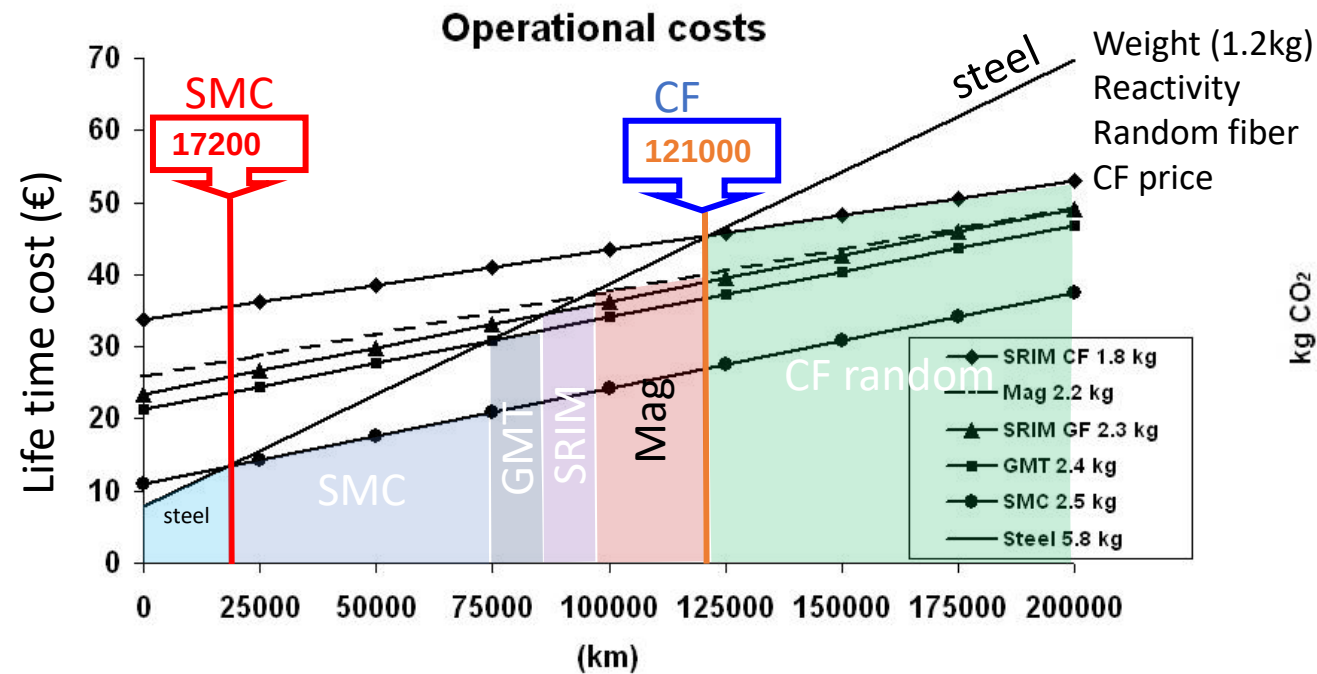
Assumes all SF6 is lost!
(not true)

Life cycle costs per part (200'000 km)



- OEM interested in materials and manufacture
- Innovation allowance for higher cost raws?
- User pays use phase costs

“Break even” analysis (€), Material ranking



- Composites give cost & impact reductions over life time, with increases in manufacturing cost (heat, time)
- SMC comes out well, despite a higher weight and issues of recyclability
- CF: update with faster reacting resins, aligned fibers for lower mass, specific CF LCA data (e.g. 50k tow, wind power, bio-mass PAN, BMW i3)
- Phase shifting was observed for the magnesium scenario: lowered use phase emissions, but higher for manufacture
- Automotive manufacturers need to reduce use phase emissions and to increase recycling at the end of life

Coupled Cost and Life cycle analysis

- Coupled TCM, LCA, LCC to assess the implementation of composite parts
- Can be further integrated into business financials
- Ideas for further developments
 - low energy cure, alternative fibers, geographic effects, circular economy, ELV, ...

- Data quality

- LCA inventory data for composite materials and processes lacking
- Can be misleading or historical (not forward looking)
- Collaboration is needed between LCA analysts, materials producers and process engineers to improve the databases (and conclusions!)

- Need to move from linear to circular business models
- Vision of the whole life cycle is important to build up a strategy
- Triple bottom line: People, Planet, Profit
(LCA does not address all the UN SDGs)



Design out waste and pollution



Keep products and materials in use



Regenerate natural systems



People

Socially Progressive

Planet

Environmentally Conscious

Profit

Fiscally Sound

Overview

- Cost modelling approaches
- Technical cost modelling deep dive
- Cost modelling and technology strategy
- Cost modelling and sustainability
- **Wrap up**
- A simple cost tool

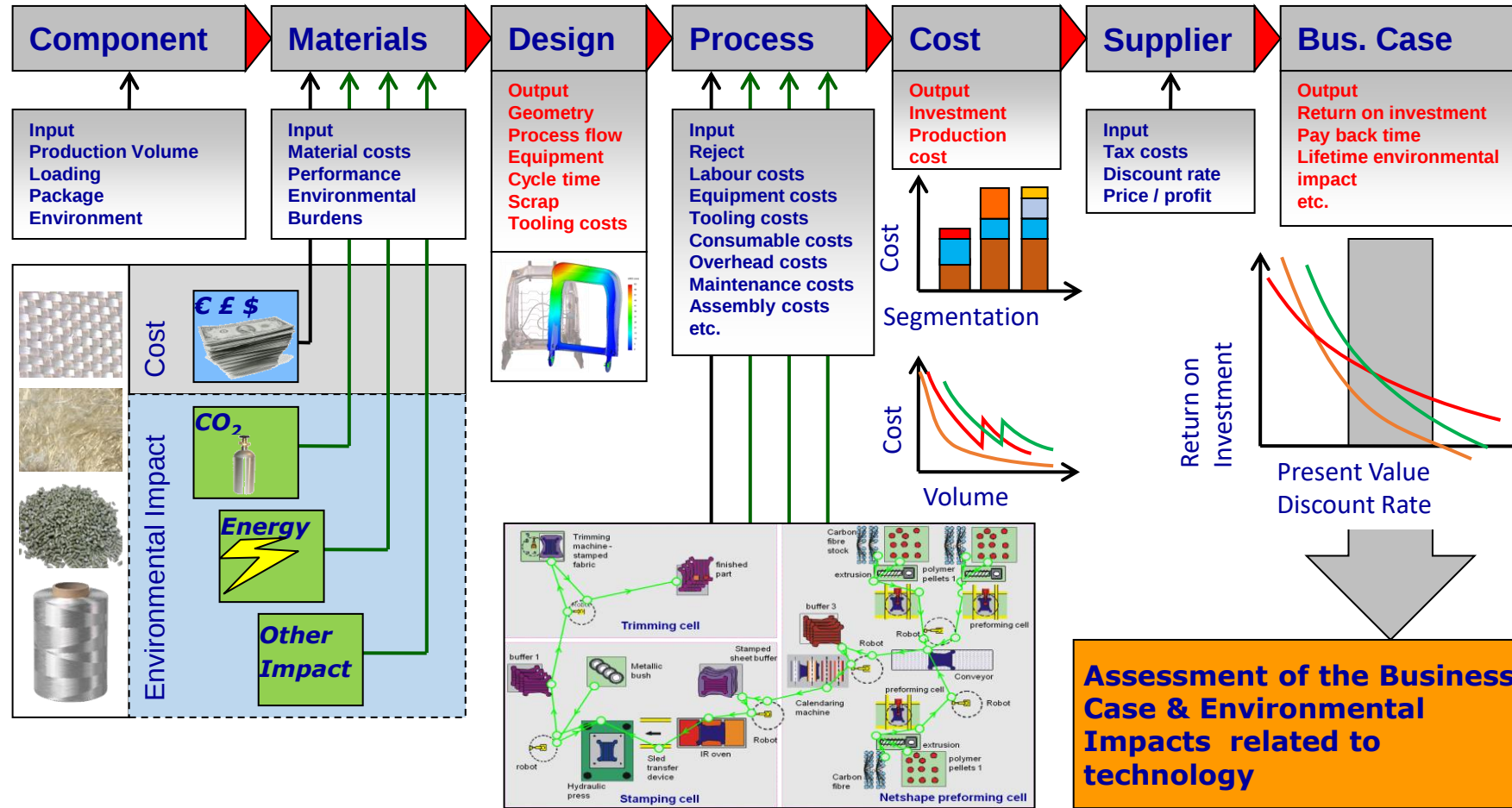


How can cost modelling help in a project or initiative?

① Start presenting to display the poll results on this slide.

Summary

- Technical, Financial & Environmental Cost Prediction



Conclusions: cost modelling

As a tool

- Helps us understand a technology
- Assess early ideas
- Gain support to research proposals / funding
- Develop a value proposition
- Establish a scaling strategy
- Build the business case and financials

Approach

- Rigorous
- Data driven
- Embed scientific and engineering principles and knowledge

Aids

- Help innovative ideas move towards industrialization
- Language for communication across functions and with customers

BREAK

Overview

- Cost modelling approaches
- Technical cost modelling deep dive
- Cost modelling and technology strategy
- Cost modelling and sustainability
- Wrap up
- A simple cost tool

A simple cost model to try out ...

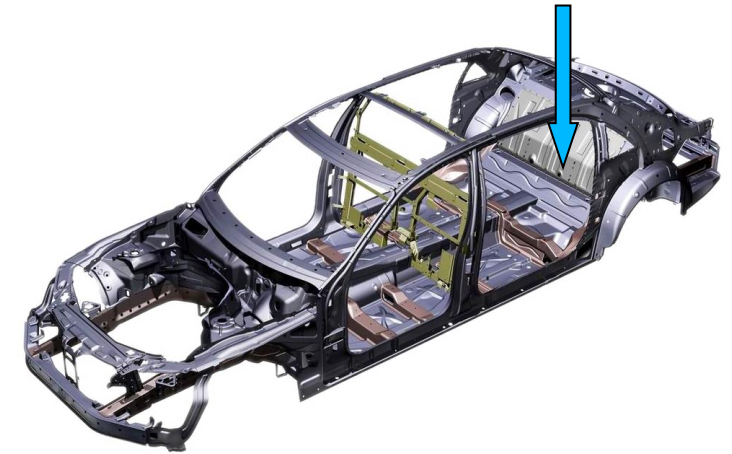
- See Template Provided

Simple technical cost model	Process Totals	Die casting	Punching	Machining
Process Goals				
Material 1 mass per part (kg)	2.2			
Material 2 mass per part (kg)				
Target production rate (p/yr)	100,000			
Production duration (yrs)	5			
Dashboard				
Hours per shift (hrs/d/sh)	7.3			
Days per year (d/yr)	220			
Available shift operational time at 100% efficiency (hr/yr/shift)		1,606	1,606	1,606
Time efficiency (.)		80%	80%	80%
Available shift operational time (hr/yr/shift)		1,285	1,285	1,285
Cycle time (s/p)		110	90	60
Available shift production rate (p/yr/sh)		42,048	51,392	77,088
Required production rate OUT (p/yr)		100,000	100,000	100,000
Reject (.)		2%	0%	2%
Actual production rate IN (p/yr)		102,041	100,000	102,041
Single shift utilisation (.)		2.43	1.95	1.32
No of shifts required (sh)	3	3	2	2
Max no of shifts (sh)	3	3	3	3
No of shifts employed (sh)		3	2	2
Available production rate (p/yr)		126,144	102,784	154,176
Actual utilisation rate (.) MUST BE < 1	0.97	0.81	0.97	0.66
Available operational time (hrs/yr)		4,818	3,212	3,212
Actual operational time (hrs/yr)		3,897	3,125	2,126
Dedicated / Utilised		utilised	utilised	utilised
Effective utilisation (.)		0.81	0.97	0.66
Material 1 Cost				
Material mass per part OUT (kg/p)		3.09	2.32	2.20
Scrap (.)		0%	25%	5%
Material mass per part IN (kg/p)		3.09	3.09	2.32
Material mass IN per year (kg/yr)		315,073	308,772	236,305
Material cost (€/kg)		3.2	0	0
Annual material cost IN (€/yr)		1,008,235	0	0
Material 1 value IN (€/p)	10.08	10.08	0.00	0.00



Exercise - Questions

- Find the following for your chosen process (5 choices):
 - To meet the Max target production volume
 - Utilisation rate
 - Number of shifts required
 - Number of tools required
 - Production capacity (parts/yr) i.e. 100% utilisation
 - Total production cost
 - Including cost segmentation (materials, energy, labour etc)
 - Total Investment in equipment
 - Plot Cost vs. Volume as a sensitivity analysis
 - for 5k to 300k parts/yr
 - Plot Cycle Time vs. Total Cost as a sensitivity analysis (!)
 - Comment on addition of parallel of machines
 - Investigate the sensitivity of one other relevant parameter



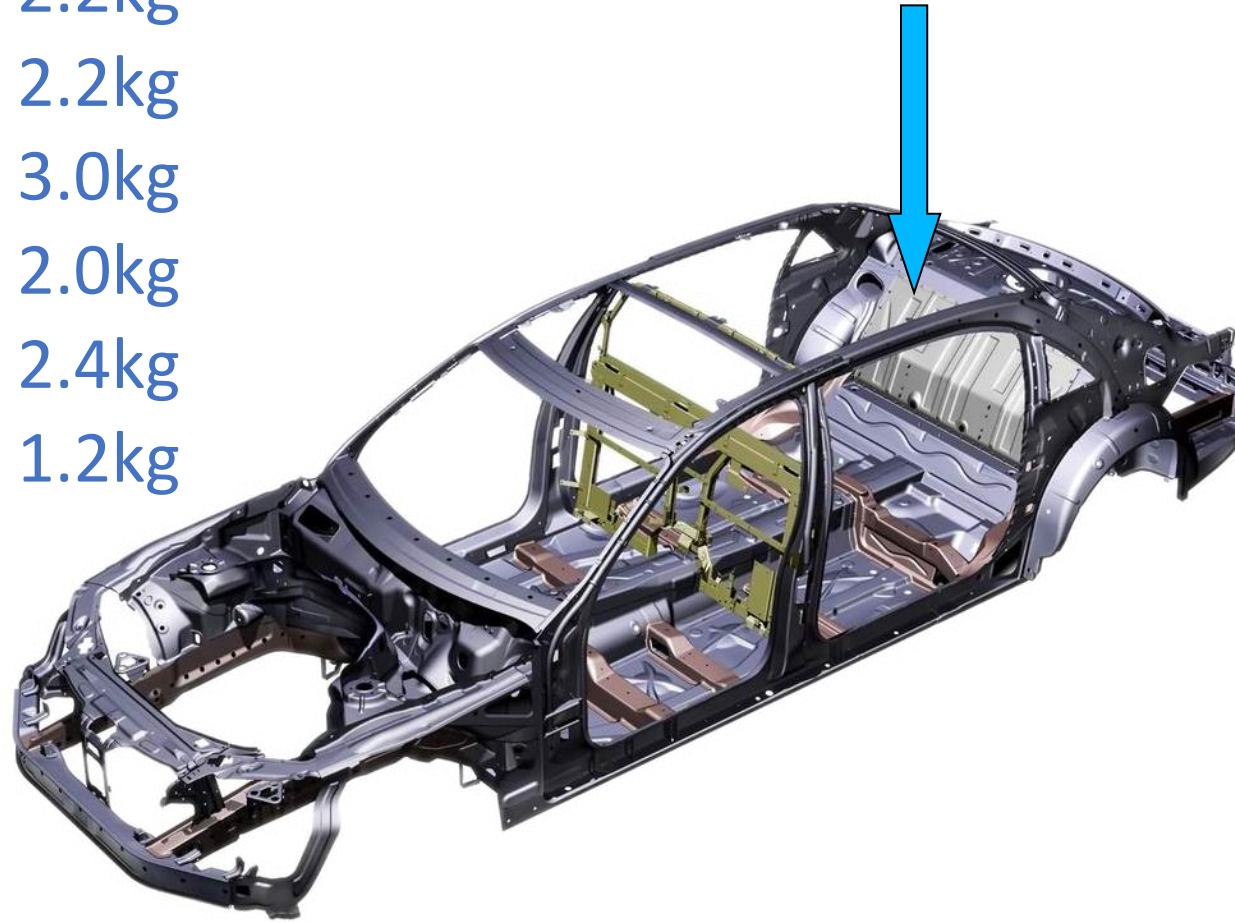
Additional Questions

- Adapt the model
 - to multiply machines in parallel for utilisation > 1
 - Find the time interval (yrs) for investment in:
 - Tooling
 - Machines
 - Plot Investment vs.Time

Data for cost exercise

Example Part

- Rear Structural Bulkhead, steel 5.8kg
 - Magnesium 2.2kg
 - GF NCF/Epoxy 2.2kg
 - SMC 3.0kg
 - GF/PA Fabric 2.0kg
 - GF/PA GMT 2.4kg
 - CF prepreg 1.2kg



Material costs for exercise

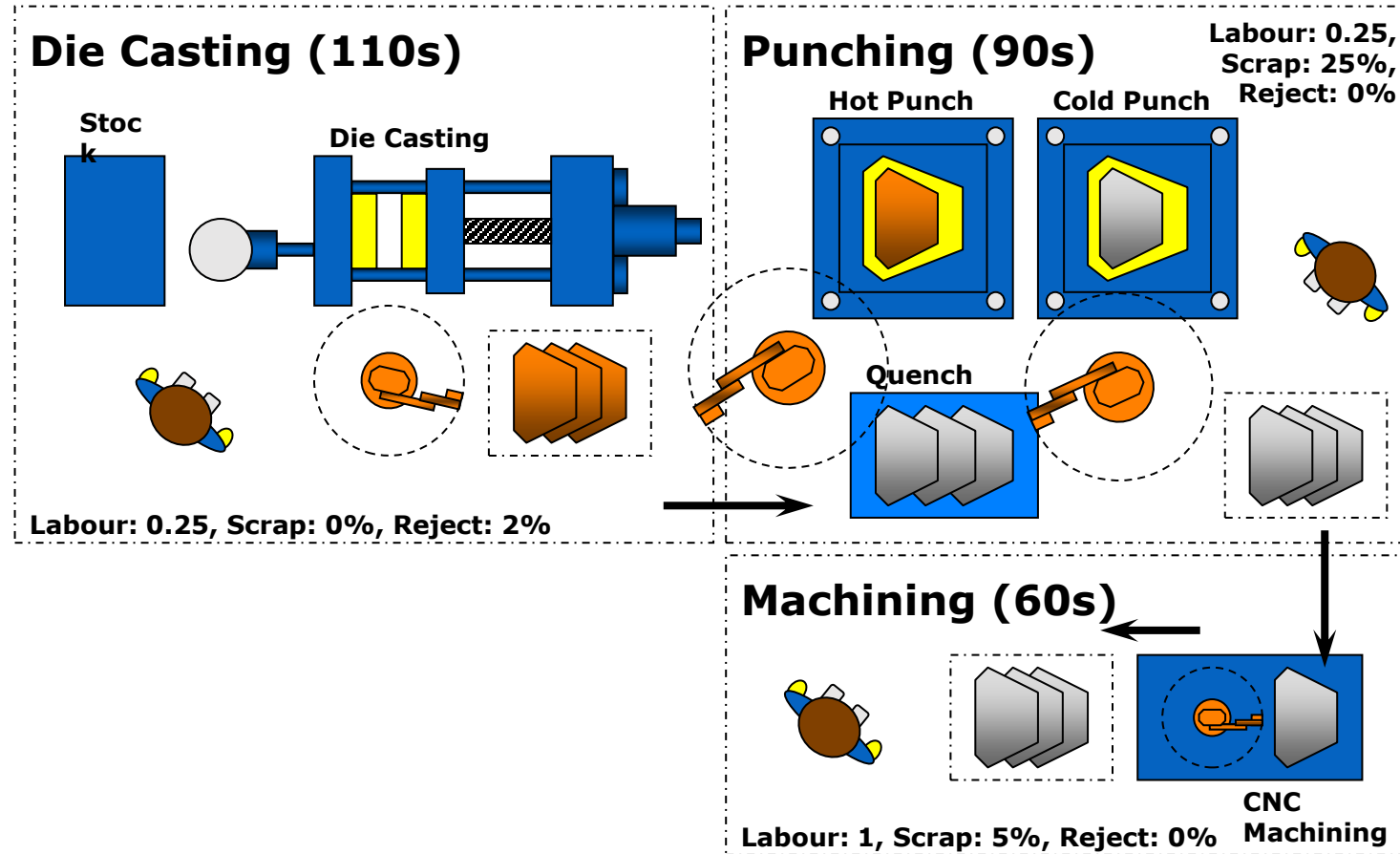
- Material Costs
 - Magnesium €2.2 /kg
 - Glass NCF €3.2 /kg
 - Epoxy resin €4.0 /kg
 - SMC €1.6 /kg
 - Glass / PA Fabric €7.0 /kg
 - PA GMT €6.0 /kg
 - CF prepreg €25 /kg

Production scenario data for exercise

- Production Scenario
 - 50' 000, 100' 000 and target of 300' 000 parts per year
 - 5 years series production
 - 7.3hr/shift
 - 220 days per year
 - Max 3 shifts per day
 - Labour cost - direct €48/hr, indirect €56/hr
 - Indirect/Direct labour ratio of 0.75
 - Energy cost €0.18/kWh
 - Plant operating cost €140/m²/yr
 - Machine lifetime 7yrs

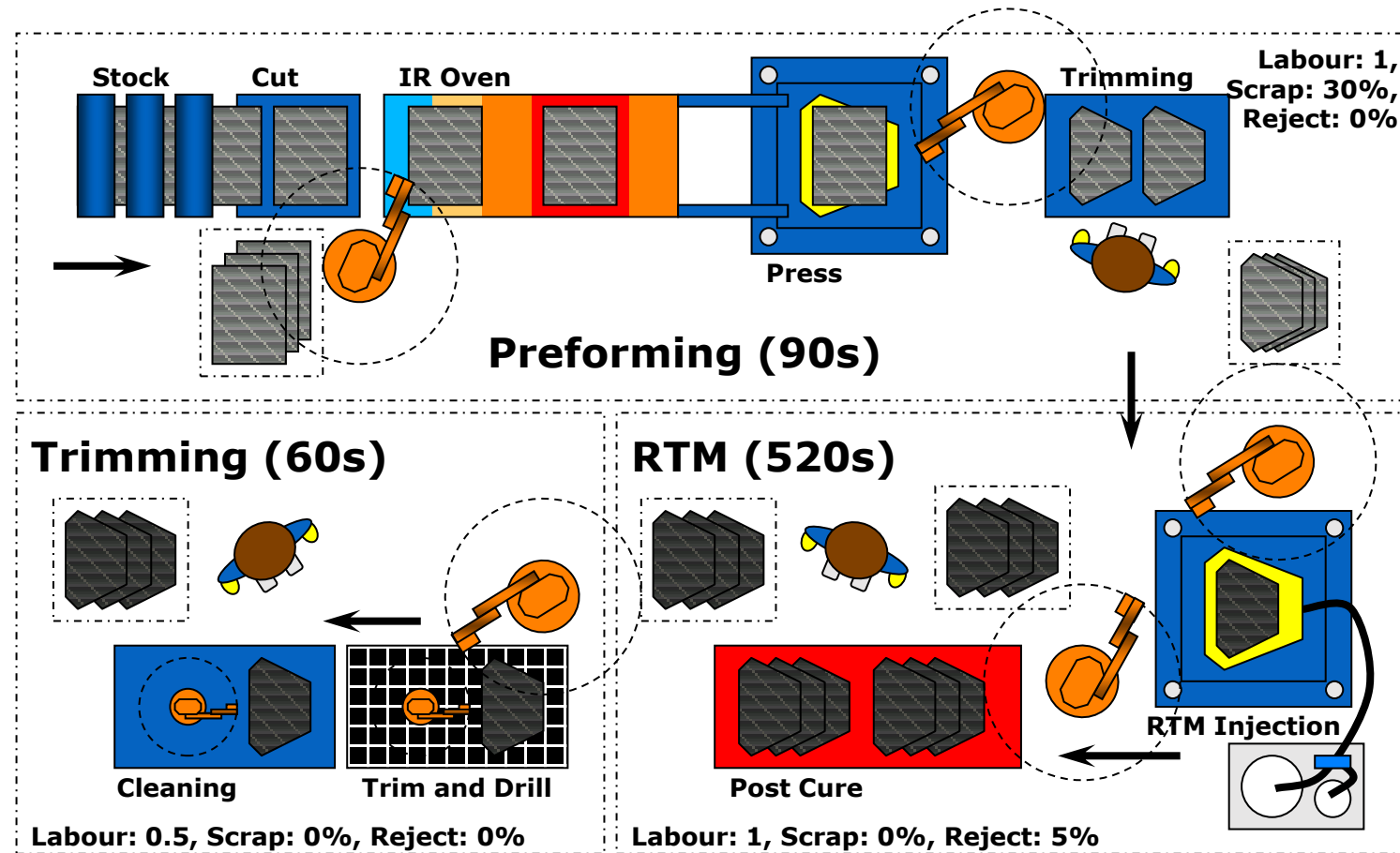
Example Process 1

- Magnesium Die Casting



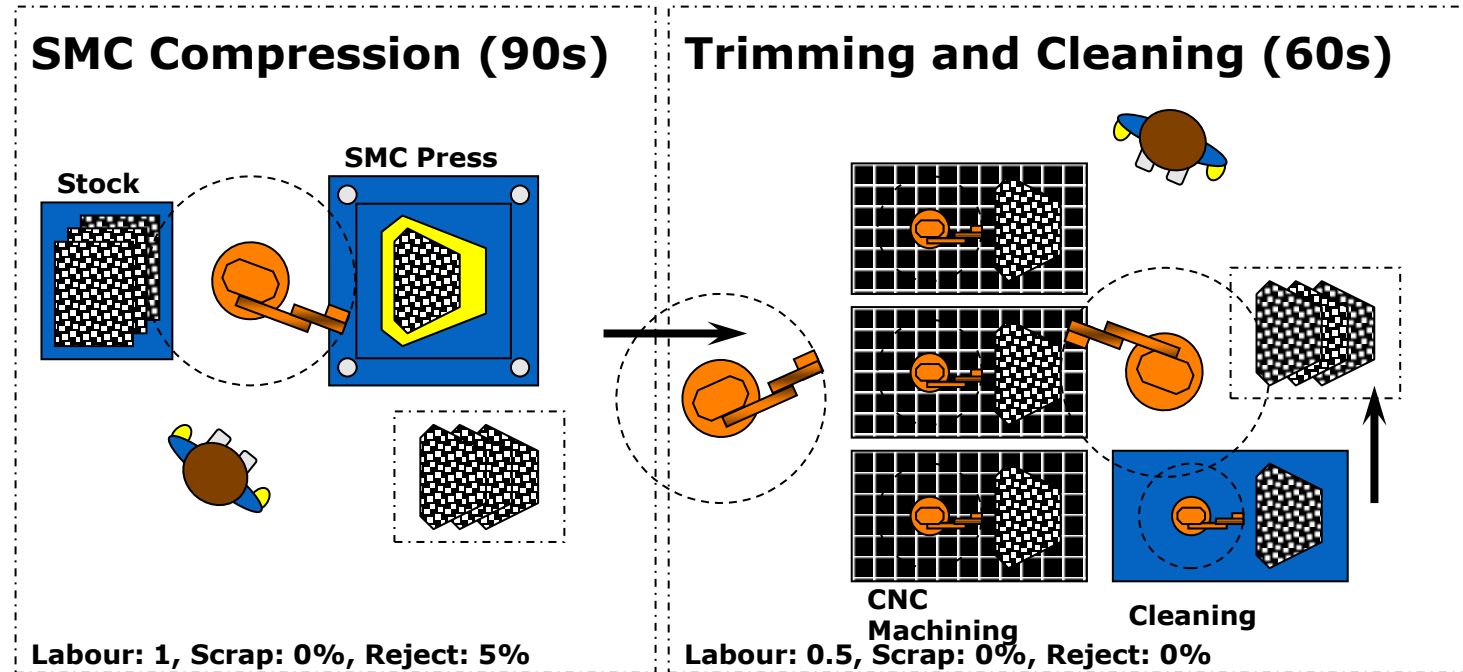
Example Process 2

- NCF / Epoxy RTM



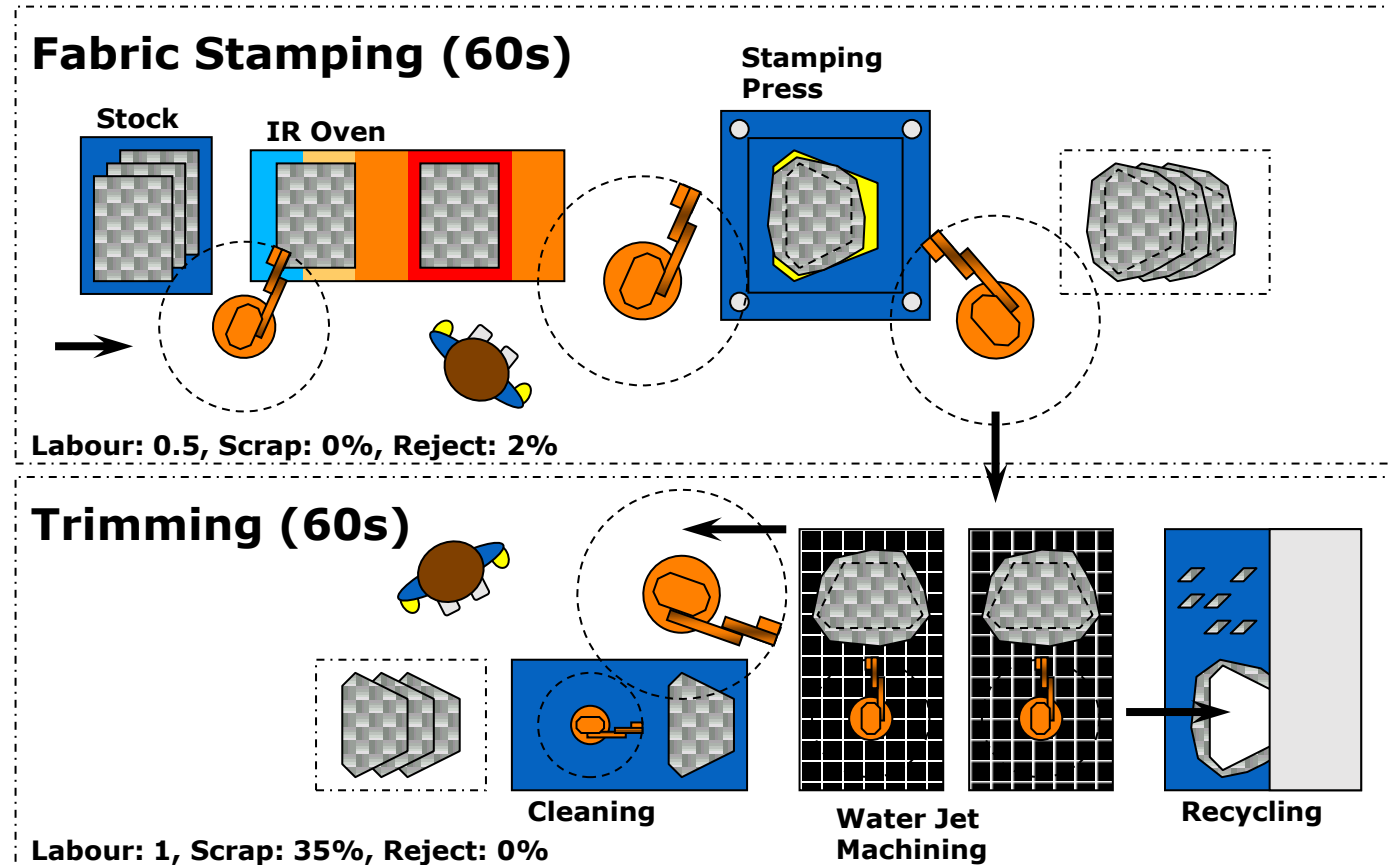
Example Process 3

- SMC Compression



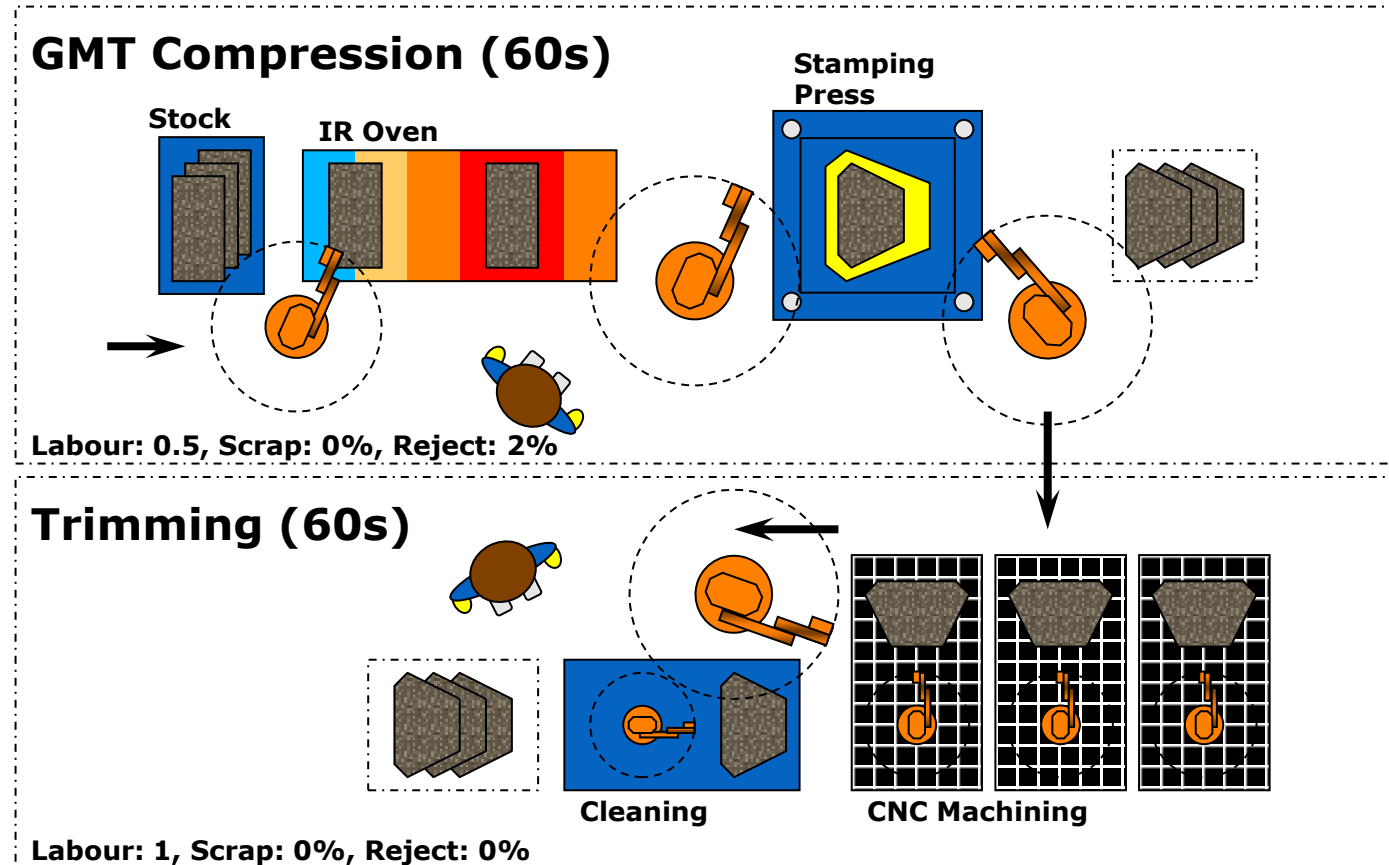
Example Process 4

- Thermoplastic Fabric Stamping



Example Process 5

- GMT Compression Moulding



Equipment costs for exercise

- Machine costs

<i>Item</i>	<i>Cost €</i>	<i>Power kW</i>	<i>Area m²</i>	<i>Life</i>
Buffer	10,000	5	15	
Die Cast Machine	900,000	150	200	
Mg Die Casting Tool	200,000	-	-	250,000 shots
Robot	75,000	10	20	
Water Quench Buffer	20,000	5	15	
Hot Trim Punching	80,000	30	15	
Cold Trim Punching	80,000	30	15	
Punching Tool	20,000	-	-	500000 shots
CNC Trimming Station	300,000	50	20	
Manual Debur	10,000	5	10	
Preforming IR Oven	100,000	15	150	
Preforming Press	200,000	20	40	
Cutting Table	10,000	5	15	
RTM Injection Machine	150,000	20	15	
RTM Press	200,000	50	25	
RTM Tool	150,000	-	-	250,000 shots
Post Cure Oven	100,000	150	50	
Trimming Machine	200,000	20	20	
Robotic Cleaning Machine	100,000	10	20	
SMC Tool	200,000	-	-	1,000,000 shots
SMC Press	400,000	50	30	
Thermoplastic IR Oven	200,000	20	200	
Stamping Press	200,000	40	15	
Stamping Tool	100,000	-	-	1,000,000 shots
Water Jet Cutting	350,000	15	20	
Shredding	200,000	100	25	
Drilling	350,000	15	20	
GMT Tool	300,000	-	-	1,000,000 shots
Compression Press	900,000	50	150	

Annex 1: Cost tool arithmetic

Production Dashboard

- Production Dashboard

Material mass per part (kg)

Target production rate (p/yr)

Production duration (yrs)

Actual operational time (hrs/yr)

Effective utilisation (.) = if a=dedicated then 1 else if a=utilised then b

└─ Dedicated / Utilised

└─ Actual utilisation (.)

No. of direct labour (pns)

Key

Data valid for entire process

Data valid for an activity / machine

Value from downstream activity

Calculated value = formula e.g. a/b

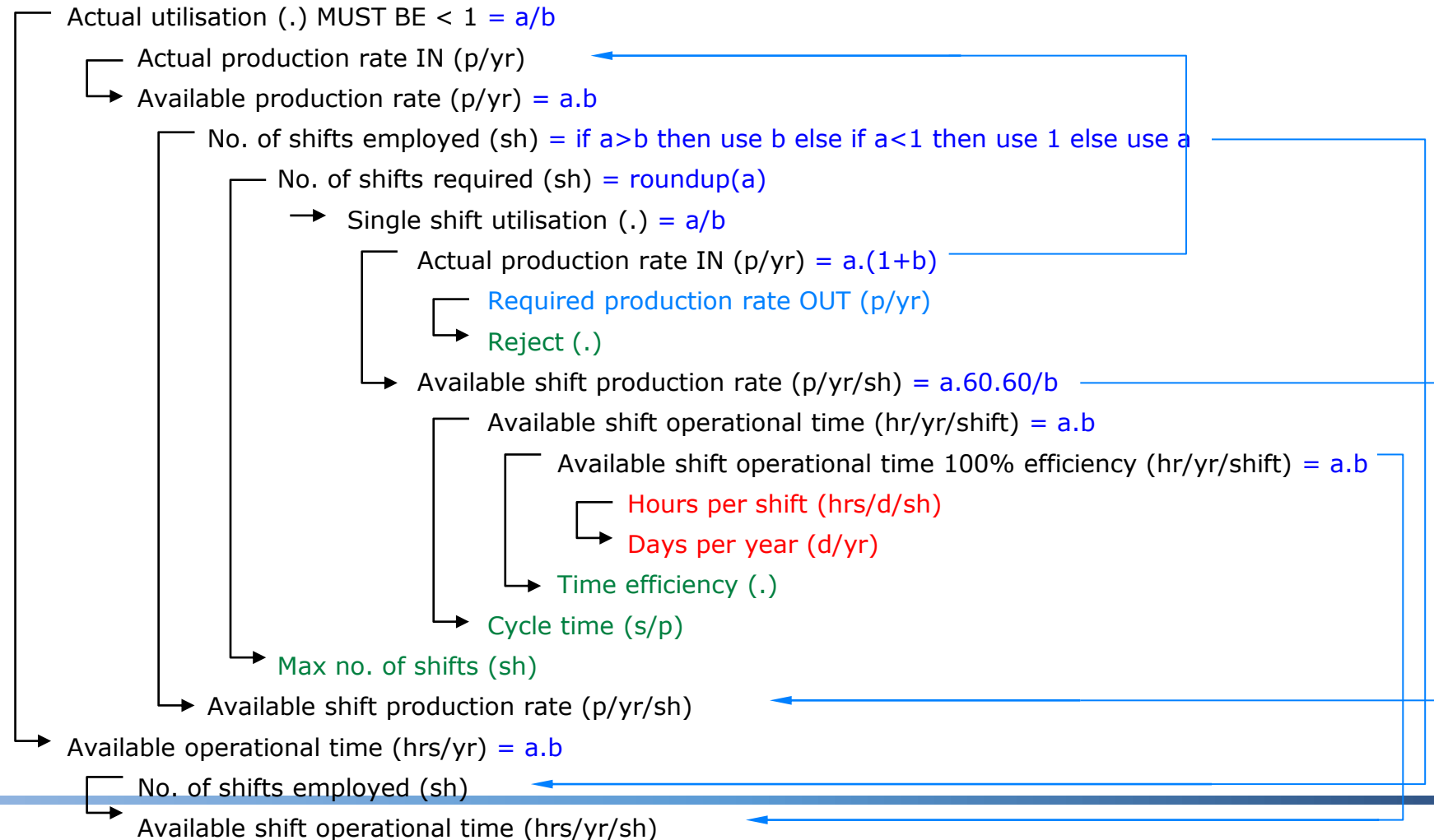
└─ value a

└─ value b

Value calculated elsewhere

Production Dashboard

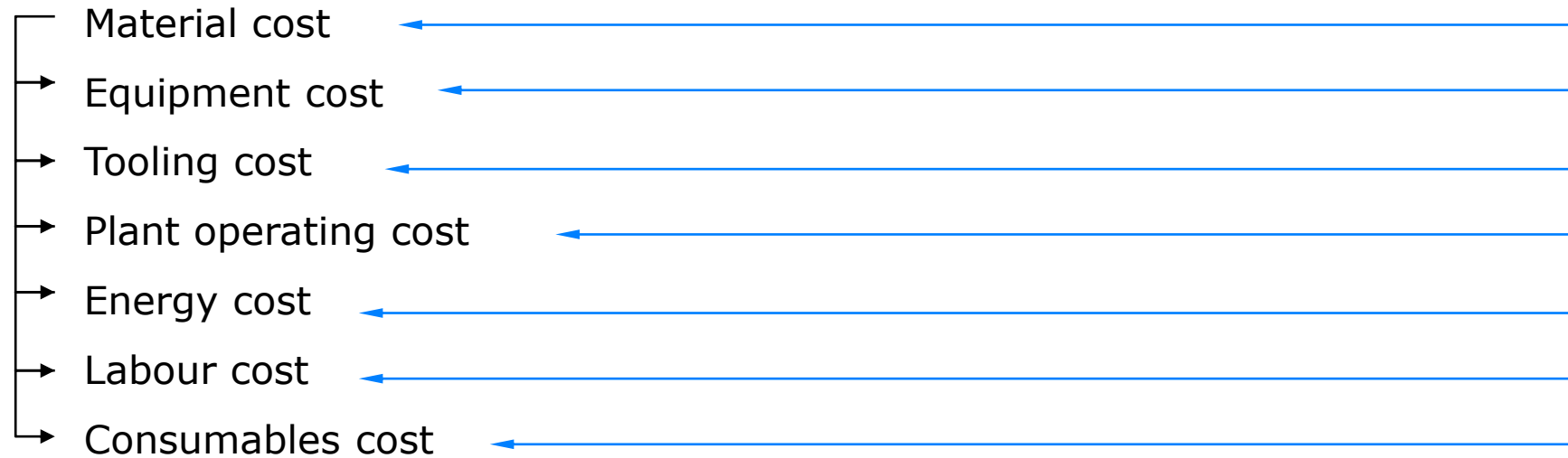
- Actual operational time (hrs/yr) = $a.b$



Cost Calculation

- Total Production Cost

$$\text{Total Production Cost (€/p)} = a+b+c+d+e+f+g$$



Material Cost Calculation

- Material Cost

Material value IN (€/p) = a/b

Annual material cost IN (€/yr) = $a.b$

Material cost (€/kg)

Material mass IN per year (kg/yr) = $a.b$

Actual production rate IN (p/yr)

Material mass per part IN (kg/p) = $a.(1+b)$

Material mass per part OUT (kg/p)

Scrap (.)

Target production rate (p/yr)

Equipment Cost Calculation

- Equipment Cost

Machine depreciation ($\text{€}/p$) = a/b

Process depreciation cost ($\text{€}/\text{yr}$) = $a.b$

Annual depreciation cost ($\text{€}/\text{yr}$) = a/b

Equipment capital cost (€)

Depreciation time (yrs) = if $a=\text{utilised}$ then b else c

Dedicated / Utilised

Time until replacement (yrs)

Production duration (yrs)

Effective utilisation (.)

Target Production rate (p/yr)

Tooling Cost Calculation

- Tooling Cost

$$\text{Tool cost (€/p)} = a/b$$

$$\text{Annual tool cost (€/yr)} = a/b$$

$$\text{Total tool cost (€)} = a.b$$

Tool cost (€/tl)

$$\text{No. of tools (tls)} = \text{roundup}(a/b)$$

$$\text{Total no of shots in process (shts)} = a.b$$

Actual production rate IN (p/yr)

Production duration (yrs)

Tool life in shots (shts)

Production duration (yrs)

Target production rate (p/yr)

Plant Operation Cost Calculation

- Plant Operation Cost

Plant operating cost (€/p) = a/b

Annual plant operating cost (€/yr) = $a.b$

Full plant operating cost (€/yr) = $a.b$

Plant operating cost (€/m²/yr)

Plant area (m²)

Effective utilisation (.)

Target production rate (p/yr)



Energy Cost Calculation

- Energy Cost

$$\text{Energy cost (€/p)} = a/b$$

$$\text{Annual energy cost (€/yr)} = a.b$$

$$\text{Energy cost (€/hr)} = a.b$$

$$\text{Energy cost (€/kWh)}$$

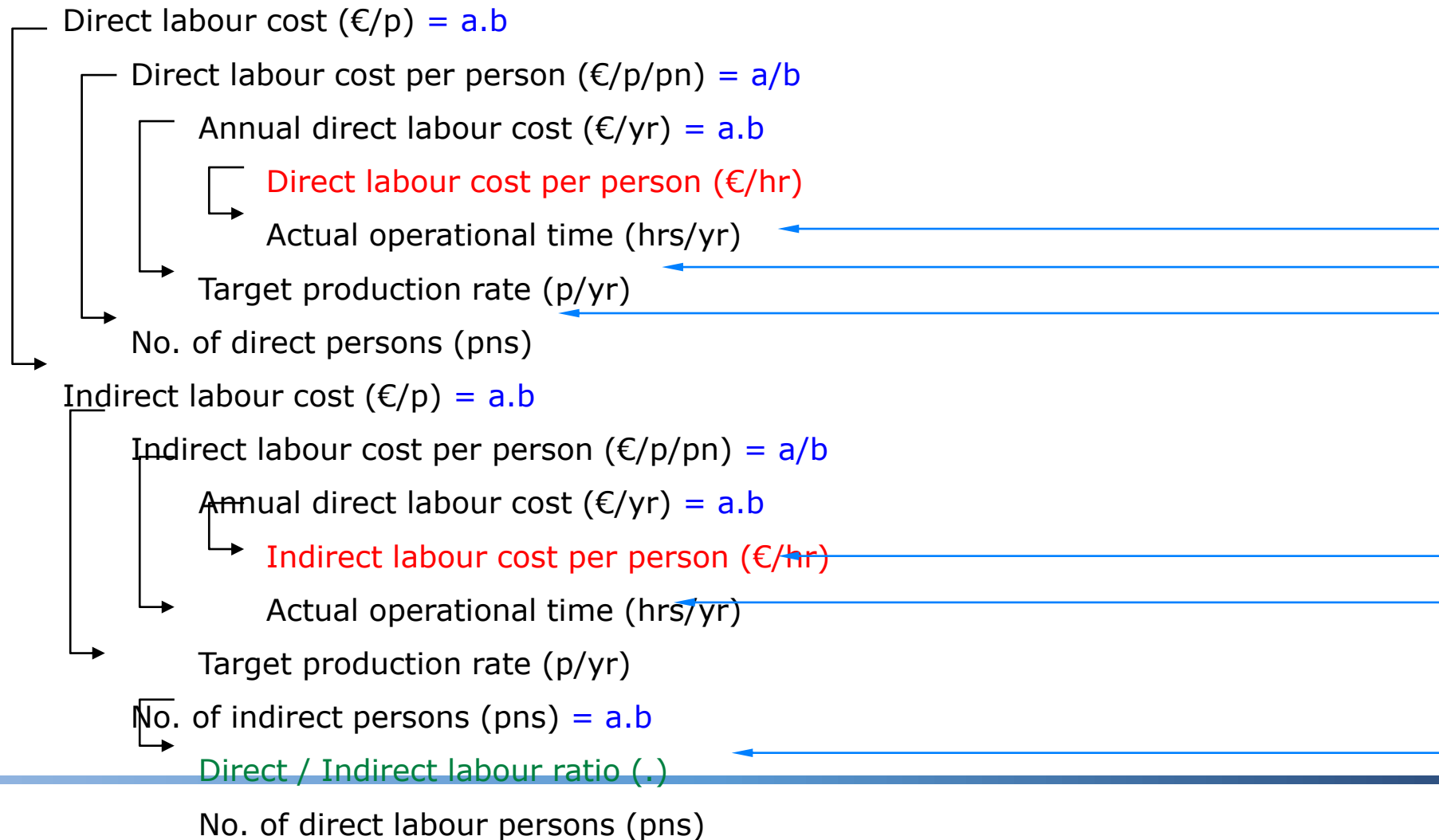
$$\text{Machine power (kW)}$$

$$\text{Actual operational time (hrs/yr)}$$

$$\text{Target production rate (p/yr)}$$

Labour Cost Calculation

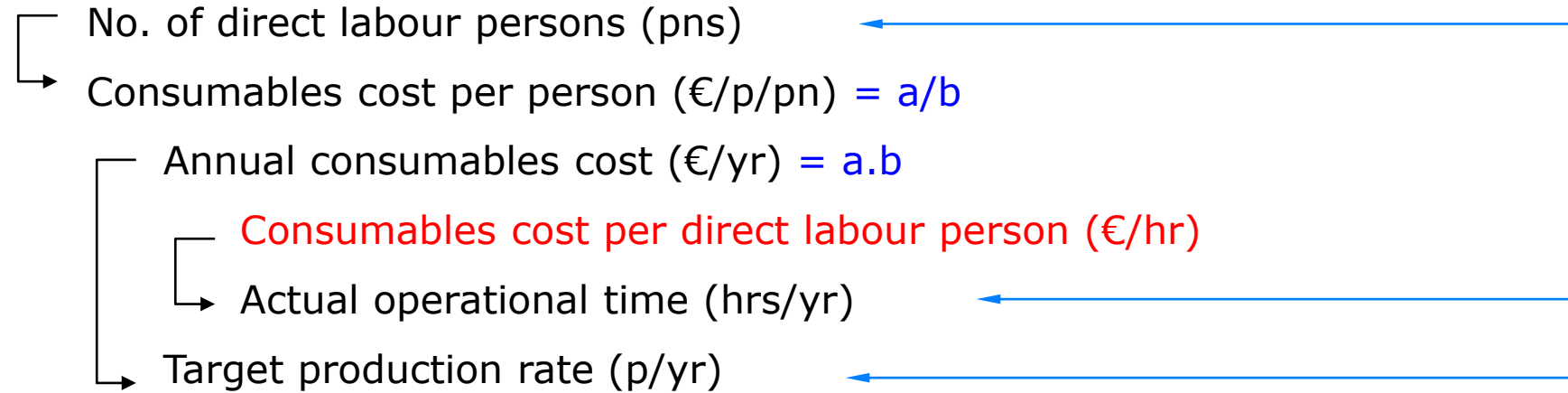
- Labour cost (€/p) = $a+b$



Consumable Cost Calculation

- Consumable Cost

Consumables cost (€/p) = $a.b$



Annex 2: Historical data

Use with caution

Raw material costs: polymers

Polymer	€/kg	Supplier
Polypropylene (PP)	0.7	Montell
Polyethylene terephthalate (PET)	3.5	DuPont
Polyamide 12 (PA12)	8.4	EMS
Polyphenylene sulfide (PPS), (40-50 for film)	5-13	GE plastics
Polyetherimide (PEI)	17.6-22	GE plastics
Polyetheretherketone (PEEK)	68-77	Victrex
Unsaturated polyester	1.1-6.6	Ashland
Vinylester	3.3-4.4	Dow Chemical
Epoxy	2.2-55	Shell
Phenolics	1.65-5	Budd
Cyanate Esters	62	Bryte
Polyurethanes	5.5-14	Dow
Bismaleimides (BMI)	78	ABR organics

Raw material costs: un-impregnated textiles

Reinforcement	€/kg	Supplier
Glass	1.6	Vetrotex/Owens Corning
Carbon (80k-12k)	15-17.5	Fortafil/Tenax
Kevlar	23	DuPont
GF weave (1200 tex, 300g/m ²)	10	SP systems (low volume)
aramid weave (300g/m ²)	47	
CF weave (HS 12k CF, 300g/m ²)	78	
CF weave (IM 12k CF, 300g/m ²)	124	
GF NCF (100" wide, 1000g/m ²)	2.9-3.2	Saertex (medium to high volume)
commercial 12k CF NCF (100" wide, 1000g/m ²)	17-31	
aerospace 12k CF NCF (100" wide, 1000g/m ²)	44-47	
GF biaxial braid	11-15	A&P Technology
CF biaxial braid, light areal weight	90	
CF biaxial braid (high volumes, automotive carbon at €15/kg)	31	

Semi-finished products: thermoplastic textile composites

Material form	€/kg	Supplier
CF/PA12 partially preconsolidated sheet	50 - 54	Schappe Techniques
GF/PA12 sheet	12.5 - 16.5	Bond Laminates (dependant on CF grade, thickness and volume)
CF/PA6.6 sheet	30 - 50	
GF/PA6 sheet	7.2 - 10.4	
GF/PET sheet	4.6 - 7.1	Vetrotex (Twintex)
GF/PP dry fabric	3 - 4.5	
GF/PP sheet	3.5 - 5.5	
GF/PP, GMT sheet	3.0	Quadrant Plastic Composites
GF/PP sheet, GMTex	3.5 - 5.5	
GF/PP UD tape	4.9 - 6.4	Plytron
PEI/GF sheet	60	CETEX consolidated sheet (Ten Cate)
PEI/CF sheet	140	
PPS/GF sheet	60	
PPS/CF sheet	140	
CF/PP tape	16 - 29	GuritSuprem/ Flex composites
CF/PA6 tape	19 - 30	
CF/PA12 tape	22 - 31	
CF/PET tape	19	

Semi-finished products: thermoset textile composites

Material form			€/kg	Supplier
GF/Epoxy	woven prepreg	720g/m ² , 1m x 50m roll	26	SP systems, also: Hexel, Cytec
CF/Epoxy	UD prepreg	476g/m ² (CG carbon), 1m x 150m roll	29	
CF/Epoxy	UD prepreg	476g/m ² (HS carbon), 1m x 150m roll	34	
CF/Epoxy	UD prepreg	476g/m ² (HE carbon), 1m x 150m roll	37	
CF/Epoxy	UD prepreg	476g/m ² (IM carbon), 1m x 150m roll	72	
CF/Epoxy	UD prepreg	461g/m ² (HM carbon), 1m x 150m roll	91	
Aramid/epoxy	UD prepreg	545g/m ² , 1m x 150m roll	50	
CF/Epoxy	woven prepreg	(HS carbon), 517g/m ² , 1m x 50m roll	59	
Closed cell	SAN core	5mm, 50kg/m ³	10/m ²	ATC Chemicals (SP systems)
Closed cell	SAN core	30mm, 50kg/m ³	41/m ²	

Typical composite processing equipment costs (1)

Equipment	Power [kW]	Area [m ²]	Cost [€]	Supplier/ contact	Cost / minute	Cost / part
Braiding machine	40	25m ²	€250-350k for 172 carriers (€1,5k/carrier)	Eurocarbon or A&P	€0.4	€0.67/m (600mm/min)
Warp knitting machine (100")	25	500m ²	€1,500k	LIBA or Karl Mayer	€2.0	€6.7/m 0.3m/min
Hydraulic press	150	90m ²	1500 tonne = €900k (€50k-€60k/1000kN)	Dieffenbacher	€1.1	€1.1 (60s)
Injection moulding machine	480	90m ²	4000 tonne = €3,200k (€80k / 1000kN)	Battenfeld	€3.8	€5.7 (90s)
IR oven	80	20m ²	€150k (medium GMT type)	Tetas	€0.25	€0.25 (60s)
LFT machine	500	40m ²	€400k (e.g. 200k parts/yr)	Dieffenbacher	€0.92	€0.92 (60s)
Transfer robot	15	25m ²	€60k + fixture costs	ABB	€0.1	€0.1 (60s)
Reactive injection machine	20	10m ²	€400k (200 tonnes/year)	ATP	€0.43	€6.5 (15min)

Utilisation based, 3 shift pattern, 7 year production,
 Including: plant area, energy costs, capital costs
 Excluding: direct operators, in-direct overheads

Typical composite processing equipment costs (2)

Equipment	Power [kW]	Area [m²]	Cost [€]	Supplier/ contact	Cost / minute	Cost / part
Preforming press	315kW	110m²	€413k (floor pan)	Cannon	€0.83	
SRIM injection system	20kW	40m²	€400k (4-8 litre lance, €200k for simpler system)	Cannon	€0.46	€2.3 (5min)
RTM press	100kW	70m²	€680k (floor pan)	Cannon	€0.85	€12.8 (15min)
Oven	150kW	50m²	€68k	many	€0.26	€15.6 (1hour)
Buffer	0	25m²	€34k	custom	€0.06	€0.9 (15min)
RTM injection unit	20kW	15m²	€170k (for floor pan; but production machines at €40k)	Dopag, Aplicator	€0.21	€3.25 (15min)
Finishing machine	5kW	100m²	€204k (floor pan)	ABB, Staubli	€0.32	€19.2 (60min)
Autoclave, small	20kW	10m²	€230k	Aeroform	€0.26	€62.4 (4 hours)
Autoclave, medium	e.g. 100kW	50m²	€775k		€0.93	€223 (4 hours)
Autoclave, large	e.g. 800kW	150m²	€1,400k		€2.32	€557 (4 hours)
Autoclave, v.large (11m x 36m)	10MW	396m²	€31,000k		€41	€9840 (4 hours)
Automated tape laying (ATL)	80kW	150m²	€5,000k (Airbus data)	Ingersol, Cincinnati	€5.3	€318 (1hour)
Automated fibre placement (AFP)	80kW	150m²	€5,000k (Airbus data)		€5.3	€318 (1hour)

Utilisation based, 3 shift pattern, 7 year production, Including: plant area, energy costs, capital costs, Excluding: direct operators, in-direct overheads

Annex 3: Financial definitions for engineers

Financial definitions for engineers

Price	the amount of money given or set as consideration for the sale of a specified thing
Factory cost	the expenses that are incurred by the business to manufacture goods that are intended to be sold to the customers in the normal course of business and includes all cost linked to production like the direct material cost , direct labor cost and other manufacturing overheads.
Fixed	A cost that does not change with an increase or decrease in the amount of goods or services produced or sold. Expenses that have to be paid by a company, independent of any specific business activities
Variable	is a corporate expense that changes in proportion to production output . Variable costs increase or decrease depending on a company's production volume; they rise as production increases and fall as production decreases. Examples: costs of raw materials and packaging.
CAPEX	Capital expenditures (CapEx) are funds used by a company to acquire, upgrade, and maintain physical assets such as property, plants, buildings, technology, or equipment. CapEx is often used to undertake new projects or investments by a company.
CAWC	cost associated with capital (installation), sometimes $\text{CAPEX} + \text{CAWC} = 1.5 \text{ to } 2.5 \times \text{CAPEX}$)
OPEX	operating expenditure , ongoing expenses inherent to operation of the asset. Includes items like electricity , salaries, R&D, travel, SG&A (selling, general and administrative expense)

Financial definitions for engineers

NPV	Net present value: Value in today's money of a future investment: difference between the present value of cash inflows and the present value of cash outflows over a period of time. Used in <u>capital budgeting</u> and investment planning to analyze the profitability of a projected investment or project. Calculation of NPV includes: CAPEX, materials, market growth, pricing, margin vs. time, the <u>time value</u> of money, the <u>discount rate</u> over project duration.
ROI	Return on investment, evaluate investment efficiency or compare a number of different investments. Measures the return on a particular investment, relative to the investment's cost. The benefit (or return) of an investment is divided by the cost of the investment, expressed as a percentage or a ratio.
CAGR	Compound annual growth rate (CAGR) is the <u>rate of return</u> (or market growth) that would be required for an investment to grow from its beginning balance to its ending balance
Gross margin	Gross margin is a company's net sales revenue minus its cost of goods sold (COGS). The sales revenue a company retains after incurring the direct costs associated with producing the goods it sells, and the services it provides.
Corporation tax	A levy placed on a firm's <u>profit</u> by the government. Calculated by deducting expenses, including the <u>(COGS)</u> and depreciation from <u>revenues</u> .
Time to first revenue	When your project receives payment for goods produced, 1st +ve cash flow



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