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Economic opportunities: Side-stream composite from sludge - Case mill: Holmen Paper

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Workshop on 6th of October 2015, Valencia, Spain

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1. Reference case – Holmen Paper mill

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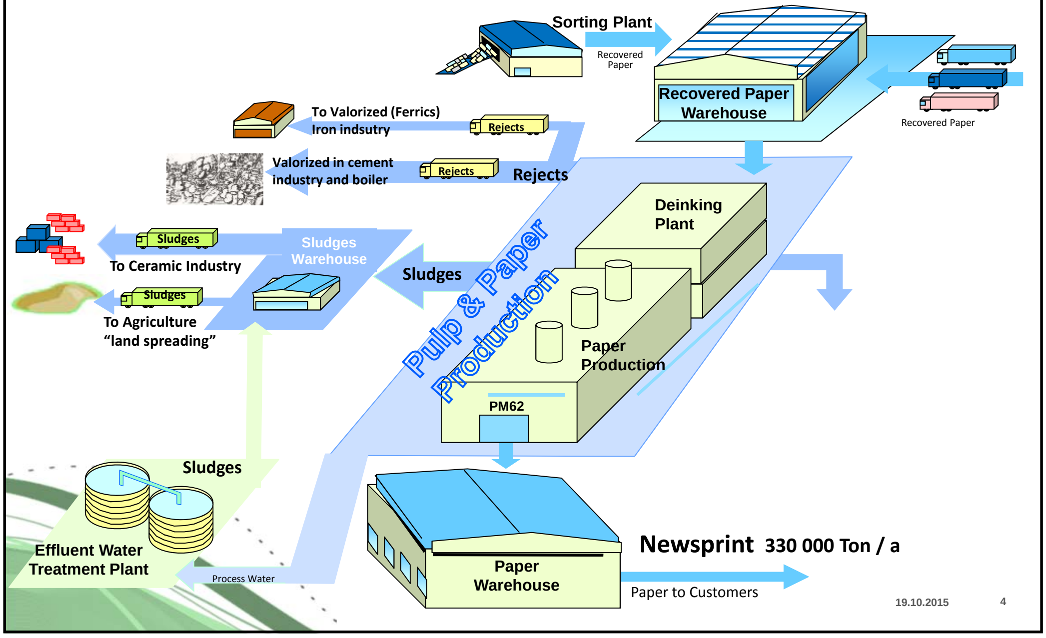
Holmen paper, Madrid –Side streams



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Holmen Paper, Madrid –Some main data 2013

(From Holmen Paper public website –true case values may differ slightly)

▪ Recycled fibre:	412	k-ton
▪ Chemicals:	11.7	k-ton
▪ Filler, pigment:	6.0	k-ton
▪ Electricity		
▪ Production:	181	GWh
▪ Purchased:	92	GWh
▪ Thermal energy		
▪ Purchased, natural gas and oil:	563	GWh
▪ Water consumption:	2.2	million m^3
▪ Production rate total:	313	k-ton
▪ Process waste water:	1.9	million m^3
▪ By products:	5	k-ton

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Reference case assumptions

Processes included:

- DIP and sorting plant
- Paper machine

Other assumptions:

- Sludge utilization / disposal included (at mill gate)
- Heat and electricity consumed are purchased
  - Power plant is not included in the system boundaries in economic analysis

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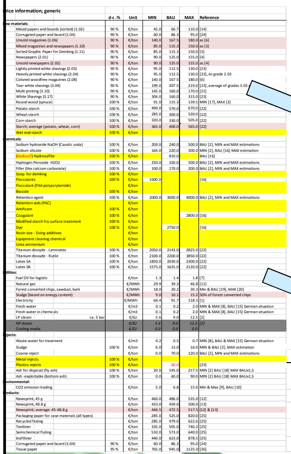
Assumptions - Generic prices (Example)

- 69 lines for raw materials, utilities and chemicals
- Mill specific prices may differ



Price information; generic

	d-c -%	Unit	MIN	BAU	MAX	Reference
Raw materials:						
Mixed papers and boards (sorted) (1.02)	90 %	€/ton	45.0	66.7	110.0	[14]
Corrugated paper and board (1.04)	90 %	€/ton	60.0	86.3	95.0	[24]
Unsold magazines (1.06)	90 %	€/ton	140.0	167.5	180.0	as [6]
Mixed magazines and newspapers (1.10)	90 %	€/ton	85.0	115.3	150.0	as [3]
Sorted Graphic Paper for Deinking (1.11)	90 %	€/ton	85.0	115.3	150.0	[3]
Newspapers (2.01)	90 %	€/ton	90.0	125.0	155.0	[4]
Unsold newspapers (2.02)	90 %	€/ton	90.0	125.0	155.0	as [4]

References

[1]	2014. Eurostat. Electricity prices charged to final consumers. Average national price without taxes applicable for the first semester of each year for medium size industrial consumers (annual consumption between 500 and 2000 MWh)
[2]	Industry information (Europe)
[3]	2014. Information from CEPI. Sorted Graphic Paper for Deinking (1.11). Prices based on ex works or free delivered. Germany, France and Italy. Assumed as air dry.
[4]	2014. Information from CEPI. Newspapers (2.01). Prices based on ex works or free delivered. Germany, Italy and Spain. Assumed as air dry.
[5]	2014. Information from CEPI. White Woodfree Shavings (3.18.00). Prices based on ex works or free delivered. France and Spain. Assumed as air dry.

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Results – Balance deviations

- Real mill data is applied (provided by the mill)
  - Average data
  - Small errors in resulting dry solids in and out balances
  - Normal situation, depends how the data is handled and gathered, measurement accuracies, process fluctuations etc.
  - Not straightforward task to detect the source or reason
    →Mill data is not fixed
- Due to real data, error in total material balance (as dry) 3.4% to 3.7 %
  - Error in DIP balance 2.9 %
  - Error in PM balance 1.1 %

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Results – reference case sensitivity

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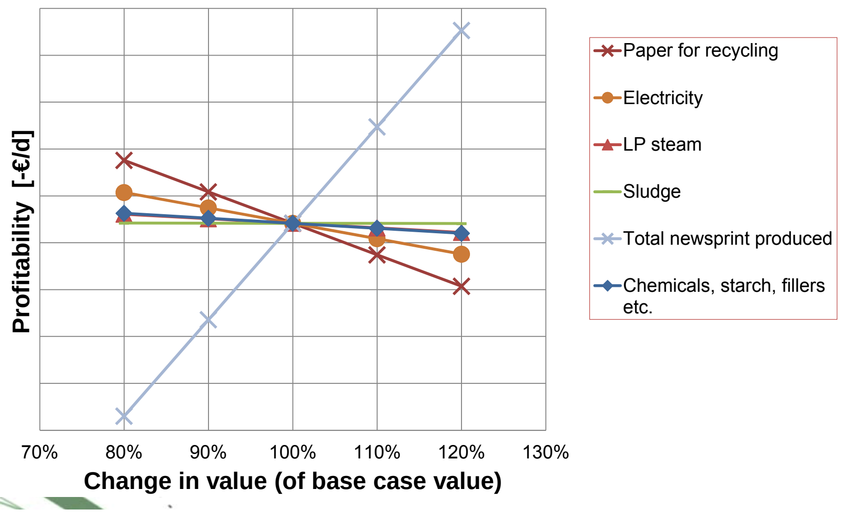
Sensitivity of profitability on main cost factors



- Fixed operation costs estimated as percentage values from variable operation costs
- Investment is not included

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2. Composite production process – stand alone study

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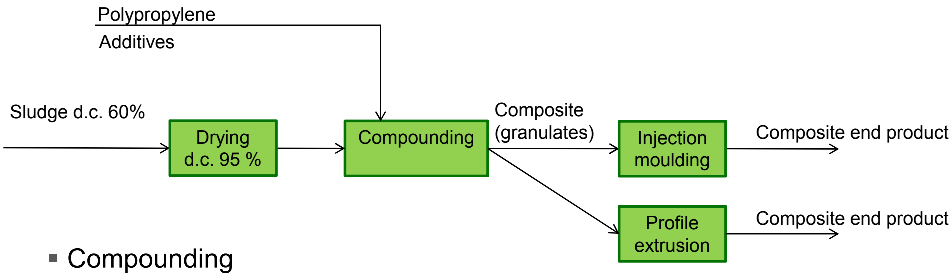
Process description - Composite production process



- Compounding
  - An extrusion process
  - Polymer is melted and fibers (or sludge), fillers, additives etc. are mixed to the polymer. The material is then cooled and granulated
- Composite granulates
  - Intermediate product
  - Further processed with injection molding, extrusion or compression molding depending on end product

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Injection moulding

- The most common modern method of manufacturing parts
  - Ideal for producing high volumes of the same object
- Basic extrusion process,
  - followed by process of moulding
    - Involves heating and cooling of a large mass of metal mould
    - plus the energy needed to close the mould
- Often an additional downstream operation, including complex assembly → additional energy consumption [1]
- Possible end products of injection moulding are numerous, for example:
  - automotive parts and components, packaging, bottle caps, one-piece chairs and small tables, storage containers, etc..
  - Example of the VTT piloting / lab sample pieces on the right

1. REDUCED ENERGY CONSUMPTION IN PLASTICS ENGINEERING, 2005 EUROPEAN BENCHMARKING SURVEY OF ENERGY, available at: http://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/recipe_benchmarking_report.pdf

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Profile extrusion

- Basic profile extrusion process
- Extrusion of a shaped product - variety of configurations
- Can include solid forms as well as hollow forms [2]
- Products ranging from tubing to window frames to vehicle door seals [2]

1. REDUCED ENERGY CONSUMPTION IN PLASTICS ENGINEERING, 2005 EUROPEAN BENCHMARKING SURVEY OF ENERGY, available at: http://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/recipe_benchmarking_report.pdf

2. http://www.ptonline.com/knowledgecenter/Profile-Extrusion/profile-extrusion-fundamentals/Typical-Extrusion-Profiles

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Assumptions - Energy and utility consumption

- Specific energy consumption values are site wide values
- Energy consumed in compounding, injection molding and profile extrusion is assumed to be electricity
  - Specific energy consumption of compounding
    - 630 kWh/t [1]
  - Specific energy consumption of injection moulding
    - 3 100 kWh/t [1]
  - Specific energy consumption of profile extrusion
    - 1 500 kWh/t [1]
- Drying
  - 70% thermal efficiency, direct heating with natural gas
    - Energy consumption estimation in drying: 0.90 kWh/kg evaporated water
- Possible need for cooling water in process.
  - Only minor impact on results, not taken into account in this evaluation

1. REDUCED ENERGY CONSUMPTION IN PLASTICS ENGINEERING, 2005 EUROPEAN BENCHMARKING SURVEY OF ENERGY, available at: http://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/recipe_benchmarking_report.pdf

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Assumptions - Composite recipe & capacity

Recipe for side-stream-composite			
		Min	Max
Sludge		30 %	50 %
Polypropylene		50 %	70 %
Additive: processing aid			

- Capacity
  - Based on available sludge amount
  - Composite production ~ 84 000 ton / year
- Operating 24/7, utility degree 80%
- Material losses in process 1%

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Assumptions – Prices - Composite production process

			Min	Max	Reference
Chemical (process agent)	€/ton	4 000			Estimate without knowing the exact additive
Polypropylene	€/ton	1 650	1 500	1 800	Estimation
Composite, general	€/ton	2 250	1 500	3 000	Rough estimation

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Assumptions - Fixed costs

- Investment costs: order of magnitude estimate based on step counting methods [3]
- Capital charge: 14 years, 5 %
- Labor costs, 21 persons, 70 000 €/a
  - 5 shift, 3 to 5 persons per shift
- Overheads, 50% of labor cost
- Maintenance 3% of investment cost
- Other fixed 1.5% of investment cost

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Evaluated cases - Composite production process

- Injection moulding
- Profile extrusion

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Results – material and energy balance

	Per ton of composite produced	Dry content	Case Injection moulding	Case Profile extrusion
Sludge	kg/t	60 %	640	640
Polypropylene	kg/t	100 %	586	586
Additive: processing aid	kg/t	100 %	20	20
Composite	kg/t	98 %	1000	1000
Losses	kg/t	98 %	10	10
Evaporated water	kg/t		236	236
Electricity	kWh/t		3730	2130
Natural gas	kWh/t		211	211

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Results - Investment costs estimate of side-stream-composite plant

- Based on step counting methods, average values used:
  - Bridgewater [3]
  - Zevnic & Buchanan [3]

	Injection moulding, M€	Profile extrusion, M€
Bridgewater	33	25
Zevnik & Buchanan	121	91
Average	**77**	**58**

BRIDGWATER'S METHOD

For processes with predominantly liquid and/or solid handling phases, the correlation equation is

$$C = 1930\ N \left(\frac{Q}{s}\right)^{0.675} \qquad (2\text{-}12)$$

where

C = capital cost £$_{2000}$, battery limits
N = number of functional units
Q = plant capacity, tonnes/year, above 60,000
s = reactor "conversion" = $\dfrac{\text{mass of desired product}}{\text{mass of reactor input}}$.

For plant capacities below 60,000 tonnes/year

$$C = 169{,}560\ N \left(\frac{Q}{s}\right)^{0.30} \qquad (2\text{-}13)$$

Zevnic & Buchanan's method

For plant capacity above 10 million pounds per year (4536 tonnes/year) and temperature and pressure above ambient:

$$C = 7470\ N\ Q^{0.6}\ 10^{\left[(0.1 \log P_{max}) + \left(1.8\times10^{-4}(T_{max}-300)\right) + (F_m)\right]} \qquad (2\text{-}8)$$

where

C = estimated capital cost, million pound, in 2000
Q = plant capacity, tonnes per year
N = number of functional units
P_{max} = maximum process pressure, atm
T_{max} = maximum process temperature, K
F_m = materials of construction factor
0 for mild steel and wood
0.1 for aluminium, brass, lower grade stainless steel
0.2 for monel, nickel, higher grade stainless steel
0.3 for hastelloy
0.4 for precious metals.

3. Holland, F.A. & Wilkinson, J.K., Perry's Chemical Engineers' Handbook, section 9 (Process Economics), McGraw-Hill, 1999

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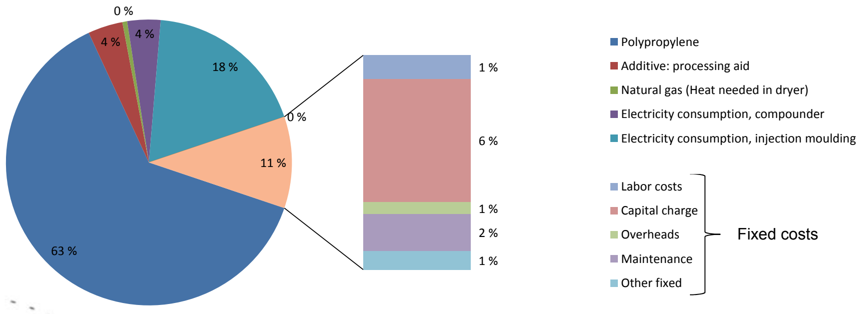
Results - Costs for injection molding

Manufacturing costs, 129 M€/a, Injection molding



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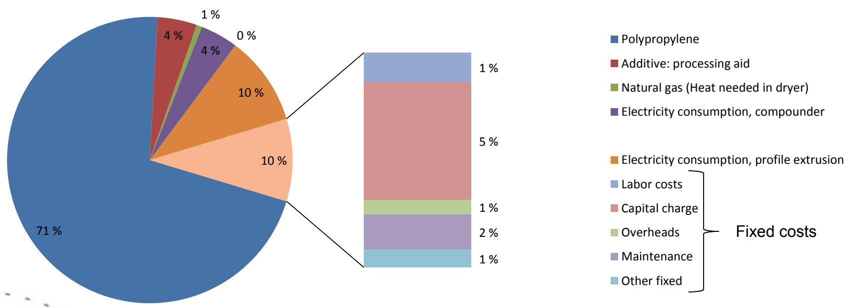
Results – Costs for profile extrusion

Manufacturing costs, 114 M€/a, Profile extrusion



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Results – Costs, revenues and profits

	Profile extrusion M€/a	Injection moulding M€/a
Variable costs	103.5	115.8
Fixed costs	10. 6	13.4
Revenues	189.2	189.2
Profit	75.1	60.0

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3. Composite production integrated with Holmen Paper mill

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Composite cases – Changes and assumptions

Case 1:
- Reference case process + composite production with injection moulding

Case 2:
- Reference case process + composite production with profile extrusion

Changes:
- New composite plant (Part 2 on slides)
- Changes in sludge utilization
- No changes in DIP or PM process or existing product qualities
- Power plant: As independent business unit – no effects due to the case
  - Electricity is purchased from the grid

Assumptions:
- Investments are not considered
- Other fixed operation cost estimations are included
  - For composite production process stand alone (part 2.) values used

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Results - Economic indicators

Variable operating costs

$$Variable\ costs = Cv = \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Pm_{ji}\,m_{ji} + P_{st}\,E_{ji,st} + P_{el}\,E_{ji,el} + P_{w}\,w_{ji} + P_{ww}\,ww_{ji} + Pwa_{ji}\,wa_{ji} + Pe_{ji}\,e_{ji}\right)\right)$$

P	= Price
mji	= Raw material / fuel
E	= Energy
w	= Water
ww	= Waste water
wa	= Solid waste
e	= *Air emissions*
Subscripts:	
el	= electricity
st	= steam

$$Cost\ indicator = I_{Cv} = \frac{Cv}{Reference\ Cv} - 1$$

Injection moulding:	**Variable cost indicator**	I_{cv} =	157 %	+ value = additional cost, negative effect - value = decreased cost, positive effect
Profile extrusion:	**Variable cost indicator**	I_{cv} =	140 %	+ value = additional cost, negative effect - value = decreased cost, positive effect

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Results - Economic indicators

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Revenue from products and by-products

$$\text{Revenue} = Rp = \sum_{j=1}^{n}\left(\sum_{i=1}^{k}\left(Pp_{ji}\, p_{ji} + Psp_{ji}\, sp_{ji}\right)\right)$$

p_{ji}	= Products
sp_{ji}	= Side products
Pp_{ji}	= Price of products
Psp_{ji}	= Price of side products

$$\text{Revenue } indicator = I_R = \frac{Rp}{Reference\ Rp} - 1$$

Injection moulding:	**Revenue indicator**	I_p =	157 %	+ value = additional revenue, positive effect - value = decreased revenue, negative effect
Profile extrusion:	**Revenue indicator**	I_p =	157 %	+ value = additional revenue, positive effect - value = decreased revenue, negative effect

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Results - Economic indicators

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Profitability function
(product revenues – variable costs)

$$Profitability\ function = V = Rp - Cv$$

Rp	= Revenues from products and side products
Cv	= Variable costs

$$Profitabiliy\ indicator = I_V = \frac{V}{Reference\ V} - 1$$

Injection moulding:	**Profitability indicator** *)	I_V =	157 %	+ value = increased profitability, positive effect - value = decreased profitability, negative effect
Profile extrusion:	**Profitability indicator** *)	I_V =	183 %	+ value = increased profitability, positive effect - value = decreased profitability, negative effect

*) Fixed costs not included. Can be applied only for positive values profitability values !

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Results - Economic indicators

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Savings and revenue changes

$$\text{Savings function} = SAV_{case} = V_{ext,case} - V_{ext,Ref} = (Rp_{Case} - Rp_{Ref}) - (Cv_{case} - Cv_{Ref}) - (Cfo_{case} - Cfo_{Ref})$$

V_{ext}	= *Profitability accounting also fixed operation costs*
Rp	= *Revenues from products and side products*
Cv	= *Variable costs*
Cfo	= *Fixed operation costs (labour, maintenance materials, overheads)*
Subscripts:	
case	= *Reffibre (test) case*
Ref	= *Reference*

$$\text{Savings indicator} = I_{SAV} = \frac{SAV_{case}}{Rp_{Ref}}$$

- Savings are considered at annual level to take into account also utilization rate, also fixed costs are partly considered (but not investment)

Injection moulding:	**Achievable savings** **)	I_{SAV} = 57.3 %	+ value =savings exist, positive effect - value = no savings, increased costs and/or decreased revenue, negative effect
Profile extrusion:	**Achievable savings** **)	I_{SAV} = 68.2 %	+ value =savings exist, positive effect - value = no savings, increased costs and/or decreased revenue, negative effect

***) At annual level, takes also into account fixed cost (but not investments) and utilization rate*

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Results - Economic indicators

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Affordable investment

$$\textit{Affordable investment} = TCI_{SAV_{case}} = SAV_{case}\, AF(n,r)$$

AF(n,r)	= Annuity factor for given cost of capital (*r*) and time period (*n*)
SAV	= Savings (annual)
Subscripts:	
SAV	= Savings (annual)
case	= Reffibre case

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Assumptions for cases sensitivity calculations

- Sludge amount in composite is varied
  - Composite production is kept constant
  - In case sludge amount (change in base case value) is over 100%, more sludge is needed than actually available
- Capacity
  - Number of labour is kept constant

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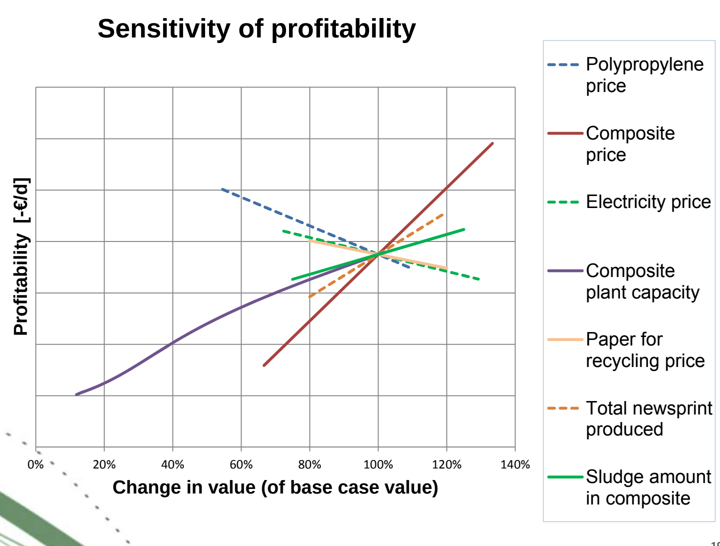
Results – Case 1 sensitivity

Reference process + composite production with injection moulding



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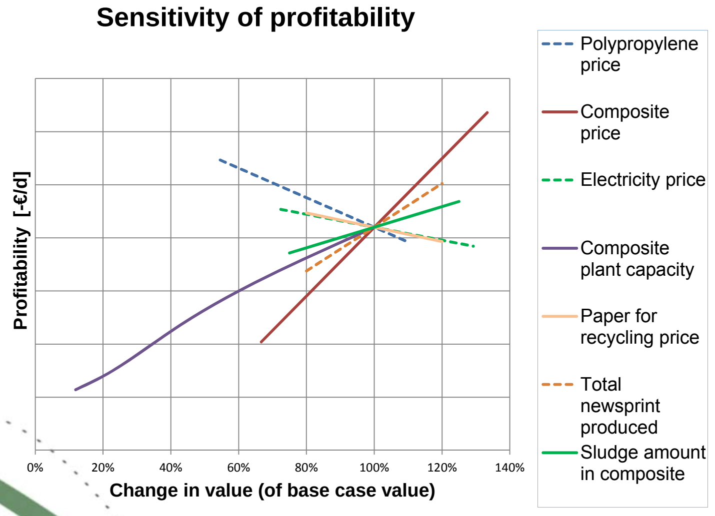
Results – Case 2 sensitivity

Reference case process + composite production with <u>profile extrusion</u>



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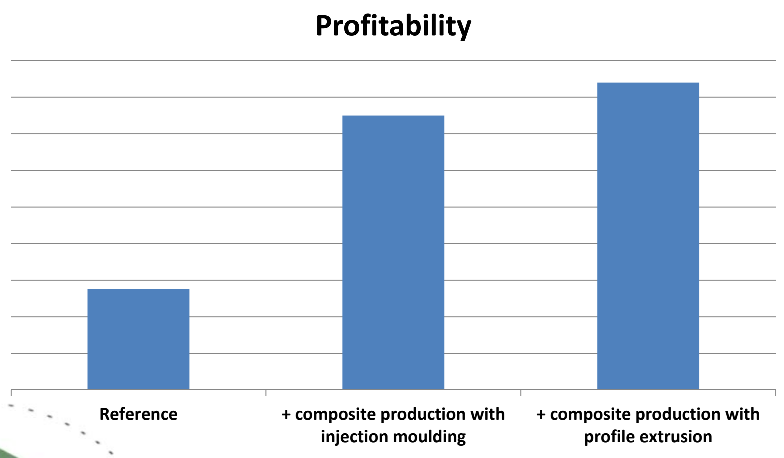
Results- Comparison side by side



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4. Conclusions

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- Side stream plastic composite utilizing sludge from the paper mill is promising
- Polypropylene is the key cost factor in composite manufacturing
- The costs of the process containing injection molding are higher than the costs in case of profile extrusion

Uncertainties:

- The variety of possible composite end products is huge
  → Only rough price estimate of composite
- Production capacity of composite plant based on sludge available is large
  → is there markets for this ?

Further work

- The end product and market to be specified and market size evaluated
- Selection of production capacity for the product and market in question
- Re-estimation of the economic concept calculations
- Players in the value chain to be specified:
  - Sludge provider → Granule producer → Final composite producer → Consumer (could be also industrial)

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Acknowledgement

The research leading to these results has received funding from the European Community's Seventh Framework Programme under grant agreement n° 604187.

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