Development of a framework integrating TEA and LCA: advances and challenges

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Outline

- Introduction
- Process description
  - Electrodeposition
  - Plasma vapour deposition
- Results and discussion
  - LCA
  - Costs
- Outlook
- Conclusion

Introduction

- Pulsatec project : show the potential of new coating technology
- Plasma vapour deposition w/ HiPIMS generator
- ULiège role : show the economic and environmental performance of the technology
- Life cycle assessment (LCA) and Techno-economic analysis (TEA)

Introduction

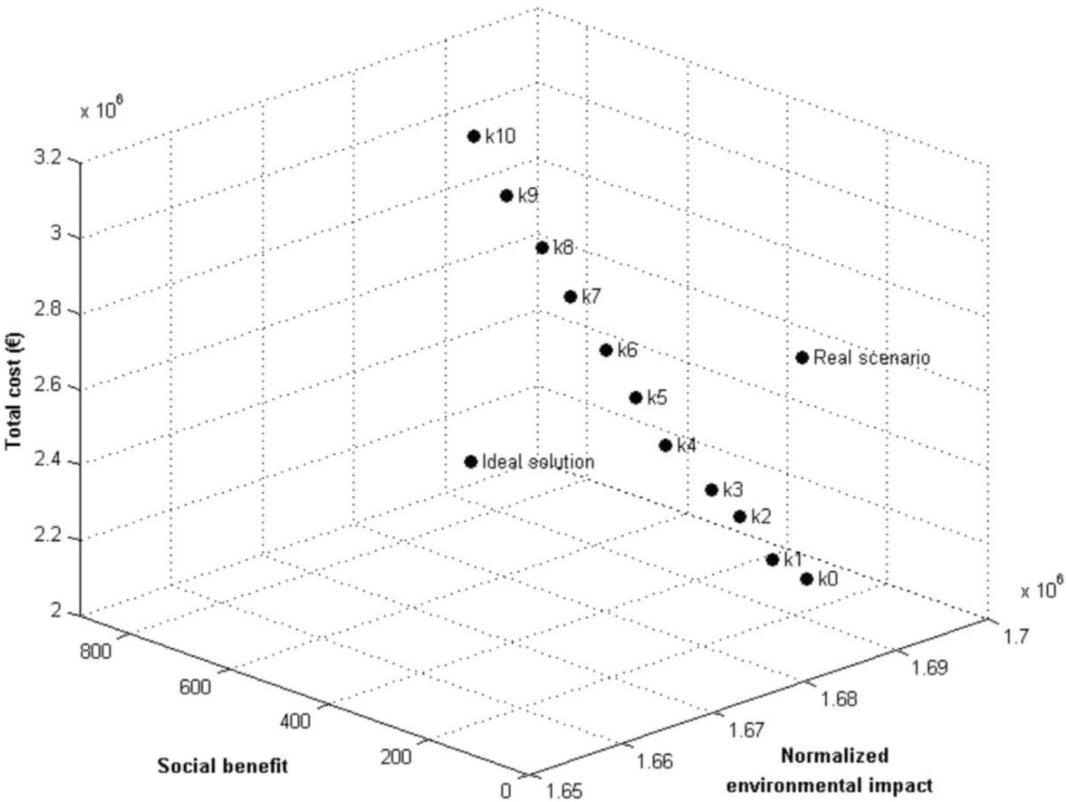
- Evaluation of cost and environmental impact of a chromium coating
  - Protective and frictionless coating
- PVD compared to electrodeposition

- Coating of a stainless steel cylinder

- Inventory of inputs and emissions

Introduction

- Integration of LCA and TEA in joint evaluations still a new field
- Environmental impacts and cost as weighed objectives
- Parameters influence
- Multi-objective analysis and optimization



Mota, B., Gomes, M. I., Carvalho, A., & Barbosa-Povoa, A. P. (2015). Towards supply chain sustainability: economic, environmental and social design and planning. *Journal of Cleaner Production*, *105*, 14–27. https://doi.org/10.1016/j.jclepro.2014.07.052

Other example : OSMOSE from EPFL

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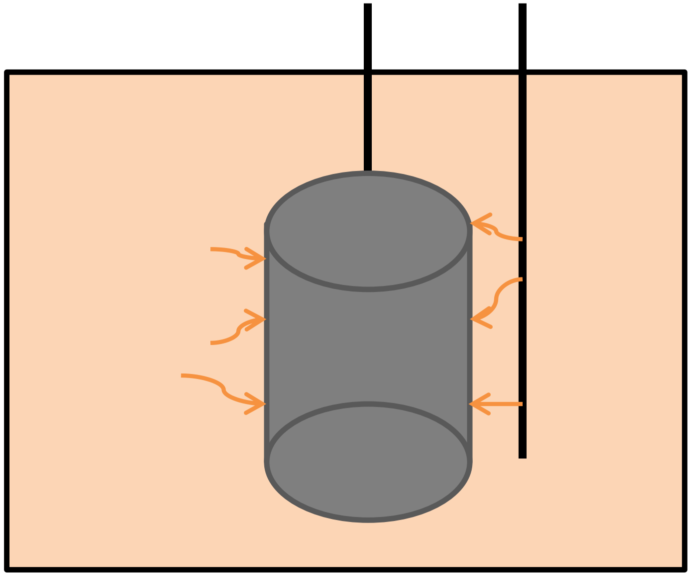
Process description : electrodeposition

- Most widespread technology
- Piece immersed in acid bath
- Voltage applied to reduce chromate ions to metallic chromium



Process description : electrodeposition

- Cheap and easiest to use
- Push by the EU to replace this technology
- Cr^{6+} highly toxic
- High use of solvents and liquid waste generation
- Safety and environmental risks

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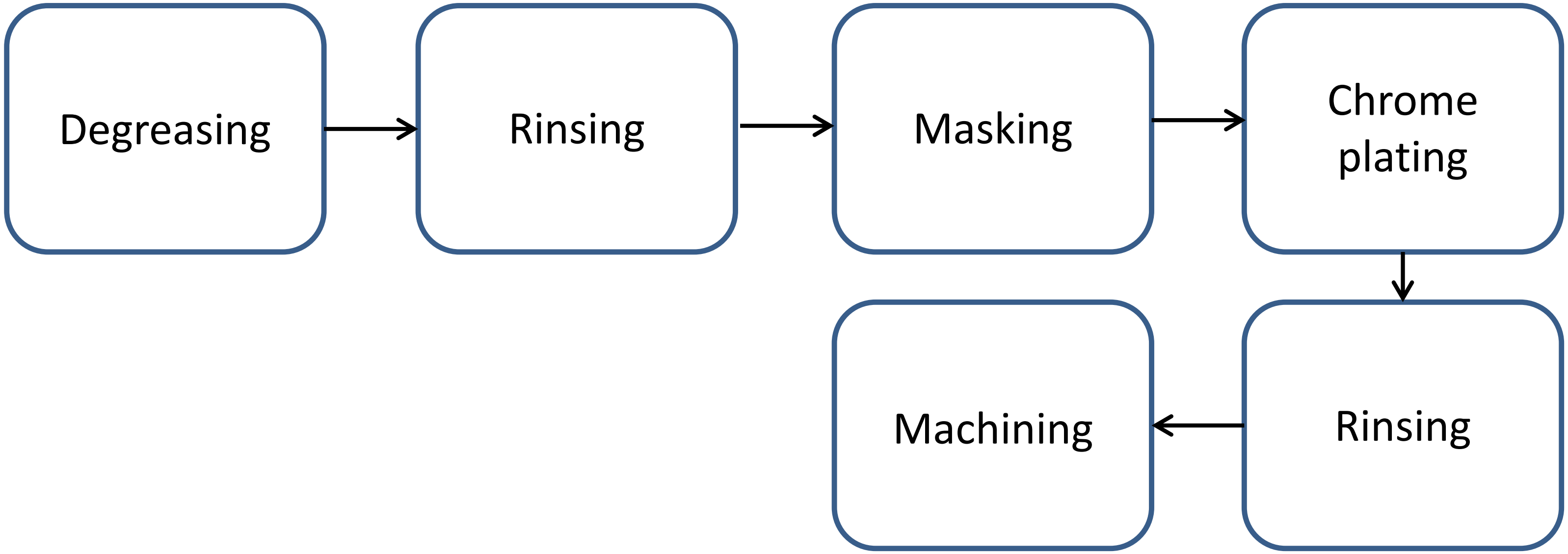
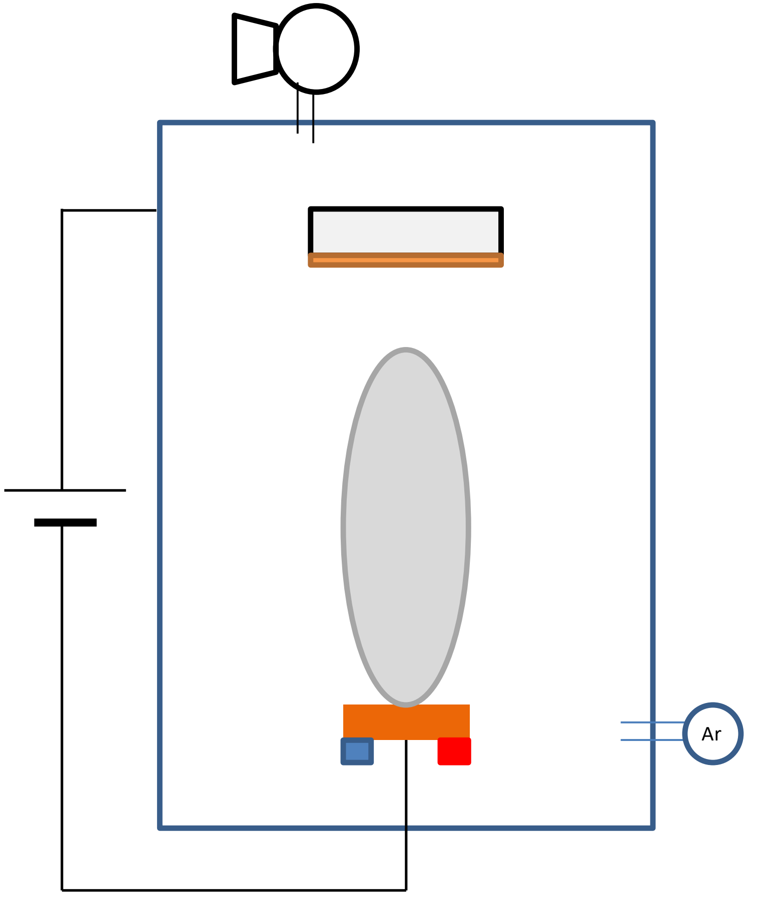
Process description : electrodeposition



Process description : PVD

- Piece placed in a vacuum chamber
- Voltage applied to a chromium target
- Plasma generation and target sputtering
- Vapour deposition



Process description : PVD

- Solvent-free process
- Virtually no emissions
- Higher power consumption (vacuum)
- Low deposition rate
  - 25µm/h for ED vs ~15µm for PVD

Advantages and disadvantages

-Almost no emission

-Solvent-free

-Ease of use

-Homogeneous coatings

-Ability to treat more complex surfaces

-Safe

-Easily installed

-Need for pumping equipment

-Pricier

-Lower deposition rates

-Higher investment and maintenance costs

-Hard to scale up

- Lower volume of production

-Cheap

-Easy

-Well tried process

-High deposition rates

-Easily scalable

-Lots of aqueous waste

-Low throwing power

-Cracking

-Need for a larger installation

-Unsafe

- High number of steps and piece preparation time

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LCA

- LCA : assess all emissions at every step of the production
- Functional unit : coating of a cylinder (d = 40cm, h =80cm, 20µm of chromium)
- Evaluation of the environmental impacts of these emissions

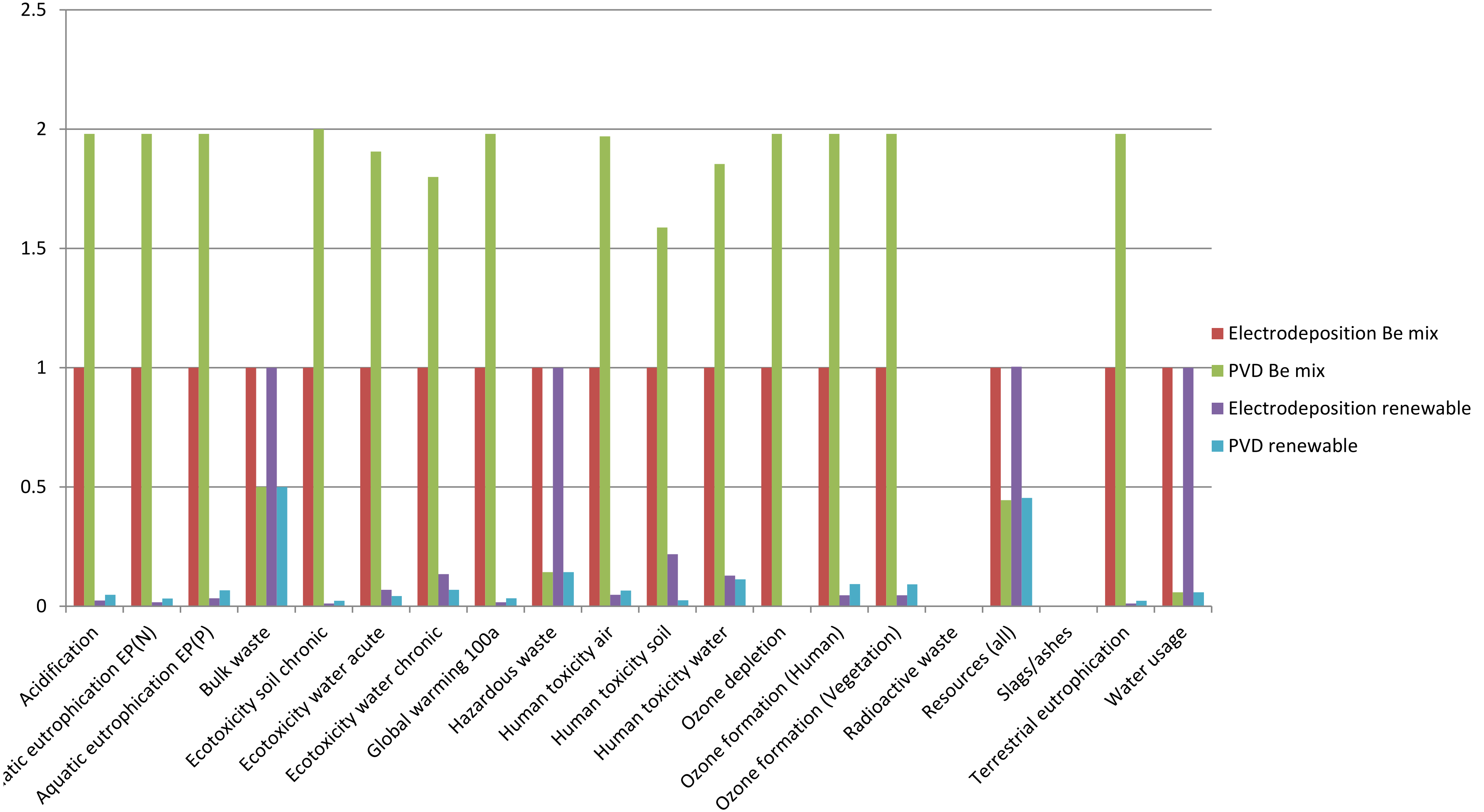
Processes parameters breakdown (ED)

- Water usage (bath, rinsing, evaporation) : **340l**
- Acids/bases (rinsing, degreasing) : 7l
- Total power usage (heating, venting, plating, …): 20 kWh
- Chromate usage : ~450g (~150g chromium)
- Deposition time : 48 min
- Chromium waste (to air, grindings, to water): a few gr

Processes parameters breakdown (PVD)

- Water usage (rinsing) : 20l
- Argon usage : 14000 sccm
- Total power usage (vacuum, plasma, electronics …): 40 kWh
- Chromium usage : ~150g chromium
- Deposition time : 70 min
- Chromium waste (chromium in chamber): a few gr

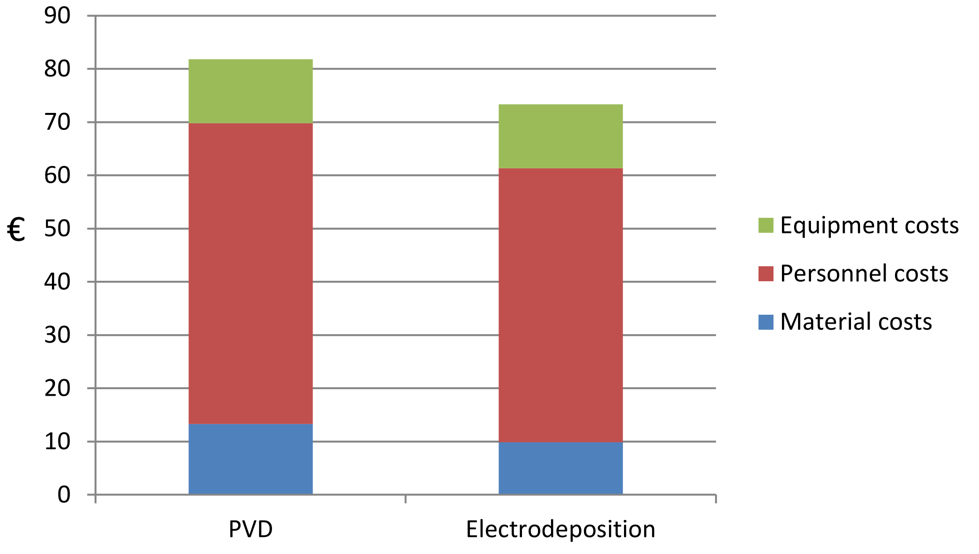
LCA Results


2.5
2
1.5
1
0.5
0
Acidification
atic eutrophication EP(N)
Aquatic eutrophication EP(P)
Bulk waste
Ecotoxicity soil chronic
Ecotoxicity water acute
Ecotoxicity water chronic
Global warming 100a
Hazardous waste
Human toxicity air
Human toxicity soil
Human toxicity water
Ozone depletion
Ozone formation (Human)
Ozone formation (Vegetation)
Radioactive waste
Resources (all)
Slags/ashes
Terrestrial eutrophication
Water usage
Electrodeposition Be mix
PVD Be mix
Electrodeposition renewable
PVD renewable

LCA Results

- Main impact factor : power generation
- Higher power consumption from PVD = Higher impact
- 100% renewable power make PVD a slightly better choice
- Need for the impact of waste treatment in ED

Cost breakdown



Costs ~10% higher for PVD!

Main factor : wages (in Belgium)

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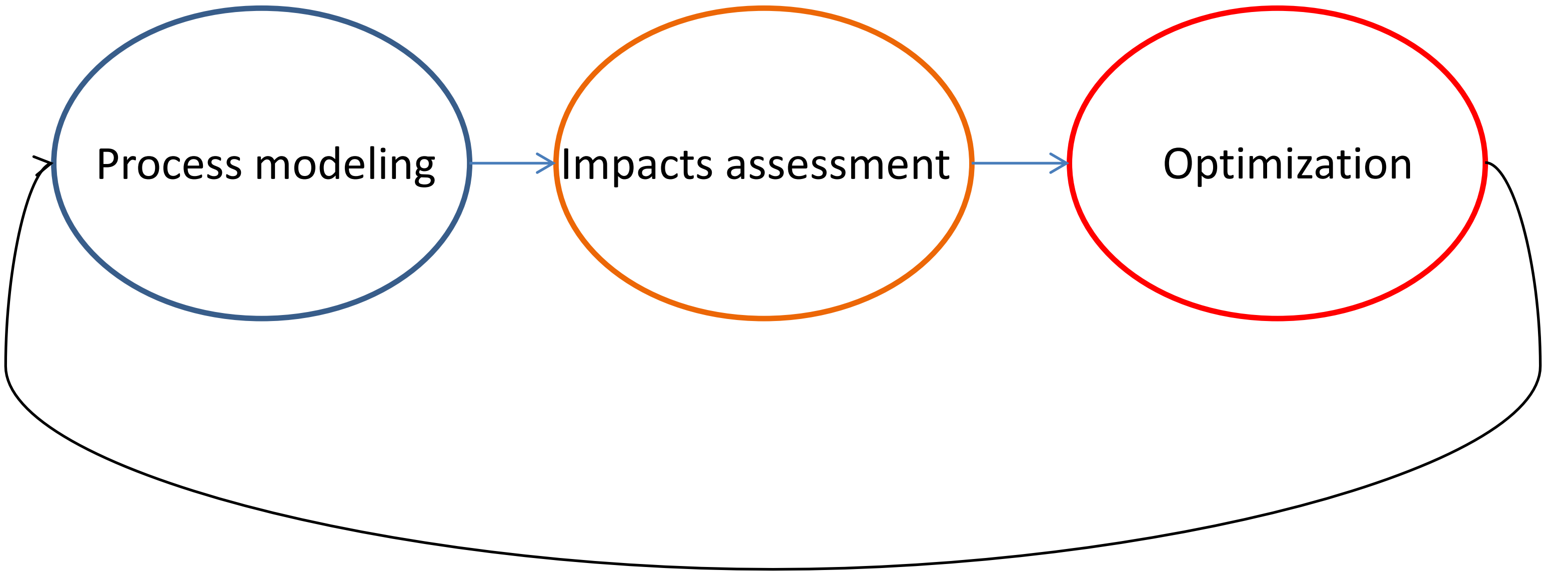
Outlook

- Current goal : extend LCA and economic analysis boundaries to include equipment impacts and investment as well as further waste streams processing

- Long term goal : develop a framework integrating LCA and TEA simultaneously as impact indicators of processes (suited for PVD)

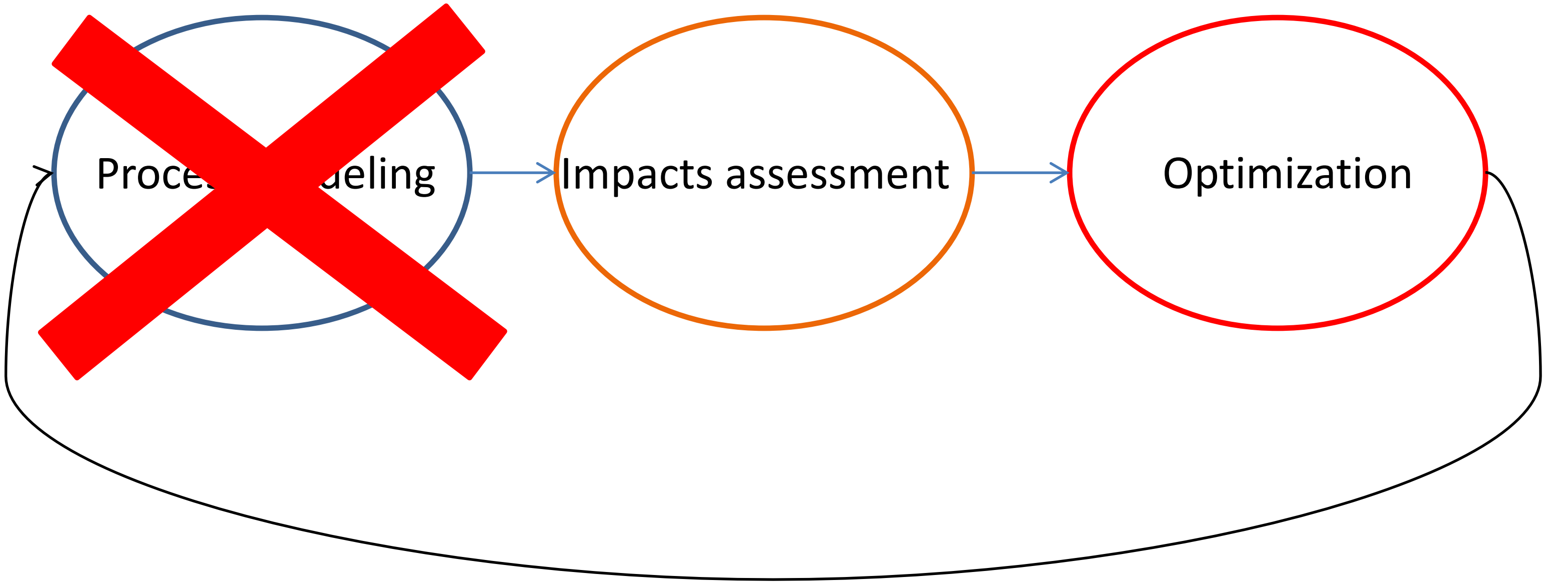
- Integrate HiPIMS technology

Framework structure



- Parameters (xi) ➔ Process flows (yi)
- yi ➔ Impacts (f(yi)) and cost (g(yi))
- Min(χ(f(y),g(y)))

Need for a PVD process modelling tool



No tool for process modeling of PVD exists at the moment !

Two options: - adapt existing software (NASCAM, Simtra) for our process engineering needs

- make an in-house software adapted for the development of the framework

Planned features

Impacts and costs in function of input parameters

Film properties

Chamber design

Weighing and optimization

Experimental data integration

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Conclusions

- PVD as it is does not compare favourably to ED
- Development of a framework to show the strengths of the technology in cases where ED has shortcomings (complex shapes, less conductive surfaces,…)
- Need for more data and a more extensive analysis of the process
- In the future : integration of LCA and TEA in a framework

Thank you for your attention!

Cost breakdown

Material costs (PVD)		
Average chromium price	90	$/kg
Argon price	10	£/m³
Chromium usage	143,759	g
Argon usage	200	sscm
Deposition time	1,176	h
Total cost	13,29707	€
Personnel costs		
Deposition time	1,176	h
Preparation time	15	min
Total workload	1,426	h
Hourly pay	39,6	€
Total cost	56,4696	€
Equipment costs		
Electricity costs	0,2	€/kwh
Electricity usage	40,29412	kwh
Miscellaneous	4	€
Total cost	12,05882	€
Total cost	81,82549	

Coûts matériels (ED)		
Average chromate price	20	$/kg
% chrome	0,320988	
Water price	5,2	€/m³
Chromate usage	447,8646	g
Chromium usage	143,759	g
Water usage	340	L
Deposition time	1,176	h
Total cost	9,837632	€
Personnel costs		
Deposition time	0,8	h
Preparation time	30	min
Total workload	1,3	h
Hourly pay	39,6	€
Total cost	51,48	€
Equipment costs		
Electricity costs	0,2	€/kwh
Electricity usage	20,06995	kwh
Miscellaneous	8	€
Total cost	12,01399	€
Total cost	73,33162	€