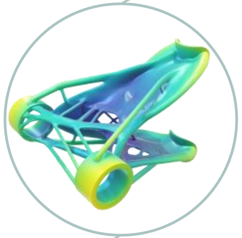
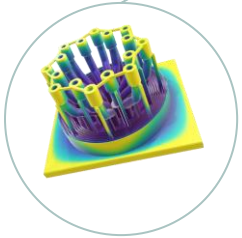
Benefits of multiphysics simulation of surface finishing processes of additive manufacturing part by addition or removal technologies





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Activities

- **R&D** in multiphysics simulation
- Custom **software** and **Digital Twin**
- **Data Science** applied to industrial processes
- **Industrial process optimisation** assisted by simulation

Areas of expertise
Electrochemical and chemical engineering (electroplating, electropolishing, anodisation, electrophoresis, chemical etching and plating, corrosion, battery, computational fluid dynamics, granular modeling…)

Industrial sectors
Aeronautic / Luxury / Automotive / Medical / Naval / Military / Electronics / Energy / Nuclear

COMSOL Certified Consultant

Additive manufacturing : benefits and drawbacks

Benefits → Lightweighting → Graded material → Innovation

Optimize part structure

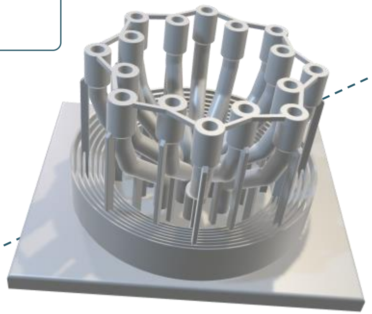
Fast prototyping

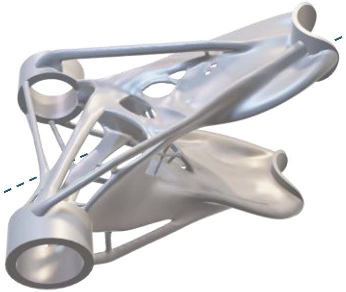
Less waste

Assembly part reduction

Lower material consumption

Add / combine functionalities

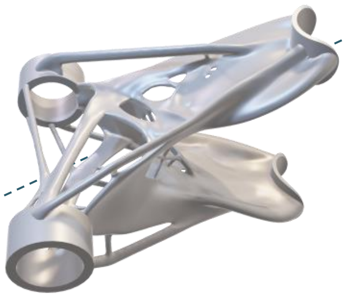


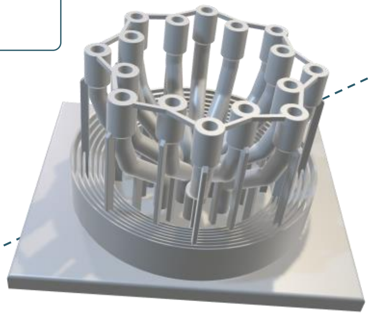


Additive manufacturing : benefits and drawbacks

Benefits → Lightweighting → Graded material → Innovation →

- Optimize part structure
- Fast prototyping
- Less waste
- Assembly part reduction
- Lower material consumption
- Add / combine functionalities
- Nonconventional geometry
- Organic geometry





- Unmelted powder
- Roughness
- High shape factor and small details

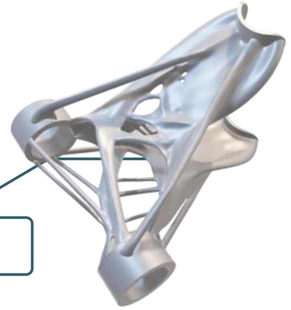
Drawbacks → Surface finishing → Complex geometry →

→ Additive manufacturing parts need to be finished to improve surface properties

Surface finishing processes

❑ Several processes are investigated to improve the surface finish of additive manufacturing parts by adding or removing material.

- Tribofinishing
- Chemical etching
- ExtrudHone AFM
- Plasma and standard electropolishing
- Hybrid process (D-Lyte / PEMEC)
- Anodization
- Electroplating



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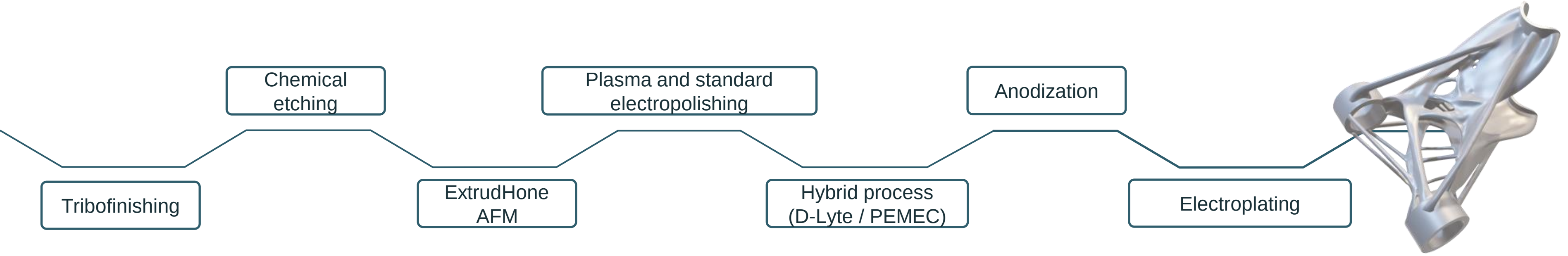

- ❑ New and hybrid surface finishing processes and well-known surface finishing processes need to be adapted to meet the challenges of AM parts

- ❑ AM parts also need coatings (anodization, electroplating...) for functional and aesthetic properties

→ Accessibility on complex geometry parts

Surface finishing processes

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Chemical etching
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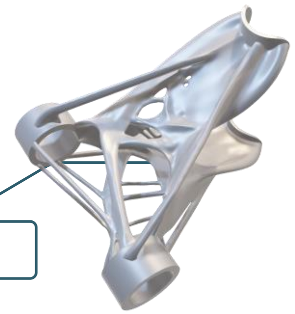

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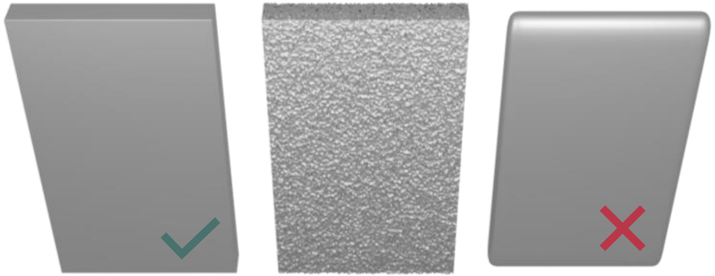


→ The challenge is to be able to control these processes optimally in order to obtain the good surface roughness while at the same time minimizing shape distortion

Why model surface finishing processes ?

Risk of failure to achieve post processing conformity

Internal network

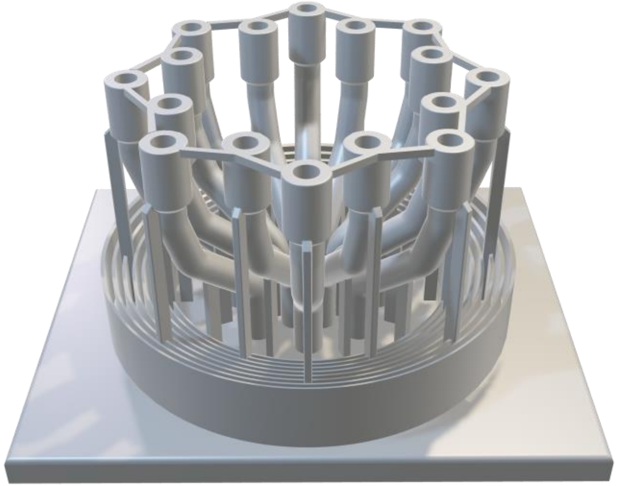
Complex shape / High shape factor

Fluid accessibility and fluid flow during chemical and electrochemical processes

Products removal (unmelted powder, oxide…)

Gas retention during chemical and electrochemical processes

Current line accessibility during electrochemical processes (electroplating, anodization, electropolishing)



Thin walls

Hole formation
Excessive attack

Sharp design
High shape ratio

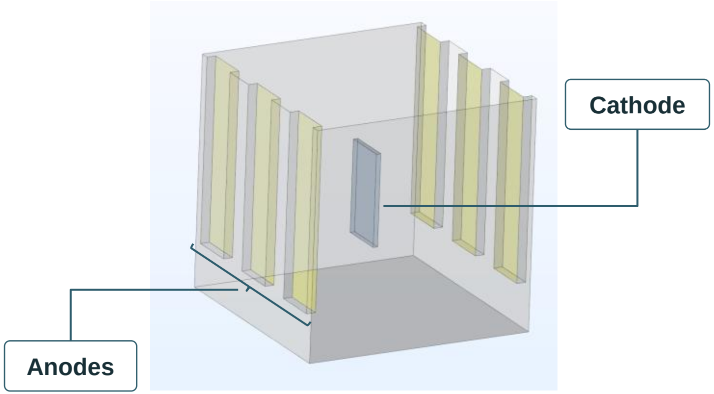
Edge smoothing

Heterogeneous current distribution during electrochemical processes

Simulation of electrochemical processes applied to AM parts

- Electrochemical processes are intrinsically heterogeneous due to the current distribution inside an electrochemical cell, in case of **electroplating, anodization, electropolishing and plasma polishing**

- Current distribution and local efficiency depend on many parameters such as process parameters (applied current, treatment duration,T°...), electrolyte chemistry and related properties (conductivity, viscosity, pH...), and fluid flow (mass transport, local concentration).



1- Direct electrohydrodynamic simulation of electrophoretic particle mobility Tom F.A. Wilms / November 2012 / MTP-1773-A

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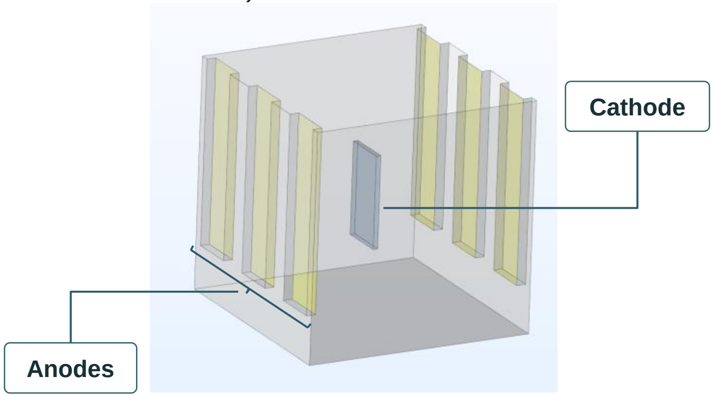
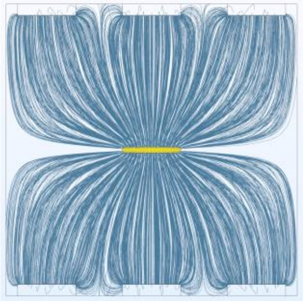
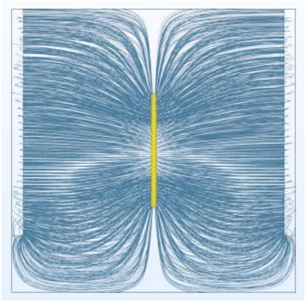




Current lines
Top view



Current lines
Lateral view

1- Direct electrohydrodynamic simulation of electrophoretic particle mobility
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1 (Nernst-Planck) — *diffusion*, *migration*, *convection*

$$\frac{\partial n_i}{\partial t} = \nabla \cdot \left[D_i \nabla n_i + \mu_i n_i \nabla \phi - n_i \mathbf{u}\right]$$

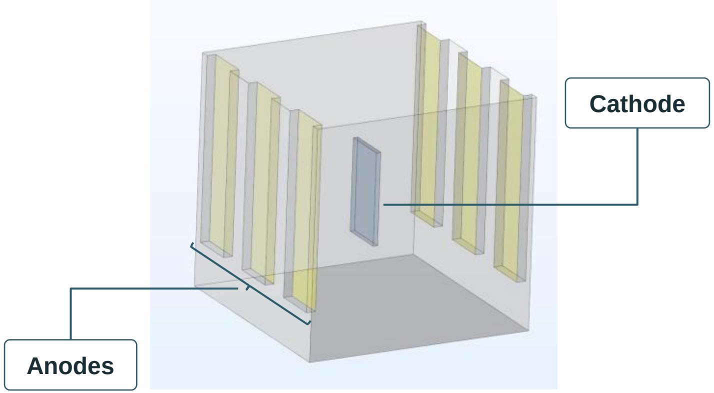
(Navier-Stokes)

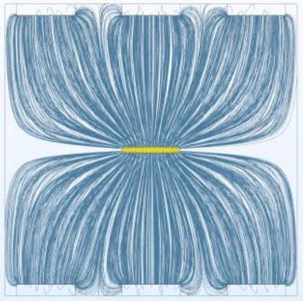
$$\rho\left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u}\cdot\nabla\mathbf{u}\right) = -\nabla p + \eta\nabla^2\mathbf{u} - \nabla\phi\sum_{i=1}^{N} z_i e n_i$$

$$\nabla \cdot \mathbf{u} = 0$$

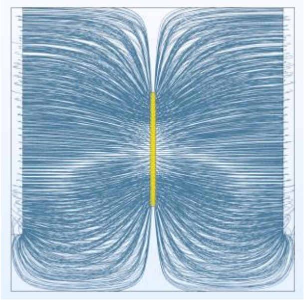
(Poisson)

$$\nabla^2\phi = -\frac{1}{\epsilon\epsilon_0}\sum_{i=1}^{N} z_i e n_i$$

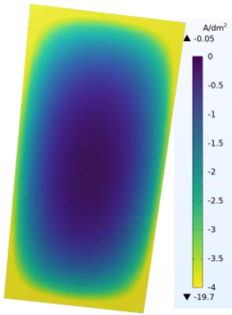




Current lines
Top view



Current lines
Lateral view



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Simulation of electrochemical processes applied to AM parts

$$\text{1} \quad \text{(Nernst-Planck)} \quad \frac{\partial n_i}{\partial t} = \nabla \cdot [\overbrace{D_i \nabla n_i}^{diffusion} + \overbrace{\mu_i n_i \nabla \phi}^{migration}]$$

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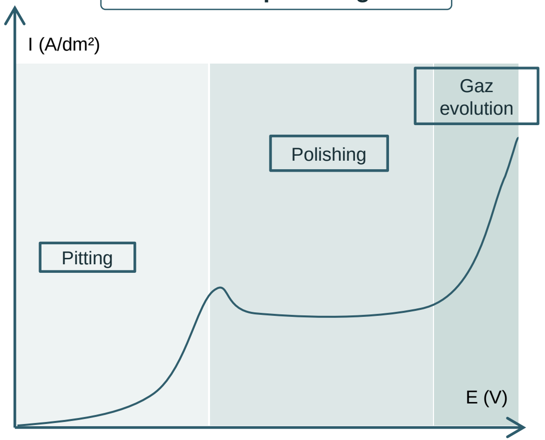
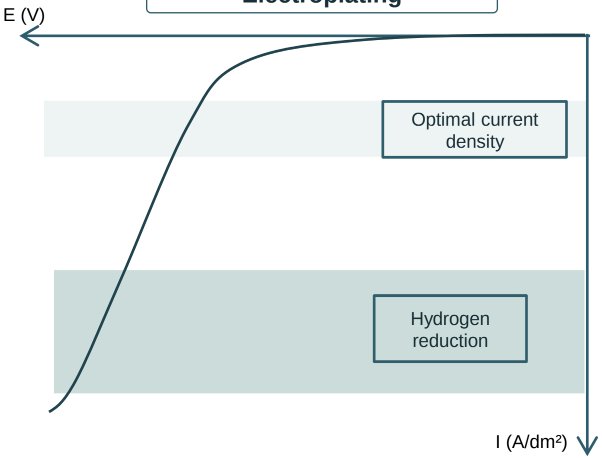
Electropolishing



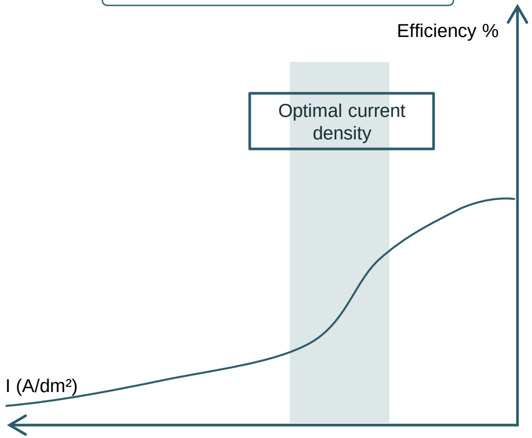
Current density vs. voltage for standard electropolishing

Electroplating



Cathodic curve polarization in electroplating electrolyte (current density vs. voltage)

Efficiency



Efficiency (plating or dissolution) function of current density

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1- Direct electrohydrodynamic simulation of electrophoretic particle mobility
Tom F.A. Wilms / November 2012 / MTP-1773-A

Simulation of electrochemical processes applied to AM parts

1 (Nernst-Planck)

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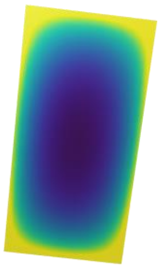
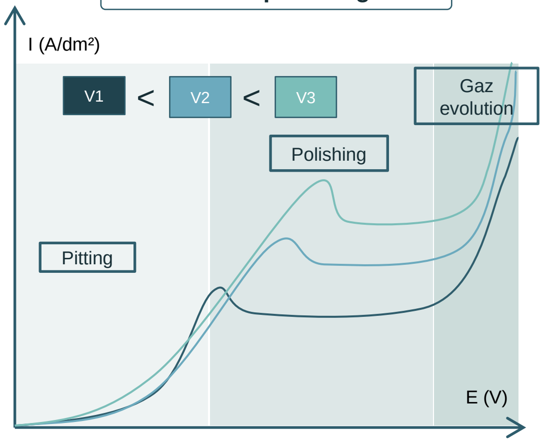
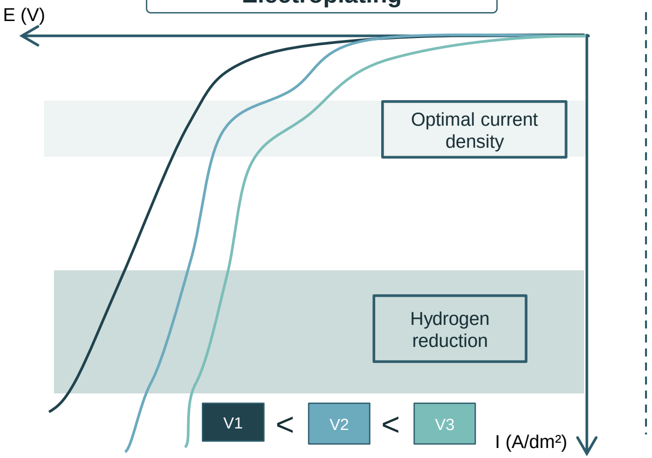


Electropolishing



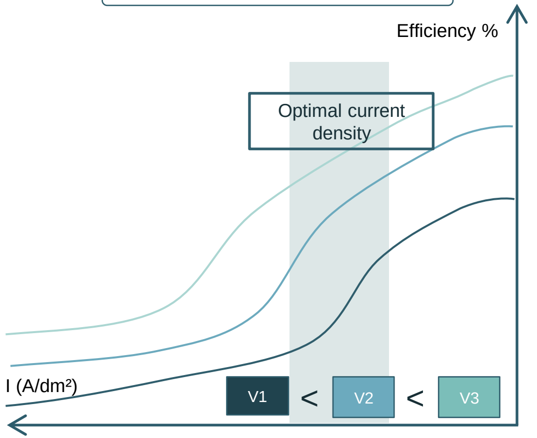
Current density vs. voltage for standard electropolishing in various agitation conditions

Electroplating



Cathodic curve polarization in electroplating electrolyte (current density vs. voltage) in various agitation conditions

Efficiency



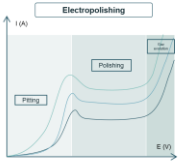
Efficiency (plating or dissolution) function of current density in various agitation conditions

I (A)

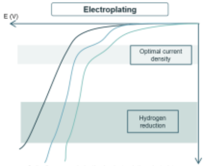
1- Direct electrohydrodynamic simulation of electrophoretic particle mobility
Tom F.A. Wilms / November 2012 / MTP-1773-A

Simulation of electrochemical processes applied to AM parts

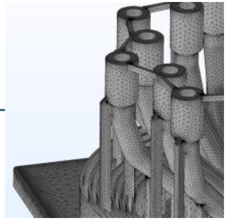
- **Physics assumptions and study scale** → Current distribution model
- **Behaviour law definition** → Experimental caracterisation of electrode kinectics
- **CAD and mesh**
- **Resolve differential equations**
- **Explore results** → Roughness; Tickness; Current density; Shape distortion



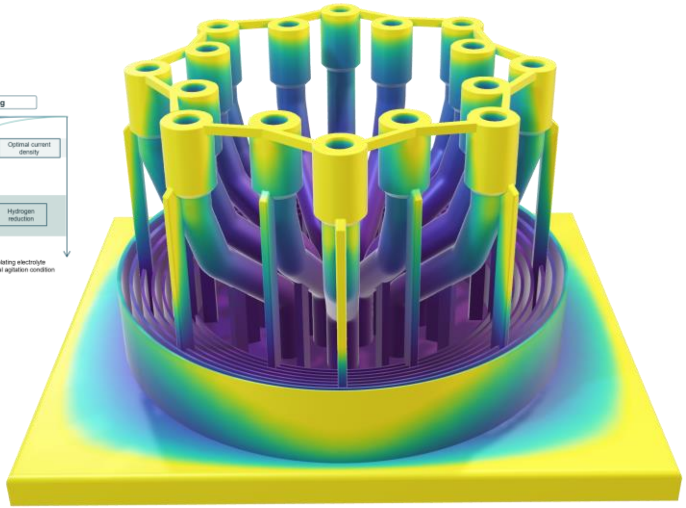
Current density vs. voltage for standard electropolishing for several agitation condition

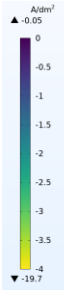


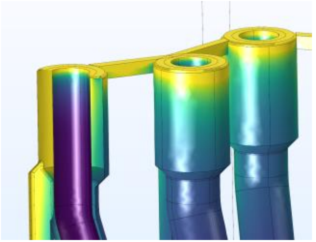
Cathodic curve polarization in electroplating electrolyte (current density vs. voltage) for several agitation condition

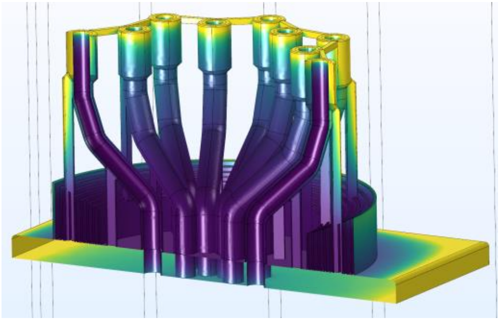


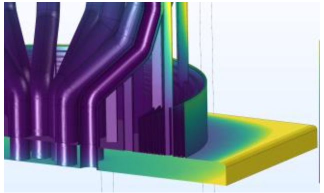
Current distribution without tooling







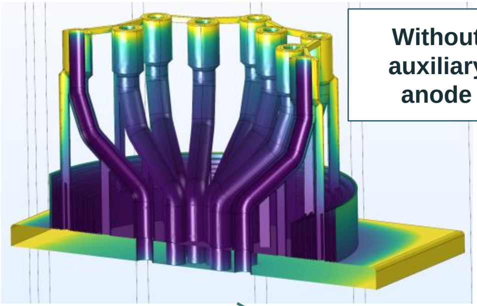




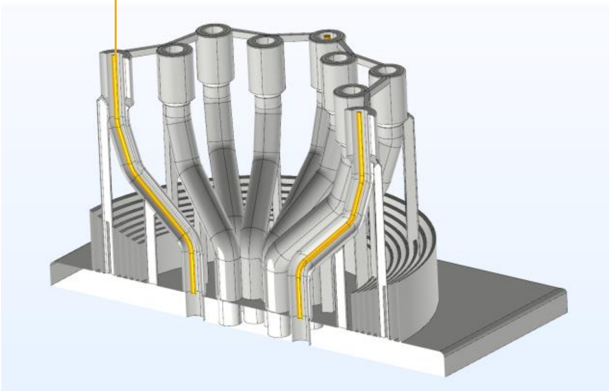
Simulation of electrochemical processes applied to AM parts

- Specific tooling can provide a better current density distribution on complex geometries

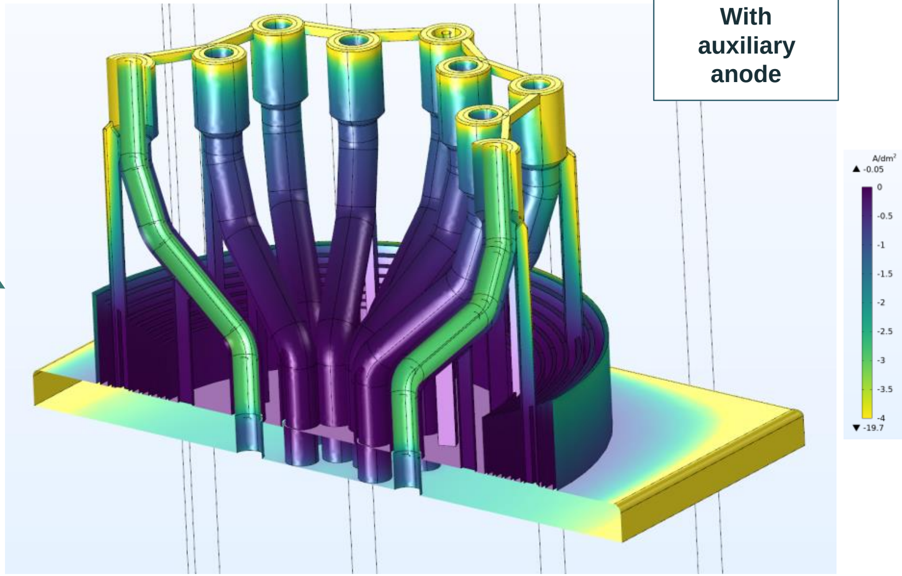
Without auxiliary anode



Auxiliary anode
(independent generator)



With auxiliary anode



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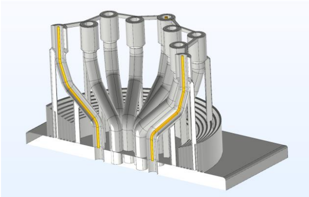
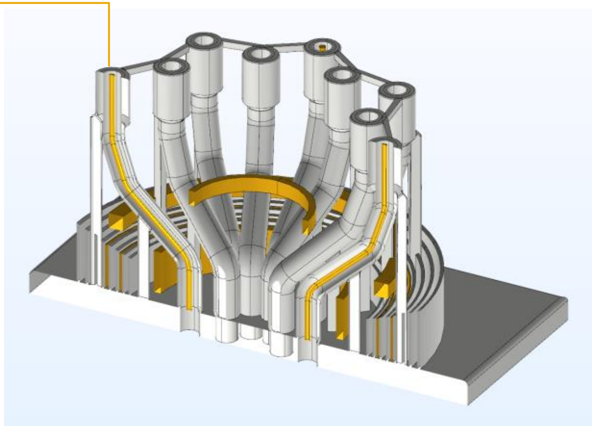
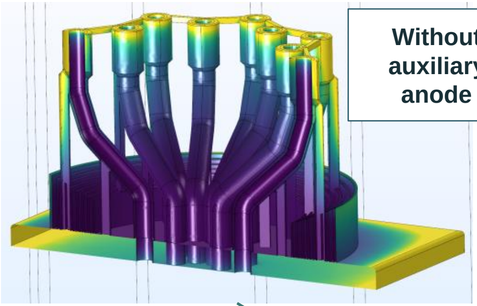
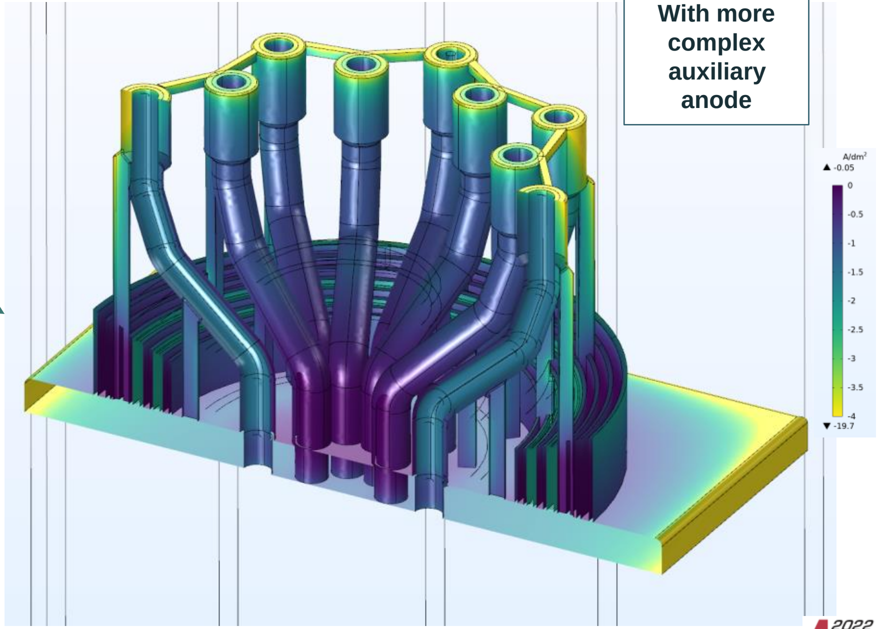






Without auxiliary anode

With more complex auxiliary anode



Simulation of electrochemical processes applied to AM parts

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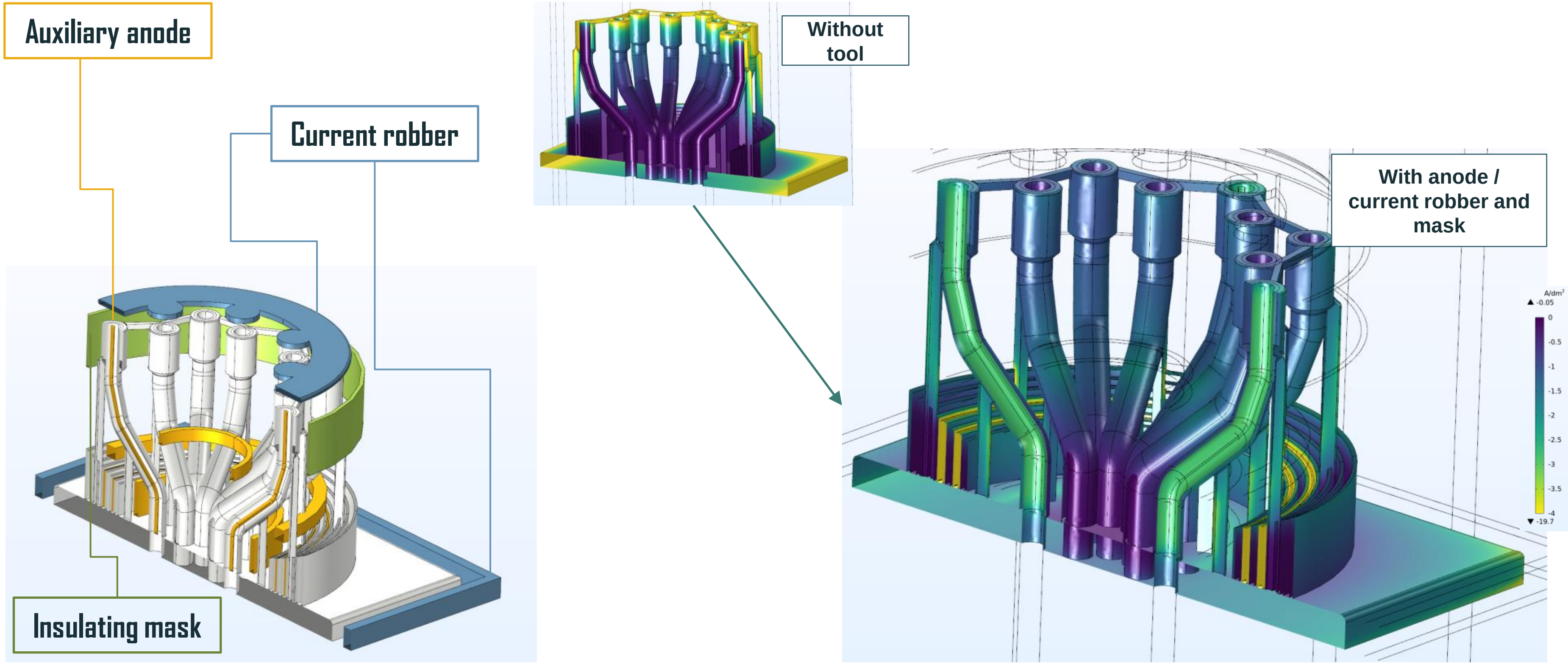
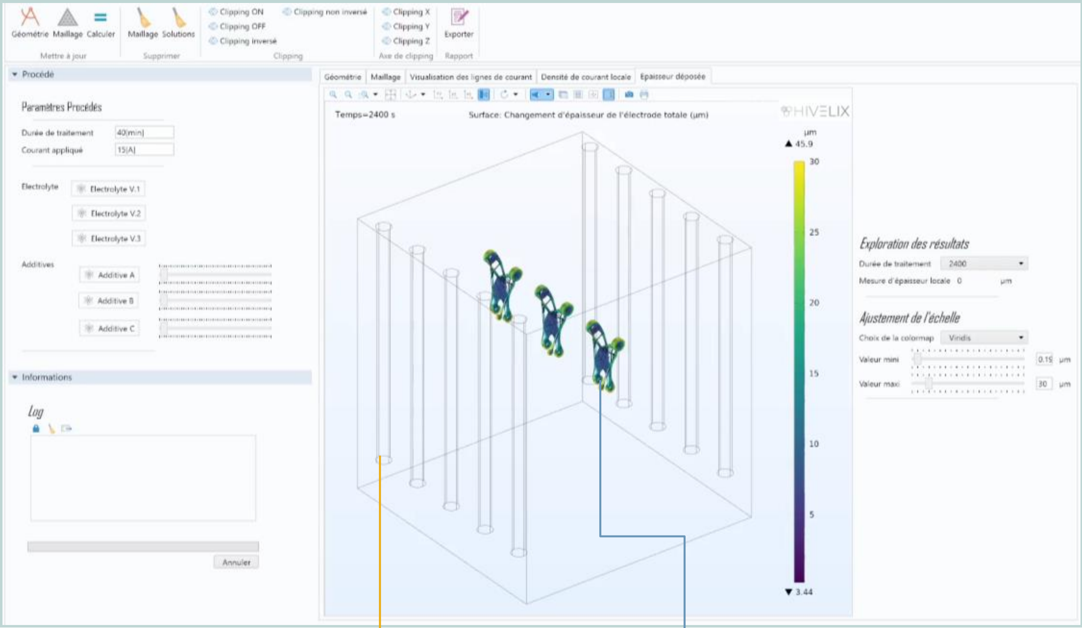


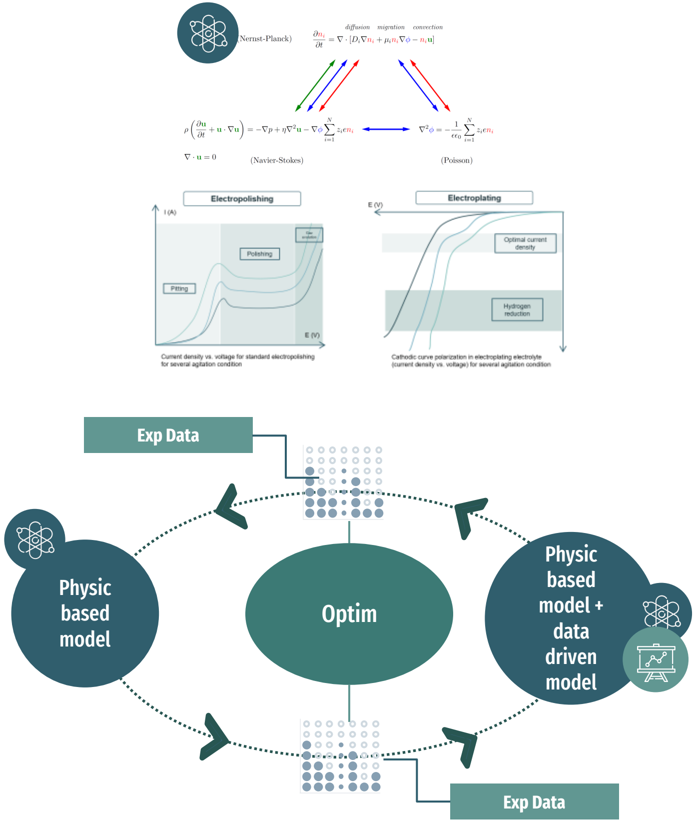
Simulation of electrochemical processes applied to AM parts

- Simulation of several parts in an industrial electrochemical cell



Main anodes

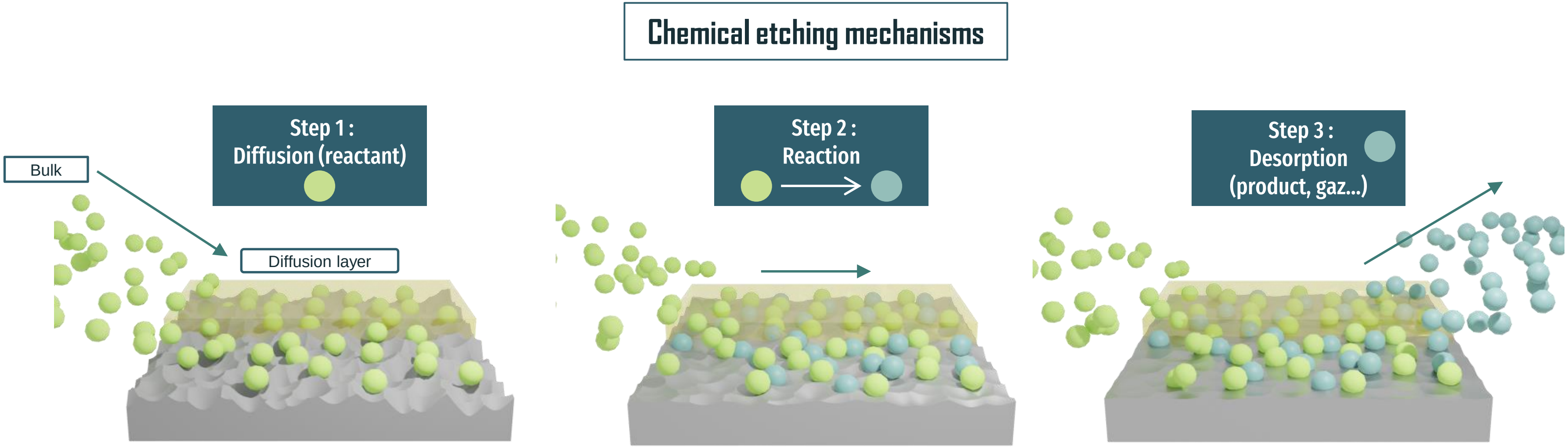
AM Parts



Hybrid physics-based and data driven models to improve prediction

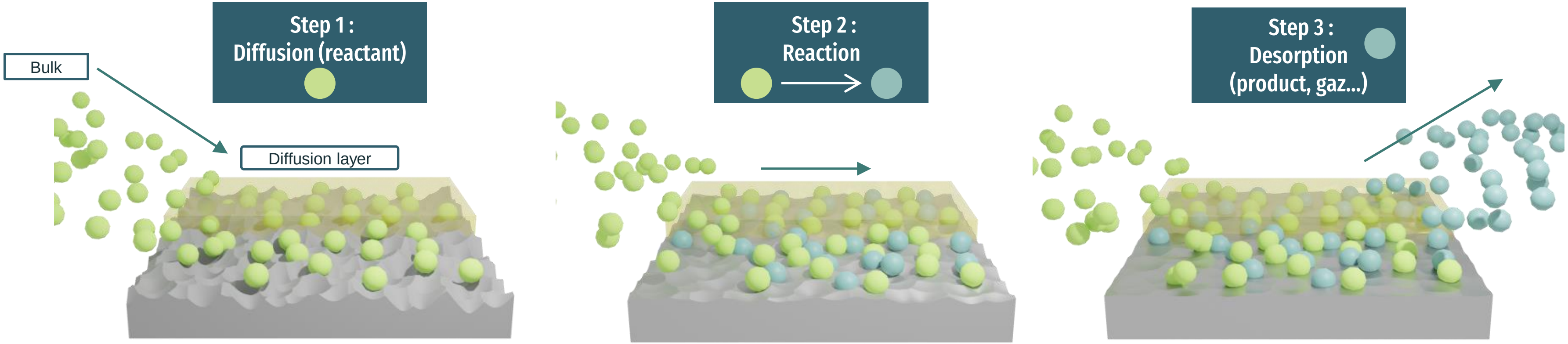
Numerical simulation of chemical etching

- **"NEMO"** is in the continuance of the AFTER ALM project completed in December 2021, the **NE**xt al**M** finishing pr**O**cesses project aims to remove important barriers related to the post-processing of complex geometry parts produced by additive manufacturing.



Numerical simulation of chemical etching

Chemical etching mechanisms → Mass transport is the most influential factor



The effective dissolution kinetics is the results of a competition between several phenomena

Mass transport of the **reactants** from the bulk to the surface

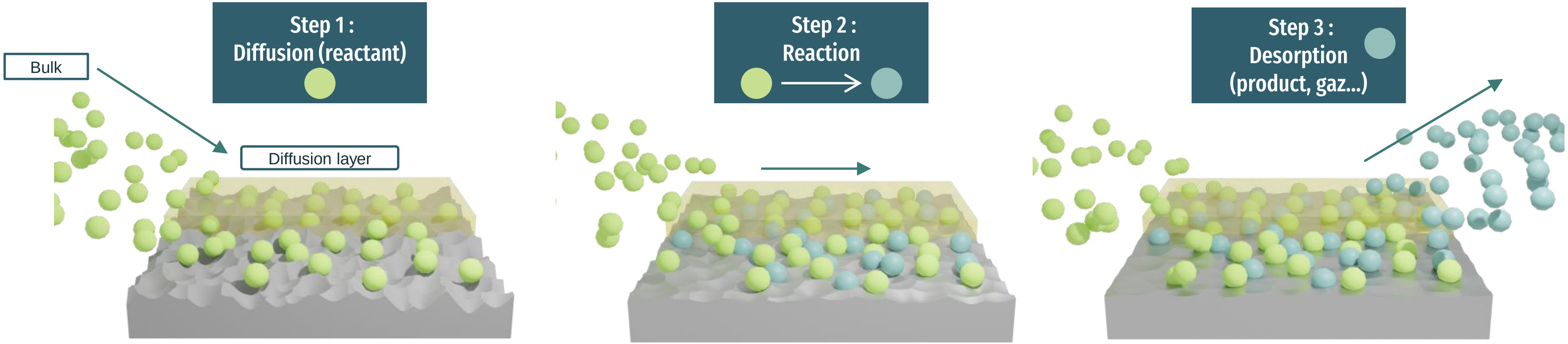
Reaction kinetics at the surface function of different parameters (T°, C°, chemistry…)

Mass transport of **products** from the surface (oxides, bubbles...) to the bulk (risk of blocking)

→ Challenge consist of being able to predict mass transport, gas mobility and etching rate

Numerical simulation of chemical etching

Chemical etching mechanisms → Mass transport is the most influential factor



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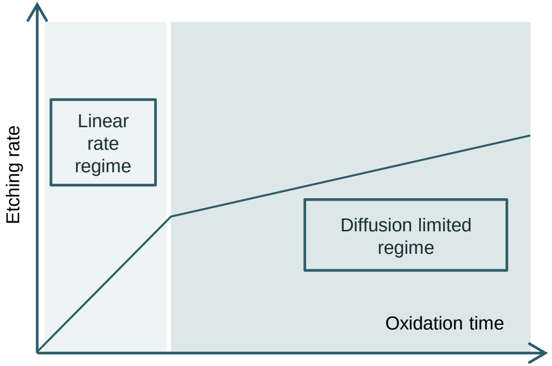
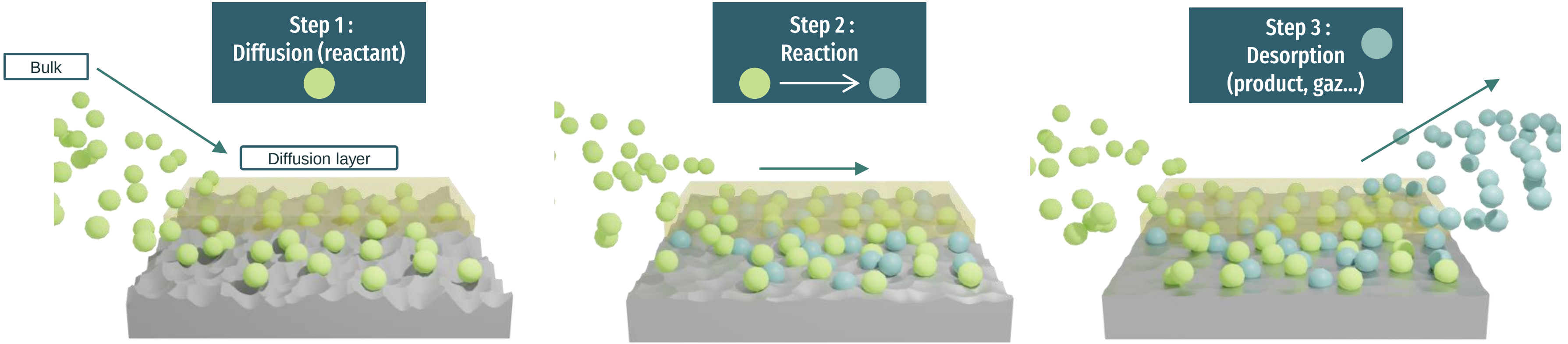


Numerical simulation of chemical etching

Chemical etching mechanisms → Mass transport is the most influential factor



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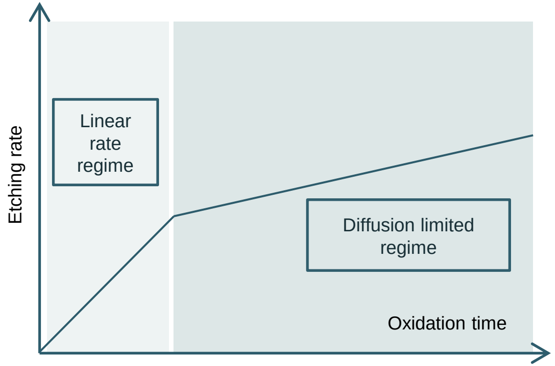
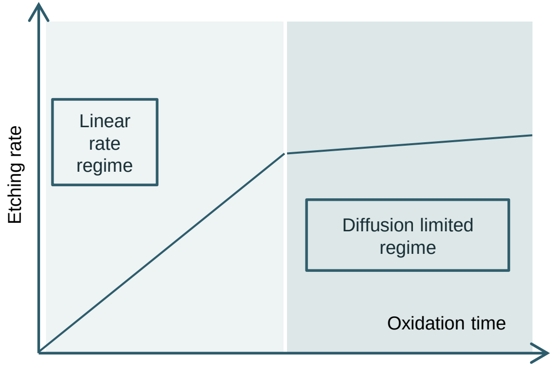
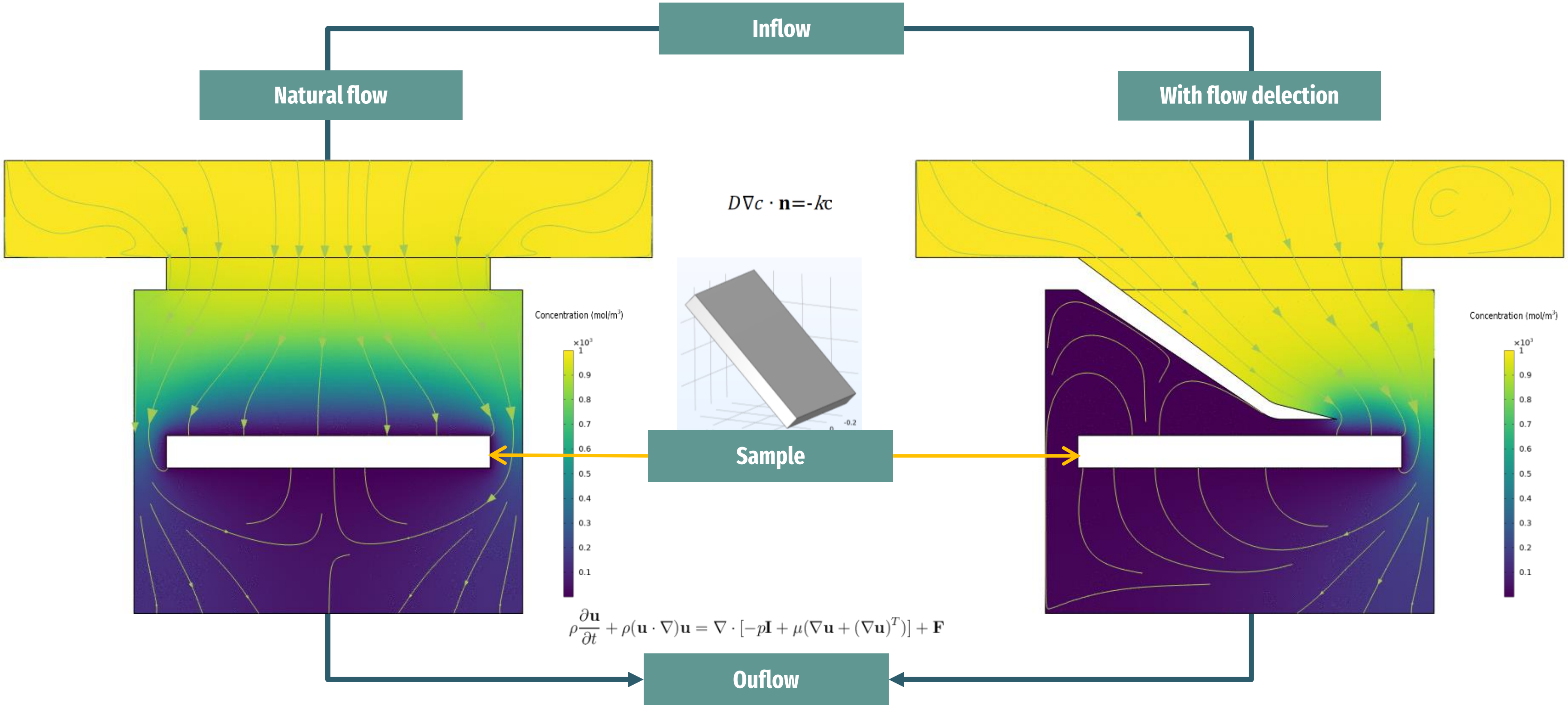




Numerical simulation of chemical etching

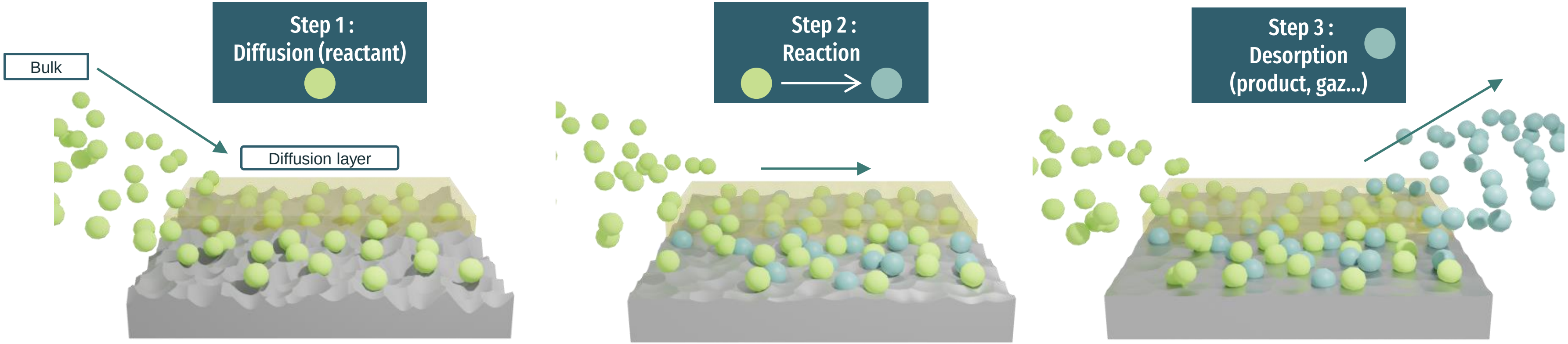
Case study of the transport impact of reactant on the surface:



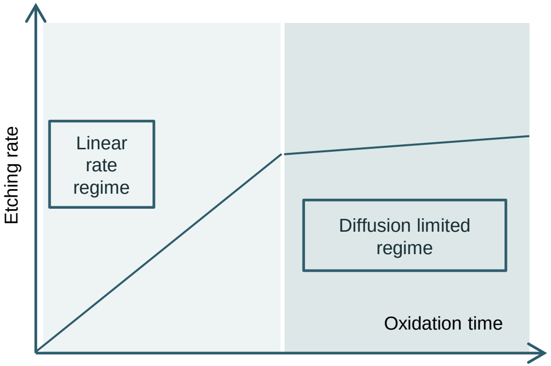
Work conducted for the project IRT M2P **"NEMO"**

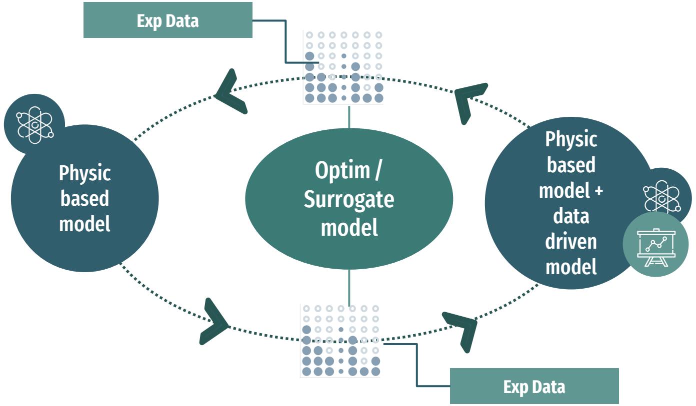
Numerical simulation of chemical etching

Chemical etching mechanisms → Mass transport is the most influential factor



Hybrid physics-based and data driven models to improve prediction rate and identify unknown parameters





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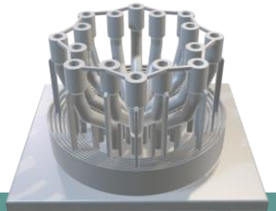
Work conducted for the project IRT M2P "NEMO"

Conclusion



Internal network / thin walls / Sharp design

Fluid accessibility and **fluid flow**

Product removal

Gas retention

Current lines accessibility

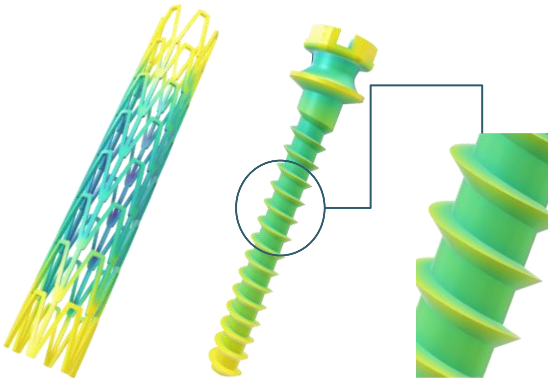
Excessive attack

Edge smoothing

Heterogeneous current distribution

→ **Reduce time and cost development**

- ❑ **Multiphysics simulation allow to**:
  - Improve **fundamental** process **understanding**
  - Improve **process management and reduce treatment heterogeneity**
  - **Predict final surface properties** in relation to the process parameters applied
  - **Anticipate shape distortion** and oversize parts
  - **Develop solutions of process control** :
    - Fluid flow circulation
    - Designed tools for electrochemical processes
- ❑ **Hybrid physics-based / data driven models allow to** :
  - Complete imperfect physics-based model
  - Increase simulation prediction rate in an industrial environment



Thank you for your attention

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