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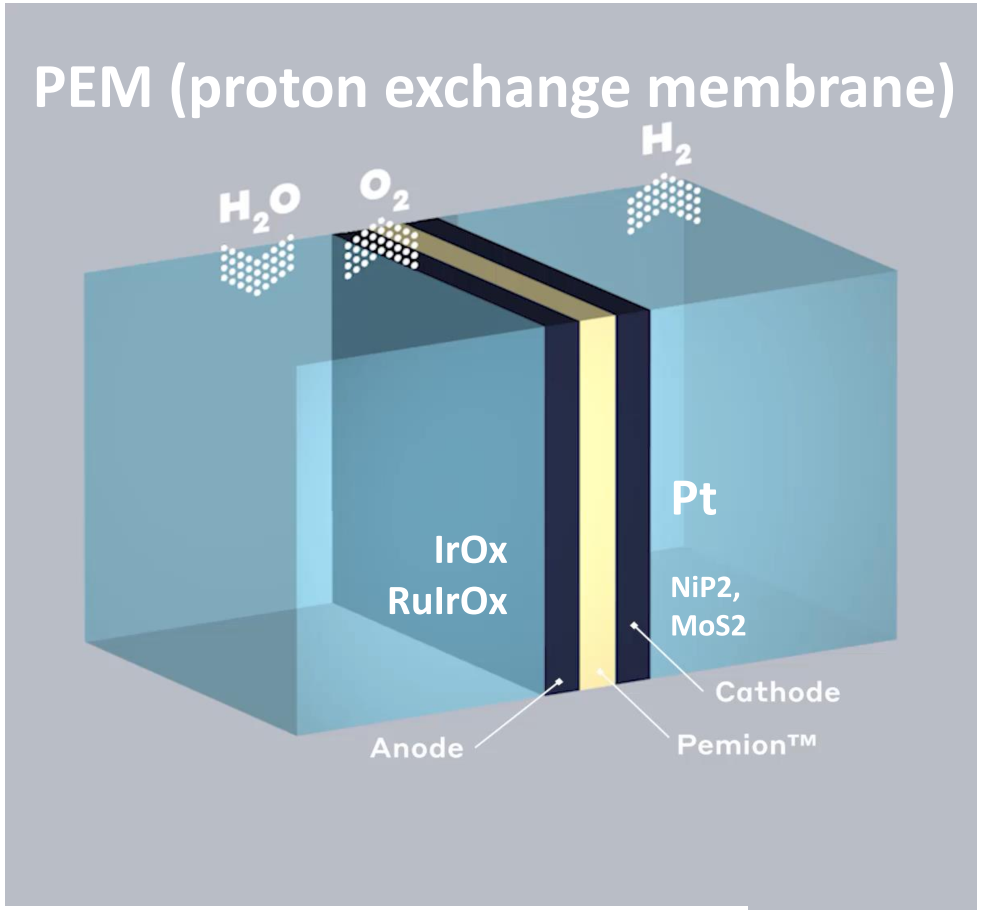
The Project

- Applications covered in the project
  - Green hydrogen (electrolysers and fuel cells)
  - Conversion of CO2 into valuable chemicals (syngas and ethylene)

- The common thread for these applications is that they are all based on electrocatalysis
  - using (sustainable) electricity and a catalyst instead of a process based on fossil fuels (enabling industrial electrification)

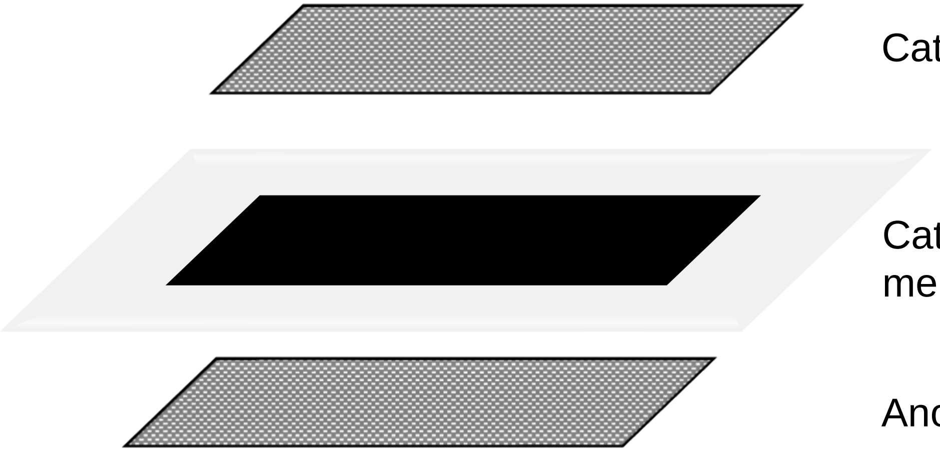
- The innovation: a new production process for catalyst coated membranes (CCMs), which are the heart of electrocatalytic equipment, such as electrolysers for hydrogen production

Catalyst Coated Membranes (CCMs)



Animation courtesy: i*n*mr (www.ionomr.com)

CCMs are the "heart" of electrolyzer and fuel cell stacks



- Catalyst films (generally consisting of metallic nanoparticles) are **deposited directly on the membrane**
- Porous transport layers are attached at each side to facilitate mass transfer and current collection

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Catalyst Coated Membranes (CCMs)

- Issues with CCMs that are addressed in the project
  - CCMs are expensive due to the complex production process from bulk metal to CCM and the use of expensive materials for the catalysts
  - CCMs use scarce metals (e.g. iridium) that might make it difficult or impossible to scale to very high volumes required for the energy transition
  - CCM to CCM variation is large due to the complex production process

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Participants in the Project

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State of the art nanotechnology

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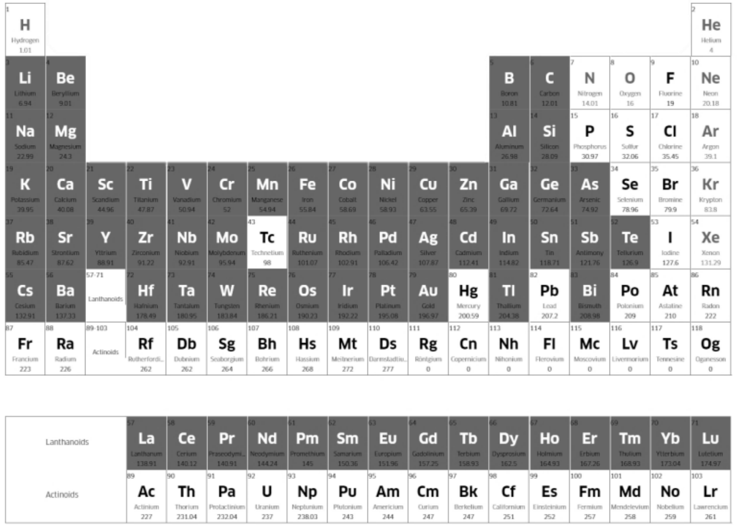
62 basic elements



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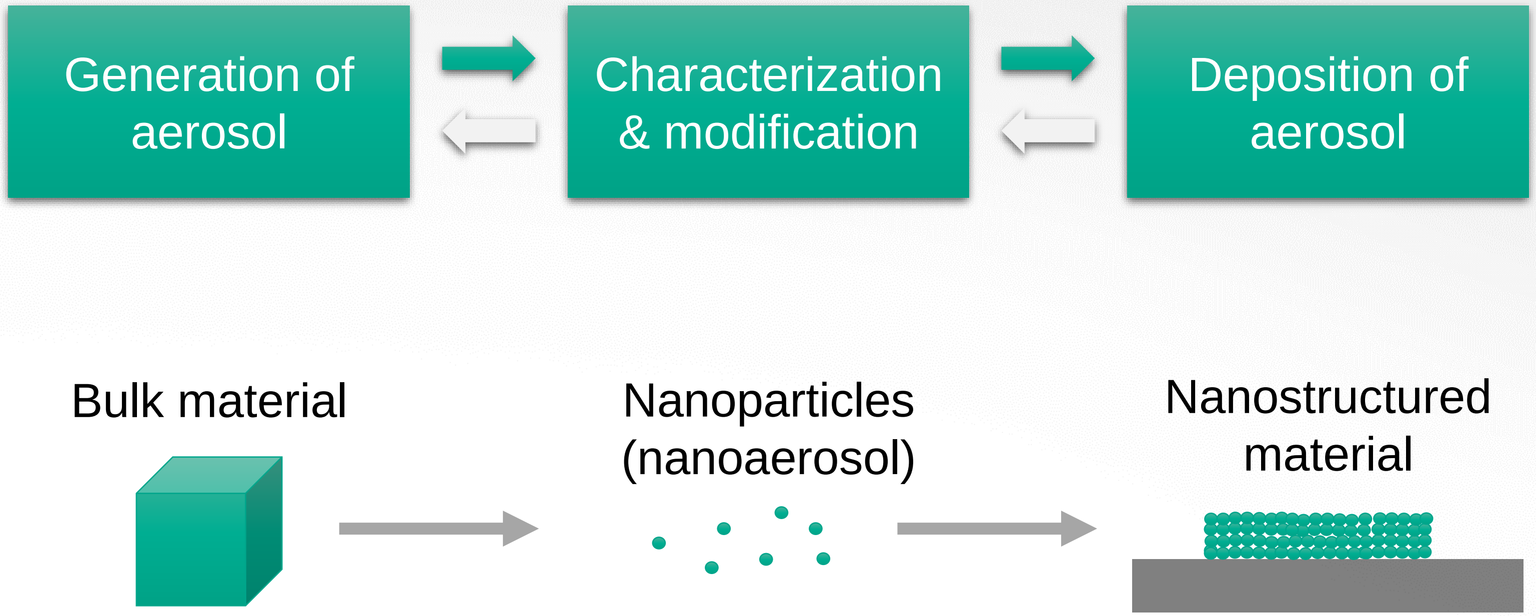
Nanoaerosol process technology

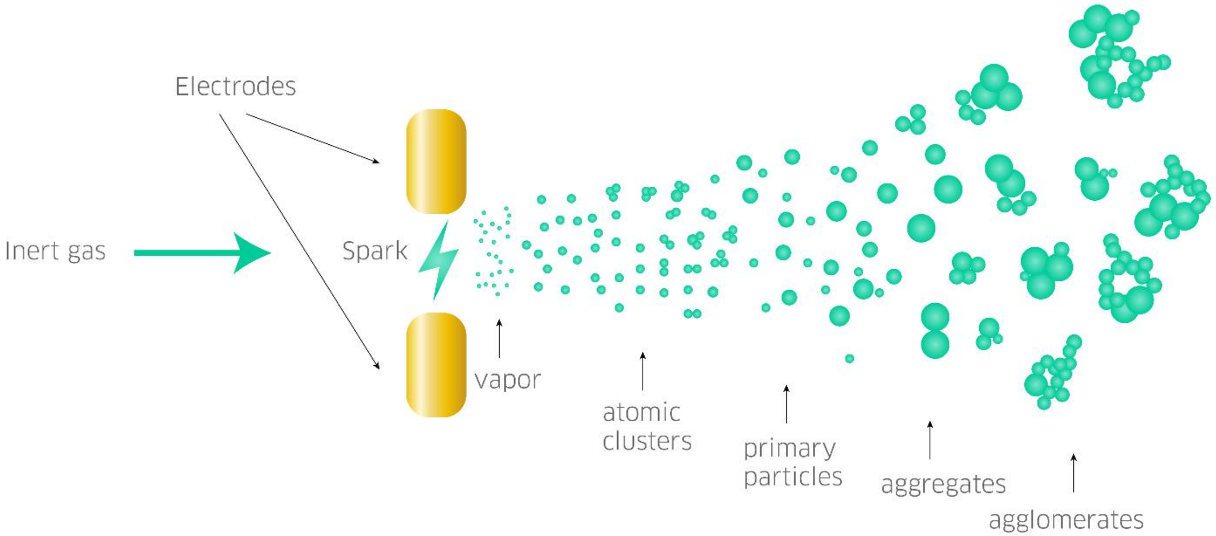
Our deposition technology is based on **nanoaerosol process technology**. We develop equipment where the generation of the nanoaerosol, inline characterization/modification and deposition is integrated into a **single continuous process**.

The process requires as input: Bulk metallic rods, process gas and electricity. The process deposits **nanostructured material** locally on a wide variety of substrates.

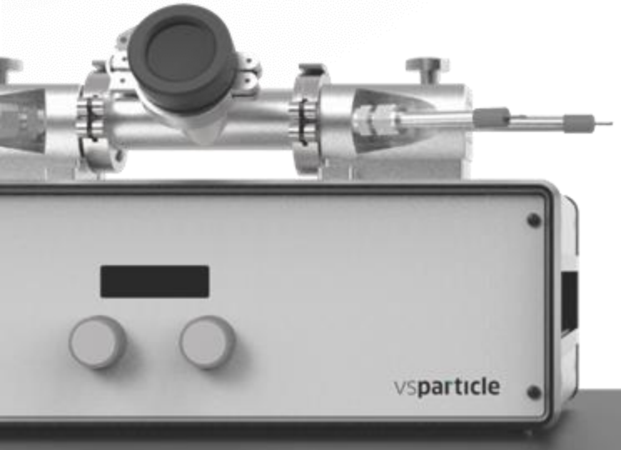


Nanoparticle generation

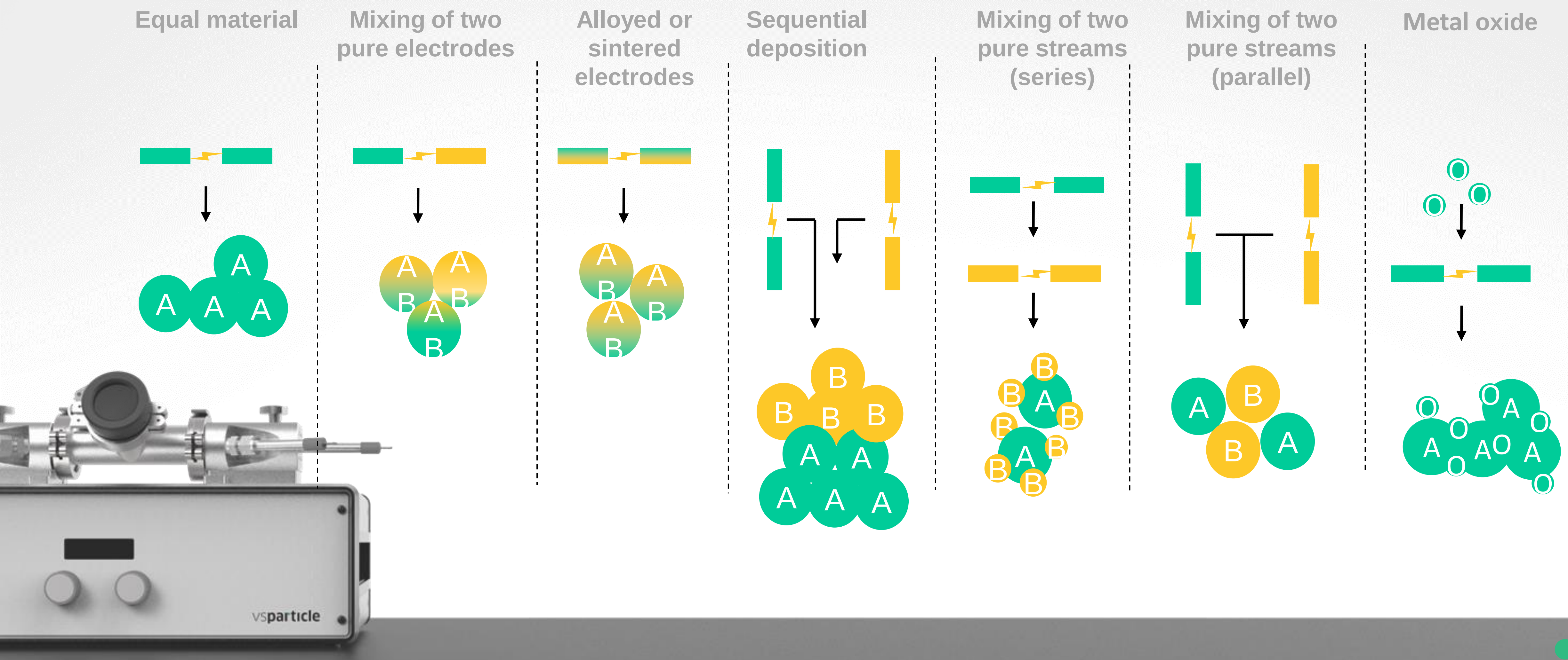
The nanoaerosol is generated by **spark-ablation** of metallic electrodes. A carrier gas transports the particles to their intended location. Reactive carrier gasses can be used to form for example metal oxide nanoparticles.



Pure, free of solvents
Deposition at room temperature

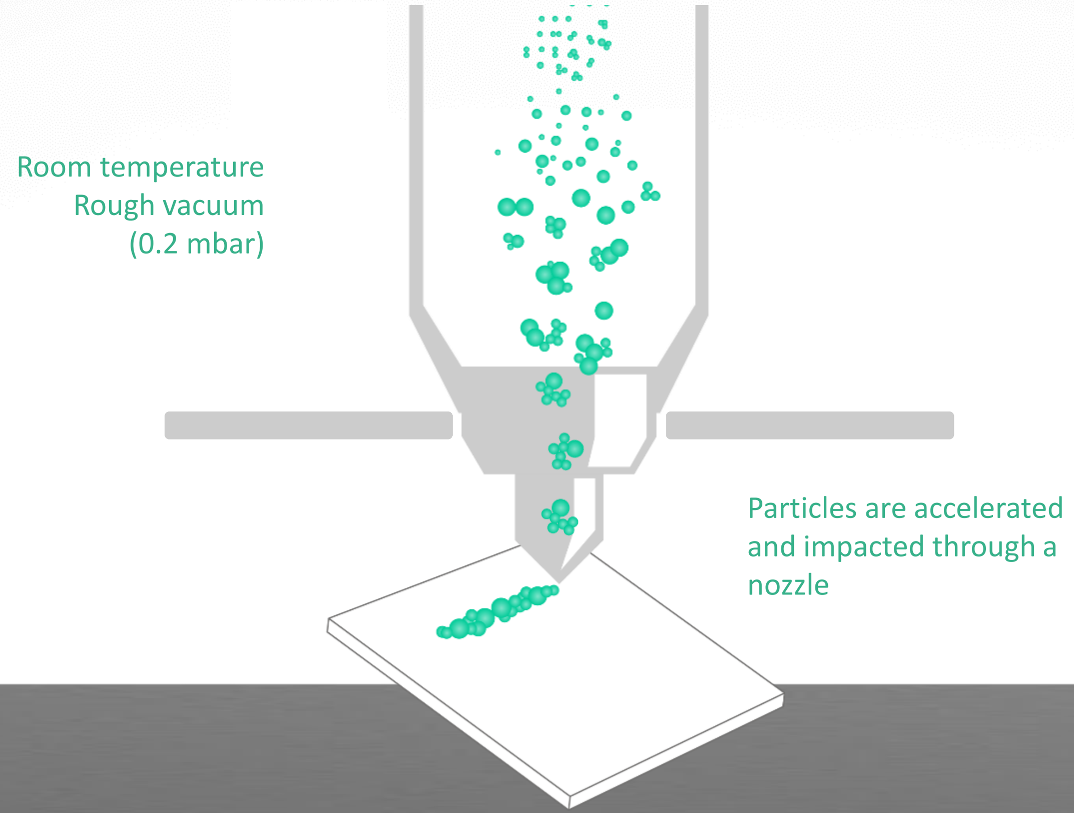


Mixing materials



Nanoparticle deposition

Using **inertial impaction**, the particles in the nanoaerosol can be locally deposited at **room-temperature** and rough vacuum. Therefore, realizing an **additive manufacturing** method of depositing nanostructured layers on a wide range of substrates. The technology is scalable to **industrial volumes**.



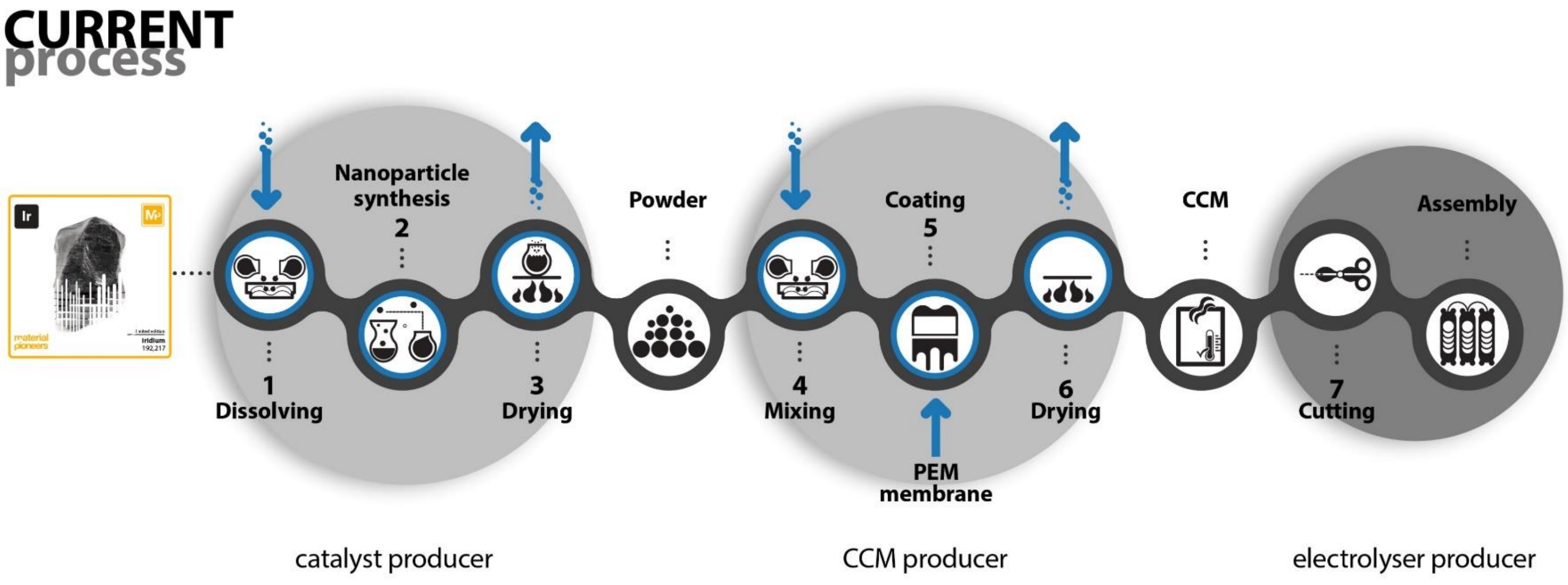
Deposition

- Layer thickness: from sparse distribution of agglomerates to multiple microns
- No binder required, preserving the cleanliness (purity) of the nanoparticles

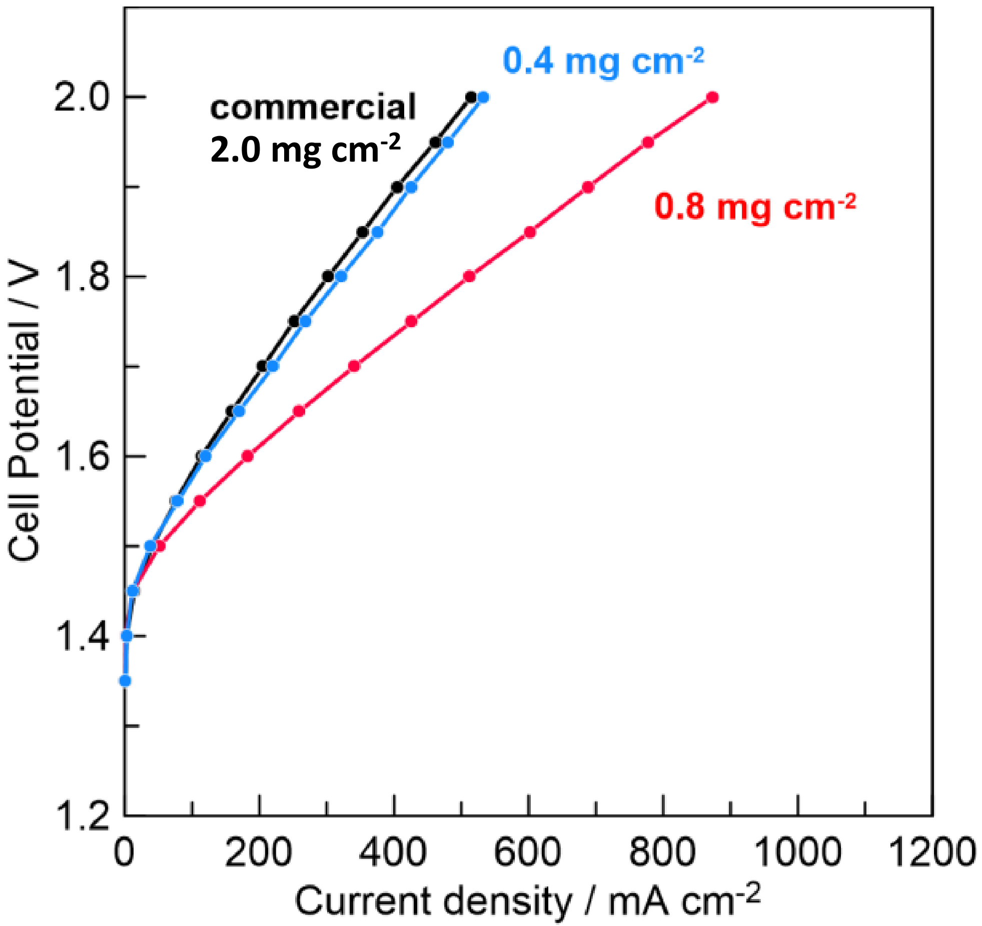
Substrates

Flexible polymers, MEMS, SERS, 6-inch Si wafer, etc.

Production of CCMs



DIFFER: CCM performance testing



Ir loading (mg/cm^2)	Ir specific power density @ 200 mA/cm^2 (g_{Ir}/kW)
2.0 (commercial)	5.88
0.4	1.15
0.8	2.35

- **The same performance using 5 times less iridium**
- **Significantly better performance using 2.5 times less iridium**

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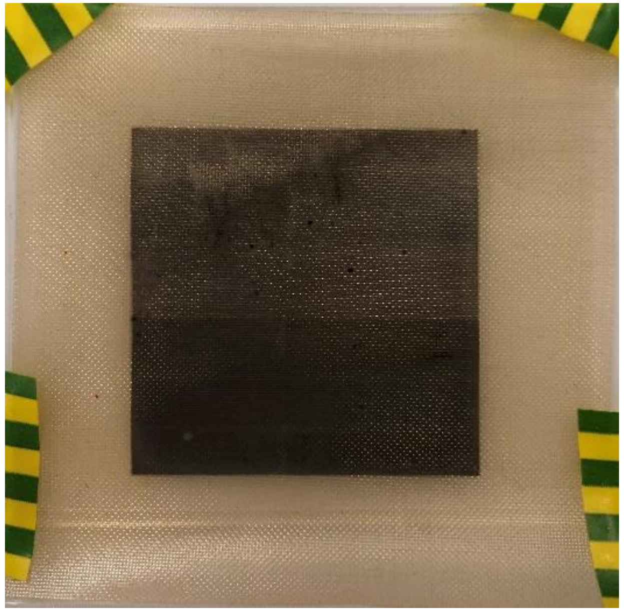
TNO: CCM performance testing

- Screening of different membrane materials that VSParticle deposits the catalyst layer onto
- Testing the performance of converting CO_2 into syngas (CO and H_2) and ethylene, which enables VSParticle to iteratively optimize the settings of the production process



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Next steps

- Validation projects with potential customers
  - Electrolyzer manufacturers
  - CCM producers
  - End-users of electrocatalytic processes

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Summary

Advantages for production of CCMs

- VSParticle's production process enables
  - nanoparticles with novel elemental compositions, to enable new applications and to reduce or eliminate the use of scarce metals
  - CCMs with higher performance
    - very clean (pure) nanoparticles
    - very porous layers (on nanoscale), due to the absence of liquids in the production process

- VSParticle's production process vastly simplifies the production of CCMs
  - Lower production costs
  - Better quality control

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