

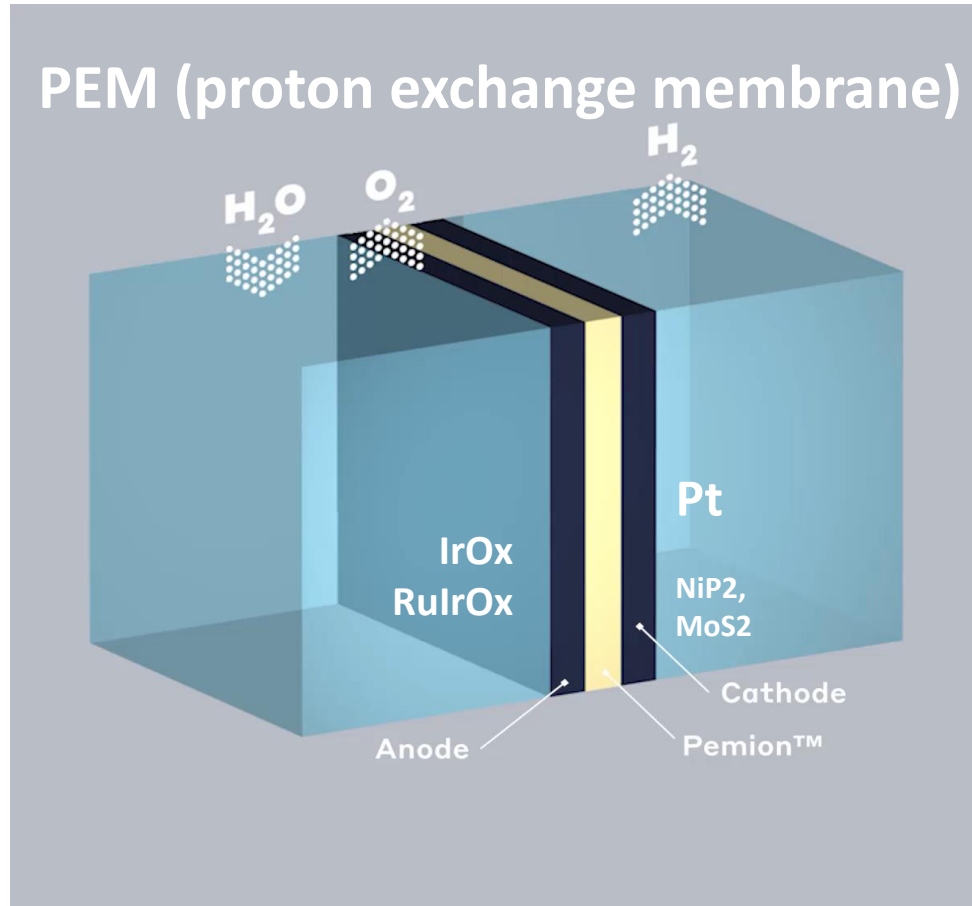
vSparticle

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

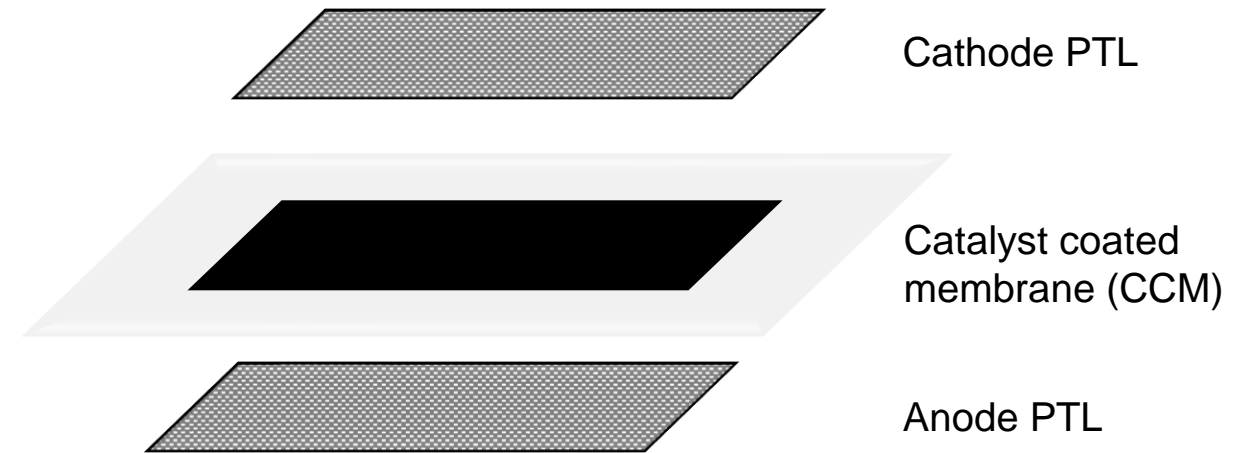


Catalyst Coated Membranes (CCMs)



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

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



Participants in the Project



Michail Tsampas



Foteini Sapountzi



Anca Anastapol



Susan Turk



Wilbert Vrijburg



Sofia Dimitriadou



Marco Kirsenstein



Jeroen Eblé



NanoPrinter



NanoPrinter

State of the art nanotechnology



NanoPrinter

62 basic elements

1	2																	3
H Hydrogen 1.008																	He Helium 4	
3	4											5	6	7	8	9	10	
Li Lithium 6.94	Be Beryllium 9.01											B Boron 10.81	C Carbon 12.01	N Nitrogen 14.01	O Oxygen 16	F Fluorine 19	Ne Neon 20.18	
11	12											13	14	15	16	17	18	
Na Sodium 22.99	Mg Magnesium 24.3											Al Aluminum 26.98	Si Silicon 28.09	P Phosphorus 30.97	S Sulfur 32.06	Cl Chlorine 35.45	Ar Argon 39.9	
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
K Potassium 39.09	Ca Calcium 40.08	Sc Scandium 44.96	Ti Titanium 47.87	V Vanadium 50.94	Cr Chromium 52	Mn Manganese 54.94	Fe Iron 55.85	Co Cobalt 58.93	Ni Nickel 58.69	Cu Copper 63.55	Zn Zinc 65.38	Ga Gallium 69.72	Ge Germanium 72.64	As Arsenic 74.92	Se Selenium 78.96	Br Bromine 79.9	Kr Krypton 83.8	
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	
Rb Rubidium 85.47	Sr Strontium 87.62	Y Yttrium 88.91	Zr Zirconium 91.22	Nb Niobium 92.91	Mo Molybdenum 95.94	Tc Technetium 98	Ru Ruthenium 101.07	Rh Rhodium 101.07	Pd Palladium 106.42	Ag Silver 107.87	Cd Cadmium 112.41	In Indium 114.82	Sn Tin 118.71	Sb Antimony 121.76	Te Tellurium 127.6	I Iodine 126.9	Xe Xenon 131.29	
55	56	57-71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	
Cs Cesium 132.91	Ba Barium 137.33	Lanthanoids	Hf Hafnium 178.49	Ta Tantalum 180.95	W Tungsten 183.84	Re Rhenium 186.21	Os Osmium 190.23	Ir Iridium 192.22	Pt Platinum 195.08	Au Gold 196.97	Hg Mercury 200.59	Tl Thallium 204.38	Pb Lead 207.2	Bi Bismuth 208.98	Po Polonium 209	At Astatine 210	Rn Radon 222	
87	88	89-103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	
Fr Francium 223	Ra Radium 226	Actinoids	Rf Rutherfordium 261	Db Dubnium 262	Sg Seaborgium 264	Bh Bohrium 266	Hs Hassium 268	Mt Meitnerium 272	Ds Darmstadtium 277	Rg Roentgenium 278	Cn Copernicium 285	Nh Nihonium 286	Fl Flerovium 289	Mc Moscovium 290	Lv Livermorium 293	Ts Tennessine 294	Og Oganesson 294	
		Lanthanoids	La Lanthanum 138.91	Ce Cerium 140.12	Pr Praseodymium 140.91	Nd Neodymium 144.24	Pm Promethium 145	Sm Samarium 150.36	Eu Europium 151.96	Gd Gadolinium 157.25	Tb Terbium 158.93	Dy Dysprosium 162.50	Ho Holmium 164.93	Er Erbium 167.26	Tm Thulium 168.93	Yb Ytterbium 173.05	Lu Lutetium 174.97	
		Actinoids	Ac Actinium 227	Th Thorium 232.04	Pa Protactinium 231.04	U Uranium 238.03	Np Neptunium 237	Pu Plutonium 244	Am Americium 243	Cm Curium 247	Bk Berkelium 247	Cf Californium 251	Es Einsteinium 252	Fm Fermium 257	Md Mendelevium 258	No Nobelium 259	Lr Lawrencium 261	

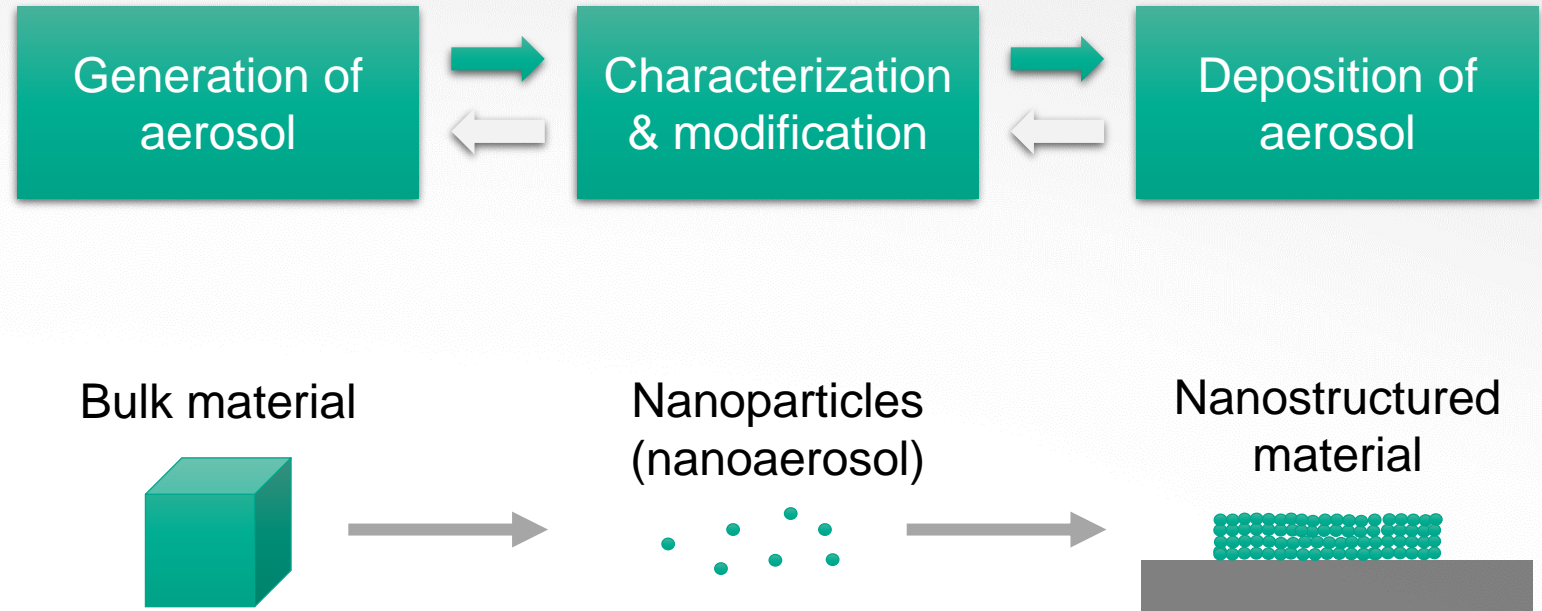
vsparticle



Nanoaerosol process technology

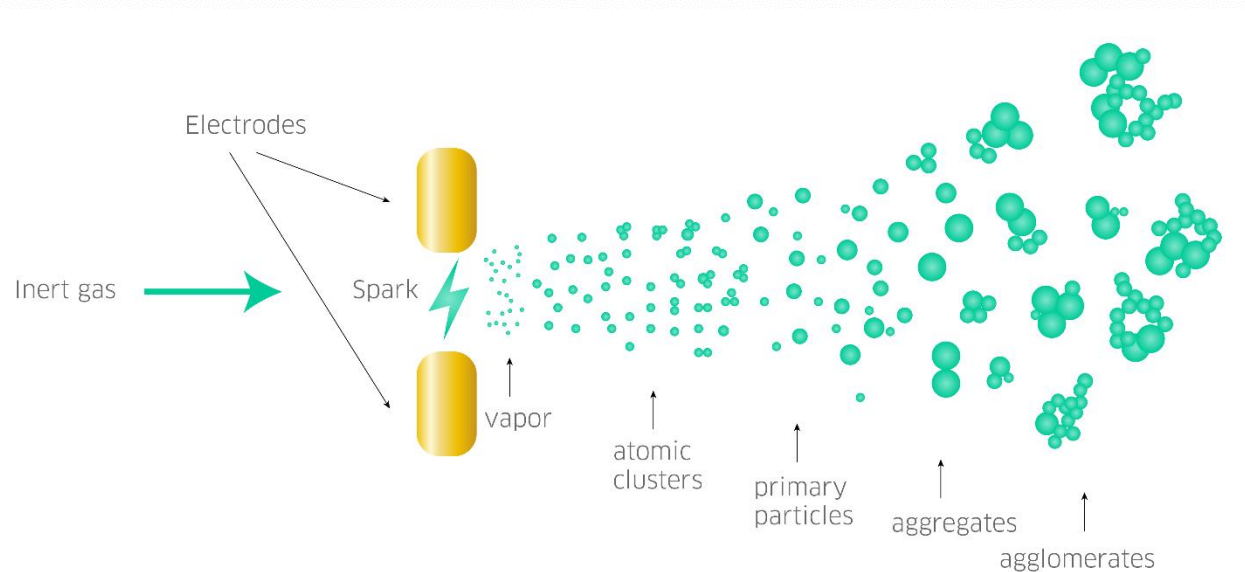
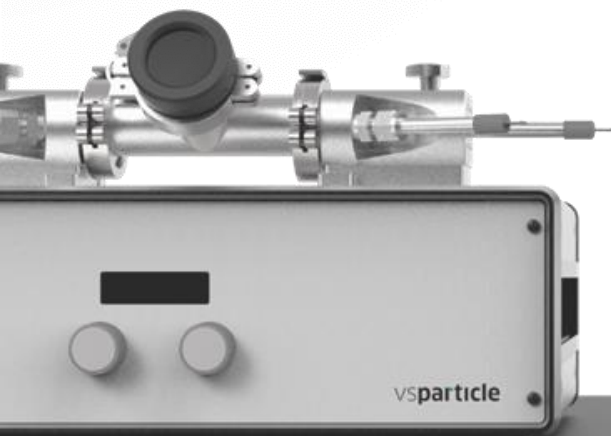
Our deposition technology is based on **nanoaerosol process technology**. We develop equipment where the generation of the nanoaerosol, inline characterization/modification and deposition is integrated into a **single continuous process**.

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

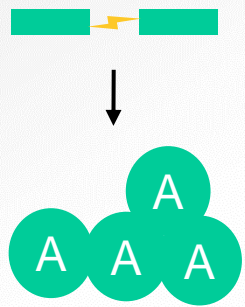
The nanoaerosol is generated by **spark-ablation** of metallic electrodes. A carrier gas transports the particles to their intended location. Reactive carrier gasses can be used to form for example metal oxide nanoparticles.



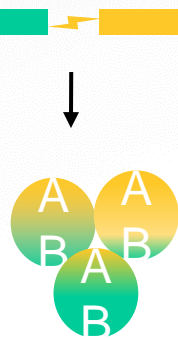
Pure, free of solvents
Deposition at room temperature

Mixing materials

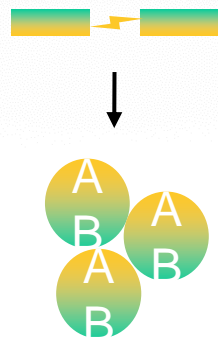
Equal material



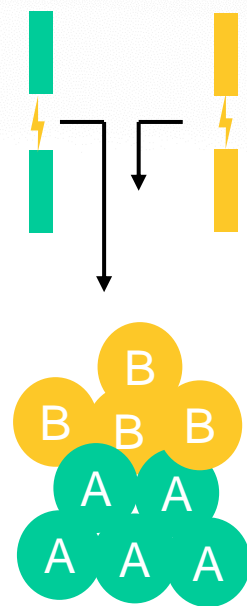
Mixing of two pure electrodes



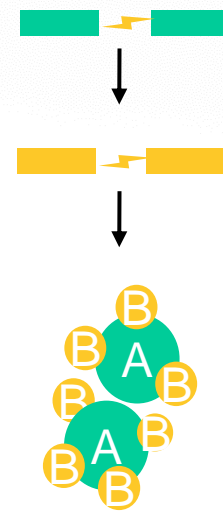
Alloyed or sintered electrodes



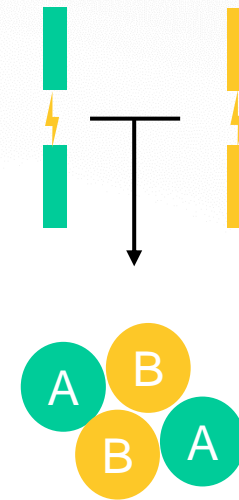
Sequential deposition



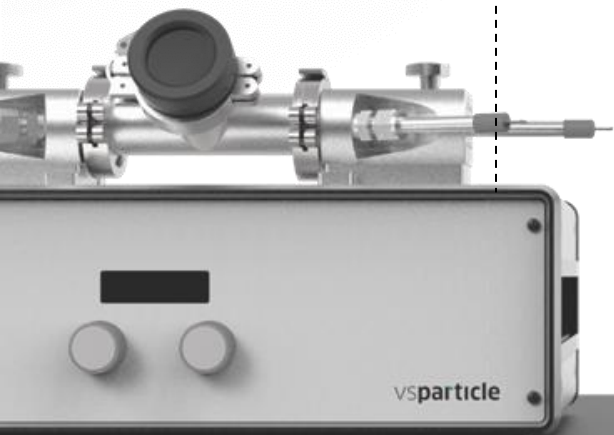
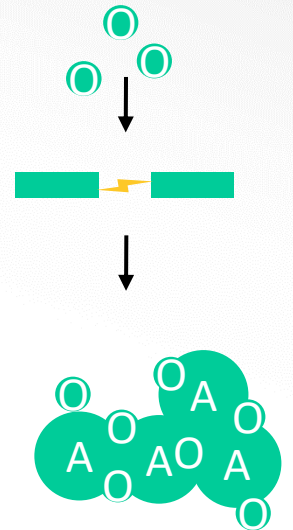
Mixing of two pure streams (series)



Mixing of two pure streams (parallel)

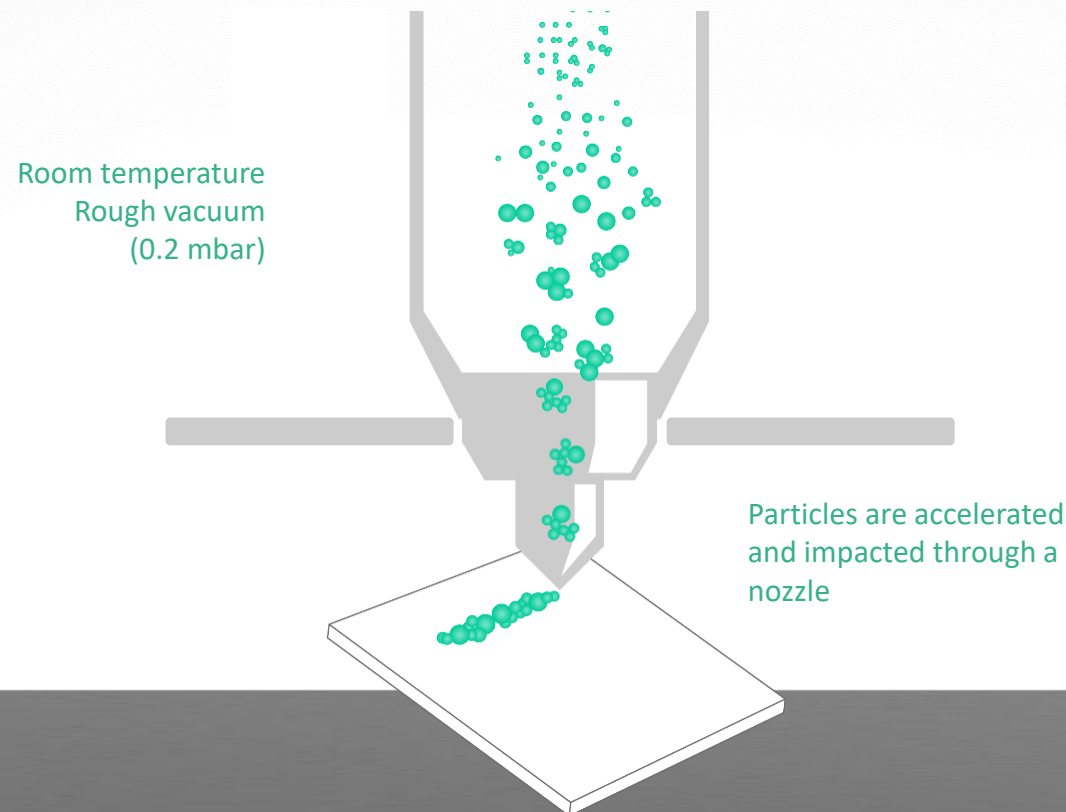


Metal oxide



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

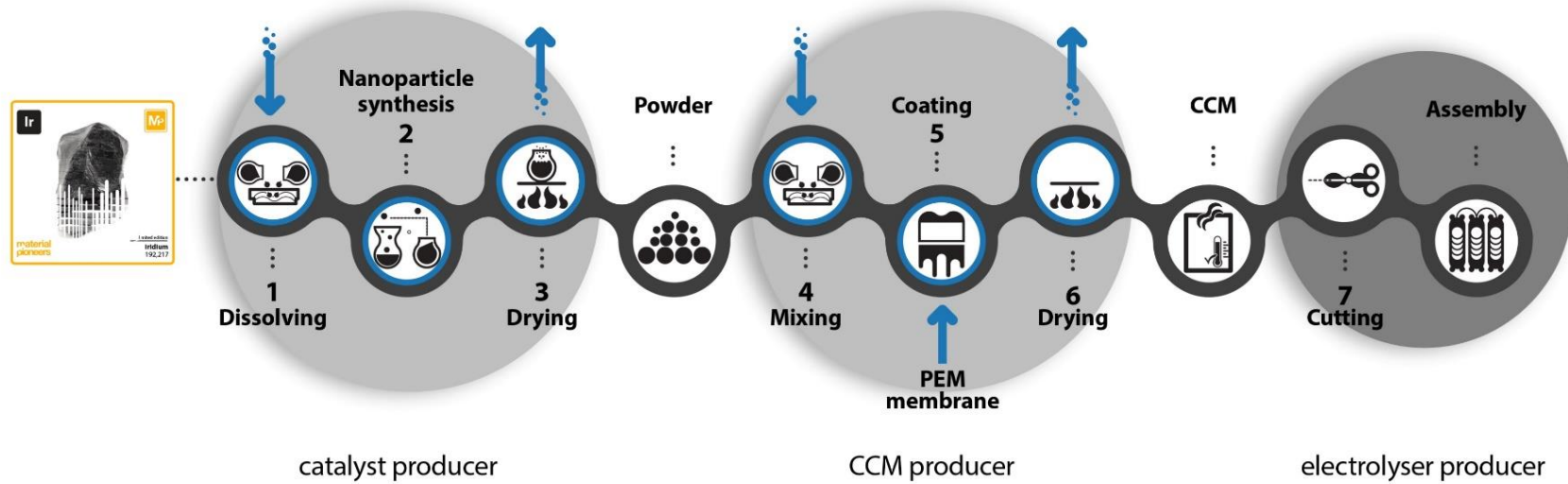
- Layer thickness: from sparse distribution of agglomerates to multiple microns
- No binder required, preserving the cleanliness (purity) of the nanoparticles

Substrates

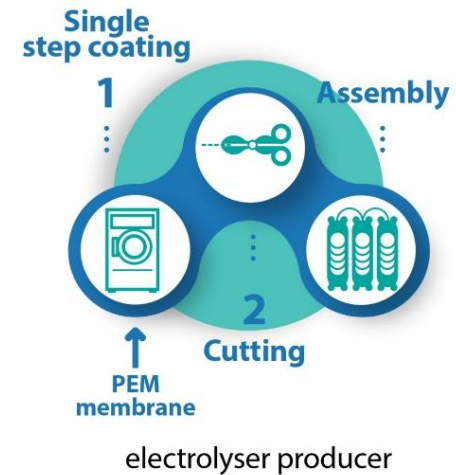
Flexible polymers, MEMS, SERS, 6-inch Si wafer, etc.

Production of CCMs

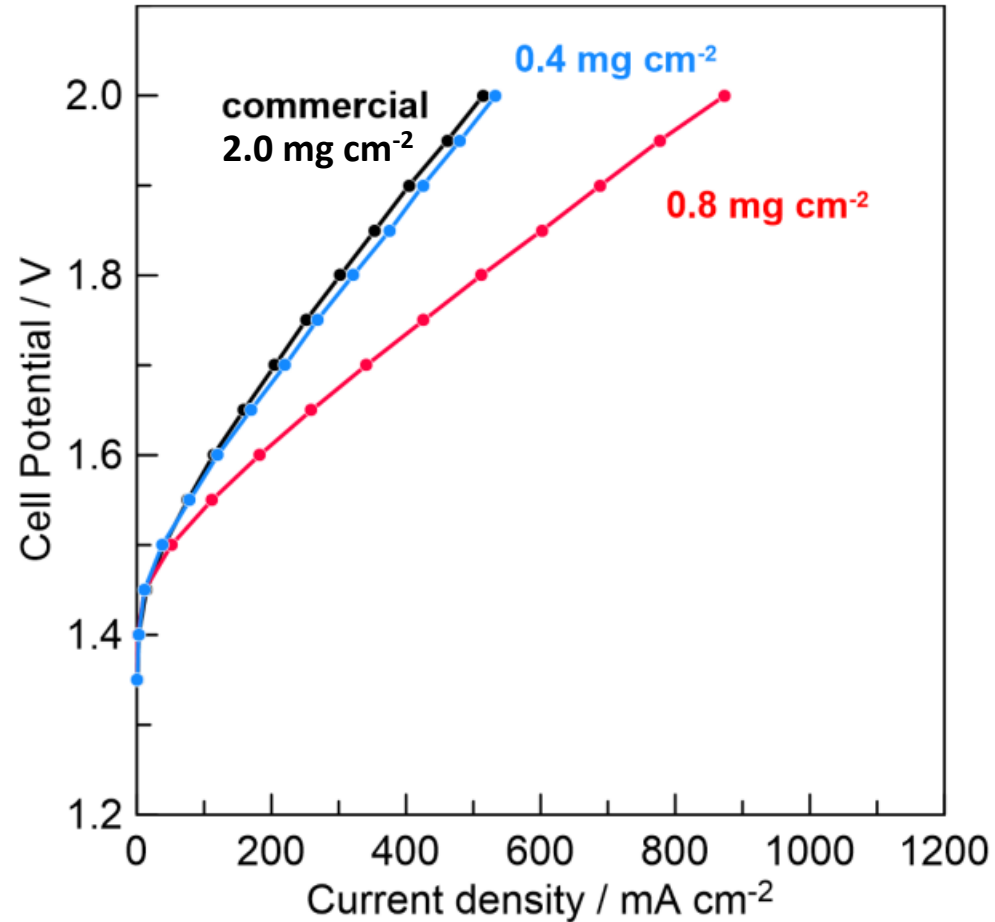
CURRENT process



VSPARTICLE process



DIFFER: CCM performance testing



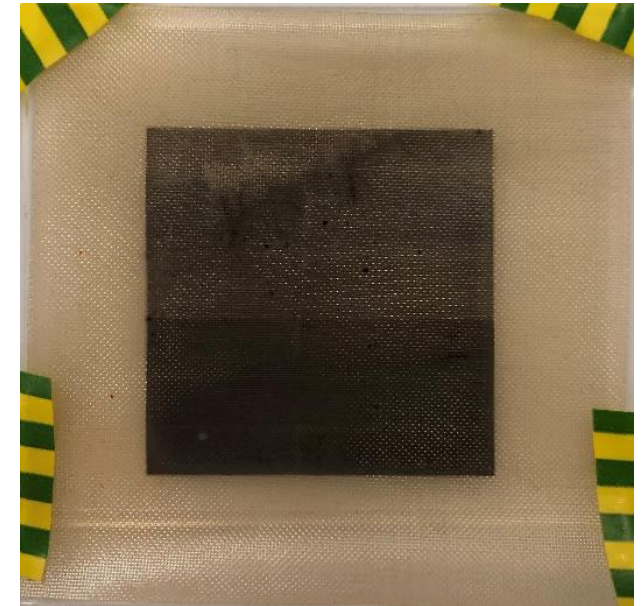
Ir loading (mg/cm ²)	Ir specific power density @ 200 mA/cm ² (g _{Ir} /kW)
2.0 (commercial)	5.88
0.4	1.15
0.8	2.35

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



TNO: CCM performance testing

- Screening of different membrane materials that VSParticle deposits the catalyst layer onto
- Testing the performance of converting CO₂ into syngas (CO and H₂) and ethylene, which enables VSParticle to iteratively optimize the settings of the production process



Next steps

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



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



vSparticle