This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101017858

Converting vibrations and environmental heat into electricity via reversible water intrusion into hydrophobic nanopores

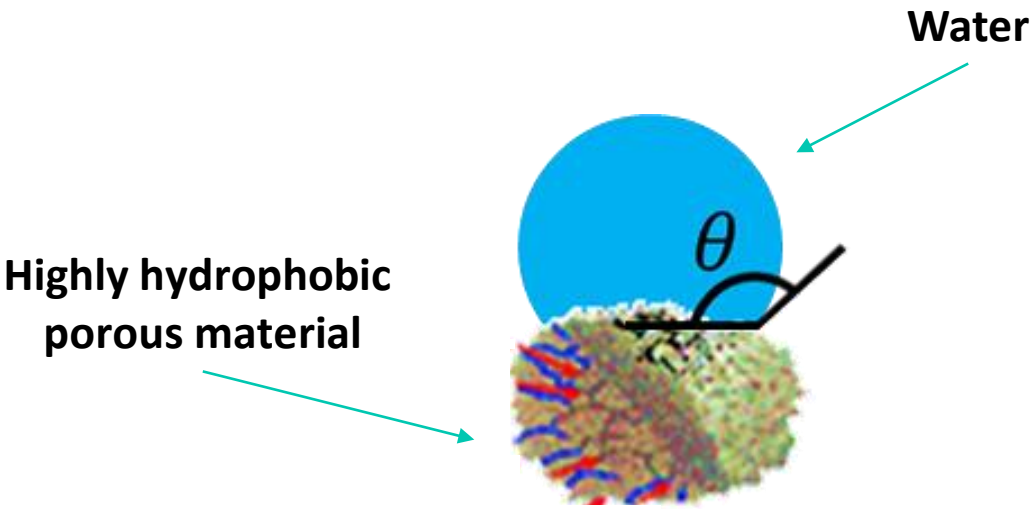
Seminar at Sapienza University of Rome
1st July 2021

CIC energiGUNE
MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE

INDEX

> Intrusion-extrusion for energy applications

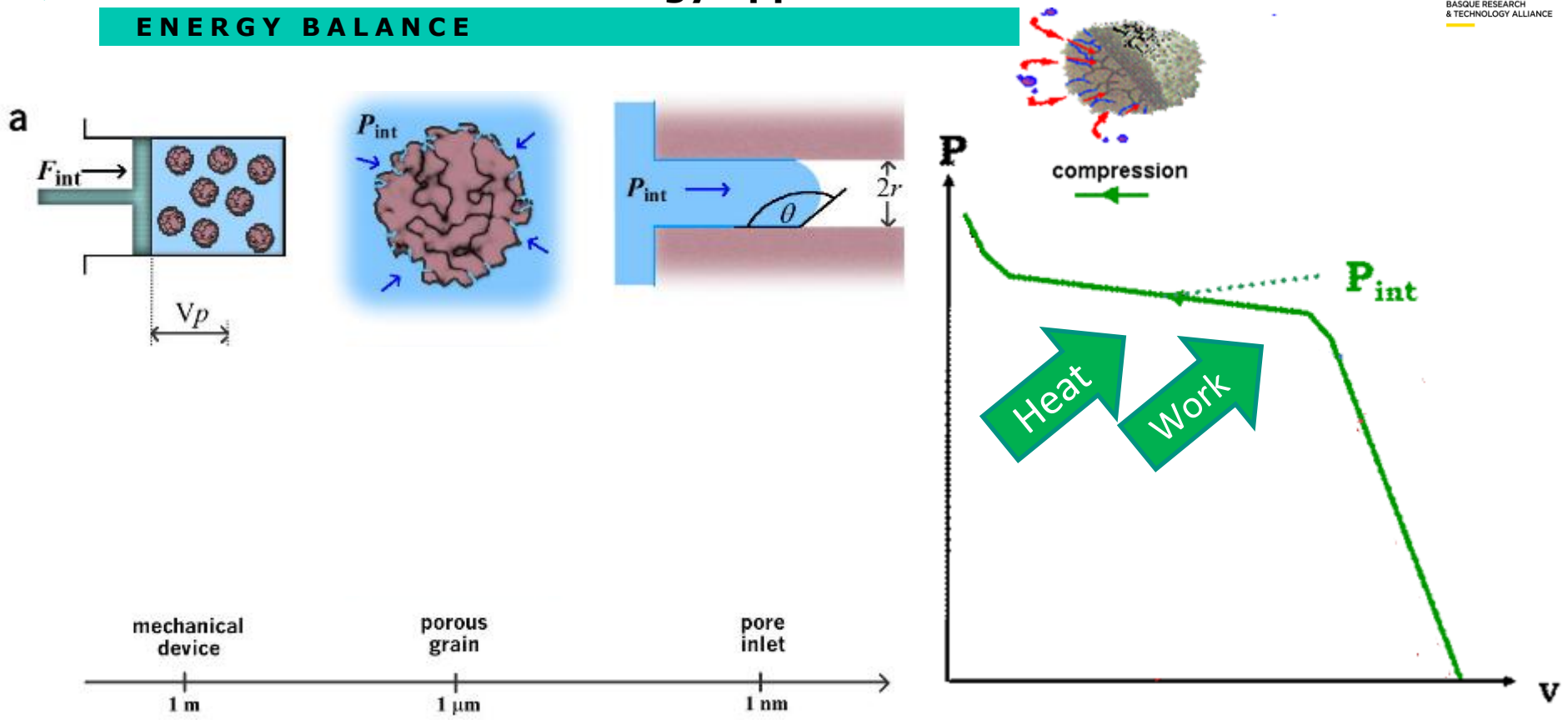
ENERGY BALANCE



$$\textbf{Non} - \textbf{wetting: } \boldsymbol{\theta} > 90°$$

> Intrusion-extrusion for energy applications

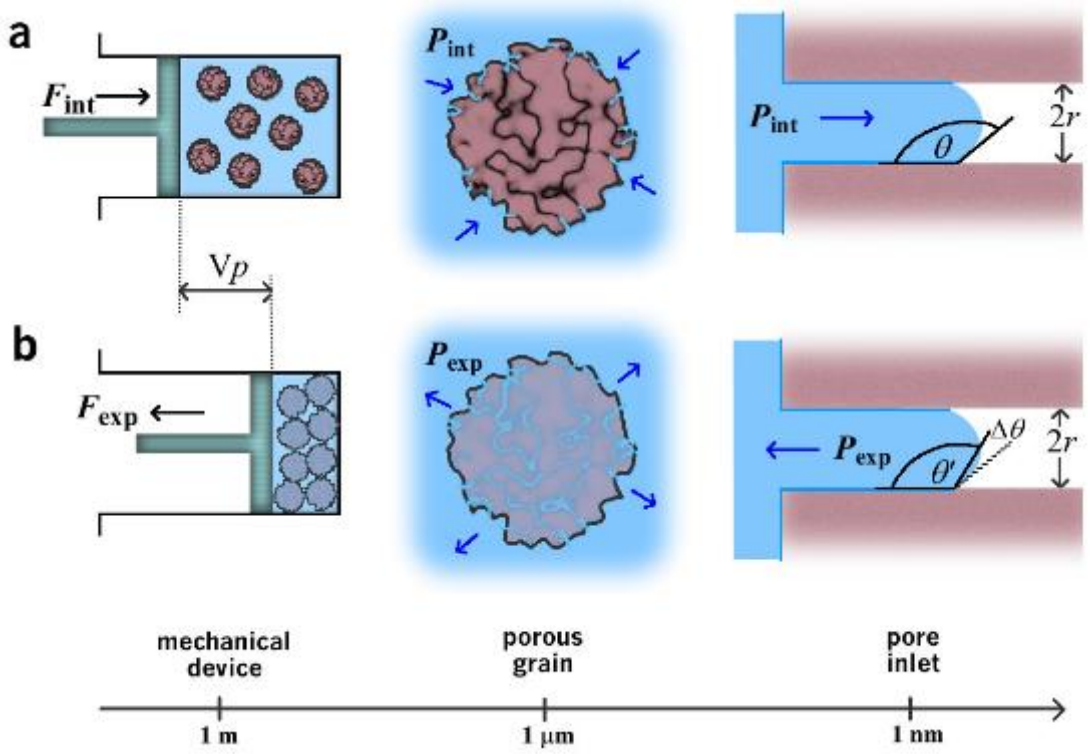
ENERGY BALANCE

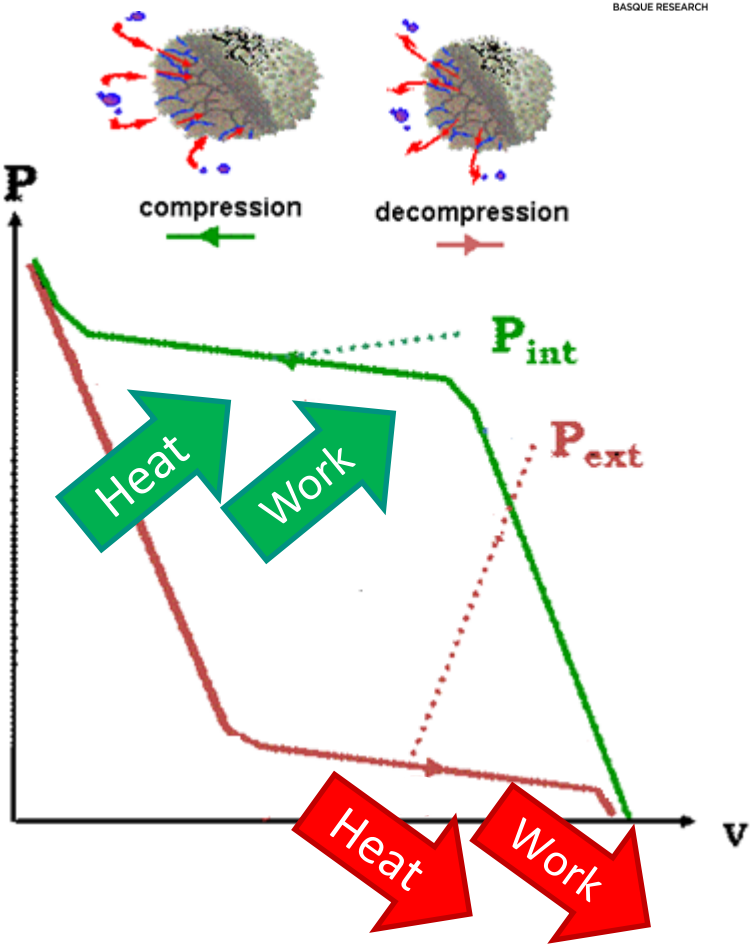


$$W_{intrusion} = P_{intrusion} \cdot \Delta V = P_{intrusion} \cdot V_{pores}$$

> Intrusion-extrusion for energy applications

ENERGY BALANCE



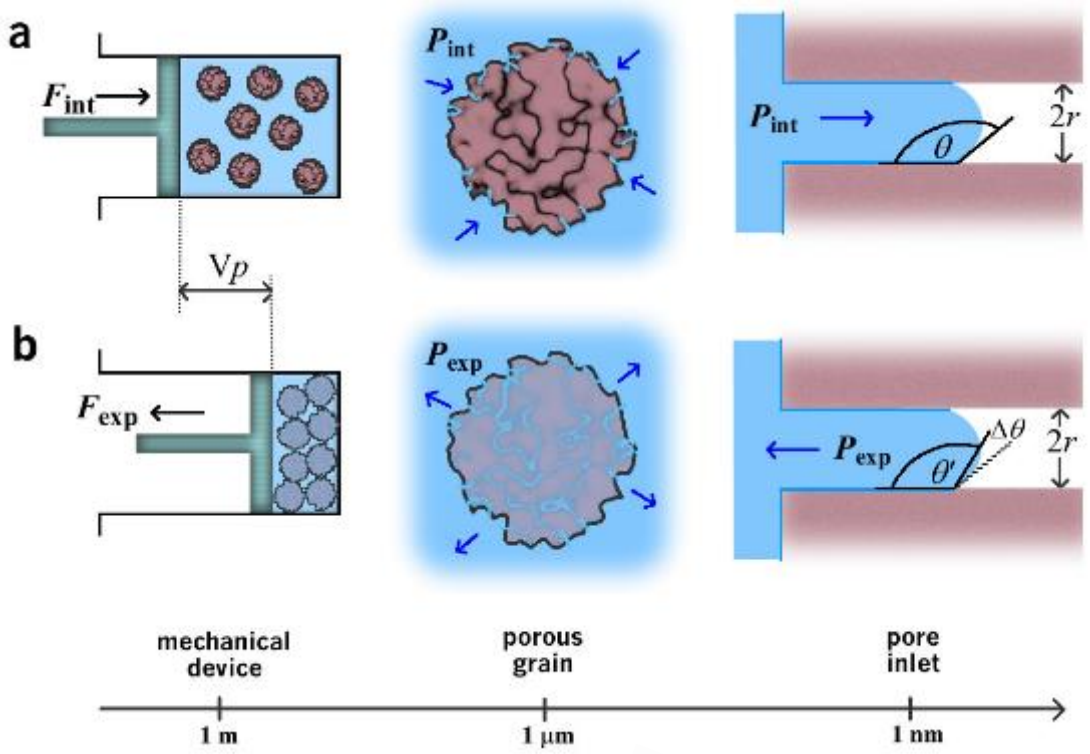


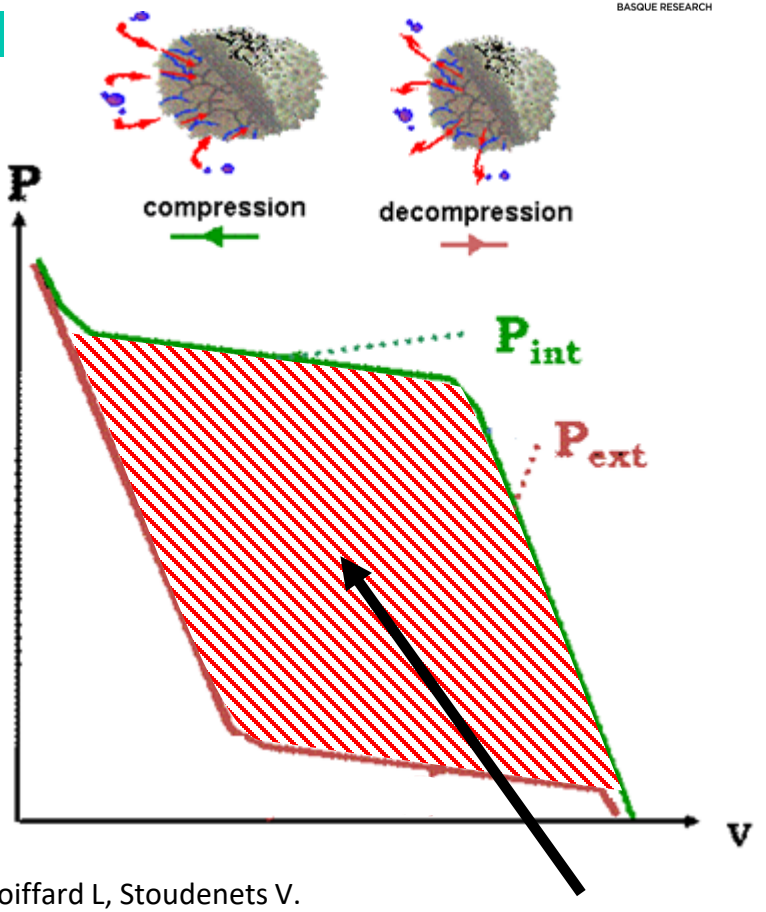
$$W_{intrusion} = P_{intrusion} \cdot \Delta V = P_{intrusion} \cdot V_{pores}$$

$$W_{extrusion} = P_{extrusion} \cdot \Delta V = P_{extrusion} \cdot V_{pores}$$

> Intrusion-extrusion for energy applications

ENERGY BALANCE





Eroshenko VA, Piatiletov I, Coiffard L, Stoudenets V. Proc. Inst. Mech. Eng. D. 2007.

Dissipated energy

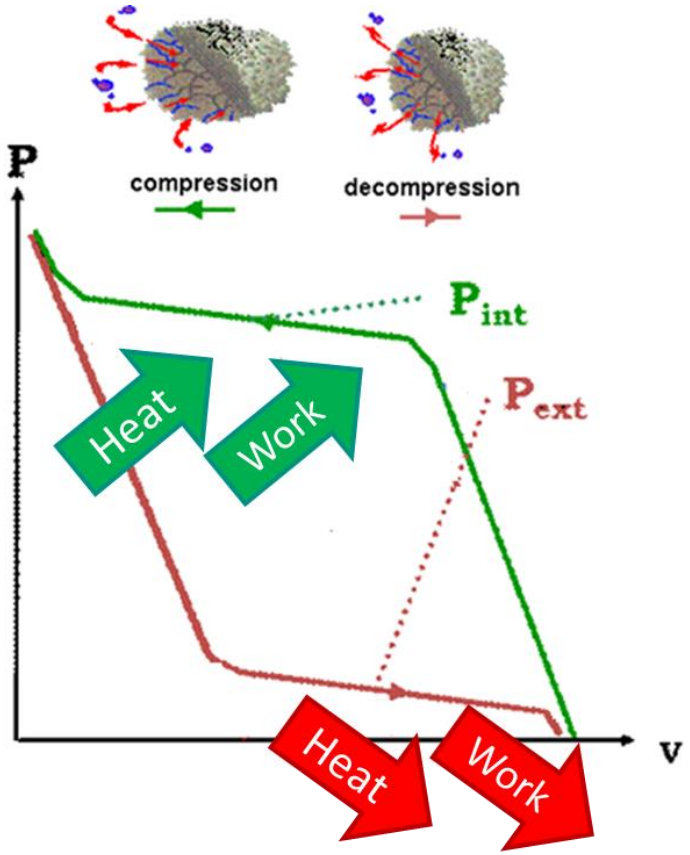
Suciu C.V. Proceedings of ISMA 2010
Suciu C. V. & Buma S. Proceedings of the FISITA 2012

> Intrusion-extrusion for energy applications

ENERGY BALANCE

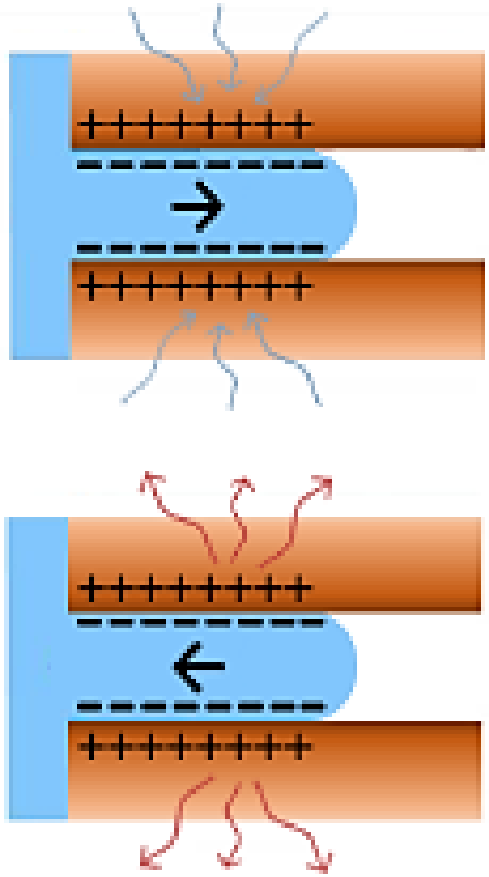
$$Work_{intrusion} + Heat_{intrusion} >> Work_{extrusion} + Heat_{extrusion}$$

2 + 2 = 1



> Nanotriboelectrification

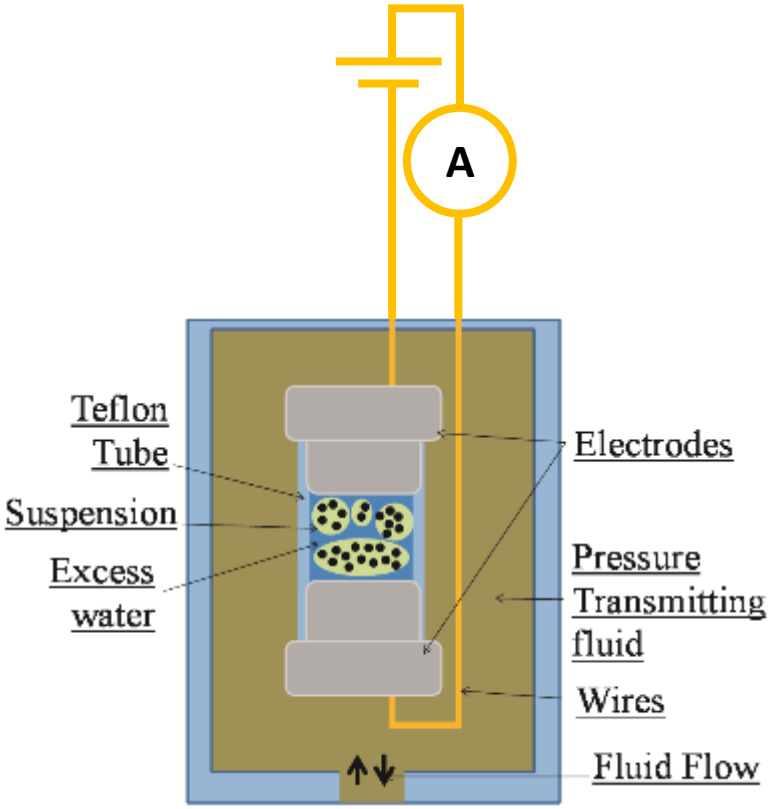
DURING INTRUSION-EXTRUSION

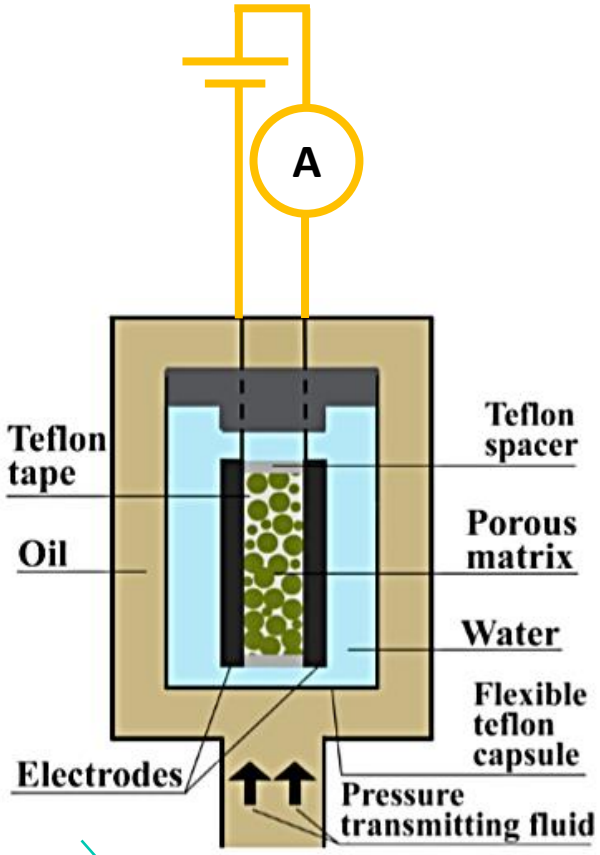


Porous materials with 500 – 2000 m^2/g are typically used for intrusion-extrusion.
That´s a lot of interface to generate charge!

> Nanotriboelectrification

ENERGY BALANCE





+ high-pressure *PVT*-calorimetry

Direct recording of

- Work
- Heat
- Electricity

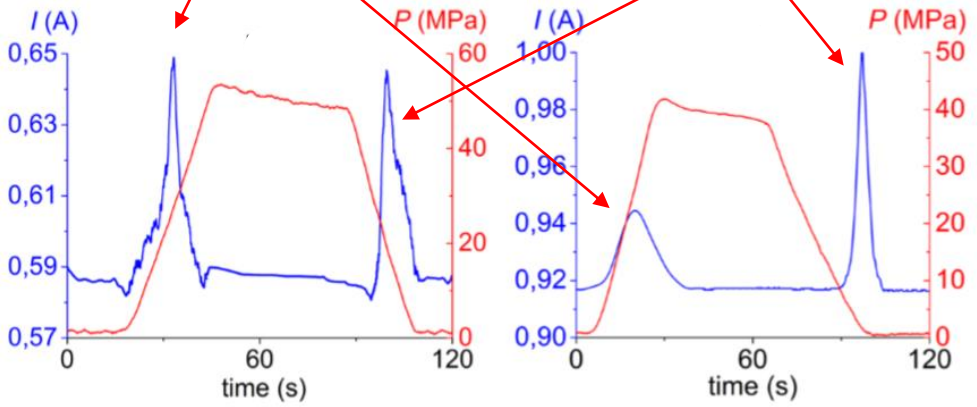
1. Grosu Y et al. 2017. ACS Applied Materials & Interfaces.
2. Lowe A et al. 2019. ACS Applied Materials & Interfaces.

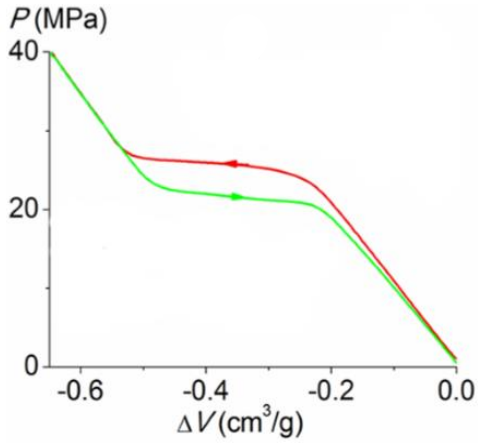
Nanotriboelectrification

ENERGY BALANCE

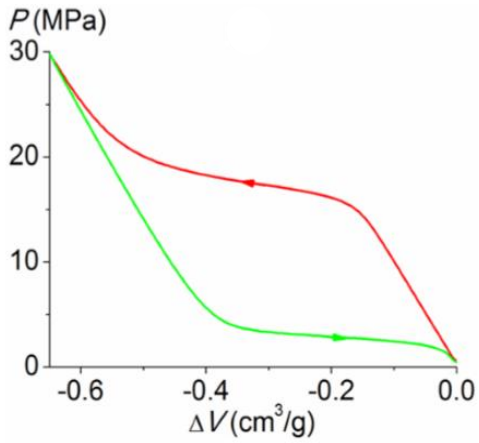
Intrusion current

Extrusion current





ZIF-8 MOF + H_2O

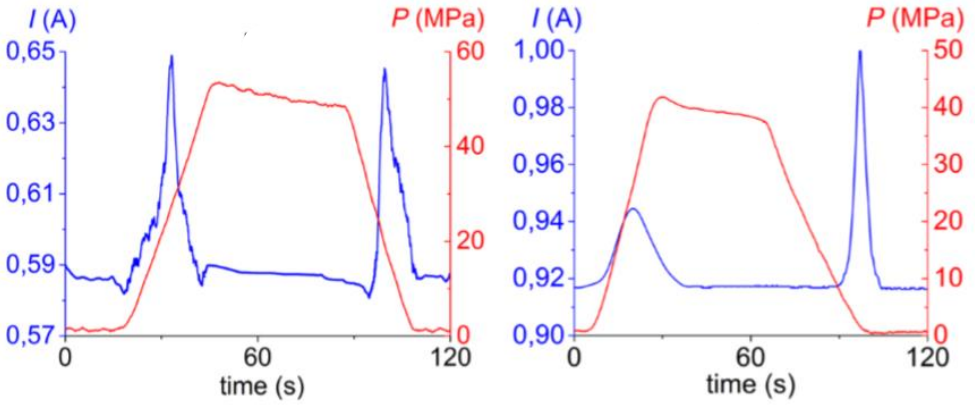


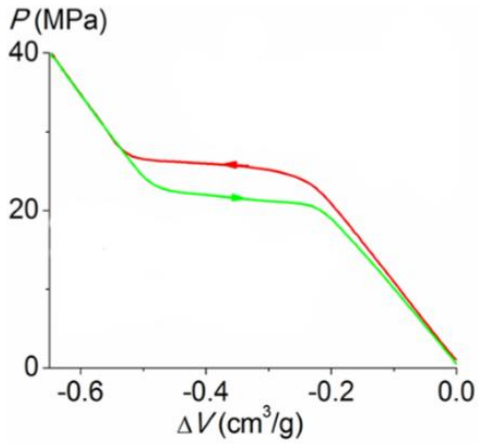
Grafted silica + H_2O

1. Grosu Y et al. 2017. ACS Applied Materials & Interfaces.
2. Lowe A et al. 2019. ACS Applied Materials & Interfaces.

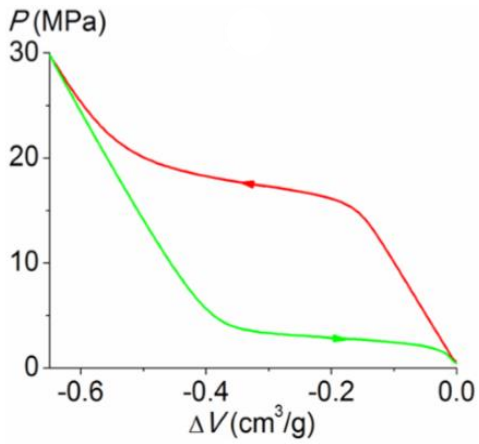
> Nanotriboelectrification

ENERGY BALANCE





ZIF-8 MOF + H_2O



Grafted silica + H_2O

Table 1. Mechanical (W), Thermal (Q), and Electrical (E) Energetic Characteristics of HLSs[a]

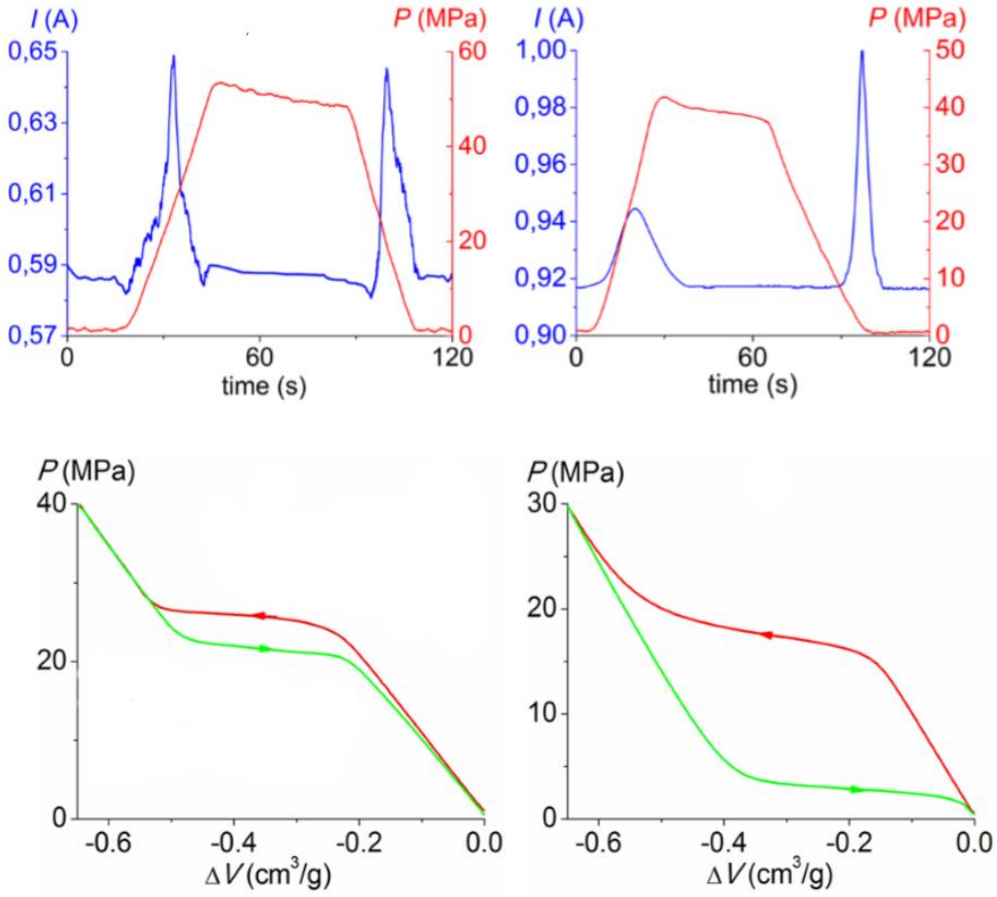
HLS	W_i	Q_i	E_i	W_e	Q_e	E_e
{ZIF-8 + water}	9.9	14.4	−1.7	−8.2	−12.7	−1.1
{WC8 + water}	8.5	10.9	−1.2	−1.3	−2.1	−1.2

$$\frac{E_{int} + E_{ext}}{W_{int} + W_{ext}} = 165\%$$

1. Grosu Y et al. 2017. ACS Applied Materials & Interfaces.
2. Lowe A et al. 2019. ACS Applied Materials & Interfaces.

> Nanotriboelectrification

ENERGY BALANCE



ZIF-8 MOF + H_2O

Grafted silica + H_2O

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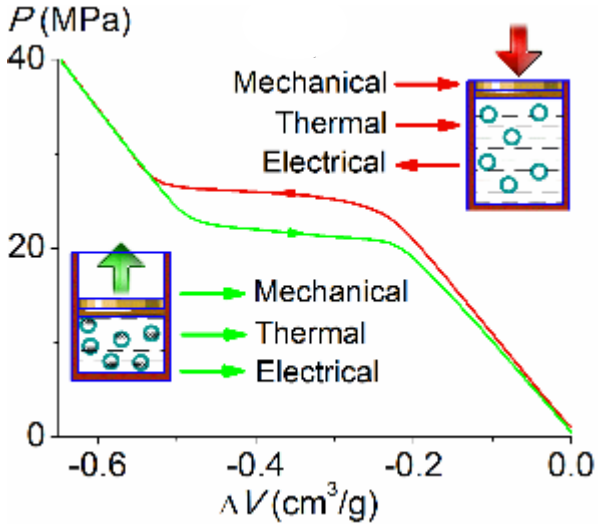
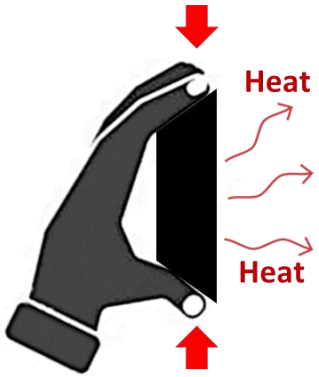


1. Grosu Y et al. 2017. ACS Applied Materials & Interfaces.
2. Lowe A et al. 2019. ACS Applied Materials & Interfaces.

Intrusion-extrusion triboelectric generator

ENERGY BALANCE

Typical working body

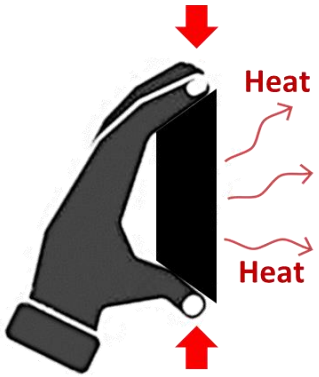


Work → Heat

Intrusion-extrusion triboelectric generator

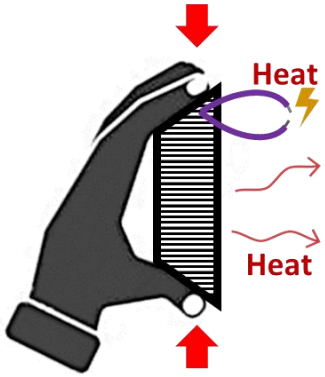
ENERGY BALANCE

Typical working body



Work → Heat

Typical Triboelectric generator

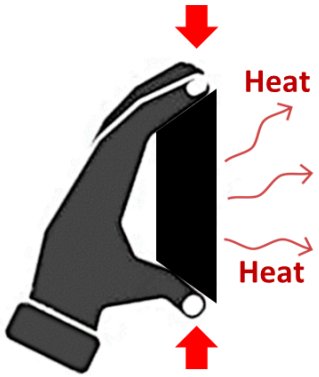


Work → Electricity + Heat

Intrusion-extrusion triboelectric generator

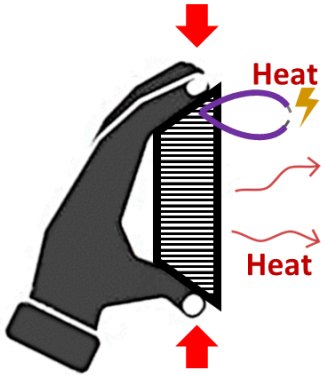
ENERGY BALANCE

Typical working body



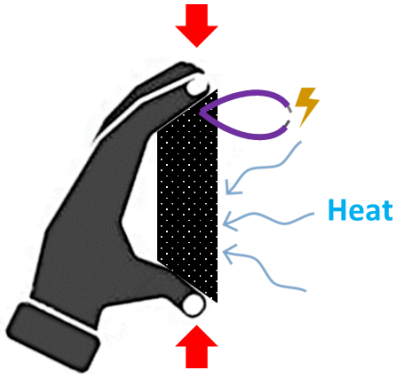
Work → Heat

Typical Triboelectric generator



Work → Electricity + Heat

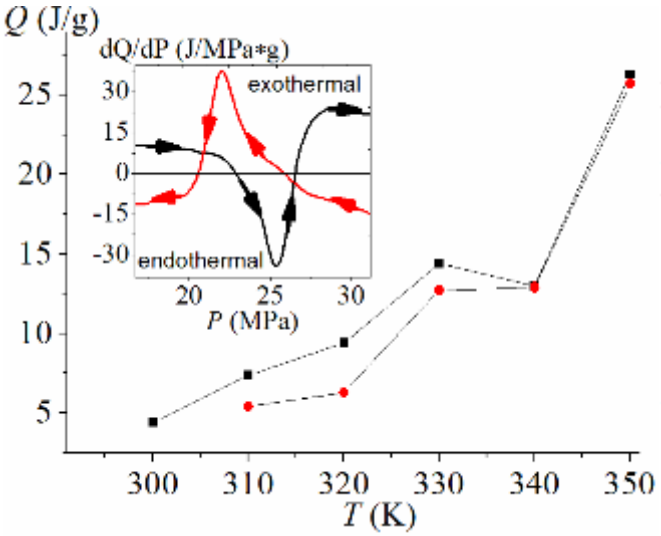
Intrusion-extrusion Triboelectric generator

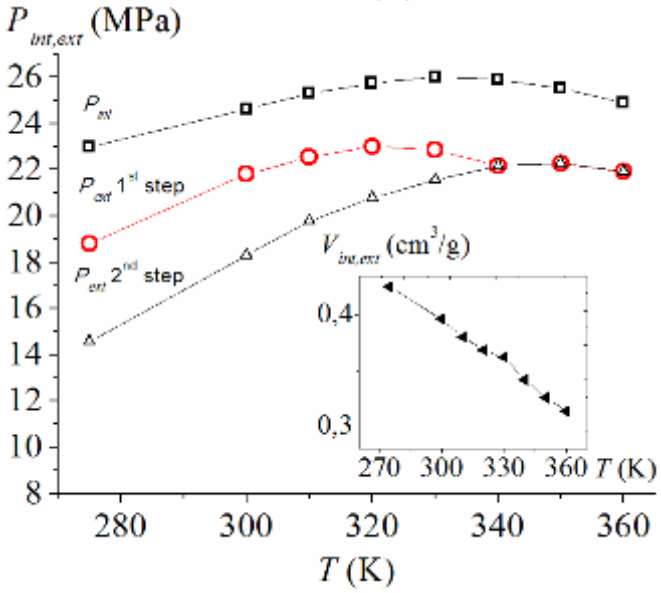


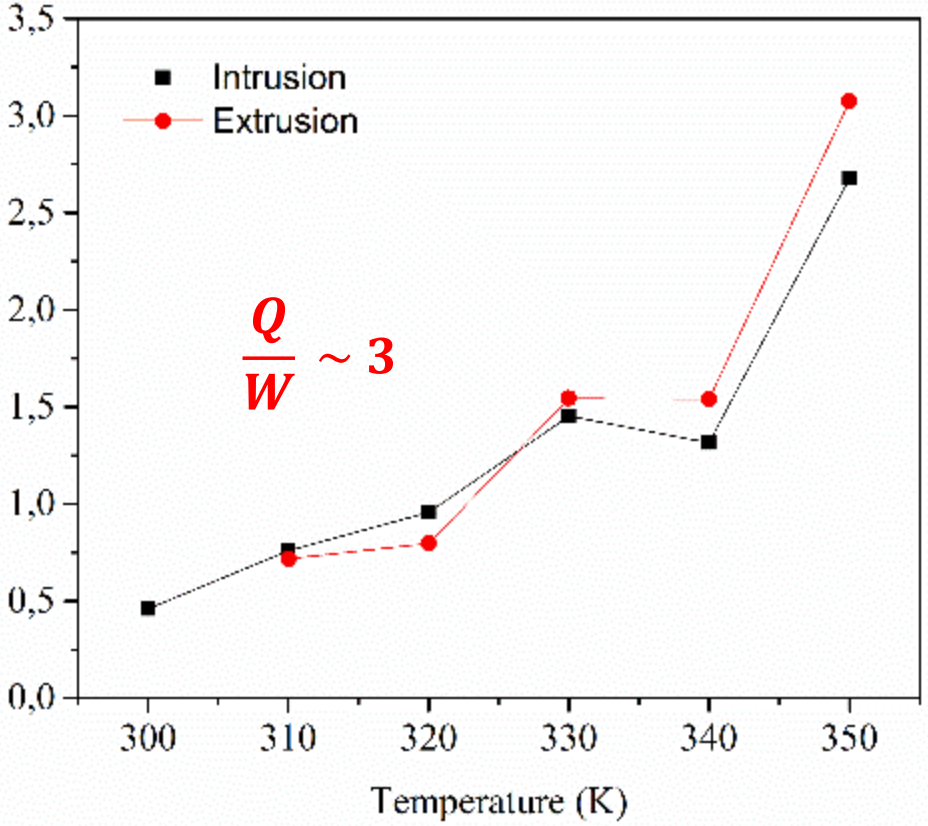
Work + ambient Heat → Electricity

$$\frac{\text{Electricity}}{\text{Work}} > 1$$

> ZIF-8 + H_2O at different temperatures





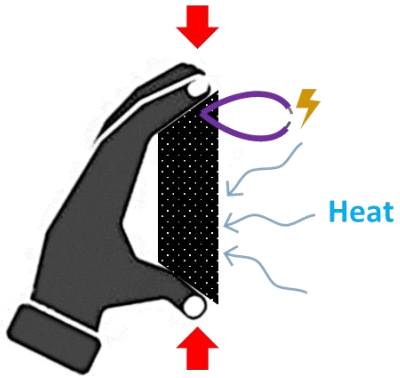


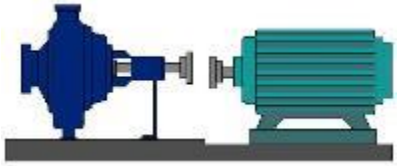
Grosu et al. 2015 Nanoscale

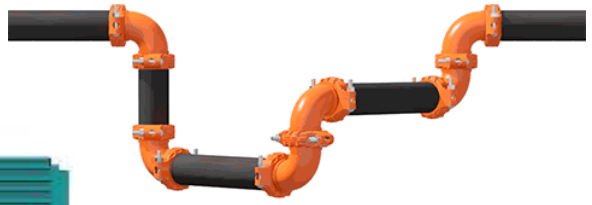
> Potential applications

ELECTRO-INTRUSION PROJECT

Intrusion-extrusion
Triboelectric generator







Work (vibrations)
+
Ambient heat

→ **Electricity**

$$\frac{\text{Electricity}}{\text{Work}} > 1$$

> THE PROJECT AT A GLANCE

DURATION, BUDGET, AMBITION

- **Budget**: 3.651.381,25 €
- **Duration**: 4 years (01/01/2021 – 31/12/2024)
- 6 partners
- H2020 Topic: FETPROACT-EIC-07-2020 – Emerging paradigms and communities

- **Ambition**:
  1. Develop a new highly efficient method for energy conversion for a wide range of applications
  2. Propose a new type of regenerative shock-absorbers and make first steps towards its implementation
  3. Generate breakthrough knowledge regarding triboelectrification and heat of intrusion-extrusion

From TRL 1-2 to TRL 4-5 by investigating the underlying physical phenomena, maximizing the electrical output and building a relevant prototype

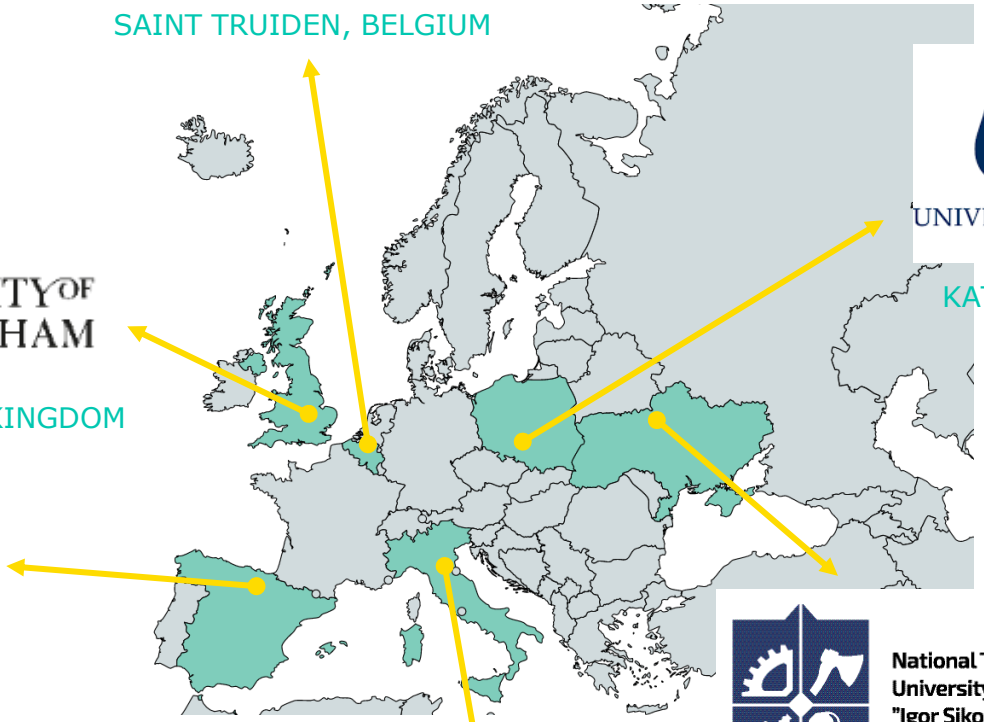
> PARTICIPANTS

THE PROJECT AS A TEAM

6 Partners
4 Universities
1 R&D Institutes
1 Company

TENNECO DRIV

SAINT TRUIDEN, BELGIUM



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BIRMINGHAM, UNITED KINGDOM

UNIVERSITY OF SILESIA IN KATOWICE

KATOWICE, POLAND

CIC energiGUNE
MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE

VITORIA-GASTEIZ, SPAIN

National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

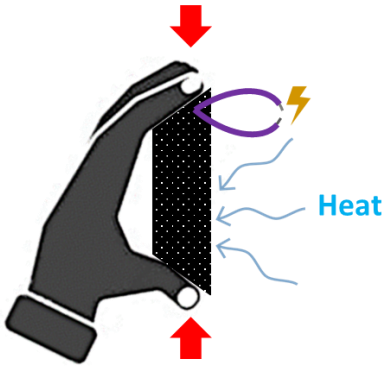
KYIV, UKRAINE

UNIVERSITY OF FERRARA - EX LABORE FRUCTUS -

FERRARA, ITALY

Conclusions

- Intrusion/extrusion of water into/from hydrophobic nanopores is accompanied by pronounced electric effects
- Such electric effects combined with endothermic intrusion and exothermic extrusion allows efficient (work + heat)-to-electricity conversion
- Considering that ambient heat is introduced into the energy balance, the ratio between input work and output electricity can be greater than 100%
- Discovered phenomena can be used for wide range of electric generators, including regenerative shock-absorbers, antivibration systems, etc.



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For more information

- Lowe A. et al. Effect of Flexibility and Nanotriboelectrification on the Dynamic Reversibility of Water Intrusion into Nanopores: Pressure-Transmitting Fluid with Frequency-Dependent Dissipation Capability. *ACS Applied Materials & Interfaces*. 2019

- Grosu Y. et al. Mechanical, Thermal, and Electrical Energy Storage in a Single Working Body: Electrification and Thermal Effects upon Pressure-Induced Water Intrusion–Extrusion in Nanoporous Solids. *ACS Applied Materials & Interfaces.* 2017

- **Electro-intrusion project FET Proactive H2020 call**

https://www.electro-intrusion.eu/en

- We are open for collaboration: ygrosu@cicenergigune.com

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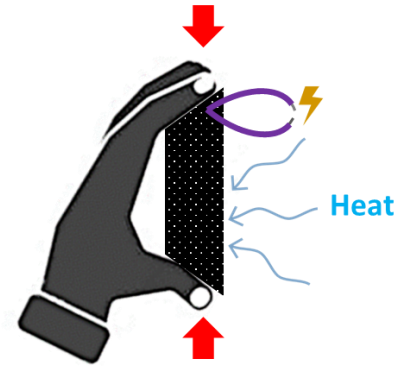

GRACIAS · THANK YOU · ESKERRIK ASKO

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Group leader

ygrosu@cicenergigune.com