



Fully oxide-based zero emission & portable energy supply

A clean way to power wireless IoT devices



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Powering wireless IoT devices

The Internet of Things (IoT) enables the communication and interaction between different devices and is the backbone infrastructure behind many future-shaping concepts such as Smart Cities and Work 4.0. To be embedded into vehicles or machines, or to be placed into remote locations away from the power-grid, IoT devices need to be fully wireless, lightweight, and energy-autonomous. Providing efficient solutions for powering wireless devices is the key for unlocking the true potential of the IoT.



“ Within the project FOXES we pursue an integrated and environmentally-sustainable approach to the problem of powering wireless IoT devices. Our goal is to realize what we call a Power Cube – an integrated $2 \times 2 \text{ cm}^2$ system, which combines a high-efficiency solar cell with a multilayer capacitor and an energy management circuit. And we want to achieve this using only low-cost and environmentally friendly processes and materials, so that the Power Cube will have no negative environmental impact at its end of life.

Marco Deluca, Project Coordinator
(Materials Center Leoben Forschung GmbH, AT)

FOXES Goal

The goal of the EU-funded project FOXES is to develop *FOXES Power Cube* – a clean, compact, low-cost and scalable high-energy density solution for powering IoT devices such as wireless sensor nodes.

The *Power Cube* combines a high-efficiency solar cell with a multilayer thin-film capacitor (TFC) with high energy density. Coupling the two devices with an energy-management circuit allows to store the solar-energy surplus in the capacitor, for being used when solar light is not available. The energy-management circuits regulate the intake and discharge of energy, ensuring a positive energy balance for powering the sensor node.

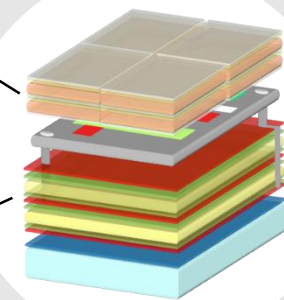
All components of the *Power Cube* are 3D monolithically integrated using low-cost and sustainable processes, minimising the use of harmful chemicals or critical raw materials.

Targeted energy generation: $> 250 \text{ mJ/day}$

FOXES Power Cube

Fully lead-free perovskite solar cell with $> 10\%$ efficiency.

Electronics based on graphene and metal-oxides for energy management circuit.



Lead-free perovskite multilayer thin film capacitor with high energy density ($> 50 \text{ J/cm}^3$).

Substrate

A challenging test bed

The test bed of *FOXES Power Cube* will be an air monitoring system. *FOXES Power Cube* will be coupled to low-power light-activated gas sensors with less than 3 mJ/day energy consumption, and to the necessary ASIC/data transmission devices for sensor operation. The combined energy supply – sensor system will be tested in the lab against gas mixtures during variable irradiation conditions. At the end of the project, the *Power Cube* will be used to power a net of wireless air-quality sensors in the urban area of Barcelona.

“FOXES demonstrators will allow an unprecedented level of spatial resolution in monitoring emissions, facilitating the identification of problematic spots and the implementation of effective countermeasures.”

J. Daniel Prades (Universitat de Barcelona, ES)

Technical objectives

Energy generating module

- Lead-free perovskite solar cell
- Energy efficiency: > 10%,
- Energy generation: > 6 $\mu\text{W}/\text{cm}^2$ (indoor illumination conditions, 400 lux)
- Output voltage: 4 V

Energy storage module

- Lead-free perovskite multilayer thin-film capacitor
- Energy density: > 50 J/cm³
- Full-capacitor charge: > 0.6 mJ (at 4 V input voltage)

Energy management circuit

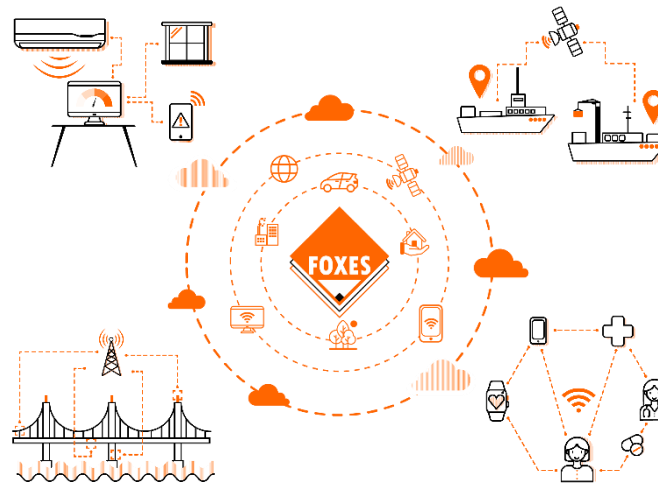
- Ensure full energy-autonomous operation of the IoT node

Gas sensors & IoT bundle

- Light-activated semiconductor gas sensor with operation power < 10 μW
- Sensor node with operation power < 50 μW

Scaling up FOXES technology

The long-term vision of FOXES is to produce *FOXES Power Cube* as a modular system that can be custom-designed according to the application needs. Stand-alone energy supply systems could be constituted by one or more cubes connected in parallel over a large surface, but still maintaining portability (e.g. 10 x 10 cm²). This will open virtually infinite possibilities of applications, targeting especially IoT devices where lightweight and low-cost energy generation is decisive, such as for sensors for autonomous driving, aeronautics, industrial process automation, GPS systems, wearables (e.g. smart watches). A roadmap for scaling up *FOXES Power Cube* will be defined within the project.



Sustainability

Sustainability is one of the keywords of the project. *FOXES Power Cube* will be free of toxic elements and with minimized use of rare raw materials. We strive for developing economically viable and eco-friendly fabrication processes without toxic or harmful substances as precursors.

FOXES Power Cubes will be core enablers for IoT devices to increase the efficiency of transport and industrial processes, reducing fuel consumption and CO₂ emissions.

Project fact sheet

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