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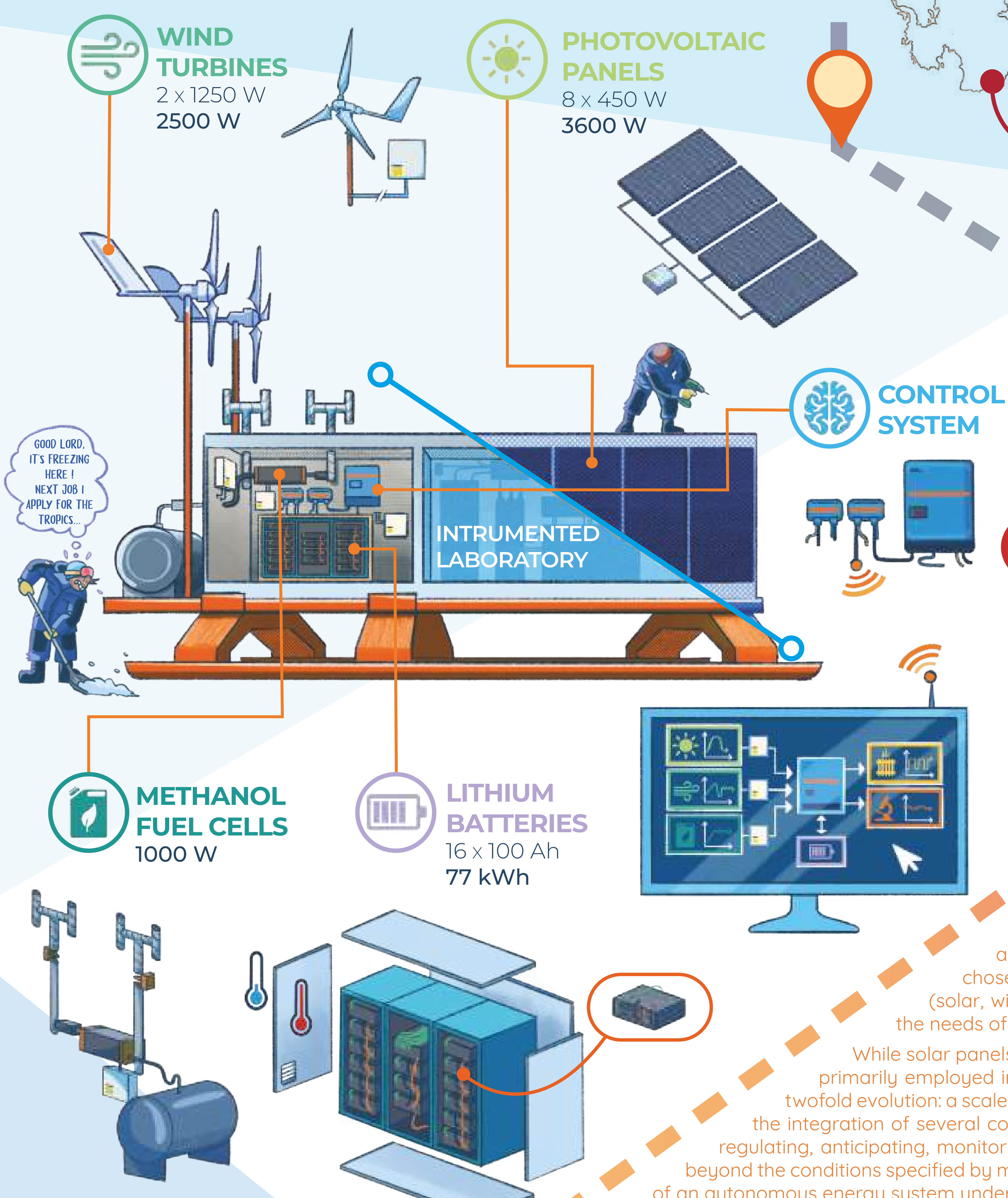
AUTONOMOUS INSTRUMENTED STATIONS IN THE HEART OF ANTARCTICA : THE ENERGY MIX AS A ROBUST SOLUTION TO THE CHALLENGES OF THE ANTARCTIC CLIMATE AND ITS SEASONALITY

"AWACA" PROJECT

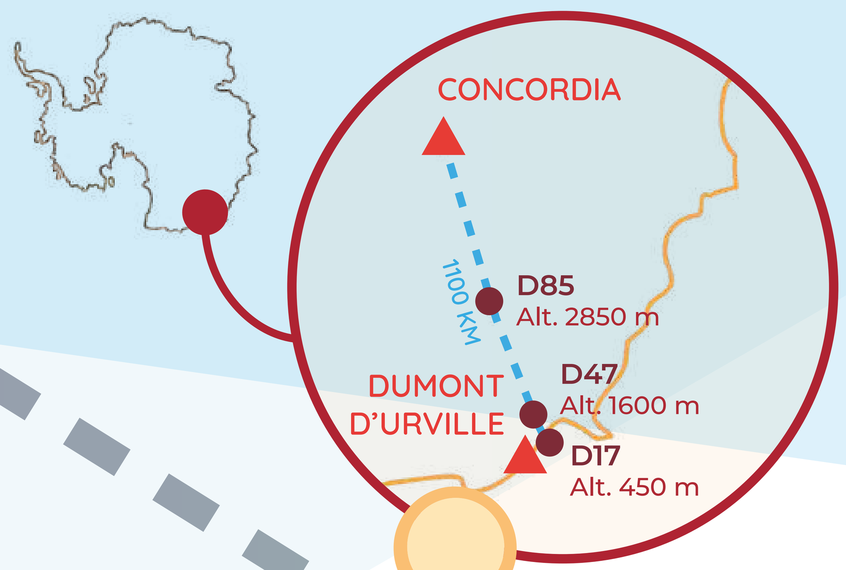
The AWACA research project aims to understand the atmospheric water cycle in Antarctica and the processes that control precipitations and snow accumulation. Through an unprecedented and ambitious measurement campaign conducted from the Antarctic coast to its Plateau, it provides the observations needed to improve the representation of these processes in climate models. These advances will enable us to improve our predictions of future changes in the Antarctic ice sheet and sea level.

To conduct these field measurements, we had to design and deploy five observation platforms equipped with instruments along a 1,100-km transect in East Antarctica, between Dumont D'Urville and Concordia stations. Three of these units are located at sites isolated from any human infrastructure, visited only a few days a year during dedicated expeditions, and therefore operate completely autonomously.

TECHNOLOGIES



ENCOUNTERED CHALLENGES



An extreme environment

Antarctica is one of the most challenging environments in the world for energy systems. Extreme sub-zero temperatures, strong and erratic winds, blizzards and drifting snow, storms, snow accumulation, high altitude, and the alternation between polar day and polar night all combine and intensify throughout the year. In this context, addressing one challenge can exacerbate another, forcing constant trade-offs in the design of technical solutions.

The simultaneous operation of several complex systems

The power module in each unit is designed to supply power to six instrumented lines, as well as all the support systems necessary for their proper operation (heating, communications and lighting), 365 days a year. To achieve this, it combines several energy production, storage, and conversion technologies to meet the challenges of the Antarctic environment: photovoltaic panels, wind turbines, methanol fuel cells, and lithium batteries. While we have mastered each of these technologies individually, integrating them into an autonomous system requires a specifically developed control system. Dedicated algorithms coordinate the various systems, optimize energy flows, and ensure a continuous power supply despite the variability of resources and extreme conditions.

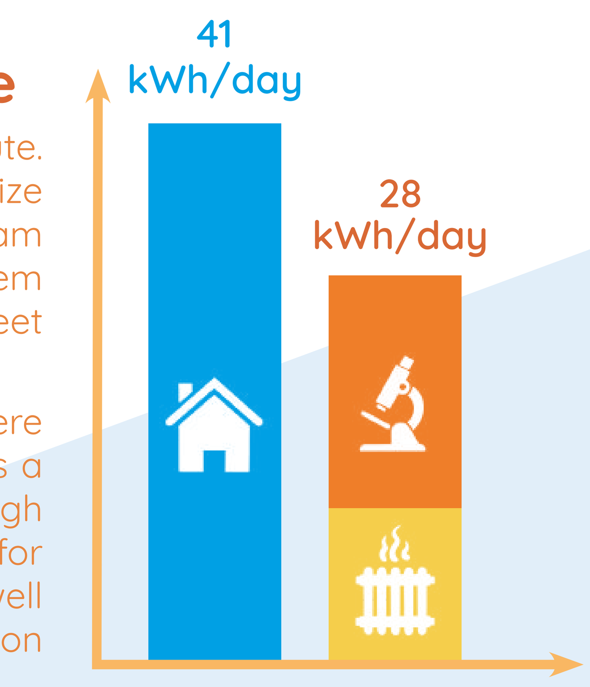
Isolated facilities that must operate autonomously

Apart from a few days of annual maintenance, physical intervention is not possible on the modules. Remote monitoring therefore becomes the only way to control the equipment, perform reliable diagnosis, and prepare for future interventions. No original design of those technical systems allow them to operate continuously without human intervention: so we had to anticipate every procedure, every control strategy, and every failure scenario to ensure autonomous operation throughout the year.

Why this is an innovative prototype

This energy module marks a first for the French Polar Institute. Deployed far from inhabited stations, any failure could jeopardize an entire season of measurements in this high-risk project. The team chose to develop a full-scale prototype; combining hybrid energy system (solar, wind, batteries, and a methanol fuel cell) designed specifically to meet the needs of scientific laboratories.

While solar panels and batteries already have quite long history in Antarctica, they were primarily employed in low-power systems with simpler architectures. This project marks a twofold evolution: a scale-up in the power levels deployed and an increase in complexity through the integration of several complementary technologies. This evolution requires new strategies for regulating, anticipating, monitoring, and supervising interactions between equipment. Operating well beyond the conditions specified by manufacturers, these systems provide unique insights into the operation of an autonomous energy system under real polar conditions.



Average daily energy consumption of :
A single family's home in Europe
One AWACA's unit

FEEDBACK AND FUTURE PROSPECTS

After two years of operation, both the **successes** achieved and the **limitations** encountered have helped identify the main technological bottlenecks, improve our understanding of equipment behavior **beyond nominal operating conditions**, and develop **targeted adaptations**. System **robustness** therefore depends not only on equipment reliability but also on **adaptive energy management**, including load prioritization, controlled degradation of non-essential functions, and preservation of critical operations until sufficient energy resources become available again. In this context, **energy efficiency** and **demand reduction** are as **crucial** as increasing generation capacity.

The performance achieved during summer and the shoulder seasons validates this approach. However, the Antarctic winter remains the greatest challenge, where **every kilowatt-hour saved strengthens system resilience** and ensures the continuity of scientific observations.

Future developments will focus on increasing energy capacity, reducing the unit's energy demand, and **optimizing** the management of **available energy** to allocate a **greater share to scientific instruments**. These advances pave the way for a **new generation** of autonomous and resilient Antarctic **observatories**, supporting the progressive **decarbonization of scientific operations**.

POSTER

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