DE-centralised Cloud labs fOr inDustrialisation of Energy materials

Popular Science Article #1

A map to define a digital laboratory platform

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Funded by the European Union

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The speed of technological development is no longer in line with the challenges we are facing. Global warming, the finite nature of natural resources, and the geopolitical constraints they impose: these are all elements that require immediate solutions. Unfortunately, the inertia of our scientific approaches leads to slow progress. This is not the result of our inability to innovate, but rather the fact that, in a world where technologies have reached unprecedented complexity, their development continues to follow empirical and, above all, isolated approaches. Numerous research institutes possessing complementary expertise and knowledge operate independently. They thus deprive themselves of tools and know-how that would significantly increase the speed of progress. This deprivation does not result from a deliberate choice, but rather from a lack of awareness of capabilities beyond the borders of their institutes and the absence of tools to easily communicate with them.

This article, guided by a cartographic metaphor, focuses on approaches aimed at simplifying this communication through the lens of developing new materials for the energy sector.

The art of cartography has always been essential to the development of humanity. It allows us to define the world around us. It offers us the possibility to identify which paths would be the safest or the fastest. Our history is marked by a desire to complete or shape maps. At first glance, it would be easy to relegate cartography to an art of the past. However, the necessity for humanity to create maps has never been greater. The approaches inherent in the development of new materials for energy usually follow an empirical logic. The given material is developed, then characterized in terms of activity and physico-chemical properties, and if its performance is promising, an attempt at rationalization is made based on theoretical calculations and/or 'operando' studies *i.e.,* conducted under operational conditions, while the material is scaled up to be evaluated in a configuration closer to commercial reality. This development cycle is costly, both in terms of time and finances, and requires a wide range of skills often spread across the globe. Thus, because of economic and efficiency interest, it is also necessary here to map out all these tools and methods capable of contributing to the development of a new material, to determine if there is an overlooked path whose adoption would **significantly reduce the time required to build the future**.

What is the essence of this mapping and the resulting maps? The cities are methods, ranging from those necessary for the fabrication of materials of interest *e.g.,* are they prepared using a pyrolytic or colloidal approach; are they shaped via doctor blading, spraying, etc, to their evaluation in the commercial system e.g., how do they perform when tested in a fuel cell; and the roads, bridges, crossings, are just as many links between them. They are sometimes known, as they have always been used within the framework of this empirical approach described earlier; sometimes they are still to be identified. These are the unknown paths whose discovery could drastically shorten the distance – and the number of cities – to cross to reach an identical final result: a better material. Such a map would also allow us to see what is missing; the paths to be created to link distant methods, the knowledge gaps. The value of such a map lies in the fact that it provides an overview of the technological landscape, enables the identification of an optimal rather than an empirical path, and consequently facilitates the development of a technology in many respects. This raises the question: **how do you build it?**

First, it is necessary to **describe the elements that it is composed of**. It is about **defining each 'city-method' in a simple, coherent, accessible, and universally accepted manner,** i.e., constructing a set of descriptive elements that allows everyone to easily understand what the method corresponds to. Such a task is not trivial as we are all accustomed to defining the methods around which our research revolves, using a set of criteria that is unique to us, reflecting our own assessment of what is important based on our expertise. This often differs from the expectations and needs of others. For instance, a theorist will not identify the same key descriptive elements as an industrialist. Once each of these 'city-methods' has been described, **they must be situated within the network: which routes should lead into and out of this city?** These are the **'inputs' and 'outputs'**, *i.e.,* the data required for the method to operate, and the information it generates (*e.g.,* does this method require current densities to operate; is its main output microscopy images). They are the cornerstones of such a map, as they enable us to understand how to link the different cities: the output of one method will connect to the input of another if they are identical. In this respect, **the existence of a common nomenclature is essential**.

This is how points of interest and the network connecting them are created; however, the topography remains unknown, as do the distances between the cities. What do they represent? They reflect the **accessibility of a method**, *i.e.,* how costly, difficult to use, and useful it is. A method that is complex to integrate into the network will be seen as difficult to access, whereas a method that is simple, inexpensive, and easily understandable will be highlighted. In our cartographic metaphor, this is the difference between a city atop a mountain and a road junction in the middle of the plains.

Within this map, it is then possible to identify an **optimal pathway for the development of a new material**, based on the distance and ease of access between the various 'city-methods' that separate its manufacture from its use within the commercial system. As mentioned earlier, this advantage is combined with another – the ability to easily identify missing methods, the knowledge gaps whose resolution would enable the creation of alternative pathways even better suited to accelerate technological development.

The creation of such **maps must break free from the constraints of isolated research, centred around the tools of a single research institute, and extend beyond borders to encompass all the expertise required for their completion**, regardless of geographical location. This necessity gives rise to new challenges. The data produced and required by the various 'city-methods' comes from remote laboratories. Thus, the **creation of a digital hub** is necessary. There, all the methods will be brought together, and **data will be able to flow in a standardized format**, enabling the seamless exchange of outputs and inputs. Thus, beyond the topology, places of interest and the routes between them, **a means of navigating this map is created** and, with it, the hope of **facilitating the development of new technologies** – via a concept not limited to the field of fuel cells and energy where it is currently being developed, but one destined to extend across all areas of research.

Building such as map was done as part of the European DECODE project (*DE-centralised Cloud labs fOr the inDustrialisation of Energy materials*). The first phase of the project consisted in gathering – and, where necessary, creating – the elements required to produce such maps. Consequently, more than **130 methods**, across **16 European and Canadian research institutes**, were identified, standardised and linked, thereby enabling the identification of **13 knowledge gaps** in the development of materials for low-temperature fuel cells.