VOLUME 8 EXECUTIVE SUMMARY

CLEAN, SAFE AND EFFICIENT ENERGY

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PREFACE

Contemporary society is undergoing a period of radical transformation in the way it meets growing energy demand. The gradually increasing environmental impact of conventional sources of energy production (coal, oil, gas, nuclear fission...) and its consequences on our lives is making people more aware of the need both to find alternative, clean ways to obtain power and use more efficient methods to manage existing resources and their emissions.

In this respect, public opinion around the world increasingly demands solutions to either sequestrate or stop the generation of harmful byproducts, such as the greenhouse gases causing climate change, or the toxic compounds that are increasingly affecting natural ecosystems and public health, as evidenced in the growing number of respiratory diseases in urban populations. This change of perception is reflected in the promotion of energy transition policies.

The current Strategic Theme identifies the main key challenges for the global implementation of a clean, safe and efficient energy system. Herein, we try to define the position of our institution as regards the main scientific and

technical challenges that mankind will face in the coming decades in the involved fields. Our goal is three-fold. First, to identify those challenges, which will be established based on previous reports by renowned international sources and the professional experience of CSIC's experts that have contributed to the writing of this Strategic Theme. This task is prospective and, as such, implies both projection, which will be based on extrapolation of current trends, and a certain degree of educated and informed prediction. Second, to establish the current position of our institution in addressing these challenges, taking into account the work that has already been carried out and the expertise, infrastructure and human resources that are currently available. This analysis will be based on different parameters, such as scientific (research articles) and technological production (patents), as well as relevant scientific and industrial projects. Our third and ultimate goal is to make recommendations on how our institution should proceed in the future with respect to each of the identified challenges. Ideally, we will be able to devise a roadmap to consolidate or establish CSIC in a position of leadership in one or several central aspects of the Challenges. In such cases, specific measures concerning human resources, infrastructure or organizational issues will be proposed. In some other cases, our conclusion will be that the challenge should not be addressed, either because there are other actors at a national level that can tackle them more suitably, or because the effort or time required to properly position ourselves is simply too large to be realistic.

The extraordinary multidisciplinary character of the subject dealt with in this Strategic Theme required the participation of experts in very diverse fields. A full list of contributors and their affiliations can be found at the beginning of each Challenge. CSIC is expected to play an important and successful role in meeting these challenges, counting on a significant scientific network, including infrastructure and highly influential researchers in the Challenges identified in the current Strategic Theme.

The Strategic Theme is divided into nine challenges that comprise the most relevant issues ascribed to the fields of Clean, Safe and Efficient Energy. The first challenge deals with *Renewable Energy Production*, describing the key sources that provide a partial solution for the generation of clean and inexhaustible energy. Another important issue is *Efficient Energy Storage*, incorporated in the second challenge, which comprises a required group of technologies that complement the intermittency of renewable energies, enabling flexibility and distributed generation at different scales. Energy saving is a

highly relevant topic as regards the preservation of natural resources, and is included in the third challenge, *Energy Efficiency and Harvesting*. Moreover, although replacing non-electrical energy, typically relying on fossil fuels, systems with electrical technologies has received much attention recently, *Industry Electrification and Grid Management*, considered in the fourth challenge, is a crucial objective for achieving full decarbonisation of industry and society. The importance of biomass as a renewable energy resource with reduced greenhouse emissions is covered in the fifth challenge, identified as *Valorization of Biomass as Energy Source*. On the other hand, the difficulty of decarbonizing several energy sectors may be palliated by the enhancement of carbon capture technologies that compensate for currently unavoidable fossil emissions, which is analysed in the sixth challenge, *Decarbonizing Energy Sectors Addicted to Carbon: CCS and CCU*. The relevance of Catalysis as a key enabling technology for many challenges in the Energy Area is analysed in the seventh challenge, *Catalysis for Industrial Production and of Energy Resources*. The last specific challenge identified in the current Strategic Theme is *Hydrogen Technologies*, and is focused on Hydrogen as an energy carrier, which represents a clean and storable solution for replacing many economic sectors based on fossil fuels. Finally, a last challenge, *Social and Environmental Aspects of the Energy Transition,* is included, which transversely relates the effect of transformation of the energy sectors considered in the other challenges on the Society and the Environment.

EXECUTIVE SUMMARY

Conventional methods of energy production are principally responsible for the generation of harmful emissions causing climate change and affecting human health. The implementation of a clean, safe and efficient energy system necessitates solutions for the way in which energy is produced and stored, and how unavoidable toxic emissions are managed. Renewable-energy production is one of the most suitable ways to produce clean and efficient energy. However, its implementation as the primary energy source requires overcoming barriers of efficiency, stability, costs and management. Not only generation of energy, but also its storage is key to introducing flexibility to the system and enabling distributed generation. Improvement in energy storage would enable generation and consumption to be disconnected, with an enormous impact on the implementation of renewable energies using the electrical grid. Portable storage technologies would also boost other electrical technologies, resulting in a drastic decrease in emission of pollutants. Energy

efficiency is a further major challenge, with a direct impact on energy savings and preservation of resources. In this regard, energy harvesting presents a growing interest for technologies based on energy-autonomous electronic devices, which would enable energy to be harvested from the environment and converted to electricity. Presently, a huge amount of pollutant emissions emanates from the energy sector, complete electrification of which is complicated and directly related to the development of renewable electricity. The transport, distribution and conversion of energy in an efficient, flexible and reliable way require the development of smart power grids. Additionally, electrochemical technologies and processing of materials using electricity have an enormous potential for reducing greenhouse-gas emissions. Exploitation of biomass will provide an alternative renewable-energy source, mitigating emissions and decreasing dependency on fossil-fuel reserves. Unavoidable CO_2 emissions may be managed by carbon-capture technologies to avoid their release into the atmosphere or for use of CO_2 in different chemical processes. Technological improvements in catalysts, which play a key role in many energy-intensive industrial processes as enabling components, could decrease greenhouse emissions and toxic substances associated with energy transformation. All these mentioned challenges must be complemented with a new energy vector, hydrogen, which should be properly managed to achieve the full environmental benefits it offers. Although hydrogen may be considered as a clean and renewable fuel, its production by current technologies is highly polluting. A transformation towards its clean and renewable production will facilitate the conversion towards a hydrogen economy, in which this energy carrier could fulfil the energy requirements of all sectors of the economy. Finally, it should not be forgotten that the transition towards a clean, safe and efficient energy system and its subsequent sustainability involves a variety of social and environmental impacts which should also be the focus for research.