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Refrigerated warehouses as intelligent hubs to integrate renewable energy in industrial food refrigeration and to enhance power grid sustainability

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ABSTRACT

Background: Independence from fossil fuels, energy diversification, decarbonisation and energy efficiency are key prerequisites to make a national, regional or continental economy competitive in the global marketplace. As Europe is about to generate 20% of its energy demand from Renewable Energy Sources (RES) by 2020, adequate RES integration and renewable energy storage throughout the entire food cold chain must properly be addressed.

Scope and approach: Refrigerated warehouses for chilled and frozen foods are large energy consumers and account for a significant portion of the global energy demand. Nevertheless, the opportunity for RES integration in the energy supply of large food storage facilities is often neglected. *In situ* power generation using RES permits capture of a large portion of virtually free energy, thereby reducing dramatically the running costs and carbon footprint, while enhancing the economic competitiveness. In that context, there exist promising engineering solutions to exploit various renewables in the food preservation sector, in combination with the emerging sustainability-enhancing technology of Cryogenic Energy Storage (CES).

Key findings and conclusions: Substantial research endeavours are driven by the noble objective to turn the Europe's Energy Union into the world's number one in renewable energies. Integrating RES, in synchrony with CES development and proper control, is capable of both strengthening the food refrigeration sector and improving dramatically the power grid balance and energy system sustainability. Hence, this article aims to familiarise stakeholders of the European and global food preservation industry with state-of-the-art knowledge, know-how, opportunities and professional achievements in the concerned field.

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1. Introduction

The food sector is one of the most energy-intensive industrial branches. The amount of energy for cultivating, processing, packing and bringing the food to European citizens' tables accounts for about 17% and 26% of the EU's gross and final energy consumptions, respectively. The EU food industries are subject to important restructurings to make their activities more sustainable, through both increased investment in renewable energies and energy efficiency improvements. Since 2005 the food industry's energy consumption started to decline in terms both absolute amounts and energy intensity capable of producing more with use of less energy (JRC, 2015).

The food sector is generally considered as comparatively conservative because of its high reliance on fossil fuels and still limited penetration of renewable energies. Renewables account for some 7% of the energy used in food production and consumption, as compared with 15% of the overall energy mix. Fossil fuels account for almost 79% of the energy consumed by the food sector, while their share of the overall energy consumption is about 72%. Furthermore, about one fifth of food consumed in the EU is imported from regions where the renewable energy share is lower than 15% (JRC, 2015).

Consequently, the aim of this commentary article is to make stakeholders of the European and global food preservation industry more aware of the political framework and the state-of-the-art achievements in integrating renewable energies in refrigerated warehousing of foods. Special attention is paid to an emerging 'clean' and intelligent technology for cryogenic energy storage as a promising tool to enhance the sustainability of both industrial food refrigeration and power supply grids.

2. Food preservation sector in light of the European Energy Union and global energy policy

The EU is the biggest energy importer in the world, importing 53% of its energy at a cost of around EUR 400 billion a year. There is not yet a real European internal energy market: energy does not flow freely across borders and some parts of the EU (such as South-East Europe, the Iberian Peninsula and the Baltic States) remain isolated energy islands. Renewable energy is not fully integrated into the electricity system. Climate change cannot be halted by countries acting on their own. These are all examples of problems where coordinated action needs to be taken at the European level (EC, 2015c). Independence from fossil fuels, energy diversification, decarbonisation and energy efficiency are paramount challenges when putting substantial efforts to make the European economy much more competitive in the global marketplace. The EU also relies heavily on fuel and gas imports, which requires reform and reorganisation of Europe's energy policy into a new European Energy Union in order to pool resources, combine infrastructures and unite negotiating power *vis-à-vis* third countries (EC, 2015a, 2015b, 2016; Juncker, 2014).

The Political Guidelines announced by the European Commission's President Jean-Claude Juncker (2014) to be followed by the sitting European Commission define *"A Resilient Energy Union with a Forward-Looking Climate Change Policy"* as the third policy area tackled under the President's Agenda for Jobs, Growth, Fairness and Democratic Change. President Juncker pointed out that *"… we need to strengthen the share of renewable energies on our continent. This is not only a matter of a responsible climate change policy. It is, at the same time, an industrial policy imperative if we still want to have affordable energy at our disposal in the medium term. I strongly believe in the potential of green growth. I therefore want Europe's Energy Union to become the world number one in renewable energies"* (Juncker, 2014). In accordance with the International Energy Agency (IEA, 2007), renewable sources are *"essential contributors to the energy supply portfolio as they contribute to world energy supply security, reducing dependency on fossil fuel resources, and provide opportunities for mitigating greenhouse gases"*.

As stated by the UN Secretary-General *"New and renewable sources of energy stand at the centre of global efforts to induce a paradigm shift towards green economies, poverty eradication and ultimately sustainable development"* (FAO, 2011). Renewable energy can be used throughout the food sector either directly to generate energy on-site or indirectly by integrating this energy into the existing conventional energy supply system. Reliable and affordable energy supply is an essential component for sustainable development (FAO, 2011, 2012; Fikiin & Stankov, 2015; United Nations, 2013). RES tend to be widely dispersed throughout agricultural areas. Wherever good renewable resources are available, farmers, fishermen, food processing and preservation businesses have various opportunities to install equipment for generating wind power, solar power, micro-hydropower, etc. In the future, it may also be commercially feasible to obtain electricity from sea and ocean resources. Solar thermal, biomass and geothermal resources, generated from decentralized facilities, can serve for both heating and cooling (FAO, 2011; Fikiin & Stankov, 2015; IPCC, 2011).

Sceptical voices often argue that (i) renewable energy technologies are more complicated and, therefore, less economically appealing than traditional sources of energy, and (ii) governments unjustifiably invest too much money and efforts to promote and sustain RES development. However, such negative views habitually disregard the massive amount of subsidies already invested in fossil fuels. In 2014 such subventions exceeded four times the overall subsidisation for renewable energy (IEA, 2015). Furthermore, large fuel importers bear a certain level of political uncertainty or risks because of their reliance on foreign resources. Although reshaping the energy infrastructure is a time- and resource-consuming venture, renewable energy technologies become thereby more cost-efficient and afford a significant competitive edge to the best adapted actors.

Given renewable energy technologies still remain burdensome, governments and public authorities employ policy instruments to promote relevant investments, thereby enhancing RES economic efficiency. Depending on location, these may include regulatory instruments, green certification schemes, financial incentives and other leverages. The broad variety of policy instruments in support of RES technologies was summarised by Fikiin & Stankov (2015). Industrial food refrigeration is one of the sectors which possess a huge but still unused potential for employing renewable energy technologies. Undoubtedly, food refrigeration deserves much more R&D efforts and investments as compared with some extravagant and fashionable applications whose environmental and economic impact is not so substantial (Maidment, 2014).

The worldwide market for industrial refrigerated storage of food, beverages and pharmaceuticals is large and constantly growing. Conventional refrigeration plants deliver temperatures in the range of −50 °C to 20 °C, while the refrigeration capacity of most plants commonly varies in the range of hundreds of kilowatts to dozens of megawatts. In practice, large electrically-driven vapour-compression refrigeration machines supply cold to a distribution network and operate with a COP ranging, most often, from 1.5 to 5 as a function of the machine design, evaporation temperature set point and other working (climatic) conditions. Large cooling towers are usually employed to dissipate condenser heat to the environment. According to the International Institute of Refrigeration (IIR, 2015), refrigeration (including air-conditioning) currently accounts for about 17% of worldwide electricity use, while over 80% of the global warming impact of refrigeration systems is due to this electricity use (IIR, 2007, 2015). Industrial refrigeration, comprising over 550