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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**

Independence from fossil fuels, energy diversification, decarbonisation and energy efficiency are key prerequisites to make a national, regional or continental economy enough competitive in the global marketplace. For instance, EU relies too heavily on fuel and gas imports, which required to reorganise the 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. Substantial research endeavours are therefore driven by the noble objective to turn the Europe's Energy Union into the world's number one in renewable energies. As is known, Europe is about to generate 20% of its energy demand from Renewable Energy Sources (RES) by 2020, so that the proper RES integration and renewable energy storage throughout the entire food cold chain must be properly addressed. 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 very often unjustifiably neglected, unlike many other industrial and comfort applications. *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, the purpose of this contribution is to raise the public awareness of emerging engineering solutions to exploit renewables of different nature in the food preservation sector, in combination with the novel sustainability-enhancing technology of Cryogenic Energy Storage (CES).

*Keywords: Food preservation; renewable energy; energy storage; cryogenics; low-carbon economy*

## FOOD PRESERVATION SECTOR IN LIGHT OF 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 still no real European internal energy market: energy does not flow freely across borders and some parts of EU are still isolated energy islands, such as South-East Europe, the Iberian Peninsula and the Baltic States. 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 of the European economy are paramount challenges when putting substantial efforts to make the European economy much more competitive in the global marketplace. EU relies too heavily on fuel and gas imports, which requires to reform and reorganise 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 (Juncker, 2014; EC, 2015a, 2015b).

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 areas 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.** Renewable Energy Sources (RES) tend to be widely dispersed throughout agricultural areas. Reliable and affordable energy supply is an essential component for sustainable development (FAO, 2011, 2012; United Nations, 2013; European SET Plan, 2010; Fikiin and Stankov, 2015). 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 possible 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 (IPCC, 2011; FAO, 2011; Fikiin and Stankov, 2015).

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 kWs to dozens of MWs. Large electrically-driven vapour-compression refrigeration machines supply cold to a distribution network and operate with a COP ranging, most often, from 3 to 6 as a function of the required refrigerating temperature and other working conditions. Large cooling towers are usually employed to dissipate condenser heat to the environment. Industrial installations, using heat from waste processes and RES to operate thermally-driven refrigeration equipment, become competitive with the vapour-compression systems in areas where the electricity supply is unstable. For example, solar thermally-driven refrigeration systems might employ roof- or ground-mounted, low- and medium-temperature solar collectors but very few industrial systems have been implemented and studied so far. The rising price of electricity increases the interest in solar refrigeration, whose capital cost is still relatively high and prevents a wider market uptake. Further research on equipment simplification, unification and cheapening is thus critically important (ESTTP, 2008; RHC-Platform, 2014; Fikiin and Stankov, 2015).

## RENEWABLE ENERGY INTEGRATION IN REFRIGERATED WAREHOUSING

A comprehensive study on different low-carbon technologies and strategies for RES integration in refrigerated warehouses was recently published by Fikiin and Stankov (2015). Refrigerating plants operating on diverse physical principles and renewables of different nature (solar, wind, geothermal, biogas, etc.) have been considered, as shown in Figures 1 and 2. Due attention was also paid to biogas-fuelled Combined Heat and Power (CHP) generation as an efficient option with low environmental impact.

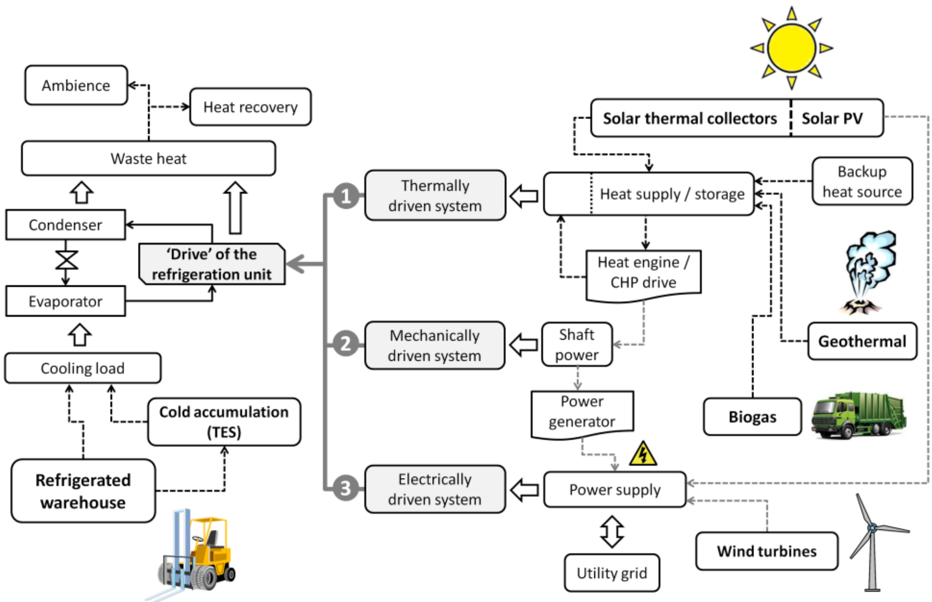


**Figure 1.** Various options to integrate RES in the energy supply of refrigeration systems for food storage facilities (Fikiin and Stankov, 2015).

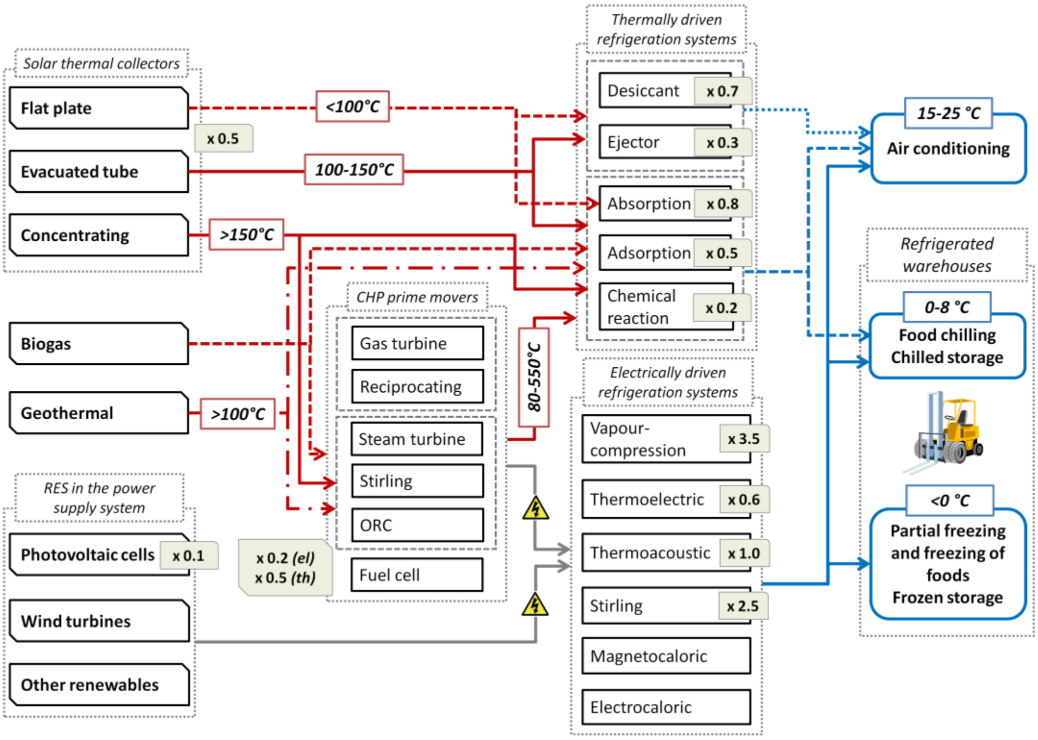


**Figure 2.** Possible applications and indicative energy conversion efficiencies of RES-powered refrigeration systems (Fikiin and Stankov, 2015).

The above-mentioned study revealed that the opportunities for RES integration in the energy supply of food cold storage facilities have often been overlooked so far. Although extensive information on RES research and developments for heating and power generation is available and easily accessible, RES-based implementations of industrial refrigeration systems are still scarce, while relevant information is fragmentary and dispersed. Presently, the RES use for on-site power generation, especially through solar PV systems, appears to have gained more ground than RES-powered thermally driven refrigeration systems, as far as large refrigerated warehouses are concerned. There is a significant progress in the roof-mounted PV systems powering conventional vapour-compression refrigerating units (for instance, see Figure 3). Such systems are susceptible to simplification, unification and mass production, which enhance their market prospects, especially in presence of substantial government incentives.


**Figure 3.** The 9 MW solar park on the rooftop of the Holt Logistics refrigerated warehouse, Gloucester Marine Terminal, New Jersey (Pereyra Boue, 2014).

Whilst on-site wind turbines and wind parks are still rare, in a smart grid context the so-called *"Night Wind"* strategy (Van der Sluis, 2008; Fikiin, 2015) can substantially benefit both cold store operators and electric utilities (Butler, 2007; Fikiin and Stankov, 2015). Solar, geothermal and biogas-driven CHP and trigeneration systems are still uncommon, but recent developments and research show promising trends. Solar-driven Stirling engines are actively investigated and developed by several companies, while development of the organic Rankine cycle technology affords encouraging prospects for low-temperature solar and geothermal applications. CHP and trigeneration systems driven by biogas present a valuable opportunity for food-processing factories which generate large amounts of food wastes. Thermally driven refrigeration systems need further improvements in order to become technically feasible and competitive for large refrigerated facilities, but the number of pilot and research projects is growing. In general, further research is required to make RES-powered systems (which are currently viable for small-scale air-conditioning and cooling applications) competitive for larger refrigeration capacities as well. In the medium term, building up of experience and increased number of market actors should significantly enhance the technical and economic performance of the aforementioned technologies (Fikiin and Stankov, 2015).

## INTEGRATION OF RENEWABLES INVOLVING A NOVEL TECHNOLOGY FOR ENERGY STORAGE

Intermittent supply is a major obstacle to the renewable power market (Boie *et al.,* 2014). In fact, RES are fickle forces, prone to overproducing when demand is low and failing to meet requirements when demand peaks (IEA, 2009). Refrigerated warehouses provide an ideal industrial environment to take advantage of RES technologies by using *'passive'* and *'active'* methods of Large-scale Energy (thermal and grid) Storage (LES), enabling on-site storage of RES energy during periods of high generation and its use (and/or return to the power grid) at peak demands, thereby balancing the grid (Fikiin and Stankov, 2015). Hence, the RES involvement fosters the LES developments and *vice-versa*, i.e. the RES and LES technologies are mutually enabling and should be deployed in parallel. Recovering of waste energy from cooling and heating enhances substantially the LES round-trip efficiency and RES desirability (Figure 4), which is another driver for implementing of RES technologies in the food processing and preservation industry worldwide.

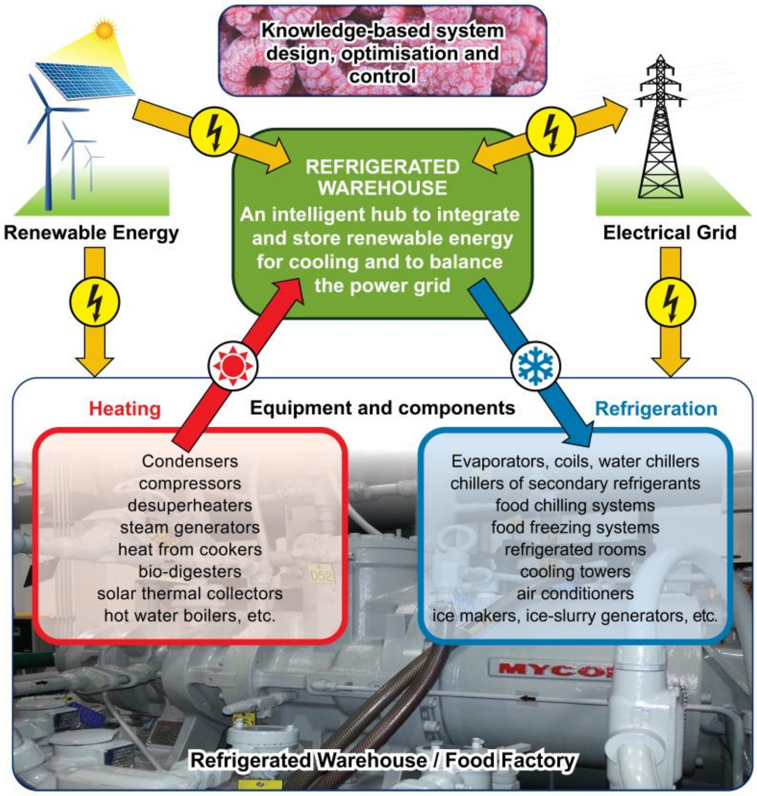


**Figure 4.** Employing renewable energy to liquefy and store cryogens is capable of balancing the power grid, while meeting the cooling demand of a refrigerated warehouse and recovering the waste heat from its equipment and components (CryoHub, 2015).

Amongst the numerous methods to store energy, the Cryogenic Energy Storage (CES) is a known but still undeveloped TES principle, which is coming again in favour due to its attractive features and advantages (Brett and Barnett, 2014). CES is a promising technology enabling on-site storage of RES energy during periods of high generation and its use at peak grid demand. Thus, CES acts as Grid Energy Storage (GES), where cryogen is boiled to drive a turbine and to restore electricity to the grid. To date, CES applications have been rather limited by the poor round-trip efficiency (ratio between energies retrieved from and spent for energy storage) due to unrecovered energy losses.

A pan-European consortium of 14 partners from industry and academia in 5 EU countries (including universities, research institutions, SMEs, large industries and international organisations) has recently elaborated an EU Horizon 2020 Project entitled *"CryoHub – Developing Cryogenic Energy Storage at Refrigerated Warehouses as an Interactive Hub to Integrate Renewable Energy in Industrial Food Refrigeration and to Enhance Power Grid Sustainability"* (CryoHub, 2015), which has been approved by the European Commission and deserved an EU grant of over 7 MEUR during 3.5 years foreseen to perform the anticipated work programme. The project is coordinated by the London South Bank University and will start in early 2016.

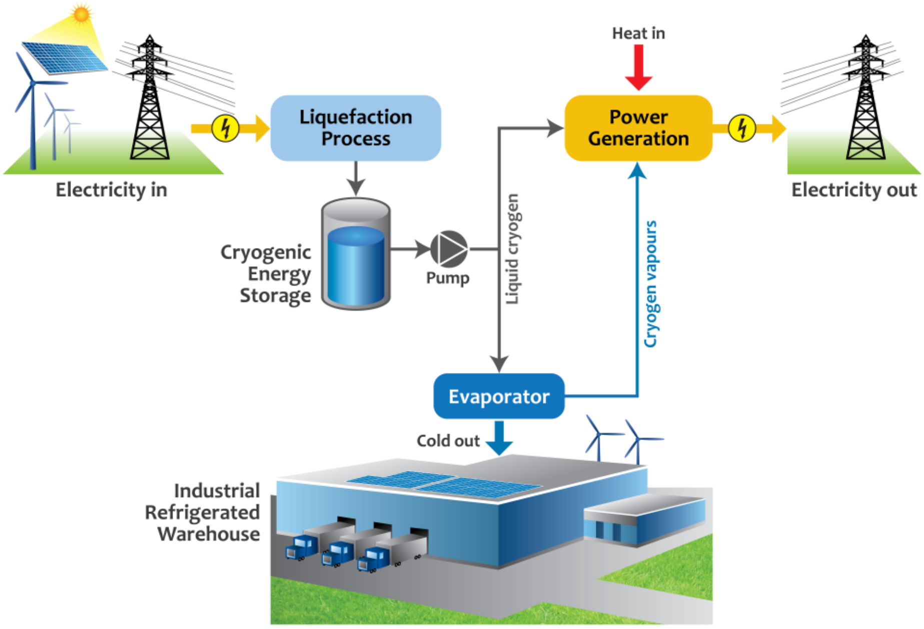


**Figure 5.** Basic concept for synergistic operation of RES and CES (CryoHub, 2015).

The CryoHub innovation project will investigate and extend the potential of large-scale CES and will apply the stored energy for both cooling and electricity generation. By employing RES to liquefy and store cryogens, CryoHub will balance the power grid, while meeting the cooling demand of a refrigerated food warehouse and recovering the waste heat from its equipment and components. The CryoHub project is therefore designed to maximise the CES efficiency by recovering energy from cooling and heating in a perfect RES-driven cycle of cryogen liquefaction, storage, distribution, efficient use and power regeneration, as illustrated in Figure 5.

## CONCLUDING REMARKS

Industrial food refrigeration did not yet enjoy the RES benefits, as compared with other manufacturing or service sectors. Refrigerated warehouses for chilled and frozen food commodities are large electricity consumers, possess powerful installed capacities for cooling and heating and waste substantial amounts of heat. Such facilities provide, therefore, the ideal industrial environment to demonstrate, elaborate and advance the emerging CES technology by enhancing substantially its round-trip efficiency. Thus, the RES integration, in synchrony with the CES development and proper control, is capable of both strengthening the refrigeration sector itself and improving dramatically the power grid balance and energy system sustainability. The CryoHub concept for synergistic use of CES and RES might overcome most of the existing technology barriers at one go, thereby paving the way for broader market prospects for a CES-based economy of the future.

## ACRONYMS

| | | | |
|---|---|---|---|
| CES | Cryogenic Energy Storage | PV | PhotoVoltaic |
| GES | Grid Energy Storage | RES | Renewable Energy Sources |
| LES | Large-scale Energy Storage | TES | Thermal Energy Storage |

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