Final report

1.1 Project details

Project title	**A novel off-grid thermoelectric-photovoltaic desalination system**
Project identification (program abbrev. and file)	**Journalnr.: 64016-0038**
Name of the programme which has funded the project	**EUDP-Solenergi**
Project managing company/institution (name and address)	**Technical University of Denmark, Frederiksborgvej 399, 4000 Roskilde**
Project partners	**SunPower Applications A/S, ALPCON A/S, All Things Considered A/S**
CVR (central business register)	**30 06 09 46**
Date for submission	**December 18th, 2018**

1.2 Short description of project objective and results

English: The project have fulfilled its overall objective, which is to develop and demonstrate a novel off-grid desalination system using thermoelectric (TE) technology combined with a photovoltaic system. The Main achievements of the project are:

- A scale-up TE module with a maximum efficiency up to 10% is developed.
- A model to predict the performance of the TE desalination process is developed.
- A PV system with a power control has been setup and tested. A maximum output power up to 279W is achieved.
- A full prototype of solar-TE desalination system with capability of producing 10-20L drinking water/day is tested in lab.
- A business plan is made and the industrial partners will utilize the project results to explore the potential for commercialization.

Danish: Projektet termoelektrisk-solarcellesystem til fremstilling af drikkevand ved hjælp af afsaltning af havvand har opfyldt de overordnede mål med hensyn til udvikling, afprøvning og demonstration af systemet til anvendelse i remot områder. Til udvikling af systemet er der anvendt termoelektrisk teknologien kombineret med solarcelleanlæg. Hovedresultaterne fra projektet er:

- Et op-skaleret TE-modul er udviklet med en effektivitet på maksimum 10%.
- Der er udviklet en computerbaseret model for at fortælle om systemets driftsforhold under termoelektrisk afsaltning proces.
- Et solarpanel system med tilhørende elektronisk kontrolsystem er konfigureret og testet. Den maksimale udgangseffekt som er opnået er målt til 279W.
- En fuld skaler prototype solar-TE-afsaltning system med en drikkevandsproduktionsevne på 10-20L drikkevand / dag er testes i laboratoriet.
- Der er udarbejdet og beskrevet en forretningsplan og projektets industripartner vil udnytte resultaterne for at undersøge mulighederne til kommercialisering af systemet.

1.3 Executive summary

DTU Energy, ALPCON AS, SunPower Applications AS, and All Things Considered AS has joined in force to carry out this project. A novel off-grid photovoltaic and thermoelectric desalination system has been successfully demonstrated with a capacity in the range of 5-20 L drinking water per day. In addition, this system design is portable and flexible to adapt the size and capacity upon the application requirement. Industrial partners have made a business plan to utilize the project results and explore the market potential.

1.4 Project objectives

The table below summarizes the progress and status of all scientific and commercial milestones of the project. All scientific milestones have been achieved and expected risks have been taken care according to the mitigation plan. Commercial milestone CM 1 and CM3 have been completed, while CM2 has not yet been fully completed. Main reasons are

- A serious delay (almost one year) of the budget reclaim resulted in many difficulties for small companies.
- Unexpected problem has happened for the project: the owner of SunPower Applications (SPA) was sick and passed away in October. SPA is the main partner responsible for the final prototype demonstration.
- The project coordinator has been 02 months on paternity leave.

Milestones	Description	Success criteria	Current
M1: 6 months	Large scale TE module	A large scale TE module with 8-10% cooling & heating efficiency is developed and tested	Achieved
M2: 8 months	Modeling of TE cooling & heating	A model to predict COP of TE-HDH system is developed	Achieved
M3: 8 months	Upscale PV system design	A PV system is set up with a controllable power in range of 100	Completed
M4: 12 months	HDH unit	a HDH unit for a capacity of 30L/day configured with	Completed
M5: 15 months	PV-TEC integrated HDH system	A fully functional PV-TE HDH system is developed	Completed
M6: 20 months	Preparation of demonstration	A full prototype of PV-TE HDH system with capability of producing 10-20L drinking water per day is tested in lab.	Completed
CM1: 21 months	PV-TE HDH prototype	Optimized prototype with COP of 1.5 is developed and tested.	Achieved
CM2: 22 months	Final prototype demonstration	Prototype is demonstrated and introduced to potential end users and buyers	Ongoing
CM3: 24 months	Business plan	Business plan to commercialize the technology is made.	Completed

Risk and mitigation plan

Risk identification	Mitigation plan
The efficiency of a large scale up TE module may be significantly decreased due to a larger heat loss and increasing internal resistance by an increasing number of p-n pairs.	Minimize the number of p-n pairs in one TE module and scale-up by connecting small modules in series.
Heat transfer from a solid surface of TE module may be not very efficient for the evaporation of brackish/sea water.	Incorporate a good and powerful fan and heating block.
Thermal leaks in HDH unit.	Minimize exposed areas, suppress leaks by insulation/shielding.

Temperature of sea water may be too cold and requires a preheating process.	An extra chamber to store and preheat sea water may be needed before pumping it into HDH unit.

1.5 Project results and dissemination of results

Project results

Thermoelectric Heating & Cooling

A large-scale thermoelectric device was successfully developed and the tested result shows a maximum efficiency of 10% (see Fig. 2).

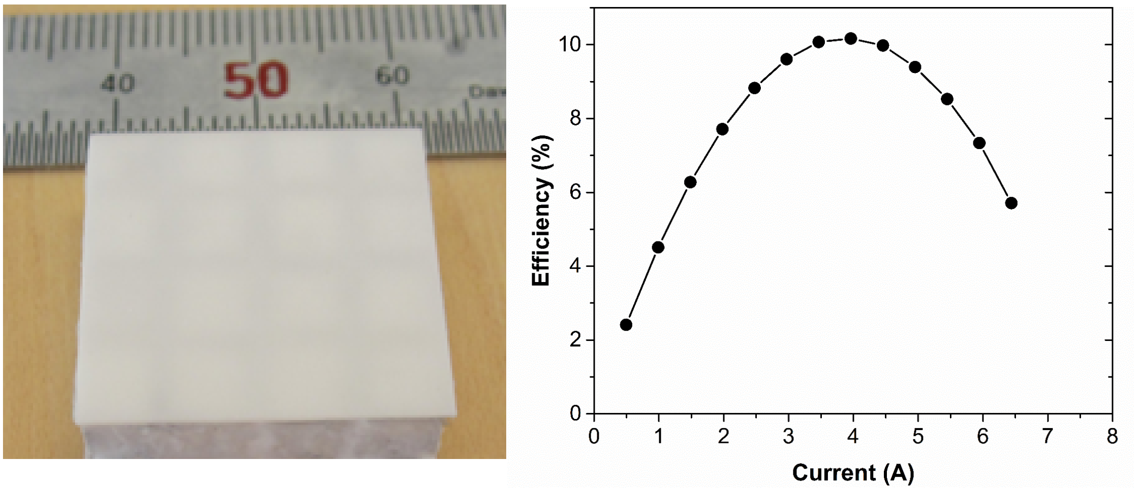

Figure 1. Photo of a typical scale-up thermoelectric device (left) and its calculated efficiency as a function of current

Modeling of TE cooling and heating

Figure 2 shows a typical process of TE heating and cooling desalination process. Temperature distribution (Fig. 3) was simulated as a function of air flowing rate. An optimum condition was found to be at an air flowing rate of 0.5, where a maximum 13L clean water per day could be possibly achieved (see Fig. 4).

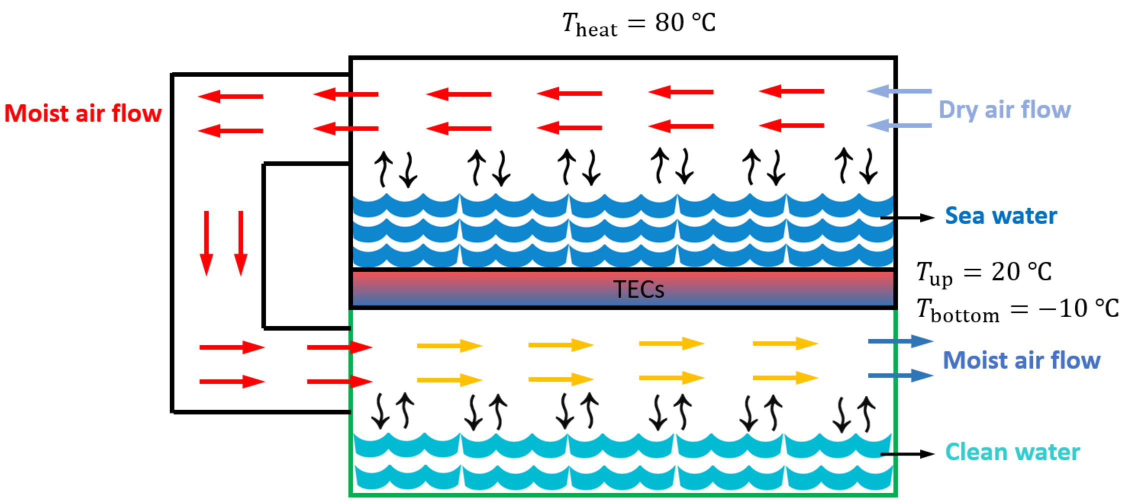

Figure 2. Modeling of the TE-desalination process

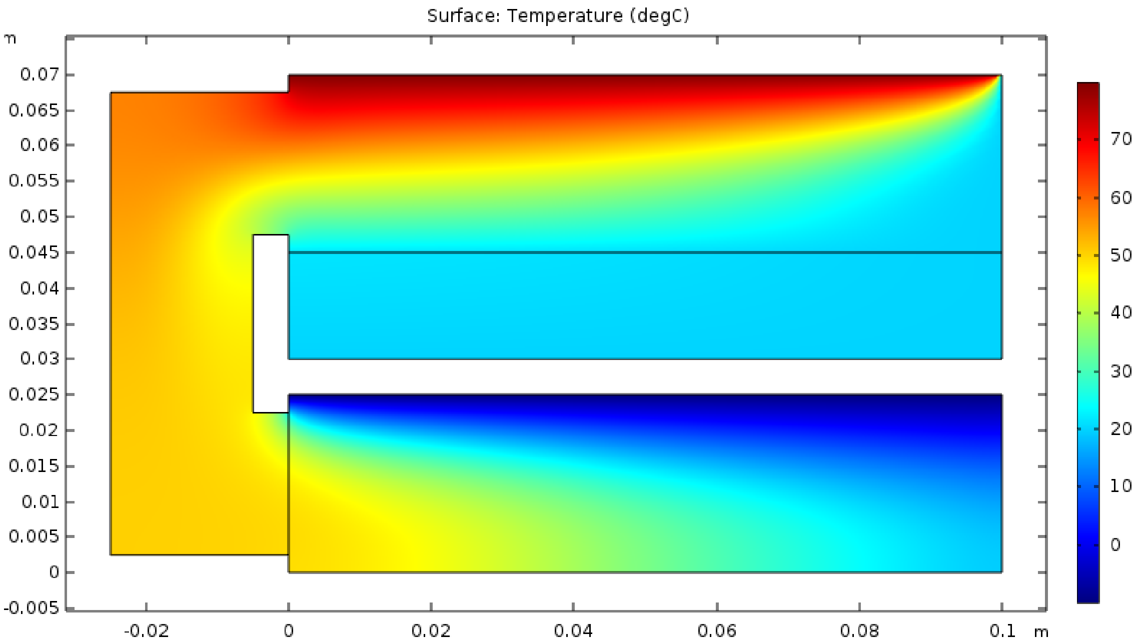

Figure 3. Temperature distribution inside the water evaporating and condensing chambers.

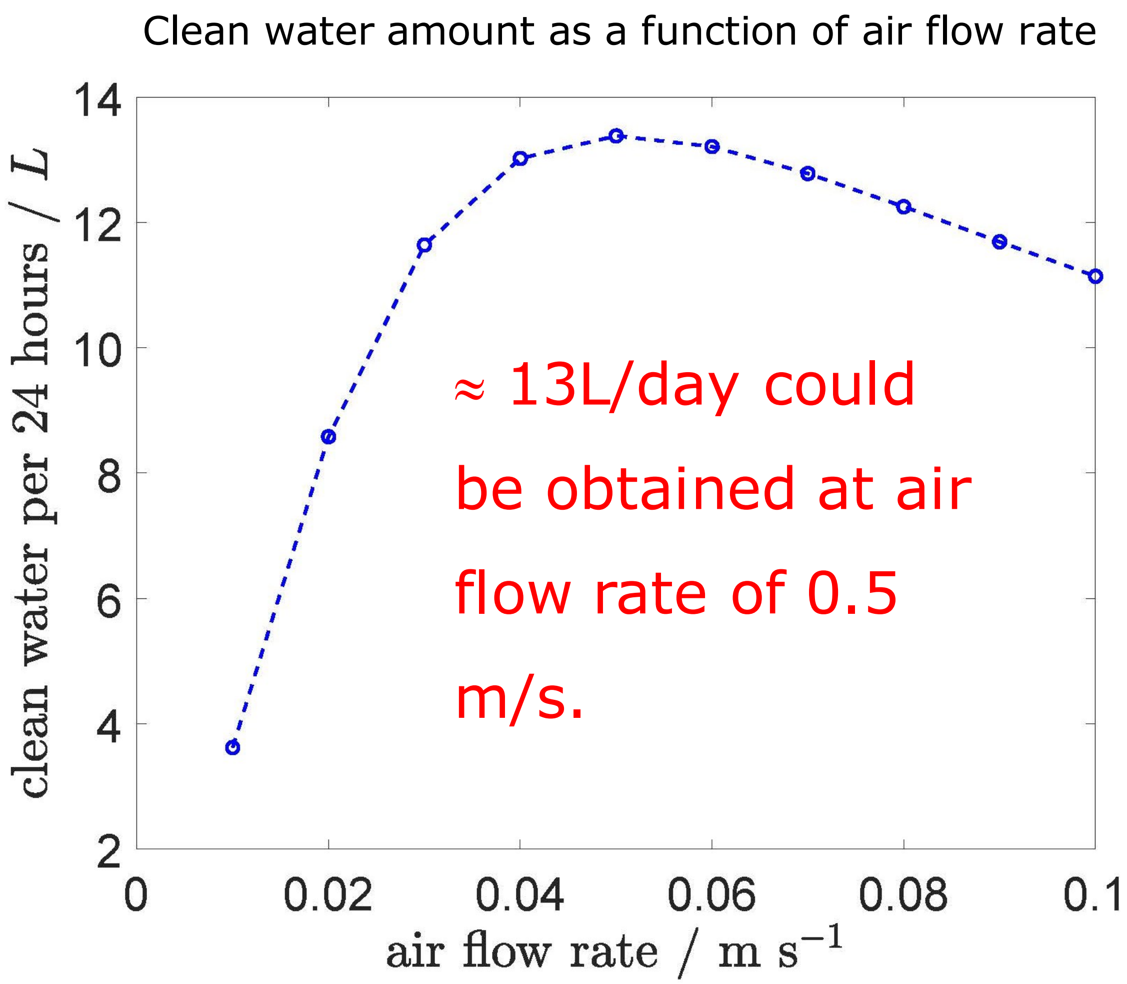

Figure 1. Clean water amount per 24h as a function of air flowing rate of TE desalination process.

PV system with power controller

Figure 5 shows photos of the PV system with a power controller, which allows the system to tune and prove a suitable power for TE system. Shown in Fig. 6 is the testing result of the PV system on working. It can be clearly seen that a maximum output power of 279W, which is beyond the project milestone of 200W, is achieved.

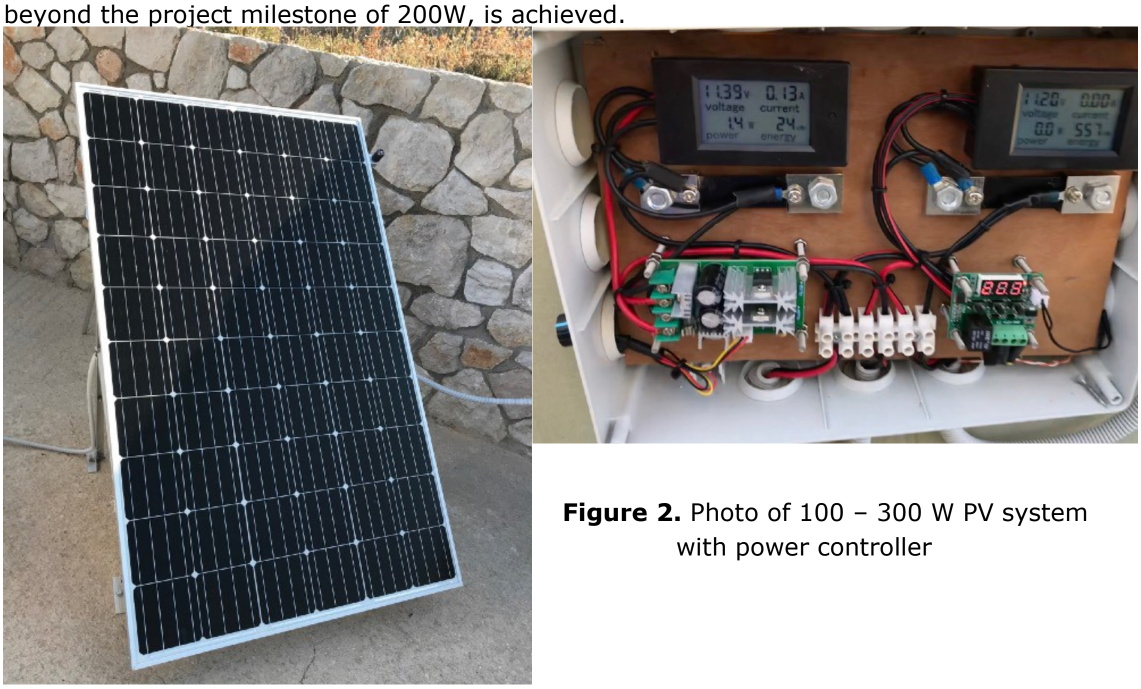

Figure 2. Photo of 100 – 300 W PV system with power controller

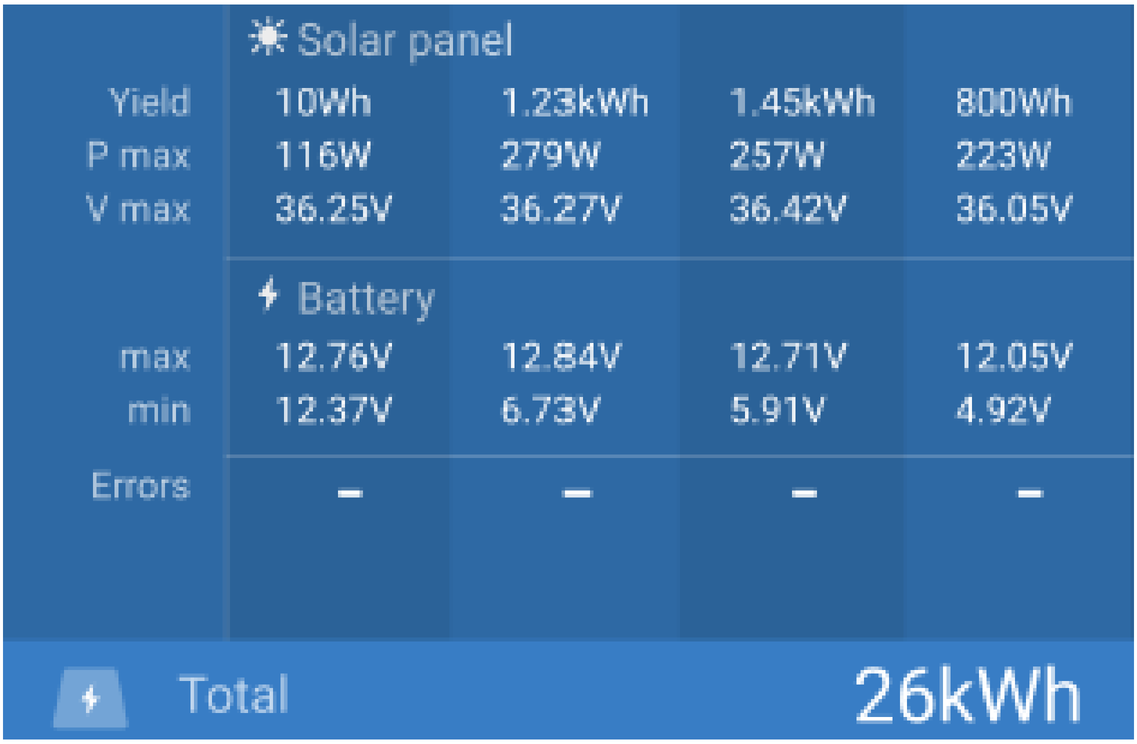

Figure 3. *Recording power output of PV system*

A fully functional PV-TE desalination system

Shown in Figure 7 is a photo of a fully functional PV-TE desalination system.

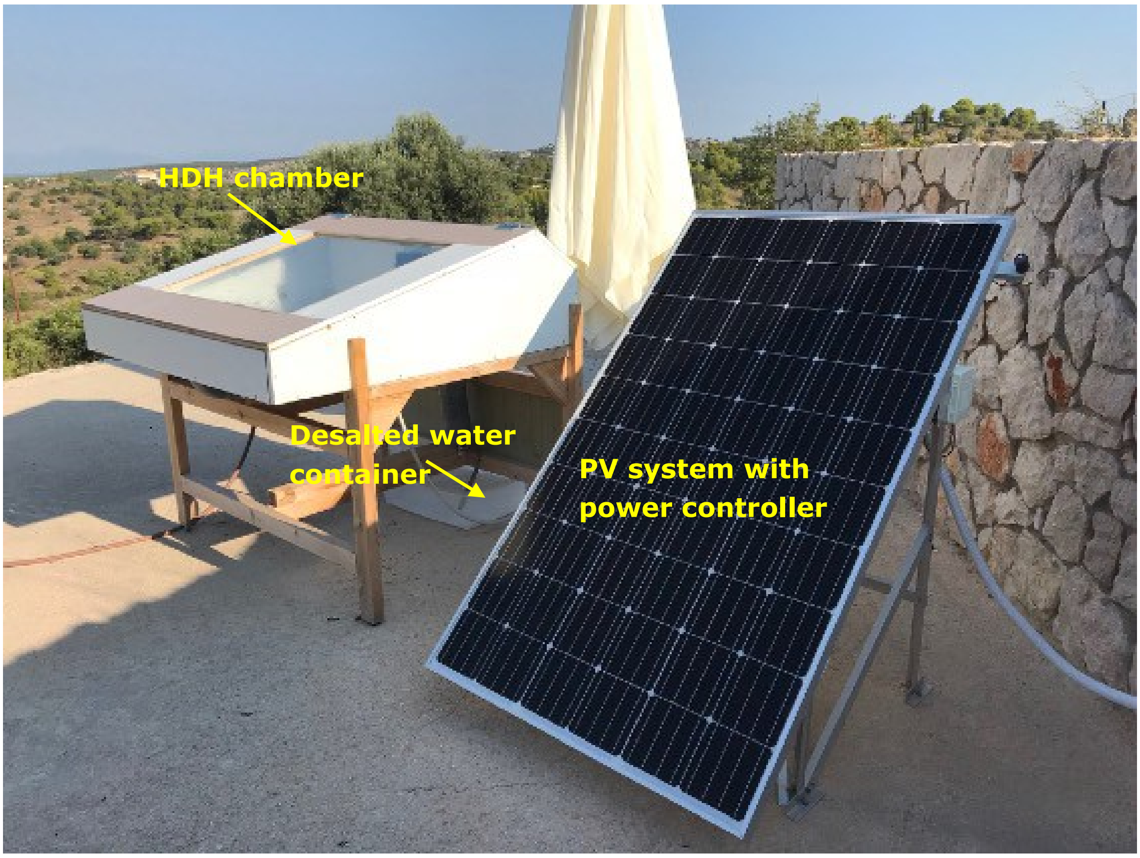

Figure 7. Fully functional PV-TE desalination system.

Optimized PV-TE desalination system

Based on the obtained experiment and modeling results, an optimized PV-TE desalination system has been designed (see Fig. 8). With this design, a single TE module of 4x4 cm^2, which consume about 48 W electrical energy, has produced an amount of 2.5 L clean water per day. A maximum of 20 L clean water per day could be possibly produced by combining 8 TE modules. Shown in figure 9 is demonstration of the system in the lab, showing drinkable water output.

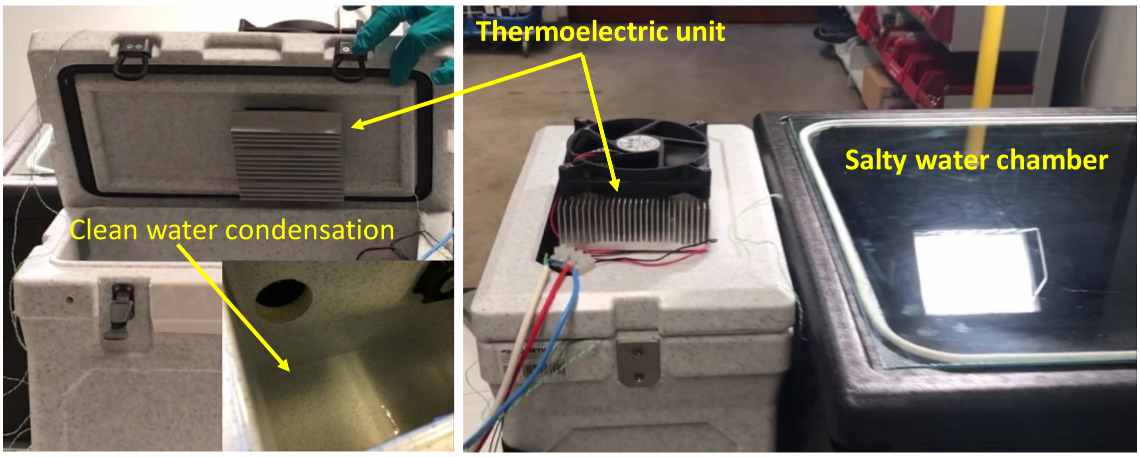

Figure 8. A lab-scale PV-TE desalination system

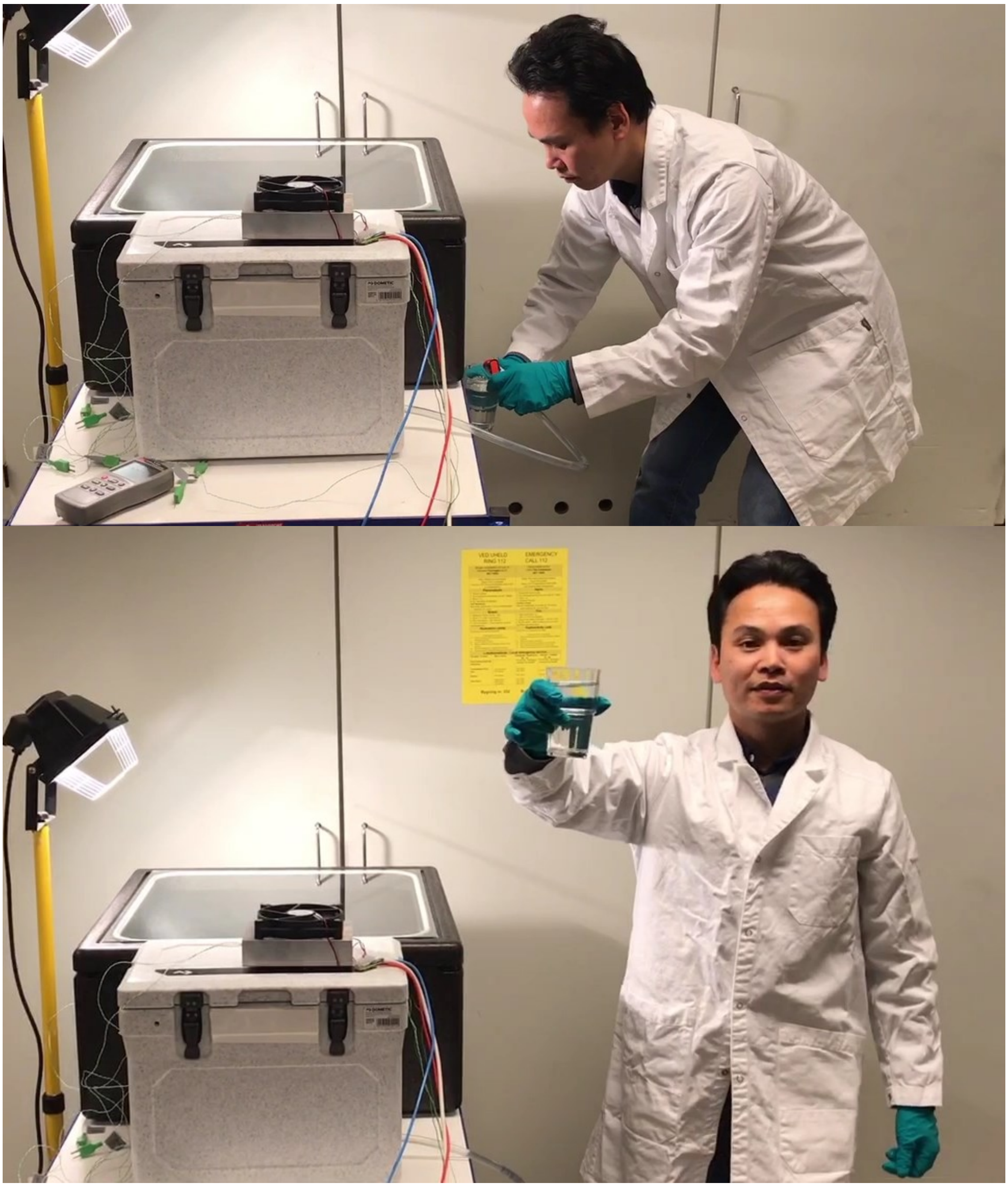

Figure 9. *Lab demonstration of novel off-grid PV-TE desalination system*

Project Dissemination

The results of the project have been presented in some international conferences/workshops as invited talks.

1. Ngo Van Nong et al., "Development of Thermoelectric Modules: A Balance between Performance and Stability", invited talk at the 15th International Conference on Advanced Materials, 27 August – 1 September, Kyoto, Japan.

2. Ngo Van Nong et al., "Development of Thermoelectric devices for a novel desalination application", keynote lecture at the 10th Vietnam National Conference of Solid Physics and Materials Science, Vietnam, 19-21 October, 2017.

3. Ngo Van Nong, George Karatzas, Ali Asghar Enkeshafi, and MaLinda Chase, "A Novel Off-grid Solar-Thermoelectric Desalination System", presented at the International and European Conference on Thermoelectrics ECT/ICT 2018, July 1-5, Caen, France.

4. Ngo Van Nong et al., "High Performance Thermoelectric Materials and Modules for Energy Harvesting", invited talk at the International Conference on Electronic Materials 2018 (IUMRS-ICEM 2018), September 19-24, Daejeon, South Korea.

1.6 Utilization of project results

All Things Considered will utilize the project outcomes and search for any commercial possibility. Alpcon will support "All Things Considered" with knowledge about relevant market segments which already have a need for water desalination. A business plan has been made (see Appendix 1) and the next phase, they will determine several areas in the world where this technology is responsive and suitable for those in need of a safe clean drinking water from non-potable brackish or salt water and to configure off grid prototypes suitable for those areas. Considerations to be make in configuring a PV-TE desalination for a specific area is first and foremost to determine the magnitude of supply of non-potable brackish or salt water, the quantity of solar energy, local material resources, the weather conditions and last but not least the culture of the local population. The unit is intended to be simple to operate and self contained, encouraging the users to take ownership of this life saving device.

1.7 Project conclusion and perspective

In conclusion, the project has fulfilled accordingly to the plan and achieved the most important objective. The project has successfully demonstrated a novel off-grid PV-TE system for making drinking water from salty water. The desalination technology developed in this project is very portable and flexible to up-scale and 100% using renewable energy resource. The concept could be further developed e.g. simultaneously producing renewable energy and clean water to broaden its potential for applications such as on Islands, Ships, Arid locations without access to the electricity and clean water.

Annex

Appendix 1: Project business plan
Appendix 2: Link to the video: Project introduction https://drive.google.com/file/d/1GqzuESfadWdJQqZxkbMzCqAjMJt1jJBa/view
Appendix 3: Link to the video: Lab demonstration of PV-TE desalination prototype https://drive.google.com/file/d/1CFKuKqybgfq-dHke6CX0XEtbE6mEgdQJ/view