Final publishable summary report

An executive summary

FP7 EFFiHEAT project ("Development of high EFFiciency Stirling HEAT pump", Grant Agreement No.: 286814) focuses on use of geothermal heat sources enabling up to 75% energy savings and reduced costs for energy consumption and aims to develop and provide the ground source geothermal heat pump market with the cost-efficient based on Stirling engine of novel design geothermal heat pump technology with 25% higher COP[1] comparing to technologies in operation.

Achievements

The RTD activities at the first project period were dedicated for development of the separate elements of EFFiHEAT Stirling heat pump.

For the development of a novel *Stirling heat machine based on free swinging piston electrical machine* which is a base core of High efficiency Stirling heat pump technology, a new material solution for first prototype of sandwich regenerator was developed. For the second regenerator prototype the geometry and properties of a new woven-wire micromesh regenerator were calculated, based on a Bronze (CuSn6)+PES (polyester) mesh as high-k component and PES as low-k component. Additionally, the production of aerogel super insulation powders has been improved by optimization of solvent-exchange and drying conditions. It was established by the physical measurements that the produced silica microgranules have super-hydrofobic properties, which could be used in many applications, for example as hydrophobe super insulation coatings. Glass-textulite case insulation panels for the Stirling heat machine cylinders were prepared. For the dynamical operation control system the new set of skew rotor with lowered cogging force has been installed and the control system hardware and software was developed that allowed to carry out testing in a limited range of parameters (limited frequency and pressure) that led to impression how heat machine should perform under normal working conditions. Finally, external heat exchangers adjusted to enable the heat amount that needs to be transferred to ensure capability for 10kW transfer and internal heat exchangers were optimized for specific generated heat transfer.

The RTD activities at the second project period were dedicated for further development and integration of the EFFiHEAT technology elements. Multiple experiments and investigations were carried out during the development and testing activities. For the evaluation of achieved results, a survey was carried out and a business case validation was conducted as well, both of which revealed that the elements of EFFiHEAT high efficiency Stirling heat pump technology meets users expectations and the product should be quite competitive in today's market. Finally, referring to all the work done, Partners jointly prepared a set of recommendations as to how the EFFiHEAT technology could be improved to ensure effective commercialisation.

After the project once all the recommendations for further improvements are fulfilled, EFFiHEAT Consortium will provide a cost-effective and highly efficient ground source heat

[1] Coefficient of Performance – COP – is defined as the ratio of heat delivered by the heat pump and the electricity supplied to the compressor. COP of 4 means that the heat pump produces four times as much heat as it requires work to generate this heat.

pump for the commercial and residential market. The key functionalities and cost-effectiveness of the EFFiHEAT technology will be fundamental for entering the new markets while the environmental friendly approach will provide an added value for choosing heat pump instead of other less ecological energy sources.

Further information can be found at http://effiheat.eu/.

1 A summary description of project context and objectives

As the energy consumption and saving trends in European Union are favouring for the environmentally friendly energy it is interesting to closer look to the most promising section of this market. One of the main energy saving measures is the improvement of energy conversion in buildings – the demand for energy efficient technologies (EE) has been identified. The most prominent growth of market share occurs for solar heating and heat pumps, but high initial costs and long return on investment time caused by insufficient efficiency of heat pumps are limiting the penetration of market for this EE technology.

The proposed project focuses on development of ground source heat pump technology (GHP) enabling up to 75% energy savings and reduced costs for heating energy consumption. To achieve the goal EFFiHEAT was to develop, prototype, test and validate cost-efficient Stirling cycle based GHP with 25% higher coefficient of performance (COP) comparing to technologies in operation. Application of the EFFiHEAT GHP has potential savings of over 0.03 billion EUR annually, which would contribute to EU targets on reduction of energy consumption and CO_2 emissions.

Hence, the overall objective of the EFFiHEAT project is **to develop and validate a cost-efficient geothermal heat pump technology** based on a Stirling heat machine of novel design having 25% higher COP as compared to technologies in operation.

This overall objective is divided into a set of scientific, technological and non-technological objectives targeted to overcome four fundamental obstacles of existing technologies:

- High material stress and corrosion, caused by either high operating pressure of the working gas or engines operating at high speed;
- Thermal losses and lower overall efficiency caused by a slower process;
- Practical application of the variable compression ratio and variable valve timing in the engine;
- The amount of mass and volume needed for higher power output of heat pump and complex mechanical mechanisms, leading to high manufacturing costs.

Therefore, the main scientific objectives of EFFiHEAT project are:

- To develop and optimize the Stirling heat machine of novel design for achievement of high performance efficiency by cost-effective means;
- To develop novel material for regenerator, ensuring (0.01 W/(m•K) thermal conductivity required for operation at low speeds;
- To develop operation control system enabling optimum and variable engine and overall system work modes.

The main technological objectives of EFFiHEAT project are:

- To develop the novel HP technology within predetermined technology performance parameters;
- To test and validate the novel HP technology.

The non-technical objective of the project is:

- To perform a business case validation for assessment of perspectives for EFFiHEAT technology and to develop the exploitation strategy.

1.1 Main project achievements

The EFFiHEAT project has been structured into three phases and broken down into eight individual work packages (WP), consisting of a number of tasks to be carried out by the teams formed within the consortium. The main activities and results of the project for the Initial research Phase consisted of research and development done under the WP1–WP4 whereas Technology Development Phase covered activities of WP5 where EFFiHEAT Heat pump prototype was integrated and tested. The final Innovation Phase included dissemination and management activities which were done under the WP7 and WP8.

The project activities started from definition of requirements and specifications for each of the elements of EFFiHEAT Stirling heat pump to ensure the technologies compatibility and fluent integration. The work was performed successfully – the requirements and specifications for the each element of EFFiHEAT heat pump and Stirling heat pump technology were defined based on theoretical data, SME requirements, EU standards, best available practice and user expectations for the heat pump performance. In addition, two major use cases of heat pump applications in the scope of EFFiHEAT project were taken into account: residential and commercial heating applications.

The main objective of **WP2** was to optimize the free-swinging piston engine mechanism to design economically viable Stirling oscillating heat pump. To this end, a thermo dynamical model was designed to get quantified results of the cycle, quantifying heat flows, coefficient of performance and distribution channel configuration was established, which enabled to get feedback about dynamics of the entire system. This led to the development of four different configurations and the comprehensive matrix allowed choosing the final design relevant for prototyping. Activities in WP2 finally resulted in proof-of-concept prototype to be used for tests of novel concept verification.

The main objective of **WP3** was to develop a specific tailored drive and control system to control this drive applied to the EFFIHEAT Stirling heat machine. During the research activities performed by PROTECH several mathematical models of the Stirling cycle heat machine were developed, allowing to predict oscillating electrical machine working properties and, in turn, to develop final geometry for the manufacturing of oscillating electrical machine itself. Two oscillating electrical motors have been manufactured for integration in EFFiHEAT Stirling heat pump prototype. In parallel, an extensive research was performed developing the EFFiHEAT dynamical control system tailored to control the voltage pulses and current flow in order to achieve movement of the motors necessary to produce heat by compressing gas inside Stirling heat machine working chambers. The developed control system consists of 3 loops control system logic, proper encoder and versatile hardware kit.

The activities in **WP4** were targeted at the development and optimization of the materials required for high performance of Stirling HP. To achieve that, a novel composite material based on polymer foils doped with ceramic nano or microparticles with a thickness 50 μm–1500 μm

was defined as an EFFiHEAT regenerator material solution. Geometrical layout of the regenerator was defined as well and testing methods for density, structure, microstructure, porosity and thermal properties evaluation were developed. A new design of a woven-wire mesh for wound EFFiHEAT regenerator has been developed to apply in the EFFiHEAT Heat pump prototype. It has proofed its applicability to reduce thermal longitudinal conductivity losses.

The activities in **WP5** were mainly testing and completion of the EFFiHEAT high efficiency Stirling heat pump technology and separate elements. Testing results came out promising. However, not all of the results have already been available during the project duration – the time frame for such scale of developments was too short. EFFiHEAT RTD teams are continuing experiments and entire SMEs team is looking forward to helping the RTDs test the prototype following defined standards and analyse the testing results.

The main objective of **WP6** was to evaluate the achieved project results from technical and economical point and to prepare recommendations for up-calling. Specific tasks for this WP consisted of acquisition of feedback from users and other stakeholders by using structured interviews with project coordinator, SME contractors and principle researchers involved in the project, planning the actions and resources required for the introduction to the market and identification of basic trends in relevant ground source heat pumps market sub-sectors.

To ensure that the achievements of the project results are made known to the targeted potential clients and (or) market segments as well as to prepare plan for future exploitation of the project results policy of dissemination was prepared at the very beginning of the project. Therefore, in an effort to disseminate the project results in various fairs and events a scientific knowledge exchange with different companies has been carried out, while the EFFiHEAT project has been made known and published in professional magazines and media. As a means to relay the public information about the project and its progress as well as to provide a related documents repository for the participants a project website (http://effiheat.eu/) has been developed and launched in addition to active dissemination efforts. Furthermore, the Interim Plan for use and dissemination of foreground providing a complete and cumulative overview of all dissemination and exploitation of foreground related activities is prepared and management and monitoring of the IPR issues derived from the shared and individual contribution of the partners into the creation of the exploitation is being performed.

Project EFFiHEAT was a high-risk project form the very beginning, brought by idea to revolutionize market of the house heating devices, by introducing clean and effective way to generate heat for the household or industrial applications. Core of the project is reverse Stirling cycle that is being executed by free piston oscillating electrical machine that is covered by the U.S. patent and is the intellectual property of one of the project consortium partners.

Stirling technology in the science world is being known as the science dense technology involving mechanical, thermodynamic, heat insulation, in our case control theory, electronics, power electronics and other problems. Due to this mass of complex relationships not all of the problems were foreseen in the start of the project this led to the situation where all the further developments were based on the initial start assumptions which weren’t similar to the real life events.

1.2 Project consortium

The consortium combines know how on electro-mechanical design, process control and material research. Contract research will be performed by a Lithuanian, Spanish and Bulgarian research institutions which provide a unique integration of know-how on high efficiency Stirling heat machine based GHP development.

2 A description of the main S&T results and foregrounds

2.1 Project background

Buildings account for 40% of total energy consumption in the European Union and the sector is expanding. Therefore, reduction of its energy consumption and the use of energy from renewable sources constitute important measures needed to reduce EU energy dependency and greenhouse gas emissions. One of the main energy saving measures is the improvement of energy conversion in buildings by substitution of the less efficient technologies (EE) with more efficient ones. The most prominent growth of market share occurs for solar heating and heat pumps, but high initial costs and long return on investment time caused by insufficient efficiency of heat pumps are limiting the penetration of market for this EE technology.

Therefore, a consortium of seven research and business partners has been formed by several SMEs to solve this significant problem. The growing need for solutions, acquaintance with existing technological solutions and market awareness led the SME consortium to propose the idea of EFFiHEAT project. The project has been partially financed by Research for the Benefit of SMEs scheme of 7th Framework Programme – the main financial tool through which the European Union supports research and development activities. The available knowledge and a high potential of investigations have resulted into ground source heat pump technology (GHP) enabling up to 75% energy savings and reduced costs for heating energy consumption. Application of the EFFiHEAT GHP has potential savings of over 0.03 billion EUR annually, which would contribute to EU targets on reduction of energy consumption and CO2 emissions.

2.2 Progress of the project

The EFFiHEAT project has been structured into three phases and broken down into eight individual work packages (WP), consisting of a number of tasks to be carried out by the teams formed within the consortium.

The EFFiHEAT consortium began by defining detailed requirements and specifications for separate components of EFFiHEAT Stirling heat pump and for EFFiHEAT Stirling heat pump itself. These requirements are being based on the knowledge and experience of SME participants and existing know-how of RTD performers. The investigations in the **Initial Research Phase** covering tasks of WP2, WP3 and WP4 have resulted into the set of new scientific knowledge, generated by performing RTD activities:

- Stirling heat machine based on free swinging piston electrical machine was developed and tested;
- In parallel, development of dynamical operation control system was performed;
- Separately, regenerator material and structure was researched and two regenerator material solutions have been proposed.

Next, during the **Technology Development Phase** of the project, **EFFiHEAT Stirling heat pump** was integrated and tested. This phase covered activities of WP 5, where the following objectives were achieved:

- Separate prototype parts were integrated into main assembly
- State of the prototype was evaluated

- A testing stand was developed and testing protocols were designed
- Prototype was tested in a testing stand, and
- Testing results were evaluated and recommendations for optimizing device performance were set out.

The final **Innovation Phase** of the project was targeted to ensure that the achievements of the project results are made known to the public and the targeted potential clients. This phase covered activities of WP 6 and WP 7, where the following objectives were achieved:

- Internal and external validation by users was performed;
- Business case validation is completed, and
- Dissemination measures are implemented and exploitation strategy is prepared.

During the scientific part of the project, most of the tasks were carried out by RTD performers, but SME partners had a great influence on directing the RTD performers to meet the needs of SME partners.

The partners of consortium have been working closely constantly keeping in touch for consulting and brainstorming during the meetings, etc. The expectations of SME partners were justified as RTD performers achieved significant scientific results by generating new knowledge and added high value for the project innovativeness on the benefit of SMEs.

2.3 Main S&T results

2.3.1 Expected final results, their potential impact and use

Project EFFiHEAT was a high-risk project form the very beginning, brought by idea to gain the competitive advantage in the market of the house heating devices, by introducing clean and effective way to generate heat for the household or commercial applications.

Stirling technology in the science world is being known as the science dense technology involving mechanical, thermodynamic, heat insulation, in our case control theory, electronics, power electronics and other problems. Due to this mass of complex relationships not all of the problems were foreseen in the start of the project this led to the situation where all the further developments were based on the initial start assumptions which were based on theoretical framework and in some cases were too optimistic.

Initial development work carried out in the consortium in the first nine months went smoothly due to development nature where all the knowledge and working material was transferable through electronic communications (drawings, e-mails, web-conferences, documents), project phase that involved physical components was going according to plans in the work packages but it wasn’t going flawlessly. One of the disturbing factors was that only one complete set of the heat machine prototype was available in the whole consortium and one partner working on the device sliced the pie of overall time from the other partners. Assigning R&D tasks for the partner who possesses the device at the moment was hardly a solution due to the high expertise field separation between the project partners. Logistics of the project device not only affected the working schedule but also the device itself, as this is a prototype device ant it is not as rugged and user friendly as the product like devices who are ready for the shipment to customer. Device

transferring gave its tool on the device affecting the alignment of the main axis, bearing clearances, sealing of the device and etc.

Another factor that was important in the time of the project activities was the fact that investigations on the control system and oscillating electrical motors developments were parallel in the project timeline and that planned workload in the field of control system and motor development was expected to be significantly lower than it really is. Parallel development of the motor and control system led to high number off assumptions in the control system development as the control object and final its properties were unknown; this number of assumptions later resulted in the massive workload in the control system area with iterative fault proofing to achieve robust system.

Despite all the circumstances that weren't in favour for achieving successful results project consortium pulled it off and at the end of the project there are measured and protocoled results. This shows that heating using reverse Stirling principle can be achieved using developed device, current testing conditions doesn't resemble exact properties that were planed and for which device was calculated for due to limits of the control system hardware. The last version of the control hardware was heavily modified for better suiting current conditions, but it isn't enough for achieving working state with planned 30 bar and 15 Hz, for achieving calculated conditions complete hardware remanufacturing must be provided.

Potential impacts of the project results are promising – fully successful project is expected to significantly impact market segments associated with hereinafter described technologies and materials, which include energy efficient technologies, industrial applications (cryocoolers, refrigerators, variable speed drivers, pump controllers), transport sector and HVAC systems.

The final project result consists of these items:

- *Stirling heat machine based on free swinging piston electrical machine* is the base core of High efficiency Stirling heat pump technology. The whole device is designed around a patent of free swinging piston electrical machine the main technological asset that was available before start of the project. Stirling heat machine is device optimized for converting mechanical movement into heating energy through thermo dynamical cycle, in the manner of reverse Stirling cycle;
- *Dynamical operational control system* – an innovative software-hardware kit designed to control the overall performance of electrical machines where oscillation movement is employed;
- *Regenerator structure and material* – a sandwich type cylindrical regenerator, based on alternating filled PP/PET films with enhanced thermal conductivity and non-filled PP/PET films. It can be used as a tool for increasing efficiency to whole applications where gas to gas heat exchange processes occur;
- *High efficiency Stirling heat pump technology* – a new cost-efficient geothermal heat pump technology based on novel design Stirling engine operating in inverse cycle with expected 25% higher coefficient of performance comparing to technologies in operation. The ozone depleting substances, usually employed in similar designs, are not needed.

The project will contribute to SME participants' competitiveness with the following:

- *Unique selling points* – the new high efficiency Stirling heat pump technology as well as the aforementioned technology components will be developed and delivered to the market

at a competitive price in 2 years after all improvements are implemented and demonstration actions are performed;

- *Market penetration* – the technology sold directly to residential and commercial sectors, meeting the growing market demands. The emerging markets are expected in the new Member States where the initial cost of HP technology historically has been a barrier.

2.3.2 Stirling heat machine based on free swinging piston electrical machine

Stirling heat machine based on free swinging piston electrical machine is the base core of High efficiency Stirling heat pump technology. The whole device is designed around a patent of free swinging piston electrical machine the main technological asset that was available before start of the project. Stirling heat machine is device optimized for converting mechanical movement into heating energy through thermo dynamical cycle, in the manner of reverse Stirling cycle.

The main defined requirements for Stirling heat machine at the beginning of the project were:

- To optimize the operational and functional processes in order to reach a maximum outcome of heat.
- To simplify the device case while avoiding the leakage of working gas and ensuring thermal properties.
- Optimizing pistons, displacers and heat exchangers to ensure the maximum / minimum heat transfer / leakage were appropriate.

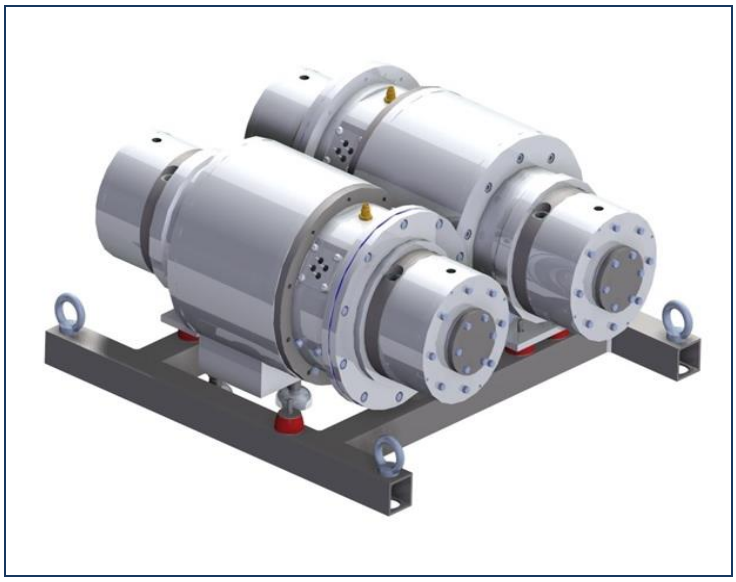

Figure 1: The model of Stirling heat machine based on free swinging piston electrical machine

The simplified design concept was the key criteria in product development. During the whole project design that is reliable was created: only four bearings are exploited to support the shaft, direct drive principle of the main motor eliminates possibility of transmission or any interconnecting part failure. Unique modular system design was approached to allow test engineers imitate different inertia properties using same machine combined with externally placed regenerator, complex gas sealing system, heat isolation cover and several sets of interchangeable pistons. In order to increase the efficiency of the Stirling engine insulation panels for cylinder case insulation have been prepared, filed with chemically obtained silica aerogels with thermal conductivity 0.03 W / m . K

Due to new functionalities such as increased performance, low electrical consumption, low noise, and expected lower cost this product can gain fast market acceptance. The novelty of the design makes it a more reliable product than standard ones, with less maintenance, and a long lifespan. It could also be used for other Stirling device applications (i.e. a refrigeration system).

2.3.3 Dynamical operation control system

Dynamical operation control system – an innovative software-hardware kit designed to control the overall performance of electrical machines where oscillation movement is employed.

The main defined requirements for dynamical operation control at the beginning of the project were:

- To control operation of oscillating electrical machine.
- To ensure the stability while working for long periods without stopping.
- To control the working volumes and torque of oscillating motors.

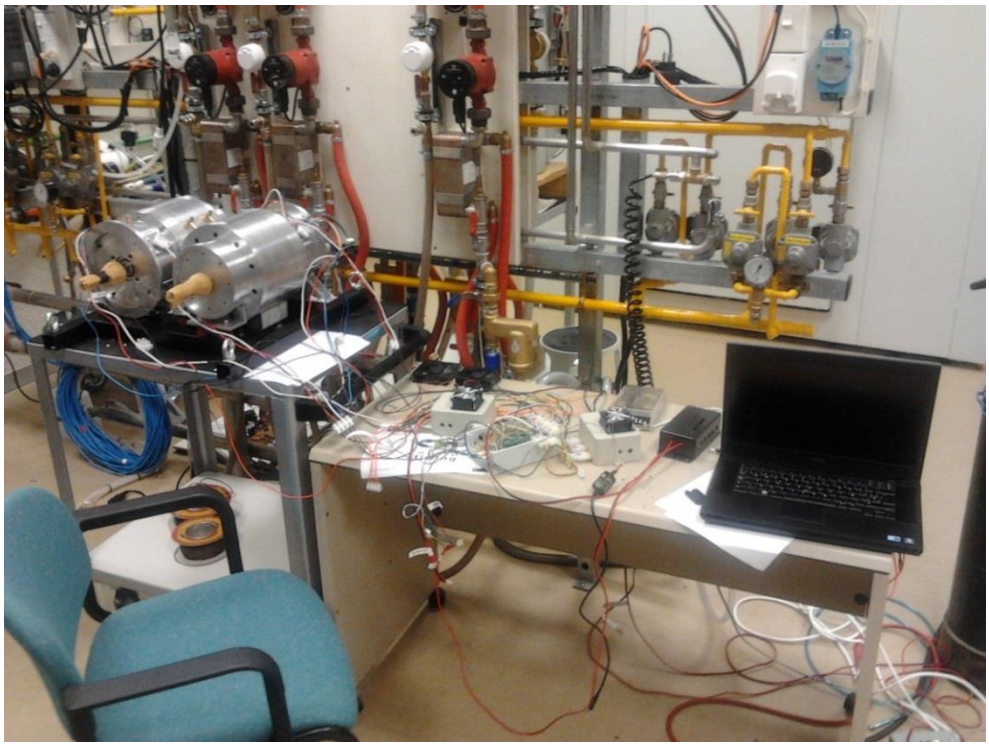

Figure 2: EFFiHEAT dynamical operation control system test bench

The system was built on the basis of prototyping control system with a variable voltage source to control the supply that is being fed to the motors; dynamical operation control system is based on H – bridge control principle where 8 IGBT drivers are controlled with a gate driver to open or close transistor gates. The fully developed dynamical operation control system can be used to control various devices that can be exploited with H Bridge. For the testing prototype main features that optimize dynamical operation control system to particular task are implemented on the software level using PIC microcontroller which allows putting a variable angle values of amplitude, impulse width and PWM signal level to all control outputs. Final features that were introduced were hardware level power cut-off to provide safe operation of the hardware and a possibility to monitor current flow on the present time basis.

EFFiHEAT dynamical operation control system for oscillating movement could be breakthrough for the oscillating electrical motors market, because in certain cases using an oscillation movement it is possible to eliminate current movement converters form machinery assemblies. Should such feature be successfully implemented, it would have a very high impact in industrial sectors improving durability, robustness and decreasing price of industrial mechanisms where oscillating movement can be exploited.

2.3.4 Regenerator structure and material

Regenerator structure and material – to increase performance of Stirling heat machine two regenerators were developed in the EFFiHEAT project material development work package activities one was a sandwich type cylindrical regenerator, based on alternating filled PP/PET films with enhanced thermal conductivity and non-filled PP/PET films with low conductivity another type regenerator is woven wire mesh regenerator wrapped around a cylindrical surface alternating bronze and polyester filaments provides required thermal anisotropy. Although regenerators are made by different manufacturing methods both type regenerators are the answer for same requirements and share same functionalities.

Regenerators can be used as a tool for increasing efficiency to whole applications where gas to gas heat exchange processes occur.

The main defined requirements for regenerator structure and material at the beginning of the project were:

- To meet market attention the regenerator has to be manufactured cost effectively, and in appealing size and design.
- Regenerator must have an excellent performance in heat capacity and conductivity.
- Physical properties of the regenerator must withstand high pressures and materials must meet the specific thermal requirements.

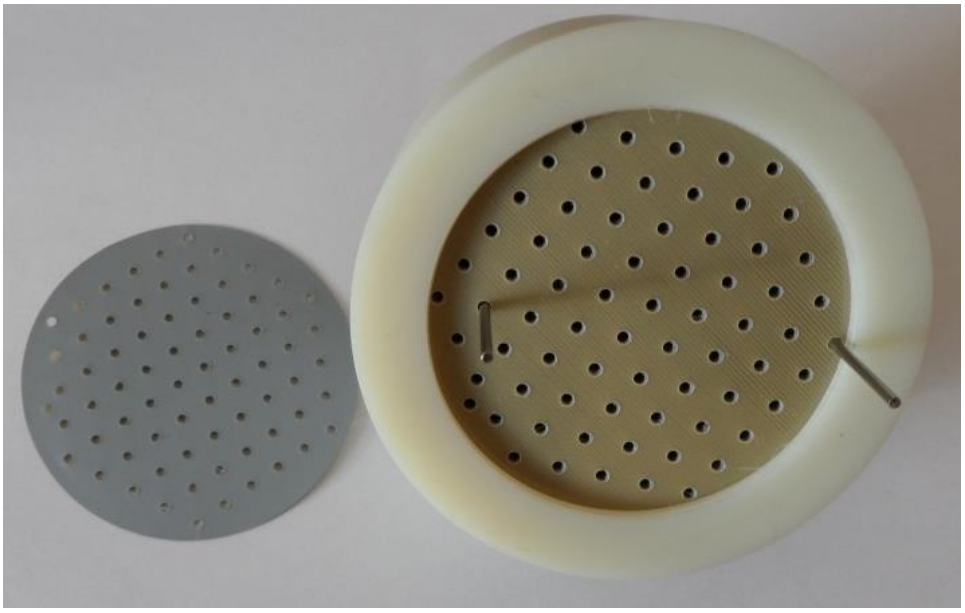

Figure 3: Picture of sandwich regenerator and plastic body. Sandwich regenerator is based on silicone foils, filled with ceramic microparticles

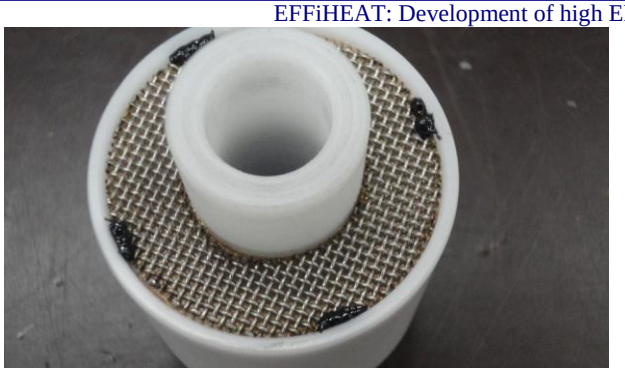

Figure 4: Picture of woven-wire mesh regenerator and plastic body. Woven-wire mesh regenerator is based on a bronze / polyester micromesh

Regenerator is the important part in every device that exploits principle of Stirling cycle operation. The regenerator is the stationary part that collects the energy from the gas in one cycle as it passes through it and releases it in the next cycle. Correct size and efficient regenerator can vastly improve performance of the Stirling cycle. To improve EFFiHEAT device performance two main concepts of the regenerator were developed: sandwich regenerator and woven wire mesh regenerator both of designs introduces thermal anisotropy that is the key factor to the regenerator performance.

2.3.5 High efficiency Stirling heat pump technology

High efficiency Stirling heat pump technology – a new cost-efficient geothermal heat pump technology based on novel design Stirling engine operating in inverse cycle with 25% higher coefficient of performance comparing to technologies in operation. The ozone depleting substances, usually employed in similar designs, are not needed.

Figure 5: Visualising scheme of EFFiHEAT Stirling heat pump technology

The primary scientific objectives for EFFiHEAT heat pump technology were set:

- To develop and optimize the Stirling heat machine of novel design for achievement of high performance efficiency by cost-effective means.
- To develop dynamical operation control system enabling optimum and variable engine and overall system work modes.
- To develop material for regenerator, ensuring (0.01 W/m K) thermal conductivity required for operation at low speeds.

EFFiHEAT project final result is the high efficiency Stirling heat pump technology – this is the solution mix incorporating all EFFiHEAT developments: Stirling heat machine, dynamical operation control system, and regenerator structure and material. Combination of all before mentioned project outputs provides a base for the novel heat pump device. Novel technology will bring the best possible options to the heat pump market: durability, easy service, high efficiency, low noise, non-hazard gas in the system.

EFFiHEAT technology can be considered technically advanced in significant ways, as compared to technologies in operation, therefore the focus should be put on technical an economical validation and business model development with the focus on service-based business to firmly establish the concept and gather feedback for improvements, before committing fully to further development and innovation.

2.3.6 Evaluation of project results

Approaching the end of the Project, its results were evaluated from technical and economical point of view by a survey, encompassing opinions of both internal and external users of EFFiHEAT Stirling heat pump and its separate components, and a business case validation. Furthermore, a set of recommendations for further improvements was prepared, in order to help up-scale the technique for commercialisation and define potential points for future development. Brief conclusions of evaluation and list of the recommendations are both presented in the subsections below.

Evaluation questionnaire

The scope of the survey encompassed mainly four EU countries: Lithuania, Bulgaria, Estonia and Spain. A grand total of 50 respondents participated in evaluation of project results, which can be considered as representative amount of answers for the analysis of the results. External respondents were mostly represented individual consumers (38%), 22 % were the external business companies (representing various geothermal products manufacturers, energy technology suppliers and service providers) and the remaining 40 % of respondents were the internal evaluators.

Analysis of data indicates that the same functionalities of the EFFiHEAT high efficiency Stirling heat pump technology are valued by both partners and external evaluators. For the EFFiHEAT technology respondents identified “design of the modern household equipment” and “competitive price” as the most valuable components. Both functionality and price specifics would be the main future selling-points of the high efficiency Stirling heat pump technology.

Partners have been also asked to evaluate whether the specific objectives have been met for each product. As the products have been still under the development in the meantime, most of the partners have indicated that they are “undecided” about the completion of the objectives. The result would differ now when the testing of the product is finished.

Individual consumers also comprise the potential target group for high efficiency Stirling heat pump technology. The results have showed that most of the individual consumers would be first interested to see the actual performance of the product rather than just have a written overview. However, many of respondents have mentioned that the technology looks interesting and would imagine using similar technology which would preferably be integrated with various comfortable in-house system technologies.

Business case validation

- All three products aim to enter the market of ground-source heat pump or in the other words – geothermal energy market. The total value of target market has reached more than 300 mil EUR last year and the market was growing by 6.29%. In average profitability has reached 15–20% in the market. It is clear that there is a market demand for the EFFiHEAT products and prospective customers are interested in using them. Several options for a route to market have been identified and recommendations are made to achieve a successful market introduction.

- The critical success factors of heat pumps are considered price (with the highest rating of 35/100), then COP (30/100), installation (25/100), environmental characteristics (5/100), and use and maintenance (5/100). The performed products' positioning analysis showed that EFFiHEAT novel technology has a high potential to enter become a leader of the market.

- The SPACE analysis has identified that the EFFiHEAT commercialization would have to be carried out with the aggressive strategy. Financial strength would help to protect the consortium's competitive advantage. However, the risk of new competition entry to the market is critical to EFFiHEAT. Additionally to the financial strength, EFFiHEAT should also gradually decrease costs of input materials, also keep up the innovativeness, and continuously update product.

- Break-even point analysis for the EFFiHEAT product has proved the need for gradually decreasing the product manufacturing costs. The analysis showed that non-decreasing costs can cause losses.

- A successful market introduction will require further developments on the EFFIHEAT products; options to finance these developments are:

    - Self-funding (Bank, Company cash flow, R&D tax credits)

    - Public funding (Recently the follow-up project EFFiHEAT-DEMO has been submitted and is at the final stage of negotiations. The project is proposed with the overall objective to carry out the targeted full-scale demonstration of the novel cost-efficient geothermal heat pump technology based on novel design Stirling engine and with 4.5/5.5 coefficient of performance in temperature difference of 50/30 ºC) (Other options: EC Eurostars, EC Horizon2020, National funding options)

    - Private funding (High net worth individuals, Business angels, Venture capital)

    - Joint venture / licensing (medium / large companies active in this area)

Recommendations for further improvements

According to current observations, the following parts need to be improved for the Stirling heat machine:

- *Shaft:* it faces alignment issues – logistics of the project device affected the device itself, the main shaft suffered in each transportation. Finally, the radial run out of the shaft was above normal limits. This issue can be resolved by redesigning shaft to have more transversal rigidity by changing construction and shortening shaft span between bearings.

- *Pistons:* high friction between pistons and work chamber walls was observed in the latest testing attempts. This issue can be solved by re-machining pistons according to cylinder surface and then ensuring mounting point stability regarding to corresponding surfaces.

- It is also recommended to improve the system sealing (to avoid the high volume gas leakage at pressures above 24 bars).

- The Stirling heat machine design should also be adjusted according to the recommendations (selecting the non-modular integrated design, minimize vibration and sound, higher integration of oscillating electrical drive).

According to current observations, the following parts need to be improved for the dynamical control system:

- It is obvious, that further investments in development of control system are needed. Further developments are required for:

    - Finalizing system design for testing without limits;

    - Making system friendly for the end user (design and simplification of encoder device)

According to current observations, the following parts need to be improved for the regenerator structure and material:

- It is expected that the full potential of the regenerator material capacities will be explored during the full scale testing of a new product-like EFFiHEAT Stirling heat pump prototype.

- It is advisable to further explore options that may allow protection of intellectual property of EFFiHEAT regenerator structure and material. Depending on the options for IP protection, the development of a protectable material may be possible.

3 The potential impact

The geothermal heat pump market in Europe has a value of 307 million Euros per annum. The EFFiHEAT technology is suited to serve the demand of this market in many ways. The market research performed within the EFFiHEAT project estimates, that EFFiHEAT technology has a potential market value of about 6 million Euros, based on a 1% market share over a period of five years after introduction EFFiHEAT products to the market. However, the geothermal heating market in general is driven through environmental legislation and standards, in addition significant geothermal projects depend on the availability of public funding or incentives for green energy users.

The technology landscape that describes the environment around the EFFiHEAT high efficiency Stirling heat pump technology is based on a snapshot of current technologies used for geothermal heating purposes and a patent searches for each of the four EFFiHEAT results. Both the technology landscape and the patent search show *that each EFFiHEAT result is among firsts in their area,* although the searches identified some similar technologies and patents. However, whilst similar technologies exist, the EFFiHEAT consortium developed functional and scalable products and has proven that their products work. The novelty of the EFFiHEAT Stirling heat machine is in the direct drive principle of the Stirling heat machine. Hence the EFFiHEAT consortium is in a good position to secure protection for the technologies, however, when filing the patents the consortium needs to take care to avoid infringements.

3.1 Economical impact

The economic benefit and production costs of the project result have been calculated according to the following assumptions:

- To simplify the estimations, the inflation was not included as a variable within the analysis;
- The yearly fixed costs (including marketing costs) are estimated to reach no more € 98000;
- The target is to achieve 1 % market penetration in 5 years;
- In order to arrive to realistic estimates, the price strategy is based on macroeconomic methodology and on presumption that earning is not less than 10% net profit from the installations.

Break-even point analysis shows that to have zero balance the 46 units of high efficiency EFFiHEAT Stirling heat pumps per year have to be sold. Manufacturing and selling less than that would bring losses and each extra unit will increase the profit. Once reaching at least 81 units of sales per year, the variable costs will stabilize and will earn 40% net profit from each extra product installation.

According to the market data and assumptions based on them, it is calculated that during the first 3 years after the project the consortium will gain M€ 1.74 in net profit, and during the 5 years period – the total of M€ 3.89. The **Error! Reference source not found.** gives a graphical representation of the EFFiHEAT product financial benefit for the 5 years period after the project.

3.2 Social impact

Controlling CO2 emissions has been a major motivating force behind the recent surge in the development of numerous heat pump systems in the world. The rapidly expanding energy consumption, heating and hot water supply account for nearly half of the energy consumed in the commercial sector for residential and business uses, which is one of the main contributors to the CO2 increase. Moreover, about 90% of hot water supply, heating and other heat-based demands are met by the heat generated by burning CO2-emitting fossil fuels. It is against this background that heat pumps are drawing huge attention as an alternative, CO2-reducing technology for fulfilling heat related demands. By replacing fossil fuel-based direct combustion systems prevalent today with heat pump equipment, which drastically improve energy utilization efficiency with the use of “heat in the air,” to meet such demands for cooling and heating, primary energy consumption and CO2 emissions can be reduced substantially without changing the amount of thermal energy available to users.

IEA Heat Pump Center has also calculated the potential of the world's CO2 emissions reduction by the widespread use of heat pump equipment on a trial basis. CO2 emissions can be reduced by 650-2,000 million t-CO2 in the residential sector, and about 6-12% or 1.2-3.7 billion t-CO2 in the business and industrial sectors, according to the trial calculation.

Application of the EFFiHEAT HP technology will enable reduction of energy consumption for heating by 75%. Taking into account the unique selling points of EFFiHEAT HP technology, the market planned market penetration is very realistic. Thus, employment of the EFFiHEAT HP technology has potential savings of over 0.03 billion EUR annually. Such savings will contribute to EU targets on reduction of energy consumption and CO2 emissions and enhance development of "low-carbon society".

Ethical and gender issues

Throughout the duration of the project, there were no known ethical or gender issues and, considering project subject, it is not likely to occur in the future.

Although equality of rights is not directly expressed in project objectives and tasks, equal rights are ensured between all project Partners for both male and female participants, disregarding their social status, religion, race, physical or mental disorder or any other characteristic.

3.3 Dissemination activities

The main purpose of dissemination efforts in EFFiHEAT project is to raise awareness of EFFiHEAT in order to maximise its impact and encourage acceptance of its results by the targeted stakeholders. This dissemination plan intends to ensure that the dissemination activities within project EFFiHEAT are closely oriented to the current and future market opportunities and to prepare the target audience including potential users, customers, researches and strategic partners for EFFiHEAT results adoption.

The EFFiHEAT consortium considers the task of dissemination to be of great importance. All partners contribute to dissemination efforts in one form or another, for instance by participating and giving presentations and demonstrations at local and international conferences, internal and customer events, publishing papers, holding press conferences, networking and similar activities and strive to maximize use of existing dissemination channels for the purpose of project result adoption and successful future commercialization of the project results.

A policy of broad dissemination of project results has been particularly focused on potential customers, energy technology related business companies (energy (especially geothermal) technology developers, technology vendors, technology users, technology verifiers, and technology investors), funding agencies and authorities making decisions in energy sector.

The dissemination actions were aimed to:

- Create awareness about the EFFiHEAT project on International, European and national levels;
- Motivate the partners and any interested parties to collaborate.

Dissemination activities were planned in accordance with stage of the development in the project. Although a number of dissemination activities took place during the first reporting period of the project, the most significant dissemination activities took place during the last period of the project (as soon as technical results were available). Dissemination was done by:

- Disclosure of information through a project dissemination tools.
- Publication in relevant magazines and newspapers.
- Set-up and maintenance of project website, which is available on http://www.effiheat.eu. The access to different kind of results depends on kind of area navigation site, Public or Private.
- Dissemination of information to the networks and established distribution channels of the individual partners. Every partner involved in EFFIHEAT project is already driven towards promoting the project within his institution. In that perspective, means of dissemination may vary (i.e.: annual review meetings, internal presentations or etc.).
- Newsletter, Promotional video (web and dissemination channels)

3.4 Dissemination channels

EFFiHEAT has been promoted through presentations at both academic and industry venues. The consortium organized different meetings and sessions and an integral part of the dissemination activities was also the cooperation with other EU projects, organizations and professionals working in the field of common interest. These dissemination opportunities represent general dissemination channels.

The selection of the appropriate channels accords with both the EFFiHEAT objectives and with the development stage of the project. With respect to character of EFFiHEAT project the following dissemination channels were selected and developed in this dissemination strategy:

- Professional magazines;
- Presenting EFFiHEAT at conferences and workshops;
- Networking, and
- Internet based communication.

Professional Magazines

The publication of EFFiHEAT results and achievements through publication in scientific and technical journals was encouraged. EFFiHEAT project has been disseminated in the following relevant magazines:

- Goiena Newspaper
- TV show “Goiena TV”
- TU Lankide magazine
- Estrategia Empresarial
- NewsAlloy
- 2020horizon.com

- Electrcial Machines (ICEM), 2012 XXth International Conference
- ICREPQ'13 International Conference on Renewable Energies and Power Quality

Presenting EFFiHEAT at conferences and workshops

Essential to the promotion of EFFiHEAT is its presence at the regional, national or international events focusing particularly on the above listed field of interests. EFFiHEAT participation at events took two forms in particular. Firstly, representatives of EFFiHEAT presented ongoing work, progress and results reached during the project, while the other form was more formal and consisted of a distribution of EFFiHEAT promotional materials and presenting project posters. In most cases both forms were applied at once.

The aim is to promote results of EFFiHEAT to relevant commercial organizations in order to influence the market and create opportunities for future exploitation and use of EFFiHEAT results. To achieve this, dissemination activities had been focused on the events (conferences, workshops, trades, exhibitions etc.) that are more oriented to energy technology field.

Existing resources and links of EFFiHEAT SME partners (PM, MC, MET, PSYS-Nord) had been used for promoting EFFiHEAT to the potential future customers of a finished product(s). The EFFiHEAT achievements were also presented to scientific community by the RTD partners (CS, PROTECH and SOFIA) through presentations given at conferences, workshops, forums of experts and publications in conference papers.

A summary of dissemination events where EFFiHEAT has been presented with the brief description of them is included in Plan for use and dissemination of foreground.

Networking

As the final EFFiHEAT results were not available till the very end of the project, a very some networking events took place at the 1st and 2nd Reporting Periods. The list below represents the summary of networking events organized during the project period.

- Lithuanian PV technologies and business association
- NTP Manufuture
- GEOPLAT – Spanish Geothermal Tech. Platform
- Brocante Tecnológica

3.5 Exploitation of project results

The EFFiHEAT Exploitation approach attempts in depth investigation of the full spectrum of exploitation opportunities – not just product development and commercialization, but involves all the partners independently of their profile and position in supply chain in the exploitation efforts based on their nature and type of activities, as well as their stated individual exploitation perspectives concerning the project results.

Although exploitation evolved in parallel with the technical work, it offers a different view of the project results and supports the partners to think about the results more from a market perspective and identify exactly what they have to offer as well as find and reveal the value of the results for the business and scientific world. Exploitation is not the same process as commercialization

hence the exploitable results from European RTD projects such as EFFiHEAT may arise in many forms. As well as technologies which might form the basis for commercial products, such exploitation opportunities could include:

- Developing new services based on the prototypes, methods and tools.
- Creating start-up businesses to commercialize results.
- Protecting results through patents and IPR agreements.
- Inputting to standardization and legislative activities.
- Feeding RTD results and know-how into further research.
- Feeding RTD results and know-how into national or industrial research projects.

The exploitation potential of the project depends mainly on the following critical parameters that are assessed during the project lifetime:

- The project results:
    - The nature of the results (research approaches or concrete prototypes);
    - The degree of innovation (proof of concepts using mature, but risking to be outdated technologies, or forward the state of the art exploiting cutting edge but immature technologies);
    - The quality of the results (results that perform just what they promise, or better than expected (easier and faster for example);
    - Their applicability in the market (they might be the perfect results but not applicable to the market).
- The project partners:
    - The nature of each partner's organisation. RTD and SME partners in general have different exploitation goals.
    - The perspectives and the expectations of each partner from the project.
    - The continuous commitment of each partner.
- The market:
    - The maturity and the trends.
    - The movements and the role of the leaders.
    - The "customers" needs.

3.6 Overall Exploitation Strategy

Aiming to facilitate the management of the project exploitation activities and taking into consideration the above mentioned issues, the consortium generic exploitation strategy has been prepared.

The main concept of the exploitation strategy is that each partner will define its exploitation plan based on 3 criteria:

- Definition of the exploitation assets / EFFiHEAT results (what is to be exploited?);
- Decision on the exploitation policy for each asset (how are we going to exploit it?);
- Decision on the market schemas (where and in which promotion channels should we implement the exploitation policy of the specific asset?).

The above answers create a set of directions, which will be aggregated into a generic exploitation strategy for each partner.

The use and monitoring of the IPR issues derived from the shared and individual contribution of the partners into the creation of the exploitation assets will ensure that there is a clear understanding and agreement of the ownership of the assets, thus avoiding any potential conflict in the consortium.

4 Project public website

The public part of the EFFiHEAT website is one of the means for increasing awareness of the EFFiHEAT project results and the project itself amongst the wider public and for attracting potential users of the EFFiHEAT project results and its applications. The EFFiHEAT web page has been created to inform about the project and its events. The Public area navigation bar has been designed to provide general public audience with basic information such as: project goals and structure, presentation of the project partners, description of the objectives, some news and information on upcoming EFFiHEAT events as well as project partners contact info.

The internal part of the web site is designed for internal use of project members. Its role is to support Project management and coordination – the internal sections are oriented towards aiding in the management and handling of the internal affairs of the Project and comprise essential collaboration information, materials and documents.

The structure of the EFFiHEAT website at **http://www.effiheat.eu** is designed in a clear and consistent way, so that visitors can easily locate all information intended for them. Upon entering the homepage of the Project, users are able to browse the Public area content, while access to Partners area requires entering password in a standard login interface that is located below the subsections list. All subsections of Public area can be accessed by all users. However, all public content within the website is read-only – changes to texts and files therein can be made by administrator only.

Partially due to security concerns and partially due to its simplicity no complex programs or separate web interfaces are used for the maintenance of the website. Notepad++ is used for coding and any standard FTP interface program (i.e.: Windows Explorer) can be used to access and manage the files within. However, access to websites internal structure to make changes from remote machines is restricted – management requires physical access to the server workstation.