Team 12
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FireWire Project Report

Intro

When we first met, we decided to just look at the problems all of us were thinking of as well as the skills that our team has all together. We had multiple choices of the projects and the project fair increased the number of possible project for our group. However, none of the projects made us feel comfortable and confident about that project. Anastasija decided to share with one project she was working on before entering Skoltech - applications of thermoelectric generators (TEGs). The last idea she was working on was a device for campers to charge their small electronic devices from the heat of the campfire. She had an idea of how the prototype should look like. Team decided that it is a great idea and very suitable project for IW so we chose to work on it.

The general idea of the problem we are solving with our prototype/project is the electrical access in the cold remote areas. The reason why we work specifically with the cold areas is that our solution requires high temperature difference, which is easy to achieve in cold areas (fire and snow/cold water). In addition, we focus on the solution for the area for which current solutions are not as effective because there is not enough sun for solar panels or running water for water generators. We had many discussions within the team and with mentors about the specific problem that people have when they do not have electricity while camping, hiking, and etc. We realized that opportunity to call someone is not the main issue simply because the coverage of the phone operators is very poor in remote areas. We also understood that many people go to remote areas for escaping technological world and they do not even need electricity access. Therefore we started intensive end user research and looking for answers on why travelers in the north need electricity and how important that is. We figured out that different end user groups have very different needs so we ended up with a slogan “We help people to stay connected to the things that matter”. In general, our problem statement is pretty easy and clear, however the end user was not as clear as we thought and we had a very interesting journey with end users that is discussed later.

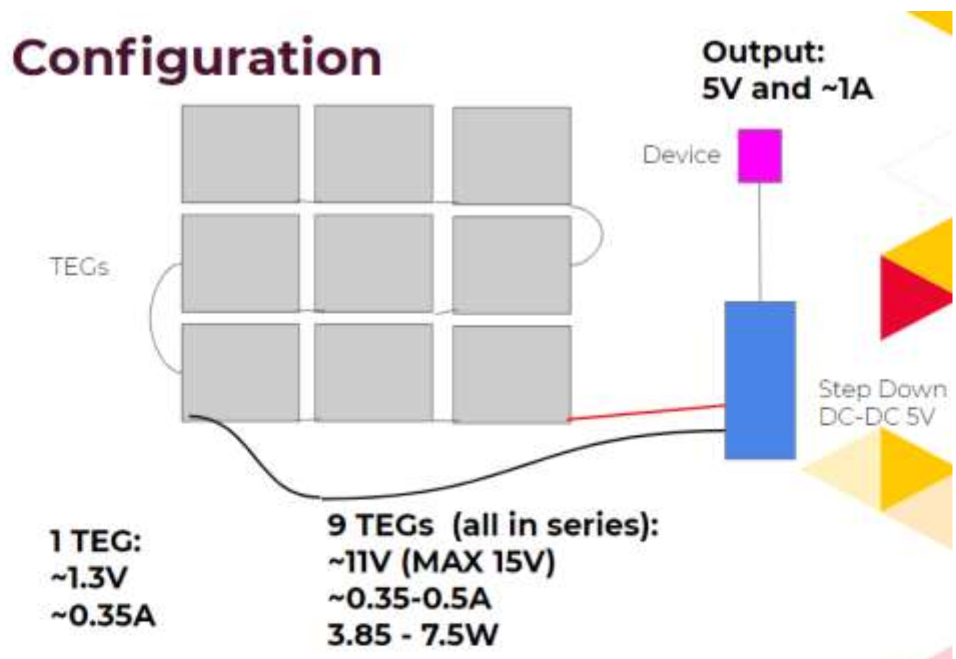
Our solution

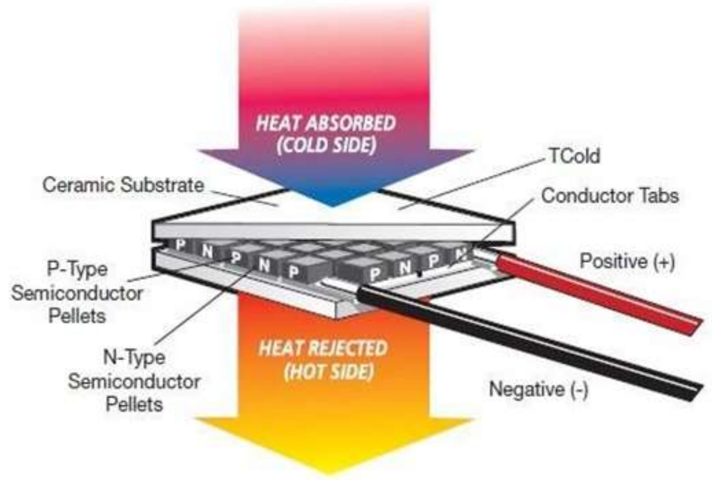
We decided to use the heat energy for generating electricity in the cold remote areas. We choose to use thermoelectric generators because they are small, durable and easy to use. Thermoelectric generators are getting more and more popular and can be used for various applications. Main part of the TEG is the TE module and it can work two ways: generating electricity from the temperature difference through Seebeck effect, or producing temperature difference when the power is applied through Peltier effect. We focus on the Seeback effect to generate electricity from the applied temperature difference (heat from campfire/ gas stove and cold from iced water/ snow).

The German physicist Thomas Johann Seebeck discovered Seebeck effect in 1821. First, he found out that when two ends of the conductor are held at different temperatures there is an electromotive force produced between those two ends. This happens because electrons diffuse from the hot side of the conductor to the cold side. Therefore, the Seebeck effect is the phenomenon when the temperature difference between two junctions of dissimilar electrical conductors produces emf (voltage). The voltage produced is directly proportional to the temperature difference as shown in the equation below. The proportionality constant is called Seebeck coefficient (α) and it is an inherent property of the conductor material.

$$V = \boldsymbol{\alpha} * \Delta T$$

We used the cheapest TEGs we found available. We purchased them on Mitinskiy radioshop for 197 rubles for a piece. These TEGs are not as efficient but good enough for the prototype. One TEG at 100 degrees difference produces around 1.3V and 0.35A. To get higher output we connect TEGs in series/ parallel. Series connection increases the voltage output and parallel connection increases the current output. For our device, we took nine TEGs and put them all in the series connection. Nine TEGs together generate 4 to 7 Watts, which is enough for charging small devices such as watches, power banks, phones and etc.





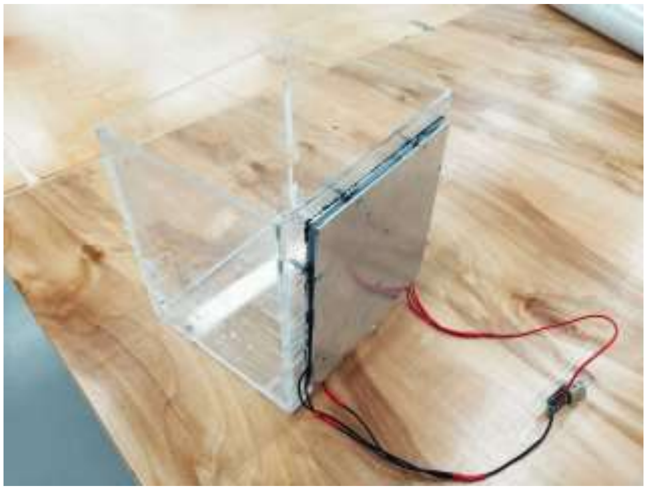
Prototype description

When creating the prototype Peltier elements TEC1-12706, aluminum sheets with a thickness of 2 millimeters, acrylic glass, tape, bolts and wooden washers were used.Initially, it was supposed to create a metal part of the prototype from a monolithic aluminum case, which would prevent moisture from entering electrical elements. However, it turned out to be quite complicated from the point of view of technology and inefficient in terms of keeping two both sides thermally isolated. After that, the case was made out of two aluminum squares of 150 times 150 millimeters and thickness of 2 millimeters.

These sheets were fastened together using bolts in the holes made along the edges. After the first experiments, it became clear that the bolts, due to the high thermal conductivity, heat the second side of the prototype, which does not allow creating the necessary temperature difference. To eliminate this thermal conductivity, it was decided to increase the holes and add wooden washers between the bolt and the aluminum sheets.

Then, more experiments were carried out, which showed the inability of the electrical circuit (3 parallels with 3 series-connected elements in each) to generate the necessary voltage and using step up stabilizer is not as efficient option as step down stabilizer. The electrical circuit was rebuilt in such a way that all 9 Peltier elements were assembled in series, which made it possible to achieve the required voltage. Despite the fact that we got less current that was enough for us on this stage of the prototype. To enhance the effect, all elements were greased with thermal grease on both sides.

The next problem was the insufficient cooling of one of the sides of the device. Therefore, it was decided to create a special container made of acrylic glass on a laser machine, which allows pouring ice water for sufficient heat removal and cooling of the device. Below on the picture you can observe how our prototype looks at this stage of development.



The output voltage from the installation was stabilized using a LM 2596 step-down stabilizer to 5 Volts. We tried different types of stabilizers and we stopped at LM2596 because it was the most reliable option for now. This is necessary so that the user can safely connect to the USB port output and charge devices.

As a result, it was possible to achieve the goal we set for this project and smart watches, a powerbank and an electronic cigarette were charged. However, the inability to connect a smartphone directly to charging became a limitation. Most likely, this is due to the limitations of smartphone software, which does not allow you to determine which source you use for the charging.

Scientific Validation

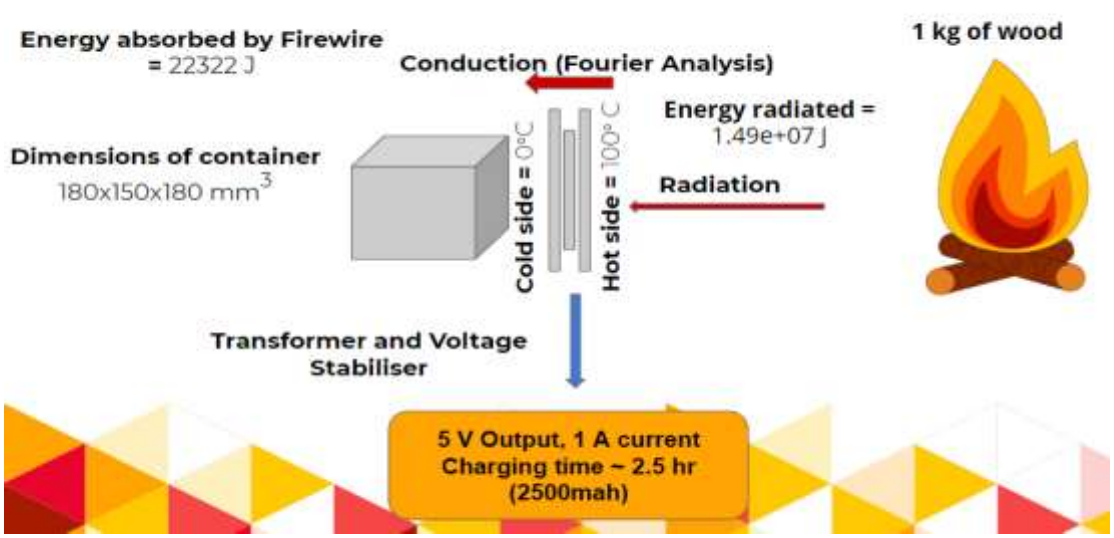
The energy is emitted from a campfire/heat stove in form of radiation packets. Some heat energy is lost in form of convection however, the majority of heat is transferred in form of radiation. For simplification, we take the mass of firewood burned to be 1 kg initially. Different types of wood have different thermal conductivity, however we take pine wood (mostly found in arctic regions). The wood has the density of 421 kg/m3. Our team faced a problem to estimate the exact amount of radiation falling on the aluminum metal plate since heat is also lost in the air and there are many modes of heat loss. However, for simplicity we assumed that 50 percent of heat radiated by the heat source is absorbed by the aluminum (Previous scientific experiments).

Wood heats up to approximately 212 F (100 C) evaporating the moisture in it. There is no heating from the wood at this point. Wood solids starts to break down converting the fuel gases (near 575 F, 300 C). From 575 F to 1100 F (300 - 600 C) the main energy in the wood is released when fuel vapors containing 40% to 60% of the energy burn. After the burning of fuel vapors and the moisture is evaporated, only charcoal remains burning at temperatures higher than 1100 F. This heat absorbed increases the temperature of the device until the hot side is 100C and is maintained at that temperature. The cold side is maintained at 0C. The heat transfer across the devices takes place through conduction.

In order to make our device generate enough electricity, a temperature difference around 100C is a good treshold. The heat transfer across the TEGs produce sufficient energy change to produce 10 t0 15 V and 0.3 to 0.4 A current But the amount of current was not enough (0.3-0.4 A). In order to obtain the required current, we decided to step down the voltage to 5V (enough to charge most small electronic devices) and thus increase the current to a sufficient value (~1 A). Of course, since the TEG's we used were cheap quality TEG's, their efficiency was low (most probably even lower than usual 5%) and thus a high temperature difference was required to produce enough electrical energy. The current TEGs have an internal resistance of ~2.3 ohms and a Seebeck coefficient of 0.053 V/K. For a device of 2500 mah(typical smartphones, cameras) , the charging time can be calculated as : 2500 mah/1 A = 2.5 hours. However, with better TEG's, the efficiency would be higher and more current could be produced decreasing the charging time of the devices.

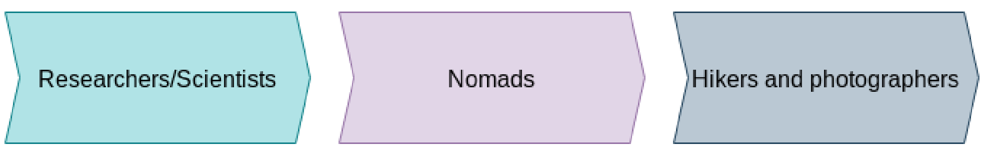
It was also difficult to estimate the exact volume of the container required so that the water doesn't heat up too soon leading to overheating. Because the heat is gained through conduction and lost through Newton's Law of Cooling and also heat is used up in the change of state of the ice (Ice-water-Steam), thus an exact value of heat transfer was tough to estimate. However, we obtained approximate values using the mathematical calculations in MATLAB software (taking a few assumptions). We are sure that the actual values won't differ too much from the estimated values. The volume of the container is only important for estimating the time that a device can be running efficiently without water change. This estimation can also be done experimentally.

Moreover, ANSYS analysis was performed to validate the calculated values and the values obtained by Analysis by ANSYS were similar to the calculated results. Hence, our estimation of the current produced, heat transfer and charging time are accurate to a reasonable extent. A simplified diagram explaining the logic behind the working of our device is shown below.

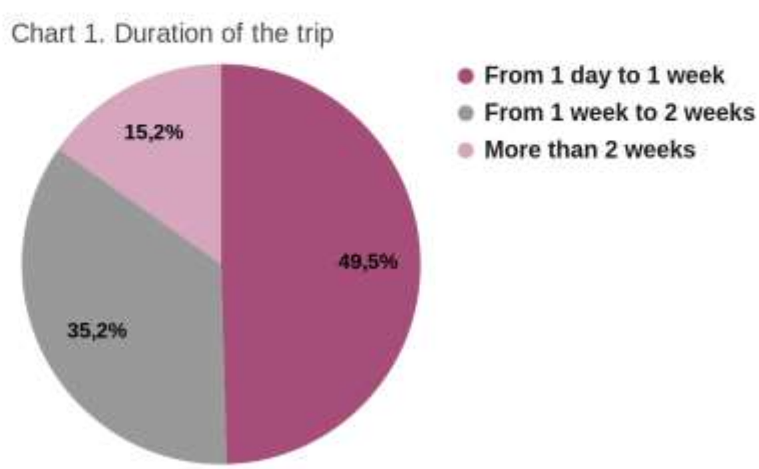


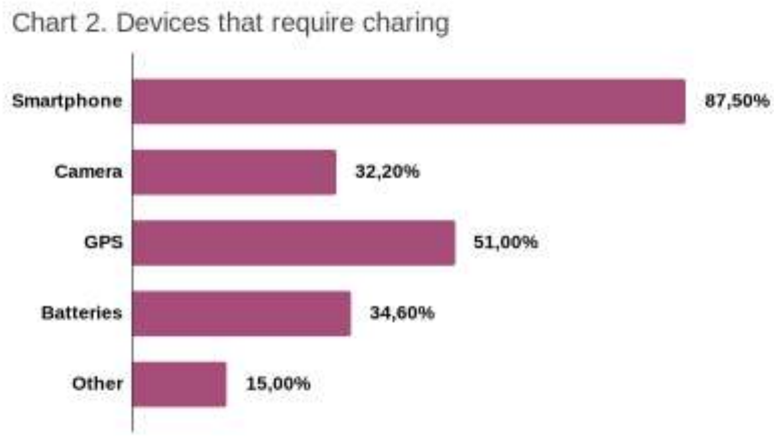
End Users

Our end user journey was very interesting and it let us learn a lot about the people who travel to the northern areas. In the beginning of the end user research, we wanted to focus on scientists who go on expeditions to cold areas. However, we figured out that they do not really need such a device because they use special equipment and cars. Then we tried to contact Nomads - people who lead a nomadic lifestyle in cold areas of Russia. Their population size is about 40 thousand. There were two problems connected with Nomads: firstly, it is hard to contact them because they do not have infinite access to the Internet, secondly, they do not have an urgent need in FireWIre because they usually use one big generator per community. Finally, we settled on hikers. Hikers expressed an interest in our device. Moreover, we contacted the Russian Union of Wildlife Photographers who make photos in cold and remote areas. The group of photographers is not that huge: the size of Association is 400 people, however they showed a great interest in FireWire because the main device they use is camera and it is needed to be charged. In addition, photographers have a budget up to 1 million rubles, so they are ready to pay for FireWire. Dmitry Petenin, Russian Union of Wildlife Photographers representative said, “If you make such a device, we will pay you any money”.



We conducted a survey among **210 people** who go hiking and camping in cold areas of Russia. The duration of the trip is usually from 1 day to 2 weeks (Chart 1). As for devices that require charging, people use smartphones, cameras, GPS, batteries (Chart 2). The results of the survey show that 82% suffer from lack of electricity. That means that the problem of access to electricity in cold and remote areas is very significant.





There are **current solutions** on the market such as solar panels, fuel, wind and water generators, power banks, dynamo machines and charging stoves. However, they have some disadvantages. For example, generators depend on weather conditions and amount of fuel, power banks have limited capacity, dynamo machines require constant physical effort, charging stoves are heavy and unreliable. Many interviewed people complained about carrying heavy bags and battery discharge. According to FireWire survey, the most important features of charging device are weight, size, and efficiency.

We develop FireWire based on drawbacks of current solutions. Firstly, we aim to make it lightweight (less than 500 gr) and easy to pack. Secondly, we want to set a reasonable price. Our main competitor BioLite Stove is 130$. We can make our device cheaper. Thirdly, we offer accessibility. It means that our user choose a heat source (stove, gas cooker, campfire).

Returning to FireWire survey, 70% of interviewed people are ready to use FireWire. Moreover, most of them are ready to pay from 2 to 5 thousand rubles (Chart 3).

We got a lot of positive messages from hikers about FireWire. Most people are ready to test our device. These are some messages from hikers:

- *"If weight is less than a kilogram and efficient enough - that's very good."*
- *"I really want to get a chance to test your device."*
- *"The price for a good autonomous charger is from $75 to $230."*
- *"Design is not as important, most important is efficiency and reliability."*

In order to get constructive end user feedback on tangible prototype, we contacted one of the hikers - Dmitry Kulish. He is also known as professor of Skoltech and Director of Innovation Workshop. Dmitry approved our idea and prototype: *"I like that it is foldable and nothing sticks out. Durability is important so that I can put it into backpack and not worry that it brakes".*

We thought that now photographers are our end user group, but after talking with mentors, we decided that this market is too small. However, we really did not want to lose them and once again, thanks to professor Kulish, we learned what we should do with them. Our end user group is regular hikers, but it's actually so hard to enter such a big market mainly because for regular hikers pain of electricity access is moderate. Therefore, we decided to find the entry point to this market – photographers and with their help spread FireWire among other hikers.

We still work on market research and finding our end user. We understand that the market is complicated. However, we have already found two main groups who really need FireWire: hikers and photographers. We are going to continue working with end user because we believe that our technology can be useful for other segments of users.

Lessons Learned

Now about lessons we learnt during Innovation Workshop. They can be divided in two, so called, groups - hard skills lessons and soft skills lessons.

Most of our team was not familiar with electrical stuff. However, to be fully contributive to our project we really needed to know how an electrical circuit works, what step-down is, and of course, what Seebeck effect is, as it was the foundation of our FireWire project. In addition, we tested several types of design, and now we know what is good, and what is bad. We also learned a lot of engineering lifehacks while working in Fablab (Thanks to Vladimir Kalyaev). We got tangible prototype! Of course, it's not perfect and there is a lot of room for improvement, but now we know how basic configuration of our working tangible prototype should look like. In addition, it's important to mention business part of our project. We learned a lot about distribution channels, market estimation, and business planning. Surely, real life business will be much tougher, but we feel much more prepared to it, then we were before. We really want to continue to work on our project, and do it ‘like grown-ups’ – talk to real investors about real money, so these lessons are very good for us.

Taking surveys was also great experience of talking with real end users, getting feedback from them to learn as much as possible about their pain. Firstly, we did not even know which questions should we ask, but after some trials and errors we managed to create really good survey and knew what we want to ask today. We faced hate-speech and abusive statements on the web (and in real life, from other teams, by the way), which is also a good lesson for real life.

Nevertheless, most importantly, we learned to work as a team. Truly speaking, it was not so hard for us. It just felt so natural. From the first day of the project, we somehow managed to create a unique atmosphere of support and open-mindless in our team. It just happened, and nobody (even professor Dorozhkin) knows why! Probably, that is one of our biggest achievements during Innovation Workshop. It was good both for personal life (each of us got 5 new friends, not bad, right?) and for professional life, as most of the mentors say that investors give money not to projects, but to people, to team. In addition, we are rather good team.

We learned that in good team not only leader should be initiative, but all of the members should be initiative. It really helps when any member of the team can become driving force and be responsible for some part of the project or project’s feature.

One more thing we would really like to mention is about innovation intrusion in our lives. Pre, we imagined. Now the most important part about innovation start-up is not to build innovation but to correctly define end user’s problem. As professor Zelko said at one of the lectures, ‘solving problem is okay, but defining problem is a challenge’ (it is not verbatim).

Future of our prototype/product

Our current prototype has many disadvantages and many things can be improved. Two main directions we have to work on are the improvement of the efficiency and design. In terms of efficiency we have to find the best and most optimal TEG configuration (maybe even decrease the number of TEGs to make it smaller and lighter). We plan to do deeper research on the TEGs available on the market and pick the best ones in the price region of 300 rubles per piece. In addition, it could be better to buy more expensive ones that are much more efficient but use smaller number of them. To make those decisions we have to do a TEG market research and run experiments with different TEGs that we potentially could use for our device. In addition, to increase the efficiency of our device we have to rethink the electronics. We want to try different stabilizers or maybe use some other piece of electronics that would be a more effective and reliable solution for us.

In terms of design, the first step is to make a “container” that is durable, light and foldable. We were thinking about such materials as silicon (used for baking so it is temperature resistant, durable and easy to fold) and Tetra Pack. But we still have to do deeper research of the materials available because we need the best solution so the container is made out of light, durable, foldable (soft), heat resistant and thermal insulating material. The other challenge we have to think through is how we connect the container to the metal part with TEGs. We have to make sure it does not have any leakage as well as we were thinking about making it detachable. Another design part we have to think about is the place where all the electronics is located. It has to be waterproof but with USB outlet. In addition, this area should not be sticking out, and should not prevent the folding of the container. We have some ideas like putting it inside the container near the metal part and USB output goes outside the container but there is a feeling that this idea needs some revision. The final aspect of the design is the metal part that goes to the both sides of TEGs. We believe we can make it thinner (1mm instead of 2mm) but still this assumption has to be scientifically validated to make sure 1mm is durable enough for our solution. In addition, we have to minimize heat transfer from one plate to another and putting some insulator might help (even though there is air but still some extra insulator could help).

There are more additions we want to implement into our prototype such as automatic temperature indicator. That would be something like Arduino based system with thermo sensors on both metal plates form the inside. The algorithm would calculate the temperature difference and based on the region that current temperature difference fits, different color LED indicators would light up. For example, if the temperature difference is too small (we would set the threshold when it is very close to being too small) to supply enough power to charge the device which could happen in two cases: too early and device did not heat up enough yet and water in the container is too warm and has to be changed. Therefore, if the water is too warm the user immediately gets notifies that he or she has to put more snow or ice in the water (or change the water). We could also install an LED screen that shows how fast your device is charging or simply shows the current that device outputs at the time. Final big issue we have to solve is that currently our device is capable of charging everything but mobile phones (at least the modern ones). The issue could be some safety that is installed in the phones and we have to do more research on how to overcome this issue and make our device ready to charge our customer phones.

After finishing our first market ready prototype we were thinking about creating multiple versions of our device that would fit the needs of different types of customers. For example, we would have a heavier and bigger device for people who can sacrifice the lightweight for high efficiency (faster charging speed) and have a lighter device for people for whom the weight is number one priority. In addition, we could have versions with and without the installed battery storage where again the version with the battery storage would be significantly heavier and bigger than the lightweight version.

Overall, there is plenty of room for improvement and a lot of engineering decisions and research has to be made but I hope we can create a prototype that we all have in mind (something that is shown in the pictures below).

Business model

We are participating in the Industry Day held at Skoltech, where we will obtain expertise of industry representatives and gain contacts with relevant companies, starting with Bask and RMT - company, specializing on thermoelectric cooling solutions. We are planning to apply for Kardifov lab grant, Lomonosov Moscow State University Umnik grant to raise primary funding. We also need to establish manufacturing process, for that we are planning to contact Pavel Dorozhkin and Alexey Cheremesin, who could provide us with the necessary connections. We are planning to meet with the IP department to obtain the expertise of registering the device and consult the CEI faculty for start-up establishment processes expertise.

We are going to develop and test multiple prototypes simultaneously to obtain the established mass-manufacturing process and technical specifications. Several iterations of prototypes still need to be run to maximize fidelity. For that, we also need to run field-testing, contacting the end users. We already have arrangements with professional photographers and hikers, who are ready to receive prototypes and test them. Therefore. we will be able to improve design and manufacturing, making the device optimized, cheaper, more available and reliable. The current solution still needs improvement technologically and the pricing model is still established with the current estimate of 90-100$ and the current manufacturing cost of approximately 40$ with only material costs taken into account. Then we are planning to contact thematic shops, related with sports and hiking, such as Sportmaster or Expedition. We are going to research the market of existing TEG solutions, test the options and choose the optimal. Depending on the contacts we obtain, we could collaborate with companies that produce TEGs and establish the supply chain. Same for materials of containers and stabilizers. Once we have a ready to test prototype we want to give it the wildlife photographer for real life testing and get their feedback in order to create the best solution for our customers.