PROJECT REPORT

MEC-E3001 PRODUCT DEVELOPMENT PROJECT V

2023–2024

TEAM MEGAMORPH

PRESENTS

COMPOSITION ULTRA

A MEGAMORPH TECHNOLOGY

MEGAMORPH

GRAPHENE DISPLAYS

CONTENTS

STUDENTS

Carl Akira King

Kaarlo Mustonen

Abdul Moiz Javed

Riina Koskinen

Tomas Jelinek

Ernest Beliasovas

Anni Toivonen

Eeva Hirvinen

Skylar Runze Wu

Talha Waqar

Michele Garzone

EXECUTIVE SUMMARY

Our project began with the task of finding new ways in which the GMOD membrane by Megamorph could revolutionize a market segment. In essence, this meant developing novel ways to utilize the GMOD membrane, ways separate to its original use case as a display technology. Over multiple ideation sessions, countless meetings and dozens of hours of both technical and market research, we narrowed our search to how gases would interact with the membrane, and more specifically, Hydrogen gas. Hydrogen gas is known to be able to permeate through graphene unlike other gas molecules, and hence the graphene-based membrane could potentially interact with hydrogen in a way that could be used to detect or quantify the gas.

Eventually, we came up with a way in which the GMOD membrane could be utilized to measure the composition of gas mixtures, by using the differences in how gases permeate the graphene layer combined with the membrane's unique ability to communicate its state optically, through the color of the light reflected off of it.

Coming up with a way to measure gas composition would partially satisfy the goals we set out to accomplish, but the measurement method itself does not demonstrate how the novel application would be revolutionary. To that end, we developed a product that drives the latter point home: *CompositionUltra*.

In this project report we will describe exactly how we arrived at our solution, and the science backing it up. The report will also present the final product concept, along with how it is intended to be used and what kind of problems it addresses. Finally, the report will describe further work required to make this product a reality, as well as learning experiences and a brief overview of our budget.

BACKGROUND

The GMOD membrane displays different colors based on the position of the graphene layer over the microscopic cavities. The graphene layer can for example be low in the cavity or high. This position can be observed to a certain extent with the naked eye, but also with specialized camera equipment.

In order to measure gas composition with the GMOD membrane, we need to modify the graphene layer of the GMOD membrane, by producing pores/holes of a microscopic size in the layer. This can be done using multiple methods, but one example would be to use a focused beam of Helium and Gallium ions [1]. These pores allow for some sizes of gas molecules to pass through while blocking others. We then make several different GMOD membranes with different pore sizes.

Once we have GMOD membranes with multiple different pore sizes, we build a chamber that can compress the gas to increase the pressure within the chamber. All the membranes are placed within the chamber in such a way that their position can be monitored by a camera viewing the membranes.

Upon compressing the gas in the chamber, the graphene layers of each type of modified GMOD membrane will compress into the cavity. This can be observed by the camera as a change in the color of the membranes. Over time the cavities in each of the membranes will normalize in pressure, so that the graphene layers return to their original positions.

The hypothesis is that based on the composition of the gas, and especially the presence of smaller molecules such as Helium or Hydrogen in the gas, the speed at which the different membranes normalize should vary. We could empirically prove this by completing the procedure described above with different types of gases. After proving it, we could develop a mathematical model to infer the composition of the sample gas based on the time it takes for the different membranes to normalize in the test. Alternatively, a machine learning algortihm could be applied to the results to estimate the gas composition.

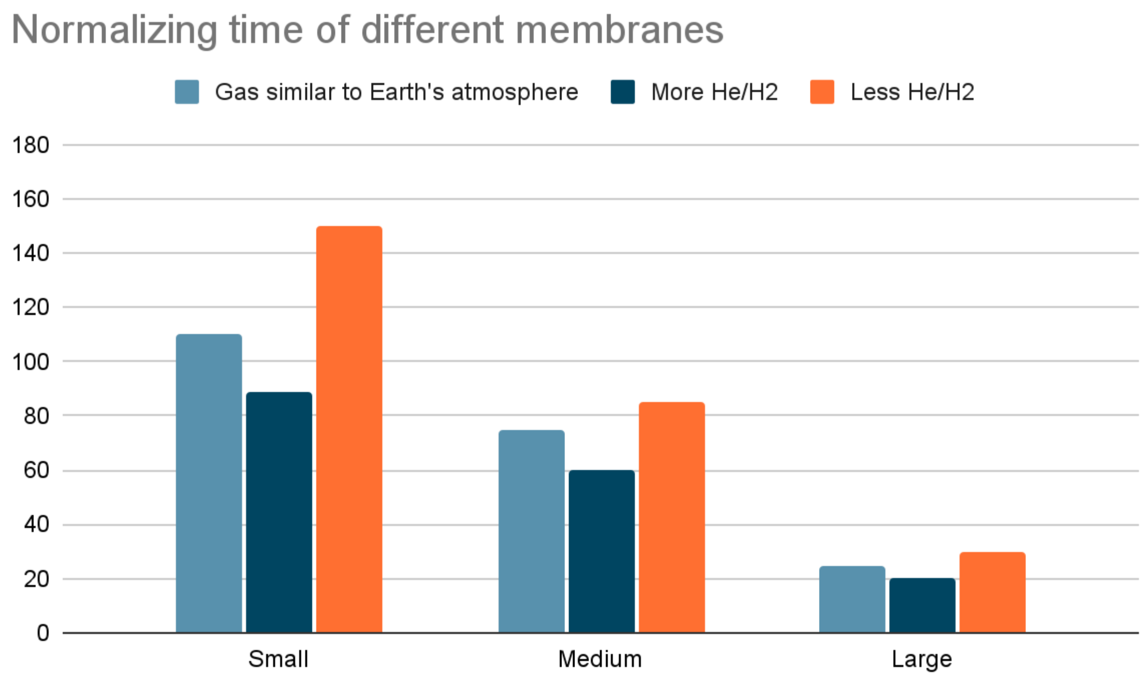

Figure 1. A bar graph demonstrating our hypothesis of how the membrane would behave.

In order to demonstrate the hypothesis on how we believe the modified GMOD membranes would behave, in Figure 1 we have plotted a bar graph. The bar graph plots different gas compositions and how modified membranes with relatively small, medium or large pores would behave in the measurement procedure described previously. In essence, the membranes would return to their original positions quicker in the presence of gas rich in smaller molecules, and slower in the presence of larger molecules. By having multiple membranes with different sized pores exposed to the measurement procedure, the gases and their quantities present in the sample can be narrowed down.

OUR SOLUTION

Now that a novel way of utilizing the membrane has been developed, we can turn our attention towards actual ways of utilizing the technology. We noticed that gas measurement seems to often require complicated procedures and human intervention. Methods such as gas chromatography or different spectrometers require a gas sample to be taken manually, as would the measurement process as well. In this day and age, doing anything manually sounds old-fashioned, and so we thought long and hard how we could automate the gas composition estimation process, and who would benefit from such a device the most?

We focused our efforts on industry, specifically the industrial gas production industry. Industrial gases, as the name implies, are gases used in industrial processes such as in chemical plants or manufacturing. These include a wide range of gases from noble gases such as Argon or Xenon, to the smaller gases mentioned earlier, Hydrogen and Helium.

Through interviews with experts working with Hydrogen we have gained confidence in the need for such a device in the gas production industry. For example, it is reasonable to expect that once the technology has matured the device could detect common contaminants in Hydrogen gas such as methane or hydrogen sulfate. Existing research in the graphene molecular sieves intended to be used in the modified GMOD membrane indicates that they are capable of separating methane gas from hydrogen fairly effectively [1], and that producing such molecular sieves is already feasible in the research domain.

COMPOSITION ULTRA

This is our final product concept. CompositionUltra is a device that is connected to a gas pipe in an industrial gas production facility. It takes periodical samples of the gas traversing the pipeline and measures the composition of the gas samples. This data is communicated via the facilities intranet to programmable logic controllers in the facility, that can relay the sample measurements to a human operator overseeing the production of gases or use the data to adjust the process control signals.

A key part of any production process is maintaining adequate feedback of the production process, which CompositionUltra can provide, real-time. Gas samples no longer have to be taken manually by plant personnel, but rather they are automatically taken from the gas production process. This closes the feedback loop much quicker than manual sampling (samples can be taken more frequently), and therefore the production process can be controlled to much more accurately produce the intended product. This in turn leads to potential improvements in the purity of the produced gas, safety in the production plant, and cost savings by minimizing costly human resources.

The body of the device is machined from aluminum, and houses components such as a microcontroller, a camera/led unit, two solenoid valves, relays, and a motor with a shaft that drives the compression screw. There are two 1” cutouts to attach the device to the pipes. This part of the concept was left vague to accommodate the results of further research into specific use cases.

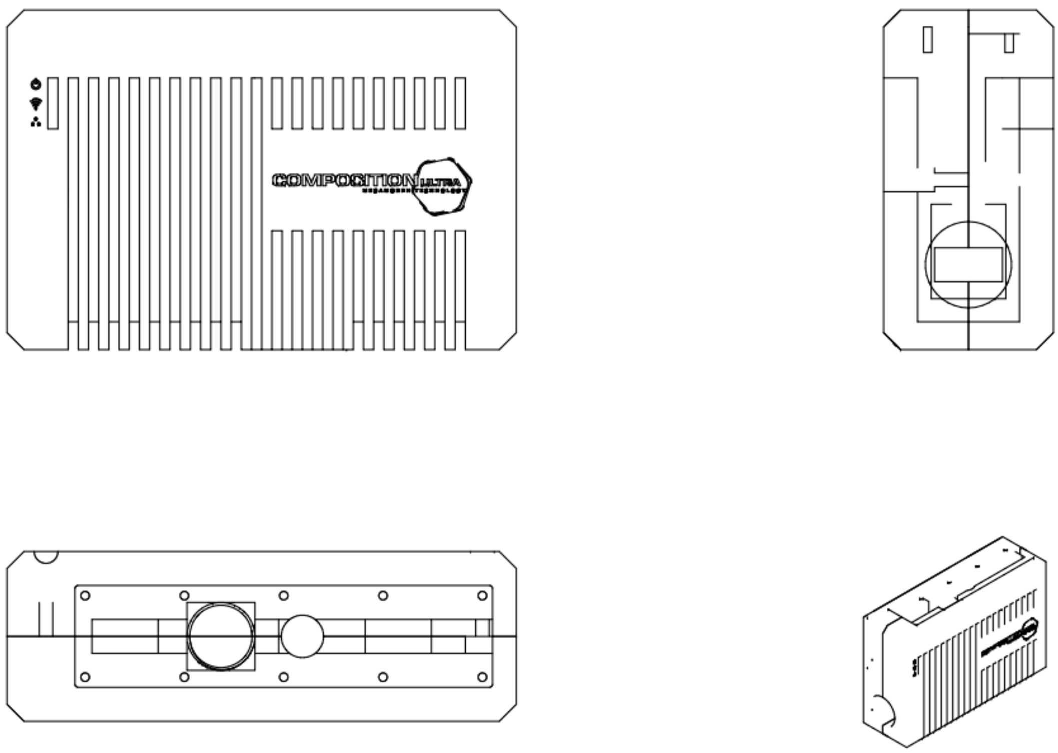

Figure 2. A technical drawing of CompositionUltra.

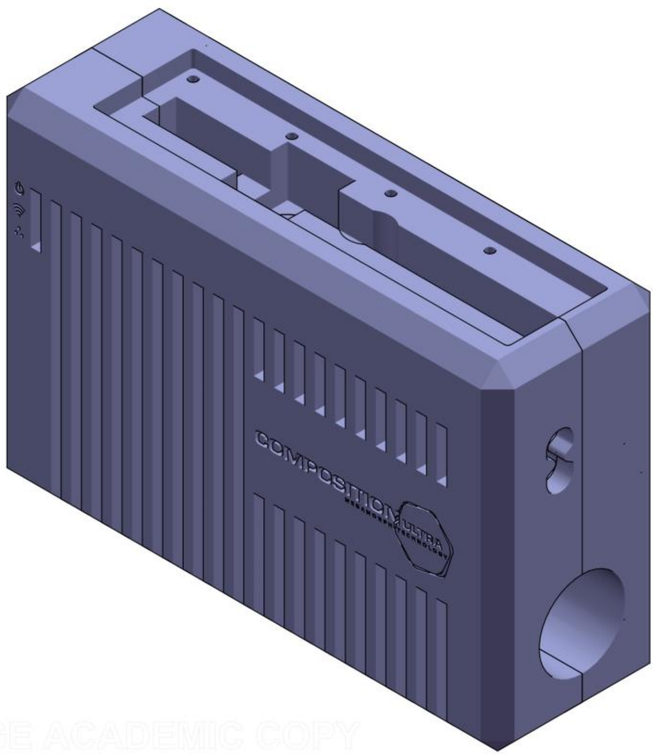

Figure 3. A render of the device's body without the top maintenance lid. Notice the hole for the power connector and the cutout for the LED indicators.

Figure 4. The body of the device showing the cutout for the membrane to be swapped out during maintenance.

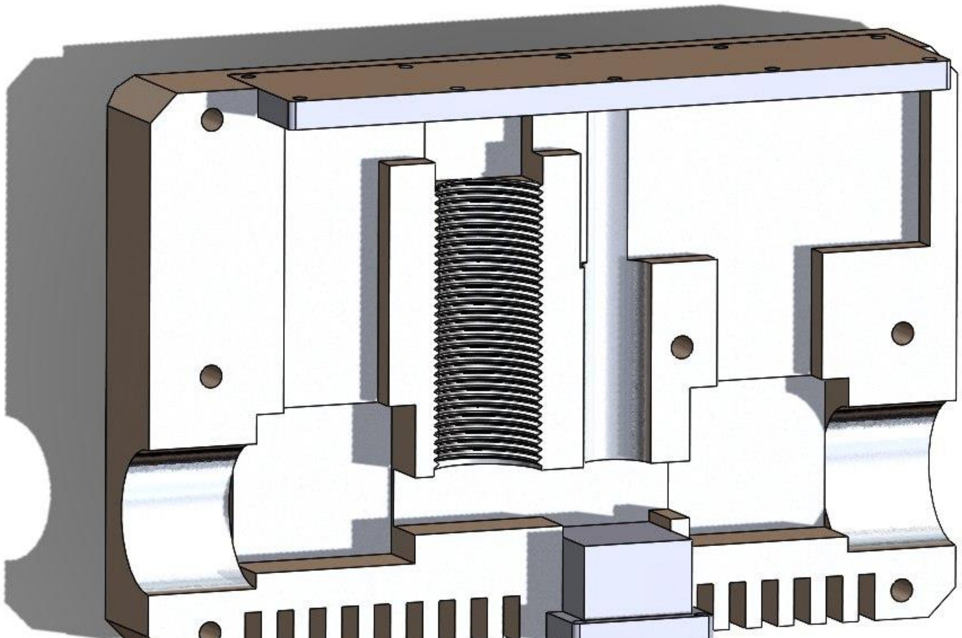

Figure 5. A section view of the device body showing the cutouts for the components. The maintenance lid on top of the device and the membrane holder on the bottom of the device are shown as well.

The bottom of the device has port secured with bolts, that allows for the exchange of the GMOD membrane during maintenance of the device. Similarly, on the top of the device there is a lid secured with bolts that allows easy access to the components inside the device. The device is machined from two halves, which are secured with 5 bolts. The outside of the device forms a heatsink to partially to maintain an appropriate temperature for the components inside, but mainly to shed weight from the device and for aesthetic reasons.

In the future details of the device will be refined to better match the needs of our potential customers. Details which will likely change include the dimensions of the attachment for the gas pipes, connectors such as Ethernet, USB or power and indicator LEDs. Furthermore, the internal electronics will likely be adapted as well, for example the Raspberry Pi Zero that the current body of the device is designed for will likely be swapped out for something cheaper and more task specific.

In addition to the changes to these aspects of the devices, additional details will need to be added, such as a software interface and programs that operate the device. The device will likely need to communicate with PLC devices in a production environment and therefore software suitable for the task must be developed. Further user research may highlight a need for access to the device through alternative means as well, such as through a smartphone app for maintenance/diagnostic purposes. These kinds of features may require the addition of physical components not presented in the original concept here, such as an NFC-chip/tag or wireless communication antennas to allow for quick access to the device.

In addition to the device presented here, as the technology matures it could become viable to produce gas composition measurement devices for other use cases as well, for example for the monitoring of aerial organic compounds or other more complex gases.

FURTHER WORK

Given the constraints of this course and the scale of work required to make this concept a reality, it is obvious that a lot of work remains to be done before the device and technology presented in this report can be made into a commercial product. In this section we want to highlight some of the work we think will be required to make this product a reality.

First and foremost, while graphene can be modified to have pores of very selective sizes in a laboratory environment, as highlighted in the research discussed above [1], there are major issues regarding the scale at which this can be done. The methods used to produce the graphene molecular sieves discussed in the research are not yet available on an industrial scale. Similarly, graphene production itself is still maturing, and the graphene currently being produced may lack the purity required to make this technology feasible.

If we were to have the prerequisites mentioned above (industrial scale manufacturing of porous graphene, purer graphene), there are still some hurdles to overcome. For one, transferring the porous graphene layer onto the other parts of the membrane is likely to require research. The properties of the modified GMOD membrane would also need to be confirmed. For example, how does the porous graphene change the optical properties of the membrane? Similarly, we need to observe how the modified membrane behaves in the measurement procedure proposed in this report and determine a mathematical model or a machine learning approach for this behaviour. After it has been confirmed that this can be done, and that the membrane does indeed behave differently with different gas compositions in a verifiable manner, further research would likely need to be done to implement it into a device.

As can be seen from the preliminary estimates of the future work required for this product, it is obvious that this product is at least a few years, maybe even a decade or more into the future. However, the method presented here is novel and does have the potential to shake up the gas composition measurement market.

CONCLUSION

All in all, we have accomplished what we set out to do in this project. Returning back to the goals mentioned earlier in this report and in the project plan: “Develop novel and revolutionary ways to utilize the GMOD membrane”. Through hours of research and ideation, we came up with a novel way of utilizing GMOD membranes, and with continued hard work were able to make a convincing case for utilizing the technology in a revolutionary manner through our final product concept. The concept and other deliverables of our project also provide a solid foundation and motivation to continue development and research on the GMOD membrane and graphene, such as in the ways outlined in the previous section. In the following subsections we will briefly cover some final takeaways from the product development project as a whole.

LEARNING EXPERIENCES AND FEEDBACK

To describe the project as challenging could in many measures be considered an understatement. For most of the group members, an ATTRACT project was seen as – ironically – less attractive, due to the constraints it set on the development process, and due to the lack of convincing presence by ATTRACT sponsors in the sponsor presentation event before sponsor negotiations. When the team couldn’t secure the initial primary sponsor candidate through negotiations, it set the tone for the team for a long time. In retrospect, many were also confused as to what exactly the task would be if Megamorph were to be our sponsor, while for other teams the tasks were clear. For example, Oras wanted to better integrate smart features into the bathroom environment. However, after Megamorph was determined to be our sponsor, the project rumbled off to a start, which involved a shift in the mindset for the entire team: the project was not our #1 choice, but we will make it work, and we will make it the best project this year.

Once project work started, we ran into yet another issue in the complexity of the technology. While the core idea of it was simple, many in the team were confused as to what it exactly entailed. Not all of the team members had technical backgrounds, and getting everyone on the same page about the technology was a major task in itself. There were also some issues early on with the slight language barrier both between the team members and between the team and the sponsor. Similarly, the people at our sponsor were academically inclined while the team was less so, making communicating ideas that bit more laborious.

From a product development perspective, the requirement of utilizing the GMOD membrane in a novel way required a totally different approach. Most of us were used to thinking all means to reach a specific goal are available, whereas in this case the means were strictly limited to those utilizing the GMOD membrane in a novel way, and the goal was rather restricting as well in that the final result had to be revolutionary. Combined with the technology still being in its infancy, the project had most of the team lost on what direction it should focus in.

Another hurdle was in identifying the avenues in which findings could be made. A strong understanding of physics, chemistry, material sciences and electronics seemed to be required from the team, as well as the skills to communicate this knowledge effectively to other team members. While our team combined skills in multiple fields, our team was also composed of a large majority seeking a role as project manager. While initiative and commitment are greatly appreciated in a project, this also resulted in many people describing their skills as rather general and crossing to other fields, rather than being specialized in their field. From this point of view, the group could be seen as quite homogenous in the skills of its members.

While a project plan was laid out in the beginning, most of the time span allocated to the project was not spent according to plan. In terms of workload, the team was not spending enough time on the project for many of the first months. In the end, major breakthroughs in the project were made largely by chance, through casual conversations and individual team members stumbling on specific research articles and developing ideas.

Until now, this section has listed challenges and issues that our team has faced, but not addressed the learning outcomes from the project. While a less challenging project would certainly have pleased everyone in the beginning, we can state with confidence that having a challenging project greatly improved our learning outcomes. These learning outcomes most likely vary for each of us, but here we'll mention a few that stand out.

In terms of coordinating tasks, one major takeaway was in the importance of determining meaningful and approachable tasks to everyone. Even with a team that is exceptionally sociable, positive, driven, committed and caring, a lack of **meaningful** and **approachable** tasks will sap motivation out of the team. As described previously, a large amount of the time in the beginning of the project was spent not exactly knowing what we should be doing, and while intermediate goals and deadlines provided some tasks to work on, the tasks were not nearly enough to keep 11 members busy. At the same time, some tasks were not approachable for all team members. For example, researching a topic which requires a deep technical understanding is not something everyone can undertake. This was likely one reason why some tasks were lagging or never completed.

Another takeaway from the project relates to how important it is to meet and spend time with people in person, face-to-face. This could be in both a casual manner, just to get to know each other, but also in a formal manner, for example in ideation, prototyping or brainstorming sessions. A large portion of the timeline of the project was spent moving from one weekly meeting to another, with little to nothing accomplished in between. Eventually, our sponsor would miss meetings, and team members would become less present in discussions and meetings. In future projects, it could prove valuable to allocate time for casual discussions under the guise of cooking together or other activities especially early on in the project, but ideally throughout the project timeline. This could be accomplished with a fixed weekly slot agreed upon with the team to be used for team activities.

Many of the learning outcomes described here relate to coordinating the project and could therefore easily be mistaken to be solely the responsibility of managerial team members. However, especially in the context of a school project this couldn't be further from the truth. Team members share a responsibility in communicating their needs and views regarding coordination of the project, and successfully doing so can greatly change the course of a project. This was highlighted when one of our team members effectively described their concerns halfway through the project, and in response coordination was handled more effectively from then on.

Of course, communicating concerns can sometimes be seen as patronizing, non-constructive or aggressive to name a few negative associations. This means it's not an easy task for either the giving or the receiving end but also doesn't diminish its importance. Adopting a system theoretic view (see Figure 6.) on this matter, if the project work were to be considered a process to controlled and the project manager a controller, the team members could be seen as actuators and sensors. Attempting to control a process without adequate feedback (from sensors), is like attempting to drive a car blindfolded. Feedback is essential for knowing how to steer a project, and giving feedback in a kind and constructive manner is every team member's responsibility as well as a skill that should be honed. As a short disclaimer, the figure represents one aspect of project work, and should be understood as a rough simplification.

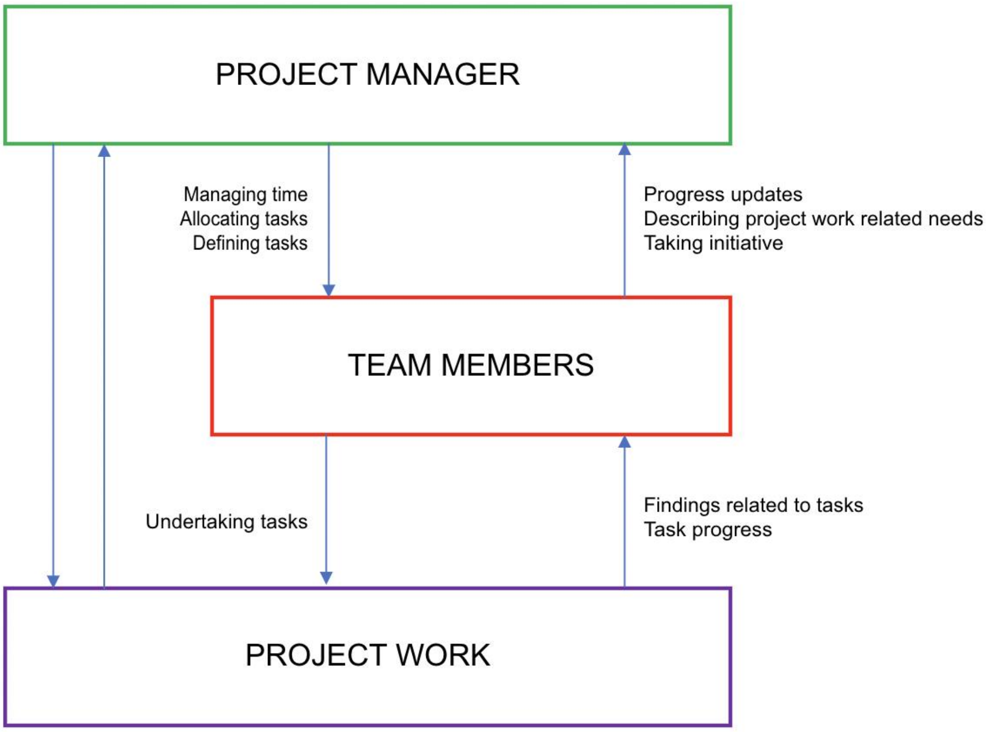

Figure 6. A diagram describing control and feedback loops in a project (excluding external stakeholders)

Another learning outcome on the coordination of tasks relates to how leadership is assigned in a group project. In retrospect, our project showed repeated instances of leadership being assigned without actual knowledge of the nature of the work needed to be led. For example, halfway through the project the project mechanical and design leads were chosen. However, what a mechanical lead or design lead would oversee and coordinate was left ambiguous. An alternative approach could prove more valuable in future projects: determine the tasks that need to be done, and then assign responsibility and leadership for those tasks.

On a smaller scale, we learnt a lot of small new things through the various activities in the course. For some of the team members, collaborative design proved to be a new and interesting experience. Developing a product for the future was also a change for many, as most projects tend to focus on what we can do now. Similarly, everybody worked out of their comfort zone on research in industrial gases and the behavior of gases in general. A lot of knowledge was shared between the team members representing different fields, and each of the members will surely to be able to use this knowledge as their own in further projects.

While we've written of quite a few learning outcomes here, there are many more that have been made during the project. Many of these are rooted in our body in ways that can only be described as experience: The experience of noticing how a group's atmosphere changes after a specific situation or how certain people act in certain situations. How people act in the face of a challenge, and how people handle and recover from disappointments. What drives people onwards and what might be demoralizing for them. These and many of the learning outcomes presented above are those which cannot be made while smooth sailing. Perhaps we could've made different learning outcomes in an easy project, but there was certainly value in a challenge like this: and it shows!

SELF EVALUATION

All in all, our team accomplished what it set out to do. Though our progress during the course of the project was not linear, and the workload could have been spread more evenly across the timeline, we feel like the project meets the criteria set out for it in the beginning. Of course, simply meeting the criteria is usually not laudable in itself. However, we do believe that the bar was set unusually high in the beginning, and considering the ideas and concepts developed during this project are novel and worth further investigation, we believe that the project exceeds the goals set for the course.

With this in mind, we believe a grade of 4 out of 5 would be suitable for our work. A higher grade would have required some of the challenges described above in the learning experiences to be managed more effectively.

BUDGET MANAGEMENT

Overall, we were far off from using our entire budget of 10 000€. In retrospect, we could have invested a part of the budget in, for example, services from companies, such as having parts machined or getting a good graphic designer to work on some part of the visual design. We had very little expenses in terms of ordering goods and materials, and the majority of the budget was spent on travel for our team members from HAMK. Spending a part of the budget on services could have alleviated some of the workload off of the team members where possible.

Our total spending at the time of writing this report was 2967 euros, which left 7033€ of our budget unused (see Table 1.) However, some additional expenses will likely be logged within the remaining two weeks of the project. Figure 7. demonstrates how up to two thirds of our expenses were spent on travel for our remote team members from HAMK.

Money Out	
Remote Team Travel	€2,000
Team Bonding	€806
Prototyping	€161
Total expenses	**€2,967**

Table 1. The table above shows what constituted our expenses at the time of writing this report (3.5.2024). Further expenses may still be logged within the last 2 weeks of the project.

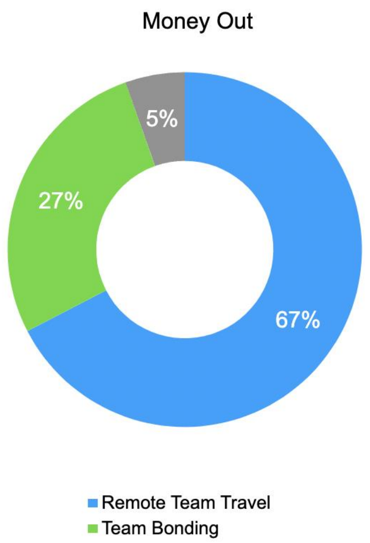

Figure 7. A pie chart shows our spending consisted largely of travel expenses.

REFERENCES

1. Alekseeva, O. K., Pushkareva, I. V., Pushkarev, A. S., & Fateev, V. N. (2020). Graphene and Graphene-Like Materials for Hydrogen Energy. Nanotechnologies in Russia, 15(3), 273–300. https://doi.org/10.1134/S1995078020030027