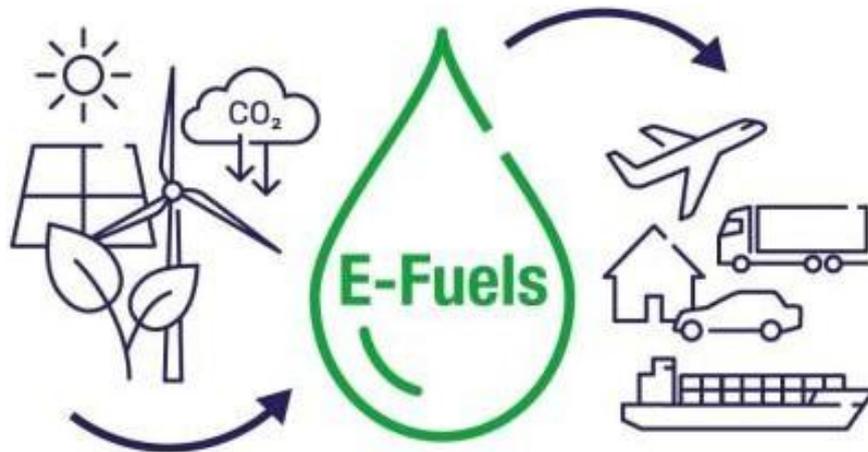


# EPS Project

## E-FUELS



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**Fall Semester 2025**

## **EPS**

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Abstract:

This project is about doing research and designing a small-scale E-methane prototype that the university can use in lectures for students. Also some research on other E-fuels is done to see what are the possibilities.

The project group worked together on this project where research is done, buy the parts, and build the prototype.

The main results are a build prototype that will be used in the lectures for students where they can produce E-methane.

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Appendices: 1

# Table of Contents

1	Introduction .....	6
1.1	European Project Semester (EPS) .....	6
1.2	Presentation of the members.....	6
2	Presentation of the project .....	8
2.1	Objectives .....	8
2.2	Stakeholders .....	8
2.3	Budget and resources .....	9
2.4	Expectations and deliverables .....	9
2.5	Timelines.....	9
3	The different E-fuels.....	10
3.1	E-Ammonia .....	10
3.1.1	Introduction about E-ammonia .....	10
3.1.2	How is E-ammonia produced .....	10
3.1.3	Safety .....	11
3.1.4	The costs for equipment and production .....	11
3.1.5	Where will E-ammonia be used? .....	11
3.2	E-Diesel.....	12
3.2.1	Introduction about E-diesel .....	12
3.2.2	How is E-Diesel produced.....	13
3.2.3	Safety .....	15
3.2.4	The costs for equipment and production .....	15
3.2.5	Where will E-Diesel be used? .....	15
3.3	E-Methanol.....	16
3.3.1	Introduction about E-Methanol .....	16
3.3.2	How is E-Methanol produced .....	16
3.3.3	Safety .....	17

3.3.4	The cost for equipment and production.....	17
3.3.5	Where will E-Methanol be used? .....	18
3.3.6	E-Methanol VS E-DME .....	18
3.4	E-DME.....	19
3.4.1	Introduction about E-DME.....	19
3.4.2	How is E-DME produced.....	19
3.4.3	Safety .....	21
3.4.4	The cost for equipment and production.....	21
3.4.5	Where will E-DME be used .....	22
3.5	E-Methane.....	23
3.5.1	Introduction about E-methane.....	23
3.5.2	How is E-methane produced?.....	23
3.5.3	Safety .....	24
3.5.4	The costs for equipment and production .....	24
3.5.5	Where will E-Methane be used? .....	24
3.6	Recap of the processes.....	25
3.7	Ranking and selection of the E-fuels .....	26
3.7.1	Explanation of the selection matrix .....	26
3.7.2	Why the Methane prototype Was Selected .....	29
4	Technical Overview from Previous Prototypes .....	30
4.1	Ontario University Prototype.....	30
4.2	Swedish Thesis Prototype .....	30
5	Design.....	33
5.1	Design V1.....	33
5.2	Design V2.....	34
5.2.1	The parts in the design V2.....	34
5.2.2	Safety considerations on the design .....	37

6	Purchase list .....	39
7	Instructions.....	41
7.1	Introduction .....	41
7.2	Safety Precautions .....	41
7.3	Chemicals .....	42
7.4	Procedure.....	42
7.5	Data recording.....	44
7.5.1	Parts Required for temperature and methane sensor .....	44
7.5.2	Opening Raspberry pi.....	44
7.5.3	Wiring / Connections : Connect the MAX6675 module to the raspberry pi as follows: 46	
7.5.4	Wiring / Connections : Connect the MQ4 sensor to the raspberry pi as follows: 47	
7.6	Raspberry PI .....	48
8	Difficulties .....	49
8.1	Difficulties.....	49
8.2	What could have improved the project.....	50
8.3	Which other E-fuel could be implemented in the future.....	50
8.4	Recommendations for Future Improvements and Upscaling.....	51
8.4.1	Product Separation and Purification.....	51
8.4.2	Improving product characterization and educational use.....	51
8.4.3	Transition to Continuous Operation .....	52
9	Conclusion .....	53
10	Project Management .....	54
10.1	Project mission and vision .....	54
10.2	WBS Breakdown .....	55
10.3	Gantt chart .....	57
10.4	RACI Matrix.....	59

10.5	Risk management .....	60
10.5.1	Risk Identification.....	60
10.5.2	Risk Analysis .....	61
10.5.3	Risk Response Planning.....	61
11	Project with Chile students .....	62
11.1	Introduction .....	62
11.2	The project .....	62
11.3	Working with the Chile students .....	63
12	Annexes .....	64
	List of figures .....	70
	List of table .....	71
	List of resources .....	72

# 1 Introduction

The E-Fuels project is part of the European Project Semester at the Novia University of Applied Sciences in Vaasa (Finland). This project aims to design a safe and educational E-Fuel production prototype. E-fuels, also known as synthetic fuels, are made of renewable electricity, water, and carbon dioxide (CO<sub>2</sub>). They intend to represent a viable carbon-neutral alternative to traditional fossil fuels without changing today's energy infrastructure, making them essential for the transition to sustainable energy.

The goal of the project is to build a small-scale E-fuel production prototype that can be used in lectures for educational purposes. This report explores the possibilities of building a small production prototype for E-fuels, focusing on E-ammonia, E-diesel, E-methanol, E-DME, and E-methane. Each of these E-fuels has its own advantages and challenges, which will be explained. The E-methane is chosen to make a small-scale production prototype. E-methane was chosen because it is the most suitable candidate for small-scale applications for this project; it has the best balance between technological simplicity and operational practicality for an educational purpose. These questions: Why E-methane? And what makes it the most suitable candidate for small-scale applications? form the foundation of the research that follows.

## 1.1 European Project Semester (EPS)

The European Project Semester is a program for students in the areas of engineering, technology, and design. Students from different countries and academic backgrounds are grouped into international teams to solve projects provided by companies or universities. In those groups, students get to work with other students with different cultures and learn from each other. The aim is to prepare students for the challenges that today's industries are facing. The EPS develops students' technical knowledge and improves teamwork, communication, and project management skills.

## 1.2 Presentation of the members

My name is Nathan Pernin, I am 21 years old and I come from France. I am in my fourth year of mechanical and industrial engineering study at ENIT (Ecole Nationale d'Ingénieurs de Tarbes). Because of my interest in technical challenges, I chose to join the European Project Semester (EPS). I wanted to do it in Northern countries to discover a new culture and to practice English as they are known for having a good English level. This semester is also a great opportunity to apply my theoretical knowledge to concrete, intercultural problems. I believe that this practical experience will enhance my profile and prepare me for future work in engineering companies, as I intend to work internationally upon receiving my diploma.



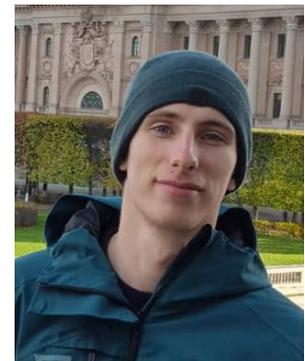
Figure 1: Picture of Nathan

My name is Gijs Rovers, I am 21 years old and from The Netherlands. I study Industrial engineering management at Avans Hogeschool in Den Bosch. I chose to do the European Project Semester (EPS), because I like to do projects in a project group. I knew I wanted to do an EPS semester after talking to some people that also did one. Then I after I knew for myself that I wanted to do an EPS semester, I had to choose a country where which provided a EPS semester. First I thought about Spain because of the good weather, but after talking to a teacher at my home school I started to hesitate about Spain. In that talk he told me to go to Finland, because of the knowledge and the perfect speaking of English. At that time I knew I wanted to go to Finland. So I started looking into places to do EPS in Finland. The only place to do the EPS is in Vaasa. That is why I chose to come to Vaasa to do EPS. After this experience I have my final internship to finish my study. After this study I want to do a master to finish my studying.



**Figure 2: Picture of Gijs**

My name is Maarten Vermeiren, I am 22 years old and I come from Belgium. I am in my 5th year and am working on my second bachelor's degree in electromechanics at the AP University in Antwerp (Artesis Plantijn University). At the moment I study automation but before that I studied process automation. For this experience I wanted to put myself out of my comfort zone and meet new people from different countries, and the opportunity came to do a EPS project. I wanted to go to one of the northern countries because I like the culture and I heard good things about their EPS programs. After this semester I finish my studies and I will start working.



**Figure 3: Picture of Maarten**

## 2 Presentation of the project

In order to understand the context of the project and its stakes, first the objectives, stakeholders and timeline will be presented.

### 2.1 Objectives

The goal of the project is to explore safe and pedagogical approaches to teaching e-fuel production design by implementing a small-scale educational laboratory for the production of synthetic fuels (E-fuels). It will then extend the existing Hydrogen laboratory facilities (which already contain an electrolyzer and fuel cells).

### 2.2 Stakeholders

This project has in total three stakeholders. Two of the stakeholders are customers and one stakeholder is the coach. Below the stakeholders will be explained how all of the stakeholders are involved in the project.

The customers of the project are Jenny Rönqvist-Norrby and Mats Borg. These stakeholders are the customers of the project. They are both teachers with a chemistry background for the Novia University of Applied Sciences. As told in the introduction the customers will use the small production prototype in the lectures for educational purposes. With the customers there are meetings every two or three weeks to inform them of the progress of the project. In those meetings there are brainstorming sessions of how to improve and work to the end result of the project.

The third stakeholder is Mikael Ehrs who is the coach of the project. Mikael is a Senior lecturer in Industrial Management at Novia University of Applied Sciences. With Mikael there are meetings every week to do brainstorming and talk about the progress of the project.

Name:	Role:
Jenny Rönqvist-Norrby	Customer
Mats Borg	Customer
Mikael Ehrs	Coach

**Table 1: Stakeholders**

## 2.3 Budget and resources

The maximum budget for this project is €5,000. This amount covers sensors (gas detection, temperature, pressure), small-scale reactor body, fittings and safety related items.

## 2.4 Expectations and deliverables

The team is expected to deliver a prototype designed for methane production. To ensure this facility is educationally valuable, it will be accompanied by documentation including operating manuals for students and safety protocols to guarantee a safe laboratory environment. . If possible, this package will also include visual assets and detailed purchase proposals covering both the current setup and future scale-up.

## 2.5 Timelines

Projected timeline (12 weeks):

- Weeks 1–2: Literature survey, benchmarking, safety research
- Weeks 2–4: Equipment identification, supplier contacts, lab design iterations, purchase proposal
- Weeks 4–10: Assembly of first-stage lab bench, equipment testing, instruction development; prepare proposals for second & third stages
- Weeks 11–12: Compile recommendations, finalize documentation, and present results

The project is structured around a preliminary 12-week schedule, established during the pre-project planning phase. This timeline was designed to guide the group through four distinct phases: initial research and safety benchmarking , equipment identification and purchase proposals , the assembly and testing of the first-stage lab bench , and finally, the compilation of results and documentation writing.

It is important to note that this schedule serves as a baseline framework. As it was developed prior to the project's commencement, it remains subject to necessary modifications. Adjustments may be required to accommodate real-world constraints, such as supplier lead times for equipment delivery or technical challenges encountered during the iterative design process.

### 3 The different E-fuels

After talking with the customers and coach what they want for this project the focus was on the different E-fuels that has the possibility for this project. In this chapter the different E-fuels will be explained. The E-fuels that will be talked about are: E-Ammonia, E-Diesel, E-Methanol, E-DME and E-Methane. About the E-fuels there will be an introduction, how it is produced, safety, the estimated costs of the equipment and production and lastly where to E-fuel will be used in the future.

#### 3.1 E-Ammonia

The first E-fuel that will be explained is E-ammonia. It is an E-fuel that has a big future when the technology and production will be improved. Below it will be explained why it can be a big E-fuel for the future.

##### 3.1.1 Introduction about E-ammonia

E-ammonia, also known as green ammonia, is ammonia (NH<sub>3</sub>) produced using renewable energy instead of fossil fuels. Traditional ammonia is made through the Haber-Bosch process. This process combines nitrogen from the air with hydrogen obtained from natural gas. E-ammonia can serve as a sustainable fertilizer feedstock and as an energy carrier or fuel, storing and transporting renewable energy efficiently. The information about the green Haber-bosch process is based on the theses of Liang C.

##### 3.1.2 How is E-ammonia produced

E-ammonia is produced through a renewable version of the Haber-bosch process, powered entirely by clean energy sources. The production starts with the production of green hydrogen via water electrolysis. In this process renewable electricity split water into hydrogen and oxygen. Nitrogen is required to start the process of synthetization to produce ammonia. The nitrogen can be captured directly from the air through an air separation unit. These gases will be reacted in the Haber-Bosch process at temperatures up to 400 °C and pressure up to 150 bar over an iron-based catalyst (Liang, 2019, p. 79). The iron-based catalyst is the only one that can withstand the pressure and temperature to produce the E-ammonia.



**Figure 4: Haber-Bosch process chemical reaction (Liang, 2019, p. 10)**

The study shows that at the same temperature of 400 °C, higher operation pressure increases ammonia yield. For example, single-pass conversions in an isothermal reactor with 50 bar has an yield of 26%, with 75 bar has an yield of 34%, and 100 bar has an yield of 40,4%. So it means that is the pressure goes up, the yield also increases.

### 3.1.3 Safety

Ammonia is toxic and corrosive, what means that safety is an important subject in producing E-ammonia. Although repeated exposure to ammonia does not produce chronic effects, even small concentrations in the air can be extremely irritating to the eyes, throat, and respiratory system (Oxford Institute for Energy Studies, 2024, p. 12). If a school wants to produce own E-ammonia the school will need safety procedures. Think about ventilation, NH<sub>3</sub> detectors, leakage procedures, goggles, and more.

The storage of ammonia requires pressure vessels. Ammonia has a relatively low boiling point of -33°C at atmospheric pressure allows for easier storage and transportation (Oxford Institute for Energy Studies, 2024, p. 6).

### 3.1.4 The costs for equipment and production

The costs of the production plant to produce the E-ammonia vary on the specifications that are being used. The study shows two ways of producing, one with 50 bar and one with 100 bar.

	50 bar micro-plant	100 bar micro-plant	Unit
CAPEX	1041	1278	€
OPEX	140	154	€/yea
Cost of ammonia	1.8	2	€/kg

**Figure 5: A green ammonia micro-plant techno-economic analysis summary (Liang, 2019, p. 81, Table 7.2).**

The CAPEX means the cost to for only the production plant and OPEX means the cost of production per year. The difference is not that big, but the pressure is. That is a discussion that every university can consider for making a plant.

### 3.1.5 Where will E-ammonia be used?

E-ammonia, produced from renewable hydrogen via electrolysis, is emerging as a crucial fuel for decarbonizing maritime shipping. The International Energy Agency (IEA) projects that ammonia will account for 44% of the sector's energy consumption by 2050, up from 0% today (Atchison, 2023). This growth is driven by ammonia's zero-emission potential and its scalability. Lloyd's Register and OCI HyFuels estimate that E-ammonia could capture 20–60% of the global shipping fuel market by 2050. To achieve this, the shipping industry must lead in developing supply infrastructure and scaling production.

## 3.2 E-Diesel

The second E-fuel to be discussed is E-diesel. This sustainable option holds significant promise, provided that manufacturing methods and technology continue to evolve. The following section details exactly why it is expected to play a major role in the years to come.

### 3.2.1 Introduction about E-diesel

Fischer-Tropsch Synthesis (FTS) is a catalytic process that produces transportable liquid hydrocarbon fuels (like gasoline and waxes) from synthesis gas (syngas), which is made from hydrogen (H<sub>2</sub>) and carbon dioxide (CO<sub>2</sub>). Even though FTS was historically utilized to produce fuel during World War II, it is now used for producing high-quality transportation fuels that reduce their negative effects on the environment and the crude oil need. The discovery made in the 1920s by German scientists F. Fischer and H. Tropsch is the basis for the information on FTS and its early development (F. Fischer and H. Tropsch 1923).

FTS syncrude property	HTFT	LTFT
<i>Carbon number range</i>	C <sub>1</sub> -C <sub>30</sub>	C <sub>1</sub> -C <sub>120</sub>
<i>Main product</i>	C <sub>2</sub> -C <sub>10</sub> olefins	waxes
<i>Normal product phases<sup>a</sup></i>		
Gases (C <sub>1</sub> -C <sub>4</sub> )	20-25%	5-10%
Oil	20-25%	15-20%
Wax	0%	20-25%
Aqueous organics	~5%	1-2%
Water	45-50% <sup>b</sup>	50-55% <sup>b</sup>
<i>Organic compound classes<sup>a</sup></i>		
Paraffins (alkanes)	20-30%	major product (> 70%)
Naphthenes (cycloalkanes)	< 1%	< 1%
Olefins (alkenes)	major product (> 50%)	15-20%
Aromatics	1-5%	< 1%
Oxygenates	10-15%	~ 5%

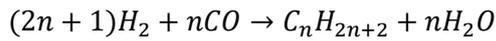
a All percentages are on a mass basis

b Closed gas loop, i.e. no wet water gas shift conversion

Figure 6: Syncrude properties from the two main classes of Fischer-Tropsch (Odunsi, 2017, p. 11, Table 2.2)

### 3.2.2 How is E-Diesel produced

The FT-synthesis is a catalyst supported polymerisation which converts CO and H<sub>2</sub> into a wide range of hydrocarbons with temperature between 200-240°C and pressure of 20 bars. In the Fischer–Tropsch (FT) synthesis, hydrocarbons are produced from carbon monoxide and hydrogen:



This reaction forms hydrocarbon chains of various lengths (C<sub>1</sub>, C<sub>2</sub>, C<sub>3</sub>, ..., C<sub>n</sub>). The Anderson–Schulz–Flory (ASF) distribution is a statistical law that describes how much of each chain length is formed. (basically what will the product be). The parameter α (alpha) is the chain growth probability, the probability that a growing hydrocarbon chain adds another carbon rather than stopping. It's an empirical parameter, meaning it's determined experimentally. (Odunsi, 2017, p. 29)

-Temperature: higher → α decreases (favors lighter products)

-Pressure: higher → α increases

-Catalyst: Co → higher α (longer chains), Fe → lower α (more gaseous products)

-H<sub>2</sub>/CO ratio: higher → favors chain termination → α decreases

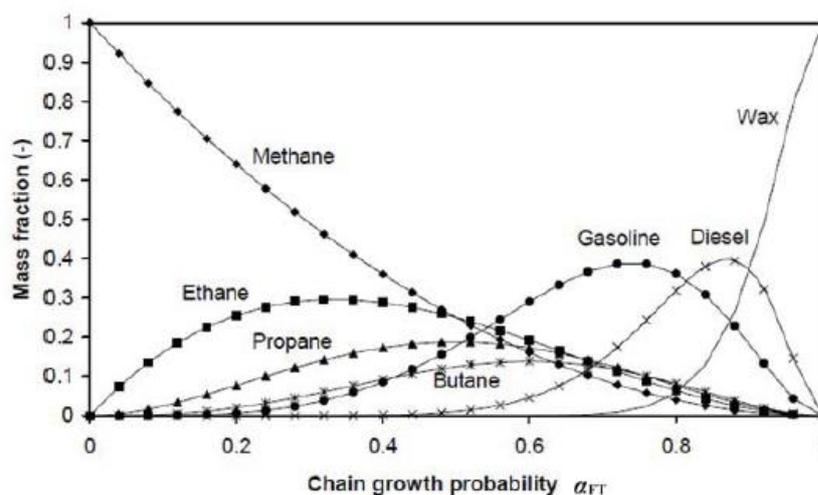


Figure 7 : Hydrocarbon selectivity as a function of the chain growth probability (Odunsi, 2017, p. 29, Figure 2.8)

The four metals exhibiting significant Fischer-Tropsch (FT) activity are Iron (Fe), Cobalt (Co), Nickel (Ni), and Ruthenium (Ru). Ruthenium is the most active but is too expensive for commercial use. Nickel is typically excluded due to its high activity for methanation, leading to excessive methane production instead of desirable long-chain hydrocarbons. Consequently, Iron and Cobalt are the only metals used commercially.

Operationally, FT reactions are highly exothermic, requiring rapid heat removal to prevent coking, sintering, and catalyst disintegration. Failure to control temperature results in the undesired formation of high levels of methane and light hydrocarbons. The type and geometry of the reactor have a crucial effect on the product distribution, heat management, scalability, and operational efficiency of reactions.

Development has resulted in three main types: Fixed-Bed Reactors, Fluidized-Bed Reactors, and Slurry Bubble Column Reactors. Fixed-Bed Reactors (Tubular Reactors) are mechanically simple, with geometries that favor heavier hydrocarbon production wax. Their drawbacks are difficult heat control with possible hot spots and limited mass transfer. On the other hand, Fluidized-Bed Reactors include bubbling or circulating fluidized beds, which give good heat removal for uniform temperature, continuous catalyst regeneration, flexibility, and scalability. But they are mechanically complex, tend to lose catalyst due to diminution into fines/dust, and the product selectivity for lighter components is favoured. Slurry Bubble Column Reactors give good conditions for the heat and mass transfer processes, as well as easy replacement of catalyst. The disadvantages are problems with the separation of catalyst from the product wax, limitations on gas-liquid mass transfer if dispersion is poor, and also scale-up complexity due to usually unpredictable hydrodynamics.

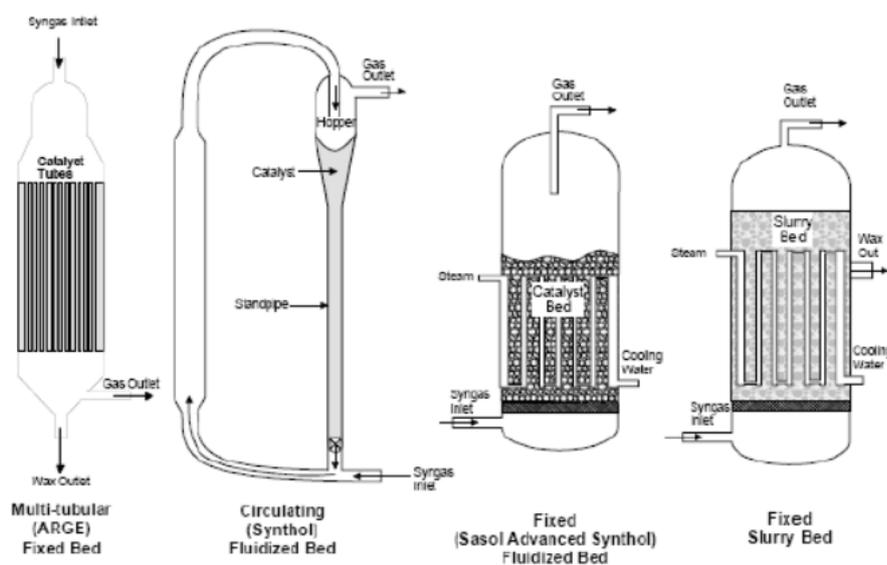


Figure 8 : Types of reactors (GEK Gasifier, s.d.)

### **3.2.3 Safety**

The major reactants, Syngas (a mixture of Carbon Monoxide and Hydrogen), are dangerous: carbon monoxide is so toxic that even at low concentrations, it can be fatal, whereas hydrogen is extremely flammable and explosive. The reaction is highly exothermic and proceeds under high temperature and pressure, requiring strong heat management in order to avoid thermal runaway and hot spots. Any facility, even including a small-scale school setup, will have to have proper safety, involving ventilation to prevent gas accumulation, detectors with audible alarm systems, leakage and emergency shutdown procedures, and the mandatory use of PPE like respiratory protection and safety goggles, along with strict control on ignition sources to prevent fire and explosion hazards.

### **3.2.4 The costs for equipment and production**

Current cost of production from the Fischer–Tropsch process is still significantly higher than conventional diesel or gasoline. This is mainly due to the energy requirement to produce hydrogen and CO<sub>2</sub> or CO as feedstocks, and the synthesizer and upgrader equipment. While conventional diesel can be produced at less than \$1 per liter, E-diesel will be twice to four times more expensive, based on electricity costs and scale of plant. But as renewable energy gets cheaper, the economic gap between of E-diesel and fossil fuels should close in the coming years (Anetjärvi et al., 2025).

### **3.2.5 Where will E-Diesel be used?**

In the future, Fischer–Tropsch-made E-fuels will play an important role in reducing carbon emissions from industry and transport. Synthetic fuel can replace conventional gasoline, diesel, and jet fuel directly in existing engines without major adaptation. They are most suitable for air transport, shipping, and heavy road vehicles, where electrification is difficult. E-fuels can also be used to produce high-grade lubricants and chemical feedstocks for the petrochemical industry. With growing supplies of renewable electricity and green hydrogen available, Fischer–Tropsch E-fuels have the ability to define a cleaner and more sustainable energy system. (Odunsi, 2017, p. 12, 2.1.1)

### 3.3 E-Methanol

The third E-Fuel that is going to be discussed is E-Methanol. It is a E-fuel that is arising quickly as a synthetic fuel because of the great potential. In this part we will explain a little bit about it and give some reasons why it is expected to become an important E-fuel in the future.

#### 3.3.1 Introduction about E-Methanol

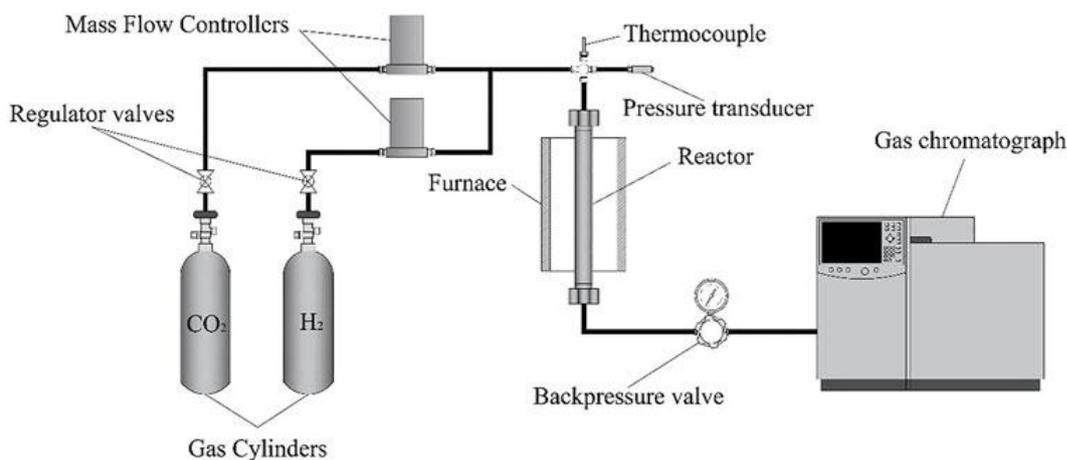
E-methanol, also represented as green methanol ( $\text{CH}_3\text{OH}$ ) is a fuel that is produced by using renewable energy instead of fossil fuel. Normally it is made from natural gas, but E-methanol is produced with green hydrogen ( $\text{H}_2$ ) and by capturing carbon dioxide ( $\text{CO}_2$ ) during the process called Power-to-methanol or methanol synthesis. This makes E-methanol a low carbon alternative and can it be used in a climate neutral industry.

#### 3.3.2 How is E-Methanol produced

E-methanol is produced through a sustainable catalytic synthesis process that uses carbon dioxide ( $\text{CO}_2$ ) and hydrogen ( $\text{H}_2$ ), powered by renewable energy sources. Hydrogen is provided through a water electrolysis, where renewable electricity splits water into hydrogen and oxygen. The  $\text{CO}_2$  can be sourced through capture emission.

The streams of  $\text{CO}_2$  and  $\text{H}_2$  are then fed into the reactor along with a heterogeneous catalyst. The synthesis of methanol usually utilizes a copper or zinc-based catalyst. Often, small additions of additional metals are used to increase the catalytic activity and, with that, the overall reaction efficiency of the catalyst. This synthesis is carried out in an adiabatic fixed-bed catalytic reactor at temperatures between 200 and 300 °C and pressures between 50 and 100 bar. Most of the times a adiabatic fixed-bed catalytic reactor is used for the project.

As a consequence of an increase in the temperature of the reaction, it will reduce the yield of methanol of a given amount of  $\text{CO}_2$  and  $\text{H}_2$ , due to less favourable thermodynamic equilibrium. Although an increase in temperature leads to an advancement in the reaction rate, it can also bring about an increased possibility of the formation of undesired by-products, such as carbon monoxide (CO). Hence, working at a lower end of a temperature scale can be considered more preferable.



**Figure 9: E-methanol process**

### 3.3.3 Safety

During the process there is a chance that toxic fumes will be released because with high pressures there is a chance that the catalysator will produce toxic metal fumes. So for a laboratory setup a good ventilation is necessary. Also is ventilation necessary for both CO<sub>2</sub> and H<sub>2</sub>. For these two we also need gas monitors/detectors and for H<sub>2</sub> you also need leak detection and we only can use ATEX certified equipment, because it is very explosive. Also the end product methanol is in both forms (pure form and highly concentrated) very toxic and can be even deadly if it is not handled correctly. And as last we need to use the correct materials while building it and if we go for a big system we need pressure relief valves, since we are working with high pressure and high temperature.

Because it is so dangerous it is not really suitable for a university to make it for a laboratorial setup to teach students.

### 3.3.4 The cost for equipment and production

At the moment the cost to produce E-methanol is significantly higher (2 to 3 times), than the methanol produced form fossil fuels. The reason for this is that the process uses hydrogen that we want to make from green sources and to produce this hydrogen there is a lot of electricity needed. With the current electricity price this is not cheep. Than from where you get your CO<sub>2</sub> is also important for the production cost, how cheaper you can capture it the cheaper you production cost is. (Pratschner, 2023)

Than the equipment cost depends on a lot of factors, for example do you invest in green energy production to help bring down your electricity cost but can cost a lot of money. But than for the real plant to produce the E-methanol, for a modest facility that only has the synthesis part, this equipment cost goes to the tens of million of euro's. But for big scale facility that includes the capturing of CO<sub>2</sub> and production of hydrogen, this equipment cost required more than hundreds of millions of euro's. (Mucci, 2023)

But in the coming years the cost of E-methanol production will be coming down, as a result of better technology that will give use electrolyzers that are more efficient, improved catalyst, ect. But the cost of CO2 emissions for companies will also become more expensive, making it more cost-effective to process them.

### **3.3.5 Where will E-Methanol be used?**

The future of E-methanol is very broad, because it will be a important in the reduction of carbon footprint. Beside on slowly taking over the methanol made of fossil fuel, used in the chemical industry. E-methanol also will play a big role in the shipping industry where E-methanol will be used as a green fuel. This is because it can be easily stored, due to the fact that it is liquid at atmospheric pressure. There are also some safety advantages such as full miscibility with water and rapid dilution in case of spills. In a report they say that E-methanol can reduce greenhouse gasses up to 95%. (Parris, 2024)

### **3.3.6 E-Methanol VS E-DME**

Why should we go from E-Methanol to E-DME, when it requires an additional processing step? There are several reasons that make this transition meaningful.

First of all, E-DME is less corrosive, which makes it much easier and safer to handle. In contrast, E-Methanol is more corrosive and requires special materials for both transport and storage, which adds to operational complexity and cost.

Second, E-DME has better storage properties. It becomes liquid under a relatively low pressure of about 5 bar, whereas E-Methanol is liquid at normal atmospheric pressure. More importantly, E-DME has a higher energy density per liter, approximately 19.2 MJ/L compared to 15.8 MJ/L for E-Methanol. This higher energy density is very valuable for storage, as it allows the same amount of energy to take up less space.

Finally, E-DME burns almost soot-free, which is a significant advantage for engines. Cleaner combustion not only reduces particulate emissions but also lowers maintenance requirements and improves engine efficiency.

In summary, despite the need for an additional conversion process, the benefits of E-DME lower corrosiveness, higher energy density, and cleaner combustion make it a more practical and efficient choice for storage, transport, and engine use.

## 3.4 E-DME

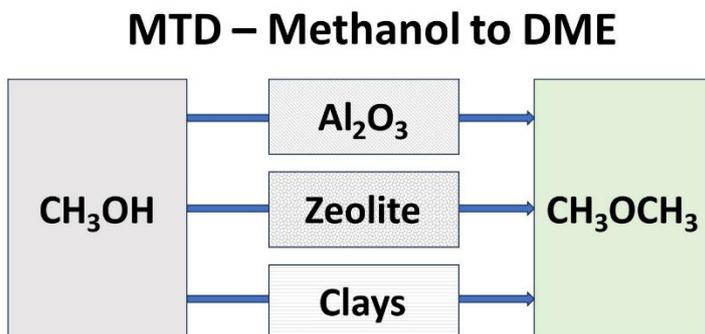
The fourth E-fuel that will be discussed is E-DME. It is a great E-fuel with a great potential for the future. Below will E-DME be explained and what role it can play in the future.

### 3.4.1 Introduction about E-DME

E-dimethyl ether (E-DME) is a synthetic renewable fuel that is produced from E-methanol. It is a cleaner oxygenated molecule ( $\text{CH}_3\text{OCH}_3$ ). It can be used as an alternative diesel that is almost carbon neutral. E-DME is very important for carbon recycling and the power-to-liquid pathways. There are a couple of different ways to make E-DME but we are going to look at the way with feedstock E-methanol.

### 3.4.2 How is E-DME produced

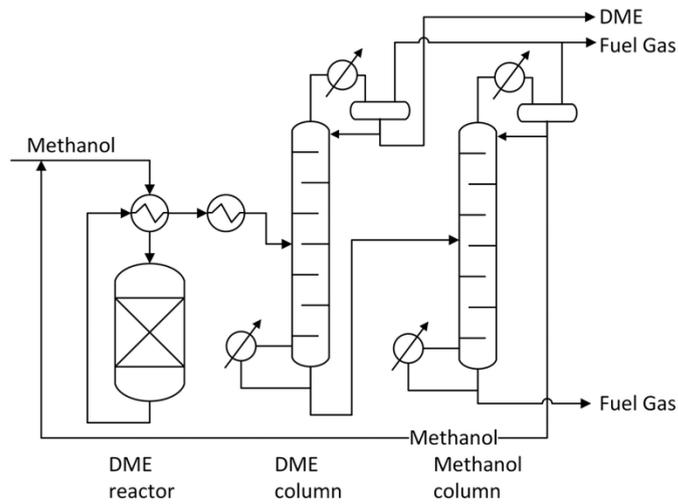
To go from E-Methanol to E-DME we need a catalyst this can be an acid catalyst like: Zeolites and Aluminum oxide. Or another catalyst like: clay minerals and membrane-based catalyst. For producing the E-DME the E-methanol needs to be dehydrated over the catalyst.



**Figure 10: E-Methanol to E-DME**

The methanol will be controlled put in the reactor where also the catalyst will be. The reactor will then heat the product up to a temperature between 220 and 400°C and under a pressure of 1-30 bar.

The outlet of the reactor is not only DME but also some side products like: water, methanol and other chemicals ( $\text{CH}_4$ ,  $\text{CO}$ ,  $\text{CO}_2$ , and  $\text{H}_2$ ). So to get rid of those side products everything needs to be cleaned, for this purpose use is made of distillation columns.



**Figure 11: E-DME process**

**Catalyst:**

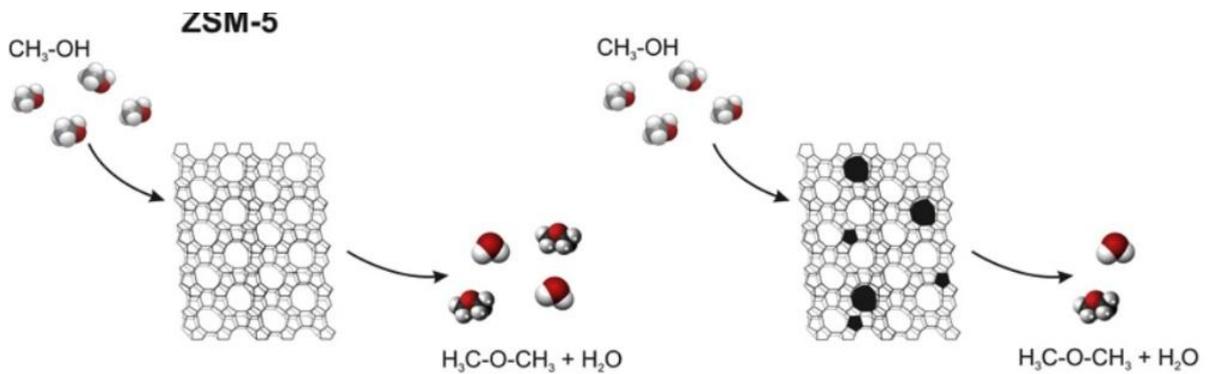
The most used catalyst for the moment is the zeolites, there are two types of zeolites: the naturals and the synthetic. For a chemical reaction the most time they use a synthetic zeolite because the reaction quality is better.

Also a big point is the price, how higher the price how higher the purity of the zeolite is and the better the reaction properties are.

To go from E-methanol to E-DME, in practice they will use most of the times the ZSM-5 zeolite.

Zeolite Type	Average Price (USD/ton)	Notes / Factors Affecting Price
<b>Natural Zeolite</b>	\$100 - \$400	Price depends on purity, particle size, mineral composition, and processing method. Examples include <b>clinoptilolite zeolite powder</b> used for water treatment and agriculture.
<b>Synthetic Zeolite</b>	\$500 - \$1,500	Price reflects controlled synthesis, energy-intensive processes, high purity, and specific pore size. Used in catalysis, petrochemical, and gas separation applications.

**Figure 12: Zeolites**



**Figure 13: ZSM-5**

### 3.4.3 Safety

DME is a very flammable liquefied gas, with low ignition energy and a wide flammability range, making leaks particularly dangerous. Because it is stored under pressure, accidental releases can quickly form vapor clouds that may ignite at distant points. DME is denser than air and therefore poses an asphyxiation hazard in confined areas through oxygen displacement. Cold burns can also result from contact with the liquid. Handling safely requires good ventilation, gas detectors with alarms, proper pressure-rated equipment, and strict control of ignition sources. Emergency shutdown procedures, leak-response protocols, and appropriate fire-suppression systems must be in place. Personnel should use proper PPE-safety goggles, gloves, respiratory protection-and receive training in safe operation and emergency response.

### 3.4.4 The cost for equipment and production

The cost of E-DME produced from E-methanol is depended on different matters, such as: the price of the feedstock (methanol), energy price, the catalyst and the maintenance whit the labor. The cost of methanol depends on which kind of methanol you buy, but because we want to produce E-DME we choose E-methanol what is already more expensive.

Also the size of the facilities are important, with a bigger facility the production cost per ton will be lower than with a smaller facility. But a big downside of a bigger facility is the cost to build it is a lot higher.

### **3.4.5 Where will E-DME be used**

In the future, E-DME will play an important role in the reduction of the carbon footprint and mainly from the transport industry and as a blend with a other gas. This synthetic fuel can be used in for couple of different things like: fuel for heavy duty transport vehicles such as trucks, busses, construction and farm equipment. But also for power generation and cooking. The reason that it is so attractive is because it has the capacity to replace or blend with LPG and Hydrogen and as a result of harder environmental regulations it becomes really interesting because it burns cleaner than normal fossil fuels. (Saurabh Bidwai, 2025)

## 3.5 E-Methane

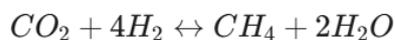
The fifth E-fuel that will be explained is E-methane. This E-fuel has a high potential to be the E-fuel that will be the one for this project. It has better circumstances with the production than the other ones.

### 3.5.1 Introduction about E-methane

E-methane is produced through the methanation process, which combines hydrogen produced from renewable electricity and carbon dioxide captured from industrial sources or the atmosphere. Even if the basic underlying chemistry, commonly referred to as the Sabatier reaction, was discovered by the French chemist Paul Sabatier back in 1902, it has gained renewed interest today as a critical "Power-to-Gas" technology. It allows the conversion of excess renewable electricity into a storable gas compatible with the existing natural gas infrastructure and constitutes a bridge between the electricity grid and the gas grid.

### 3.5.2 How is E-methane produced?

Methanation is a catalytic process that converts carbon monoxides and hydrogen into methane and water. The chemical reaction, the Sabatier reaction, is described as follows:



Unlike Fischer-Tropsch, which produces a chain of hydrocarbons, methanation is highly selective towards a single product: Methane (CH<sub>4</sub>). The reaction is highly exothermic. Lower temperatures favor high methane conversion but higher temperatures are needed for the reaction rate. A good range is usually found between 250°C and 550°C. Higher pressure also favors the formation of methane. A stoichiometric H<sub>2</sub>/CO<sub>2</sub> Ratio of 4:1 is ideal; excess hydrogen promotes conversion but requires separation later. The choice of catalyst is critical. Nickel (Ni) is the most widely used commercial catalyst due to its high activity and relatively low cost. Ruthenium (Ru) is more active and works at lower temperatures but is too expensive for large-scale applications (Kofler, 2024).

Catalytic methanation typically uses Fixed-Bed Reactors (often a series of adiabatic reactors with intermediate cooling) or Fluidized-Bed Reactors. Fixed beds are simple but face challenges with hot spots due to the strong exothermicity. Fluidized beds offer excellent heat transfer (isothermal operation) but are mechanically complex and risk catalyst deactivation.

### **3.5.3 Safety**

The safety risks of E-methane production are mainly about the properties of Hydrogen and Methane. Hydrogen is highly diffusive, has a wide flammability range, and requires specific safety equipment to wear. Methane is also flammable. Since the Sabatier reaction is strongly exothermic, thermal runaway is a significant risk. If heat removal fails, temperatures can rise rapidly, potentially damaging the catalyst or the reactor.

Consequently, production setup requires certified pressure vessels, rigorous leak detection and monitoring of temperature and pressure.

### **3.5.4 The costs for equipment and production**

The production cost of E-methane is currently higher than that of fossil natural gas. The primary reason is the production of green hydrogen via electrolysis (accounting for 60-70% of the total cost). However, E-methane production is generally simpler and slightly cheaper than E-Diesel production because no complex product upgrading (cracking/distillation) is required. The output is ready to use after drying. As electrolyzer costs fall and carbon taxes on fossil gas increase, E-methane is expected to become more cost-competitive in future (Hollo, 2020).

### **3.5.5 Where will E-Methane be used?**

The advantage of E-methane is its compatibility with existing infrastructure. It can be injected directly into the national natural gas grid, acting as a massive energy storage solution for renewable electricity (seasonal storage). It can replace fossil natural gas in residential heating, industrial high-temperature processes, and power generation. It serves as a carbon-neutral fuel for heavy transport and maritime shipping, utilizing existing engines and distribution networks without the need for modification (Hollo, 2020).

### 3.6 Recap of the processes

Before deciding which process is the best for a laboratory test setup a quick recap of the five processes we have looked at during this report was made. We are going to recap the temperature range, the pressure range and what catalyst is needed for each process. We do these three parameters because these are very important data for making the decision.

PROCESS	TEMPERATURE	PRESSURE	CATALYST
E- AMMONIA	350-550°C	100-250 bar	iron catalyst
E-DIESEL	200-240°C	25 bar	Iron or Cobalt
E-METHANOL	200-300°C	50-100 bar	Copper or zinc
E-DME	220-400°C	1-30 bar	Zeolites or Aluminum oxide
E-METHANE	250-400°C	1-30 bar	Nickel supported on alumina

Table 2: recap processes

### 3.7 Ranking and selection of the E-fuels

In the **figure 16** the different E-fuels are ranked in a selection matrix. In the selection matrix it is possible to see that the E-methane has the highest score with a score of 53 and therefore suits the best for this project. How this selection matrix is made will be explained.

#### 3.7.1 Explanation of the selection matrix

This selection matrix has the purpose of showing which E-fuel will suit the best for this project. Every E-fuel will be graded on five different factors. The Pressure, heat, safety, costs, and lastly the production process. Every factor has a scale that shows which points are the most important for this project. The amount of points that are given in the first table will be multiplied by the scale. So the higher the scale points, the higher the importance in the project. Then in the total score Selection Matrix will show which E-fuel will have the most amount of points.

	Pressure	Heat	Safety	Costs	Production process		
Scale	3	1	3	2	2		

**Figure 14: Scale of the Selection Matrix**

One of the two most important factors is pressure. The customers and coach have told in the beginning of the project that they do not want to have a production prototype that requires a lot of pressure in the process. That is because a lot of pressure requires a lot of safety requirements. Safety is also the one of the most important, because when testing or when students will use the equipment we want nobody to get injured. That is why there will be safety considerations when making the design. Then the costs and production process are both with 2 points are the second most important factor in the project. Costs because we have a budget of 5000 euros. We can not spend more money than that and we want to make the prototype as good as possible. The production process is important that the process will not be industrial. This prototype will only be used in lectures. That is why it can not be complicated. The heat is the least important factor, because it will not be very dangerous when the people working with the production prototype are wearing protective equipment.

Every E-fuel will be graded with 1, 3, or 5 points with 5 being that it suits for this project and 1 that it would not fit. These points will get multiplied with the scale. In Figure 15 you can see the grades that are given on the E-fuels. Those will be explained below:

- Pressure
  - E-methane: In the process requires pressure from 1-30 bar. This means that it could be really low but also still a little to high.
  - E-diesel: In the process 25 bar of pressure is required. This is not ideal for this project where the customers want it as low as possible.
  - E-ammonia: This is a no go for pressure, because it requires to be around 100-250 bar of pressure to get good E-ammonia. It is possible to do it with less like 50 bar, but that is still to high.
  - E-DME: has the same as E-methane. This means that it could be really low but also still a little to high.
  - E-Methanol: need 50-100 bar of pressure. This is like the E-ammonia to high for this project.
- Heat
  - E-methane: The process requires to have between 250-400°C, what is compared to E-diesel high but not a problem.
  - E-diesel: This process requires the least amount of heat with 200-240°C.
  - E-ammoina: This process requires the most amount of heat with 350-550°C.
  - E-DME: This process requires 220-400°C of heat. It is compared to E-diesel higher but not a problem.
  - E-methanol: This process requires 200-300°C of heat. It is compared to E-diesel higher but not a problem.
- Safety
  - E-methane: This process is safe to do when wearing gloves, glases, and some safety detectors. The
  - E-diesel: This process does not need a lot of pressure and the heat is also not that high. So this is a quite safe E-fuel.
  - E-ammoina: To Produce E-ammonia you need a lot of pressure, what is with the right equipment not dangerous. But it still a safety consideration.
  - E-DME: To produce E-DME E-methonol is needed. So because in this process you don not produse E-methanol, but use it it is still dangerous.
  - E-methanol: The E-methanol itself is already dangerous, it is really toxic and it needs a lot of safety changes if this E-fuel will be used for this project.
- Costs
  - E-methane: To produce E-methane is quite simple and the cost to produce is not high. The most expensive part is buying the equiment. But with a budget of 5000 euros it is possible to build a small prototype.
  - E-diesel: The production of E-diesel is in both the process itself and to build a protorype more expensive then E-methane. More equipment is needed for this process.
  - E-ammoina: E-ammonia is quit cheap in comparrison then the others. A study showed that with a few thousent euros it is possible to build a small

prototype. but the safety equipment will be higher than the others. So this one also depends on the place where the prototype will be build.

- E-DME: In comparison with the other E-fuels E-DME is significant more expensive.
- E-methanol: In comparison with the other E-fuels E-methanol is significant more expensive.
- Production process
  - E-methane: The E-methane process is quite simple to do.
  - E-diesel: This process is compared to the others a little more difficult.
  - E-ammonia: This process is quite simple to do.
  - E-DME: This process is compared to the others a little more difficult.
  - E-methanol: This process is compared to the others a little more difficult.

Then in the “Total score Selection Matrix” the total amount of points are shown. It is clear to see that E-methane has the most amount of points. This E-fuel will suit the best for this project.

	Pressure	Heat	Safety	Costs	Production process	
Scale	3	1	3	2	2	
Score (1-3-5)						Total
E-Methane	3	3	5	5	5	21
E-Diesel	3	5	5	3	3	19
E-Ammonia	1	1	3	5	5	15
E-DME	3	3	1	3	3	13
E-Methanol	1	3	1	1	3	9
Total score Selection Matrix						Total
E-Methane	9	3	15	10	10	47
E-Diesel	9	5	15	6	6	41
E-Ammonia	3	1	9	10	10	33
E-DME	9	3	3	6	6	27
E-Methanol	3	3	3	2	6	17

**Figure 15: Selection Matrix**

### **3.7.2 Why the Methane prototype Was Selected**

The E-methane production process (Sabatier process) has been chosen for this project as the most suitable solution. It has the highest score with a score of 53 points in the selection matrix and therefore is the most suitable for this project. Another reason behind this decision is that the goal of the project is to provide a small-scale educational tool for lectures rather than a true industrial production prototype. Technically, this process has the advantage of operating under low pressure, indeed it can operate at atmospheric pressure even if the best condition is around a maximum of 10 bars of pressure. Being able to operate the reaction under low pressure simplifies the design and safety requirements in comparison with other methods of synthesis. The maximum operating temperature of about 400°C is also within acceptable limits for the components of the system. Given the time available, this E-methane process is the most realistic and feasible design that can be built and tested in these conditions.

## 4 Technical Overview from Previous Prototypes

Research were made about two similar project with academic prototypes: a Canadian Ontario University (Bolt, 2024) and a Swedish master's thesis (Deiana et al., 2025). The two projects are focused on small-scale methanation systems with diverse experimental conditions and reactor layouts. We extracted the essential technical infos and findings from these works to guide our own prototype design.

### 4.1 Ontario University Prototype

The Ontario University (Bolt, 2024) process consisted of CO<sub>2</sub> methanation over a 34 wt% nickel/Al<sub>2</sub>O<sub>3</sub> catalyst in pellet form 5 mm × 5 mm. The reaction took a 4:1 hydrogen to carbon dioxide ratio, in order to minimize byproduct formation (basically CO and carbon depositions that can deactivate or alter the catalyst). The operating temperature was set around 200 °C, in the low temperature methanation range but it allow a moderate conversion with little catalyst deactivation.

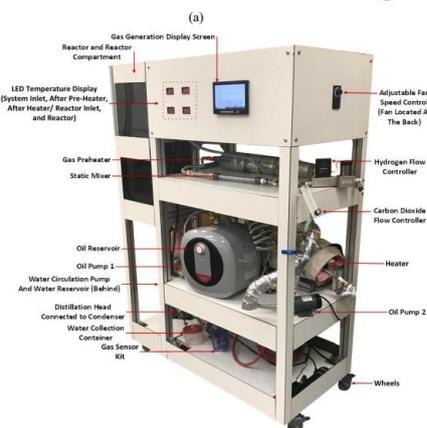


Figure 16: Example of the design

For an accurate gas analysis, the equipment included a steam separation unit. Water vapor formed during the reaction was condensed and led away from the gas stream by a condenser and distillation head since steam can interfere with gas sensors. An inert gas (helium) was used to sweep out the reactor to prevent unwanted side reactions on shutdown or startup. This prototype is quite complex because it is a continual production process with a closed oil circuit with pump, heaters and reservoirs for cooling and maintaining a stable temperature.

### 4.2 Swedish Thesis Prototype

The Swedish thesis (Deiana et al., 2025) use a Katalco 11-4MR catalyst (Johnson Matthey), a commercial nickel-based catalyst for methanation. The reactor is made of AISI 316/316L stainless steel, which provides excellent resistance to high temperature and corrosive gases such as CO<sub>2</sub> and H<sub>2</sub>O. A thermal expansion compensation system was also included to provide structural integrity throughout the heat cycle.

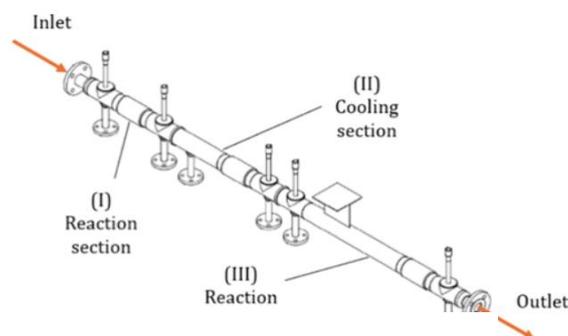


Figure 17: Example of the design

An intercooling section was filled with alumina-silica granular matter, the same as the size of the catalyst particles.

Two modes of operation were tested:

- Case A: One-hour intervals, with flow rates of 1.08 Nm<sup>3</sup>/h of H<sub>2</sub> and 0.2 Nm<sup>3</sup>/h of CO<sub>2</sub>, and pressure at 0.2 barg.
- Case B: Thirty-minute intervals of the same flow rates but 9 bar pressures.

Increased pressure improved efficiency of conversion and methane generation but required stronger mechanical components and safety features.

parameter	value	unit of measure
maximum operating pressure	10	barg
design pressure	14	barg
maximum operating temperature	400	°C
design temperature	480	°C

Figure 18: Parameters of the experiment

catalyst parameter	value	unit of measure
diameter	3.1	mm
length	3.6	mm
nickel content	30	% wt Ni
charged bulk density	1.1	g/cm <sup>3</sup>
mean axial crush strength	30	kgf

Figure 19: Description of the catalyst used

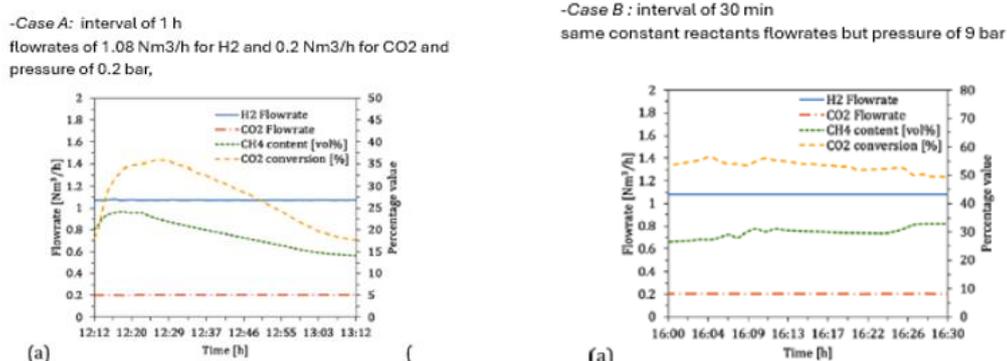


Figure 20: Experiment results

Based on the analysis of these two prototype, several features have been integrated into our reactor design. Commercial Nickel catalysts will be used if possible because of their proven durability and cost-effectiveness, also to ensure complete conversion, we will try to have a 4 to 1  $\text{H}_2:\text{CO}_2$  ratio. The system will run within a moderate temperature range, between 200–300°C. We chose to operate a batch process and not continuous to simplify the prototype as explained in the design section and the tube will be made out of stainless steel.

## 5 Design

The design has been through some changes within the project. Multiple brainstorm sessions brought new ideas that needed to be implemented. Looking at the time of the project there were made some changes on the design to make it in time. In total there were three designs that were considered to build.

Eventually The prototype of the Swedish thesis was chosen between the Swedish thesis and the Ontario University prototype as the example for the prototype of this research. The reason for that is that the Ontario University prototype is more complicated than the Swedish one. In the time of this project the Swedish prototype is more realistic to build than the Canadian one. Also to build the Canadian one we need to find the same products that are needed but in European specifications. This means that this one would take a lot more time to find the products. That is why in the rest of this chapter there will be talked about the Swedish prototype and not the Canadian one.

### 5.1 Design V1

The first design that was drawn in this project is based on the Swedish thesis. That design is talked about in the chapter of E-methane. This one was chosen because it looked more simple than the one of the Ontario University, which suits better for this project.

The first design has three components. The first reaction, the cooling section, and the second reaction. This design has a batch process. This means that an amount of both gasses goes into the tube and then e-methane comes out. For our prototype it is also chosen to work with a batch process. The batch process is easier to build.

Before entering the first reaction section the gasses will be mixed in a gas mixer. After the gasses are mixed they enter the first reaction section. In this section the gasses will react for the first time together to produce e-methane. This process needs to have a maximum temperature of 400°C. The second component is a cooling bed section. This is needed because if it is not used the temperature will rise up with no control (Deiana et al., 2025). Then the third component is another reaction section. This prototype has two catalysts where reactions happens. When the design was made, a better drawing was made to get a good visual of how the prototype should look like.

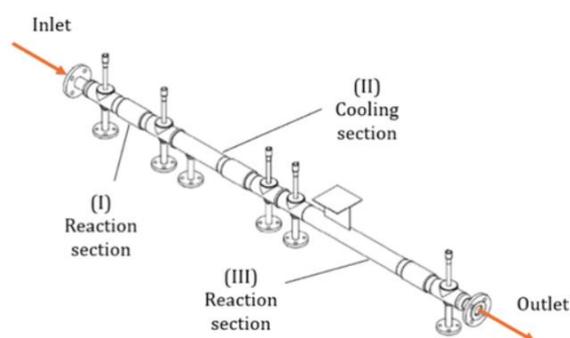


Figure 21: Example of the design

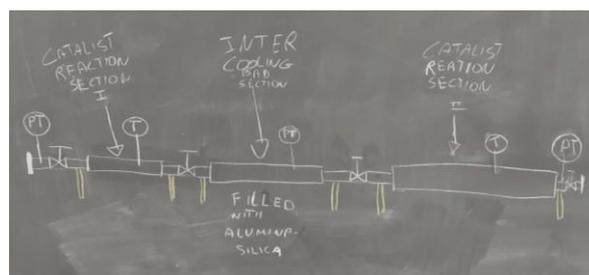
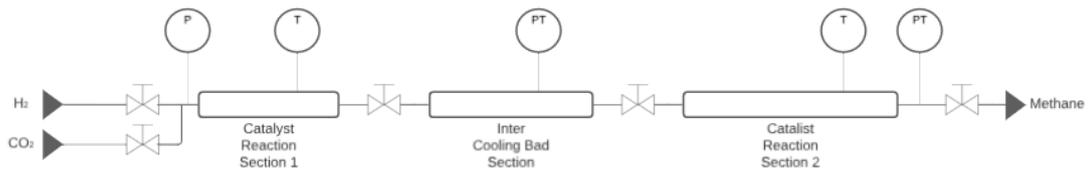


Figure 22: Design V1



**Figure 23: Improved drawing Design V1**

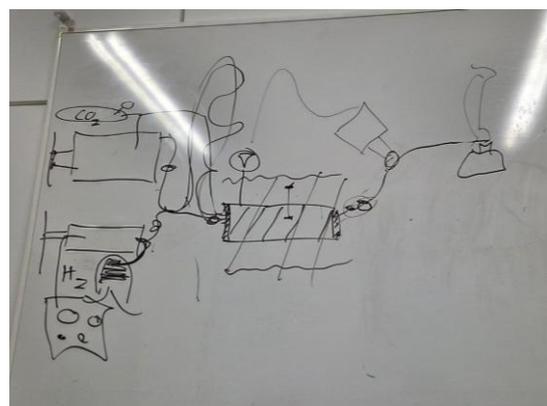
After making the design and the purchase list there was a meeting scheduled with the customers and the coach to talk about the design and the parts that for this prototype. In this meeting there was feedback given from the customers to improve the design. The Design V1 was too much industrial than needed for this project. The customers gave us feedback that only one reaction section is needed for this project. The total length of the prototype needs to be around one meter. That is why in the meeting there was a conclusion made that the reaction section will be around 70cm. In this meeting there was a quick drawing made of what the prototype could look like. After this meeting the project group started working on Design V2

## 5.2 Design V2

This design is the final one the is made for the prototype. The parts will be explained that are used in the building of the prototype. Also some safety considerations have been made. It is important to build a safe prototype that can be used by the students.

### 5.2.1 The parts in the design V2

In figure 24 the second design of the project is shown. This drawing is made in a brainstorm session with the customer and coach talked about earlier. This design is based on the one in Figure 17, but it does not have the cooling section and a second reaction. In this meeting there was a discussion if the cooling section and a second reaction is needed. Eventually the conclusion was that because this prototype will only be used in lectures to show that it is possible to make E-methane, it was possible to eliminate those components. The one in figure 16 is too much industrial than this project needs.



**Figure 24: Brainstorm session on the Design V2**

So there will be only one reaction component were the catalyst will be implemented. This section will be 70cm long with a diameter of around 2inch. This part will be a steel tube so it can handle the pressure and the heath. Before this tube there will be a tube installed that

is 10cm long with a diameter of 1inch. And after the big tube there will be a tube installed of 20cm with a diameter of 2inch. Those two parts are only 1inch because in the 10cm one the gasses are more compressed to get mixed before entering the big tube. The one in the back is smaller because then the it will be easier to measure the amount of E-methane that is produced. The measurements are in figure 26. In this figure, an new drawing is made of the second design after the meeting with the customer and coach. When this drawing was made the start of a new purchase list started. This was not easy, a lot of parts that were chosen in the first purchase list did not have the European specifications. So searching to similar products with European specifications was needed. But first this design will be more explained.

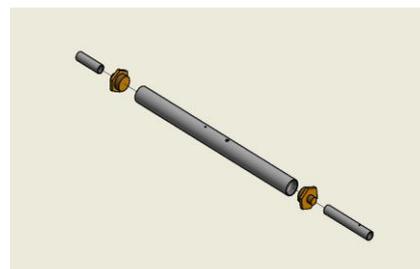


Figure 25: Drawing of the tube

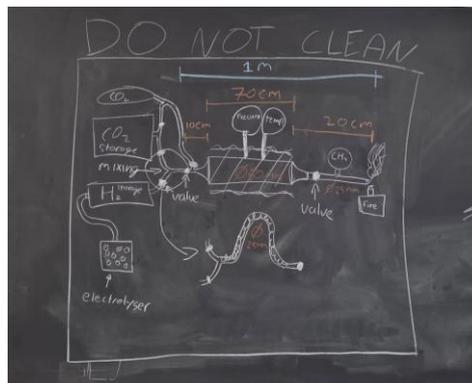


Figure 26: Design ~~V1~~V2.2

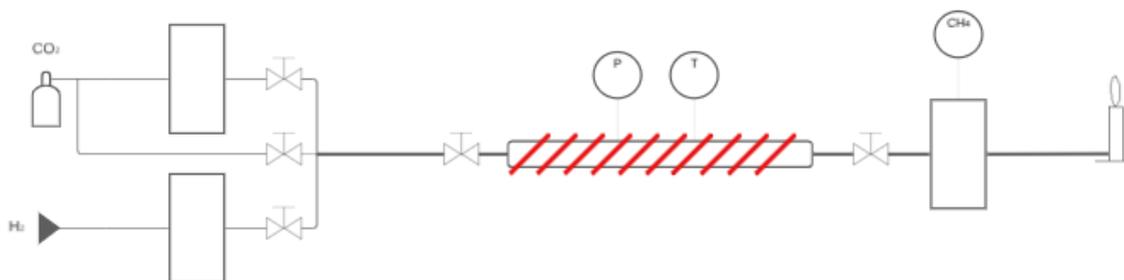


Figure 27: Improved drawing of the design

The first step is that the tube will be cleaned with carbon dioxide so no oxygen will be left in the in tubes. The next step is to put the needed amount of hydrogen and carbon dioxide in the silicone tube with syringes. In this silicone tube the gasses get compressed and therefore they will be mixed. After this process the mixed gasses will go to the big tube where the reaction will happen. After this reaction the gasses will go into another gasbag. Before entering the gasbag the amount of E-methane will be measured. After we caught the E-methane it will be burned.



Figure 28: 2L gas sampling bag

The hydrogen will be produced of an electrolyzer that is already in the school. This will be used to produce the hydrogen and the gas sampling bag is used to store that hydrogen. This bag can store up to two liters. This bag will also be used to store the carbon dioxide. The carbon dioxide will be produced out of a SodaStream bottle. To get the amount of carbon dioxide on a safe way out of the bottle a regulator for the SodaStream bottle will be installed. This piece of equipment will show how much pressure of carbon dioxide will go in the tube of the prototype.



**Figure 29: Regulator for the SodaStream bottle**

Valves will be installed in multiple places in the prototype. With the valves we can make sure the gasses will not leave at places we do not want them to go. Also it is possible to keep gasses in places for a longer period if needed. The valves will be opened after the prototype is used so all the gasses can get out of the tube. This valve is made for a 1 inch tube and can be opened by the blue handle. Also there is a red handle valve, but the colors will not have a meaning.



**Figure 30: Picture of a valve**

For the reaction of the process we need heat up the tube. To heat up the steel tube we will use a heating tape that will be put around the tube. This piece of equipment has all the different components in one product. It can heat up more than 400°C what we need for this process.



**Figure 31: Picture of the heating tape**

In the prototype there will be three important sensors installed for safety and to see what is happening in the process. The first one is a methane sensor, the second one is a pressure sensor, and the third one is a temperature sensor. The pressure and temperature sensor are important for the safety. With those sensors it is possible to see when the temperature or pressure are getting to high. The methane detector is there to show how much e-methane is produced in the process.

Also there will be handheld gas detectors for extra safety. There will be two handheld gas detectors. One that measures the methane and hydrogen, and one that measures the carbon dioxide. Those will be standing close to the prototype when it is being used.



**Figure 32: Handheld gas detector**

## 5.2.2 Safety considerations on the design

One safety concern was about a leak of the SodaStream bottle resulting in a an instantaneous and total emptying of the SodaStream cylinder into the room with no ventilation. So the resulting concentration of CO<sub>2</sub> was calculated in order to know what security precautions needed to be implemented.

The total volume of the room in which the experiment is taking place is:  $4 \times 2 \times 2.5 = 20$  cubic meters (m<sup>3</sup>) or 20,000 liters.

Gas Source: Standard CO<sub>2</sub> cylinder (425g net weight).

Calculations at atmospheric pressure and at 20°C :

1. Moles of CO<sub>2</sub>:  
 $n = 425 \text{ g} / 44 \text{ g/mol} = 9.66 \text{ moles}$
2. Gas Volume Released:  
 $V_{\text{gas}} = 9.66 \text{ moles} * 24 \text{ L/mol} = 232 \text{ Liters}$
3. Volume Concentration in the Room:  
 $C = 232 / 20,000 = 0.0116$

In the event of a total leak, the CO<sub>2</sub> concentration in the room will reach 1.2% (or 12,000 ppm). The calculated value of 12,000 ppm is compared below with official public health and occupational safety standards (INRS/NIOSH) : INRS (National Research and Safety Institute), Toxicological Sheet No. 238 - Carbon Dioxide.

VME (Average Exposure Value): This is the limit not to be exceeded if staying in the room all day (8 hours of work).

- The limit is: 5,000 ppm (or 9,000 mg/m<sup>3</sup>).

VLCT (Short-Term Exposure Limit): This is the limit for very brief exposure (15 minutes maximum). It is the threshold for immediate danger or irritation.

- The limit varies by country: Between 10,000 ppm (Germany) and 30,000 ppm (USA).

The immediate danger begins at exposure levels around 40,000 ppm, because the risk is severe respiratory distress and confusion, which can lead to fainting and inability to exit. At a concentration of 1.2% (12,000 ppm), a person present in the room will experience the following effects:

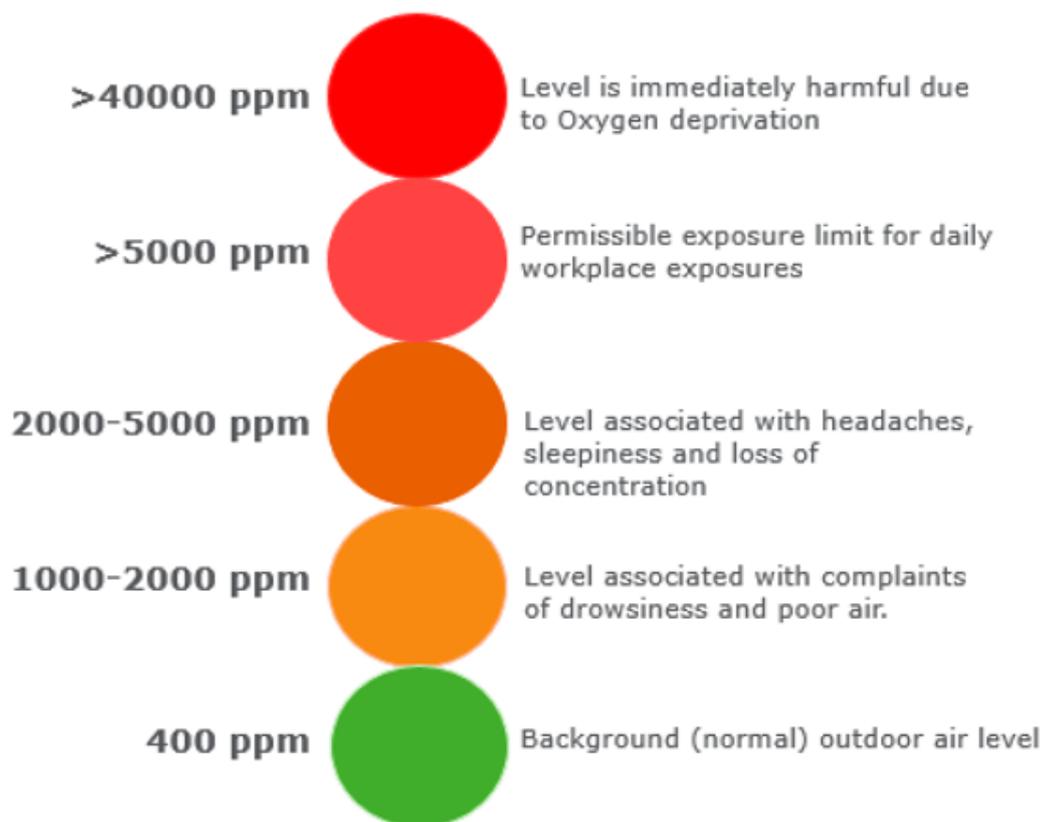
- Immediate Effects: Slight increase in respiratory rate, sensation of "stuffy" air.

- Effects after prolonged exposure : Headaches, mild drowsiness, shortness of breath upon exertion.
- Aggravating Factor: CO2 is heavier than air. It accumulates at floor level. The concentration at ground level (0 - 50 cm) may be significantly higher than 1.2%.

To conclude, a Sodastream leak is not dangerous for a short duration if we react correctly:

Simply opening the door to a larger room and leaving the area to let it ventilate is enough to quickly dissipate the gas and remove any risk. We need to listen regularly to the ventilation to be sure that it is functioning, leave the door open when doing the experiment and watch the CO2 detector that will be standing on a table next to the experiment.

### How CO2 levels impact on the human body



## 6 Purchase list

Successfully completing a small-scale E-Methane production project with short deadlines requires a well-structured shopping list. We must balance cost, availability, delivery time, and technical specifications. Knowing this constraints, we were looking for equipment in Finland if possible, because it would reduce the time needed for the equipment to arrive. When this is not possible, we try to purchase from European suppliers to avoid taxes for shipping.

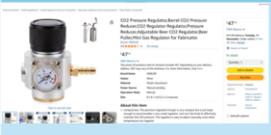
Name	Amount	Price	Total price	Description/Comment	Delivery time	Delivered	Supplier / Link	Picture
1. Stainless Steel Tube (1 m)	1	€ 1000,00	€ 1000,00	75cm long, diameter 50mm, 3mm wall thickness. Compatible with H <sub>2</sub> and CO <sub>2</sub> . It needs threads on both sides Pressure up to 2 bars		NO	SJP-Neos Oy (Local supplier)	
2. syringes	2	€ 17,92	€ 35,84	100mm if possible / maybe in the lab they already have a supplier	1 week	Yes	<a href="#">Link to item</a>	
3. SodaStream cylinder	1	€ 32,90	€ 32,90	We can buy it directly in Vaasa at multitronic shop		Yes	<a href="#">Link to item</a>	
4. Adaptor / regulator for sodaStream	1	€ 47,19	€ 47,19	An Amazon SodaStream regulator is a small pressure-control device that connects directly to a SodaStream CO <sub>2</sub> bottle to safely release and adjust the gas flow for applications like homebrewing or gas experiments.	1 week	No	<a href="#">Link to item</a>	

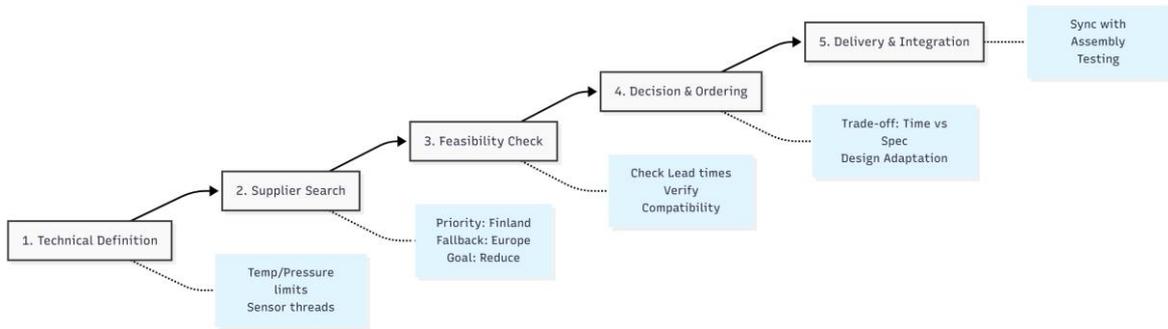
Figure 33 : Extract from the group shopping list

The first item is the tube for the reactor itself. This is not a standard item we can simply buy, because it needs to fit with the rest of the system, support high temperatures and pressure, and integrate several sensors. The approach was to write precise specifications and send them to local suppliers. They could then propose a compatible solution and custom threads for the sensors. This item was the most critical one, both technically and logistically.

Another part of the shopping list concerned the pressure and flow control equipment. For safety reasons, the project needed certified valves, pressure regulators and fittings compatible with CO<sub>2</sub> and hydrogen. Availability was a major limitation: some had long delivery times, so sometimes it was necessary to compare alternative brands or change the design slightly to match what was possible within the project deadlines.

As explained in the Design section, SodaStream bottles with adapters are used to supply CO<sub>2</sub>, so that it can be bought locally. However, the adapters themselves had to be ordered online, and it was needed to check their pressure rating and material compatibility before validating the purchase because pressure is the main concern for safety.

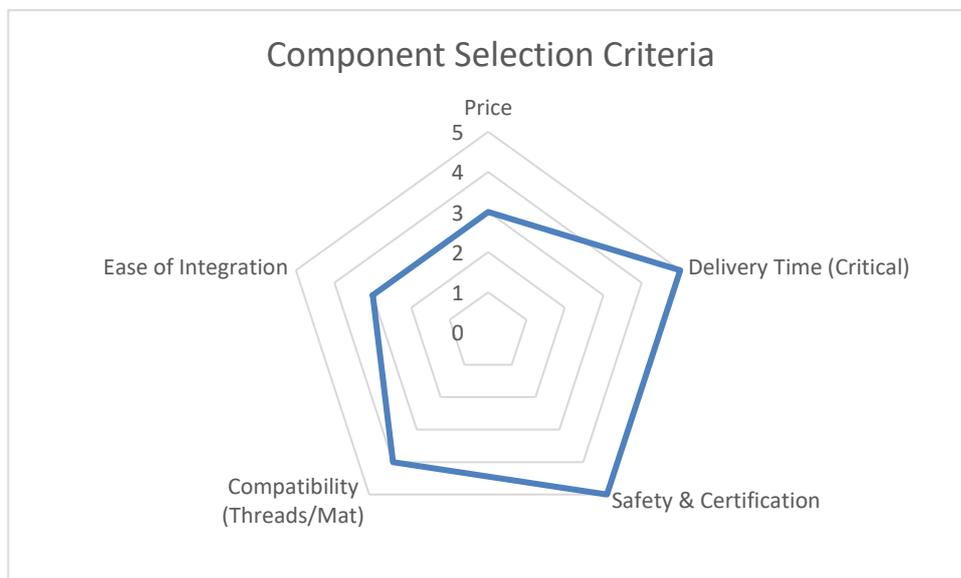
Several instruments and sensors needed to be purchased (thermocouples, pressure sensors, flowmeters). Even though these components exist in many versions, finding models with the correct measurement range and thread type was not easy. A comparison table was made to evaluate each option based on price, response time, delivery date, and integration into the control system.



**Figure 34: Purchase workflow**

In the part concerning E-methane production, we presented two theses of similar project including a Canadian thesis. In order to have a first draft of a purchase list we looked at the items they used, it was useful for knowing what kind of part will be needed but we couldn't buy same parts because the suppliers and most importantly the units of measurement were different.

Overall, the shopping list was not just a list of components: it was a project management tool allowing us to control budget, adapt the design to what was realistically obtainable, and ensure that all critical equipment would be delivered in time for assembly and testing.



**Figure 35: Comparison of the criteria's importance**

## 7 Instructions

### 7.1 Introduction

Before starting to experiment, it is imperative to establish a safe working environment. The guidelines below define the critical safety precautions that must be observed to ensure the protection of the users and the equipment integrity throughout the process.

### 7.2 Safety Precautions

Hydrogen and the produced Methane are extremely flammable gases. Therefore, all ignition sources must be strictly prohibited in the laboratory area. The experiment must be conducted within a functioning fume hood to prevent gas accumulation in case of leaks. The pathway to the emergency exit and the fire extinguisher must remain unobstructed at all times.

Although the process has been adapted to operate at atmospheric pressure, gas leaks remain a significant risk due to the custom adaptation of the tubes. All connections between the tubing, the reactor, and the sensors must be checked for airtightness (e.g., using a leak detection solution) before introducing flammable gases.

The methanation reaction requires high temperatures. Consequently, the reactor and adjacent tubing will become extremely hot during operation. Heat-resistant gloves must be worn when handling equipment near the reactor. The setup should be allowed to cool down completely before any disassembly or maintenance.

The solid catalyst used for the reaction should be handled with care. Inhalation of catalyst dust must be avoided, and protective gloves are required to prevent skin contact. If any catalyst is spilled, it should be cleaned up immediately using a dry method (brush and pan), avoiding water contact.

As non-industrial sensors are being used, care must be taken not to exceed their thermal limits. The electronic components of the sensors must be kept away from the main heat source to prevent melting or signal failure. Only the probe tip should be exposed to the process environment.

Unreacted gases and products must be safely vented through the fume hood extraction system. They must not be released directly into the laboratory atmosphere. The used catalyst and solid chemical waste must be collected in designated hazardous waste containers in accordance with laboratory protocols and local environmental regulations.

## 7.3 Chemicals

	What	Target in Liters
Part A	Producing Hydrogen	0.3 Liters
Part B	Producing Carbon dioxide	1.15 Liters
Part C	Producing E-methane	-

Calculation of estimated reactant targets in liters for one experiment.

$$Total\ volume = V_{total} = \pi \frac{d_1^2}{4} L_1 + \pi \frac{d_2^2}{4} L_2 = 1.4235\ L$$

With  $d_1$  and  $d_2$  the diameters of the tubes,  $L_1$  and  $L_2$  the respective lengths.

$$Molar\ volume = V_m = \frac{RT}{P} = \frac{8.314 * 298.15}{101325} * 10^3 = 24.465\ L$$

With  $R$  the gas constant  $J/(mol.K)$ ,  $T$  for temperature (K) and  $P$  for pressure (Pa)

$$\eta_{total} = \frac{v_{total}}{v_m} = \frac{1,4235}{24,465} = 0,05819\ mol$$

Since  $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

$$n_{CO_2} = n_{total} \frac{1}{5} = 0,011637\ mol \Rightarrow v_{CO_2} = n_{CO_2} V_m = 0.2847L \approx 0.3\ L$$

$$n_{H_2} = n_{total} \frac{4}{5} = 0,046548\ mol \Rightarrow v_{H_2} = n_{H_2} V_m = 1.1388\ L \approx 1.15\ L$$

## 7.4 Procedure

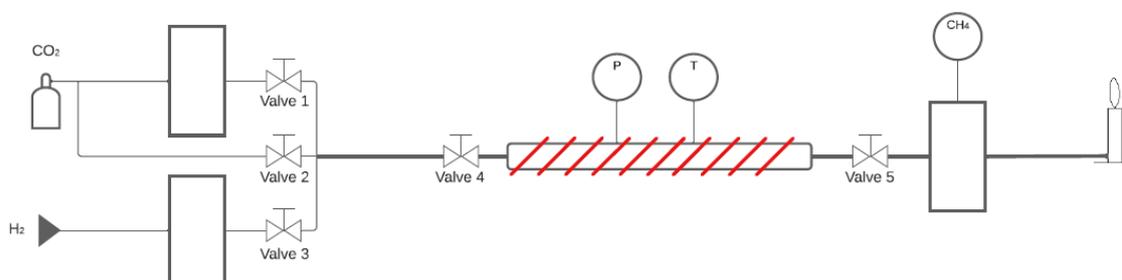


Figure 36: Drawing of the prototype

Part A: preparation.

1. Close all the valve's.
2. To start the electrolyzer, make the connections as shown below (red with red and lack with black), using only distilled water to avoid damaging the equipment. The generator should be set at 3A and max of 10 V.



**Figure 37 : Electrolyser setting**

3. Fit the pressure regulator on top of the SodaStream bottle and link it to the CO2 bag.
4. Fill the carbon dioxide bag with carbon dioxide from the SodaStream bottle, by setting the pressure on the regulator to 20 psi (a little more than atmospheric pressure).
5. Open the valves and purge the system by injecting pressurized CO2 (or an inert gas such as Helium) into the empty tube, so without catalyst to evacuate any residual air or contaminants.
6. Follow the instructions of the section '7.5 Data recording' to prepare the Raspberry.
7. Close the valves and fill the middle tube with glass wool and catalyst following the safety instructions above. The catalyst powder should be sandwiched between two plugs of glass wool to keep it firmly in place inside the tube
8. Fill the one litter syringes with the reactants following quantities written in section "7.3 Chemicals" above.
9. Heat to 300-400 °C the Middle tube section with the heating tapes

## Part B: Reaction

1. Close valves 4 and 5 so the reaction can happen in the tube with the catalyst.
2. Open the first tube valve and fill the tube with both reactants if possible with 4 to 1 H<sub>2</sub> / CO<sub>2</sub> ratio by applying asymmetric force to the syringes.
3. Turn off the heating tape
4. Apply cold spray to the tube
5. Wait until cool-off and open valves 5 and fill a bag with the gas produced.

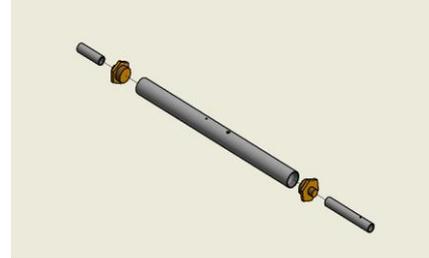


Figure 38: Where to spray cold spray

## 7.5 Data recording

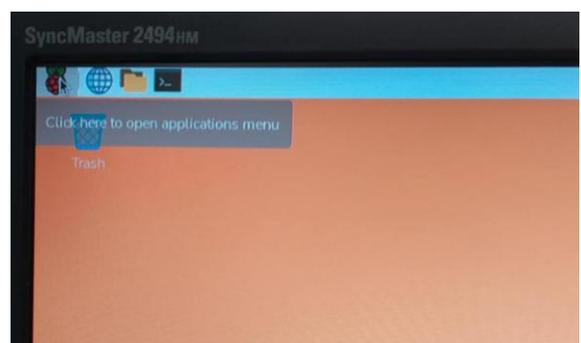
### 7.5.1 Parts Required for temperature and methane sensor

- Raspberry pi
- MAX6675 Thermocouple Module
- MQ4 Analog methane sensor
- Screen + mouse and keyboard
- Jumper Wires

### 7.5.2 Opening Raspberry pi

To watch the live data via the raspberry pi you need to open up Thonny like in the following steps.

1. Plug the raspberry pi in the socket and make sure the screen is plugged.
2. When started open click the pi logo in the to left corner.



3. Then open up the map “Programming” to than open up “Thonny”.
4. once opened you need to check of the correct program is opened: “EPS2025.py”.
5. if this is the case you need to click run and the measurement will be visible underneath the code in the “shell”.

Figure 39: raspberry pi open 1

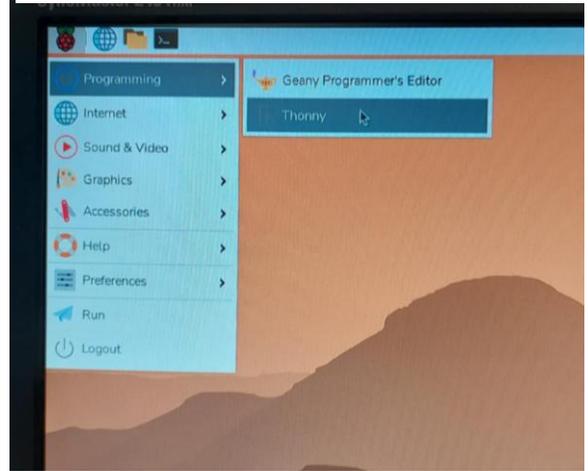


Figure 40: raspberry pi open 2

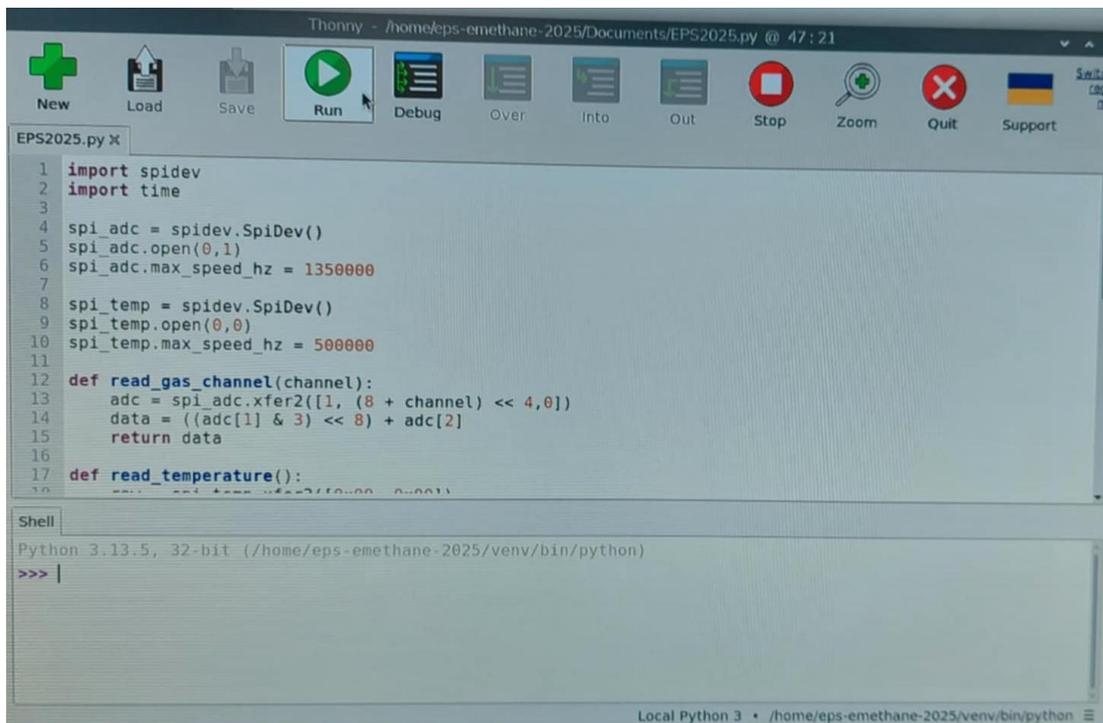
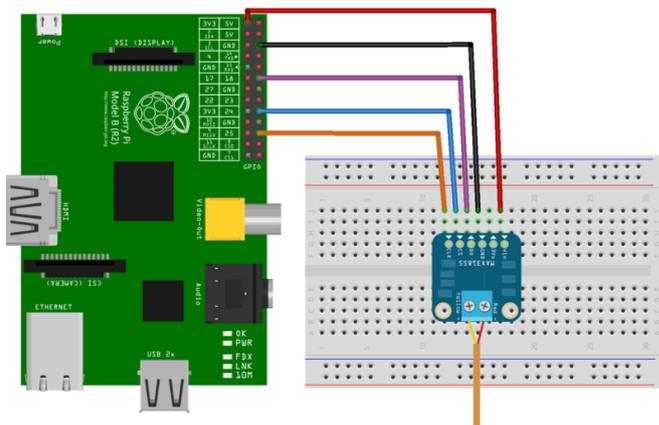


Figure 41: start Thonny program

**7.5.3 Wiring / Connections : Connect the MAX6675 module to the raspberry pi as follows:**

MAX6675 Pin	Raspberry pi Pin	Note
GND	GND (pin6)	Ground
VCC	3,3V(pin 1)	Power Supply
SCK	Pin 23	Serial Clock
CS	Pin 24	Chip Select
SO	Pin 21	Serial Output

**Table 3: Max6675 connection**



**Figure 42: connection diagram max6675**

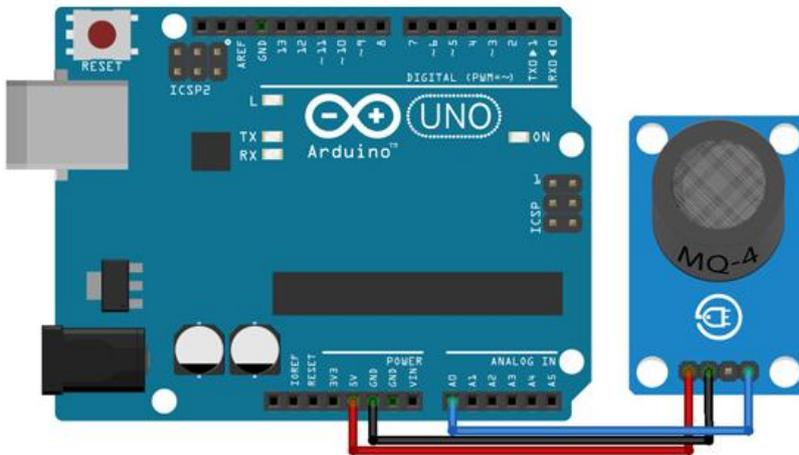
Note :

The K-Type thermocouple wires must be connected to the module terminals (+ and -). If the temperature decreases when you heat the sensor, swap the wires.

**7.5.4 Wiring / Connections : Connect the MQ4 sensor to the raspberry pi as follows:**

MQ4 Pin	Arduino Pin	Note
GND	GND	Ground
VCC	5V	Power Supply
AO	A0	Serial Clock

**Table 4: MQ4 sensor connection**



**Figure 43: connection diagram MQ4 sensor**

To make the connection between the Arduino and the raspberry pi we use the USB connection. Than connect the Arduino to the raspberry pi via the USB port

Note :

The MQ4 methane sensor can not be connected directly to the raspberry pi because he does not have analogy inputs. This is why a Analog-to-digital converter is needed. Or you need to reed only a digital signal when, so it reeds only when there is methane and not how much but our sensor does not have a digital output.

## 7.6 Raspberry Pi

The raspberry Pi is a small computer that can be used as tool to programme electronics projects and basic computer task. For this reason It is verry useful in this setup because it can be used as a computer to show the students the measured value of the sensors in the setup.

If there is a problem with the raspberry pi the following username and password are used.

Username: eps-emethane-2025

Password: semester1-2025

## 8 Difficulties

Several difficulties were encountered throughout this project. In order to get to the goal of the project we needed to handle those difficulties. In this chapter we tell what kind of different difficulties we had to handle and what we could have done differently to eliminate the difficulties.

### 8.1 Difficulties

Figure 37 illustrates the initial timeline estimated by the customers before the project began. However, these deadlines turned out to be quite optimistic. Since the team lacks an educational background in chemistry and initial knowledge of E-Fuels was limited, significantly more time than expected was needed to research the various processes and select the most suitable one. So because of that the whole time schedule got moved to the back. This means that we can do less testing of the prototype than expected on beforehand.



Figure 44 : Estimated timeline

Logistical difficulties also were faced regarding the purchasing list. Specifically, sourcing the tubes was problematic. It took a few weeks longer to find a company that could produce the tube we needed for the project. Because the tubes were not standard parts, specific adaptations were required to fit the sensors. The sensors are specific, some of them have metrics thread and others have British measurement units, so it is necessary to have custom tube and threads. Moreover, issues were encountered regarding the acquisition of the catalyst. Indeed, to purchase the catalyst on specialized websites you need to have a professional account, or a laboratory account. That means that it takes more time to purchase the products we need which is critical regarding the tight deadlines. Concerning the catalyst, at first we wanted it under pellets form but it was easier to purchase powder catalyst. These two parts are the most important in for the project that had some problems

with ordering and delivering. But also other products took a long time delivering. In this time waiting there was time to work on the report. This gave us more time to work on the building at the end of the project.

One technical challenge concerned the operating pressure. While working at high pressure is more efficient, it requires specific equipment certifications. Obtaining these certifications would have caused excessive delays, especially considering the short timeline and the deadlines for the midterm and final reports. Therefore, the process had to be adapted to work at atmospheric pressure. This took a lot of time designing and searching for the products that were needed to build the prototype.

Safety was another major priority. Due to the absence of a chemistry background, extreme care was required regarding the flammability of the reactants. Considerable time was spent studying safety protocols. This task was further complicated by an unfamiliarity with Finland's specific regulations for this type of installation. It took a few meetings and a lot of research to get to the final design for this prototype.

Finally, difficulties were faced regarding the temperature. It was hard to find non-industrial sensors capable of withstanding the high temperatures required for the experiment, as standard components are often not resistant enough.

## **8.2 What could have improved the project**

It would have helped if we had more educational background in chemistry and initial knowledge, because we needed a few weeks to learn more about the chemistry and E-fuels. This took a few weeks of our time what was more than expected. Also in the designing phase it would have been useful to have more knowledge. With the knowledge it is easier to foretell what could happen when using different products or whatever. Now we needed to search for all the information and sometimes we did not know what we were reading.

Finding all the parts we needed to build the prototype took a few weeks what is a lot of time, especially when there is not much time. It would have helped if we could have found all the parts earlier so ordering everything would happen a few weeks earlier then it happened now. That would have saved some time in the end so all the products would arrive on time. Then we could have done more testing on the prototype what would have resulted in a better outcome.

## **8.3 Which other E-fuel could be implemented in the future**

The E-fuel that would fit the most after the E-methane to be implemented in this school for the future is E-diesel as is shown in Figure 15: Selection Matrix. The E-diesel is just a little more expensive than the E-methane to build and produce with the information we have found. All the other E-fuels have more complications that are not suitable for the school.

## 8.4 Recommendations for Future Improvements and Upscaling

In this section, perspectives of evolution will be discussed. The current prototype demonstrate the feasibility for production of E-Fuels, but its performance and educational value could be improved.

### 8.4.1 Product Separation and Purification

A future improvement could be made concerning the product characterisation. Indeed, the current products are expected to be a mixture of synthetic methane, unreacted hydrogen and a significant amount of water vapor. To separate the methane produced, a condensation and phase separation unit could be implemented.

In order to separate the water vapor, a heat exchanger must be implemented. This works by cooling the gas mixture below  $100^{\circ}\text{C}$  so that the water vapor will condense into liquid while the methane will stay in a gaseous state. Then, a gas liquid separator should be added. The aim would be to use gravity to separate the phases: liquid water would accumulate at the bottom, while the methane gas exits from the top. And finally, a drying column could be added too for a higher purity. These devices can be purchased directly or made from standard equipment such as a simple copper tube (coil) immersed in a tank of cold water. The gas passes through it, cools down and the water condenses on the walls.

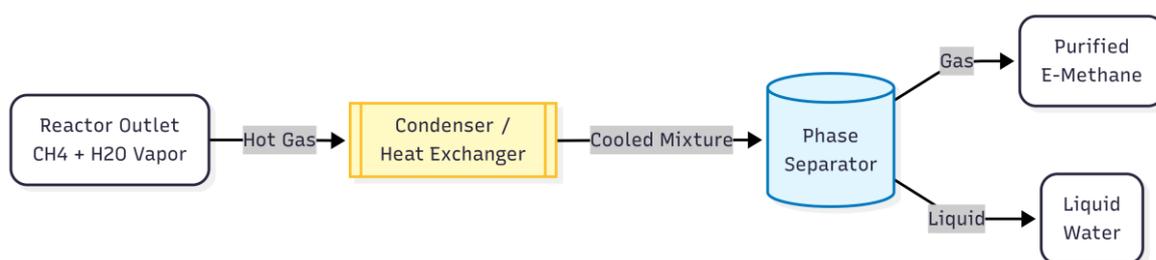


Figure 45 : Product separation improvement

### 8.4.2 Improving product characterization and educational use

The prototype could be upscaled with a bigger inner volume and a future perspective could concern the pressurisation of the tube for a better conversion ratio.

Future developments should focus on a better characterization of the products. By analysing the output gas, conversion rate and reaction selectivity could be measured. Indeed, to adjust parameters such as pressure and temperature would be a major improvement as it would allow students to experimentally observe how these variables influence the reaction conversion rate and reaction selectivity (efficiency). In the prototype current form, the temperature can be controlled, but for safety reasons there is no pressure so no control of the pressure flows between the different part of the tube.

### **8.4.3 Transition to Continuous Operation**

Currently, the system works as a batch process, where the reaction occurs in a closed, static volume. A major future step would be to upgrade the system to a continuous flow loop. In this type of configuration, reactants would be continuously fed into the reactor while products are extracted. Implementing a continuous prototype would increase production rates and also allow to study of the kinetics of the reaction. It would also be closer to what is used in the industry.

## 9 Conclusion

This EPS-project initiated by Novia University aims at closing the gap between theoretical knowledge and practical competence in the field of renewable energy. By designing a safe and educational laboratory prototype for the synthesis of E-methane, usable in university practical work, this project allow a better understanding of the production of different kinds of E-Fuels.

Throughout this European Project Semester, the EPS group studied the different E-Fuels suitable for a small-scale production and designed a prototype balancing different constraints such as technical feasibility and budget.

This project also is a solid foundation for future developments. As discussed in the perspectives section, the current architecture still allows significant scalability. Future iterations could integrate better product separation and purification. Also it could be possible to look into producing E-diesel. This E-fuel is after

To conclude, this project provides a practical and ready to use design for the university laboratory. It creates a safe environment for students to study the Sabatier reaction and is designed to support future upgrades. This project ensures that students gain practical skills in the growing field of renewable energy.

## 10 Project Management

Project management is essential for the success of complex engineering projects like our e-methane production project. It provides a clear structure to organize the different tasks, manage resources, and ensure that all deadlines are met. By using specific tools and methods, the team can communicate better, avoid as much as possible delays, and solve problems quickly. Ultimately, good project management transforms a technical concept into a finished, professional result by keeping the team focused and efficient.

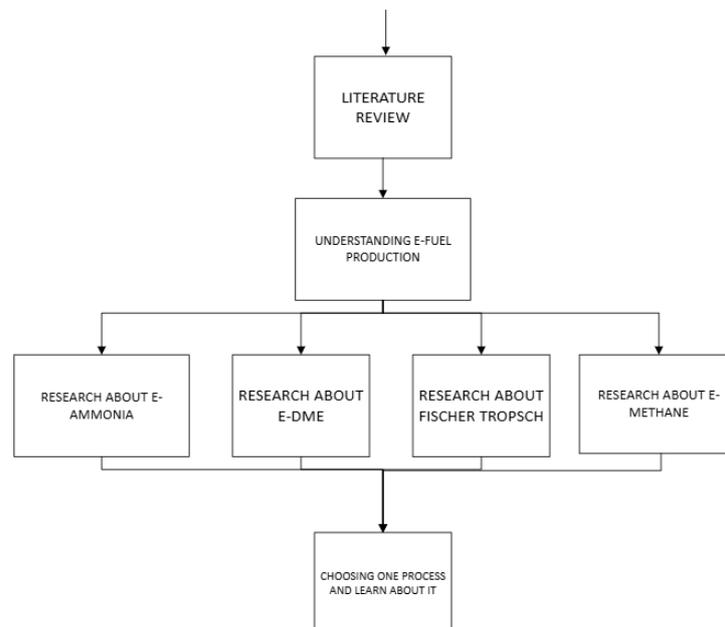
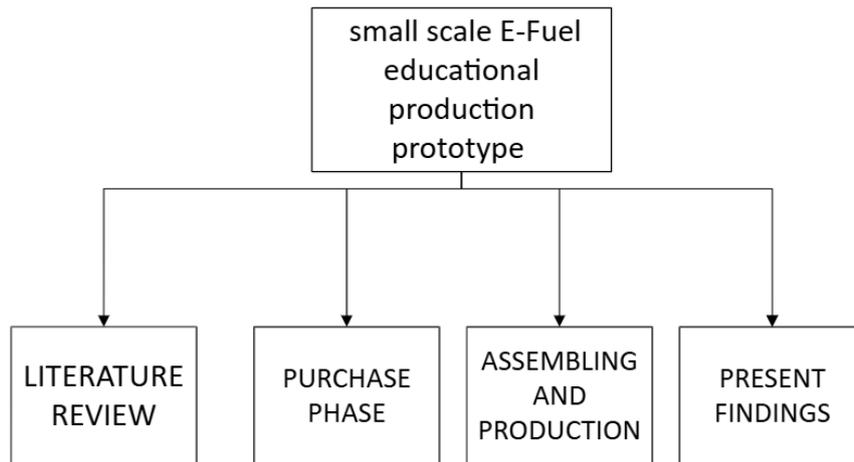
### 10.1 Project mission and vision

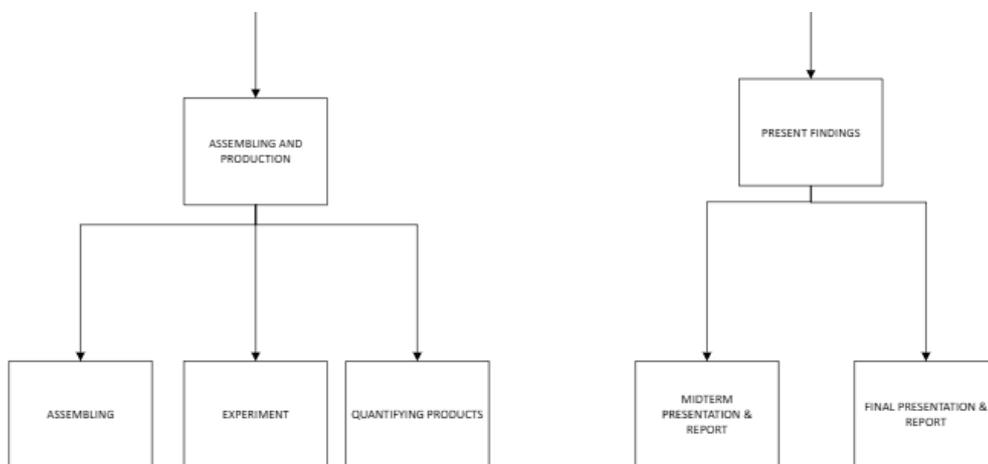
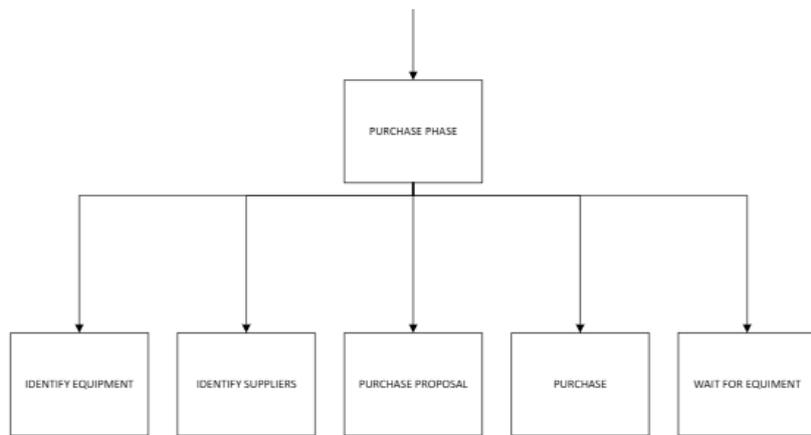
**Vision :** The vision for this project is to help students understand the technologies behind the green energy transition and more precisely by breaking down the technicals steps of E-Fuels production.

**Mission :** The mission is to design and build a functional small-scale prototype of the e-methane unit to demonstrate the process in real life.

## 10.2 WBS Breakdown

The Work Breakdown Structure (WBS) was developed to divide our project into a understandable way, measurable tasks. We divided the project into four highest-level sections: Literature Review, Purchase Phase, Assembling and Production, and Present Findings. All are deliverables that represent an actual outcome, not an activity. In each section, we added smaller tasks that can be done within a matter of days and are suitable for our objectives.



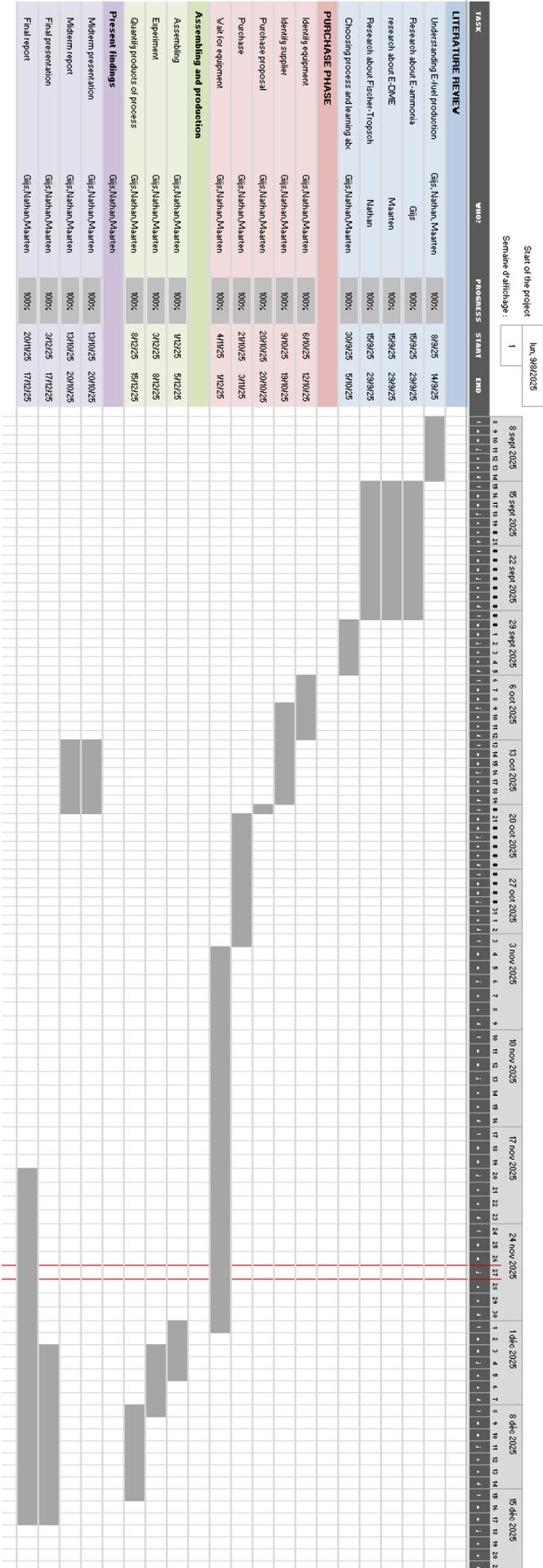


### **10.3 Gantt chart**

To manage the schedule effectively, a Gantt chart was used. A Gantt chart is a visual tool that displays the project timeline in a horizontal bar chart format. Each bar represents a specific task, showing exactly when it starts and when it must finish. The Gantt chart helps making it easier to track progress and understand which tasks are linked together. It is crucial for ensuring that the project stays on track from start to finish.

Refuelition

Novia UAS



## 10.4 RACI Matrix

To clarify roles within the team, we used a RACI matrix. RACI stands for Responsible, Accountable, Consulted, and Informed. This matrix is a table that assigns a specific level of involvement to each team member for every task. By clearly defining who does the work (Responsible) and who answers for the final result (Accountable), the matrix prevents confusion. It ensures that everyone knows exactly what is expected of them and who needs to be updated on progress.

Person WBS-package	Gijs Rovers	Nathan Permin	Maarten Vermeiren	Mikael Ehms	Jenny Rönnqvist-Norby	Mats Borg	Comments
Understanding E-fuel production	C	A	R	I	I	I	
Research about E-ammonia	R	C	A	I	I	I	
Research about E-DME	C	A	R	I	I	I	
Research about Fischer tropesch	A	R	C	I	I	I	
Identify equipment	A	R	C	I	I	I	
Identify suppliers	R	C	A	I	I	I	
Purchase proposal	C	A	R	I	I	I	
Purchase	C	C	A	I	R	I	
Assembling	R	C	A	I	I	I	
Experiment	A	R	C	I	I	I	
Quantifying products	C	A	R	I	I	I	
Midterm presentation & report	R	C	A	I	I	I	
Final presentation & report	R	A	C	I	I	I	

Table 5: RACI matix

## 10.5 Risk management

A risk management process was implemented to ensure the success of the project. We divided it in three steps which are identification, analysis and response planning.

### 10.5.1 Risk Identification

At first, potential events that could impact the project were identified, then they were ranked as threat (negative) or Opportunities (positive)

<b>Risk ID</b>	<b>Risk description</b>	<b>Risk type</b>
<b>R1</b>	Unexpected budget saving	Opportunity
<b>R2</b>	Erasmus Extra-Activities	Threat
<b>R3</b>	Sickness within the project group	Threat
<b>R4</b>	Problems with delivery	Threat

Table 6: Risk ID

## 10.5.2 Risk Analysis

After the identification of the potential risks, each risk was evaluated based on its Probability (P) and Impact (I) on a scale of 1 to 3 (3 being the highest and 1 the lowest). The risk score allow to prioritize them before thinking about the action that could be taken.

<b>Risk ID</b>	<b>P (1-3)</b>	<b>I (1-3)</b>	<b>Risk score (P xI)</b>	<b>Priority (High, Medium, Low)</b>
<b>R1</b>	3	1	3	Medium
<b>R2</b>	3	2	6	Low
<b>R3</b>	1	2	2	Low
<b>R4</b>	3	3	9	High

**Table 7: Risk Analysis**

## 10.5.3 Risk Response Planning

Finally, specific strategies were defined for the risks that requires an action to limit their impacts.

<b>Risk ID</b>	<b>Risk Type</b>	<b>Chosen Strategy</b>	<b>Specific Action Plan</b>
<b>R2</b>	Threat	Mitigate	Establish a good communication so we can adapt the planning
<b>R3</b>	Threat	Accept	Work on other tasks when waiting

**Table 8: risk response planning**

# 11 Project with Chile students

In week eight of this project four Chile students came to Vaasa to do a little project with us about how E-ammonia could be made and used in Chile. In this chapter we will talk shortly about this little project we did together with the Chile students.

## 11.1 Introduction

In this project with the Chile students we worked together for five days on a little project how to produce E-ammonia in Chile. In Chile they use ammonia in explosives for the mines. Right now Chile has a high dependence on imported ammonia. For this project we were researching to produce E-ammonia in Chile so they would get more independent. In a week of time we had to do the research and prepare the final presentation.

## 11.2 The project

The project which we did was short but still took a lot of research to get to the final presentation. we needed to do research about how the ammonia is going to Chile and what needs to be changed to produce E-ammonia in Chile itself. Chile is one of the countries where there is an exceptional renewable energy potential. Chile has a lot of sources to produce the green energy which will be used in the production of green ammonia. Because Chile is right next to the ocean, wind turbines are a good solution for the production of the green energy that needs to be used for the production of green ammonia. Right now the production of green ammonia will be too expensive. The technology needs still a lot of improvement to be the better solution than the normal ammonia.

In this project we calculated what the cost of the hydrogen plant that is needed in the industrial green ammonia production plant will be made. Because of the short time we had those are not the realistic numbers, but it gives an idea of how expensive it is on the moment to produce green ammonia on a big scale. As you can see the total amount of 2297 million USD is needed for just the hydrogen plant. This is on the moment to much to build a production plant in comparison of buying ammonia from a supplier.

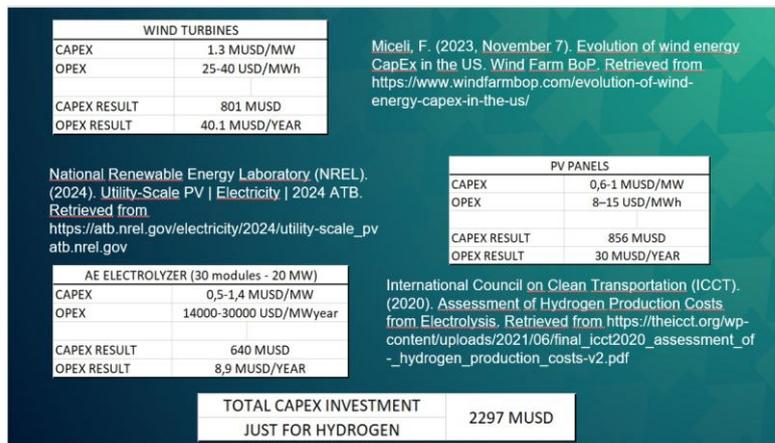


Figure 46: Screenshot of the costs of the hydrogen plant

This is on the moment to much to build a production plant in comparison of buying ammonia from a supplier.

### **11.3 Working with the Chile students**

Working together with the Chile students went quite good. In the beginning we needed to get to know each other a little bit. We divided the work in little groups, but one of us three got together with one of the Chile students to get to know about our cultural differences. After some time the group went quite close and working together went really smoothly. We got to know about our differences in culture of working in a project, but also we talked a lot about the personal lives. After all the project went good and we got a nice final presentation that we presented to the teachers and our classmates.

## 12 Annexes

### I. Raspberry pi Thonny code

```
1 import spidev
2 import time
3 import serial
4
5 ser = serial.Serial('/dev/ttyACM0', 9600, timeout=1)
6 time.sleep(2)
7
8 spi_temp = spidev.SpiDev()
9 spi_temp.open(0,0)
10 spi_temp.max_speed_hz = 500000
11
12 def read_Methane_usb():
13     try:
14         line = ser.read().decode().strip()
15         if line.isdigit():
16             return int(line)
17     except Exception as e:
18         print("Serial error:", e)
19     return None
20
21 def read_temperature():
22     raw = spi_temp.xfer2([0x00, 0x00])
23     value = (raw[0] << 8) | raw[1]
24
25     if value & 0x04:
26         return None
27
28     temp_data = value >> 3
29     return temp_data * 0.25
30
31 print("start reading gas + temp")
32 try:
33     while True:
34         gas_value = read_Methane_usb()
35         temp = read_temperature()
36
37         print("---")
38         print(f"methane: {gas_value}")
39
40         if temp is None:
41             print("Thermocouple not conected or Error")
42         else:
43             print(f"Temperature: {temp:.2f} C")
44         time.sleep(1)
45 except KeyboardInterrupt:
46     print("stopped")
47 finally:
48     spi_adc.close()
49     spi_temp.close()
```

## II. Arduino code

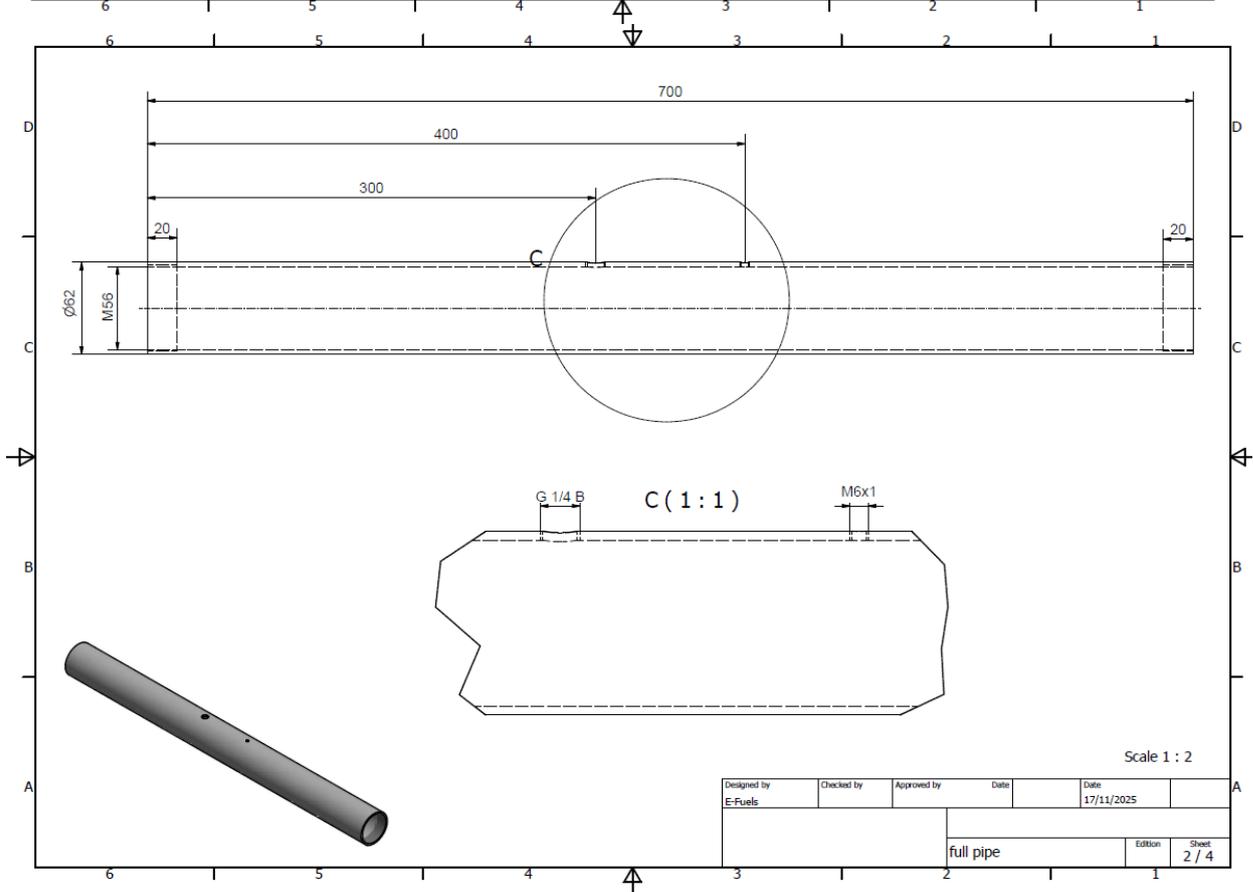
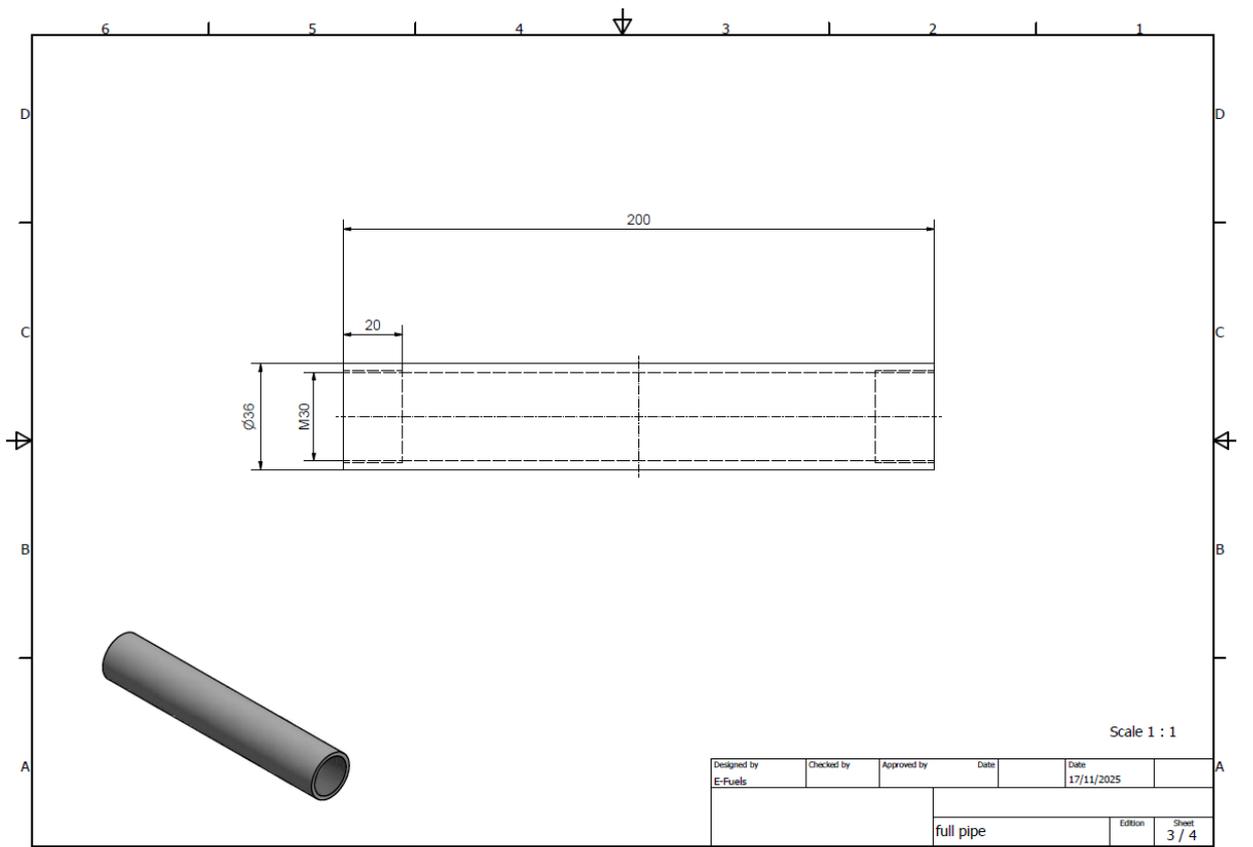
EPS2025

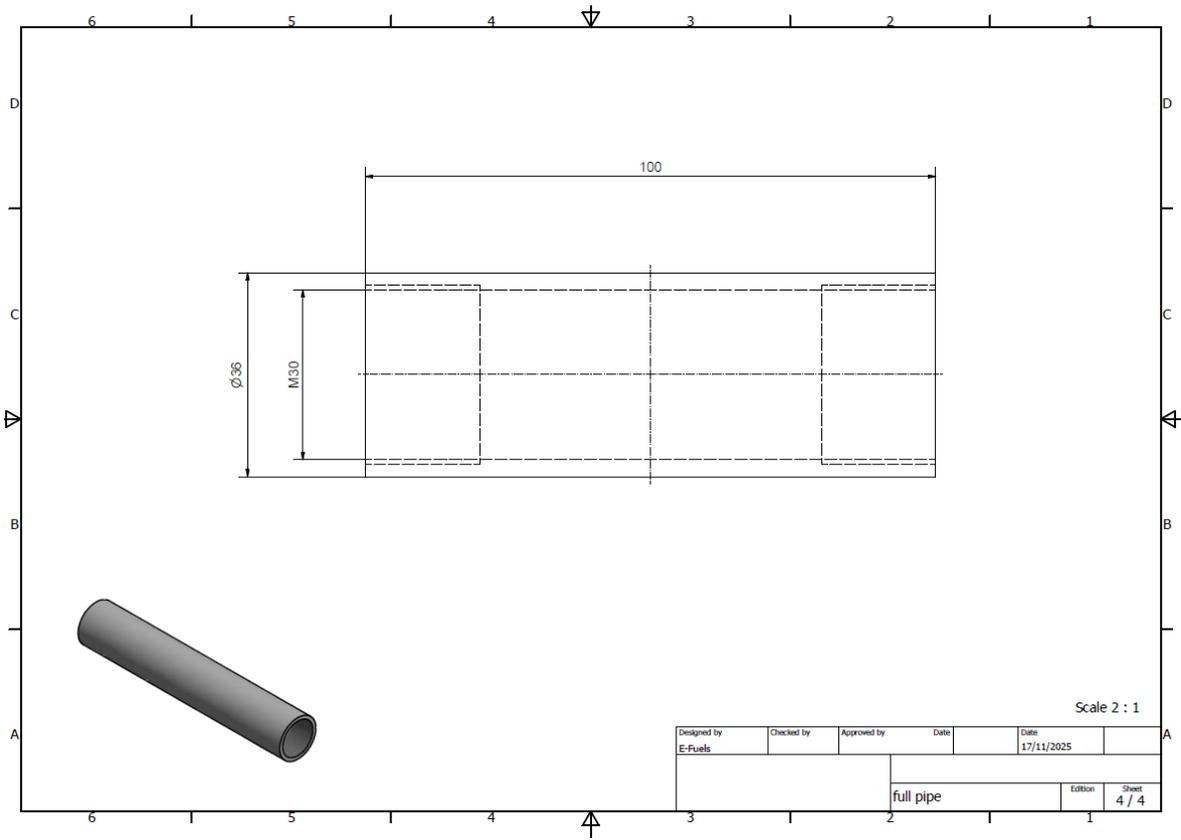
```
int mq4Pin = A0;

void setup() {
  Serial.begin(9600);
  delay(300000);
}

void loop() {
  int Methane = analogRead(mq4Pin);
  Serial.println(Methane);
  delay(1000);
}
```

### III. Pipe drawings





Scale 2 : 1

Designed by	Checked by	Approved by	Date	Date	
E-Fuels				17/11/2025	
				full pipe	
				Edition	Sheet
					4 / 4

# IV- Shopping list

Item	Amount	Price	Unit Price	Description/Comment	Delivery time	Delivered	Supplier / Link	Picture
1. Stainless Steel Tube (1m)	1	1000,00	1000,00	70 cm long, diameter 50mm, mm wall thickness. Compatible with H <sub>2</sub> and CO <sub>2</sub> / I needs threads on both sides Pressure up to 2 bars		NO	SOP-Metal Dy (Local supplier)	
2. syringes	2	17,32	35,84	100mm if possible / maybe in the lab they already have a supplier	1 week	Yes	<a href="#">link to item</a>	
3. Sodastream cylinder	1	32,30	32,30	We can buy it directly in Vaasa at multitronic shop		Yes	<a href="#">link to item</a>	
4. Adaptor / regulator for sodastream	1	47,19	47,19	The Amazon SodaStream regulator is a small pressure-control device that connects directly to a SodaStream CO <sub>2</sub> bottle to safely release and adjust the gas flow for applications like homebrewing or gas experiments.	1 week	Yes	<a href="#">Link to item</a>	
5. Co2 Storage	3	37,77	113,31	The Tedlar gas sampling bag is a chemically resistant, airtight container used to collect, store, and transport gas samples safely at atmospheric pressure.		Yes	<a href="#">link to item</a>	

6. Valve	4	24,77	99,08			Yes	<a href="#">link to item</a>	
7. Flexible tube	1	19,80	19,80	see-tought flexible 2m tube 20mm inner diameter > can be fit with zerflex collar	1-2 Week	Yes	<a href="#">link to item</a>	
8. Connector with thread 1 inch female	15	7,10	106,50		1-2 Week	Yes	<a href="#">link to item</a>	
9. Connector with thread 1 inch male	15	8,29	124,35	<a href="#">Back up item</a>	1-2 Week	Yes	<a href="#">link to item</a>	
9. Oil burner nozzle	1	10,64	10,64	We still need to find one with more standard thread or adapter	2-3 Weeks	Yes	<a href="#">link to item</a>	

10. Support for the tube 1 inch	1	19,85	19,85	need to elevate the tube 10 mm		Yes	<a href="#">Link to item</a>	
11. Support for the tube 2 inch	3	14,45	43,35	need to elevate the tube 10 mm		Yes	<a href="#">Link to item</a>	
13. 1 inch to 2 inch male	2	15,97	31,94			No	<a href="#">Link to item</a>	
14. 1 inch to 2 inch female	2	25,25	50,50			Yes	<a href="#">Link to item</a>	

<b>15. Heatingtape</b>	1	1615,00	1615,00	Because of the price we could still discuss about it. It is possible to buy every part on its own to get a lower price. But with this one everything is integrated in one product and it is the easy option in comparison with building one.	Yes	<a href="#">Link to item</a>	
<b>16. Pressure measurement</b>	1	155,30	155,30	300 degree max but we can't find one capable of more G 1/4 B (thead externe 13,16 mm diameter) for the tube hole	No	<a href="#">Link to item</a>	
<b>17. Temperature measurement</b>	2	8,99	17,98	Tutorial: <a href="https://tandemnerdtutorials.com/arduino-k-type-thermocouple-max6675/">https://tandemnerdtutorials.com/arduino-k-type-thermocouple-max6675/</a>	Yes	<a href="#">Link to item</a>	

<b>8. Cables for arduino</b>	2	5,99	11,98		Yes	<a href="#">Link to item</a>	
<b>9. Gas leakdetector</b>	1	185,74	185,74		No	<a href="#">Link to item</a>	
<b>10. Arduino</b>	2	16,99	33,98		Yes	<a href="#">Link to item</a>	

## List of figures

Figure 1: Picture of Nathan .....	6
Figure 2: Picture of Gijs .....	7
Figure 3: Picture of Maarten.....	7
Figure 4: Haber-Bosch process chemical reaction (Liang, 2019, p. 10) .....	10
Figure 5: A green ammonia micro-plant techno-economic analysis summary (Liang, 2019, p. 81, Table 7.2).....	11
Figure 6: Syncrude properties from the two main classes of Fischer-Tropsch (Odunsi, 2017, p. 11, Table 2.2).....	12
Figure 7 : Hydrocarbon selectivity as a function of the chain growth probability (Odunsi, 2017, p. 29, Figure 2.8).....	13
Figure 8 : Types of reactors (GEK Gasifier, s.d.).....	14
Figure 9: E-methanol process .....	17
Figure 10: E-Methanol to E-DME .....	19
Figure 11: E-DME process.....	20
Figure 12: Zeolites .....	20
Figure 13: ZSM-5.....	21
Figure 14: Scale of the Selection Matrix.....	26
Figure 15: Selection Matrix .....	28
Figure 16: Example of the design .....	30
Figure 17: Example of the design .....	30
Figure 18: Parameters of the experiment.....	31
Figure 19: Description of the catalyst used .....	31
Figure 20: Experiment results .....	31
Figure 21: Example of the design .....	33
Figure 22: Design V1 .....	33
Figure 23: Improved drawing Design V1 .....	34
Figure 24: Brainstorm session on the Design V2 .....	34
Figure 25: Drawing of the tube.....	35

Figure 26: Design V2.2 .....	35
Figure 27: Improved drawing of the design .....	35
Figure 28: 2L gas sampling bag .....	35
Figure 29: Regulator for the SodaStream bottle .....	36
Figure 30: Picture of a valve .....	36
Figure 31: Picture of the heating tape .....	36
Figure 32: Handheld gas detector .....	36
Figure 33 : Extract from the group shopping list .....	39
Figure 34: Purchase workflow .....	40
Figure 35: Comparison of the criteria's importance .....	40
Figure 36: Drawing of the prototype .....	42
Figure 37 : Estimated timeline.....	49
Figure 38 : Product separation improvement .....	51
Figure 39: Screenshot of the costs of the hydrogen plant .....	62

## List of table

Table 1: Stakeholders .....	8
Table 2: recap processes.....	25
Table 3: Max6675 connection .....	46
Table 4: MQ4 sensor connection .....	47

## List of resources

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