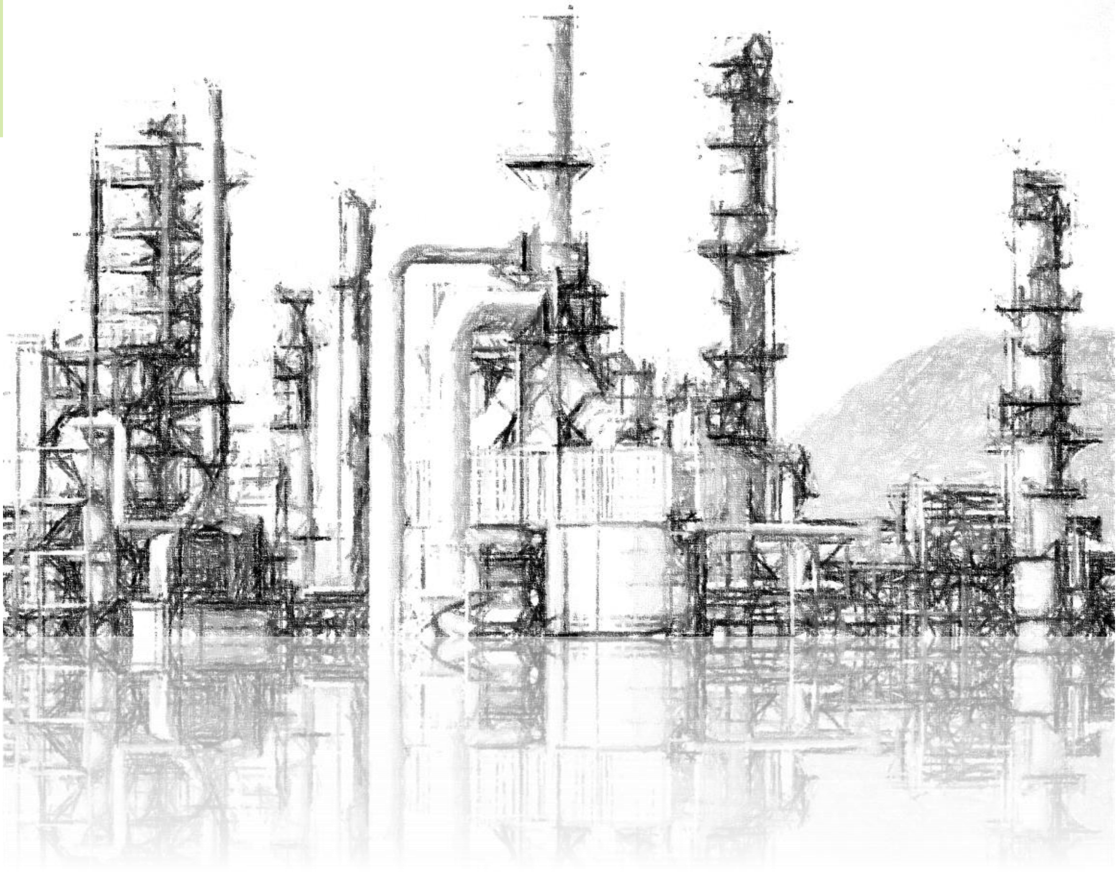
PIPE 4.0 TECHNOLOGY

CBI-ATTRACT PROGRAMME

Pipe4.0

# PROCESS-EYE

## FINAL REPORT



ATTRACT

CERN IdeaSquare

Pietro Fiorentini

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# Introduction

The Challenged Based Innovation (CBI) programme powered by ATTRACT EU[1] selected Process-eye team to develop different applications for the Pipe 4.0 technology.

Pipe 4.0 was originally developed by a consortium between the University of Padova and InanoEnergy as a perpetually functioning network of barometers and a central Raman Spectroscope to grant quality and safety assurance of fuel-gas distribution routes.

## Project & team

CBI-ATTRACT facilitates innovation through human centered design because it is strongly believed that to innovate beyond the technological scope different perspectives are needed. For this reason the project has been developed by a multidisciplinary team of 6 master students (listed below) with backgrounds ranging from soft sciences to hard ones. Thanks to this programme the team developed group dynamic skills such as communication, brainstorming, problem solving and time management.

### Who are we?


[1] In 2018, the European Commission (EC)'s Horizon 2020 Programme funded ATTRACT phase 1, which supported 170 breakthrough technology concepts in the domain of detection and imaging technologies across Europe. The projects were each granted €100,000 in seed funding to create a proof-of-concept.
See https://attract-eu.com/about-attract-phase-2/

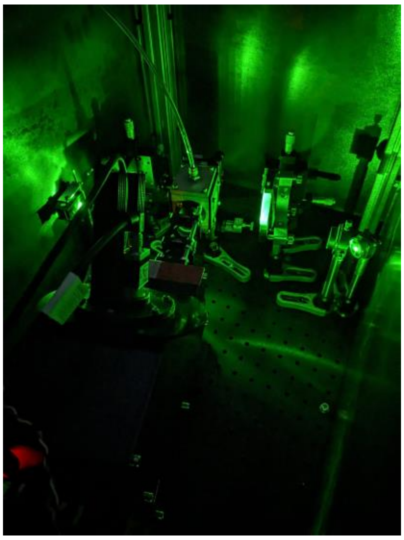
## Our technology and its implementation

The Pipe 4.0 technology [2]consists in a consortium between two technologies - Gas Raman Spectroscopy and Thermoelectric System - described and discussed in detail below.

- **Gas Raman Spectroscope by the University of Padova**

This consists in a novel form of Raman Spectroscopy capable of capturing the composition of gas mixtures through use of a 450nm (blue-light) laser diode and an industrial quality CMOS sensor, a special configuration for a reflective measuring chamber and a clear 10mm sampling pipe, which can be rerouted back to the main flow stream, being able to assess the quality of various gas mixtures without the need for sampling. This technology constitutes a reliable and affordable alternative to current methods[3] for the qualitative analyses of gas mixtures.

The main features of Gas Raman are being compact and lightweight, with low power consumption (1W normal, up to 3.5W) and ready to integrate into the internet of things (IoT). This technology has been implemented to calculate the heating value and mixture composition percentages according to the UNI EN ISO 6976:2017 standard (0.5% max error, 0.2% precision). It has been calibrated for natural gas, biogas, biomethane mixtures with or without hydrogen content and tested for operational temperatures between -20°C and 70°C.



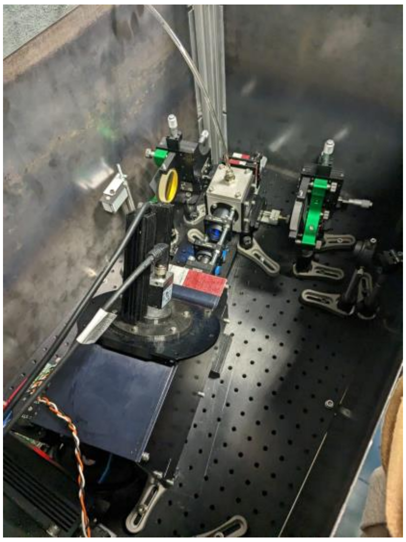


Figure 1 - Gas Raman Spectroscopy from CNR in Padua

[2] See https://www.pipe40-project.eu/
[3] current methods apply the Gas Chromatography.

### Tribo-thermoelectric system by InanoEnergy

The second component of Pipe 4.0 is the tribo-thermoelectric system designed for boosting the system-wide energy efficiency in a non-invasive way. This technology recaptures the heat dissipated through friction from harsh environment flows (up to 12000psi & 130ºC) and generates electrical power of approximately 1W in laboratory conditions which can be used to charge small sensors (10-100mA).

The tribo-thermoelectric technology is based on nanogenerators that work on a temperature or pressured difference between intra-pipe flows and the surrounding environment to facilitate an electric current.

Through the ventures of *InanoEnergy*, this feature has been extensively developed for multiple application fields ranging from *Water & Waste Management* to *Oil & Gas* initiatives making it a well-tested and well-established form of technology.

# Discover

(Tech Understanding)

## Divergence process and evidence collecting

Upon delving into the theory behind the technology in question, i.e. Pipe 4.0 and its fundamental components, the subsequent phase of our project was dedicated to ideating potential opportunities to reuse this technology. After this process, which we refer to as the divergence process, we proceeded to select the top five most relevant opportunities from our perspective.

Subsequently, we collected numerical evidence for the relevance of each of the chosen top-five opportunities' application fields and formalized the concrete problems that the Pipe 4.0 technology could address in the respective context for each field.

- ### Divergence process

The first part of this procedure, the divergence process, consisted of several principal stages. Firstly, we ideated all conceivable application opportunities and fields in which the Pipe 4.0 technology could be feasibly reused and collected them into a specially organized divergence map. This map is arranged in such a way that mentions of Pipe 4.0 technologies are placed in its center, and the farther from the center of the map, the more the mentioned ideas are related to specific fields of application.

To populate this divergence map, we conducted primary proofreading and research on the related problems in their respective industrial domains. The result was an extensive map encompassing 11 areas, including applications for both the Pipe 4.0 tribo-thermoelectric system and Raman spectroscopy technology. These areas ranged from using Raman spectroscopy to detect water in turbines to prevent corrosion, to employing tribo-thermoelectric technology for rocket fuel applications. The comprehensive divergence map is depicted in the fig.1.

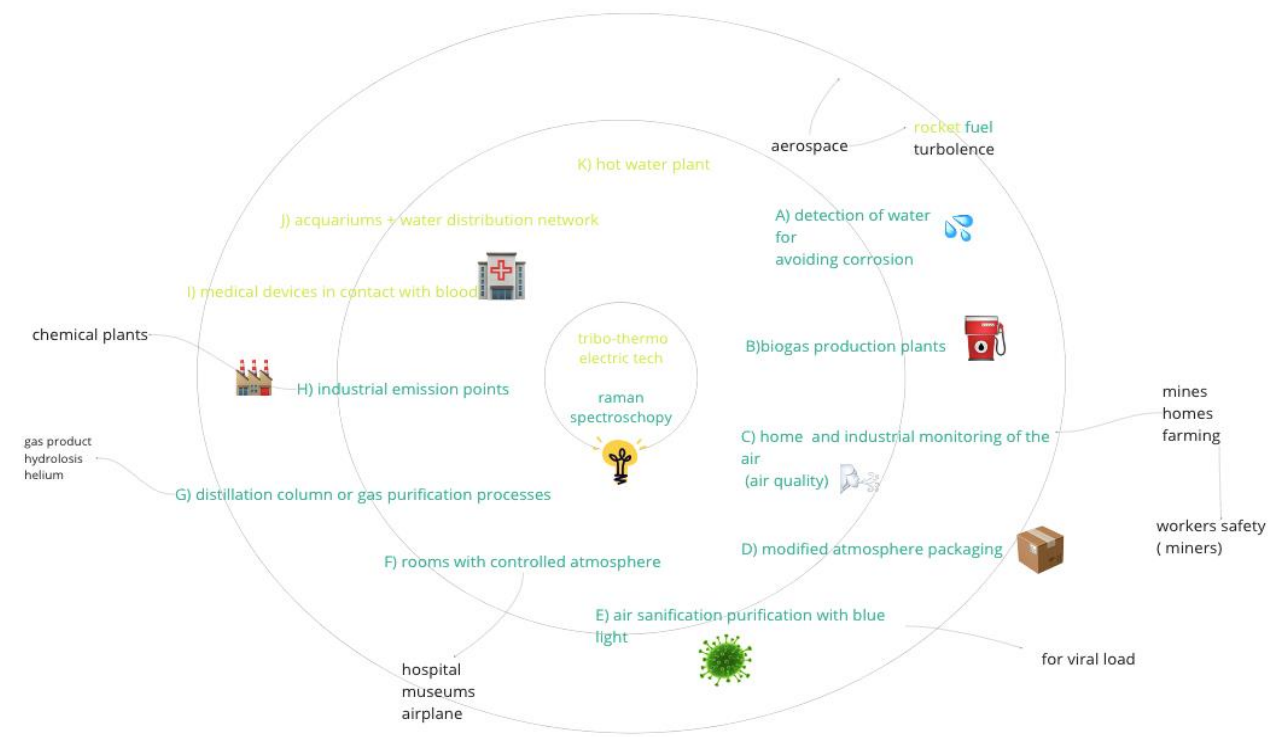



Figure 2 – divergence map

- ## Opportunities ranking

After plotting the opportunities on the divergence map, we ranked them based on their respective application fields' relevance and their potential to address specific problems in those fields. To do that, in addition to proofreading and primary analysis of the application fields, we utilized two additional tools: Sustainable Development Goals (SDGs) correspondence and the scenario framework.

The SDGs[4] are a set of 17 global goals established by the United Nations in 2015 as part of the 2030 Agenda for Sustainable Development, aimed at tackling poverty, hunger, environmental sustainability, and other pressing issues. By integrating the SDGs into our project's framework, we aimed to identify the key advantages of the selected opportunities from the perspective of these large-scale globally recognized goals.

The scenario framework, on the other hand, served the complementary purpose of evaluating the opportunities' relevance at a more specific level. This involved considering

[4] https://sdgs.un.org/goals

how users in various industries could leverage the Pipe 4.0 technology to their advantage. To establish a suitable scenario, we employed the *Need*/*Enabler*/*Experience*/*Outcome* framework:

- The *Need* identifies the users and the problems they faced in their industries;
- The *Enabler* represents the part of our technology that could be valuable to these users;
- The *Experience* explains how users could utilize the technology to address their needs;
- The *Outcome* describes the benefits users could gain from interacting with the technology.

For instance, in the case of the chemical emission control opportunity for the Pipe 4.0 technology, the users in need would be the technicians reporting industry emissions to their supervisor. The enabler for this opportunity would be acquiring specific data on the emissions utilizing the Raman spectroscopy technology used in Pipe 4.0. As for the experience and outcome, we could say that by using Pipe 4.0 the technicians could access precise parameters of interest, thereby automating the reporting process and gaining a better understanding of the emissions' environmental impact.
In this manner, our evaluation of the opportunities considered different levels: from addressing the global sustainability goals represented by the SDGs to focusing on specific user-scenarios and the problems our technology could solve for potential users.

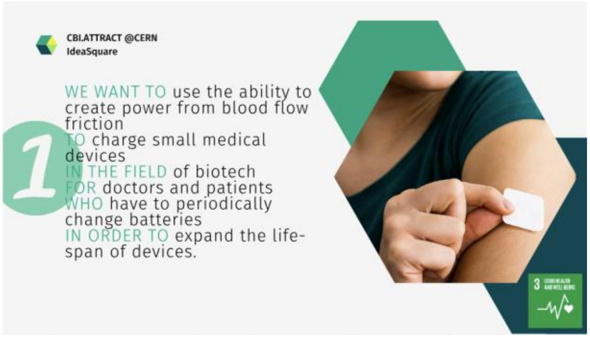
## Top 5 opportunities selection

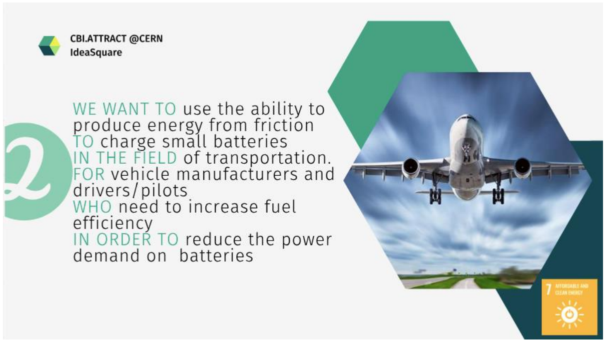
Following the evaluation and ranking of the opportunities based on the aforementioned criteria, we identified the top five most promising opportunities for the reuse of the Pipe 4.0 technology from our perspective:

1. Charging small medical devices using the tribo-thermoelectric system.
2. Charging devices in the transportation field using the tribo-thermoelectric system.
3. Assessing the composition and properties of the air in controlled environment rooms using Raman spectroscopy.
4. Monitoring specific pollutants to infer filter efficiency in factories, farming, households, and natural environments using Raman spectroscopy.
5. Assessing the quality of products and resources for industrial inspection using Raman spectroscopy.

To finalize this design process stage and select the five most promising opportunities, each opportunity was revisited and summarized using the Tech/Opportunity/Application

Field/User/Need/Benefit framework. This allowed for a more detailed elaboration of the opportunities' contexts.



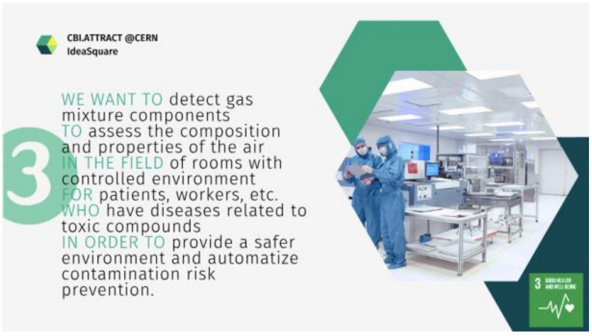






Fig.3-7- Selected opportunities summaries

## Evidence collection and problem formalization

The final step in converging to the five opportunities involved double-checking the selection through the lens of each opportunity's respective application field context. In this step, our aim was to collect concrete numerical evidence regarding the problems that our technology could solve in each application field. In this way we were aiming to evaluate the problem's relevance and urgency as well as to measure how feasible the solution would be using Pipe 4.0 technology. In the stage of the evidence collecting, as well as in the next stages of our design process, we tried to support our ideas and estimations by consulting

with the technological partners and our PhD mentor as well as by referring to scientific and industrial articles addressing similar issues.
For example, for the opportunity of using Pipe 4.0 technology in distillation, after researching the industry context, we discovered that the field is large to the extent of 3% of global energy consumption. The main source for our knowledge about the distillation technology opportunities throughout the evidence collecting process was an article by Anton A. Kiss[5]
As another example crucial for our design process, from the article "Sampling and detection of corona viruses in air: A mini review", largely comprised as a compilation of numerous articles on virus detection, we discovered that of five children admitted to intensive care unit, one child had acquired a viral respiratory infection – which proves an immense scale and importance of the problem in question.

Having collected evidence for each opportunity, we proceeded to formalize the problem in question and the opportunity of solving it with Pipe 4.0 by deriving primary numerical


Figure 8 – Pipe 4.0 at IdeaSquare @CERN during the collision week

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[5] "Distillation technology – still young and full of breakthrough opportunities"[

## PROS and CONS of the 5 solutions found

At the end of the Collision Week spent at CERN, our group managed to identify five promising applications where the use of Pipe 4.0 technologies could enable a radical transformation of the state of the art in their respective industries.
In this paragraph, we will attempt to delve into all the pros and cons of these applications, along with qualitative considerations of feasibility, desirability, and viability based on the knowledge available to us.

**Self-powered medical devices**

Our initial idea was to utilize one of the two provided technologies, namely the tribo-thermoelectric system, to power sensors for the detection of biological parameters, such as glucose monitoring sensors, which have gained significant popularity in recent years.
Given that the device can generate a current from a temperature difference, it could function seamlessly in contact with human skin, where the temperature rapidly transitions from 36 degrees Celsius to an ambient temperature of 20. Based on a review of the provided documentation, the idea appeared to be perfectly feasible, and the technology seemed ready for further studies towards potential implementation. The level of convenience it would offer to users would be tremendous, as it would eliminate the need for frequent sensor replacement due to battery exhaustion, resulting in significant battery savings and a positive impact on both the environment and the value chain.
However, the idea presented notable challenges from a prototyping perspective, and from the outset, it was evident that significant efforts would be required in terms of regulatory compliance to obtain approval for such a sophisticated instrument based on a technology that is still not fully mature in one of the most sensitive and regulated sectors.
Furthermore, we learned that the *InanoEnergy* research team, who conducted the study on the aforementioned nanomaterial, was already actively engaged in research involving the utilization of these materials in the production of medical devices. This news discouraged our team due to the concern of overlapping with them and the fear to start parallel research, potentially diminishing the value of our own efforts. At a certain point, we decided to abandon this opportunity and instead focus more on the technology being studied at the research center in Padua.
The technology could have been pivoted towards the wearable devices sector, but at that point, it would have lost competitiveness on the market, and the advantage over a battery-powered device would have been less clear.

**Tribo-thermoelectric system in the transportation field**

We have also considered that the same technology mentioned earlier could be used to harness small temperature gradients generated by the friction between a moving body and the surrounding air, for example. Our attention then turned to vehicles for human and goods transportation, especially where, given the speeds achieved, we could anticipate interesting temperature gradients for our purposes, such as automobiles, high-speed trains, and airplanes.

While this application may appear promising due to the readiness of the technology and its relative feasibility, as it aims to innovate a sector traditionally more open to innovation with fewer regulatory barriers, after conducting some calculations, it seemed that the thermoelectric material is capable of producing only a few watts per square meter under optimal laboratory conditions. These levels of power are sufficient to power a small glucose sensor but are entirely insignificant when applied to a vehicle that requires hundreds of kilowatts of power to operate. To conclude, this idea lacked viability.

**Environment quality control in clean rooms**

Regarding the technology of Raman spectroscopy, we considered its potential application in the field of environmental monitoring in closed environments where there is a need to control atmospheric composition, detect leaks, or identify the presence of organic and inorganic pollutants. The target market is vast, diverse, and the competitors often use more suitable technologies for specific purposes than ours. In order to explore this option further, we organized a call with the CEO of BAQ, a Switzerland-based company specialized in detecting radon in domestic environments. After extensive research, we realized that our technology could not compete with other methods of detecting gas traces.

Finally, we decided to focus on the problem of detecting the presence of bacterial or viral pathogens within a closed environment. We immediately recognized the potential of this market, which is vast and entirely unexplored. After experiencing a viral pandemic, it is clear that there is a significant demand for a device capable of providing real-time alerts of pathogen entry into a room. The need is evident, and the potential for returns is high, but the technical feasibility of such a project required further discussions.

**Pollution control in mines and other human activities**

Given that our technology is capable of analyzing the composition of gas solutions, we also considered the possibility of collecting data on atmospheric emissions. We chose mines primarily due to their significant impact, as the gathered evidence shows that mines are among the largest emitters of greenhouse gasses. Additionally, within this context, we are solely interested in gasses and not in other volatile organic compounds in small quantities. If, on the other hand, we were to focus on other human activities where the main emphasis was on human health, such as detecting pollutants in industrial and agricultural settings, dangers in hay barns or odors in urban contexts, our technology would have been less reliable than its competitors in detecting small gas concentrations with much greater precision.
In mines scenarios, instead, we saw a great opportunity to make our technology helpful in collecting data both for monitoring mine safety and understanding the environmental impact of these locations on the planet's system. This solution proved to be quite intriguing 12 as the technology was theoretically ready for potential implementation in this field, and the positive impact was evident and easily explainable to the stakeholders involved. Regarding this hypothesis, we have received great assistance from our affiliated PhD, Mariasole Cipolletta. Her advice has been truly invaluable in understanding the complexity and scope of the mining emissions problem, and regardless of the outcome of our research, she has informed us of the current urgency for a solution to this issue. Unfortunately, the limited capability of our technology to detect small gas concentrations narrowed our market to only closed mines, excluding open-pit coal mines, which constitute the vast majority of coal mines in Europe and worldwide. Thus, it was uncertain whether Raman spectroscopy was the best solution in terms of versatility and adaptability. Moreover, doubts arose regarding the ease of selling a product that provided data from a specific site on which no intervention could be made. We were also unsure whether those data would provide researchers with a more accurate understanding of the quantitative methods currently used to estimate emissions and construct models

**Process control in industrial plants**

The final option pertains to real-time monitoring of industrial processes involving the use or production of gasses. In the industrial context, we identified several processes in which monitoring the composition of a gas in a confined environment is crucial for product quality and process control. Once again, we extend our gratitude to Mariasole for her invaluable assistance, which has allowed us to navigate through uncharted waters of opportunities. Her advice has been truly beneficial during this exploratory phase and in the subsequent stage of selecting the investigated opportunities. Some examples of these processes include:

- Modified atmospheres for food preservation

- Modified atmospheres for inertization of substances for safety purposes or prevention of deterioration
- Monitoring of atmospheric composition in ovens where thermochemical treatment processes occur
- Monitoring the composition of hydrogen-containing gas for future pipelines
- Control of distillation and purification processes in large chemical plants.

By delving deeper into the potential applications of our technology in these fields and analyzing the various industries that could benefit from it, we immediately realized that there was scientific literature attesting to the need to make processes more efficient and competitive. Moreover, we found a significant number of stakeholders interested in flexible or customized solutions, as well as a strong capital-intensive nature characterizing the analyzed sectors, which led us to consider a greater availability of capital to be employed in improving these processes. 13 Among the aforementioned opportunities, we decided to remain open to each of these possibilities for the time being, awaiting feedback during our visit to the research center in Padua. However, we decided to temporarily focus on the application related to the chemical sector, excluding the first three as it was unclear where in the production and distribution chain a tool monitoring and controlling the composition of such atmospheres could be placed. In the production phase, meticulous gas control upon entry might not be necessary, and it was uncertain whether there was a need to monitor atmospheres during transportation for products with lower value. Moreover, we were not certain if our technology was reliable enough to handle the control of inert atmospheres for highly hazardous products. Lastly, we chose not to further explore the field of hydrogen transportation due to the fact that it was already covered in the assigned tech card. Therefore, we decided to direct our attention towards sectors that were still relatively unexplored.

At that time already, the chemical processes of purification and distillation appeared to be an optimal industry to further our research. In fact, it requires huge energy inputs for its operations and involves significant capital investments. The potential added value by a technology like ours could have been significant.

Figure 9 - Pipe 4.0 team at the *Universe of Particules* @ CERN

# Design

(Critical Prototypes)

## Desirability analysis

The aim of the second part of the project was to select just one opportunity field to address in order to develop our final product. The choice was between environmental quality control for bacterial or viral pathogens in clean rooms and process control in industrial plants, specifically in distillation columns for the aforementioned reasons. To make an informed choice we sought validation for both fields on the market. The idea was to find out if there was an actual need for our technology and, if so, which were the specifications needed.
During this phase of the project Mariasole was a big help to us. By sharing her thoughts, she gave us a professional opinion about what was needed for the validation in the different fields, for example she suggested to make a comparison with other already existing instrumentation. She also supported us in the research by asking some questions to her colleagues working in chemical plants.

**Distillation columns**

Distillation columns are complex processing sites because the product of one unit serves as the feed for other, consecutive steps. Any deficiency in one of these stages will immediately affect the entire production chain. The efficiency of distillation units in chemical plants is highly challenged by the ability of optimizing the process conditions, which means:

- Minimizing the influence on the production capacity and distillate quality of changes in the initial feed
- Maximizing the production of high value distillates. Overlapping characteristic boiling ranges exist between neighboring refinery fractions and being able to precisely control the cut points is key to increase the profit.
- Maximizing the stability of the equality of each product throughout the whole distillation process
- Minimizing the production of off-spec materials and the need for reprocessing.

This was the reason for us to look at distillation columns monitoring and find that nowadays the entire procedure is regulated through gas-chromatography. This technique is used to separate and detect chemical components of a mixture to determine their presence or absence and/or quantities. Gas-chromatography is usually performed in a laboratory and requires a sample. This means that it is impossible to know what is going on at each level of the column while it is actually occurring due to the waiting required to carry out the analysis. Thereby we concluded that a full and real-time monitoring of the incoming feed and outgoing distillate is a necessity to increase efficiency and profit by producing the required range of distillates at maximum yield and at minimum cost. This would produce an impact in terms of responsible production by avoiding materials and energy waste as well as in terms of economic growth.

**Intensive care units**

An intensive care unit is an equipped area of hospitals dedicated to the cure of patients with life-threatening illnesses, injuries or complications. The challenges of maintaining such environments safe for people with immune deficiency are many, most of which related to the need of isolating the patients to prevent the spreading of infections. Our consciousness about airborne viruses has risen in the past years, especially after the COVID-19 experience. The pandemic has brought to the scene how the lack of space to allocate people during convalescence is an extremely felt problem in many hospitals. Most of the time people are separated only by a simple curtain, with no additional protection. The analysis of the current situation in hospitals and interviews with some of the nursing staff made us feel the urgence of a device able to detect possible infections spreading through air as it would help in buying time to save lives.

**Outcome**

Choosing between these two opportunities was challenging because both looked promising. What helped us in the decision was talking with the research group in Padua. The experience began with a warm welcome and some lessons to dig deeper into some topics related to our research. Professor Alberto Bertucco provided an overview on climate change, Donatella Banzato let us in the world of biomethane manufacture and usage, Elena Barbera instructed us on renewable methane and liquefied natural gas production, while Luca Poletto, director of the National Research Council, guided us through the different kinds and applications of spectroscopy with a particular emphasis on Raman.
In the afternoon Lorenzo Cocola also gave us an insight on how Raman spectroscopy actually works and led us through some of the projects that have been carried out at the CNR laboratories. Furthermore, during our stay we were pleased to find out that many of the applications we had dreamt of were actually being implemented. In particular, we had

the amazing opportunity of visiting one of the facilities of Pietro Fiorentini and a new start up called FT System[6].

At Pietro Fiorentini we talked a lot about hydrogen ($H_2$) as they are working on a solution to use it in the existing gas distribution network as a renewable source of energy. In fact, $H_2$ can be produced by electrolysis starting from water. However, the research team wasn't really thrilled by this project because of the low efficiency of the production process (around 30-40%) and also because the amount of energy that $H_2$ supplies per unit of volume is lower than the one of gas and biogas. Upon these findings we were glad to have not pursued our investigation in this direction. At FT System instead we were delighted to learn that they had already made reality our intuition about food packaging. They created a device to effectively check the composition of the atmosphere inside a diverse range of products, from wine and drinks to vacuum-sealed cheese and yogurt. This is extremely important to avoid the spoiling of the product ahead of time and as a control for product quality. They are also able to detect leakages, which is important for the integrity of the different goods. This experience had a huge impact on our work, so we want to thank the whole research team for mentoring and supporting us.  Especially when it came to share their point of view on the opportunity we selected to go further with the project. They were really thrilled about our ideas, but also pointed out some complications. For distillation columns the main concern was about the calibration of the instrument which would have to be adapted to every single kind of refinery, based on the products being produced. While, when it came to intensive care units, they suggested that the classic Raman spectroscopy may have not been the best method to carry out an analysis for really small particles and that the micro-Raman may have been more suitable. They also hinted that there probably would have been many regulations to look into before being able to operate in an environment such as a hospital. For these reasons and because of the limited amount of time we had, at the end we decided to proceed with the process control in industrial plants, specifically applied to distillation columns.

[6] https://www.antaresvisiongroup.com/beverage/it/


Figure 10 - Pipe 4.0 team at the *Hydrogen Innovation lab* in Fiorentini Spa

# Develop

(proof of concepts)

The final part of our project was focused on the further development of the distillation opportunity, selected as the preferred one. We investigate more about the marketability, desirability and feasibility of our idea, and we customize our research on the user experience, since we wanted to come up with a human centered solution.

First of all, we built a prototype called Process-eye, i.e. the name of our new product, powered by Pipe 4.0 technology; secondly we defined how the user will interact with this new product, and how his work can benefit from it.

## Ideation of the prototype

The challenge we faced was about building a simple but functional prototype: the core of the prototype project was to explain the installation of the Process-eye device in a distillation column and describe the user experience.

**Concept**

The aim of our prototype is to deliver:

- The information on the installation of Process-eye on a distillation column;
- The versatility of our solution since it can be calibrated for different gas mixtures and process monitoring;
- The easy retrieval of data since it is IoT-implemented.

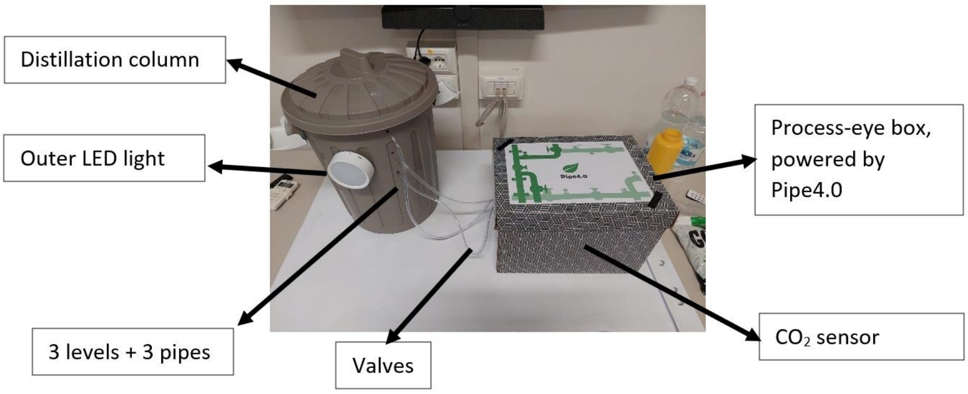



Figure 11 - Schematic explanation of the protype

## Realization

We built a distillation column as a starting point: it is made of a bin with 2 LED lights (one inside and one outside) and 3 holes. The LED lights can make transitions between different colors, and each color means a gas made in the distillation process that will be monitored by Process-eye, such as carbon dioxide, nitrogen, hydrogen, methane, butane, propane... In this way the public knows that there are different gasses inside the column, but still doesn't know anything about the concentration (or other parameters) of these gasses at each of the 3 levels of the column, symbolized by the 3 holes.
Then, there are 3 different pipes, each one with its own valve, coming from these holes: the pipes inject the gasses inside the Process eye-box (and virtually recirculate it through a feedback loop – this is one of the possible implementations of our prototype and solution).

Now let's have a look inside the distillation column first and then inside the process-eye box. Inside the distillation column we put 2 different containers, in which we mixed different amounts of two solutions to make a reaction and create different concentrations of gaseous $CO_2$. The aim was to explain that we can have different concentration values at each level of the distillation column, and thanks to the Process-eye technology we can have real time data on what is occurring inside the column itself. In particular, in this prototype we focused on $CO_2$ production, since it is one of the easiest gas to make and it is not harmful (so we used a $CO_2$ sensor inside the Process eye box to measure it).
We want to point out that this is just an explanatory test, and the real Process-eye technology is actually able to measure all the different gasses mentioned above.

We made the $CO_2$ gradient lower at the bottom and higher at the top of the column:

- First level from the bottom: pipe 1 is connected to the atmospheric $CO_2$ contained inside the bin, so we expect to have a $CO_2$ concentration of about 400 ppm;
- Second level from the bottom: pipe 2 is connected to the smaller container, in which we mix a small amount of the two solutions, so we expect to have a higher $CO_2$ concentration than before;
- Third level from the bottom: pipe 3 is connected to the bigger container, in which we mix a big amount of the two solutions, so we expect to have the highest $CO_2$ concentration.

The solutions are made of:

- Solution A: mix of citric acid and water;
- Solution B: mix of bicarbonate and water.

We used the 3:1 ratio (3 parts of bicarbonate : 1 part of citric acid), and this reaction make gaseous $CO_2$:

$3NaHCO_3 + C_6H_8O_7 \rightarrow 3H_2O + \underline{3CO_2\ (g)} + Na_3C_6H_5O_7$

Bicarbonate + Citric acid → Water + Carbon dioxide (gas) + trisodium citrate

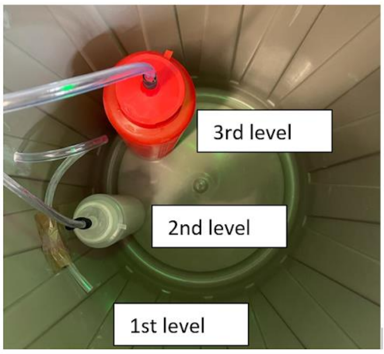



Figure 12 - Inside the distillation column

Inside the Process-eye box we collected the 3 pipes coming from the different levels in a hermetic bag, where there is the $CO_2$ sensor. It is important to create a closed environment to assure that the variation of $CO_2$ concentration can be easily and quickly measured by the sensor. Once the set-up is finished, the Process-eye box can be closed, and the user can read and collect the data using his smarthone or laptop, thanks to the bluetooth connection to the sensor. As before, we want to point out that this is a simplification of real technology, which uses the IoT to share data.

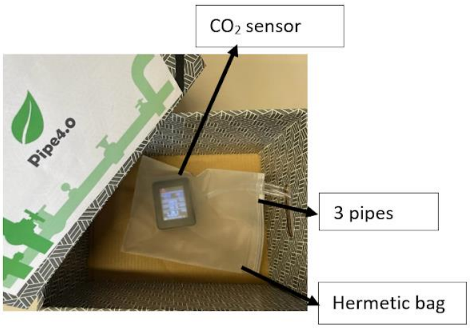



Figure 13 - Inside the Process-eye box

## Functioning

Following the steps listed below it is possible to run different experiments with this prototype:

- Make sure that everything is set up properly, as described above;
- Mix different amounts of solutions A and B in the bigger and smaller containers, and close them firrmly, in order to avoid gaseous $CO_2$ dispersion in the bin;
- Open the valve related to the selected pipe;
- Read the data from the sensor app.

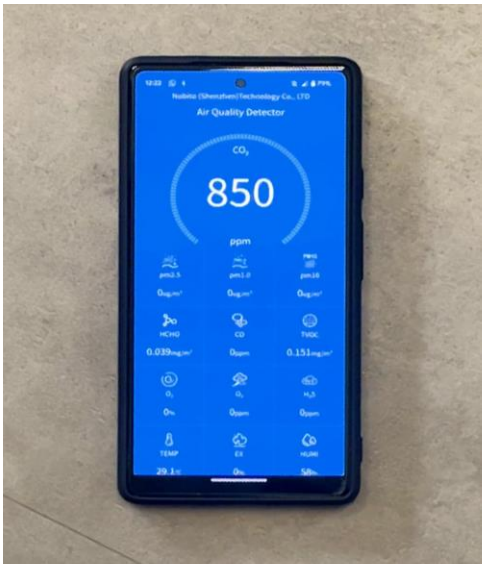



Figure14 – screen of the sensor app

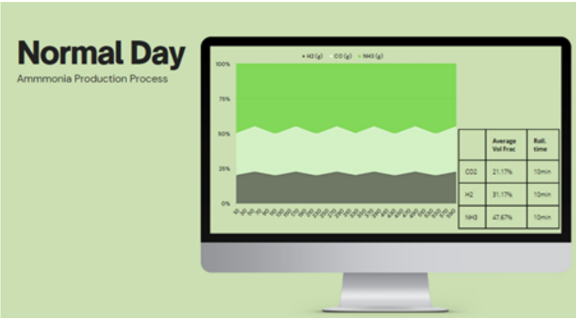
If you want to see what is gooing n in another key stage of the distillation column, you can:

- Close the valve;
- Open the Process-eye box and the hermetic bag, in order to bring back the measurement to the atmospheric $CO_2$ concentration;

- Set-up the Process-eye box again, open the other valve and get the new measurement.

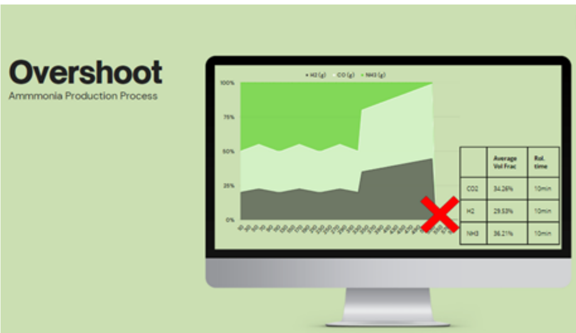
### Final user experience

To make the user experience more realistic and tangible, we created examples of graphical interfaces, as the ones shown in pictures.




On a normal day, the gas composition stays the same over time: it can oscillate a little bit, which is the normality in a chemical process, but largely remains consistent.


In the maintenance, you can see the composition levels trending towards a different level, so you know when the critical level is reached and where to perform maintenance.




In the overshoot phase you can see when the composition levels are suddenly trailing off, so you can anticipate a shutdown protocol, in order to contain possible damages to the plant and lose production.

These interfaces can be implemented by customizing the graphs on the specific gas mixtures monitored in the specific processes: we thought that it could be useful to navigate from the graph related to one gas to the other, or to compare the two using a specific programme, or having a visual or acoustic alarm if some values are dangerously different from the expected ones.

## Student Project Expo

We had the chance to show our work about the Process-eye solution and prototype in the Student Project Expo, which took place on the University of Bologna campus.
In this event, on one hand we had the opportunity to have a pitch presentation and to set up a booth with our prototype in action, on the other hand we met international students working on similar Eu-founded project ( such as Sugar[7]): we shared ideas and energy, learning from each other. Here there are some shots from that day:


Sx: Exchanging ideas about Process-eye with international students and professors.
Dx: Process-eye prototype in action on our booth.

As shown in these pictures, we completed our booth showing some posters and flyers to make the understanding of our problem statement easier and catchy, in order to shine the value embedded inside the solution proposed.

[7] https://site.unibo.it/idea/it/la-nostra-idea/attivita-e-iniziative/sugar-network

# Conclusion

During this journey lasted for 4 months we've seen how our team studied different fields, brainstorming and diverging at the beginning to come to a converging thinking. Thanks to this process the team members developed both hard skills (understanding the technology and its implications) and soft skills ( working together, having a healthy professional communication, solving problems and finding solutions for the prototype experience ).

Pipe 4.0 team had the opportunity to work with a technology present in the market that can tackle a real world problem making the distillation quality control easier and faster. The efficiency of the control of the gas flow would improve not only the final products but also the process per se. Indeed, thanks to the technology of Process-eye, the chemical plant would benefit of several advantages over the competing technologies:

- Saving time: Real time data (measurements every 1-10 sec) instead of the 10-20 min analysis required now;
- No waste of product to analyse it: no sampling is needed, the control can be done directly in the pipe without extracting the gas mixure;
- Flexibility: it can detect different components with just one measurement;
- Simple: Process-eye is enough to make measurements, there is no need to build a lab in the chemical plant;
- No wastes of material: it is possible because environmental conditions are accurately defined;
- Easily accessible data: the technology includes a device that is already IoT ready.

CBI-ATTRACT programme represented for the students an alternative approach to study innovation, different from the common university methodology, based on theoretical study. We put in practice what we learned, we had the chance to see in presence the partners collaborating with the project in Padua. Thanks to this feature of the project, Pipe 4.0 team gained an enriching experience that we hope it's just the beginning of something new to implement together with the research team.

### Next steps and future plans

The distillation is used in many fields, ranging from water purification to pharmaceutical industries. Referring just to the national (Italian) market, we find more than 5000 chemical plants only in the pharma sphere

Considering the several market outlets, Process-Eye team strongly believe that it can find an application in the real world. Its implementation would require a 5k budget for the technology per se plus the installation costs and some adjustments ( such as connecting the valves to the Process-eye).

Given its flexibility, Process-eye can be implemented in different chemical plants as long as a modification to the calibration is made. Indeed, the calibration software is what is nowadays lacking in our technology and it should be done differently according to the chemical plant chosen for the installation.

After the 3rd milestone we received promising feedback from the team of Padua: they are already negotiating with an Italian multinational energy company in order to install the technology in their chemical plants. We were glad to hear that our final solution was already circulating in the market and we are ready for further future projects together.

# Thanks

Finally, we would like to thank the CBI ATTRACT organization for making this opportunity possible. Thanks to Almacube for handling the programme, especially thanks to our coaches Eleonora Musca and Lucia Monti for the constant guidance in the project and for the activities planned for us. And, of course, thanks to our team coach, Elena Colombo, who guided us along this journey. She helped us especially through the SGMs, during which we got clarifications about the deliveries, and in connecting with the research team from Padua. We're happy to had the opportunity to work with students from other universities, for this reason we thank the collaboration between Bologna, Modena e Reggio Emilia, Ferrara Universities for developing such project. Thanks to the professors Matteo Vignoli, Bernardo Balboni and Giuseppe Mincolelli for their precious feedback before every milestone. Lastly, more related to our project Pipe 4.0, we would like to thank the research team in Padua, especially professor Alberto Bertucco, for hosting us and giving all the support and information needed to develop the project. For the same reasons we're thankful for having Mariasole Cipolletta as our PhD, for her expertise knowledge and support given to us through these months


And remember that..

*WITH PROCESS-EYE YOU'LL NEVER BE BLIND*