ADVANCEMENT DOCUMENTATION

Team Avogadro – Term Project 2023

Member: Bilal Younis, Juan Fernado Rua Arce, Linnéa Desaulty, Thuy Trang Dao

LINKÖPING UNIVERSITY

Bilal Younis, Juan Fernado Rua Arce, Linnéa Desaulty, Thuy Trang Dao

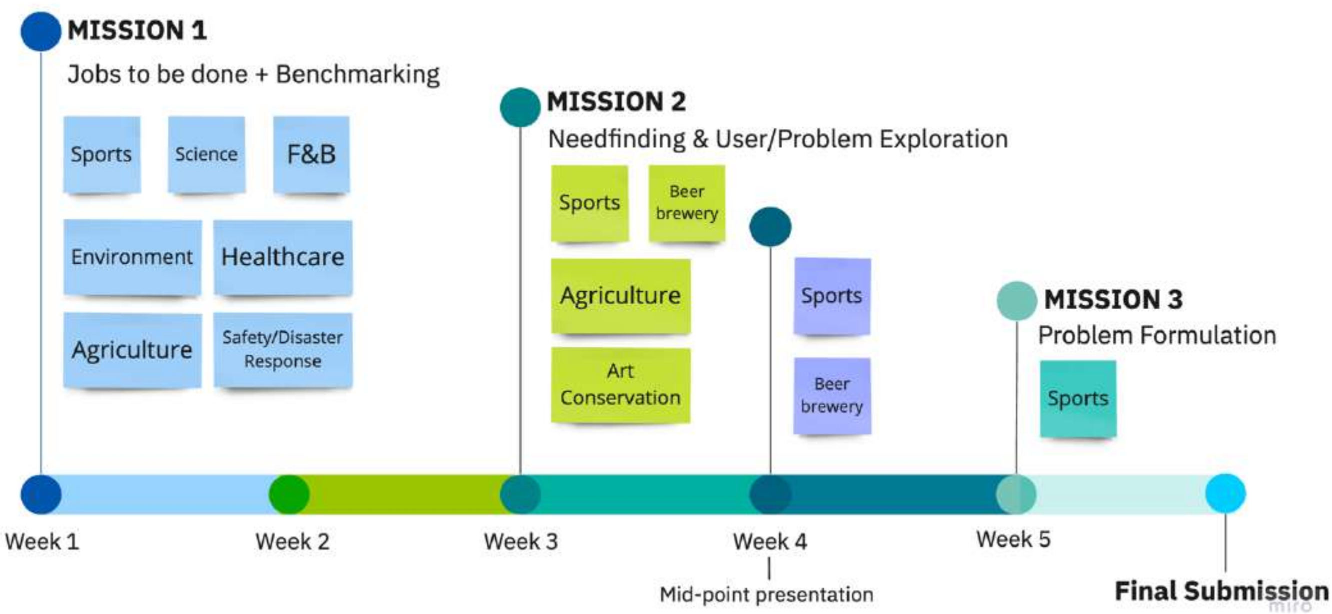
Term Project – Pipe 4.0

Table of Content

Preface

Students can learn a lot by working together on a project, including how to communicate effectively, operate as a team, and solve problems creatively. We are a group of four students working together on this project, and we all bring something special to the table. The project's timeline, which is estimated to be roughly five weeks, is the single most important factor. We start out knowing absolutely nothing about PIPE 4.0 or Gasraman. It was challenging at first because nobody on our team has an engineering background, but we eventually figured it out. These concepts have been developed and perfected over time, and we are honored to have the chance to share them with you.

In the first week, we started our journey by generating ideas as a group, and now we're working on a number of fronts, including environmental protection, agricultural output enhancement, the safe management of hazardous materials, and landfill waste reduction. The objective is to generate a flood of thoughts. Even though there are several leads we have collected by the end of 2nd week, when we compare them to the state-of-the-art technology in the field, we have to exclude quite a few of them. We have no doubt that some of the current technologies are succeeding admirably and that the people in indicated fields are happy with the current offerings. After much deliberation, we finally presented our top four study hypotheses to the Attract team by the end of the third week. Our ideas were well received by the Gasraman development team, and we were directed to concentrate on two possible applications: the use of Gasraman in the brewing industry, and the control of athletes' physical fitness which is our main in fourth week to study this area in more depth and find out which one is more attractive. The Sports Industry and Gasraman's potential role in it has been our focus at the end of the project.



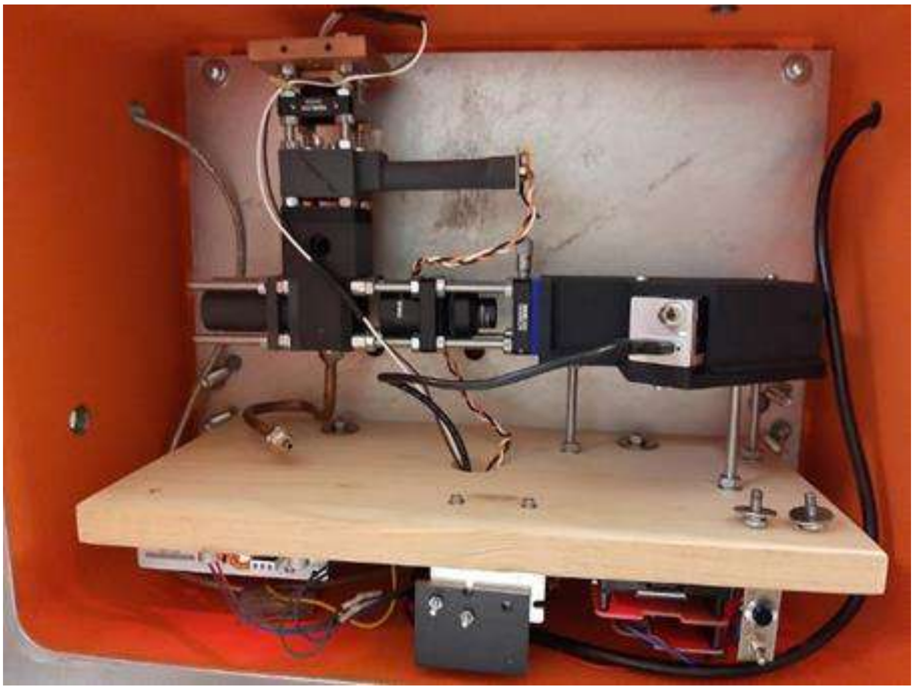
I. Mission 1: Jobs to be Done

1. About the Technology

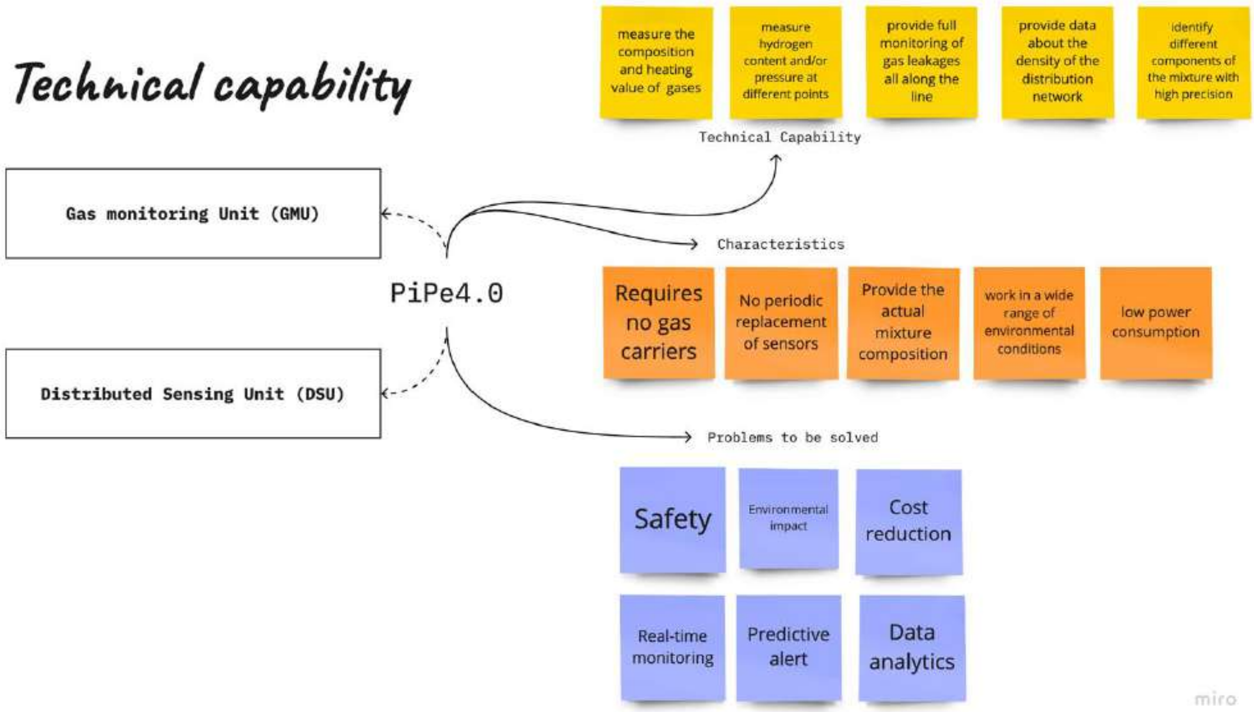
1.1. Technology details and its characteristics

Raman spectroscopy is a highly effective method for detecting and characterizing a wide range of gases. This method can be applied to the study of both liquid and gas samples without causing any harm to them. Raman spectroscopy is a technique that uses the scattering of light caused by the interaction of light with materials. The initial step in the operation of a Raman sensor for the measurement of flammable gases would be to subject the sample of gas to a laser source. The interaction of the laser light with the gas molecules would result in the gas molecules vibrating and producing an individual Raman spectrum. After that, this spectrum would be evaluated to identify whether or not the sample contains combustible gases, as well as the concentration of those gases.

Raman spectroscopy has various benefits when applied to gas analysis. To begin with, this method does not involve destroying the gas sample in order to analyze it. Because of this, it's perfect for uses in which preserving samples is crucial. Second, the Raman spectra of various gases can be used to differentiate between them, making Raman spectroscopy a very selective technique. Last but not least, Raman spectroscopy is a fast technique, with data available in real-time, making it well-suited for uses that call for speedy examination.



1.2. Technical capability



For the diagnosis of flammable gases in industry, the GASRAMAN project created a prototype Raman multigas analyzer. The design's **simplicity, low price, and high quality components** make it ideal for a large customer base. The tool can reduce carbon emissions from the natural gas (NG) and improve energy efficiency. By converting biogas to biomethane and transporting it through already-built pipelines, the process' effectiveness and energy supply can be greatly improved. Electric power plants, automobile or other industries could all use combustible gas as an energy source in the future. NG mixes, biogas, biomethane, hydrogen, and contaminants can all be measured with the GASRAMAN instrument, making it ideal for use in a smart energy network. The device has a low power requirement, thus it can be used in uninhabited locations with just solar panels and a few small batteries. As a steady, non-contact method, the sensing equipment can detect nitrogen, hydrogen, and other gases in the medical gas, life support, and chemical process control industries.

1.3. Which problems it could solve?

- Provide predictive maintenance and alert operators even in **remote locations and harsh environments.**
- **Safer** management of gas distribution (of both natural gas and biomethane, as well as hydrogen) and the related infrastructures.
- **Environmental impact:** Improvement of air quality by reducing pollution due to fossil fuels (coal and liquid fuels derived from oil) and their combustion.

- **Cost reduction**: reduce the cost of biogas production by optimizing the process and reducing waste. It could also lead to the reduction of market prices of energy, based on renewable methane and hydrogen.
- **Real-time monitoring**: provide real-time monitoring of key parameters such as temperature, pH, and gas composition. This allows operators to optimize the process and ensure that biogas production is as efficient as possible.
- **Data analytics**: generate **large amounts of data** that can be analyzed to identify trends, patterns, and areas for improvement.

1.4. How has the technology of these jobs evolved?

Usage of workers -> Single-gas sensors -> Remote sensors with cloud-based technology

Gas detection is a crucial aspect in ensuring safety in various industries such as manufacturing, oil and gas, mining, among others. The evolution of gas detection technology has taken a leap from traditional methods of detecting gas leaks to modern-day sensors.

Traditionally, the detection of gas leaks relied on **workers** such as miners and oil rig workers to detect the presence of gas by smelling, tasting, or visually inspecting for signs of gas leaks. These traditional detection methods were not reliable, putting the workers' safety in danger. As a result, technological advancements have led to the development of more accurate and sophisticated gas detection products.

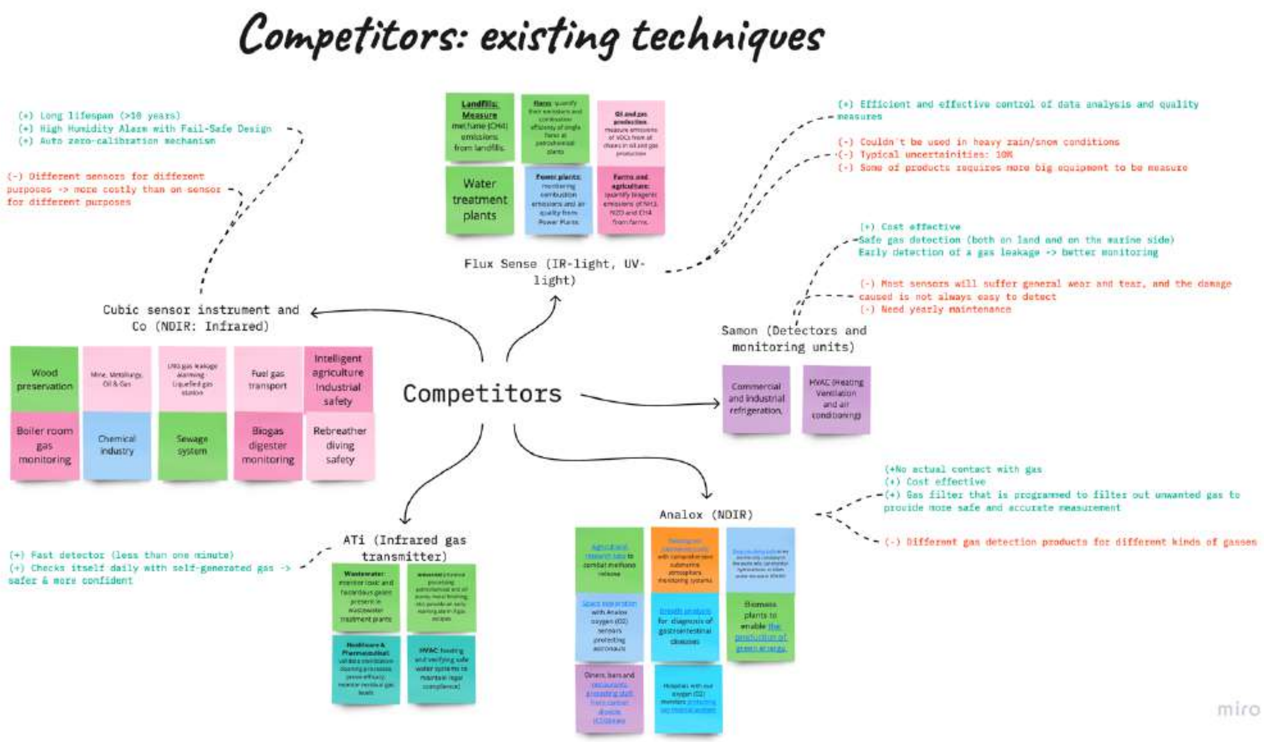
The evolution of gas detection has come a long way in the past decades. Early gas detectors were bulky, large, and required a lot of power. However, the invention of semiconductor technology in the 1970s led to the development of **smaller, more portable detectors that required less power**. These early detectors were based on **single-gas sensors**, which could be used to detect a single gas leak. However, the development of multi-gas sensors made it possible to detect more than one gas at a time, hence increasing the accuracy and reliability of gas detection. [1]

Moreover, the invention of wireless networking technology led to the development of **remote sensors**, which are essential in remote monitoring and control of gas in industries. Modern-day gas detection systems are equipped with **cloud-based technology**, which allows for centralized monitoring hence simplifying the maintenance and management of gas detection systems. The importance of gas detection in ensuring safety in industries cannot be overemphasized. Gas detectors are used to detect a wide range of gases, including toxic gases, combustible gases, and asphyxiants, among others. Gas detectors play a critical role in preventing gas-related hazards such as fires and explosions, which could result in loss of life, destruction of property, and damage to the environment.

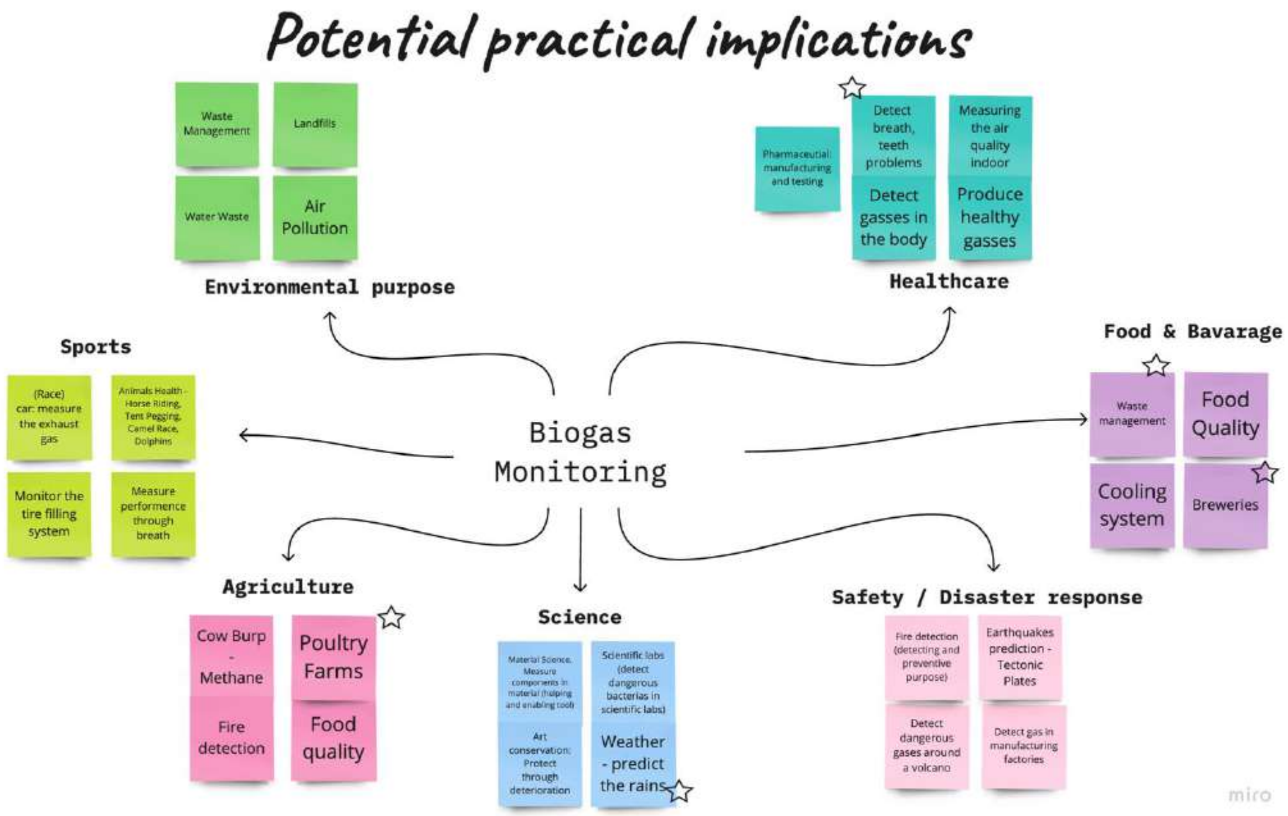
---

[1] DOD Technologies. (2021, March 5). The Evolution of Gas Detection. DOD Technologies. https://dodtec.com/news/the-evolution-of-gas-detection.html.

1.5. Competitors



2. Potential Practical Applications



2.1. Environment

Areas	***Practical Applications***	***Invented Workaround***
Waste Management	Detect and determine the quantitative composition of compounds comprising odour -> measure the concentration of a single odorant and its odour threshold	• Ultrasonic sensors • Olfactometry • IR (Infrared) thermography
Landfills	• Measure the Methane and CO2, monitor the gas production in landfills • Gas analysis to identify the most effective extraction points and adjust the flow rate of gas to maximize recovery.	• Air dispersion modeling • IR sensors • Electrochemical sensors
Water Waste	Monitor toxic and hazardous gases present in wastewater treatment plants	• Microfiltration, ultrafiltration, nanofiltration, and reverse osmosis • ozonation, UV/hydrogen peroxide • IR gas transmitter
Air pollution	Detect and measure concentration of harmful emissions in environment/manufacturing factories	• Fourier transform infrared (FTIR) spectroscopy • Optical remote sensing (ORS) • Ultraviolet-visible (UV-Vis) spectroscopy

2.2. Healthcare

Areas	***Practical Applications***	***Invented Workaround***
Pharmaceuticals	Gas analyzers manage gas concentrations during medicine	• Photoacoustic gas analyzers (Laser Based)

	research and manufacture. They can detect oxygen during fermentation to optimize microbial growth. Medicinal gas purity is also measured by gas analyzers. They may detect nitrogen concentration in packing materials to assure inertness and product compatibility.	• Fourier Transform Infrared (FTIR) gas analyzers • Mass Spectrometry (MS) gas analyzers • Electrochemical gas analyzers
Breath Analyzer	Breath analysis is used to detect diseases, track treatment, and evaluate health, its fast and non-invasive	• Laser Spectroscopy • Infrared Spectroscopy (IR) • Mass Spectrometry (MS) • Electronic Nose (E-Nose)
Indoor Spaces: House, Cinema, Clubs, Hospitals	Air analyzers are instruments that are typically utilized in enclosed settings, such as workplaces, private residences, and other types of indoor areas, with the purpose of assessing the quality of the air and determining whether or not it is fit for human inhalation. Asses HVAC or Hygiene levels in hospitals, clubs or factories.	• Ion mobility spectrometry (IMS) detects trace of volatile organic compounds VOCs in the air. • Radon analyzers assess air radon levels. Radon, a radioactive gas present in soil and building materials, can cause lung cancer. • Photoionization detectors (PID)

2.3. F&B

Areas	***Practical Applications***	***Invented Workaround***
Food production and quality monitoring	• Detect the presence of excess O2, N2, etc in wine, milk, meat, egg, fermented food, fruits (beginning of ripening process), etc	• Gas chromatography • Mass spectroscopy • Electrochemical sensor

	• Gas detectors in food production rooms with ammonia • monitor the status of the packed food (measure the concentrations of specific gases that are produced by the food during storage. As food spoils, it produces gases such as ammonia, carbon dioxide, and volatile organic compounds (VOCs)	
Cooling system/Distillery	Ensure that it is working smoothly by detecting different compositions in the air, including both industrial (for food preservation, dairy, butchers) and commercial (Supermarkets and large kitchens) cooling systems	• Ultrasonic leak detection • IF Cameras
Breweries	• Monitor CO2 and Amonia, excess oxygen in Carbonation and bottling activity • Monitor Ozone or Chlorine in settling, aeration, coagulation, filtration, and sterilization treatment to produce pure water used	• IF sensors • Electrochemical sensors • Photoionization detectors • Gas Chromatography

2.4. Safety/Disaster Response

Areas	***Practical Applications***	***Invented Workaround***
Fire detection	When a fire occurs, it produces a range of gases, including carbon monoxide, carbon dioxide, and other hydrocarbons. By analyzing	• Smoke detectors • Heat detectors • Flame detectors • Gas detectors

	the levels of these gases in the air, Gasraman technology could identify the presence of a fire and provide an early warning to occupants of a building or facility.	• Infrared detectors • Video analytics • Human detectors
Volcano detection	Gasraman technology could be used for volcano detection by monitoring the composition of gases emitted by the volcano. As magma rises towards the surface, it releases gases such as sulfur dioxide, carbon dioxide, and water vapor. By analyzing the levels of these gases, Gasraman technology can provide insight into the behavior of the volcano and the potential for an eruption. The data can be analyzed in real-time to detect any changes in the gas composition that may indicate an increase in volcanic activity.[2]	• Multi-Component Gas Analyzers • Electrochemical Sensors • Differential Optical Absorption Spectroscopy (DOAS) (ultraviolet and visible light) • Fourier Transform Infrared Spectroscopy (FTIR) • Mass Spectrometry
Earthquake prediction	Gasraman sensors could be used to monitor the levels of gases that are emitted by the Earth's crust, which can provide insight into geological activity in the vicinity of fault lines.	• Seismometers • Global Positioning System (GPS) • Satellite Remote Sensing • Geochemical Monitoring • Machine Learning
Munfastring factories	Gasraman technology could be used to detect and monitor various gases in manufacturing factories to help manufacturing factories maintain a safe and healthy working environment for their employees.	• Gas sensors • Catalytic bead sensors • Infrared sensors

[2] https://www.iris.edu/hq/inclass/animation/volcano_monitoring_measuring_magmatic_gas

2.5. Science

Areas	***Practical Applications***	***Invented Workaround***
Material science	Detect the gases emitted by materials during various processes, such as manufacturing, curing, or degradation. By detecting the gases produced, Gasraman technology could provide insights into the composition of the materials and the underlying chemical reactions. This information could be used to optimize manufacturing processes, design new materials, or identify potential quality issues.	Some researchers are exploring the use of mid-infrared spectroscopy or other optical techniques for material analysis. These alternative technologies may be less complex and more widely available than Gasraman sensors.[3]
Scientific labs	Detect and analyze the gases produced by dangerous bacteria in workspace. By detect the gases emitted, Gasraman technology could identify the presence of certain bacterial strains or biohazards in the lab environment. This information could be used to improve safety protocols, prevent contamination, and ensure a healthy work environment for lab personnel.	Actually they are using spectroscopy to identify gases in the air, gas sensors to monitor workspace air in real time, and also air quality monitors, to alert workers if the concentration of gases or particulates exceeds safety limits.[4]
Art conservation	• Detect the gases produced by materials in artwork and identify potential sources of deterioration, which could	• Currently, there are researchers who test the paint and submit it to an analysis to

[3] https://www.msm.cam.ac.uk/research/research-disciplines/spectroscopy#:~:text=Spectroscopy%20is%20the%20study%20of,of%20radiation%20from%20the%20sample

[4] https://www.interempresas.net/Proteccion-laboral/Articulos/393993-Nuevos-dispositivos-permiten-empresas-hospitales-administraciones-publicas-detecten-gases.html

	provide insights into the underlying chemical reactions and environmental conditions that are contributing to degradation. • Can be used in archeology (detecting buried remains, identifying underground structures, and monitoring the condition of artifacts)	identify its conservation or deterioration.[5] • Photoionization detectors
Weather	Detect atmospheric gases that are indicative of humidity levels, which could be used to predict weather. By monitoring the concentration of certain gases in the air, Gasraman sensors could provide real-time data on the likelihood for example of precipitation in a particular area. This information could be used to help farmers plan their crops, or for emergency responders to prepare for potential flooding events.	Nowadays, there are a lot instruments to detect weather changes. Also, researches are exploring the use of alternative sensing technologies, such as satellite-based remote sensing or ground-based weather stations, to collect atmospheric data for weather forecasting purposes. [6]

2.6. Agriculture

Areas	***Practical Applications***	***Invented Workaround***
Cow Burp	Monitor the levels of methane in the air around cows, which can provide insight into their enteric methane emissions -> identify areas for improvement in the cows' diet or	• Respiration chambers • Individual cow collars equipped with methane sensors

[5] https://www.deingenieur.nl/artikel/test-predicts-degradation-of-paintings
[6] https://www.weather.gov/ajk/OurOffice-Sat#:~:text=In%20a%2024%2Dhour%20period,to%20five%20to%20ten%20days

	management practices to reduce their methane output.	• Satellites[7]
Fire Detection	As mentioned before	As mentioned before
Poultry farms	Gasraman technology could be used as a tool for monitoring air quality and ensuring the safety of workers and animals in poultry farms. By using Gasraman sensors, farmers can identify potential hazards and take steps to mitigate the risk of exposure to harmful gases.	• Electrochemical Gas Sensors. • Infrared Gas Sensors • Catalytic Gas Sensors • Photoionization Detectors
Food Quality Monitoring	As mentioned before	As mentioned before

2.7. Sports

Areas	***Practical Applications***	***Invented Workaround***
Cars (Race)	Used in automotive exhaust systems to detect emissions levels of gases that produce vehicles. The high sensitivity and selectivity of the Gasraman sensor could enable more accurate and precise measurements of these gases in real-time	Some researchers are exploring the use of infrared sensors for exhaust gas measurement and capacitance-based sensors for tire pressure monitoring and also for the gas of vehicles. These alternative technologies may be less expensive and more widely available than Gasraman sensor and could be used as a workaround to the potential limitations of the Gasraman technology.[8]
Animal health (Competition)	Gasraman technology could be used in veterinary sports medicine to analyze the breath or other gases emitted by animals (for example:	Some companies and researchers may be working on alternative biosensor technologies that could provide similar functionality at a lower cost.

[7] https://www.reuters.com/lifestyle/science/satellites-detect-california-cow-burps-major-methane-source-space-2022-04-30/
[8] https://www.crowcon.com/US-EN/industries-and-applications/car-park-monitoring/

	volatile organic compounds (VOCs) in the breath), which can provide important insights into their health and wellbeing for their performance in competition and enable earlier detection and treatment of health issues in animals.	These by electronic biosensors for breath analysis or other ways to analyze the in animals.[9]
Measure athletes performance	The product could be used in sports science to analyze the breath of athletes during training or competition by detection of the expel gases, which can provide important insights into their physiological responses and performance. For example, the Gasraman sensor could be used to detect changes in the levels of carbon dioxide or oxygen in the breath of athletes, which can be indicative of changes in metabolism or respiratory function. By providing real-time measurements of these gases, Gasraman technology could enable coaches and trainers to adjust training regimens or make other interventions to optimize performance.	Currently there are systems that provides analysis of the gases expelled by athletes such as breath gas analysis or metabolic gas analysis testing.[10]

[9] https://www.sciencedirect.com/science/article/pii/S2214180416301350
https://www.news-medical.net/news/20200226/Imperial-researchers-invent-a-new-health-tracking-sensor-for-pets.aspx
https://www.lasercomponents.com/de-en/application/spiroergometry-makes-endurance-measurable/
https://simplifaster.com/articles/buyers-guide-metabolic-gas-analysis-systems/10

3. Conclusion

3.1. Where are these new technologies necessary or more impactful?

- R&D Labs, Indoor Poultry, Dairy or Cattle farms.
- Harsh environments
- Where needs a high level of selectivity and sensitivity

3.2. Potential markets for the technology

Based on the investigation that we did; we can see that there are a lot of markets where Pipe could be useful to "Solve a job". However, we see that there are a lot of markets where some kind of gas detection is already used. The **competitive advantage** for Pipe is that it is **cheaper** than existing products, they have a **higher level of selectivity and sensitivity**. It also has a **higher accuracy rate, fast processing time** for data analysis**.**

Medical research and development laboratories, where viruses are developed, provide the greatest threat of contamination, and the enhanced continuous monitoring is made possible in real time by this technological advancement.Most of the potential applications of that technology in **Environment** are in use widely. There are several products available in the market, however this technology has competitive advantage in pricing, which could be affordable for even small companies - when sustainability is becoming significantly important nowadays. Several areas where Pipe and the Gasraman technology would help companies with that, for example Waste management, Water waste and Air pollution.

When it comes to the **Food & Beverage** industry, there are lots of products in the market using similar technology in food production process. However, it seems challenging to use the Gasman in the food quality monitoring, as it uses the laser that could affect the product itself.

An area that could be improved is **gas separation**. In particular, it can work with other device to be used in Gas separation (currently: IF/Hollow fiber membrane but Membrane fouling could occur, and the fiber is highly sensitive with the temperature), that could be valuable in gas producing or production of nitrogen-charged beers (for example)

When it comes to **Safety and disaster response** such as Volcanos, Fires and earthquake prediction, several firms already uses gas detection. Here we see that the it becomes crucial that Gasraman is as least as reliable as other tools on the market to become competitive. In **earthquake** for example, it has to be compared to other techniques and gas detection is perhaps not enough to be considered as reliable on its own.

Also, regarding the **science industry**, there exist other available products for the evaluation of material science, weather or detect harmful gases in workspace of labs. However, nowadays there are not many ways to evaluate **art conservation** as there are not many products on the market for this purpose. That is why our product may represent an opportunity in this market. The product, for example, can be delivered to museums, art exhibitions, auctions to find out how much the art is worth and so on.

In addition, **Sports** represent a large market with continuous growth in data evaluation or analysis. That is why for the product a possibility would be to enter the market of **gas detection in racing vehicles for their performance**. It could also be used in the **evaluation of animals** based on respiration and gases to evaluate their performance. Also, it could be used in evaluating the performance of an athlete based on their respiration. The idea is that by entering this market the product can detect certain harmful or not harmful gases that directly affect performance.

II. Mission 2: Research and Synthesis

1. F&B – Breweries

1.1. Main users

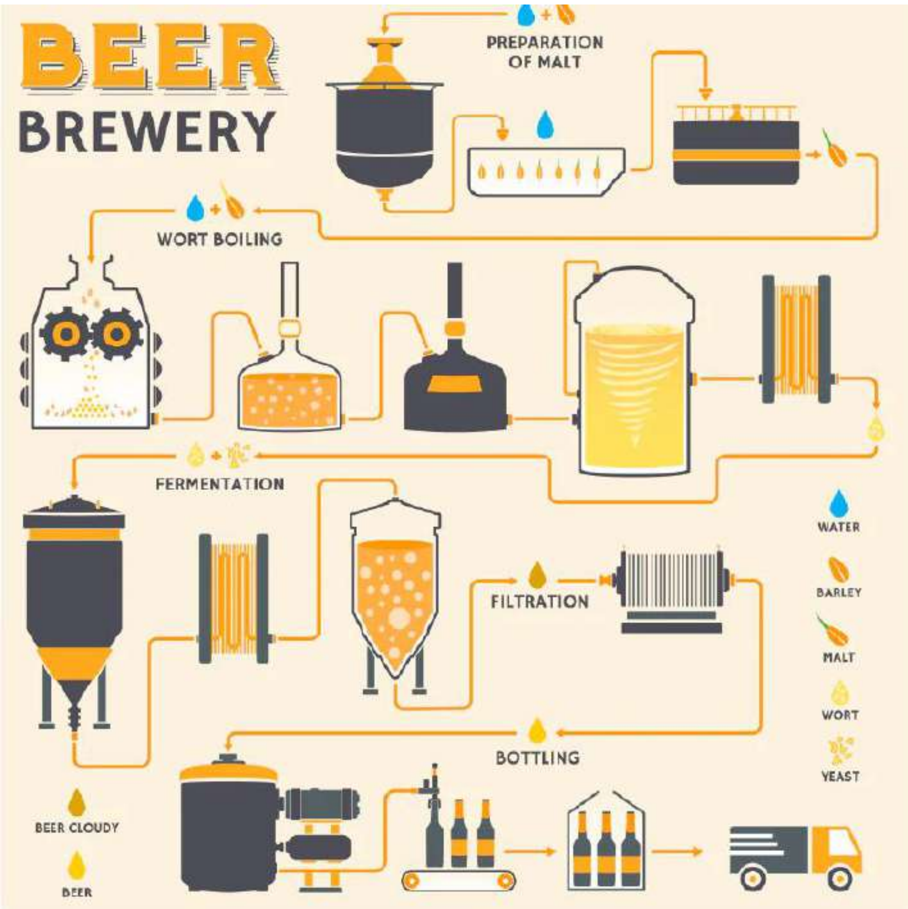
- Beer brewer

- Brewery production company

1.2. Drivers to use product

- Improve quality control: Raman gas technology can be used to analyze the composition of the gases used in the brewing process to ensure that the gas is of high quality and properly mixed. This can lead to better beer quality with consistent taste, texture and mouthfeel.
- Optimize gas usage (reduce waste and increase efficiency): By monitoring gas consumption in real time using Raman gas technology, breweries can optimize gas flow rates, reduce waste and improve efficiency. This can lead to cost savings and reduced prices.
- Optimize production process: Raman gas technology can be used to monitor and optimize various stages of the brewing process, including carbonation and nitrogen infusion.
- Regulatory compliance: Many breweries are subject to regulations regarding gas usage and emissions. Raman gas technology can be used to ensure compliance with these regulations, such as monitoring the purity of nitrogen gas used in the brewing process.
- Ensure personnel safety: Gas Raman technology can detect gas leaks in real-time and measure gas pressure to ensure it is within safe limits (remotely).

1.3. Processes



- Quality control: analyze the composition of gases in finished beers, helping to ensure product quality and consistency. Oxygen can cause oxidation of the beer, leading to off flavors and aromas.
- Packaging and storage: analyze the composition of gases in the headspace of beer containers, such as bottles and cans. This information can help breweries optimize their packaging and storage processes, minimizing the risk of spoilage. [11]
- Detect and measure concentration of CO2 and ammoniac: Ammonia can be used as a refrigerant, but it is also toxic and can be lethal in high concentrations. CO2 can accumulate in confined spaces such as fermentation vessels or storage tanks. Early detection of excess gases could help protect personnel from exposure.
- Carbonation: monitor the concentration of gases used for carbonation, such as carbon dioxide and nitrogen, thus optimize the carbonation process and ensure consistent product quality.
- Monitor fermentation (check with client): During the fermentation process, yeasts could produce various gases, including carbon dioxide and ethanol. The technology could monitor

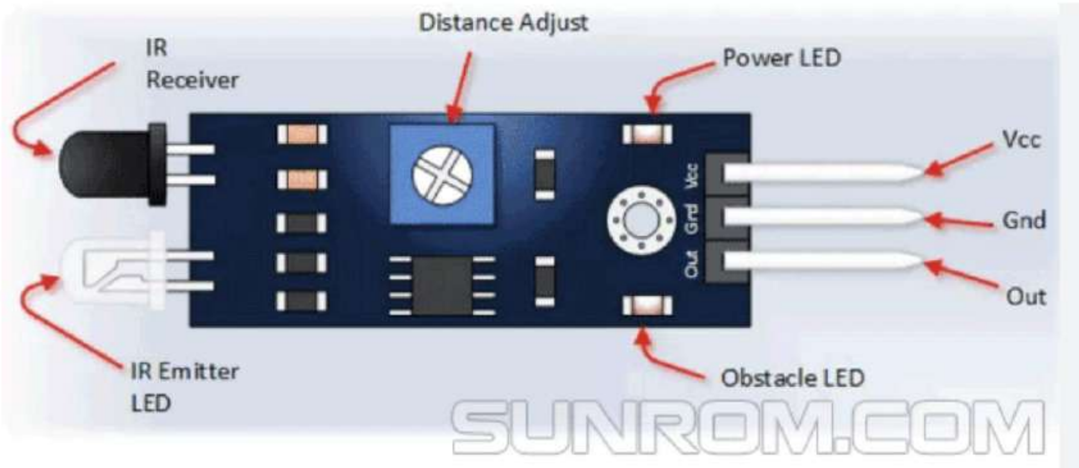
[11] https://www.tandfonline.com/doi/abs/10.1094/ASBCJ-44-0072

the concentration of these gases in real-time, providing insights into the progress of the fermentation and the health of the yeast.[12]

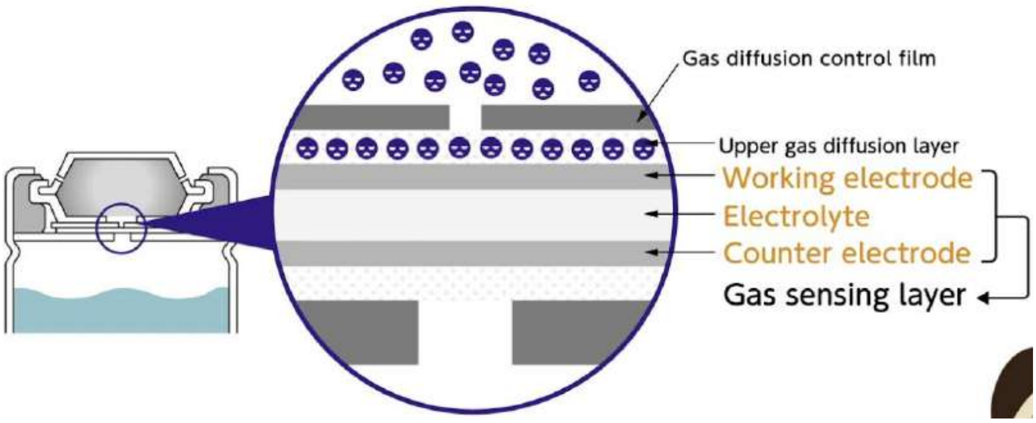
- Analyse the purity, monitor the effect of gasseparation [13]

1.4. What do people do (tools and technology)

- IF sensors



- Electrochemical sensors



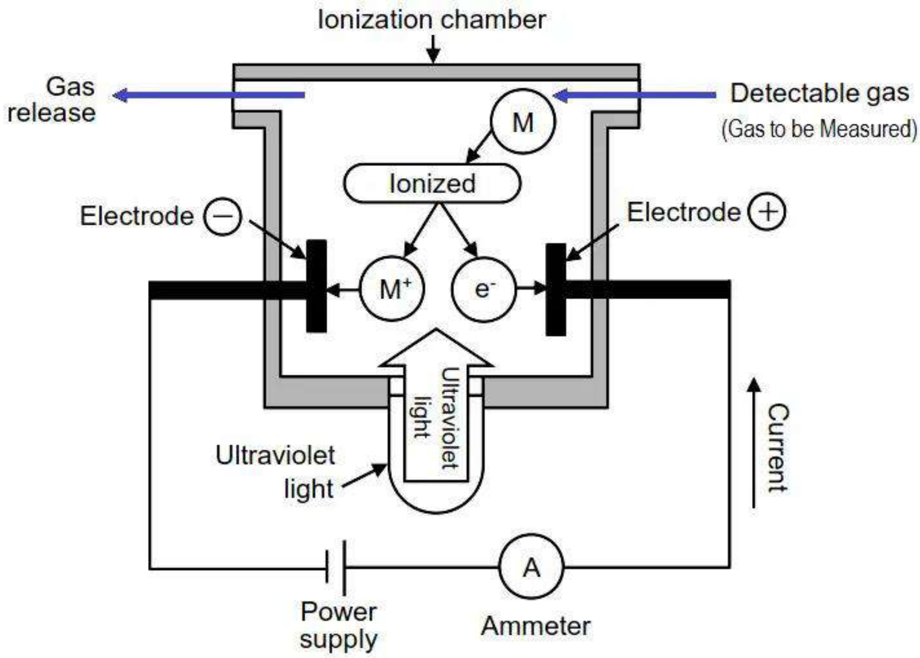
- Photoionization detectors

[12] http://uu.diva-portal.org/smash/get/diva2:753737/FULLTEXT01.pdf
[13] The Air Separation Process – Gases Perspective

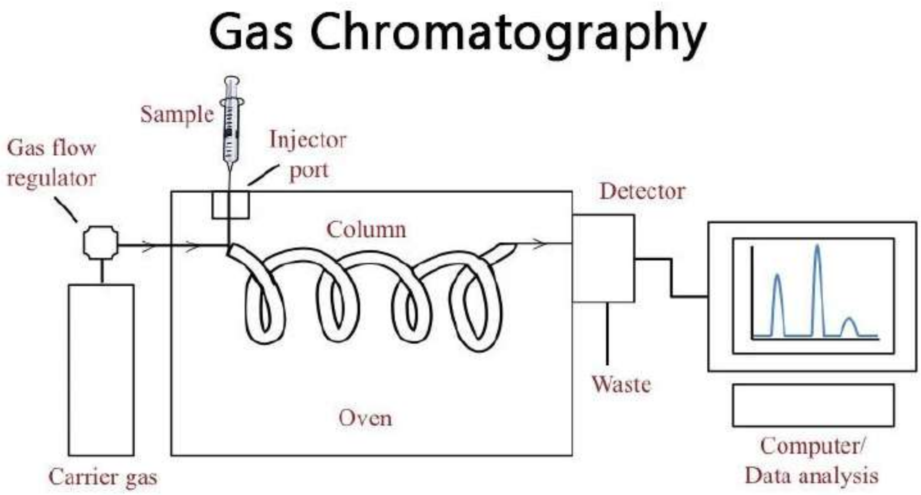
https://pubs.acs.org/doi/10.1021/ie8019032 -

https://www.sciencedirect.com/science/article/abs/pii/S037673881631002X?casa_token=rmgs3HqGqVUAAAAA:

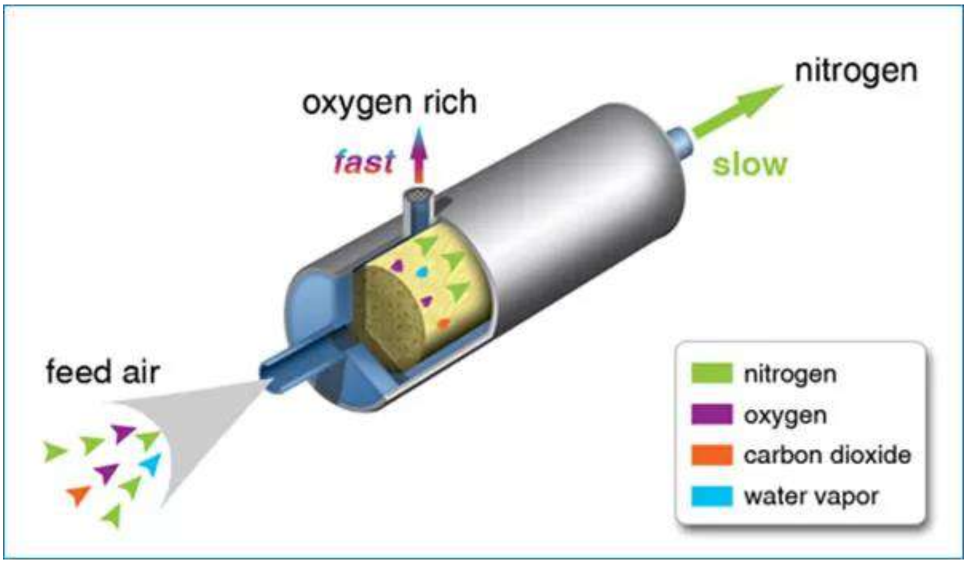
4XIlPlWvhye8QUzV0ZNG67PWSpEwB5e3UIpPxGtzLCAZdbRKImolJw64URQ8XSJMTQjSEvUAI8Y



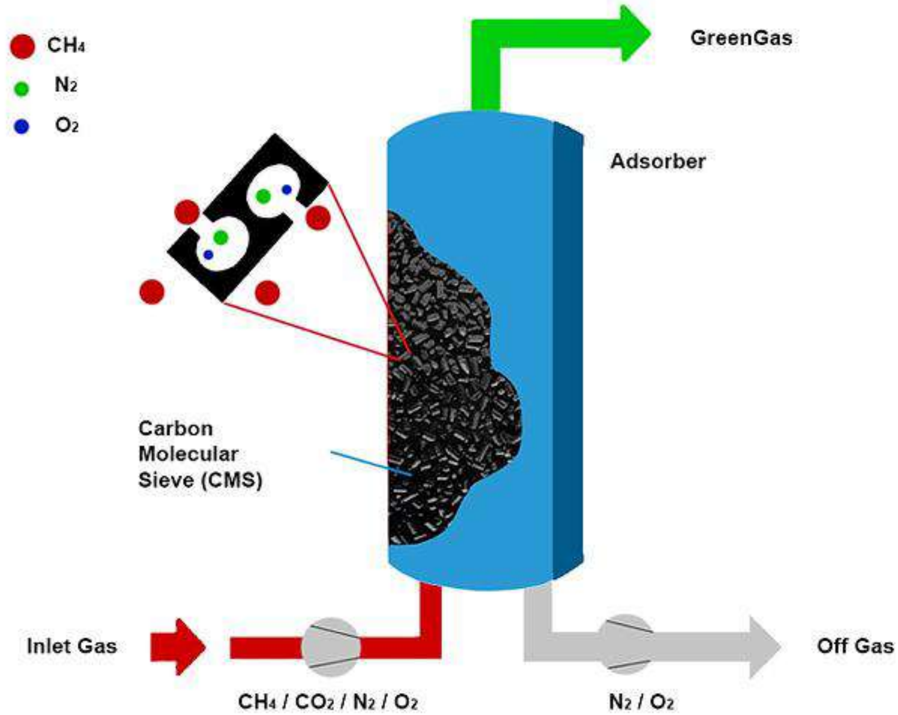
- Gas chromatography



- Membrane Gas Separation (for gas separation): the system use a membrane or adsorbent material to separate the gases based on their molecular size and affinity



- Adsorption technology (for gas separation): use of a material, such as activated carbon or zeolite, that selectively adsorbs carbon dioxide from the gas mixture. The gas mixture is passed through the adsorbent material, which traps the carbon dioxide and allows nitrogen to pass through. The separated nitrogen is then collected and used for beer production.



1.5. Main challenges of the users in existing solutions

General: efficiency, maintenance needs, sensitivity to environmental factors, selectivity issues, scaling capability

IF Sensors:

- Less sensitive
- Can not detect trace amounts of gases
- Can not identify the specific type or concentration of the gas

Electrochemical sensors

- Sensitivity to environmental factors
- Have degradation of the sensing electrode

Photoionization detectors

- Be affected by interfering substances in the environment.
- Not be able to distinguish between different types of VOCs
- High cost
- Less selective

Gas chromatography

- Require extensive sample preparation
- Time and cost-consuming
- May be not portable

Membrane Gas Separation:

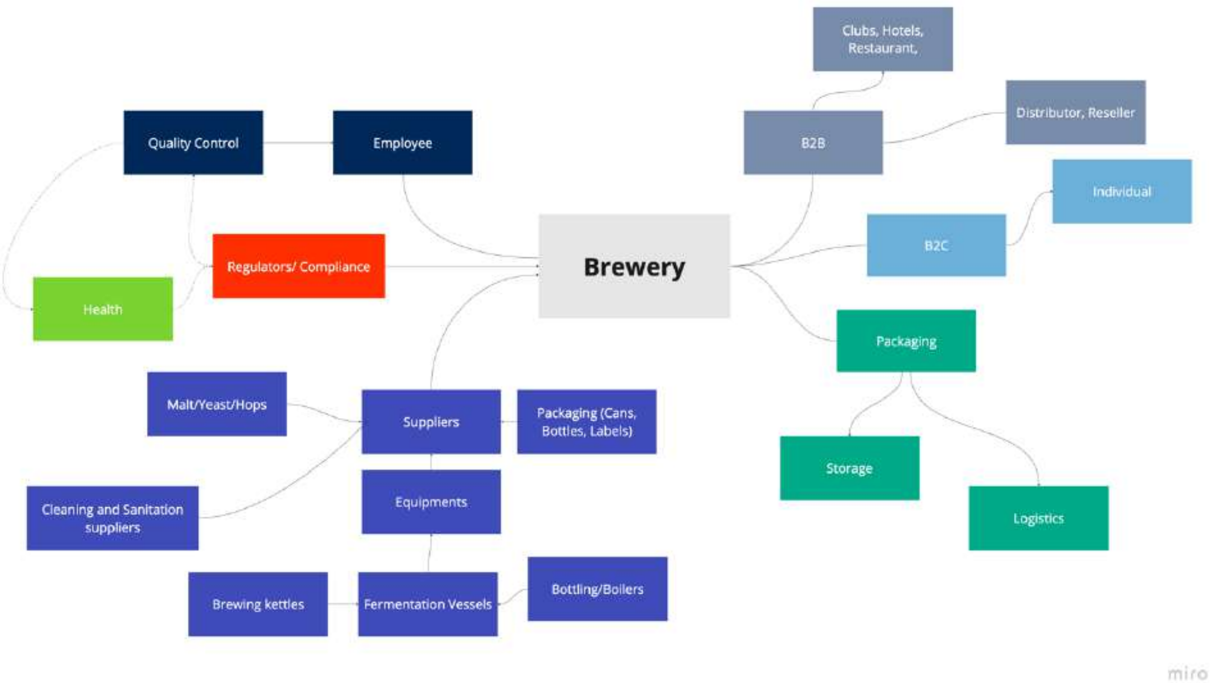
- Different level of selectivity (Membrane and adsorbent materials have different affinities for different gases)
- Requires high pressure, which can be energy-intensive and expensive
- Can be clogged with contaminants, reducing their efficiency and lifespan
- Requires regular maintenance
- Can be challenging to use in large-scale industrial applications

Adsorption Technology:

- Less efficient
- May require more frequent replacement of the adsorbent material

1.6. Journey Map

1.7. Stakeholder Map



1.8. Persona

(Not real people)

Anders is a technical guy working in a small-sized brewery production company (<50 employees) in Sweden who works in the fermentation and conditioning everyday to make locally produced beer.

As a Swedish brewing company, his company has to comply with certain regulations for gas emissions or gas purity.

As a result, he wants to monitor the gas produced by the yeasts during fermentation and conditioning such as carbon dioxide, nitrogen and ethanol. The concentration of the gases is needed to monitor the process and control consistent quality. Based on this data, he would also be able to detect the health of the yeast, which could be affected by the previous processes, and then better control them.

In addition, he needs real-time monitoring to ensure that he can intervene at any time if necessary and avoid hazards to the working environment and human safety.

1.9. Our Decision

After the first two weeks of exploration, we found that brewery seems to be a promising area as there are not many companies with cutting-edge solutions on the market and this could be our chance to enter the market as Pipe 4.0 has a competitive advantage. Also, when we presented our idea to the Pipe 4.0 team, they were aware of the market potential and the technical possibilities of the product and encouraged us to pursue the topic further.

We started by looking into the brewery operations in Linkoping. To get detailed information and learn as much knowledge as possible from the staff, we visited Centralbryggeriet (https://www.centralbryggeriet.se/) and had a short interview with the founder to understand the work and the problems he and his team might face throughout the production process. He indicated that dissolved oxygen measurement is an important step in production, but that they are not currently using any specific technology. However, it is noted that he is considering using a carbon dioxide meter in the near future.

We also contacted two other companies, Klosterbryggeri (https://klosterbryggeri.com/) and Nynäshamns Ångbryggeri (https://www.nyab.se/). Unfortunately, we could not see any potential matches of the technology with their production process. As a result, after pursuing the topic in 4 weeks, we decided to go with another option as the final area.

It should be noted, however, that the contacts and time available to us are quite limited, which may somewhat limit the possibilities for further research. From our point of view, it is still a promising area that can somehow be linked to related areas in the F&B industry, such as wine, sparkling water, etc.

2. Sports (Metabolostic gas analyser)

2.1. Main users

Athletes, NASA, hospital patients, physiogoly research

2.2. Drivers to use the product

- Sport performance, cardiac output, access to metabolic health
- Accurately measure and understand an individual's metabolic response to exercise. Critical in sports and exercise physiology research Can be used to design individualized training programs, improve athletic performance, and monitor overall health and fitness.
- Clinical settings to assess the metabolic health of individuals with various medical conditions. For example, they can be used to diagnose and monitor conditions such as obesity, diabetes, and heart disease.

2.3. Processes [14]

- **Grasp the breath of the individual:** An individual typically wears a mask or mouthpiece that is connected to a metabolic cart or analyzer. The metabolic cart measures the concentration of oxygen and carbon dioxide in the inhaled and exhaled air, which is used to calculate the individual's VO2 and VCO2. The ratio of VCO2 to VO2 is known as the respiratory exchange ratio (RER) and provides information about the type of fuel being used by the body (e.g. carbohydrates or fats).
- **Measure:** Metabolic gas analyzers use various methods to measure the concentration of oxygen and carbon dioxide in the air. The most common method is based on the principle of gas diffusion, where gases diffuse across a membrane from a region of high concentration to a region of low concentration. The metabolic cart typically includes a pump that draws in a sample of exhaled air through a membrane, which separates the O2 and CO2 from other gases in the air. The concentration of O2 and CO2 in the air is then measured by various sensors.
- Other methods for measuring **O2 and CO2 concentration include infrared spectroscopy, which uses the absorption of light to measure the concentration of gases, and electrochemical sensors**, which use electrodes to measure the concentration of gases.
- **Calculate:** The metabolic cart or analyzer typically includes software that calculates VO2, VCO2, and other metabolic parameters based on the measured O2 and CO2 concentrations. This information can be used to design individualized training programs, assess an athlete's performance, and monitor overall health and fitness.

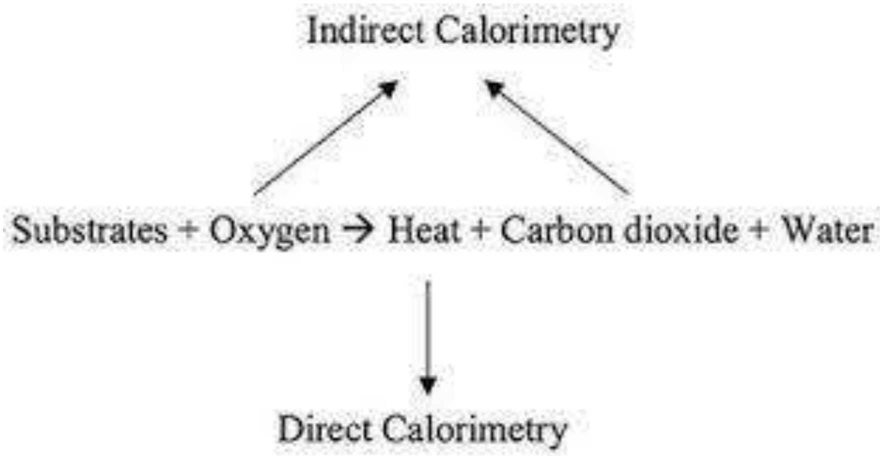
2.4. What do people do (tools and technologies)

Techniques that can be used to measure energy expenditure and metabolic rate

- **Indirect Calorimetry**: technique used to estimate energy expenditure and metabolic rate by measuring the rate of oxygen consumption (VO2) and carbon dioxide production (VCO2) during rest or activity. [15]

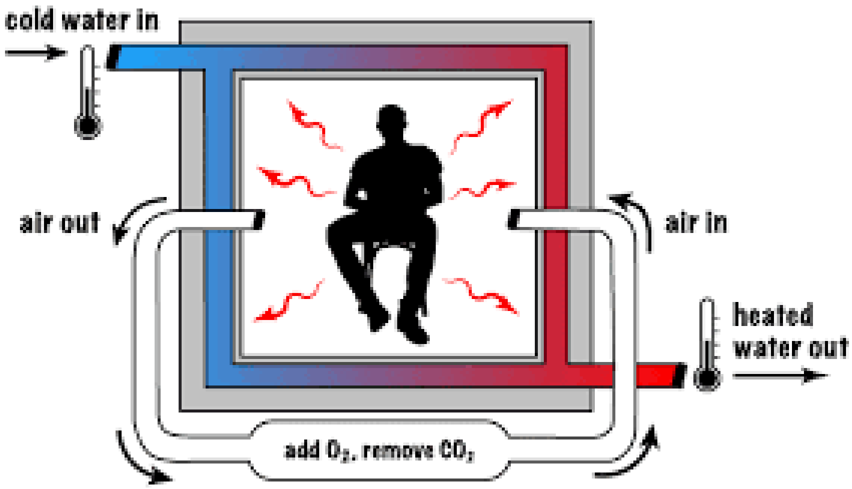
[14] Indirectcalorimetry.net. (2017). *Understanding Indirect Calorimetry – Indirect Calorimetry*. [online] Available at: https://www.indirectcalorimetry.net/understanding-indirect-calorimetry/ [Accessed 6 May 2023].

[15] marcos (2014). *Measuring Energy Costs of Exercise*. [online] SlideServe. Available at: https://www.slideserve.com/marcos/measuring-energy-costs-of-exercise [Accessed 6 May 2023].

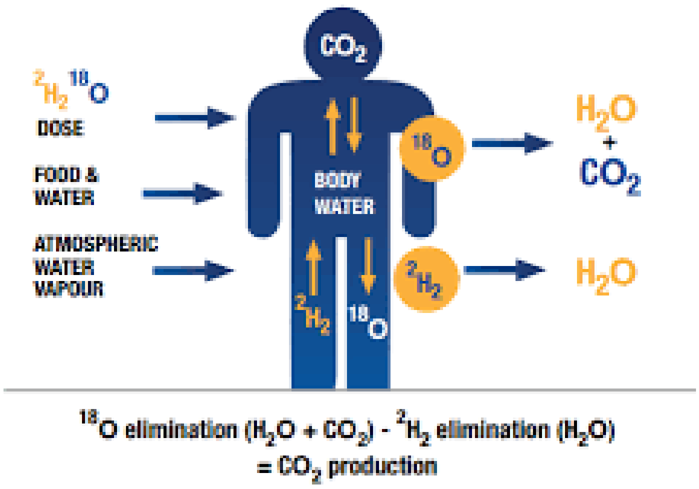


- **Direct calorimetry:** Direct calorimetry involves measuring the heat produced by an individual in a closed chamber. This technique provides a direct measurement of energy expenditure but is less commonly used due to technical challenges. [16]

[16] Cervantes, M.K. and Bross, R. (2022). Energy metabolism and requirements in chronic kidney disease. *Nutritional Management of Renal Disease*, [online] pp.61–75. doi:https://doi.org/10.1016/b978-0-12-818540-7.00050-1.



- **Doubly labeled water:** This technique involves administering a dose of water that contains a known amount of isotopes of hydrogen and oxygen. By measuring the rate at which the isotopes are eliminated from the body, it is possible to calculate energy expenditure over a period of several days. Electrochemical [17]



- **Research: respiratory gas analyser** [18]

[17] Westerterp, K.R. (2017). Doubly labelled water assessment of energy expenditure: principle, practice, and promise. *European Journal of Applied Physiology*, [online] 117(7), pp.1277–1285. doi:https://doi.org/10.1007/s00421-017-3641-x.

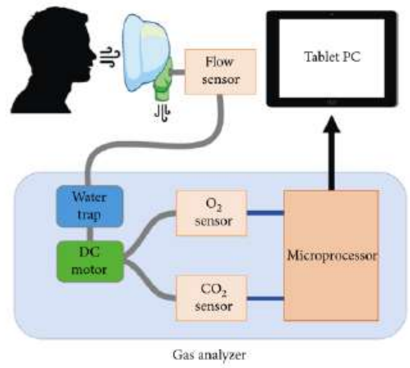
[18] Seo, H.-C., Shin, D., Leem, C.H. and Joo, S. (2021). Development of a Portable Respiratory Gas Analyzer for Measuring Indirect Resting Energy Expenditure (REE). *Journal of Healthcare Engineering*, [online] 2021, pp.1–10. doi:https://doi.org/10.1155/2021/8870749.

Research Article

Development of a Portable Respiratory Gas Analyzer for Measuring Indirect Resting Energy Expenditure (REE)

Figure 1

Functional diagram of the respiratory gas analyzer. The flow velocity of the exhaled gas is measured on the mask, and some of it (5%~10%) is collected using a DC motor. Since the vapor in the collected exhaled gas affects the measurement, the partial pressure of oxygen and carbon dioxide is measured after water is removed using a water trap.



Companies using indirect calorimetry and what kind of sensors they use

- **https://simplifaster.com/articles/buyers-guide-metabolic-gas-analysis-systems/**
- COSMED: indirect calorimetry; electrochemical and infrared sensors https://www.**cosindirectmed**.com/en/
  Parvo Medics: electrochemical and infrared sensors http://www.paindirvo.com/
- VO2 Master: Electrochemical and infrared sensors https://vo2master.com/
- KORR: electrochemical and infrared sensors https://korr.com/products/vo2-max-testing-system/
- Vacumed: electrochemical and infrared sensors https://www.vacumed.com/268.html
- Cortex Medical: Electrochemical sensors, Infrared sensors, Mass spectrometry, Paramagnetic sensors, Zirconium oxide sensors:
- PNOE: https://pnoe.com/
- Respiratory gas analyser An infrared CO_2 sensor and an optical O_2 detector fed from a damped micro vacuum sampling pump.
- Adinstruments: https://www.adinstruments.com/products/gas-analyzer

2.5. Main challenges of users in existing solutions and processes

Electrochemical[19] and infrared sensors[20]

- **Cross-sensitivity:** Electrochemical sensors are often cross-sensitive to other gases in the air, such as nitrogen oxides, which can affect their accuracy. Infrared sensors may be sensitive to humidity or other factors that can affect the composition of exhaled air.
- **Drift and calibration:** Both types of sensors may drift over time and require calibration to maintain accuracy. This can be time-consuming and expensive.
- **Sensor response time:** Electrochemical and infrared sensors may have a slow response time, which can affect the accuracy of measurements during rapid changes in gas concentrations, such as during exercise.
- **Maintenance and replacement**: Electrochemical and infrared sensors require regular maintenance, including cleaning and replacement, which can be costly and time-consuming.
- **Cost**: Electrochemical and infrared sensors can be expensive, particularly those with high levels of accuracy and reliability.
- **Humidity**: Infrared sensors may be affected by humidity, which can affect the accuracy of measurements in humid environments.
- **Accuracy:** While both electrochemical and infrared sensors are accurate, there may be slight variations in accuracy between different models and manufacturers.

Limitations and potential problems associated with indirect calorimetry:[21] [22]

- Variability in respiratory quotient (RQ): RQ is the ratio of carbon dioxide produced to oxygen consumed and varies depending on the type of fuel being oxidized. The RQ value can vary significantly during different metabolic states, which can lead to inaccurate measurements of energy expenditure.
- Equipment accuracy: The accuracy of the equipment used to measure oxygen consumption and carbon dioxide production can impact the accuracy of indirect calorimetry measurements.

---

[19] Safetyandhealthmagazine.com. (2011). *The pros and cons of electrochemical sensors*. [online] Available at: https://www.safetyandhealthmagazine.com/articles/the-pros-and-cons-of-electrochemical-sensors-2 [Accessed 6 May 2023].

[20] NevadaNano (2021). *Infrared Gas Sensors: The Benefits And Dangers*. [online] NevadaNano | MPS™ Gas Sensor. Available at: https://nevadanano.com/benefits-dangers-of-infrared-gas-sensors/

[21] https://www.sciencedirect.com/topics/nursing-and-health-professions/indirect-calorimetry

[22] Achamrah, N., Delsoglio, M., De Waele, E., Berger, M.M. and Pichard, C. (2021). Indirect calorimetry: The 6 main issues. *Clinical Nutrition*, 40(1), pp.4–14. https://hal-normandie-univ.archives-ouvertes.fr/hal-02906137v1/preview/S0261561420303356.pdf

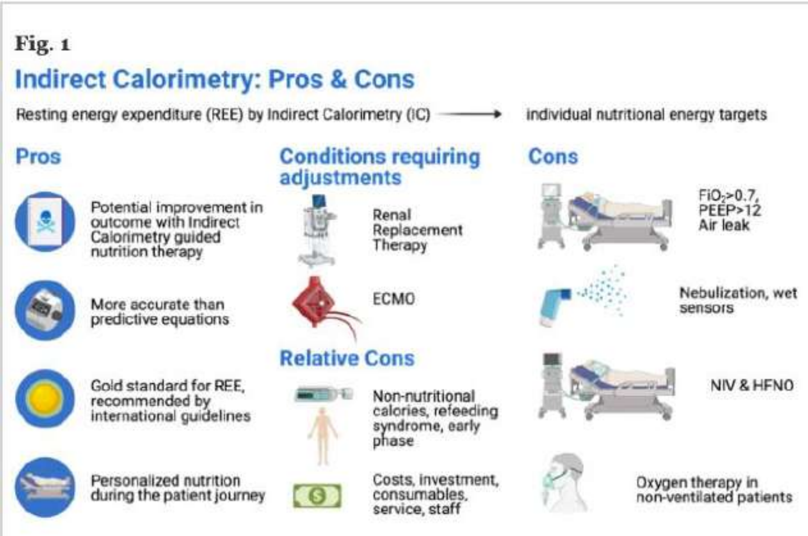
Small errors in the equipment can lead to significant errors in energy expenditure measurements.

- Limited applicability: Indirect calorimetry may not be suitable for certain populations, such as those who are critically ill, have respiratory or cardiac diseases, or are unable to tolerate the equipment required for the measurement.
- External factors: The measurement of energy expenditure using indirect calorimetry can be affected by external factors such as ambient temperature, humidity, and physical activity levels.
- Cost and time: Indirect calorimetry can be expensive and time-consuming, making it less practical for routine use in some settings.

2.6. Things that are difficult to do [23]

- Indirect calorimetry measures the *consumption* of metabolic substrates; it is powerless to predict the *requirement* for them, which is what one actually wants to know.
- Inaccurate results will fool you into underfeeding or overfeeding your patient, in the false belief that this method is more accurate than predictive equations.
- Thus far, there has been no mortality benefit from its use.
- Variations in breathing patterns,
- Assumptions about metabolic gas exchange, and equipment calibration.
- Challenge of accurately measuring energy expenditure in a diverse population
- Potential for errors and inaccuracies in the measurements.

[23] Yartsev, A. (2021). *Estimation of energy expenditure by indirect calorimetry*. [online] Deranged Physiology. Available at: https://derangedphysiology.com/main/required-reading/endocrinology-metabolism-and-nutrition/Chapter%20113/estimation-energy-expenditure-indirect-calorimetry



[24]

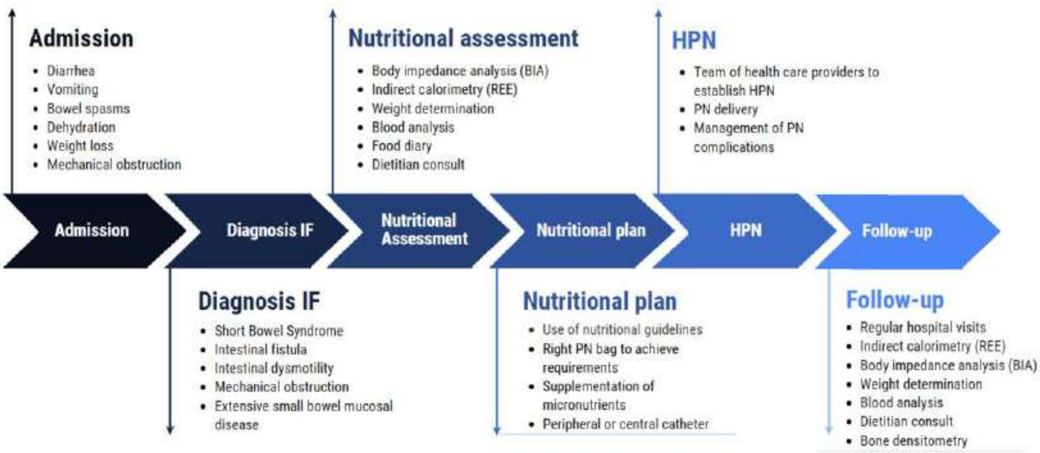
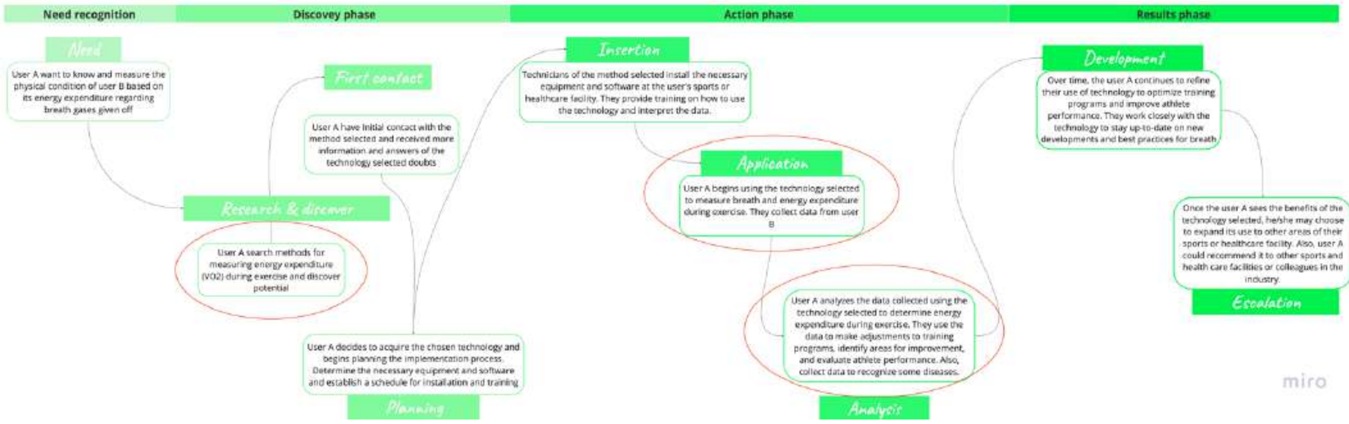


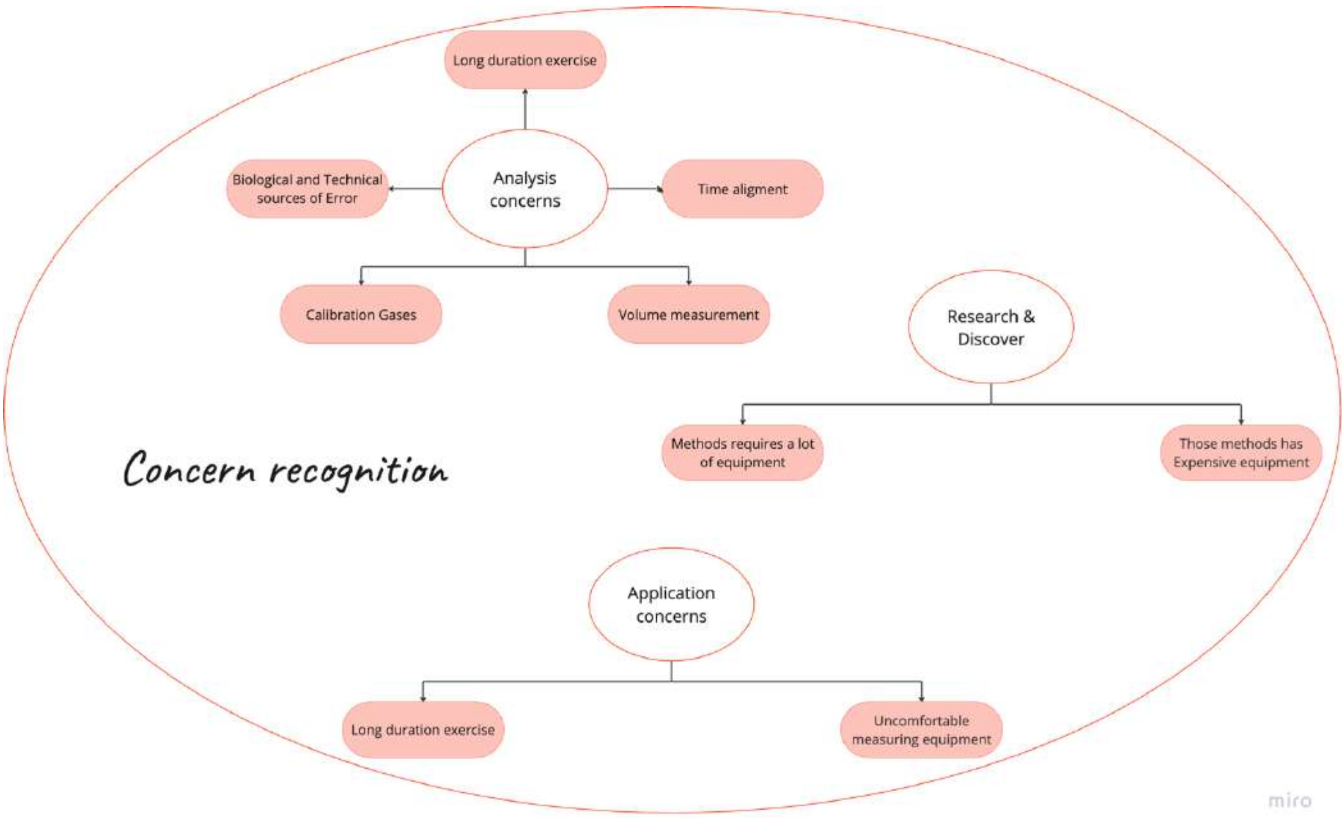
Figure: Different steps, from hospital admission to discharge and follow-up with HPN. Protocol used in UZ Brussel.[25]

[24] De Waele, E. and van Zanten, A.R.H. (2022). Routine use of indirect calorimetry in critically ill patients: pros and cons. *Critical Care*, [online] 26(1). doi:https://doi.org/10.1186/s13054-022-04000-5.

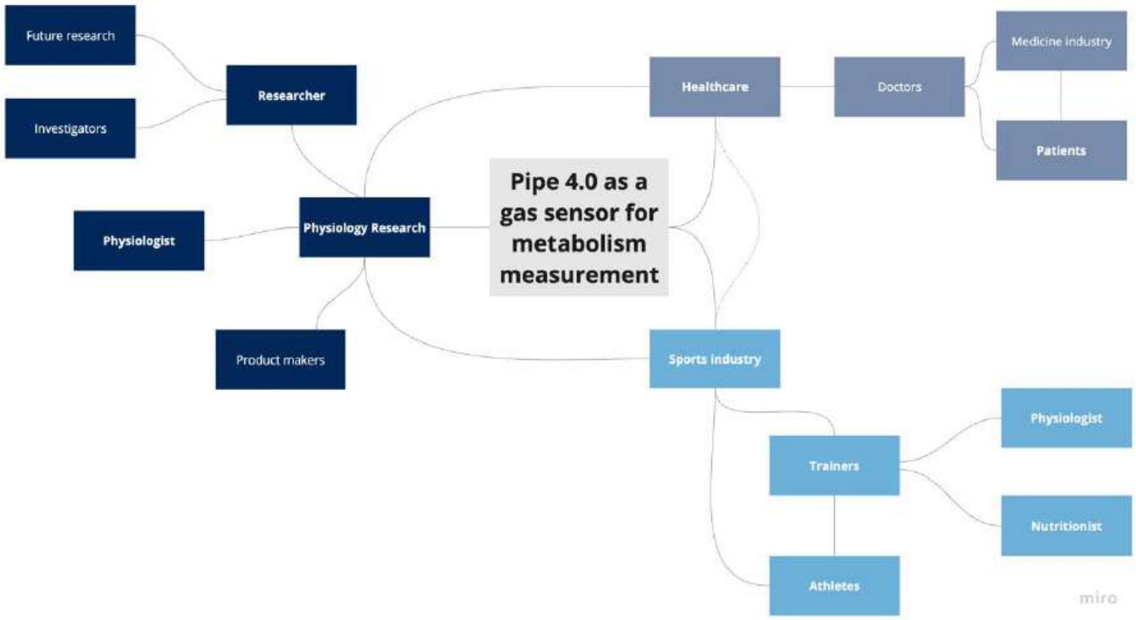
[25] Rosseel, Z., Cortoos, P.-J. and De Waele, E. (2023). Energy Guidance Using Indirect Calorimetry for Intestinal Failure Patients with Home Parenteral Nutrition: The Right Bag Right at the Start. *Nutrients*, [online] 15(6), p.1464. doi:https://doi.org/10.3390/nu15061464.

2.6. Journey Map





2.7. Stakeholder Map



2.8. Persona

Persona 1

- Athlete
- High expectations on performance
- Crucial to understand what to eat to perform better
- Need a better understanding for energy expenditure
- When to work out
- How to work out

Persona 2

- Suffer from obesity
- Do not know if she/he suffer from an underlying disease
- If a disease is causing or being caused by obesity
- Need guidelines for energy expenditure
- Need guidelines for meal plan

Persona 3

- Researcher in physiology
- Need to develop a better understanding for how the body works in health and how it responds and adapts to the environment
- Increase the knowledge to improve conditions for health and sports industry
- Need for reliable and accurate data to to research on

2.9. Our Decision

The idea of using Pipe 4.0 for sports came up early in the journey when we were wondering if breath analysis could be useful for athletes. In mission 2, we narrowed it down and decided to stick with this idea because it was unique and had more potential than others. Following additional research, we discovered current technologies, and that gas analysis is a part of the process when detecting human metabolism. We also contacted some companies who were into indirect calorimetry, physiologists, and dietitians, but only received a few responses and did not get the chance to book an interview.

Companies contacted:

- COSMED: https://www.cosmed.com/en/
- ADInstruments: https://www.adinstruments.com/
- Physiology department at Karolisnka Institutet: https://ki.se/en/labmed/division-of-clinical-physiology
- Physiology department at Gothenburg University: https://www.gu.se/en/neuroscience-physiology/about-us/physiology

Hence, we decided to stick with the idea anyway and discovered that a product that can detect metabolism, can cover a wide range of stakeholders and have an impact on a wide range of users and markets. We have speculated around how we could improve existing solutions with help from Pipe 4.0s technology. We have concentrated on physiologists as a target market, although the product might also have the possibility to be manufactured to target the sports or medical industries more directly.

We have included additional research, more in-depth information, and statistics on this chosen topic in a chapter of the Mission III.

3. Art conservation

3.1. Main users


- Museums and galleries
- Art conservation firms
- Art collectors

- Historical preservation organizations

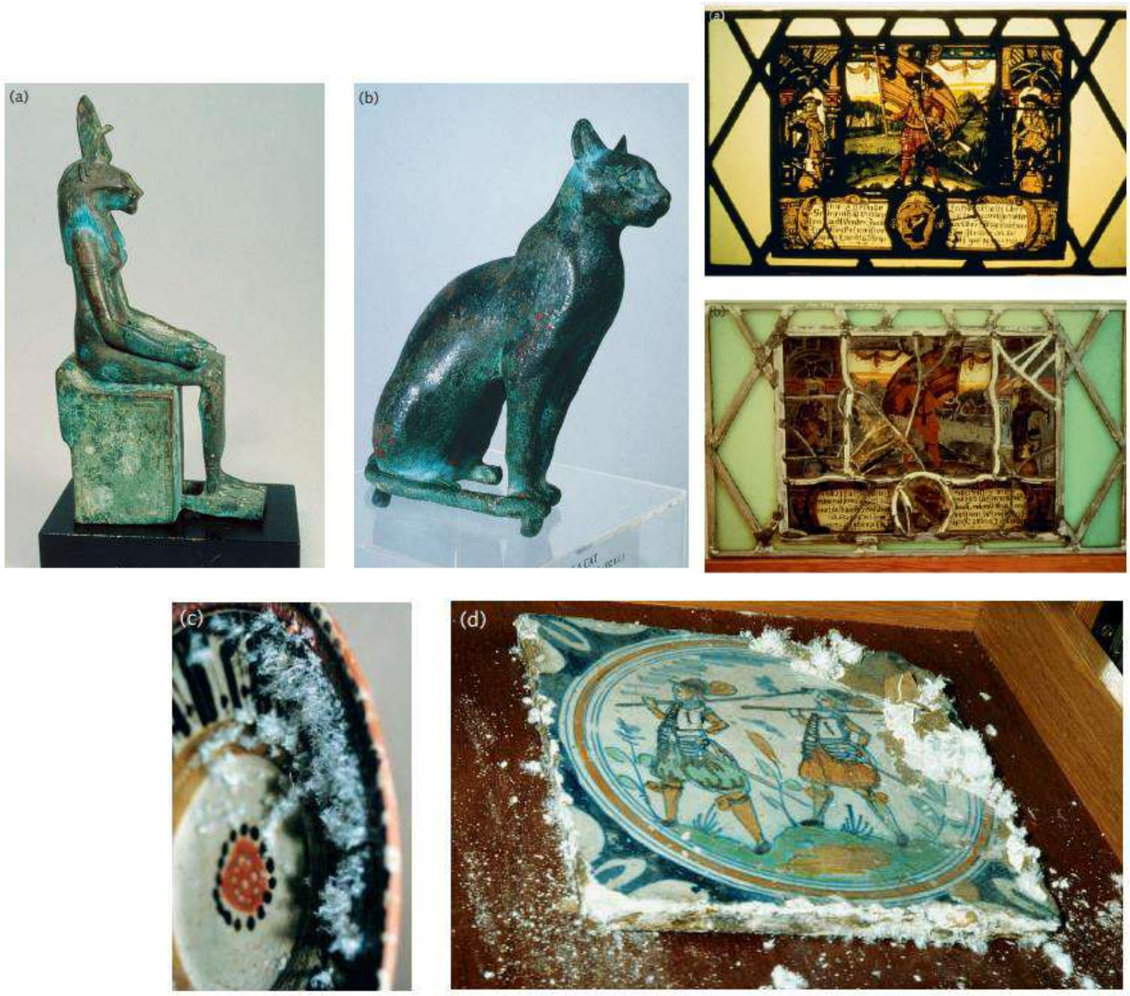
3.2. Drivers to use the product

The need of inspect and analyse the condition of artwork, sculptures, historical buildings, monuments and artifacts without the need for invasive testing or damage to the objects by detect indoor or outdoor gases. According to this, there exist two factors that affects the art conservation and which requires continuous monitoring and detection of gases that could affect artwork: Outdoor-generated vs Indoor-generated pollutants in art exhibition spaces.[26]

- **Outdoor pollutants:** Can enter a building, especially a naturally ventilated building (Druzik 1991), and pose a risk to collections. However, buildings with heating, ventilation, and air-conditioning (HVAC) systems that have gas-phase filtration minimize the infiltration of pollutants. Most common outdoor pollutants that are found inside museums and that pose a risk to cultural property are sulfur dioxide, nitrogen dioxide, nitrogen oxide, ozone, and reduced sulfur gases such as hydrogen sulfide (Grzywacz, Cecily.,2006).
- **Indoor pollutants:** The most common indoor-generated gases that pose a serious risk to cultural property are acetic acid, formic acid, acetaldehyde, formaldehyde, hydrogen sulfide, carbonyl sulfide, and ozone. These pollutants can be off gassed from paints, boards, carpets, and cleaners, as well as many other materials and products. They can also be generated during such processes as cooking, cleaning, and heating (Grzywacz, Cecily.,2006).

Pollutants modify or destroy susceptible surfaces, and, in the process, valuable information about cultural heritage can be lost forever. This is why detecting this this type of gases, can be useful to create solutions and preventions for both people and art.

[26] Grzywacz, C.M., (2006). *Monitoring for Gaseous pollutants in Museum environments: Tools for conservation. The Getty Conservation Institute. Los Angeles. Retrieved from* https://www.getty.edu/publications/resources/virtuallibrary/0892368519.pdf



3.3. Processes [27]

- Detecting gases: Use the product to detect the indoor and outdoor gases in the artwork and in its environment.
- Data analysis and interpretation: Once the artwork and its environment gases has been detected, the data would need to be analysed and interpreted by a team of experts. This could identify potential issues or areas of concern relying on the expertise of trained art conservators and historians.
- Material identification: Other process involved according to the use of the product in art conservation is identifying the materials used in the construction of artwork. This could include using Gasraman to detect the presence of specific chemicals or compounds in the artwork, which could help to identify the original materials or techniques used by the artist. Also, could

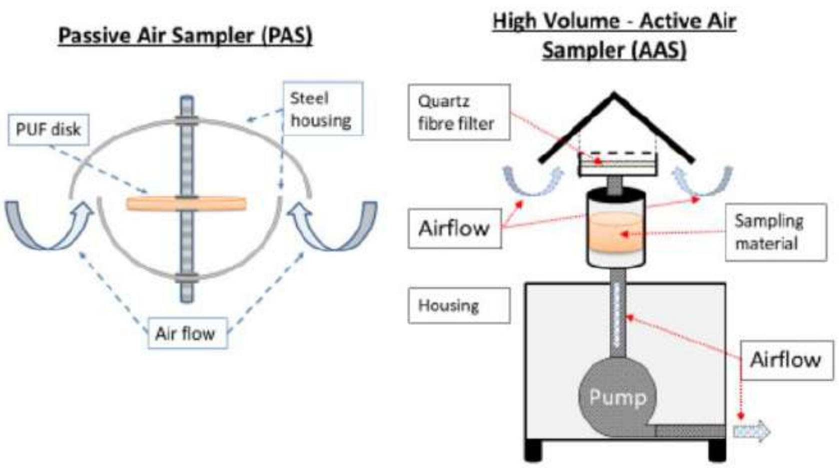
[27] UNC Health Talk. (2019). *Your No-Nonsense Guide to Metabolism | UNC Health Talk*. [online] Available at: https://healthtalk.unchealthcare.org/your-no-nonsense-guide-to-metabolism/

be useful to detect its history and certain gases that may affect both the art and the people in the environment.

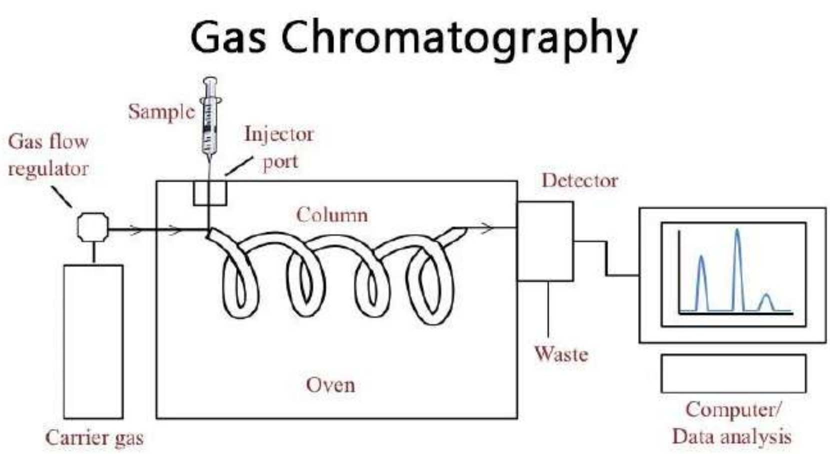
- Environmental monitoring: Another process the product is involved could also be monitor the environmental conditions in which artwork is stored or displayed. This could involve monitoring temperature and humidity levels, detecting the presence of pollutants or contaminants, and assessing the effectiveness of environmental control measures.

3.4. What do people do (tools and technologies)

- Museum air quality monitoring can be done with either an active or a passive system. An active system uses a pump to pull a sample of air into the monitoring device. On the other hand, passive system (Passive Sampling Devices, PSDs) allows air to diffuse into the device naturally.

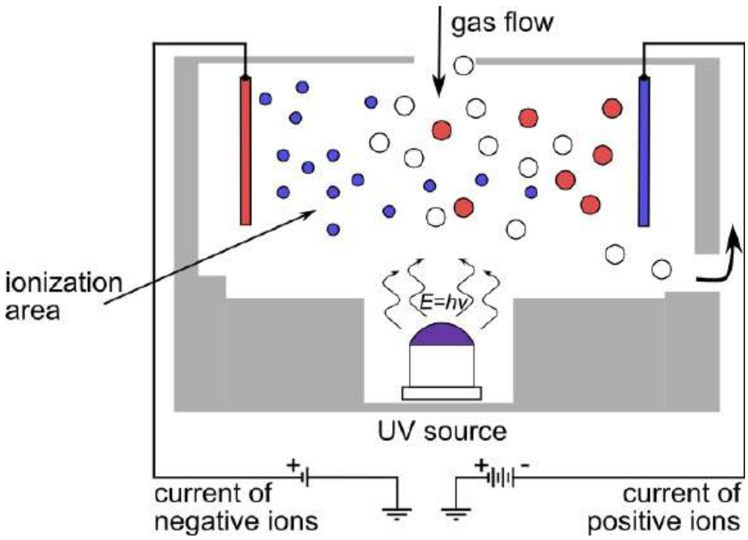


- Gas Chromatography/Mass Spectrometry (GC/MS) instrument.



- Infrared Spectroscopy:

- PID sensors



3.5. Main challenges of users in existing solutions and processes

- Active monitoring typically requires costly, sophisticated instrumentation and technical expertise.
- Passive monitoring (Passive sampling devices) a possible disadvantage is that long exposure times are usually required, from hours to days to weeks, depending on the device

Device Type	Advantages	Disadvantages
Direct-reading PSD	Lower expense per unit Easy to use No analysis required Immediate results	High detection limits Lower accuracy Subject to interferences
Laboratory-analyzed PSD	High accuracy High precision Pollutant specific Low detection limits	Higher cost per unit Complexity of use Results not immediate (weeks)
Qualitative PSD	Indicates overall corrosivity of the environment	Nonspecific: reacts with classes of pollutants, not necessarily individual gases
Quantitative PSD	Pollutant specific	Complex methodology

- Gas Chromatography is Expensive, requires supplies and maintenance
- For infrared there are different sensors for each component. Nitrogen and hydrogen not detected
- PID sensors controversial issue is their lack of selectivity towards the detected compounds. In principle, without upstream separation techniques such as chromatography or selective filter, it is not possible to determine a chemical individual using photoionization detector measurements only

3.6. Things that are difficult to do

The problem with this technology is that it is currently not advanced enough to be fast in the analysis process and is not cheaper to use. Due it is not mass produced; its price is high making it difficult and costly to acquire any of these technologies.[28]

3.7. Our Decision

When we looking to focus on **art conservation** area or job to be done, ee came up with the idea through brainstorming and came up with a potential and innovative area to use the product. For this we decided to investigate about art and what gas influence it has. We found that there were two types of gases that could be detrimental to works of art that were mentioned above. We gathered the information from different resources such as articles, videos and so on.

[28] Grzywacz, Cecily. (2006). Monitoring for Gaseous Pollutants in Museum Environments. The Getty Conservation Institute: Los Angeles, California 90049-1682. Retrieved from https://www.getty.edu/publications/resources/virtuallibrary/0892368519.pdf

Art of change. Retrieved from https://artofchange21.com/en/what-are-the-main-environmental-impacts-of-a-contemporary-work-of-art/#:~:text=Artworks%20may%20release%20chemical%20substances,puts%20human%20health%20at%20risk.

Also, to learn a little more about this area we decided to go to the Östergotlands museum. There is a specific area of the museum called "art conservation", however, they were not at the museum that day due to work. Even though we got the contacts instead, unfortunately, we could not make an appointment timely.

On the other hand, during the Mid-point presention with the product team, art conservation seems not a potential field, as they explained currently there are several mechanisms and technologies that are special for that area and that this area would be quite competitive. For this reason, we decided to focus on other areas where the PiPe 4.0 team would see potential because even though we sees a good potential according to the research done, they are the ones who know the most about this type of technology. Likewise, during the research we would have discovered current technologies used to detect harmful gases for the conservation of art, which could represent a problem in using the product in that field. Knowing this, through a group meeting we decided to reject this area or job to be done.

For the possible interviews, we also created an interview guide (see below).

Can you tell me about the effect of environmental gases on art objects?	Understand the concept of gases in this area
Can you tell me about the types of gas analysis/detection techniques used in the conservation of art objects in this museum?	know about compeitors and current technnology used
How is gas analysis/detection used to assess the condition and history of art objects?	Identify the use of gas in the art objects history and conditions
What kind of information can be obtained by gas analysis/detection that cannot be obtained by other analytical techniques?	Know about the advantages of gas analysis
Can you give examples of how gas analysis/detection has been used to conserve or restore specific art objects in this museum?	Learn and expand ideas by Examples
How is the data obtained by gas analysis/detection used to determine appropriate storage and display conditions for art objects in the museum's collection?	Understand the use of gas analysis in their conservation actions
What are some of the challenges associated with the use of gas analysis/detection in the conservation of works of art and how are these challenges addressed?	Identify disadvantages/challenges of gas analysis/detection and adresses it
How does the museum ensure that the gas analysis/detection techniques used in the conservation of art objects are reliable and accurate?	Understanding the accurate and reliable techiques uses
How does the museum keep abreast of advances in gas analysis/detection technology and techniques?	What is the museum's knowledge, use, and immersion in gas analysis/detection techniques and technology

4. Agriculture

4.1. Main users

Animal Husbandry

- Laying Hens – Battery Cage

- Broilers – Indoor

4.2. Drivers to use the product

- Health Problems
    - The confinement and overcrowding of birds in battery cages can lead to poor air quality, which can cause respiratory problems and other health issues for the birds.
    - Dust from feed, excrement, and feathers that accumulate can irritate and inflame the respiratory system of the chickens.
    - Ammonia Toxicity: High airborne ammonia levels can irritate the respiratory system and damage the lungs, causing respiratory distress, pneumonia, and death. Poor ventilation, stocking density, and manure management can raise ammonia levels.
    - Fungal Infections: Feed or bedding contaminated with fungal spores can induce respiratory infections such aspergillosis, which can kill birds.
    - Mycoplasma diseases: Crowded, poorly ventilated cages can spread mycoplasma germs, which cause respiratory diseases in chickens.
- Egg/Meat Quality
    - Hens can get respiratory sickness from battery cage air quality. Respiratory sickness reduces egg production and weakens eggshells and albumen.
    - Ammonia: Chicken dung breaks down uric acid into ammonia. Hens' respiratory systems can be damaged by high airborne ammonia. High ammonia levels damage eggshells and lower albumen quality.
    - Carbon dioxide levels, humidity, dust, and odors reduce egg production and weakens eggshells and albumen.
    - Chickens can get infectious bronchitis (IB), a viral respiratory disease that causes sneezing, coughing, and nasal discharge. IB reduces feed intake, growth, egg production and meat quality.
    - Newcastle Disease (ND): Another viral disease that affects chickens, ND causes coughing, sneezing, and nasal discharge. ND can cause paralysis, tremors, and death.

    - Avian Influenza (Bird Flu): Broilers can contract this viral respiratory disease. Commercial poultry operations may experience epidemics from highly contagious AI strains.
- Ethical Concerns
    - Animal Welfare
    - Antibiotics for disease prevention
    - Environmental Impact.

4.3. Processes

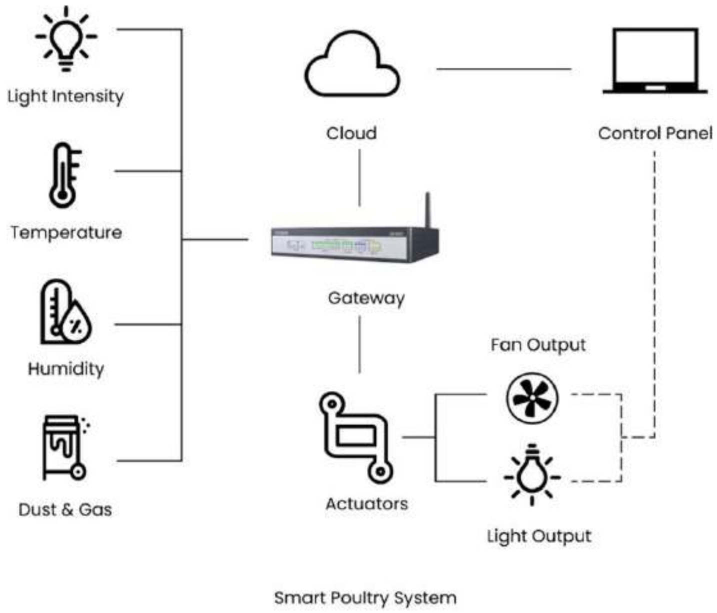
- Gas sensors monitor ammonia, carbon dioxide, hydrogen sulfide, and methane levels in the air. These sensors can monitor these chemicals in real time and warn farmers of health risks.
- Particle counters: Particle counters can be used to monitor the levels of dust and other particulate matter in the air. These devices can provide real-time data on the levels of particulate matter and help farmers identify potential respiratory hazards.
- Temperature, humidity, and air quality are just few of the environmental factors that may be tracked with the use of environmental monitoring systems in poultry houses. These technologies can assist farmers spot potential health risks and give real-time data on the condition of the chicken housing facility.

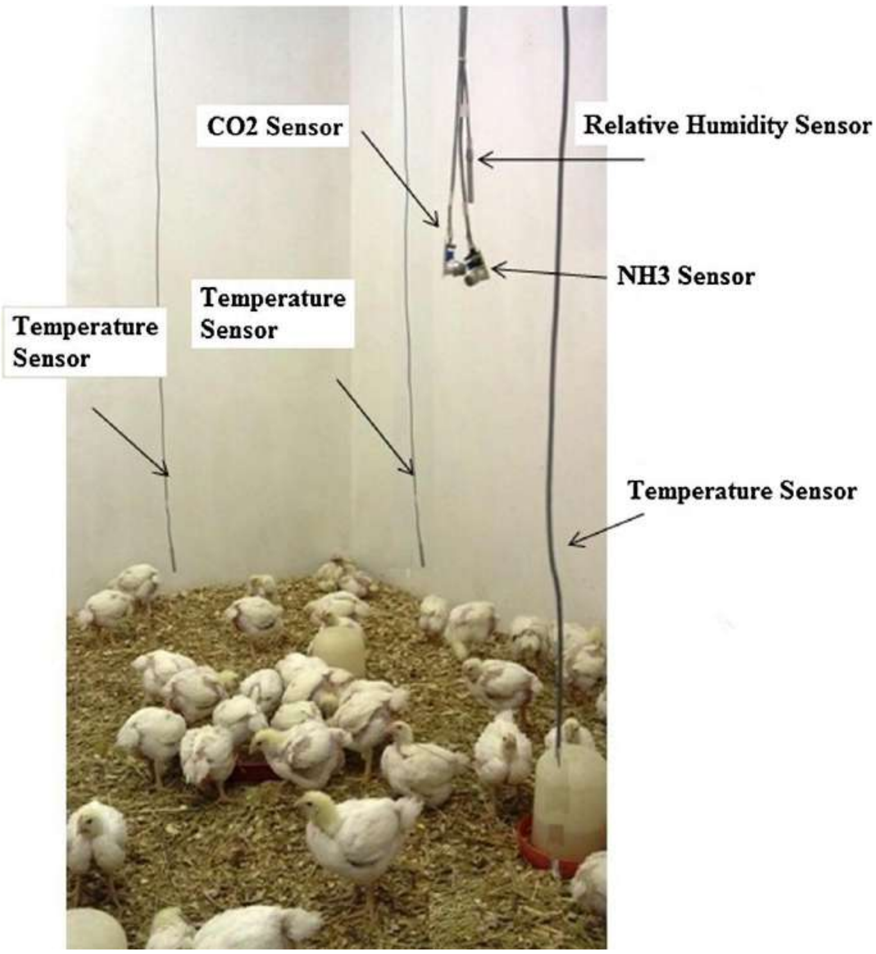
4.4. What do people do (tools and technology)

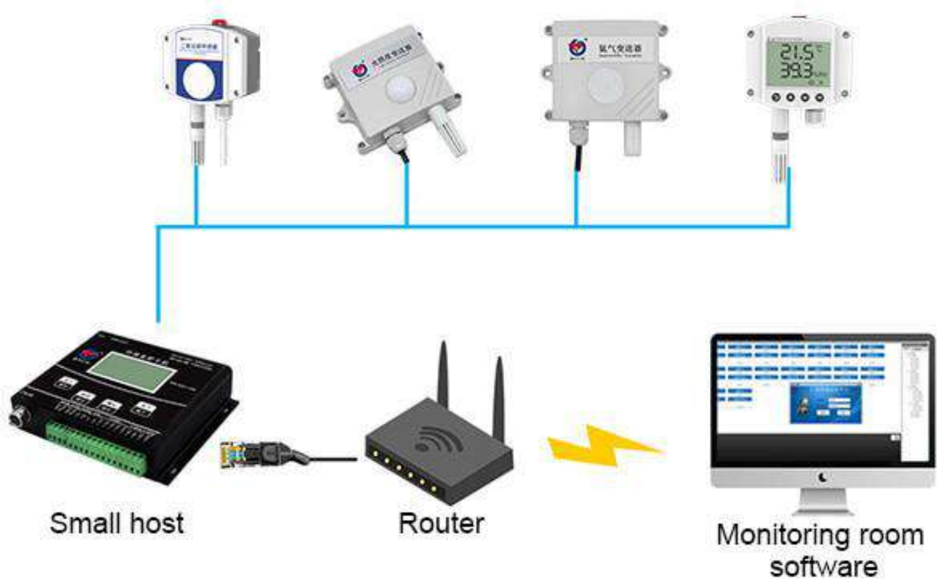
- Real-time PCR testing: PCR testing can detect specific viruses or bacteria in chicken nasal swabs or tracheal washes. Real-time PCR testing lets producers limit disease transmission rapidly and accurately.

- ELISA testing can detect antibodies to viruses or bacteria in chicken blood samples. This can identify illnesses or monitor chickens' immunization responses.
- Electronic Monitoring Systems (Nybsys Smart Poultry system)

- Nybsys Smart chicken optimizes chicken flock health and productivity with electronic monitoring systems. Temperature, humidity, carbon dioxide, ammonia, water quality, and feed intake sensors can be connected to a computer or smartphone app for real-time monitoring.







4.5. Main challenges of users in existing solutions and processes

- Cost: Smaller farmers may find available technology too expensive. When assessing these technologies, installation, maintenance, and replacement costs must be considered.
- Remote or off-grid places may struggle to power some of these technologies.
- Maintenance: These systems need sensor cleaning, calibration, and replacement. Maintenance can prevent inaccurate readings and reduce reliability.
- Sensor placement affects accuracy. Air quality observations in different poultry housing facility locations may require numerous sensors.
- Calibration, sensor drift, and electronic interference can influence sensor accuracy. These factors can cause reading inaccuracies, which can influence monitoring system reliability.
- the sampling frequency of some of these technologies may not be adequate for continuous monitoring of air quality.

4.6. Our Decision

When we first began looking into **poultry farms** as a potential area of focus, we were struck by how unusual it was that farmers there were having such a hard time understanding the causes of mortality. There is a significant chasm between farmers' needs and the technology that is currently available to address these challenges, with most solutions focusing on simple monitoring of methane levels, humidity, and temperature in a given facility.

In order to keep a close eye on things and learn as much as possible from the people who work there, we traveled to a laying farm in Norrkoping, where the most important issue is mortality. We met Mr. Maratab Ali who is working in egg layring farms and condected interview with him to understand the operational work and issues he and his team is struggling with. He especially highlighted the mortality problem and the sverity of this problem.

The plant has sensors, but they told us that they can't always rely on them because of calibration and maintenance issues. We looked into the possibility that Gasraman can play a major part in solving these problems. Farmers can save money by installing a single Gasraman in one central location rather than a scattershot array of sensors across their facility.

However, when we pitched our idea to Pipe 4.0 team, they're aware of the market's potential, but they also know that the current technology is successful and that consumers won't be ready to adopt this notion because of the price. They advised us to drop the plan for the time being in favor of pursuing other leads.

III. Mission 3: Design Brief

As mentioned earlier, after 4 weeks, we ended up with the final topic of the Sports industry.

First, to formulate the final problem and figure out the potential users and markets, we tried to ask some questions:

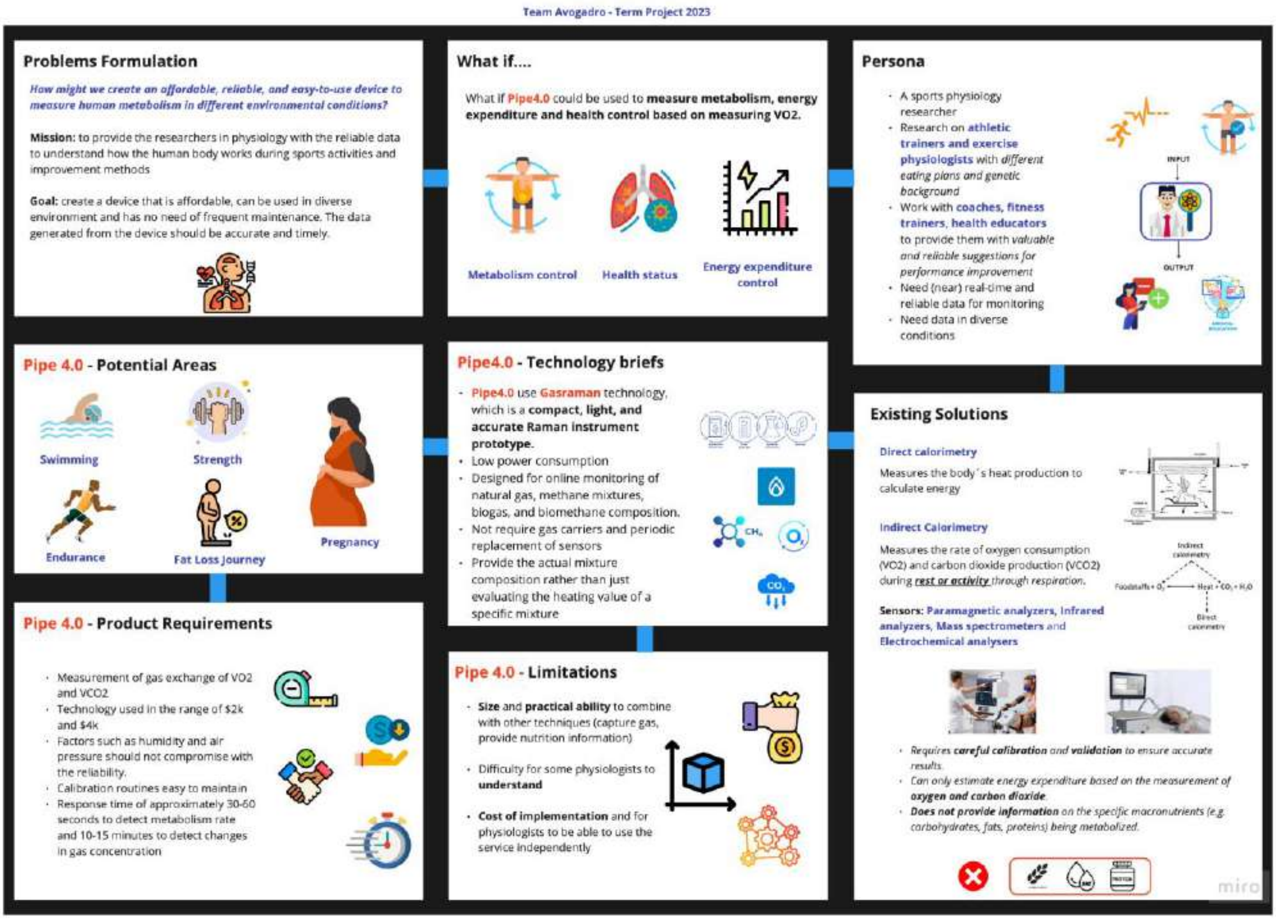
1. What-if questions?

- What if there is a connected application that suggests improvement plans based on the measured data?
- What if the device is not convinient for people to use during the sports activities?
- What if with the help of Pipe 4.0 we could predict the dangers in sports?
- What if with the help of Pipe 4.0 we could have data measured in diverse environmental conditions (water, humid, dry, high pressure, etc)
- What if with the help of Pipe 4.0 we could have data to support the research on genes and eating plans?

2. How might be questions?

- How might we identify potential disease by the gas collecting breath analysis?
- How might we reduce the time to measure?
- How might we research on the connection between metabolism, diabetes, genes and sports?
- How might we design an easy-to-use and user-friendly device?
- How might we make the device works in different environmental conditions?
- How might we notify users timely in case danger is detected?
- How might we make the measurement device affordable and easy to maintain?

3. Design Brief



3.1. Problems (Definition, Goal, Mission)

How might we create an affordable, accurate, and easy to use device to measure human metabolism in different environment conditions?

Mission: to provide the researchers in physiology with reliable data to understand how the human body works during sports activities and improvement methods

Goal: create a device that is affordable, can be used in humid environment and has no need of frequent maintenance. The data generated from the device should be reliable and timely.

3.2. Target Markets

3.2.1. Athletics (Swimming, Strength, Endurance)

- Breath carbon dioxide can be measured to estimate rest and recovery time between workouts.
- Breath analysis can help athletes determine their aerobic threshold, the point at which they switch from fat to carbs.
- Breath analysis helps athletes train better. It measures oxygen and carbon dioxide to assess the body's energy production and oxygen utilization.

3.2.2. The Journey of Fat Loss or Pregnancy

- Carbon dioxide and acetone levels, etc. in breath can suggest metabolism and fat burning. It can help fat-loss trackers.
- Non-invasive mother-fetus health diagnostics. Oxygen and nitric oxide fluctuations indicate respiratory, inflammatory, or metabolic problems.

3.2.3. Side note about the use of Gasraman Spectroscopy for plants

It is worth mentioning that there has been some research on what is called Isothermal Calorimetry: Raman Spectroscopy and measurement of Plants metabolism[29]

This review presents applying a typical chemical method such as isothermal calorimetry and Raman spectroscopy to study the response of plants to abiotic and biotic stress, so how analytical techniques can be used to better understanding of plant physiology. Plants produce heat during metabolism, and measurements of these metabolic heat could lead understanding of plant physiology. Calorimetric measurements have proven to be useful as monitors for many types of biological processes such as seed germination, seedlings growth or plant tissue vitality. Differences in amount of heat production give the information about how big is the impact of stress factors on plant. Raman spectroscopy can be used for in situ analysis of valuable substances in living plant tissue.[30]

This information could be relevant to have some relative information about how Gasraman Spectroscopy could be used to measure metabolism in general and therefore potentially also for human beings. The information could also be relevant as a potential idea. Although we have chosen to narrow down our design brief to measurement of metabolism for physiology research, we still find this information relevant for Pipe 4.0.

4. Further Researchs

4.1. Quick facts

Sport performance

- 80% of professional sports teams use some form of performance analytics (Abdalslam, 2023)
- Increase in player performance by using analytics: 5-10% (Abdalslam, 2023)[31]
- Sports performance analytics market is estimated to grow to $4.4 billion by 2025 (MarketsandMarkets, 2020)[32]

---

[29] https://link.springer.com/chapter/10.1007/978-81-322-0807-5_11

[30] https://www.researchgate.net/publication/271701789_Isothermal_Calorimetry_and_Raman_Spectroscopy_to_Study_Response_of_Plants_to_Abiotic_and_Biotic_Stresses_11

[31] https://abdalslam.com/sports-performance-analytics-statistics#key-sports-performance-analytics-statistics-2023--my-choice

[32] https://www.marketsandmarkets.com/Market-Reports/sports-analytics-market-35276513.html

Sweden - A Sport nation

- 68.9% of the total adult population participates in sports and physical activity on a regular basis (Swedish Sports Confederation, 2023)
- 3.9 million active members in sports clubs and associations (Swedish Sports Confederation, 2023)

Sweden - Physiology research

- >16,000 physiologists (Statista, 2021)
- 1,000 research projects in the field of psychology funded by Swedish Research Council (Swedish Research Council, 2021)

Statistics around the need for indirect calorimetry:

- Resting metabolic rate (RMR) accounts for approximately 60-70% of daily energy expenditure in sedentary individuals. Measuring RMR using indirect calorimetry can provide important information about an individual's energy needs. [33]
- Inaccurate estimates of energy expenditure can lead to underfeeding or overfeeding, which can have negative health consequences. Indirect calorimetry is considered the gold standard for measuring energy expenditure and is recommended for individuals with clinical conditions such as obesity, diabetes, and critically ill patients.[34]
- According to a study published in the Journal of Parenteral and Enteral Nutrition, 77% of dietitians reported that they used indirect calorimetry to determine energy needs in critically ill patients.[35]
- According to a survey conducted by the American Society for Parenteral and Enteral Nutrition, 89% of respondents agreed that indirect calorimetry was an important tool for assessing energy needs in critically ill patients.[36]

---

[33] Li, Ziru., Li, Yin. and Zhang, Weizhen. (2013). Ghrelin Receptor in Energy Homeostasis and Obesity Pathogenesis. *Progress in Molecular Biology and Translational Science*, [online] pp.45–87. doi:https://doi.org/10.1016/b978-0-12-386933-3.00002-9.

[34] Duan, J.-Y., Zheng, W.-H., Zhou, H., Xu, Y. and Huang, H.-B. (2021). Energy delivery guided by indirect calorimetry in critically ill patients: a systematic review and meta-analysis. *Critical Care*, [online] 25(1). doi:https://doi.org/10.1186/s13054-021-03508-6.

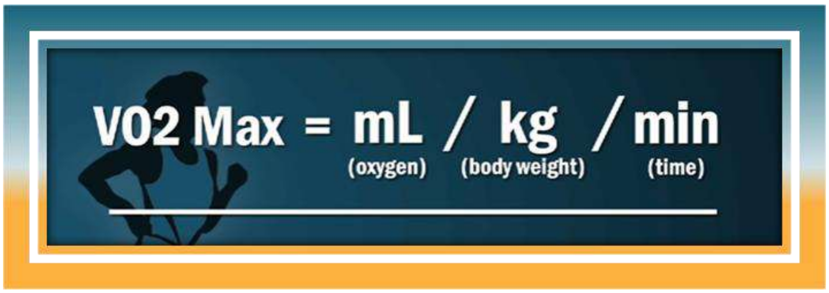
[35] Poster Abstracts. (2022). *Journal of Parenteral and Enteral Nutrition*, [online] 46(S1). doi:https://doi.org/10.1002/jpen.2345.

[36] Mehta, N.M., Skillman, H.E., Irving, S.Y., Coss-Bu, J.A., Vermilyea, S., Farrington, E.A., McKeever, L., Hall, A.M., Goday, P.S. and Braunschweig, C. (2017). Guidelines for the Provision Assessment of Nutrition Support Therapy in the Pediatric Critically Ill Patient: Society of Critical

4.2. Others

4.2.1. Measure performance and metabolism

VO2



VO2 is the maximum volume of oxygen that our body can absorb, transport and consume.

Oxygen is a critical ingredient in the respiratory process that's involved in breathing. As you breathe in oxygen, your lungs absorb and turn it into energy called adenosine triphosphate (ATP)Trusted Source. ATP powers your cells and helps release the carbon dioxide (CO_2) that's created during your respiratory process when you exhale. The benefits are simple: The greater your VO_2 max, the more oxygen your body can consume, and the more effectively your body can use that oxygen to generate the maximum amount of ATP energy.[37]

VO2 measures the concentrations of oxygen and carbon dioxide in the incoming and outgoing respiratory gases. Also, it is performed to determine your pulmonary and cardiac performance or capacity. Rate of oxygen consumption and carbon dioxide production can be calculated, which is then used to determine metabolic rate. Basically, subjects breathe into a mask or mouthpiece connected to the gas analyzer, which measures the concentrations of oxygen and carbon dioxide in the expired air. Normally this is called Indirect calorimetry.[38]

4.2.2. Ppm gas concentration used on Indirect Calorimetry sensors

Typical response time of oxygen sensors is 1–10 s, accuracy and resolution values are reported of 100 ppm in the range of 10–100% oxygen. NDIR CO2CO2 sensors exist, e.g., SprintIR-6S, with a response time (T90) of 300 mmss at a flow rate of 1 LL/minmin, an accuracy of ±70 ppm + 5% of reading and

---

[37] Jewell, T, D. (2023). Everything to Know About VO_2 Max. Medically reviewed by Danielle Hildreth. Healthline. Retrieved from https://www.healthline.com/health/vo2-max

[38] Top Doctors. (n.d.). VO2 max. Diccionario Médico. Retrieved from https://www.topdoctors.es/diccionario-medico/vo2-max

a resolution of 10 ppm CO_2. NDIR CO_2CO_2 sensors exist with an accuracy of ±2.9%, which is ±145 ppm if the exhaled breath contained 50,000 ppm CO_2.[39]

On the other hand, the gas analyzer used in a VO_2 test is designed to measure the percentage of oxygen and carbon dioxide in the air, rather than the concentration in parts per million. The specific concentrations of oxygen and carbon dioxide in the air can vary depending on a number of factors, including the individual's breathing rate and the specific protocol used during the test.

[39] Priem, S., et al., (2023). Indirect Calorimetry in Spontaneously Breathing, Mechanically Ventilated and Extracorporeally Oxygenated Patients: An Engineering Review. MPDI Journal. Retrieved from https://www.mdpi.com/1424-8220/23/8/4143

Sources for further investigation

Ainslie, P.N., Reilly, T. and Westerterp, K.R. (2003). Estimating Human Energy Expenditure. Sports Medicine, [online] 33(9), pp.683–698. https://link.springer.com/article/10.2165/00007256-200333090-00004

Atkinson, G, Davison, R. & Nevill, A. M. (2005). Performance Characteristics of Gas Analysis Systems: What We Know and What We Need to Know. International journal of sports medicine. 26 Suppl 1. S2-10. 10.1055/s-2004-830505.

Attract EU (2020) GASRAMAN | A novel Raman-based sensor for combustible gas analysis.

Youtube link: GASRAMAN | A novel Raman-based sensor for combustible gas analysis

Borel, A. L., Proença Rosselló, R., Tamisier, R., Böhme, P., & Pépin, J. L. (2020). Indirect calorimetry in adults: a systematic review of physiological, methodological and practical issues.

Obesity reviews, 21(6), e13029. https://doi.org/10.1111/obr.13029

Brooks, S. and Mongeau, R. (2003). DIETARY FIBER | Energy Value. Encyclopedia of Food Sciences and Nutrition, [online] pp.1850–1859. doi:https://doi.org/10.1016/b0-12-227055-x/01386-9.

Care Medicine and American Society for Parenteral and Enteral Nutrition. *Journal of Parenteral and Enteral Nutrition*, [online] 41(5), pp.706–742. https://aspenjournals.onlinelibrary.wiley.com/doi/full/10.1177/0148607117711387?casa_token=nLqsSfl9PHkAAAAA%3AIylUp2kSRHxxdkiEg6AUMRSONuCIH2TUqciTZbrlJc239ZkSe2sd1BSTKd7ktnPL-jYE5pMhkl7E8eFN

Cervantes, M.K. and Bross, R. (2022). Energy metabolism and requirements in chronic kidney disease. Nutritional Management of Renal Disease, [online] pp.61–75. doi:https://doi.org/10.1016/b978-0-12-818540-7.00050-1.

Chen, K.Y., Smith, S., Ravussin, E., Krakoff, J., Plasqui, G., Tanaka, S., Murgatroyd, P., Brychta, R., Bock, C., Carnero, E., Schoffelen, P., Hatamoto, Y., Rynders, C. and Melanson, E.L. (2020). Room Indirect Calorimetry Operating and Reporting

Cocola, L., Melison, F., Scarabottolo, N., Tondello, G., Banzato, D., Barbera, E., Bertucco, A. and Poletto, L. "GASRAMAN: a novel Raman-based sensor for combustible gas analysis" https://phase1.attract-eu.com/wp-content/uploads/2019/05/GASRAMAN.pdf

Cocola, L., Melison, F., Scarabottolo, N., Tondello, G., Poletto, L. (2020) "Diode-based Raman sensor for fuel gas analysis," Proc. SPIE 11354, Optical Sensing and Detection VI, 113541A https://doi.org/10.1117/12.2554538

Davison, R.CR., Nevill, A.M. (2005). Performance Characteristics of Gas analysis systems: What we Know and what we need to know. International Journal of sports medicine. Article retrieved from https://www.researchgate.net/publication/8031228_Performance_Characteristics_of_Gas_Analysis_Systems_What_We_Know_and_What_We_Need_to_Know

Davison, R.CR., Nevill, A.M. (2005). Performance Characteristics of Gas analysis systems: What we Know and what we need to know. International Journal of sports medicine. Article retrieved from

De Waele, E. and van Zanten, A.R.H. (2022). Routine use of indirect calorimetry in critically ill patients: pros and cons. Critical Care, [online] 26(1). doi:https://doi.org/10.1186/s13054-022-04000-5.

Ekelund, U., & Besson, H. (2019). What do we know about physical activity and weight loss in obesity and are we doing any harm? Obesity Reviews, 20(2), 255-263. https://doi.org/10.1111/obr.12810

Elia M, Livesey G. Energy expenditure and fuel selection in biological systems: the theory and practice of calculations based on indirect calorimetry and tracer methods. World Rev Nutr Diet. 1992;70:68-131. doi: 10.1159/000422357. PMID: 1429774.

GE Healthcare (2020). Gas Exchange and Indirect Calorimetry. [online] Clinical View. Available at: https://clinicalview.gehealthcare.com/appliguide/gas-exchange-and-indirect-calorimetry

Glaeser, C. (2018). Buyer's Guide to Metabolic Gas Analysis Systems for Sport - SimpliFaster. [online] SimpliFaster. Available at: https://simplifaster.com/articles/buyers-guide-metabolic-gas-analysis-systems/ [Accessed 6 May 2023].

Grzywacz, C.M., (2006). Monitoring for Gaseous pollutants in Museum environments: Tools for conservation. The Getty Conservation Institute. Los Angeles. Retrieved from https://www.getty.edu/publications/resources/virtuallibrary/0892368519.pdf

Harvey-Banchik L, Jackson A, White M, et al. A survey of current practices for determining energy needs in critically ill adult patients. Nutr Clin Pract. 2014;29(4):458-464. doi: 10.1177/0884533614527959. PMID: 24796043.

Indirectcalorimetry.net. (2017). Determining the Accuracy and Reliability of Indirect Calorimeters – Indirect Calorimetry. [online] Available at: https://www.indirectcalorimetry.net/accuracy-reliability-indirect-calorimeters/ [Accessed 6 May 2023].

Jewell, T, D. (2023). Everything to Know About VO_2 Max. Medically reviewed by Danielle Hildreth. Healthline. Retrieved from https://www.healthline.com/health/vo2-max

Korth, O., Bosy-Westphal, A., Zschoche, P., Glüer, C. C., & Heller, M. (2019). Limitations and challenges of metabolic phenotyping in human subjects. Journal of Endocrinology, 242(3), R85-R100. https://doi.org/10.1530/JOE-19-0083

Macfarlane, D.J. (2001). Automated Metabolic Gas Analysis Systems. Sports Medicine, [online] 31(12), pp.841–861. doi:https://doi.org/10.2165/00007256-200131120-00002.

MARIA CRISTINA FLORIAN (2021). Handbook of Gas Exchange and Indirect Calorimetry. [online] Academia.edu. Available at: https://www.academia.edu/41535363/Handbook_of_Gas_Exchange_and_Indirect_Calorimetryhttp:/www.differencebetween.net/science/nature/difference-between-direct-calorimetry-and-indirect-calorimetry [Accessed 2 May 2023].

Matthews, E. (2021). Measuring Energy Expenditure of the Body - Direct and Indirect Calorimetry and Oxygen Consumption. YouTube. Available at: https://www.youtube.com/watch?v=bCjaT_WtwTU [Accessed 5 May 2023].

McClave SA, Spain DA, Skolnick JL, et al. Achievement of steady state optimizes results when performing indirect calorimetry. JPEN J Parenter Enteral Nutr. 2003;27(1):16-20. doi: 10.1177/014860710302700116. PMID: 12549517.

Mtaweh, H., Tuira, L., Floh, A.A. and Parshuram, C.S. (2018). Indirect Calorimetry: History, Technology, and Application. Frontiers in Pediatrics, [online] 6. doi:https://doi.org/10.3389/fped.2018.00257.

Priem, S., et al., (2023). Indirect Calorimetry in Spontaneously Breathing, Mechanically Ventilated and Extracorporeally Oxygenated Patients: An Engineering Review. MPDI Journal. Retrieved from https://www.mdpi.com/1424-8220/23/8/4143

Roberts, C. K., & Barnard, R. J. (2005). Effects of exercise and diet on chronic disease. Journal of Applied Physiology, 98(1), 3-30. https://doi.org/10.1152/japplphysiol.00852.2004

Schoeller, D. A. (2013). Limitations in the assessment of dietary energy intake by self-report. Metabolism, 62(Suppl 1), S44-S47. https://doi.org/10.1016/j.metabol.2012.08.017

Schoeller, D.A., Cook, C.M. and Raman, A. (2013). Energy Expenditure: Indirect Calorimetry. Encyclopedia of Human Nutrition, [online] pp.170–176. doi:https://doi.org/10.1016/b978-0-12-375083-9.00092-1.

Sheean PM, Peterson SJ, Gomez Perez S, et al. The prevalence of inaccurate indirect calorimetry determinations in practice: a structured review. JPEN J Parenter Enteral Nutr. 2010;34(1):55-70. doi: 10.1177/0148607109347593. PMID: 20028939.

Standards (RICORS 1.0): A Guide to Conducting and Reporting Human Whole-Room Calorimeter Studies. Obesity, [online] 28(9), pp.1613–1625. doi:https://doi.org/10.1002/oby.22928.

Swedish Sports Confederation (2023) https://www.rf.se/. [Accessed 3 May 2023]

The BikeFit Physio (2021). Video podcast all about metabolic gas analysis fitness testing using the

PNOE unit. YouTube. Available at: Video podcast all about metabolic gas analysis fitness testing using the PNOE unit.

Top Doctors. (n.d.). VO2 max. Diccionario Médico. Retrieved from https://www.topdoctors.es/diccionario-medico/vo2-max

Westerterp, K. R. (2017). Limitations in the use of basal metabolic rate (BMR) for scaling body composition data. European Journal of Clinical Nutrition, 71(1), 1-2. https://doi.org/10.1038/ejcn.2016.168

Weyer, C., Snitker, S., Rising, R., Bogardus, C., & Ravussin, E. (1999). Determinants of energy expenditure and fuel utilization in man: effects of body composition, age, sex, ethnicity and glucose tolerance in 916 subjects. International Journal of Obesity and Related Metabolic Disorders, 23(7), 715-722. https://doi.org/10.1038/sj.ijo.0800940

Williams, C. B., Satyapal, S., & Fletcher, P. (2014). Challenges in measuring energy expenditure. Journal of Endocrinology, Diabetes and Obesity, 2(1), 1016.

Zaya, R. and Francisco, A. (2020). MEASURING CHANGES IN FUEL UTILIZATION: VALIDATION OF A NEW PROTOTYPE DEVICE. [online] Available at: https://scholarworks.calstate.edu/downloads/5425kg404