PiPe 4.0 Technology

Extended Documentation

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Executive Summary

This document serves to exhibit the iterative process and experiences of Team Ramsay, in a bid to come up with one final design brief. To elaborate, this is our scrap book in which we have documented the evolution from the exploration of several ideas to the exploitation of one ultimate idea, over a period of 5 weeks. The purpose of having this document is to allow any future interested stakeholder to take a closer look into the ideas we did not pursue further to the finish line, which they may find interesting and worth investigating. The contents herein are divided into 6 cumulative sections which are reflective of the missions we had to execute on a weekly basis; hence, for the topics/ideas explored further, replication may be incurred. However, we believe it was necessary for the purpose of our project, as it was supplementary to our understanding of the problems in the dominant areas of application pursued.

Section 1: Introduction of the Pipe 4.0 technology, understanding the jobs it can do.

In the first section, we define the Pipe 4.0 technology in our understanding and highlight the jobs it can do as it important to understand how the technology could be applicable to other areas or industries.

Section 2: Exploration of Several Ideas

In this section we open up to several areas in which the Pipe 4.0 technology could be applicable. In total, we start off with 17 possible ideas and explore them through arms chair research we scan through the market problems and how they are currently being solved. Without delving much into all topics, we quickly ask ourselves about the technological feasibility of our technology and if the idea is worth pursuing further, based on the findings of our arm's chair research. Here, we realize that some of the interesting ideas may not be feasible in the meantime, maybe in the future they could be.

Section 3: Digging deeper into the most promising ideas

Based on the idea analysis in the preceding section, we eliminate the seemingly infeasible ideas and shortlist only 6 ideas from the initial 17. The reason for this exercise is the time constraints we faced, hence the need to scale down the ideas so we could further pursue the more practicable ones. To get a deeper comprehension of these 6 areas of application, we ask additional questions like *Who are the main users?, What are the main pain points?, What are the known problem areas?, What are the unknown problem areas?, and What questions could we ask users in the field research?* This iterative processing of data augments our interpretation of these possible areas of application of the Pipe 4.0 technology.

Section 4: Decision Making: Phasing out Infeasible ideas

After our Mid Term Presentation to the Pipe 4.0 team, we got feedback on the viability of our outstanding ideas. Here we were enlightened about the technology and got reasons why the technology could not be workable in some interesting areas. For example, our supposedly exceptional

Beehive Air Sampling idea was not a feasible area of application as the technology only works in at least 1000PPM gas concentration levels. From this important discussion, we managed to phase out 4 ideas and immediately commenced our field research.

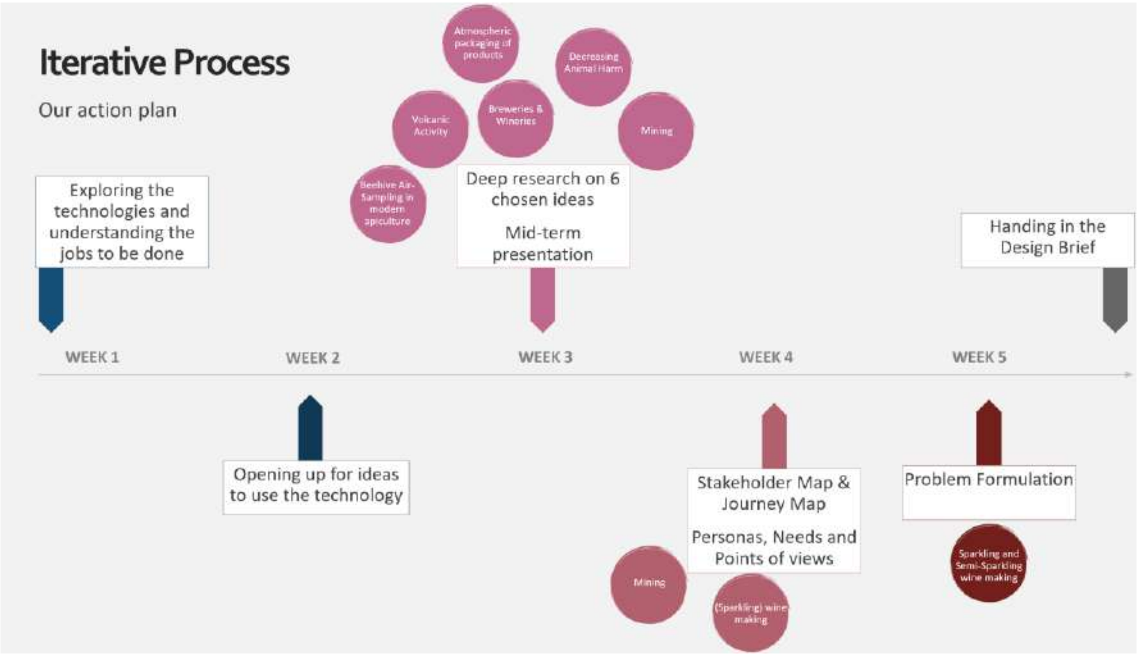
Section 5: Chasing the remaining 2 Ideas: Mining and Winemaking Field Research

This section is a transcription of the field research carried out in the remaining two ideas, i.e., Mining and Winemaking. Interesting angles were discovered in this section, and this highlights the importance of wholesome market research in product development. For both applications, we managed to find areas of application we had not initially thought of e.g., using the Pipe 4.0 technology in the compliance of tax regulations in sparkling and semi-sparkling winemaking and applying the technology in the blasting process of underground mining. Additionally, through engaging with an expert professor in sensor technology research, we browsed through a new area i.e., Fuel Cells. However, due to time constraints, we decided to focus on the two main ideas and follow through with them. Incorporating the field research data, we use several tools such as Personas, POVs and Stakeholder Maps to underline the problems identified.

Section 6: Sticking to the last standing idea and creating a design brief.

In this section we decide on the final idea for the design brief: Sparkling and Semi-Sparkling Wine Making🥂

Visualization of the Process



SECTION 1: INTRODUCTION OF THE PIPE 4.0 TECHNOLOGY, UNDERSTANDING THE JOBS IT CAN DO.

1. What are these pieces of technology and ***what jobs can they do***?

1.1 Technology explained in detail

Monitoring of gas composition

Purpose is development of a compact, light, low-cost Raman instrument prototype with low power consumption for on-line monitoring of natural gas (NG), methane mixtures, biogas and biomethane composition.[1]

- Non-contact (only optical access to gas sample required which can also be provided by using a glass in between the sample and the measurement device).

It is a system consisting of two interconnected units (two-folded technology):[2]

a) A Gas Monitoring Unit (GMU) which performs a measurement of the gas parameters in injection cabins or gas distribution cabins

- Uses Raman spectroscopy as an alternative to gascromatography for mixture composition measurement. The composition of the gas is identified without taking a sample.
- Suitable for any type of gas mixture.
- Ready for remote operations since it does not need any consumable supply
- Not intended for trace elements monitoring.

A novel Raman-based sensor for combustible gas analysis (GasRaman) - ATTRACT Project (attract-eu.com)

b) Self-powered secondary sensors, the Distributed Sensing Unit (DSU) that measures hydrogen content and/or pressure at different points.

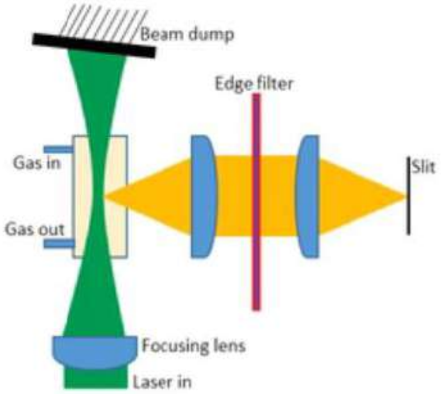
- Uses a diode laser of the lightning-grade types.
- Self-powered by a constant energy production provided by a hybrid tribo/thermoelectric system -> can be even installed where solar energy production is low.

Energy harvesting under harsh conditions: towards a safe oil & gas industry (Energy4Oil) - ATTRACT Project (attract-eu.com)

➔ Device is a reliable and low-cost alternative to current analysis methods and used at the gas pipelines and biogas/biomethane facilities.

[1] Cocola, L., Melison, F., Scarabottolo, N., Tondello, G., Poletto, L. (2020). Diode-based Raman sensor for fuel gas analysis. Retrieved April 5th, 2023, from https://www.spiedigitallibrary.org/conference-proceedings-of-spie/11354/113541A/Diode-based-Raman-sensor-for-fuel-gas-analysis/10.1117/12.2554538.short?SSO=1.

[2] Cocola, L., Melison, F., Scarabottolo, N., Tondello, G., Poletto, L. (2020). Diode-based Raman sensor for fuel gas analysis. Retrieved April 5th, 2023, from https://www.spiedigitallibrary.org/conference-proceedings-of-spie/11354/113541A/Diode-based-Raman-sensor-for-fuel-gas-analysis/10.1117/12.2554538.short?SSO=1.



Measurement of gas

Currently, gas is tested mainly following two techniques:[3]

1) The calorimetric one, which essentially combustion based, and is not able to resolve contaminants and mostly used for clean natural gas and suitable for energy billing purposes.
2) The gaschromatographic one, which is more analytical and performs a complete gas analysis and allows a resolution of contaminants in the part per million range. This is more expensive and requires a supply of a carrier gas.
   a) Gas Monitoring Unit (GMU)

- It can measure the main parameters of fuel gases and therefore determine the composition and heating value of fuel gases.
  - ➔ It is a system suitable for a broad set of gas mixtures within an extremely variable range of compositions.
- Compact, low-cost and low-power instrument, fully automated operation.

   b) Distributed Sensing Unit (DSU)

- Distributed gas parameters (pressure and/or hydrogen content) measured and transmitted to the monitor unit to characterize the gas injection process.
- Full monitoring of gas leakages (detection of undesired contaminants).
- Self-powered sensors.
- Suitability for harsh environment.

1.2 What jobs can they do (Chistensen et al., 2016)?

The technology…

… measures gases and determines its mixture/components
… converts gas flows through temperature difference into energy for self-sustaining purposes
… monitors gases

[3] Cocola, L., Melison, F., Scarabottolo, N., Tondello, G., Poletto, L. (2020). Diode-based Raman sensor for fuel gas analysis. Retrieved April 5th, 2023, from https://www.spiedigitallibrary.org/conference-proceedings-of-spie/11354/113541A/Diode-based-Raman-sensor-for-fuel-gas-analysis/10.1117/12.2554538.short?SSO=1.

SECTION 2: EXPLORATION OF SEVERAL IDEAS

2.1 Decreasing Animal Harm

Topic	Decreasing animal harm following a disease outbreak OR for food production
Problem description	Raising animal welfare standards in the processing of pigs, poultry, and the meat industry as a whole has become a growing concern in recent years. This includes both the methods employed during the slaughtering process as well as the surroundings and food of the animal.[4] <u>Using gas for killing animals (mostly used for poultry: chicken, hens and turkeys)</u> It is the most feasible option for the mass culling of poultry on-farm during among others a disease outbreak: it requires less handling and a higher number of birds can be processed in a relatively short time. A number of gas mixtures can be used to stun and kill poultry. For welfare reasons the HSA suggests:[5] • Any mixture of argon, nitrogen, or other inert gases (maximum of 2% total oxygen by volume) OR • A mixture of argon, nitrogen or other inert gases and CO2 (provided the CO2 does not exceed 30% and maximum free O2 2% by volume). Some commercially available welding gas mixture may be suitable+. Birds can be exposed to these gas mixtures by three methods:[6] (for the explanation of the methods see: https://www.hsa.org.uk/gaseous-methods/gaseous-methods) 1. In the first technique, controlled atmosphere stunning/killing, animals are stunned or killed by exposing them to a specified gas mixture in a gas-filled container or apparatus; the animals are then added. 2. The second technique likewise involves using a controlled environment to kill chickens. This procedure involves putting birds in crates or transport modules before placing them in a sealed container and introducing a gas mixture into it; in other words, the animals are placed inside the container before the gas is turned on. 3. The third method includes injecting gas into a poultry house that has been tightly sealed. The use of foam that is nitrogen-filled falls under this. When stunning and killing using gas, it is essential that the equipment allows the oxygen concentration to be constantly and reliably monitored. It is also advisable that, where

[4] Edinburgh Instruments Ltd. (2018). Monitoring CO2 Concentrations In Pig and Poultry Processing. Retrieved April 11th, 2023, from https://edinburghsensors.com/news-and-events/monitoring-co2-pig-poultry-processing/.
[5] Humane Slaughter Association (2023). Gaseous methods. Retrieved April 11th, 2023, from https://www.hsa.org.uk/gaseous-methods/gaseous-methods.
[6] Humane Slaughter Association (2023). Gaseous methods. Retrieved April 11th, 2023, from https://www.hsa.org.uk/gaseous-methods/gaseous-methods.

	possible, a viewing window allows operators to visually inspect birds while they are in the apparatus or house.[7] <u>Using gas for stunning animals (mostly used for pigs)</u> Stunning is legally required in many countries. Animals must be stunned before slaughter to avoid fear, pain, and distress. Carbon dioxide stunning is the most common method used in Europe.[8] In addition, gassing is very efficient and cost-effective, allowing for faster slaughterhouse operations. Hence, mostly used in mass slaughter. Pigs in commercial CO2 stunning are exposed to high CO2 concentrations (>80% by volume in air), which causes a progressive loss of consciousness. A number of welfare concerns with high concentration CO2 stunning have been identified by recent investigations. These include that:[9] o concentrations >30% are highly aversive (very unpleasant, painful) for pigs. o high concentrations of CO2 gas can cause significant pain to pigs when inhaled. CO_2 exposure causes intracellular acidosis in the mucous membranes, resulting in stabbing pain in the nose, throat and pharynx. o Even a slight increase in the CO_2 concentration in the breathing air results in an increase in the depth of breathing, a feeling of breathlessness develops, which leads to panic and distress for the animals. In human research, low CO_2 concentrations (5% to 35%) are used to induce panic attack. o Insufficient stunning performance if used improperly. o o Before the slaughtering process starts, the temperature of the gas must be verified to be accurate, i.e., to the manufacturer's specifications. The CO2 level in the pit is impacted by temperature variations as well as changes in relative humidity. Throughout the day, deviations could happen because of technical issues. The breathtaking performance will suffer if this is not fixed. The UK's Welfare of Animals (Slaughter or Killing) Regulations 1995 (WASK 95)5 specifically addresses the gas mixtures that can be used for animal stunning purposes and specifies that the carbon dioxide concentration must not exceed 30%. It also mandates the use of devices to measure the maximum concentration by volume and the installation of audible warning systems should concentrations deviate from the law.[10]
The jobs to be done	<u>Using gas for killing animals</u> Monitoring the gas concentration to confirm the death of the animals before the animals are released from the container.

[7] Humane Slaughter Association. (2023). Gaseous methods. Retrieved April 11th, 2023, from https://www.hsa.org.uk/gaseous-methods/gaseous-methods.
[8] European Comission. (2023). Slaughter & Stunning. Retrieved April 11th, 2023, from https://food.ec.europa.eu/animals/animal-welfare/animal-welfare-practice/slaughter-stunning_en.
[9] RSPCA Australia. (2023). Is carbon dioxide stunning of pigs humane? Retrieved April 11th, 2023, from https://kb.rspca.org.au/knowledge-base/is-carbon-dioxide-stunning-of-pigs-humane/.
[10] Instrumatics. (2023). Monitoring CO2 Concentrations in Pig and Poultry Processing. Retrieved April 11th, 2023, from https://instrumatics.co.nz/index.php?p=news/news-monitoring-co2-for-poultry.

	Without measuring the gas concentration and as the humans and animals are apart, the confirmation of death of the animals is difficult and animals which are not killed may go unnoticed. Using gas for stunning animals Monitoring the gas concentration to make sure that the animals are unconscious but do not feel any pain and distress when inhaled. The lack of industry action to address the suffering of animals during slaughter is indicative of a broader problem with the way animal welfare science is funded and governed. In addition, gas monitoring can be used to for gas detection outside the slaughter cabins (gas leakages) to increase personal safety in slaughterhouses (but there are already a few solutions on the market).
How it is done now	• Gascard NG (Infrared Gas Sensor) https://edinburghsensors.com/products/oem/gascard-ng/ Gascard NG is designed to measure one single-use gas at a time. It has the ability to include additional gas detection technology and incorporates on-board sensors for real-time temperature and atmospheric pressure correction. One device specifically used for this purpose is the Gascard NG from Edinburgh Sensors. However, there are many devices which are able to measure the CO2 composition in a closed room.
Conclusion: is it worth pursuing this topic?	The PiPe 4.0 technology might be a low-cost and low-power alternative. More research is needed in terms of what is on the market and how the current technologies work to see the advantages of the PiPe 4.0 technology.

2.2 Mining

Topic	Mining (Warning System for explosive gases and oxygen measurement)
Problem description	Increasing mine explosions emanating from methane ignitions in abandoned workings that breached the mine seals and extended into the active areas or a deficiency in rock dust related to poor rock dusting practices (CDC, 2022).[11] • The buildup of methane in an unventilated area (Ray et al., 2022). The study showed that the major factor contributing to coal mine explosion is accumulation of methane as it contributes about 56% of the total number of accidents. • Significant deaths and fatalities caused by these explosions (Ray et al., 2022).[12]
How it is done now	**History of gas detection in mines (7 Solutions, 2021)** [13] **Wet Blanket and a wick** The first known gas detector or gas tester was developed in the early 19th century. They hired a person to carry a wick with the end lighted on fire while wearing a damp blanket. If

[11] Centers for Disease Control and Health Prevention (2022). Mining Topic: Explosion Prevention. Retrieved April 11th, 2023, from https://www.cdc.gov/niosh/mining/topics/explosions.html.
[12] Ray SK, Khan AM, Mohalik NK, Mishra D, Mandal S, Pandey JK. *Review of preventive and constructive measures for coal mine explosions: An Indian perspective*. Int J Min Sci Technol 2022;32:471–85.
[13] 7 Solutions (2021). *History in gas detection:* Coal Mine Canaries & Flame Safety Lamps. Retrieved April 11th, 2023, from https://7solutions.eu/7solutions-blog/a-brief-history-in-gas-detection-coal-mine-canaries-flame-safety-lamps

	there was a pocket of methane gas, the lit wick would ignite as it was moved down the mine walls. **Singing Canaries (Bird Detection)** Canaries are birds that have been employed to find carbon monoxide and methane, two hazardous chemicals found in mines. The fact that birds in perilous mines died before miners did, allowing the miners time to act, was due to their rapid breathing rate, small size, and high metabolism in comparison to the miners. Canaries in cages would be carried by minors into the mine tunnels, and they would routinely check on the songbirds. Miners knew there was methane present when a canary began shaking its cage or stopped singing, and they had to leave the area right away (7 Solutions, 2021) **Flame Safety Lamp** The flame safety lamp, created by Sir Humphrey Davy in 1815, was a lamp with an oil flame that could be raised to various heights to purify the air. A wire gauze sleeve that encased and absorbed heat served to restrict the flame. As a result, the flame's heat was unable to get through the wire gauze and ignite the methane, preventing further combustion. The light was always lit at the center of the mine, where there was plenty of fresh air. Miners could tell the area lacked oxygen if the flame dimmed or began to die down because fire requires oxygen to survive. They knew the location had both methane and oxygen because the flame would increase in height. **The modern era of gas detection** Dr. Oliver Johnson's invention of the catalytic combustion (LEL) sensor in 1926–1927 marked the beginning of the current era of gas detection. In 1926, he started working on a demonstration model known as the Model A as he started researching and developing a way to identify combustible combinations in the air to assist prevent explosions in fuel storage tanks. With the introduction of the Model B in 1927, production of the first usable "electric vapor indicator" meter got underway. Dr. Oliver Johnson and Phil Williams founded Johnson-Williams Instruments, also known as J-W Instruments, the first gas detection business in the world, in Palo Alto, California, in 1928. The first electronics business in Silicon Valley is known to have been J-W Instruments. J-W Instruments set many "firsts" throughout the ensuing 40 years. Before the 1980s and 1990s saw the development of electronic home carbon monoxide detectors, the only way to detect the presence of the gas was with chemically infused paper that turned brown when exposed to it. Since then, a wide range of electronic technologies and apparatus have been created in order to identify, track, and notify gas leaks of all kinds. Electronic gas sensors have been implemented into a larger variety of devices as their performance and cost decreased. Gas sensors were originally employed in cars to manage engine emissions, but they can now also be utilized to assure passenger comfort and safety. Buildings are getting carbon dioxide sensors as a part of demand-controlled ventilation systems. Research is being done on sophisticated gas sensor systems for application in medical diagnosis, monitoring, and treatment systems beyond their initial use in operating rooms. In the Netherlands, it is becoming legally necessary to have gas monitors and alarms for carbon monoxide and other toxic chemicals in homes and offices (7 Solutions, 2021). The innovation in gas detection keeps evolving and it keeps improving. • Any gasses are detectable with electrical components like VOCs with a PID and hydrocarbons and CO2 with an infrared sensor

	Disadvantages of using sensors in gas detection (MacKenzie-Wood, 2011)[14] Calibration is required. This normally involves a daily check on zero and voltage, a weekly span check and a calibration test by an authorized external authority every 6 months. • Sensors have a finite life. If not dated by the manufacturer, the date of acquisition should be inscribed. • Sensors can be poisoned. • Sensors may suffer from cross-sensitivity. • Overexposure may saturate the sensor causing its slow recovery. • Inclination may affect the reading (Risk of inaccuracies). • Batteries require charging and regular discharging. **However;** There are possibilities that we still can't even detect half of the existing gasses with a sensor hence the need to use other emerging technologies like the Pipe4 which uses the Raman Spectrometer.
Conclusion: is it worth pursuing this topic?	While the technologies in detecting gases in mines have evolved over the years, the modern technology used in detecting the gas in mines still has quite a number of shortcomings especially the fact that the sensors could be compromised, and the readings could be affected hence causing inaccuracies. The Pipe4.0 technology which uses the Raman effect could be the solution as it is quite accurate and there is no risk of the measuring elements being compromised as long as there is good optical quality.

2.3 Fire Fighters

Topic	Warning systems for (potentially explosive) dangerous gas as important equipment of fire fighters.
Problem description	Measuring gas composition in their environment is an important action conducted by fire fighters in order to plan further actions, use the of resources and ensure the safety of their own, civilians or the environment. Firefighters mostly use detectors to monitor four or five different gases in the environment, such as: oxygen (O2), carbon monoxide (CO), hydrogen sulfide (H2S), and lower explosive limit (LEL); potential fifth one: ionization potential (IP) or sulfur dioxide (SO_2) (CO, H_2O H2S, SO2 and the IP are monitored with ppm, O2 and LEL are measured in percentage).[15] Existence of toxic twins: carbon monoxide (CO) and hydrogen cyanide (HCN), both dangerous or even deadly, are together even worse; both are colorless, CO is odorless and HCN has odor of almonds (which could be masked by smoke or smells[16]
How it is done now	Multi-gas meters are used daily in different settings. Even though they are produced by different manufactures, they all are based on the same basic operations.

[14]MacKenzie-Wood, P. (2011). Detection of gases. Retrieved April 10th, 2023, from https://www.iloencyclopaedia.org/part-xi-36283/mining-and-quarrying/item/608-detection-of-gases#:~:text=There%20are%20also%20some%20disadvantages,for%20CO2%20or%20hydrogen.
[15] Fire Engineering. (2015). The Multigas Meter. Retrieved April 11th, 2023, from https://www.fireengineering.com/firefighting/the-multigas-meter/
[16] Drägerwerk AG & Co. KGaA (2023). Gas Detection on the Fire Ground. Retrieved April 11th, 2023, from https://www.draeger.com/en-us_us/Safety/Firefighting/Gas-Detection.

	• Dräger: Identifying air contaminants (Dräger distinguishes between single, dual and multi gas detectors.[17] ○ Colorimetric detector tube technology, which provides accurate analysis of gases and vapors → Technology aims on replacing conventional laboratory analysis and providing results right on site. ○ Measurement possible with low level of gas. ○ Selective gas measurement possible due to different layers which can serve as filter → significant reduction of cross-sensitivities and number of false-positive test results. ○ Life-span of one year. ○ Device is powered by five AA batteries, which enable a testing of ten hours. ○ Connector piece of Dräger allows measurement for longer distance. ○ Example device: Dräger X-act 7000: consists of Dräger MicroTubes (10 measurements per MicroTube possible) and opto-electronic analysis device that lets you precisely measure gases in the low ppb range.[18] • Bertin technology: Second Sight gas detection system that allow early warning and real-time visualization of suspicious clouds. ○ The system works with infrared (IR) gas cloud detector, which is also working in open area or harsh conditions.[19]
Conclusion: is it worth pursuing this topic?	The topic suggests much potential for the application of the Pipe4.0 technology, especially in light of it's ability to measure gas composition based on optical analysis. However, in light of the broad range of already offered solutions, we decided to not further pursue this topic.

2.4 Volcanic Activity

Topic	Natural Disasters (Volcanic Activity)
Problem description	The composition of gases could forewarn of increased volcanic activity. Analyzing the magma gas composition could aid in the forecasting of potentially harmful volcanic eruptions. The information gained from this discovery will be used by researchers to create a system for continuously monitoring and alerting about volcanic activity. In 2022, scientists from the University of Tokyo discovered that the ratio of atoms in particular gases produced from volcanic fumaroles, or openings in the Earth's surface, can serve as a proxy for the condition of the lava below. Changes in the ratio of argon-40 and helium-3, in particular, can show how foamy the magma is, which signals the likelihood of various eruption types.[20]

[17] Drägerwerk AG & Co. KGaA (2023). Gas Detection on the Fire Ground. Retrieved April 11th, 2023, from https://www.draeger.com/en-us_us/Safety/Firefighting/Gas-Detection.
[18] Drägerwerk AG & Co. KGaA (2023). Dräger X-act 7000. Retrieved April 11th, 2023, from https://www.draeger.com/en-us_us/Products/X-act-7000.
[19] Bertin technologies (2023). Turnarounds for leak detection. Retrieved April 11th, 2023, from https://www.bertin-technologies.com/gas-detection/application/turnarounds-for-leak-detection/.
[20] Obase T., Sumino, H., Toyama, K. et al. (2022). Monitoring of magmatic-hydrothermal system by noble gas and carbon isotopic compositions of fumarolic gases. *Scientific Reports*, 12 (17967).

	(see more about this research here: https://scitechdaily.com/evading-volcanic-disaster-monitoring-frothy-magma-gases-for-eruption-signals/?utm_content=cmp-trueand https://www.nature.com/articles/s41598-022-22280-3)
How it is done now	For now, gas samples have to be collected out in the field and brought back to the lab for analysis, which is a challenging and time-consuming process. The researchers' next objective is to create a portable technology that can offer on-site, real-time measurements for a 24/7 monitoring and early warning system for volcanic activity. [21]
Conclusion: is it worth pursuing this topic?	There is a possibility that the Pipe 4.0 technology could measure the gases from a distance without requiring a human going into the volcano field. Further research is needed to get a deeper understanding, also, about the technologies in place used in this field.

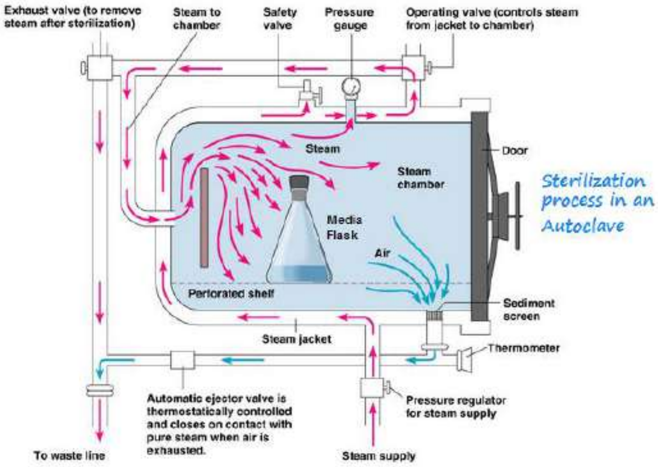
2.5 Earthquake Warning

Topic	Natural Disasters (Earthquake Warning)
Problem description	The Earth's crust may leak gases like radon or carbon dioxide before an earthquake. Some animals can identify these gases due to their specialized sensors or receptors. Gases like radon and argon, which are created when radioactive substances decay underground, are found in minute concentrations in rocks. Even in rocks as small as a soda can, these gas molecules can build up over millions of years to levels that are thousands of times greater than the background. These gases may be generated when rocks are stressed by occurrences like volcanic eruptions or earthquakes. By monitoring the release of helium and argon, scientists can detect real-time deformation in a rock before the rock begins to break.[22]
How it is done now	Seismographs are instruments used to record the motion of the ground during an earthquake.
Conclusion: is it worth pursuing this topic?	The idea is not promising due to more reliable measurement techniques in place.

2.6 Medicine & Pharmaceuticals

Topic	Meeting regulations and ensuring product quality as well as personnel safety in the production of pharmaceuticals
Problem description	Gas measurement in pharmaceuticals is needed during the sterilization process of products such as drugs, medical devices, and packaging materials. There are numerous methods and gases used for sterilizing medical devices such as moist heat (steam), dry heat, radiation, ethylene oxide gas, vaporized hydrogen peroxide, and

[21] University of Tokyo (2022). Evading Volcanic Disaster: Monitoring „Frothy" Magma Gases for Eruption Signals. Retrieved April 12th, 2023, from https://scitechdaily.com/evading-volcanic-disaster-monitoring-frothy-magma-gases-for-eruption-signals/?utm_content=cmp-true.
[22] Lipuma, M. (2016). Gas released from rocks can predict impending breakage. Retrieved April 12th, 2023, from https://blogs.agu.org/geospace/2016/12/30/gas-released-from-rocks-can-predict-impending-breakage/#:~:text=When%20rocks%20are%20put%20under,the%20rock%20begins%20to%20break.

	other sterilization methods (for example, chlorine dioxide gas, vaporized peracetic acid, and nitrogen dioxide).[23] Gases like ethylene oxide (ETO) and hydrogen peroxide (H2O2) are commonly used for sterilization, and their concentrations need to be carefully monitored and controlled to ensure effective sterilization while avoiding residues that could be harmful to patients or compromise product quality.[24] The sterilization process in an autoclave  (please find more information on the process here: https://www.sciencedirect.com/topics/engineering/sterilization-chamber) Further areas: • The environmental monitoring within the production halls is important for personnel safety. • In research on drug discovery, development and quality control it is needed to know components of gas (gas chromatography is often used here). • Packaging integrity testing such as blister packs and vials to ensure that they are sealed properly and maintain their integrity during storage and transportation (helium leak testing and carbon dioxide headspace analysis are commonly used).
How it is done now	https://ionscience.com/en/industries/pharmaceutical-and-medical/ https://www.coregas.com.au/applications/pharmaceuticals-and-biotechnology https://www.sgs.com/en/services/gas-analysis-in-pharmaceutical-production https://www.solidtoo.com/en/ncg-sensor-system/#voordelen In addition to chemical sterilization methods, there are also physical ones by using heat, radiation or filtration.
Conclusion: is it worth pursuing this topic?	Especially for personal safety, there are already various devices in place where the PiPe 4.0 technology does not have any advantages. Also during the sterilization process, gas measurement devices are integrated ensuring the process.

[23] U.S. Food & Drug Administration (2023). Sterilization for Medical Devices. Retrieved April 12th, 2023, from https://www.fda.gov/medical-devices/general-hospital-devices-and-supplies/sterilization-medical-devices.
[24] U.S. Department of Health & Human Services (2023). Disinfection & Sterilization Guidelines. Retrieved April 12th, 2023, from https://www.cdc.gov/infectioncontrol/guidelines/disinfection/tables/table6.html.

2.7 Contamination

Topic	Detection of radioactivity leakages and radon in homes and public services such as schools and offices.
Problem description	The radioactive gas radon has no flavor, color, or odor. All rocks and soils contain uranium, which naturally decays into radon in the process. Water can contain radon as well. High amounts of the gas may be found in enclosed spaces like houses and offices.[25] In the air, radon that has escaped from the ground undergoes radioactive decay and creates new radioactive particles. These particles are deposited on the cells lining our airways when we breathe, where they have the potential to harm DNA and result in lung cancer. According to estimates, radon causes from 3% to 14% of all lung cancers in a nation, depending on the average radon level there and the incidence of smoking.[26]
How it is done now	Leak detection methods like radiotracers and thermography can help find leaks and, as a result, reduce the performance and financial problems they cause. There are various cost-effective testing devices available which measure Radon in long-or short-term in closed rooms such as homes or offices. Those devices can be used for self-checking or by professionals.
Conclusion: is it worth pursuing this topic?	There are already lots of devices in place fulfilling the same purpose as the PiPe 4.0 technology. However, there might be the possibility to use the DSU for faster and cheaper energy production through nuclear power due to the temperature difference.

2.8 Aerospace

Topic	Monitor for in-flight conditions and air quality maintenance to ensure crew productivity, as well as overall passenger comfort and safety. Space Exploration (Mars and Moon)
Problem description	• Possible gas leakages • Toxic, harmful gases (criminal activities) No visible problems
How it is done now	Portable Gas Detectors
Conclusion: is it worth pursuing this topic?	Based on the field research, the coal transportation idea is more applicable to ships and not necessarily to aerospace.

2.9 Fracking

Topic	Measurement of greenhouse gas out of drilling sites and pipelines as a result of fracking
Problem description	Fracking, also known as hydraulic fracturing, is a method for extracting gas and oil from shale rock. To liberate the gas inside a layer of rock, it entails drilling into the earth and applying high pressure to a solution of water, sand, and chemicals.[27]

[25] World Health Organization (2023) Radon. Retrieved April 12th, 2023, from https://www.who.int/health-topics/radon.
[26] World Health Organization (2023). Radon. Retrieved April 12th, 2023, from https://www.who.int/health-topics/radon.
[27] BBC News Services (2022). What is fracking and why is it controversial? Retrieved April 13th, 2023, from https://www.bbc.com/news/uk-14432401.

	A fracking site can be anywhere with natural gas and starts at 2500-3000 meters in the earth. Fracking fluid is pumped down into the well so high that it cracks the shale rock creating fractures through which the trapped gas and oil can escape. The general consensus is that burning natural gas is better for the environment than burning coal. However, methane that leaks out during the drilling and pumping process is many times more potent than carbon dioxide as a greenhouse gas. (See the process here: https://www.youtube.com/watch?v=Tudal_4x4F0)
How it is done now	Gas leakage is currently tolerated as a side-effect of Fracking. Nevertheless, it is being criticized by many environmental activists and the whole process of Fracking is therefore being questioned. Especially as gas is a non-renewable raw material, the potential in renewable energies is currently seen as much higher for the future.
Conclusion: is it worth pursuing this topic?	Gas measurement during Fracking seems not to be a job to be done as the release of the gases is tolerated as a side-effect.

2.10 Breweries & Wineries

Topic	Monitoring of fermentation process and securing the health and safety of the personnel
Problem description	Quality of fermentation process • Measuring the gas can provide important information about the progress and health of the fermentation process. If the concentration of CO2 is too low, it may indicate that the fermentation has stalled or stopped. If the concentration is too high, it may indicate that the yeast are producing too much CO2 and may be stressed or dying. • Besides CO2, oxygen or hydrogen sulfide can also provide valuable insides in the fermentation process.[28] Safety of personnel • Fermentation produces a quantity of CO2 (colorless and odorless gas), which can be a danger for the personnel of wineries or breweries.[29] • Carbon produced by winemaking "five times more concentrated than planes".[30] • Temperatures and conditions have to be carefully controlled.[31] • Besides CO_2, multiple other gases are an additional risk for the personnel. Besides carbon dioxide, sulfur dioxide (SO_2) and ethanol (C_2H_6O) also are potential risks. Thus, it is recommended to install combustible gas detectors.[32]
How it is done now	Quality of fermentation process

[28] Hiden analytical (2022). What equipment to use for fermentation monitoring. Retrieved 12th, 2023, from https://www.hidenanalytical.com/blog/what-equipment-use-fermentation-monitoring/

[29] Beeandthistlewinery. (2020). Carbon dioxide: dangers of CO2 in the winery. Retrieved 12th, 2023, from https://beeandthistlewinery.wine/winemaker-weekly/2020/6/8/co2-in-the-winery

[30] Shaw, L. (2019). Carbon produced by winemaking 'five times more concentrated than planes'. Retrieved 12th, 2023, from https://beeandthistlewinery.wine/winemaker-weekly/2020/6/8/co2-in-the-winery

[31] Edinburgh Sensors (2019). The role of CO2 measurement in wine production – wine gas. Retrieved 12th, 2023, from https://edinburghsensors.com/news-and-events/co%E2%82%82-measurement-wine-production/

[32] Gazdetect (2022). CO2 hazards in winery & brewery. Retrieved 12th, 2023, from https://en.gazdetect.com/blog/co2-hazard-in-winery-brewery

	• Gas analyzers for fermentation monitoring are providing real-time analysis of sample off-gases for species that are critical to a fermenter's product yield.
	• Multi-stream fermentation analysis system possible.[33]
	
	Safety of personnel
	Different system deployed to monitor and mitigate hazard of CO_2 exposure; CO_2 monitor near the floor level (as CO_2 is heavier than air):
	• Example company: Edinburgh Sensors:[34]
	  ○ Range of instruments ideal for CO_2 measurement, gas detection and monitoring.
	  ○ Example product: GasCheck CO_2 sensor, which allows CO_2 detection for concentrations between 0-3000 ppm; measurement is unaffected by 0-95% relative humidity.
	  ○ Some detectors only weight 125g.
	• Example from Webpage GazDetect:[35]
	  ○ Offers/shows different CO_2/Multi-gas detectors, that already enable the measurement of gas.
	  ○ Fixed as well as portable gas detectors offered.

Conclusion: is it worth pursuing this topic?	Potentially interesting application, as Pipe-technology allows measurement through glass or crystals. However, further research is beneficial.

2.11 Regulation Monitoring and Testing for Coal Cargoes (Gas monitoring and ventilation)[36]

Topic	Tracking air emissions to ensure compliance with rules (for vehicles, ships, and boats) and protecting the production process (by ensuring the quality of gases produced and used on the customer's side). Important to collect precise gas measurements in order to establish the appropriate ventilation needs (Safety4sea, 2022). Accurate gas measurements must be taken in order to calculate the proper ventilation needs because improper ventilation can also result in a cargo fire or explosion.
Problem description	• Potential gas leaks. • Hazardous, toxic gases (criminal activity). • The International Maritime Solid Bulk Cargoes (IMSBC) Code mandates that ships carrying coal monitor the concentration of methane inside the cargo holds using external sampling stations because methane is a combustible gas. For this purpose, many carry around portable gas detectors.

[33] Hiden analytical (2022). What equipment to use for fermentation monitoring. Retrieved April 12th, 2023, from https://www.hidenanalytical.com/blog/what-equipment-use-fermentation-monitoring/.
[34] Edinburgh Sensors (2019). The role of CO2 measurement in wine production – wine gas. Retrieved April 12th, 2023, from https://edinburghsensors.com/news-and-events/co%E2%82%82-measurement-wine-production/.
[35] Gazdetect (2022). CO2 hazards in winery & brewery. Retrieved April 12th, 2023, from https://en.gazdetect.com/blog/co2-hazard-in-winery-brewery.
[36] Safety4sea (2022) Watch: How to conduct a proper gas measurement of coal cargoes. Retrieved April 12th, 2023, from https://safety4sea.com/watch-how-to-conduct-a-proper-gas-measurement-of-coal-cargoes/

How it is done now	**Portable Gas Detectors** The majority of portable gas detectors used at sea have catalytic sensors for combustible gases. The hold's oxygen level will drop if the coal starts to oxidize and self-heat. The catalytic sensor's flammable gas measurements might not be reliable if the oxygen content drops to 10% or less. If the amount of methane in the hold environment is greater than 100% of its Upper Explosive Limit, catalytic sensors may also give misleading readings for flammable gases. **Disadvantages** To ensure that there is enough oxygen present for the flammable gas readings to be accurate, the sample taken from the cargo hold must be diluted in order for the measurement to be accurate. To do this, a regulated amount of external air must be added. **Infrared Gas Detectors** Regardless of the oxygen level, a cargo hold's methane content can be measured using an infrared gas detector. Additionally, flammable gas concentrations above the UEL can be measured by infrared gas detectors.
Conclusion: is it worth pursuing this topic?	The Pipe4.0 technology using the Raman effect could be used effectively as it is able to measure the gas composition without touching the gas hence the risks of inaccuracies are lower. Also, the Pipe4.0 technology hold another important advantage that it does not require any adjustments for accuracy like the portable gas detectors used, hence it could be the best alternatives to be used for increase safety of ship passengers' as it is more accurate.

2.12 Prediction of Diamonds

Topic	Prediction of Diamonds through the measurement of emanating gases from the earth
Problem description	The source of diamond-forming carbon is the methane component produced by the solid–solid decomposition of methane hydrate. Subsequently, diamond formation is the result of the molecular dissociation and polymerization of methane.[37] Predicting the presence of diamonds through gases typically involves analyzing the composition and characteristics of gases in the vicinity of diamond deposits through:[38] • Indicator Gases such as methane (CH4) and hydrogen (H2). • Geochemical Signatures. • Soil Gas Sampling (collection of gas samples from the soil in areas where diamonds are suspected). • Remote Sensing Techniques such as airborne or satellite-based spectroscopy.
How it is done now	Geochemical analysis (for more information see here: https://www.jstor.org/stable/24111889)
Conclusion: is it worth pursuing this topic?	The prediction of diamonds through gases is not foolproof and other factors such as geological data seem to be more promising to do this job.

[37] Kadobayashi, H., Ohnishi, S., Ohfuji, H. *et al.* (2021). Diamond formation from methane hydrate under the internal conditions of giant icy planets. *Scientific Reports,* 11 (8165).
[38] Kadobayashi, H., Ohnishi, S., Ohfuji, H. *et al.* (2021). Diamond formation from methane hydrate under the internal conditions of giant icy planets. *Scientific Reports,* 11 (8165).

2.13 Measuring Gas in Shipping Containers

Topic	Gas measurement in Shipping Containers as important element of securing the safety of employees, which otherwise could be exposed to dangerous gases.
Problem description	To stop the spread of viruses or infections, shipping containers are frequently gassed before being opened. The procedure, which is also known as fumigation, "is normally performed by licensed specialists who adhere to rigorous safety regulations to ensure that the gas is utilized properly and successfully. To let people know they have been fumigated and are safe to handle, the treated containers are typically labelled with a warning label or certificate.[39] This intentionally placed gas in a container is a potential risk for personnel. Besides that, also unintentionally gas, e.g., off-gassing from products, could also be dangerous for the personnel.
How it is done now	Gas detection tubes and sensors are used in the conventional method to find and measure the gas in containers. This method has a number of drawbacks. It is expensive, time-consuming, and might have a standard variation of as much as 20%. The target gases that can be measured using this method are also few in number. The Gasmet FTIR approach is a more advanced method. One of the main benefits of this method is that, as opposed to only one or a small number of components, FTIR analyzers can simultaneously detect hundreds of components. You can precisely identify the gases present in a container and their concentrations thanks to test findings. The FTIR analyzer works quickly and provides reproducible, visible, and clear readings in just a few minutes. The results are real-time. Each gas has its own infrared spectrum which the analyzer can read to determine what gas is in the container.[40] <u>FTIR Technology</u> An FTIR (Fourier Transform Infrared) gas detector operates by examining how gases in a sample absorb infrared light. Although there are some design differences, the fundamental idea behind an FTIR gas detector is similar to that of a spectrophotometer. An IR source that generates a beam of IR radiation through the sample gas makes up the detector. A detector on the other side of the gas cell then collects the radiation. Radiation flows via a Michelson interferometer, which divides it into two beams, before it reaches the detector. While the other beam travels through a reference gas, typically air, the first beam travels through the sample gas. Recombining the beams results in interference between them, which creates an interferogram—a display of the radiation's strength as a function of wavelength. An absorption spectrum of the sample gas is created by mathematically transforming the interferogram using a Fourier transform technique. The gas kinds and concentrations in the sample are revealed by the absorption spectrum. Volatile organic compounds, greenhouse gases, and hazardous gases are just a few of the many gases that the FTIR gas detector is capable of detecting. It is frequently used in applications for environmental monitoring, industrial hygiene, and process control since it is a non-destructive and non-intrusive method of gas detection. The method is an

[39] Hygiene-standard. (2023). Background: Validatable container preparation with reproducible disinfection quality. Retrieved 05th, 2023, from https://hygiene-standard.com/en/container-desinfektion
[40] Greensen, J. (2021). The Importance of Measuring Gas in Shipping Containers. Retrieved 05th, 2023, from https://www.customssupport.com/insights/importance-measuring-gas-shipping-containers

	indispensable tool in many gas detection applications since it is extremely sensitive, precise, and fast.[41]
Conclusion: is it worth pursuing this topic?	General advantage of the Pipe technology is that you do not need a sample. However, further research into current technology beneficial.

2.14 Beehive Air-Sampling in modern apiculture

Topic	Beehive air measurement in beekeeping (Szczurek and Maciejewska, 2021).[42]
Problem description	Alarming decrease in bee population around the world emanating from; • shifting flowering seasons due to climate change. • reduced floral diversity. • use of pesticides. • habitat loss, lack of genetic diversity. • insect parasites • harmful microorganisms Bee populations must be kept in the best possible health and given opportunities to expand if bee colony losses are to be avoided. Unique and complicated, the gaseous mixture inside the hive is made up of several volatile chemicals. These substances come from a variety of sources, including the bees themselves (pheromones, other chemicals released to ward off pests and predators, metabolites, etc.), honey, nectar, larvae, beeswax, pollen, and propolis; the materials used to build hives (wood, paint, plastic, etc.); and external sources, such as nearby homes, businesses, and vehicles. For a honeybee colony to survive, the air in the hive must have a precise chemical makeup. It produces the distinctive and essential nest odor which is responsible for the fundamental and important task of identifying the colony's inhabitants. Beehive air's chemistry provides insight on the cleanliness of the hive and the health of the honeybee colony. Therefore, it's crucial to gauge the beehive's temperature and air quality in order to maintain the health of the bees.
How it is done now	Gas sensing devices are used in which are capable of detecting, identifying, and quantitating the specific chemical species in beehive air: • Infrared analyzers • Fourier-transform infrared spectrometers (FT-IR spectrometers) • Ion mobility spectrometers (IMS) • gas chromatographs with an appropriate detector (usually FID • tuned mass spectrometer MS or other mass-selective detector)

[41] Gasmet Technologies Oy. (2023). FTIR – Fourier Transform Infrared. Retrieved April 17th, 2023, from https://www.gasmet.com/products/technology/ftir-fourier-transform-infrared/

[42] Szczurek. A, Maciejewska M. (2021). Beehive Air Sampling and Sensing Device Operation in Apicultural Applications-Methodological and Technical Aspects. Retrieved April 17th, 2023, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8230472/#:~:text=Beehive%20air%20contains%20gases%20as%20well%20as%20particulate%20matter.

	Pros • objectivity • good accuracy • sensitivity • repeatability **Cons** • Environmental impact (The beehive and ambient environment) during gas sensing device operation in field conditions, they significantly affect the measuring process and make it more complicated. • the cost of such analytical instruments is prohibitive and beyond the reach of the average beekeeper. • equipment is bulky in size, heavy in weight, inconvenient to transport. • High energy consumption. • Measurement procedure is time-consuming and labor-intensive. • trained and experienced personnel is required to attain reliable measurement results. **Other alternatives** 1. Measuring instruments based on **Sensor technology** . They allow to reduce the cost of tests and increase the number of applications in field conditions. **Advantages** Low-cost sensing systems often cost orders of magnitude less than conventional instruments. Sensor devices can be used in modern apiculture for: (1) the identification and quantification of chemical substances that are indicators characterizing the state of the honeybee colony and the beehive conditions. (2) the classification of beehive air quality. **Limitations (Meikle and Host, 2015)** [43] In extremely intricate gaseous mixes, beehive air indicators are found. At PPB or PPM, their concentration is extremely low. Commercial gas sensors' detection limits typically do not allow for the detection of these compounds. The majority of gas sensors lack the sensitivity to distinguish between individual chemical species in a gaseous mixture. Indicators of honeybee colony statuses are also not well understood or recognized. Because of this, a comprehensive strategy based on the classification of beehive air quality is commonly suggested and considered in the prospective uses of machinery based on gas sensors. 2. Gases (including water vapor) have been sampled in beehives primarily using one of three methods: • placing the colony in a metabolic chamber and passing respiratory gases of known composition through the colony while measuring [O2] and [CO2] in the output (e.g., Milner 1921) [44]

[43] Meikle, W.G., Holst, N. (2015) Application of continuous monitoring of honeybee colonies. Apidologie 46, 10–2. Retrieved April 17th, 2023, from https://link.springer.com/article/10.1007/s13592-014-0298-x#citeas.
[44] Milner E.F. (1921) *Heat production of honeybees in winter*, United States Department of Agriculture, Dept. Bull. No. 988.

	=>ideal for colony-level studies of gas exchange rather than studies of within-colony gradients • removing air samples from the hive using either pipettes (e.g., Van Nerum and Buelens 1997)[45] or plastic tubing (e.g., Seeley 1974[46]; Southwick and Moritz 1987[47]) and then measuring gas in detectors outside the hive; =>allows researchers to sample air at very precise locations within the hive but will likely require hive modification or some disturbance and may be difficult to implement over large numbers of hives • placing sensors within the hive (e.g., Human et al. 2006)[48] **Pros** =>convenient in that commercially available gas sensors can fit easily between or within frames and large numbers of hives can be monitored simultaneously **Cons** =>however, in the hive, bees tend to cover foreign objects with propolis or wax which would interfere with air movement across the sensor, so in-hive gas sensors must be checked with some regularity to ensure that they or their protective covers are sufficiently clean => Sensor can interfere with comb maintenance and with bee emergence => Data from tubes or sensors at fixed sites may also be affected by movement of the brood cluster
Conclusion: is it worth pursuing this topic?	There seems to be potential for the Pipe4.0 to work in this technology, the only downside is the complexities of the gases and the low concentration, but it could really be a great area of interest as it does not compromise the bee environment while measuring it. Unsure if all the Raman spectrum conditions apply for all this to work.

2.15 Historical findings as part of scientific research

Topic	Gas measurements in historical findings to provide insights into the environmental conditions
Problem description	Gas measurements have been conducted in various historical findings as part of scientific research to understand the composition of gases in different contexts. Gas measurements often take place in ancient burial sites, tombs, ancient caves, crypts, underground structures and other historical structures to study the gases that may have been produced or accumulated over time. These measurements provided insights into the environmental conditions and helped researchers understand the preservation and deterioration of the artifacts inside.[49]

[45] Van Nerum, K., Buelens, H. (1997) *Hypoxia-controlled winter metabolism in honeybees* (Apis mellifera). Comp. Biochem. Physiol. Vol. 117A(4), 445–455
[46] Seeley, T.D. (2010) *Honeybee democracy*. Princeton University Press, Princeton
[47] Southwick, E.E., Moritz, R.F.A. (1987) *Social control of air ventilation in colonies of honey bees* (Apis mellifera). J Insect Physiol. 33(9), 623–626
[48] Human, H., Nicolson, S.W., Dietemann, V. (2006) *Do honeybees, Apis mellifera scutellata, regulate humidity in their nest*? Naturwissenschaften 93, 397–401
[49] Buckley, B. (2006) The Physical and Chemical Characterization of Ancient Egyptian Embalming Materials. *Journal of Archaeological Science*, 33 (11), 1586-1595.

How it is done now	The measurements are usually carried out using specialized equipment and techniques by qualified researchers to ensure accuracy and reliability of the results. Insufficient data on which devices are used.
Conclusion: is it worth pursuing this topic?	Insufficient data due to niche market. In order to further pursue this topic, stakeholder interviews are needed to collect more information.

2.16 Quality Control in medical Oxygen Gas Production and Verification (Horiba, 2022) [50]

<table>
<tr><td>Topic</td><td>Quality control in order to ensure a high quality of air used for medication i.e., gases used for the life support element to maintain the life of patients.</td></tr>
<tr><td>Problem description</td><td>Lack of oxygen, such as during the oxygen crisis in India caused by the Covid Crisis, made it difficult to get the medical oxygen needed for life support, etc.

Risk of contamination during the oxygen production process: If the gas separation is not done correctly, the oxygen may become contaminated with other gases, necessitating the measurement of the gas during the production process to ensure that the gas quality is within regulatory thresholds, such as those set by the European Pharmacopoeia Standards;

The analytical methods and the concentration are strictly addressed in the guideline

<table>
<tr><th>Component</th><th>Specification</th></tr>
<tr><td>Assay O_2</td><td>≥ 99.5%</td></tr>
<tr><td>Impurity CO</td><td>≤ 5 ppm</td></tr>
<tr><td>Impurity CO_2</td><td>≤ 300 ppm</td></tr>
</table>
</td></tr>
<tr><td>How it is done now</td><td>Medical Oxygen Gas Analyser- A Horiba product/technology (Horiba, 2022)


</td></tr>
</table>

[50] Horiba (2022). Quality Control in Medical Oxygen Gas Production and Verification. Retrieved April 15th, 2023, from https://www.horiba.com/int/process-and-environmental/applications/quality-control-in-medical-oxygen-gas-production-and-verification/

Component	Specification	Analytical Method	HORIBA Analyzer
Assay O_2	≥ 99.5%	Paramagnetic Detector (PMD)	Medical Oxygen Analyzer (VA-5003RH, VA-5003R, VA-5006R)
Impurity CO	≤ 5 ppm	Infrared (IR)	Trace Gas Monitor (GA-370)
Impurity CO_2	≤ 300 ppm	Infrared (IR)	Multi-Component Gas Analyzer (VA-5001)

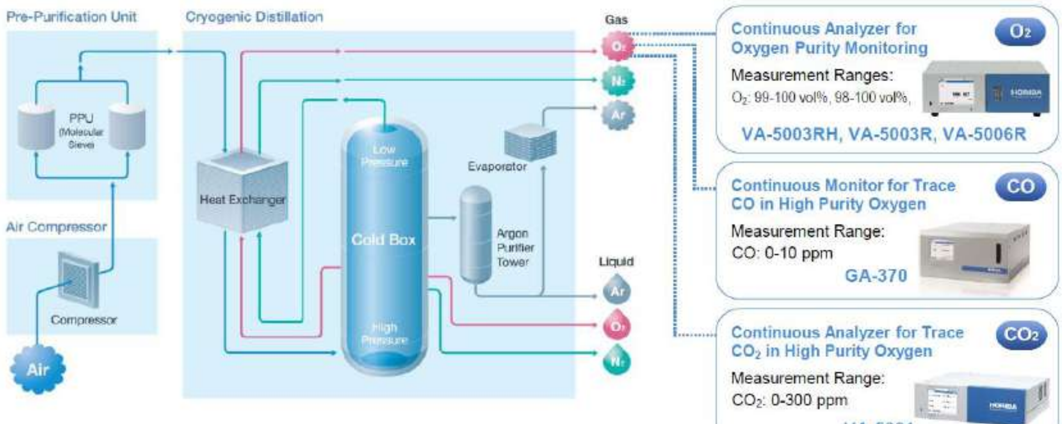


Figure 2: Air Separation Plant

Advantages

- Enable quality assurance process is conducted before distribution to ensure, if the oxygen product meets the required standard and its expectations.
- Oxygen monitoring is done continuously.
- Auto calibration function.

Disadvantages

Insufficient data to determine the disadvantages but the possible disadvantage could be;

- high cost
- High power - 100 240 V AC plus or minus 10%; 50/60 Hz plus or minus 1.0%

Conclusion: is it worth pursuing this topic?	Compared with the pipe4.0 technology, this alternative technology seems to be more advanced, however there are possible cons of high costs and high-power usage, hence if we were to dig deeper and get more data on this technology, we could analyze the possible disadvantages in order to determine if the Raman Spectrometer technology could be a better option for this job.

2.17 Atmospheric packaging of products

Topic	In order to ensure an optimized CO_2 concentration to slow the rate of respiration and preserve freshness of products but also mitigate the detrimental effects of excessive CO_2 concentration, the measurement of the composition of atmosphere packaging gas is required.
Problem description	The practice of "modified atmosphere packaging" (MAP) entails altering the internal atmosphere of a box in order to extend its shelf life. The gas needs to be a specific composition to be able to sufficiently do this task.

	For instance, meat benefits from MAP containing 70-80% CO_2, whereas seafood benefits from lower levels of CO_2. An optimization of gas composition requires the measurement of it.[51]
How it is done now	Atmospheric packaging Companies like Gasporox create optical spectroscopy, which analyzes gas "without preparing or altering the sample by passing low-power laser light through a container, probing the gas content.[52] The Guardian series, offered by Edinburgh sensors, is a full-featured, standalone gas monitor that uses infrared detection to track CO2 levels in real-time in environments with concentrations between 0 and 3000 ppm and 0 and 100% volume. The sensor is made to be simple to use and has an exceptionally short 1.5 minute warm-up time. It also has an on-device display with set-up menus that can be used for graphical display of past readings over a user-defined period. The sensor is perfect for MAP applications since it can function in a range of temperatures and relative humidity from 0 to 95% and 0 to 45 °C, respectively.[53] AMETEK offers on-line gas analyzers which extract and monitor packaging gas from the MAP-line,[54]
Conclusion: is it worth pursuing this topic?	General advantage of the Pipe technology that you do not need a sample. However, further research into current technology beneficial to improve overview of application.

[51] Edinburgh Sensors (2018). Gas sensors for the development of modified atmospheric packaging. Retrieved 13th, 2023, from https://edinburghsensors.com/news-and-events/gas-sensors-development-modified-atmospheric-packaging/ ; Precisa Gravimetrics AG. (n.d.). Blog from farm to fork step 2: Food processing and packaging using gas sensing and precision weighing. Retrieved 13th, 2023, from https://www.precisa.com/blog/from-farm-to-fork-step-2-food-processing-and-packaging-using-gas-sensing-and-precision-weighing/.
[52] Gasporox AB (2021). The Gasporox technology. Retrieved 13th, 2023, from https://gasporox.se/this-is-gasporox/.
[53] Edinburgh Sensors (2018). Gas sensors for the development of modified atmospheric packaging. Retrieved 13th, 2023, from https://edinburghsensors.com/news-and-events/gas-sensors-development-modified-atmospheric-packaging/.
[54] Ametek mocon. (2023). On-line MAP gas analyzers. Retrieved 13th, 2023, from https://www.ametekmocon.com/products/onlinemapgasanalyzers.

SECTION 3: DIGGING DEEPER INTO THE MOST PROMISING IDEAS

Problem Space Exploration: Research and Synthesis

Potential Application	Comments	Final
2.1 Decreasing Animal Harm		✓
2.2 Mining	Seems interesting and has quite a lot of potential looking at the evolution of technologies used thus far. However, there is need to dig deeper into the current challenges, issues faced in measuring the gas.	✓
2.3 Fire Fighters	Broad range of technologies already do depicted jobs sufficiently.	✗
2.4 Volcanic Activity	- Check answer of company (-20 to 50°C) (Question: why does the one paper say 70°C?) - https://www.scinexx.de/news/geowissen/gase-verraten-vulkanausbruch/	✓
2.5 Earthquake Warning	Does not seem too promising due to better technologies available without measuring gases.	
2.6 Medicine & Pharmaceuticals	Insufficient data.	
2.7 Contamination		
2.8 Aerospace	Using technology in this industry seems to be infeasible. Besides, there are already sufficient technologies to measure the oxygen available and raise alarms when there are any leaks. Further, spaceships also have backup and have technologies that generate oxygen.	✗
2.9 Fracking	Gas leakages are tolerated as side-effects.	✗
2.10 Breweries & Wineries	This field of application is promising as the measurement of the gas composition in wine tanks can provide important information about the progress and health of the fermentation process. In addition, measuring the gas in wineries outside the tanks is crucial to ensure the health of the personnel.	✓
2.11 Regulation Monitoring and Testing for Coal Cargoes (Gas monitoring and ventilation)	This ideas is interesting, however, in terms of priority, we would rather focus on the problem of explosive gas produced by coal in mining. There we have more data on the evolution of technology used in gas measurement, hence we would rather pursue that for now and see where it takes us.	✗
2.12 Prediction of Diamonds	Interesting idea, but there is insufficient data to fully pursue it. Further, we could imagine that there are better technologies in place already used to identify minerals rather than using gas analysis. Also, the Pipe4.0 technology which used laser effects may not be applicable to soil, rather open space where you can have quality optical access to the gas and good lighting.	✗
2.13 Measuring Gas in Shipping Containers	I have the feeling that the sterilization of containers often works with steam; thus I am not sure if gas measurement is really crucial here. I would rather drop it.	✗
2.14 Beehive Air-Sampling in modern apiculture	A bit skeptical about the idea but not ready to give up on it yet. Major issues include; • Behive air sampling seems to be a new area under research and there is not many documentaries,	✓

	youtube videos on it; hence making it difficult to do the armchair research. • There are other smarter technologies used to monitor beehive conditions but mainly focus on other areas e.g., the death of the queen bee and the temperature. However, these technologies have no focus on gas measurements, hence we could check if the Pipe4.0 technology could be of relevance.	
2.15 Historical findings as part of scientific research	Insufficient data to pursue the idea	❌
2.16 Quality Control in medical Oxygen Gas Production and Verification	Insufficient data	
2.17 Atmospheric packaging of products	Advantage of Pipe4.0 technology to work only with optical access suggest potential in this field.	✅

3.1 Decreasing Animal Harm

Question	Answer
Gases to be measured	A mixture of argon, nitrogen or other inert gases and CO2 (provided the CO2 does not exceed 30% and maximum free O2 2% by volume)
How its done?	Both the Guardian and GasCard NG (https://edinburghsensors.com/) provide highly precise online carbon dioxide detecting capabilities with real-time data logging and the option to combine the sensors with alarm features or additional gas-monitoring sensors as necessary.[55] Both sensors are field-deployable non-dispersive infrared (NDIR) gas sensors, with the Guardian NG providing a range of 0 to 3000 ppm and 0 to 100% volume for the detection of carbon dioxide. There are several GasCard NG variations available, including 0 - 5000 ppm, that provide either the same characteristics or wider ranges.[56]
Who are the main users; What drives them and how do they influence one another?	The main users are slaughterhouses proceeding a high amount of animals in a relatively short time and hence, focusing on efficiency and effectiveness at the same time. In addition, there are strict regulations in food production which need to be followed. Further, reducing costs and producing as efficient as possible is important in this competitive market.

[55] Instrumatics (2023). Monitoring CO2 Concentrations in Pig and Poultry Processing. Retrieved April 17th, 2023, from https://instrumatics.co.nz/index.php?p=news/news-monitoring-co2-for-poultry.

[56] Edinburgh Instruments Ltd. (2020). Animal Husbandry: The Best Sensors to Monitor Emissions. Retrieved April 17th, 2023, from https://edinburghsensors.com/news-and-events/animal-husbandry-the-best-sensors-to-monitor-emissions/.

problems and pains that these users experience in existing solutions and processes *(i.e. in what way do they do a poor job?)?*	Non-dispersive infrared (NDIR) is the most widely used method for measuring CO2. These sensors work by using infrared light to detect the different wavelengths of flammable gases. In addition to requiring a lot of power to operate, NDIR sensors frequently need to be calibrated, which raises their overall cost of ownership. NDIR gas sensors also have spectral interference and a high detection limit as drawbacks.[57] (see all disadvantages here: https://nevadanano.com/ndir-sensor-are-there-disadvantages-to-consider/#:~:text=In%20addition%20to%20their%20inadequacies,a%20rapid%20change%20in%20conditions)
what is already known about the problem space?	Without measuring and monitoring the gas concentration and as the humans and animals are apart the confirmation of death of the animals is difficult. While insufficient CO2 gas concentrations may leave animals not stunned or killed which leads to the suffering of animals, too high CO2 gas concentrations have been shown to cause distress and pain to animals when the gas is inhaled. Regulations in some countries dictate that the carbon dioxide concentration must not exceed 30 %, and external devices must be used to measure by volume the maximum concentration with audible warning systems should concentrations deviate from the legislated limits. "the use of carbon dioxide over 40% is not permitted for stunning poultry in slaughterhouses."[58] ➔ small deviations in gas concentrations can cause issues with the stunning process and compliance with legislation.

3.2 Mining

Question	**Answer**
Gases to be measured	Methane, Carbon Dioxide (CO2), Carbon Moxide (CO), Oxides of Nitrogen (NO, NO2), Hydrogen Sulphide (H2S) and Sulphur Dioxide(SO2) (Chaulya and Prasad (2016)[59].
How its done?	Gas Sensors (Chaulya and Prasad, 2016) These devices show the concentration of gas in the form of an electrical response. If the concentration exceeds the threshold concentration limit,

[57] NevadaNano (2021). NDIR Sensor: Are There Any Big Disadvantages to Consider? Retrieved April 17th, 2023, from https://nevadanano.com/ndir-sensor-are-there-disadvantages-to-consider/.
[58] European Comission (2023). Slaughter & Stunning. Retrieved April 17th, 2023, from https://food.ec.europa.eu/animals/animal-welfare/animal-welfare-practice/slaughter-stunning_en.
[59] Chaulya, S.K., and Prasad, G.M. (2016). Sensing and Monitoring Technologies for Mines and Hazardous Areas. pp 161-212. Retrieved April 14th, 2023, from https://www.sciencedirect.com/science/article/pii/B9780128031900039)

these sensors give an alarm or activate other remedial actions, such as increasing the ventilation, switching off the power supply, etc. (Kumar et al., 2013)[60]

Table 3.9 Mine Gases and Their Detecting Principles (McPherson, 1993)

Name	Methods of Detection
Oxygen	Electrochemical, paramagnetic, flame lamp
Methane	Catalytic oxidation, thermal conductivity, optical, acoustic, flame lamp
Carbon dioxide	Optical, infrared
Carbon monoxide	Electrochemical, catalytic oxidation, semiconductor, infrared
Sulfur dioxide	Electrochemical, infrared
Nitric oxide	Electrochemical
Nitrous oxide	Electrochemical
Nitrogen dioxide	Electrochemical, infrared
Hydrogen sulfide	Electrochemical, semiconductor
Hydrogen	Catalytic oxidation

Table 3.10 Classification of Sensors by Transducer Operating Principle (Gupta et al., 2012)

Sl. No.	Types of Devices	Physical Change	Operating Principles
1	Catalytic gas sensors (pellistors), thermal sensors	Temperature or heat	Changes in resistance in Wheatstone bridge
2	Optical sensors (infrared, laser, optical fiber)	Absorbance Luminescence Refractive index Scattering	Either caused by gas itself or due to reaction with certain indicators Emission caused by chemical reaction or change in solution composition Caused by particles of definite sizes present in the sample
3	Semiconductor (solid state) gas sensors	Electrical conductivity	Changes in work function
4	Electrochemical gas sensors (potentiometric or amperometric)	Voltametric	Changes in current between electrodes
5	Piezo-electric sensors (quartz crystal microbalances)	Mass	Changes of resonant frequency of quartz oscillator plate due to adsorption of a gas on its chemically modified surface
6	Flame ionization detector, photo ionization detector	Ionization	Amount of ionization
7	Paper tape technology	Absorbance	Changes in color
8	Microelectromechanical systems	Electrical conductivity and piezoelectric	Variation of electrical conductivity/resistance and molecular adsorption
9	Nanotechnology	Quartz crystal microbalance	Changes in the photoluminescence spectroscopy and the mass of sensing element

Source : Chaulya and Prasad (2016)

Types of Sensors (Chaulya and Prasad, 2016)

- ⇨ **Catalytic bead sensors;**

[60] Kumar*, A., Kingson, T.M.G., Verma, R.P., Kumar, A., Mandal, R., Dutta, S., Chaulya, S.K., and G.M. Prasad. *Application of Gas Monitoring Sensors in Underground Coal Mines and Hazardous Areas*. Vol 3:Issue 3. International Journal of Computer Technology and Electronics Engineering.

	⇨ Monitors combustible hydrocarbon (CHC) gas. ⇨ A circuit for measuring an unknown resistance by comparing it with known ⇨ resistance. ⇨ Coil used is electrically heated. ⇨ **Infrared Gas Sensors** The natural frequency is the set frequency at which gas molecules bind. A portion of the energy from infrared (IR) radiation that interacts with gas molecules is absorbed, while the remaining energy is transmitted. The gas molecules gain energy and vibrate more forcefully as a result of absorbing this radiation. The temperature of the gas molecules increases as a result of this vibration. Temperature rises in direct proportion to gas concentration, and the detector displays this temperature rise in terms of gas concentration. **Types of Infrared** **Non-dispersive IR Gas Sensor (NDIR)** consists of a single IR source, a beam splitter, and two detectors. One detector is used to monitor the characteristic hydrocarbon wavelength. The other is a reference where no IR active gases are normally present. IR energy is emitted from the source; it passes through the gas cell and is reflected back to the detectors. The reflector is usually parabolic in shape to collimate the IR light through the sample chamber towards the detector as it can increase available light intensity by two to five times. The reflector surface can also be coated with gold to further enhance its efficiency. **Fourier Transform IR Gas Sensor (FTIR)** Contrary to a non-dispersive IR (NDIR) gas sensor, the scan area of IR wavelength is large in the case of an FTIR gas sensor. In an FTIR gas sensor, the gas to be analyzed is sent through a cuvette with an IR light source at one end and a modulator that cuts the light into different wavelengths. ⇨ Electrochemical Sensors ⇨ Catalytic Bead Sensors; Infrared Gas Sensors (Non-dispersive IR Gas Sensor- NDIR and Fourier Transform IR Gas Sensor FTIR) ⇨ Electrochemical Sensors ⇨ Semi-Conductor Sensors ⇨ Laser Sensor ⇨ Fiber Optic Sensor ⇨ Thermal Conductivity Sensor ⇨ Flame Ionization Detector ⇨ Photoionization Detector ⇨ Paper Tape Technology

- ⇨ Microelectromechanical System
- ⇨ Nanotechnology

Who are the main users; What drives them and how do they influence one another?

The main users of this technology would be mining engineers. Miner are driven to measure gas composition to avoid accidents;

=>Many accidents occur due to a sudden rise in toxicants such as carbon monoxide (CO) or dangerously flammable gases like methane (CH4) in mine air. Sometimes, insufficient oxygen causes death for mine workers (Chaulya and Prasad, 2016).

Table 3.8 Flammability Limits, TLVs, and Hazards of Mine Gases (McPherson, 1993)

Name of Gas	Flammability Limits in Air (%)	Guideline for TLVs	Hazards
Oxygen		>19.5%	Oxygen deficiency may cause formation of explosive mixtures with reactive gases
Nitrogen		CL = 81,000 ppm	No harmful effect
Methane	5–15	At 1%, isolate electricity, at 2%, remove personnel	Causes explosion
Carbon dioxide		TWA = 0.5%, STEL = 3.0%, CL = 1.5%	Enhances rate of respiration
Carbon monoxide	12.5–74.5	TWA = 0.005%, STEL = 0.04%, CL = 200 ppm	Very poisonous; can cause explosion
Sulfur dioxide		TWA = 2 ppm, STEL = 5 ppm, CL = 10 ppm	Very toxic, irritant to eyes throat and lungs
Nitric oxide		TWA = 50 ppm	Oxidizes rapidly to NO_2
Nitrous oxide (laughing gas)		TWA = 50 ppm	Causes narcotic effects
Nitrogen dioxide		TWA = 3 ppm, CL = 5 ppm	Very toxic; throat and lung irritant; can cause pulmonary infections
Hydrogen sulfide	4.3–45.5	TWA = 10 ppm, STEL = 15 ppm, CL = 15 ppm	Highly toxic; irritant to eyes and respiratory tracts; can cause explosion
Hydrogen	4–74.2		Highly explosive

problems and pains that these users experience in existing solutions and processes *(i.e. in what way do they do a poor job?)*?

Catalyst based Sensors

1. **Catalyst poisoning:**
   Poisoning compounds cause a permanent reduction of the sensor sensitivity and the exact cause of poisoning is very difficult to identify.
   - ⇨ Tetraethyl lead and silicon compounds (present in common oil and lubricants used as additives in machinery) are among the most common poisons.
   - ⇨ Sulfur compounds (often released with gases), chlorine and heavy metals also cause the poisoning of the sensor.
2. **Sensor inhibitors:**
   Inhibitors cause a temporary loss of sensitivity of a sensor. Sensitivity may be partially or totally recovered after a short

Infrared Gas Sensors

While these have notable advantages over catalytic bead sensors, they have their short comings;

1. **Inability to detect H2O**

	They are extraordinarily good at detecting methane, but they struggle to pick up other hydrocarbon-based gases since hydrogen does not absorb infrared light. In many mining and petroleum extraction and processing environments, hydrogen is a gas that could be harmful. **2. Function poorly in extreme environments or where there is a rapid change in conditions.** susceptible to moderate changes in the environment's temperature and humidity, freezing their output during temperature transitions.
what is already known about the problem space?	Failure to measure gas composition accurately could lead to injuries of miner, death or explosions.
what is not known about the problem space?	Whether or not the measurements is affected by gas concentration level or if the raman technology is applicable to mines, i.e. could the laser pose any harmful risks in the mines?
Question to ask in research mode 2	At what process level in the mining journey map are gases measured and what risks are there. What specicific gases are measured and what tools are in place. In all these tools/ devices, what are the pain points and how could the Pipe4.0 technology be of help in solving the problem.

3.3 Volcanic Activity

Question	Answer
Gases to be measured	Some active volcanoes release gases before magma. These gases include sulfur dioxide (SO2), carbon dioxide (CO2), water vapor (H2O), hydrochloric acid (HCl), and hydrogen sulfide (H2S). [61] Also, changes in the argon-40/helium-3 ratio can reveal how foamy the magma is, which indicates the likelihood of certain eruption types.[62] Comparable to a breath or blood test, is the analysis of the chemical and isotopic composition of elements in fumarolic gases. This means that in order to understand exactly what is happening with the magma, genuine material that was directly generated from magma needs to be examined.[63]
How its done?	To understand and predict the behaviour of volcanoes, an increasing number of scientists are combining geological monitoring and geochemical models:[64]

[61] USGS (2023). Volcanic gases can be harmful to health, vegetation and infrastructure. Retrieved April 18th, 2023, from https://www.usgs.gov/programs/VHP/volcanic-gases-can-be-harmful-health-vegetation-and-infrastructure.

[62] University of Tokyo (2022). Evading Volcanic Disaster: Monitoring „Frothy" Magma Gases for Eruption Signals. Retrieved April 12th, 2023, from https://scitechdaily.com/evading-volcanic-disaster-monitoring-frothy-magma-gases-for-eruption-signals/?utm_content=cmp-true.

[63] Obase T., Sumino, H., Toyama, K. et al. (2022) Monitoring of magmatic-hydrothermal system by noble gas and carbon isotopic compositions of fumarolic gases. *Scientific Reports*, 12 (17967).

[64] Oregon State University (2023). Measuring Volcanic Gases. Retrieved April 18th, 2023, from https://volcano.oregonstate.edu/measuring-volcanic-gases.

	1) Gas Sampling It is necessary to gather gas samples out in the field in the open area close to the volcano's vent by dipping a container right into the gases. The samples were collected, and then transported back to the lab for examination. In the lab, scientists examined the components of the gas using a noble gas mass spectrometer. Direct sampling of gases escaping from fumaroles is currently the only way to (1) fully characterize the composition of gases discharging from volcanoes; and (2) collect isotope data needed to determine the origin of specific gases. 2) MultiGAS instruments (NDIR technology) These instrument sets can accurately detect the amounts of CO2, SO2, and H2S as well as ambient variables like temperature and pressure using a combination of optical and electrochemical sensors. During measurement campaigns, they are often transported to fumaroles or degassing vents, or they may even be put permanently at locations downwind of such vents. The acquired data can be radio-transmitted to a volcano observatory, providing a minute-by-minute record of changes in gas concentration, as opposed to collecting gases for subsequent study. 3) Gas Sensing Drones A gas sensing drone was created with an emphasis on CO2, H2S, and SO2, and improvements included sensor options for CH4 and O3. The system offered up to four electro-chemical sensors in addition to a high sensitivity laser diode. The sensors can be modified to meet a variety of sensitivity and species-specific requirements. (see more about gas sensing drones here: https://edinburghsensors.com/news-and-events/drone-inspection/) There are a variety of available monitoring techniques that scientists use to characterize and predict volcanic eruptions besides measuring gases such as Ground Vibration, Deformation and Remote Sensing through for example Satelites, Thermal Imaging and Cameras.[65]
Who are the main users; What drives them and how do they influence one another?	- Researchers and Scientists - Disaster mitigators such as Meteorological Agencies - Society Volcano events can be deadly and are notoriously difficult to predict. Therefore, the main driver for using this technology is security to forewarn residents of the next potential disaster.
problems and pains that these users experience in existing solutions and processes *(i.e. in*	1) Gas Sampling Collecting gas samples from fumaroles is not only challenging and time-consuming process but also dangerous due to the toxic gas and hot steam, so a gas mask, goggles, helmet, and gloves are required. 2) MultiGAS instruments

[65] Estrada, C. (2023). The Science of Predicting Volcanic Eruptions. Retrieved April 17th, 2023, from https://open.maricopa.edu/hazards/chapter/5-5-monitoring-volcanoes/.

what way do they do a poor job?)?	NDIR sensors cannot detect hydrogen because this gas does not absorb infrared light.[66] 3) Gas Sensing Drones. The gas cannot be measured and monitored on a constant level. Instead, it requires costly operations to monitor the gases.
what is already known about the problem space?	Some eruptions can occur without any clear signals beforehand. Hence, also measuring the gases is not a reliable way of monitoring movements in volcanos.

3.4 Breweries and Wineries

Question	**Answer**
Gases to be measured	CO_2 (Carbon dioxide) SO_2 (Sulfur dioxide) Hydrogen sulfide Nitrogen Argon C_2H_6O (Ethanol) Glycerol Succinic acid
How its done?	<u>General</u>[67] • Real-time analysis of sample of-gases for species that are essential to a fermenter's product production is provided by gas analyzers for fermentation monitoring. • Various systems for measuring gas, depending on the type of the aforementioned gases that are to be measured. • Possibility of a multi-stream fermentation analysis system • Headspace gas chromatography with flame ionization detector for the identification of methanol and higher alcohols; sampling is required. <u>Current methods for CO_2 detection</u>[68] • CO_2 concentration provides information about the state of the fermentation process. • CO_2 monitors (esp. near the floor) to monitor gas exposure of personal, potential multi-stream fermentation analysis also possible. <u>Current methods for SO_2 detection</u>[69] • Methods and generally interesting information about the detection of sulfur dioxide: • Methods: ○ Aeration oxidation (AO; commonly known as Rankine method): old technique that uses classical glassware to aspirate the acidified

[66] NevadaNano. (2021). NDIR Sensor: Are There Any Big Disadvantages to Consider? Retrieved April 17th, 2023, from https://nevadanano.com/ndir-sensor-are-there-disadvantages-to-consider/.
[67] Hiden analytical (2019). Gas analyzers for fermentation monitoring. Retrieved 18th, 2023, from https://hideninc.com/gas-analyzers-for-fermentation-monitoring/
[68] Ibid.
[69] Winemakers Research Exchange (2021). April 15th, 2021: Sulfur Dioxide measurement and management (WRE Sensory Session). Retrieved April 18th, 2023, from https://www.youtube.com/watch?v=_ogowu-1zTc

	sample, and then captures and oxidizes the released SO_2 in a flask, the content of which are then titrated using sodium hydroxide.[70] ○ Spectrophotometric. ○ "Headspace Gas detection", e.g., using a chromatograph, which offers an easier sample preparation than conventional methods.[71]
Who are the main users; What drives them and how do they influence one another?	Personnel of wineries • Winemakers are often driven by their goal of producing a high-quality wine, which also aims to give them an edge in comparison to other competitors in their region. Measuring the gas enables the winemakers to test whether the fermentation process runs correctly. • During ageing, wine needs to be protected from microbial spoilage or oxygen to prevent oxidation and to become a good wine. Thus, the fermentation tanks are not supposed to be opened more than necessary. • Currently, inerted gases (e.g. CO_2, nitrogen, argon as those are heavier than oxygen) are used to build a gas blanket to protect the wine. However, there is always a risk that those gases are to some extant displaced by oxygen ("Inert" = substances that are not chemically reactive). Regulators • Enabling quality and regulatory control (announced as well unannounced). • Possible checks: inspection of growing and production practices, or alcohol content.
problems and pains that these users experience in existing solutions and processes *(i.e. in what way do they do a poor job?)?*	There are various methods for measuring the gas in wineries, and each one has its own set of issues. For instance, the inert gas used as the present oxidation solution runs the risk of being replaced by oxygen, which would cause the wine to oxidize. In addition, following problems are often perceived with current gas measurement techniques: • Some of the measurements (e.g. inexpensive detection tubes) require sampling. For instance, the solution of Labthinks required over 20mL for the CO2 analysis[72] • Existing testing is often not perceived to be accurate as winemaker/lab analyst originally thought[73] Characteristics of inerted gas not optimal • Nitrogen: mixes easily with air; cannot be used to blanket

[70] Howell, G. (2020). How accurate is your sulfur dioxide testing?. Retrieved 18th, 2023, from https://www.vintessential.com.au/how-accurate-is-your-sulfur-dioxide-testing/
[71] Aberl, A. and Coelhan, M. (2012). Determination of sulfur dioxide in wine using headspace gas chromatography and electron capture detection. Retrieved 18th, 2023, from https://www.tandfonline.com/doi/full/10.1080/19440049.2012.743191
[72] Direct industry be virtualexpo group. (2023). Headspace analyzer for measuring O2 concentration in head space of wine bottles. Retrieved 19th, 2023, from https://pdf.directindustry.com/pdf/labthink-instruments-co-ltd/headspace-analyzer-measuring-o2-concentration-head-space-wine-bottles/58198-890889.html ; Pegram et al. (2013). Simplified method for free SO2 measurement using gas detection tubes. Retrieved 19th, 2023, from https://www.ajevonline.org/content/64/3/405.short
[73] Howell, G. (2020). How accurate is your sulfur dioxide testing?. Retrieved 18th, 2023, from https://www.vintessential.com.au/how-accurate-is-your-sulfur-dioxide-testing/

	• Argon: typically, the most expensive; if using gas for blanketing, argon is preferred over nitrogen • Carbon Dioxide: will dissolve into wine from headspace; may be purchased as dry ice pellets & if oxygen concentrations in headspace are not tested after blanketing, the effectiveness of the process can not be determined[74] Method: Aspiration/Oxidation • Commonly used Aspiration/Oxidation method is laborious and uses some dangerous chemicals. • Technique must be calibrated and checked In an ISO17025 accredited laboratory to be accurate (e.g. too high air flow in lab does influence the testing) → this certification is expensive. • Sample handling is crucial in order to ensure accurate results → ease of use not given. Method: Spectrophotometer • More expensive in comparison to Raman spectrometer.[75]
what is already known about the problem space?	• Too much oxygen exposure in the fermentation process leads to browning, loss of freshness, sherry-like aromas and flavors, and volatile acidity production (vinegar).
Question to ask in research mode 2	The current state of research suggests a potentially interesting application. Thus, in the second research mode, the following questions are interesting: • Would it be beneficial for you to measure the headspace gas of your wine production (inerted gas as well as CO2 and SO2)? • What are you currently measuring?

3.5 Beehive Air-Sampling in modern apiculture

Question	Answer
Purpose	All around the world, the population of these insects has recently been declining at an alarming rate. This hazardous phenomenon is still not fully acknowledged or comprehended. Information about the condition of the bee colony forms the basis of efficient beekeeping. Beehive air is a reliable source of pertinent information. Due to the drawbacks of visual examination, monitoring based on instrumental techniques is quite popular in apiculture. It has been observed that the chemical makeup of the air in beehives contains important information for contemporary apiculture. Unique and complicated, the gaseous mixture inside the hive is made up of several volatile chemicals. A

[74] Gravity wine house. (2021). Inert gas use in the winery. Retrieved 18th, 2023, from https://gravitywinehouse.com/blog/gas-use-in-the-winery/
[75] Melison, F., Scarabottolo, N., Tondello, G., Poletto, L. (2020). Diode-based Raman sensor for fuel gas analysis. Retrieved April 5th, 2023, from https://www.spiedigitallibrary.org/conference-proceedings-of-spie/11354/113541A/Diode-based-Raman-sensor-for-fuel-gas-analysis/10.1117/12.2554538.short?SSO=1.

honeybee colony cannot thrive without the precise chemical makeup of the air inside the hive.
The honey bee colony's health and the hive's cleanliness are both indicated by the air's chemical composition.[76]

Possible purposes related to diseases:

- Varroa destructor mite
- foulbrood

Gases to be measured

CO, CO2, O2, temperature, humidity, chemical pollutants (NO2, H2, NH3, Toluene, Isobutane)

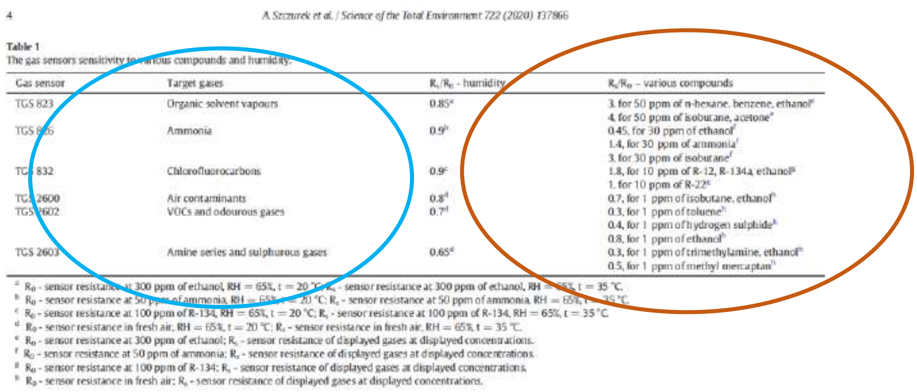


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Table 1
The gas sensors sensitivity to various compounds and humidity.

Gas sensor	Target gases	R_s/R_0 - humidity	R_s/R_0 – various compounds
TGS 823	Organic solvent vapours	0.85[a]	3. for 50 ppm of n-hexane, benzene, ethanol[e] 4. for 50 ppm of isobutane, acetone[e]
TGS 826	Ammonia	0.9[b]	0.45, for 30 ppm of ethanol[f] 1.4, for 30 ppm of ammonia[f] 3. for 30 ppm of isobutane[f]
TGS 832	Chlorofluorocarbons	0.9[c]	1.8, for 10 ppm of R-12, R-134a, ethanol[g] 1. for 10 ppm of R-22[g]
TGS 2600	Air contaminants	0.8[d]	0.7, for 1 ppm of isobutane, ethanol[h]
TGS 2602	VOCs and odourous gases	0.7[d]	0.3, for 1 ppm of toluene[h] 0.4, for 1 ppm of hydrogen sulphide[h] 0.8, for 1 ppm of ethanol[h]
TGS 2603	Amine series and sulphurous gases	0.65[d]	0.3, for 1 ppm of trimethylamine, ethanol[h] 0.5, for 1 ppm of methyl mercaptan[h]

[a] R_0 - sensor resistance at 300 ppm of ethanol, RH = 65%, t = 20 °C; R_s - sensor resistance at 300 ppm of ethanol, RH = 65%, t = 35 °C.
[b] R_0 - sensor resistance at 50 ppm of ammonia, RH = 65%, t = 20 °C; R_s - sensor resistance at 50 ppm of ammonia, RH = 65%, t = 35 °C.
[c] R_0 - sensor resistance at 100 ppm of R-134, RH = 65%, t = 20 °C; R_s - sensor resistance at 100 ppm of R-134, RH = 65%, t = 35 °C.
[d] R_0 - sensor resistance in fresh air, RH = 65%, t = 20 °C; R_s - sensor resistance in fresh air, RH = 65%, t = 35 °C.
[e] R_0 - sensor resistance at 300 ppm of ethanol; R_s - sensor resistance of displayed gases at displayed concentrations.
[f] R_0 - sensor resistance at 50 ppm of ammonia; R_s - sensor resistance of displayed gases at displayed concentrations.
[g] R_0 - sensor resistance at 100 ppm of R-134; R_s - sensor resistance of displayed gases at displayed concentrations.
[h] R_0 - sensor resistance in fresh air; R_s - sensor resistance of displayed gases at displayed concentrations.

<u>Components of Beehive air</u>

There are studies available which measure the beehive air in order to determine whether this air could be beneficial for beehive air treatment for the diseases of asthma, bronchitis, lung fibrosis, and respiratory tract infections.

(for more information please see: https://www.beecurasystem.de/wp-content/uploads/2022/04/Tag-1-8-Identifizierung-chemischer-Verbindungen-der-Bienenstockluft-Tiago-Guardia.pdf)

Components of beehive air: [77]

- 6 fatty Acids, 6 Alcohols, 10 Aldehyde, 5 Ester, 1 Ether, 9 Hydrocarbon, 7 Ketone, Nitrogenous compound, 1 Phenol, 10 Terpenes.
- The most abundant constituents were short-chain fatty acids (26.32%) while the lowest were the nitrogenous compounds (0.82%)

Sensitivity and detection ranges of sensors (Pipe is measuring 1000ppm)

[76] Szczurek, A. & Maciejewska, M. (2021). Beehive Air Sampling and Sensing Device Operation in Apicultural Applications – Methodological and Technical Aspects. Retrieved April 20th, 2023, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8230472/.
[77] Abd El-Wahed, A. A., Farag, M. A., Eraqi, W. A., Eraqi, W. A., et al. (2021). Unravelling the beehive air volatiles profile as analysed via solid-phase microextraction (SPME) and chemometrics. *Journal of King Saud University Science*, (5).

Gas Sensor	Sensitivity	Detection Range
TGS 823	Solvent vapors	50–5000 ppm Ethanol, n-Hexane, Benzene, Acetone
TGS 826	Ammonia	30–300 ppm Ethanol, Ammonia, Isobutane
TGS 832	Chlorofluorocarbons	10–600 ppm ethanol, R-407c, R-134a, R-410a, R-404a, R-22
TGS 2600	Air contaminants	1–100 ppm Ethanol, Isobutane, Hydrogen, Carbon monoxide
TGS 2602	Volatile organic compounds and odorous gases	1–30 ppm Ethanol, Ammonia, Toluene
TGS 2603	Amine series and sulfurous odor gases	1–30 ppm Ethanol 0.1–3 ppm Trimethyl amine, 0.3–2 ppm Methyl mercaptan

For the detection of the *Varroa destructor* mite
https://www.mdpi.com/1424-8220/20/1/117
The statistical analysis revealed a reasonable and constant correlation between the reactions of the gas sensors and the degree of *V. destructor* infestation. More responses indicated higher levels of infestation.[78]
(read more about the research here: https://www.sciencedirect.com/science/article/pii/S0168169918317526)
However, the following sensors used in this study have a quite low sensitivity range compared to PiPe 4.0:

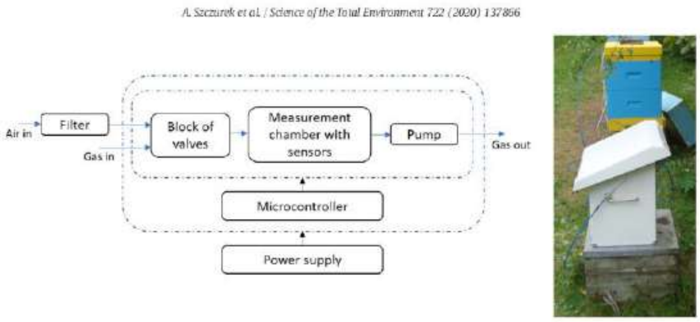
Type of sensor	General classification of major substances detected	Detection range for the exemplary compounds	Heater power consumption [mW]
TGS 823	Organic solvent vapours	50–5000 ppm ethanol, n-hexane, benzene, acetone	660
TGS 826	Ammonia	30–300 ppm ethanol, ammonia, isobutane	833
TGS 832	Chlorofluorocarbons	10–600 ppm ethanol, R-407c, R-134a, R-410a, R-404a, R-22	835
TGS 2600	Gaseous air contaminants	1–100 ppm ethanol, isobutane	210
TGS 2602	VOCs and odorous gases	1–30 ppm ethanol, ammonia, toluene	280
TGS 2603	Amine-series and sulfurous odour gases	1–30 ppm ethanol 0.1–3 ppm trimethylamine, 0.3–2 ppm methyl mercaptan	240

For the detection of foulbrood
Because foulbrood emits a distinct smell, knowledgeable beekeepers with keen senses of smell can identify the disease as soon as a hive is opened.[79]

Also, a similar study to the one above is available here where the gas sensors manufactured by Figaro with the lower sensitivity were used.

(read more about this research here:
https://www.researchgate.net/publication/358407596_In-

[78] Szczurek, A., Maciejewska, M., Bak, B., et. al. (2019) Semiconductor gas sensor as a detector of Varroa destructor infestation of honey bee colonies – Statistical evaluation. Computers and Electronics in Agriculture, 162, 405-411.
[79] Bak, B., Szkola, J., Wilk, J., Artiemjew, P. (2022). In-Field Detection of of American Foulbrood (AFB) by Electric Nose Using Classical Classification Techniques and Sequential Neural Networks. *Sensors*, 22(3), 1148.

	[Field Detection of American Foulbrood AFB by Electric Nose Using Classical Classification Techniques and Sequential Neural Networks])
How its done?	1) Infrared analyzers, Fourier-transform infrared spectrometers (FT-IR spectrometers), ion mobility spectrometers (IMS) or gas chromatographs with an appropriate detector (usually FID, tuned mass spectrometer MS or other mass-selective detector), which are capable of detecting, identifying, and quantitating the specific chemical species in beehive air[80] 2) Measuring instruments based on a sensor technology **Semiconductor gas sensors**  A pump is used to send the gas to the chambers of the gas sensors through the gas line after it has been sampled from the sampling point during a measurement. The instrument has eight gas inlet ports, allowing it to connect to eight sample stations concurrently and provide intermittent service to each of them. The multisensory detector is customizable and self-contained. The internal controller controls all of the device's operations and features.[81]
Who are the main users; What drives them and how do they influence one another?	Industrial Beekeepers monitoring the health of bees and their production process. Beekeepers driven by the need to maintain the health of their bees.
problems and pains that these users experience in existing solutions and processes *(i.e. in what way do*	The equipment is difficult to transport, heavy, and big, and it consumes a lot of energy. The measurement process requires a lot of time and labor. To get accurate measurement data, qualified and experienced workers are also needed. When the speciation is absolutely important, analytical equipment are still mostly used in laboratory work.[82]

[80] Szczurek, A. & Maciejewska, M. (2021). Beehive Air Sampling and Sensing Device Operation in Apicultural Applications – Methodological and Technical Aspects. Retrieved April 20th, 2023, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8230472/.
[81] Szczurek, A., Maciejewska, M., Bak, B. et al. (2020). Detecting varroosis using a gas sensor system as a way to face the environmental threat. Science of The Total Environment, 722.
[82] Szczurek, A. & Maciejewska, M. (2021). Beehive Air Sampling and Sensing Device Operation in Apicultural Applications – Methodological and Technical Aspects. Retrieved April 20th, 2023, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8230472/.

they do a poor job?)?	
what is already known about the problem space?	The process of beehive air sampling and other beehive conditions are critical for maintaining the health of the bee colonies. Changes in these conditions could indicate the overall health of the bees.
what is not known about the problem space?	What level of gases of the specific gases measured is the benchmark for a healthy beehive? The complexity of the beehive air, what does it really compose of? The financial feasibility of introducing a new measurement technology, would it require the procurement of glass beehives?
Question to ask in research mode 2	Are gases in beehives predominantly measured, i.e., is gas measurement a crucial part of the beekeeping journey map or process flow? Which market would be more suitable for the Pipe 4.0 application, small scale beekeepers or industrial beekeepers?

3.6 Food spoilage detection

During the course of research and discussions, the topic of food spoilage detection has been identified as an interesting application in the context of atmospheric packaging of products. Past research has shown that the freshness (and spoilage) of food has an impact on the oxygen concentration in a cealed food containter.[83]

Question	**Answer**
Gases to be measured	Carbon dioxide (CO2) Ammonia (NH3) Hydrogen sulfide (H2S) Methane (CH4) Acetaldehyde (C2H4O)
How its done?	Currently, different technologies aim to analyze the gas inside of atmospheric packaging. For instance, companies such as Gasporox offer optical spectroscopy (Tunable Diode Laser Absoprtion Spectroscopy (TDLAS)) that analyzes gas by sending low-power laser light through the container after it has been sealed. This technology offer a non-destructive approach, where no preparation or change of sample is necessary.[84] Further interesting literature for this field of application: https://www.frontiersin.org/articles/10.3389/fpubh.2021.816226/full https://cen.acs.org/articles/94/web/2016/12/Handheld-artificial-nose-sniffs-rotting.html

[83] Gasporox AB (2021). Minced meat at-line measurement. Retrieved 18th, 2023, from https://gasporox.se/minced-meat-at-line-measurement/

[84] Gasporox AB (2021). GPX1500 film food. Retrieved 18th, 2023, from https://gasporox.se/gpx1500-film-food/ ; Gasporox AB (2021). Product data sheet GPX1500 film food. Retrieved 18th, 2023, from https://gasporox.se/wp-content/uploads/DataSheet_GPX1500-Film-Food-O2_20220621.pdf

	https://www.linkedin.com/pulse/detection-food-spoilage-using-machine-learning-muttireddy/?trk=pulse-article
Who are the main users; What drives them and how do they influence one another?	The main users are diverse. Production companies could use it in order to conduct quality checks. Personnel of supermarkets could use the technology to test whether the food is still good to sell, and regulators can apply these technologies in order to test whether the packaging is conducted in the way it is supposed to be.
problems and pains that these users experience in existing solutions and processes *(i.e. in what way do they do a poor job?)?*	The above-depicted technology generally performs easy and fast analysis. However, selected characteristics can potentially lead to problems in the process. First, the device primarily identifies the concentration of O_2 and CO_2. Other gases which might emerge in the process are not identified. In addition, the narrow bandwidth of typical TDLAS sensors may limit the simultaneous measurement of multiple gases with overlapping absorption bands. Lastly, the cost of the TDLAS instruments should be considered too.

3.7 Technologies in place

Technology	Advantages	Disadvantages
Detection tubes	• Ease to use	• Sampling necessary • Tubes can only be used ones
Aeration oxidation	• Limited interference • Robust and repeatable method	• Reagents and gas flow rates have to be carefully maintained. • Long time of analysis (20 min) • Constant attention of personnel required
Electrochemical	• Lost-cost device	• Limited measurement to only reactive gases (usually no hydrocarbons)
Non-dispersive infra-red (NDIR) gas sensors technologies	• not susceptible to poisoning • do not burn out even when exposed to high concentrations of gases • rarely require calibration • long-life sensors • Can even detect gases in low-oxygen environments	• Cannot detect hydrogen because this gas does not absorb infrared light • do not work well when multiple hydrocarbon-based gases are present do not work well when multiple hydrocarbon-based gases are present -> high potential for false readings • susceptible to moderate changes in the environment's temperature and humidity, freezing their output during temperature transitions • require a great amount of power to function. Together with the frequent calibration this leads to a high total cost of ownership • Expensive when purchased • Potential interference
Fourier Transform Infrared (FTIR) technology	• Wide range of gases • High sensitivity (low concentrations possible) • Non-destructive and non-intrusive • Rapid analysis • Quantitative analysis	• High cost • Complexity; specialized knowledge and training necessary • Interference (affected accuracy due to other gases) • Limited sensitivity compared to other gases detection methods • Limited portability due to size of technology
MPS Sensors	• Especially accurate and reliable with flammable gases	• Poor selectivity
Raman Analyzer	• Enable multi-gas analysis like H2, N2, O2, CO2, NO2 and other gases at atmospheric pressure to ~0.02% • No extractive sampling • Not altered by water vapor	• Requires optical access • Does not allow the examination of traces • Selected gases (e.g. argon) not detectable

	• Simultaneous multiple gas analysis • Rapid, easy measurements; faster than Gas Chromatography (GC) • Faster cycling time, Less maintenance • Accurate identification and quantification	

References for above depicted advantages:

https://www.compur.com/en/gas-detectors/
https://nevadanano.com/ndir-sensor-are-there-disadvantages-to-consider/
https://www.draeger.com/en-us_us/Products/X-act-7000
https://edinburghsensors.com/
https://www.spiedigitallibrary.org/conference-proceedings-of-spie/11354/113541A/Diode-based-Raman-sensor-for-fuel-gas-analysis/10.1117/12.2554538.short?SSO=1

SECTION 4: DECISION MAKING: PHASING OUT INFEASIBLE IDEAS

Narrowing down to the main idea

Potential Application	Comments	Final
3.1 Decreasing Animal Harm	• Argon is not detectable • CO_2 is also measurable with lots of other techniques	✗
3.2 Mining	- Suitable for Pipe4.0 - Question if raman spectroscopy is cost-effective, maybe electrochemical might be also fine (even though it bit less reliable) - Next step: Wait on beehive decision; Potential alternative	✓
3.3 Volcanic Activity	- Axial scattering (Lidar) maybe more suitable than Raman spectroscopy	✗
3.4 Breweries & Wineries	- Problem of co2 and residual oxygen detection - Measurement at top of the tank - Next step: Further research	✓
3.5 Beehive Air-Sampling in modern apiculture	- Also other techniques possible - Check concentration that are expected - Next step: Check concentration/composition of gas	✗
3.6 Food spoilage detection (atmospheric packaging of products)	Food spoilage detection - Spectroscopy better suited because of traces - Material of packaging not suitable for optical access (according to Pipe4.0 midterm presentation)	✗

4.1 Stakeholder interactions

4.1.1 Interview guideline and questions

1. Introduction
   Who we are – students from LiU
   We are currently investigating the use of a gas measurement technology in wineries/mining
2. Questions
   a. Where do you encounter gases?
   b. Which gases need to be measured?
   c. What is the purpose of measuring gases?
   d. Are there already technologies in place?
      i. How many ppm are needed?
      ii. Which pains do you have with these technologies?

   Questions for wineries:

   e. Do you produce white and red wine?
   f. How does the fermentation process take place? What kind of tanks do you use?
   g. What are typical pain points in the production of wines/that you have?
   h. Are the current regulations in place (quality…) strongly affecting your work? Could our device potentially mitigate the harm?

4.1.2. Interview notes

Interviewee	Winery A, Germany
Date	24.04.2023
Notes	• The mitigation process is open and there is a CO2 detector to ensure the safety of the staff • There is a hollow space in the tank above the wine where it could be possible to measure gases • However, measuring the CO2 level in wine is not relevant • There are some wines which should have limited contact to oxygen and need to be protected. This is a challenge during the filtration process • During the aging process, samples are taken and tested • There are no nobel gases in use as they are too expensive • The bottling process is done with vacuum • There are many differences in the procedures in different wineries • Wooden barrels are oxidative; oxygen is desired during the aging process • Sulphur is often added to stabilize • Differences can be seen in the process of producing sparkling wines or champagne. Those wines should absorb CO2 and it must be determined how much sugar should be added
Actions taken after the interview	Get in contact with the University with its own winery, Germany (see interviewee below) & a suggested state winery in Germany

Interviewee	Winery B, Germany
Date	24.04.2023
Notes	• They use steel tanks for the fermentation process and wooden tanks for the aging process

	• Right now, they do not measure any gases within the tanks • During the aging process samples are taken daily to control the process • In the production of sparkling wine are gases involved. • A second fermentation process, that takes place in the bottles. In those bottles, the CO2 levels must be checked on a regular basis • The wine will be transported to a sparkling wine cellar which is specialized in making sparkling wines, carbonated, stored, CO2 monitored and sold • The pressure within the pressure tanks should have 2,49 bar • There is a sparkling wine tax which is why it crucial to know how much CO2 is in a bottle and follow the regulations • The tax amounts to 1,02€/ 0,75l bottle and demonstrates especially a competitive issue in regions close to borders (such as Luxembourg) where no taxes are applied • After Corking & Labeling, the bottles will be stored in a customs warehouse where each bottle gets documented
Actions taken after the interview	Get in contact with sparkling wine cellar (see interviewee below) to get further insights into the sparkling-wine production process

Interviewee	University with its own winery, Germany
Date	25.04.2023

Notes	• Distinction between bottle fermentation and tank fermentation Sparkling wine (German: “Sekt”) and semi-sparkling wine (German: “Perlwein”)
	• Sparkling wine bottle fermentation:
	    ○ CO_2 during fermentation; currently measured using a Manometer pressure gauge, where the pressure is then converted into a CO_2 content → existing table that enables conversion
	    ○ New approach: Laser technic, which enables test for all bottles (not only a sample as done with the pressure gauge)
	    ○ Issue of application in the context: concentration of CO_2 in this process always 100%, as no other gas can be inside the bottle → gas composition not relevant
	• Semi-sparkling (wine/bottle) fermentation:
	    ○ Headspace more promising
	    ○ Composition of gas of interest here; Regulatory threshold of regulator/government existing, which defines type of taxation (different between both wine types) → 2.5 bar CO_2 → **Current Problem**: the pressure in the bottle could also come from different gases, such as nitrogen or oxygen
	    ○ Thus, measuring the gas composition using the Rama spectroscopy could be beneficial → qualitative outcome of Raman already interesting

Actions taken after the interview	None

Interviewee	Sparking-wine cellar, Germany
Date	25.04.2023

Notes	• Differentiation between Semi-sparkling wine and sparkling wine
	• Sparkling wine
	  ○ processed in dark-green bottles (as protection of UV light in ageing process) → potential barrier for Raman measurement
	  ○ rather uninteresting for application of Raman (despite in case of unlikely wrong fermentations), as traditional tests are cheap and CO_2/other gas levels not critical (variations not an issue as long they are above the threshold for sparkling wine)
	• Semi-sparkling wine
	  ○ Addition of carbon in ordinary wines, e.g. by means of membrane gassing
	  ○ Overpressure due to external gases possible, which could affect the assessment of CO_2 pressure → interesting application of Raman technology to detect external gases
	• General:
	  ○ Interviewee performs 4,000-5,000 tests for CO_2 pressure/gas composition a year
	  ○ Interviewee produces approx. 2 Million bottles a year
	  ○ New technology could potentially lower the cost and reducing the number of (lost) samples
	  ○ Current process of test: freeze bottle, open it, use Manometer, dispose sample
	  ○ Temperature of 20°C during the measurement given by the regulator
	  ○ The measurement takes place during the process and right after the disgorgement before the corking and labeling and when the product is almost done
	  ○ Manual measurements are taken place with the end product every 15-30 min (every 500th to 1000th bottles) which ultimately lead to scrap
	  ○ The material costs at this stage of the bottle account to €0,70/ bottle
	  ○ Inbetween 2,5 and 3 bar, the bottle is considered as non-marketability
	  ○ There are frequent wine controls every 14-21 days where measurements from the government are done on site and in laboratory

Actions taken after the interview	None

Interviewee	Associate professor in applied sensor science
Date	25.04.2023
Notes	• Interesting technology, so far he has mainly been aware of Raman technologies for liquids or solids • Explains why Raman technology is not able to detect traces but is able to detect minimal changes in higher-concentrated gas compositions • Discussion about application in mines: Are there only traces? Are these measurable? • Application in fuel cells could be highly interesting

	○ Suggestion to analyze potential application in ammonia/hydrogen fuel cells
Actions taken after the interview	After the interview we decided to also get an idea of the potential application of this technology in the field of fuel cells.

Interviewee	Mine A, Sweden.
Industry	Mining- Zinc, Led , Copper, Silver
Date	27.04.2023
Notes	The mine's health and safety department is responsible for the gas measurement job. **Harmful gases measured and monitored.** • Carbon Monoxide • Nitrogen Oxide • Nitrogen dioxide Currently, the mine measure gases on a continuous bases as part of their health and safety. Additionally, underground miners have to go under with personal gas detectors for emergency purposes. These gas detectors measure against a certain occupational exposure value for example having a 50% threshold as the maximum level and having 10% as the minimum level. In that case, having the gas for example Nitrogen Oxide below the minimum occupational exposure level will be safe (10%) and if the gas percentage value gets up to the maximum value, the underground miner would need to evacuate immediately. When we asked about current technologies used in measuring the gas, the Manager was not ready to share the data right away and requested us to send an email with all the questions we had regarding the journey map of gas measurement.
Actions taken after the interview	A follow up email was sent on the same day and a reminder email was sent the following morning. We are currently waiting on the response with the finer details.

Interviewee	Mine 2, Germany
Date	28.04.2023
Notes	• The company interviewed operates mines, especially for the extraction of salts. In this context, CO_2 is a problem because it can occur in the course of mining activities. Due to the characteristics of the gas, larger intensities can collect in sinks (so-called "puddles"). • Currently, the Group uses standard mobile warning devices, such as those from the manufacturer Dräger (e.g. X-am 8000 multi-gas detector) or stationary measuring devices to ensure employee safety. Infrared devices are often used here, which enable the identification of various gases. • A disadvantage of the traditional, mobile warning devices is the local measurement of the gas. Because of this, miners must be on site in person to perform the measurement of the gases. Especially

	against the background of the dangers posed by the gases, a measurement at a distance would be a very advantageous change. • Against this background, alternative measuring equipment was sought in cooperation with a research institute, which would allow the gases to be measured at a distance (e. g. 20 meters). In the context of this, the Ramen technology was examined more closely. A prototype resulting from this cooperation was successfully created and found to work. However, since the development of the prototype to actual use was thought to be comparatively long and there were also concerns about protecting personnel from possible laser (reflections), the project was not pursued further and continued to rely on the standard warning device. • In the context of concentrations and measured data, we also discussed air concentrations and occupational exposure limits. While 400 ppm CO_2 is usually present in the air, the following limits are defined according to TRGS 900: o Occupational limit value over the day: 0.5 CO_2 volume concentration → 5,000 ppm o Working limit four times 15 minutes per shift: 1 CO_2 volume concentration → 10,000 ppm
Actions taken after the interview	None

Interviewee	Associate professor in energy management
Date	26.04.2023
Notes	• Information about the person: the interviewee has been working on the development of an Ammonia cracker which enables the transformation of Ammonia into hydrogen and nitrogen (and last rests of ammonia) with a particularly high efficiency. → End product of this cracker is 75% hydrogen, rest is nitrogen and ammonia → the traces of ammonia in this production process cannot be avoided, however decreased when the temperature of the device is increased (Ammonia cracker works with the trace of Ammonia and burns that to heat the process) → lowest level of Ammonia after high-temperature fuel cell process around 100 ppm. • As there is no carbon/carbon dioxide in this process included, it has a high potential in light of the current climate discussion. • Ammonia is easier to handle and transport then hydrogen. • Besides the above-depicted application, the gas measurement technology might also be interesting when ammonia is directly used in engines which are operating with a combination of hydrogen and ammonia. → in this process, 10-30% of ammonia is given directly into the engine. → measurement in combustion might be interesting. • There are gas measurement technologies used in the laboratory, which for instance operate on the UV-spectroscopy technology; however, in practice there is not measurement as ammonia is not used yet.
Actions taken after the interview	Expand research on fuel cell application with focus on two topics: - measurement of combustion gas in direct ammonia use.

	- monitoring of gas composition behind ammonia cracker.

Interviewee	PhD candidate on alternative ship fuels
Industry	Shipping advisory
Date	26.04.2023
Notes	• Measurement technology relevant as Ammonia is already dangerous with concentration of 0.5% in the air. • Regulatory requirement of a double-walled tube to increase safety.
Actions taken after the interview	None

4.1.3 Investigation of Fuel cells

Idea: During the interview with the Associate professor in applied sensor science, we became aware of the potential application of the technology in the fuel cells of ships, airplanes etc. Even though fuel cells technologies are currently intensively researched and not yet broadly distributed, the market is expected to growth quickly in light of the current sustainability discussion.

In this area, two possible energy carriers are of interest: Ammonia and Hydrogen. In comparison to Hydrogen, Ammonia has the big advantage that it can stored much easier. Whereas hydrogen needs either 250 bar pressure or -253°C to be stored as a liquid, ammonia only requires 8 bar, which is comparable with the pressure in a camping cooker.

The usage of ammonia can be done in two ways. It can either by separated into hydrogen and nitrogen, which can then be used in the fuel cell, or directly burned in a combustion engine. Both application do not emit CO_2, as there is no carbon dioxide in the process. The first process is also known as ammonia cracking. During this, ammonia is burned to be converted into hydrogen and nitrogen. The usual composition after that is: 75% hydrogen, remains of nitrogen and traces of ammonia. To check whether the process of the cracking runs correctly, a monitoring of the gas composition is beneficial (accordingly to the interview with the associate professor in energy management). In this regard, the Raman spectroscopy might be suitably applied to monitor whether the process is performed correctly. The proportion of ammonia in hot condensing cells is very low (around 100ppm). However, a measurement might be possible by measuring changes in the composition of hydrogen and nitrogen. Besides that application, the ammonia could also be directly burned in a normal combustion engine. For that, around 10-30% of ammonia could be combined with hydrogen. In this application, the waste gas could content nitrogen gas and water vapor. As nitrogen oxide (NOx) is harmful and contributes to air pollution and acid rain, proper emission controls and treatment systems would need to be in place. In the light, the Raman spectroscopy could be promising to monitor and subsequently mitigate potential issues.

Both depicted application seem to be interesting for a potential application of the Pipe4.0 technology, especially in light of the expected market growth and importance for a sustainable transformation. However, due to the progress made in the wine and mining sector and the special requirements for the transportation of hydrogen and ammonia, which consequently can be potential barriers for the measurement using the Pipe-technology, we have decided to not further pursue this field.[85]

[85] Reference of whole abstract: Interview notes; Engel, K.M. (2021). Unter grünem Volldampf. Retrieved 24th, 2023, from https://www.spektrum.de/news/ammoniak-als-schiffstreibstoff-unter-gruenem-volldampf/1856677 ; thyssenkrupp Uhde. (2023). How does ammonia cracking work? Retrieved 24th, 2023,

SECTION 5: CHASING THE REMAINING 2 IDEAS: MINING AND WINEMAKING FIELD RESEARCH

1.1 Mining

5.1.1 Persona & POV

1.1.2 Mining Journey Map

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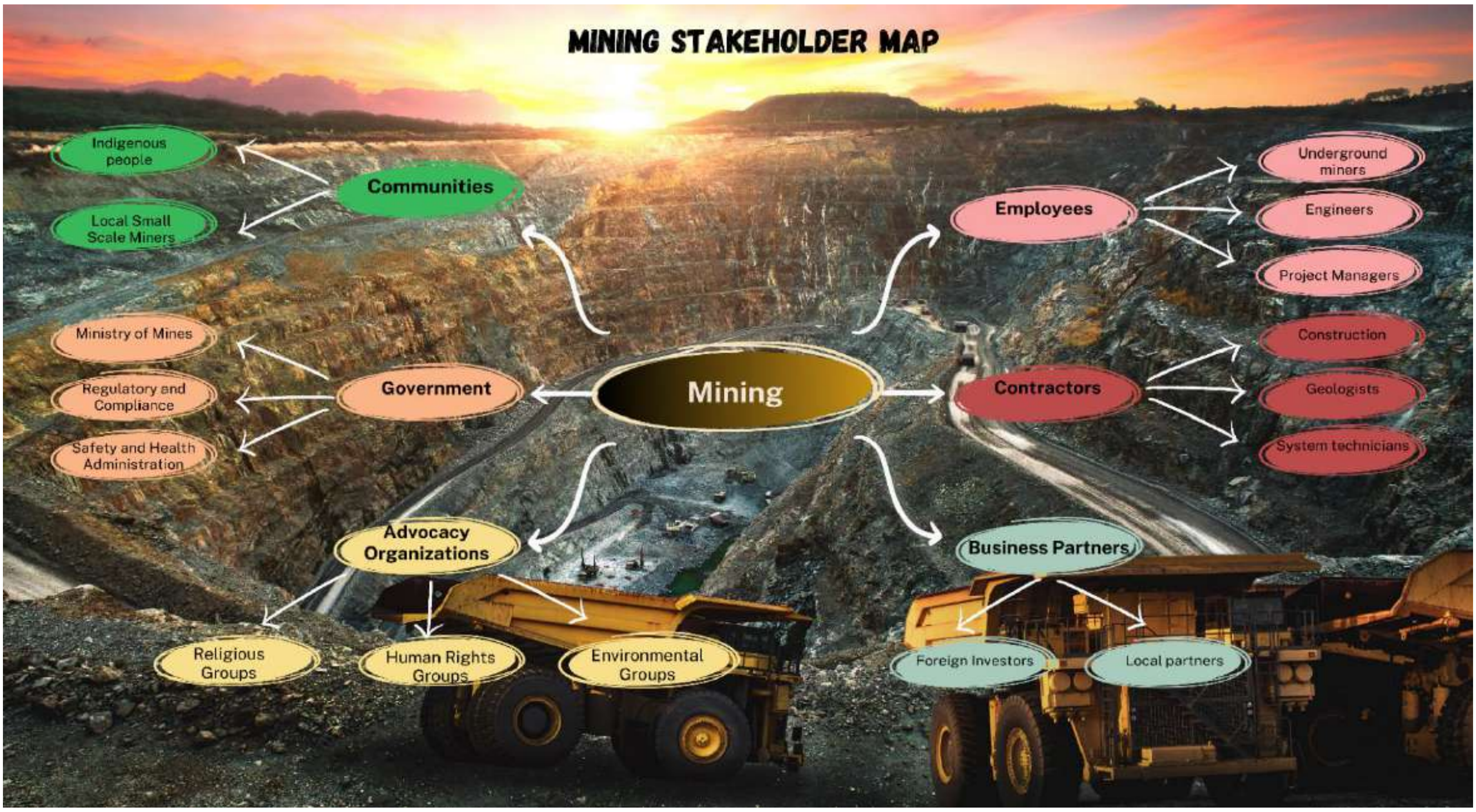
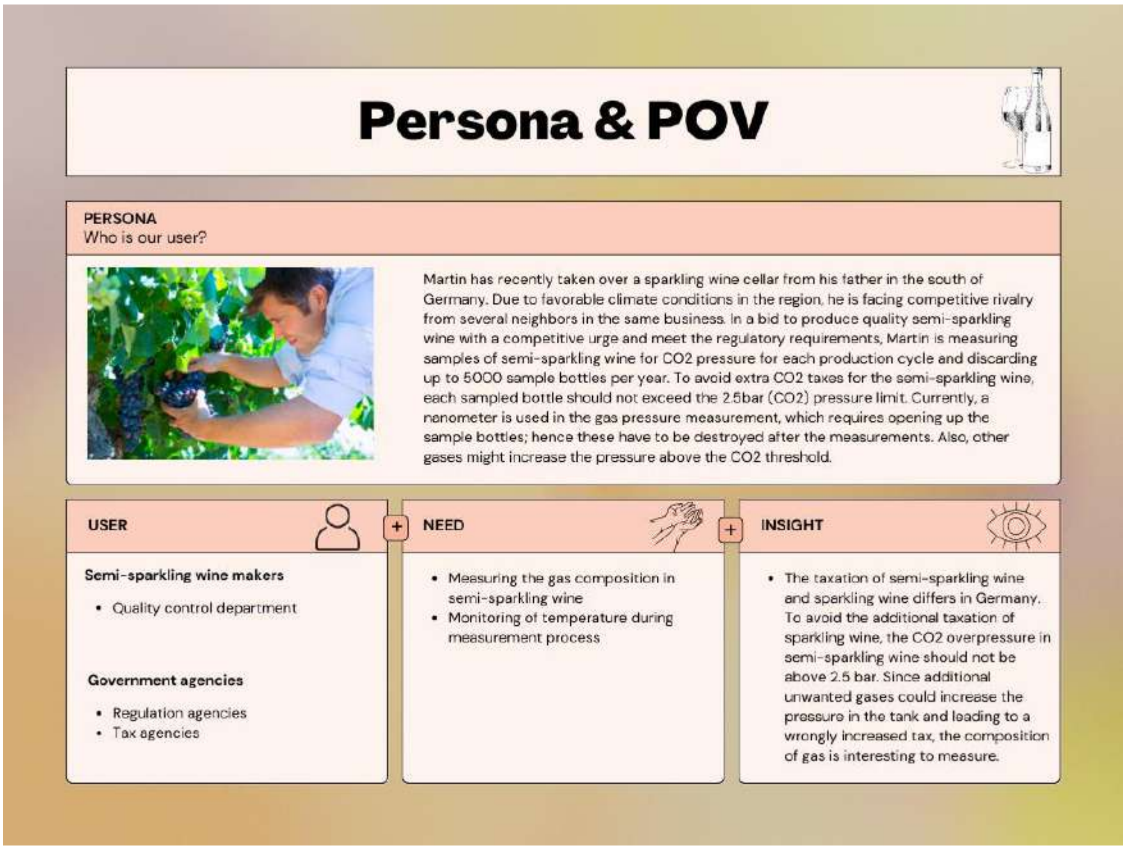
from https://www.youtube.com/watch?v=QwlEpyAyX6k ; Fraunhofer institute. (2021). The world's first high-temperature ammonia-powered fuel cell for shipping. Retrieved 24th, 2023, from https://www.fraunhofer.de/en/press/research-news/2021/march-2021/worlds-first-hightemperature-ammonia-powered-fuel-cell-for-shipping.html

1.1.3 Stakeholder map

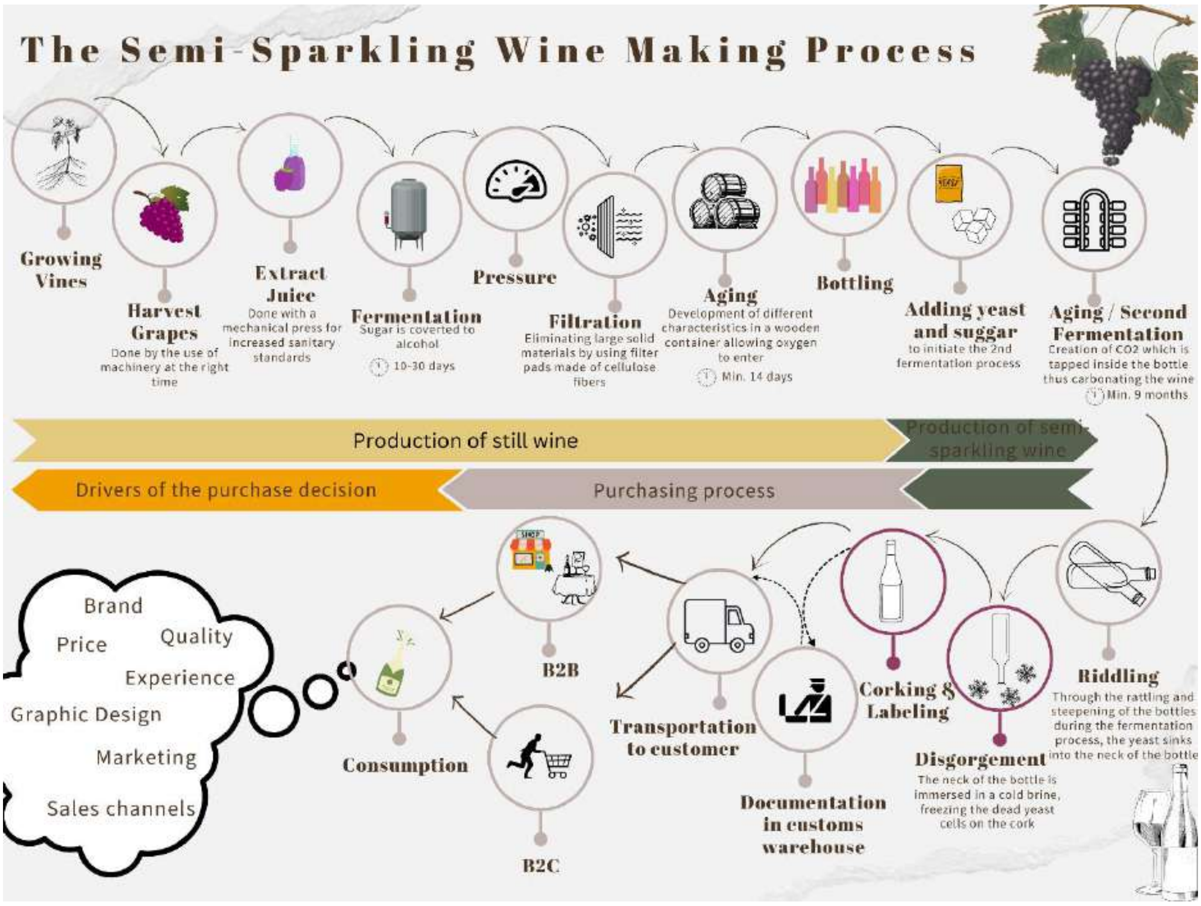


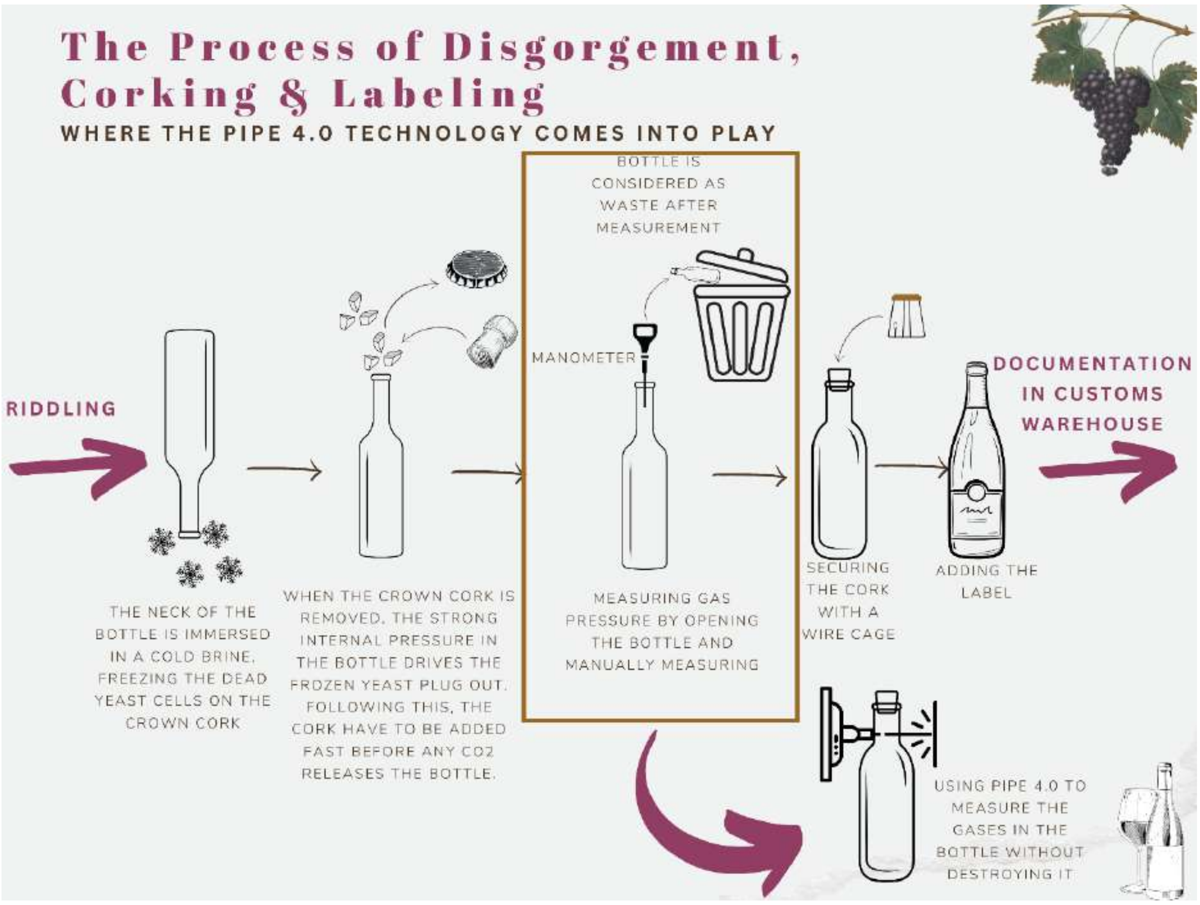
1.2 Sparkling Wine

5.2.1 Persona & POV

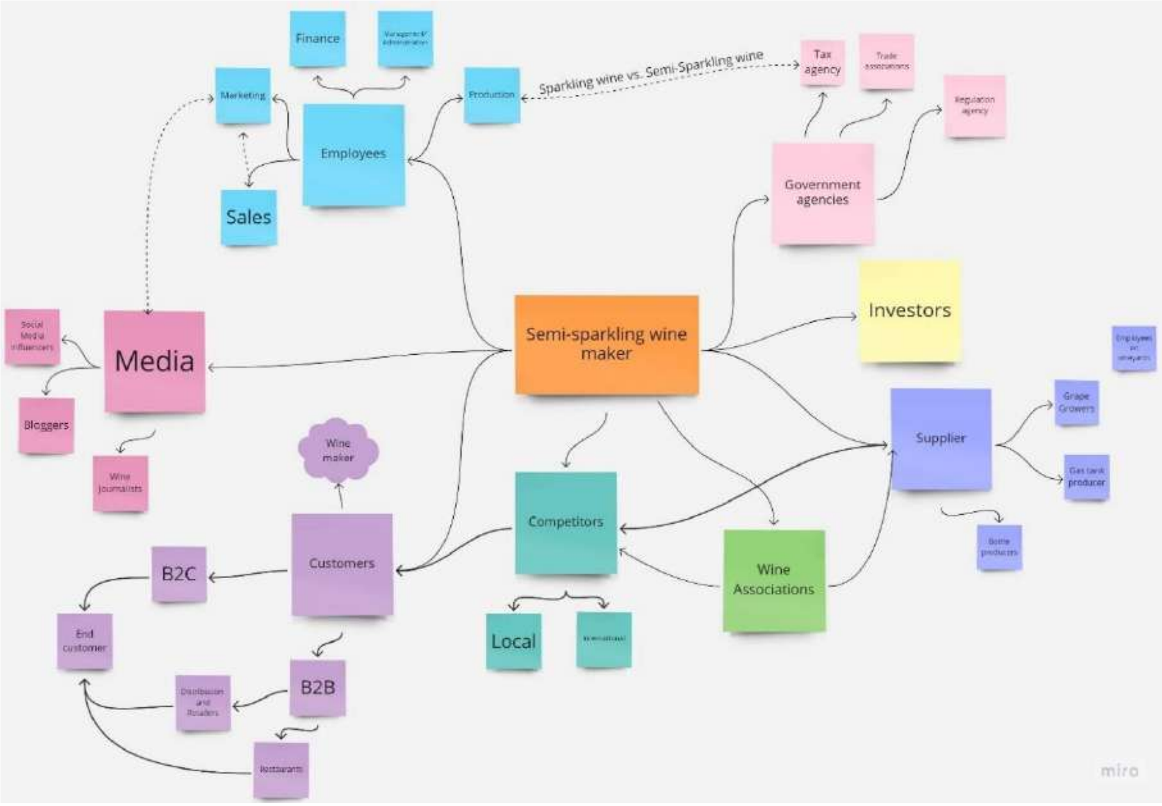


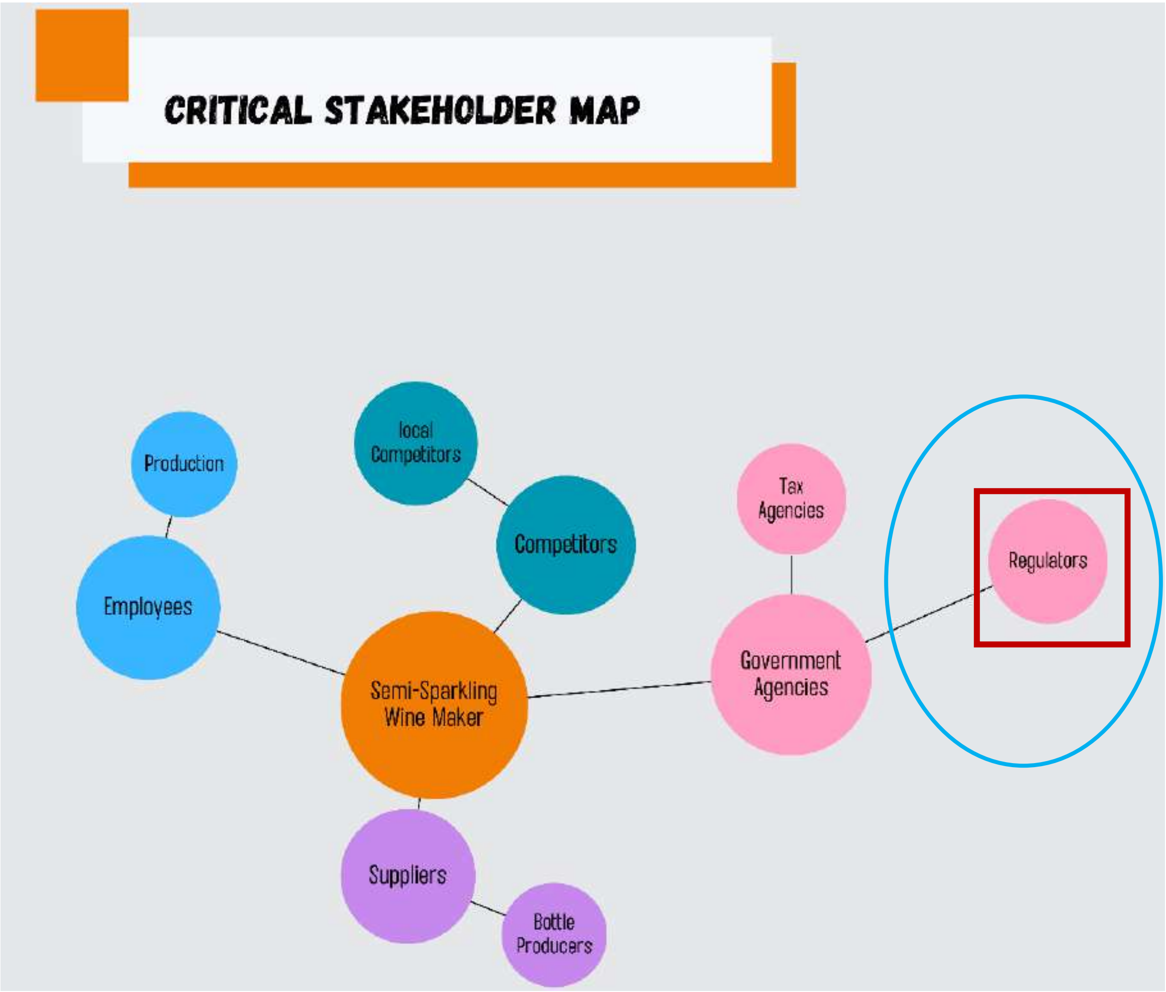
5.2.2 Journey map





5.2.3 Stakeholder map





Purpose	Wines which include a high amount of carbon dioxide (CO2) are called sparkling and semi-sparkling wines. This carbon dioxide overpressure can occur through fermentation or through technical impregnation by means of carbonic acid. As well as ethanol, gaseous carbon dioxide is generated as a natural part of the fermentation processes.[86] Legal limit values (2.5 and 3 bar) for differentiation of the categories of sparkling and semi-sparkling wine can be determined by using the PiPe 4.0 technology. Therefore, the purpose of measuring gases in the production process of sparkling and semi-sparkling wines is to comply with regulations regarding trade and taxation.
Types of wines	**Sparkling wine** (e. g. Champagne, Sekt): Fermentation process can be done in bottles or tanks. Can have above 3 bar (atmospheres). Champagner**:** French sparkling wine. Produced according to the traditional bottle fermentation method; grape varieties: Chardonnay, Pinot Noir (Pinot Noir), Pinot Meunier (Black Riesling). Sekt**:** German sparkling wine. Fermentation mostly in tanks. Grapes depend on the region. There are three ways to produce sparkling wine:[87] - the classic or traditional bottle fermentation - the transvasation process - the large-capacity process (To get an insight into the production process: https://www.youtube.com/watch?v=r1TZre7N3lk) **Semi-Sparkling wine:** between still wine and fully sparkling wine, 1-2.5 bar (atmospheres); in Italy: Frizzante; usually produced with the addition of carbonic acid. Prosecco is available as a fully sparkling wine as well as a semi-sparkling wine (Frizzante).
Gases to be measured	CO2 (main component), Nitrogen, Argon[88]
How it is done	An easy possibility of measuring this overpressure is using a manometer.

[86] Prasnikar, N., Fuchs, A., Patzl-Fischerleitner, E. (2016). Method comparison for the determination of total pressure and CO2 content in semi-sparkling and sparkling wine. Mitteilungen Klosterneuburg, 66, 344-357.
[87] Schiessl, C. (2023). How Sparkling Wine is Made. Retrieved April 26th, 2023, from https://www.winemag.com/2019/05/14/how-sparkling-wine-made/.
[88] Schiessl, C. (2023). How Sparkling Wine is Made. Retrieved April 26th, 2023, from https://www.winemag.com/2019/05/14/how-sparkling-wine-made/.

Pains	Using a manometer requires opening the bottle making it not saleable anymore. In addition, the value showed by the manometer does not only include the CO2 level but also other gases such as nitrogen or oxygen.[89] So far, there is no reliable technology in place which measures all components of the gases within the bottle without destroying the bottle and taking manual samples. The measurement is needed to get information on the fermentation process, guarantee high quality as well as to fulfil regulatory and tax compliances.

5.2.4 Brainstorming on concentration and sampling issue

During our research we came along the potential application of the Pipe4.0 technology to detect the composition of gas inside a semi-sparkling wine bottle. With that, potentially wrong categorization can be avoided. As 2.5 bar CO_2 is the threshold for semi-sparkling wine, all above this threshold is unsaleable (from 2.5 till 3 bar CO2) or treated with a higher tax (3 bar and above). This is could also be the case even though other additional gases are also increasing the threshold. For instance, traces of oxygen and nitrogen might lead to an increased pressure, even though they are not important for the threshold for increased tax.

In light of this problem, the Raman spectroscopy seems highly interesting. However, as nitrogen and oxygen are only expected to be in the bottle/tank as traces, concentration of 1-20 ppm of both are expected. This, unfortunately, is below the suggested concentration levels of 1000 ppm as minimum level of identification. Because of that, a workaround is required. This could for instance be accomplished by focusing on the measurement of CO_2. Potential deviations in concentration might give insights of the overall gas composition in the bottle/tank. And as CO_2 is expected to be at least 1000pm in the bottle because of the bubbles insight the semi-sparking wine, this should be easily feasible to determine.

Please see below a table for the relation between pressure (bar) and g/l of CO_2 at the required temperature of 20°C. Below that, the table depicts the relation of mg/l and ppm.

	Pressure	~ CO2 @ 20°C	EU Excise Duty	
Still	< 1 bar	<2 g/l	Still	Vinho Verde
Semi sparkling	1 to 2.5 bar	2 to 5 g/l	Still	Prosecco
Sparkling	3 bar +	> 6 g/l	Sparkling	All

Source: Wine and Spirit Trade Association.

Reference: Wine and Spirit Trade Association. (2009). Role of carbon dioxide in still wines. Retrieved 27th, 2023, from https://www.winewisdom.com/articles/techie/role-of-carbon-dioxide-in-still-wines/.

[89] Prasnikar, N., Fuchs, A., Patzl-Fischerleitner, E. (2016). Method comparison for the determination of total pressure and CO2 content in semi-sparkling and sparkling wine. Mitteilungen Klosterneuburg, 66, 344-357.

Source: Endmemo unitconverter (2023), Retrieved 27th, 2023, from
http://www.endmemo.com/convert/

SECTION 6: FINAL DECISION

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6.1 Why Sparkling and Semi-Sparkling Winemaking.[90]

THANK YOU

[90] Source: Canva (2023)