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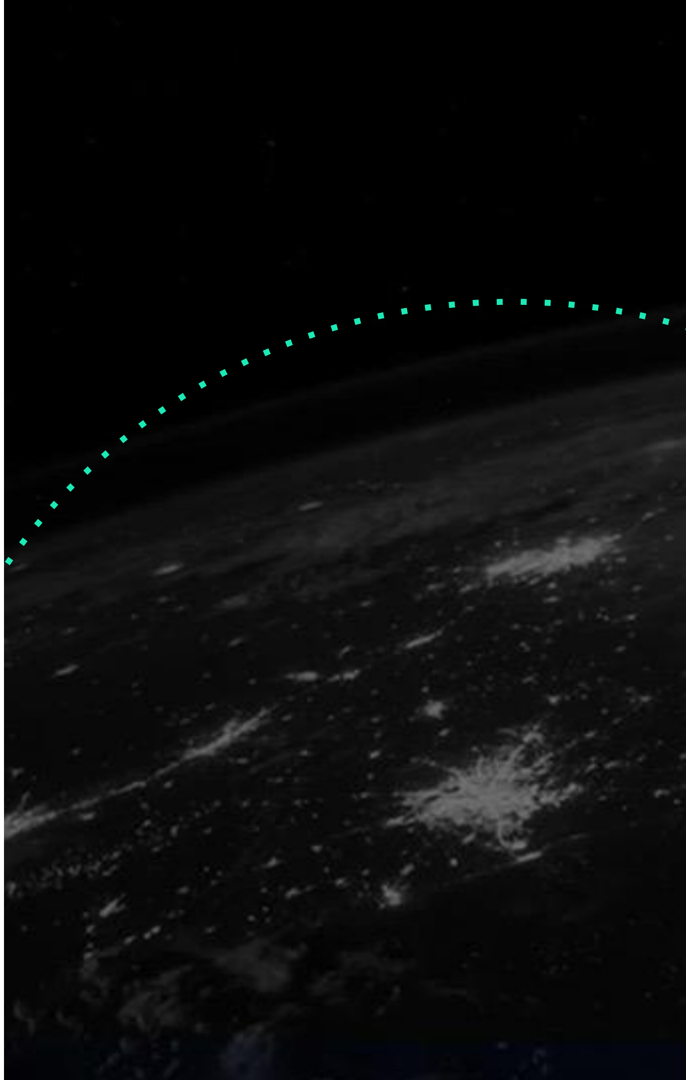
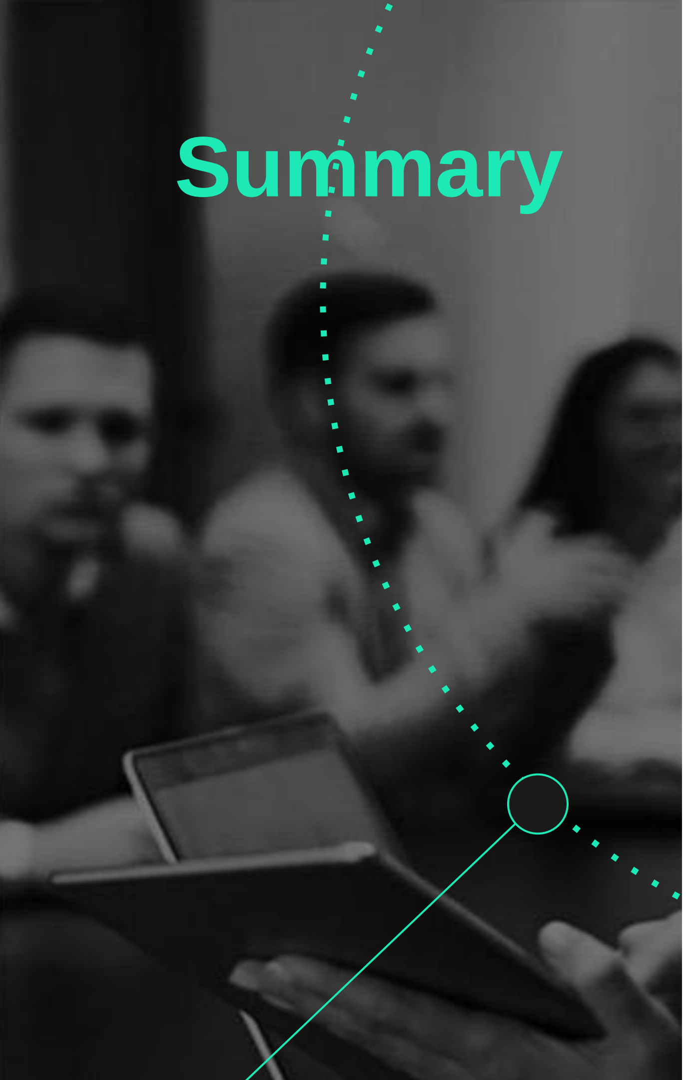
Tackling Methane Emissions in Upstream Oil and Gas Sectors – Technological Benchmark

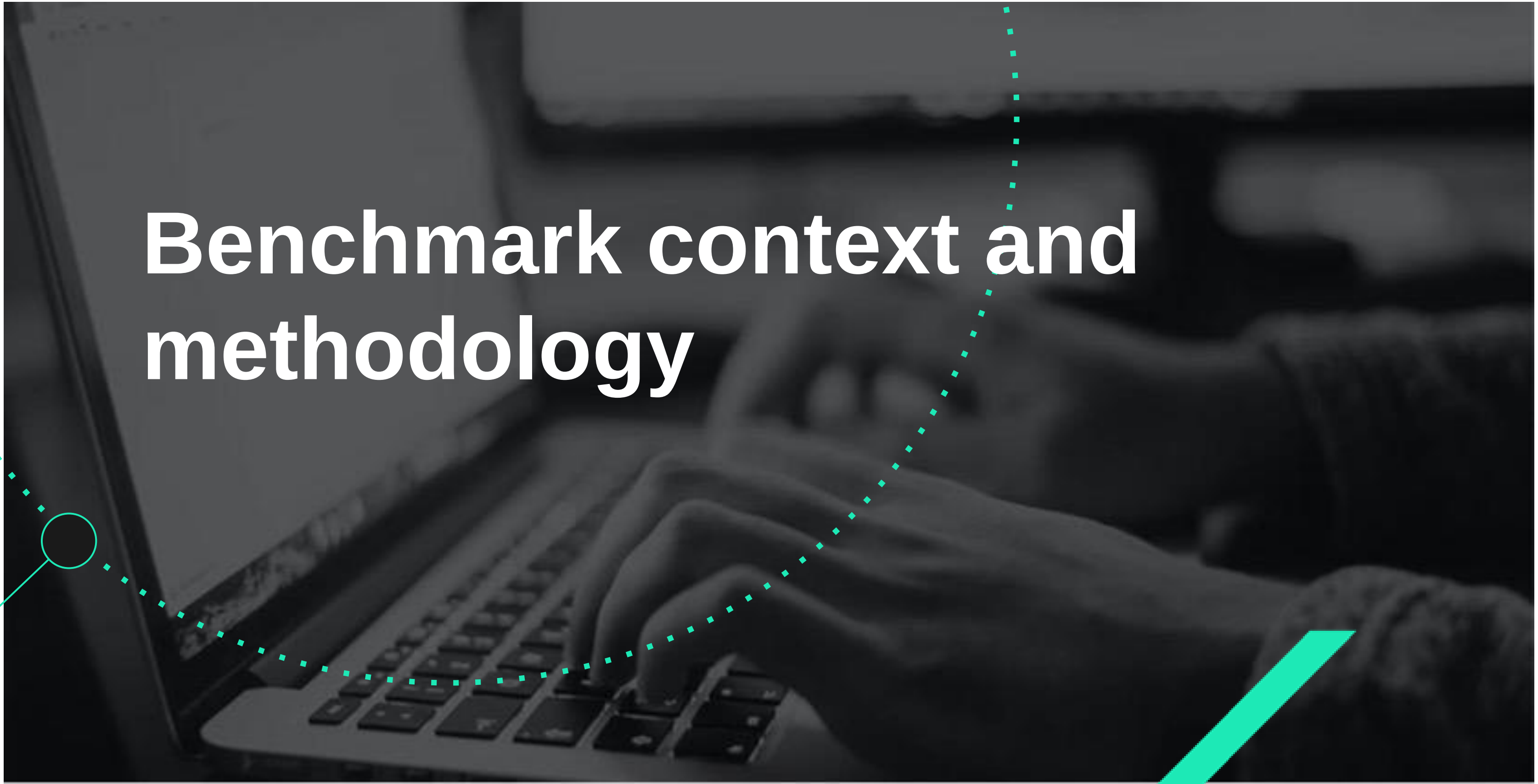
Jean-Baptiste Hecquet
Managing Director, Energy, Utilities & Environment
+33 6 70 59 28 01
jean-baptiste.hecquet@sia-partners.com

Armand de Cholet
Supervising Senior consultant, Energy, Utilities & Environment
+33 6 26 27 15 10
armand.decholet@sia-partners.com





Summary



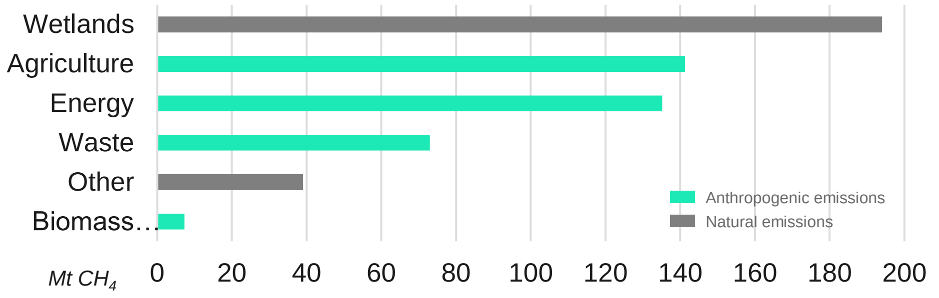
Benchmark context and methodology

1. Context, issues, and expectations

Methane is responsible for around 30% of Global Warming

- **Methane is the second largest greenhouse gas contributor to global warming, after carbon dioxide (CO_2).** Methane has a much shorter atmospheric lifetime than CO_2 – 12 years compared to centuries – but absorbs much more energy while it exists in the atmosphere. According to the latest IPCC report, the Global Warming Power (GWP) of methane is 81 times that of CO_2 over a 20-year period.
- **The concentration of methane in the atmosphere is currently two-and-a-half times greater than its pre-industrial levels.**
- **Methane also affects air quality in the ground-level ozone, also known as the tropospheric ozone or surface-level ozone.**

Sources of methane emissions in the world in 2021



Sources : IPCC report and IEA figures

Methane characteristics:

- Composition: **CH_4** *(Carbon & Hydrogen)*
- Lifetime: **11.8 years**
- Global Warming Power in 20 years: **81**
- Global Warming Power in 100 years: **28**

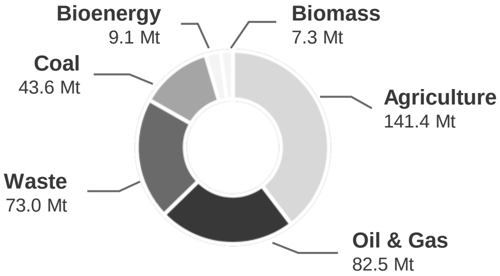
Source : IPCC report

Given the significant warming power of methane and its limited lifetime in the atmosphere, **reducing methane emissions from the energy industry represents one of the best near-term opportunities to contribute to climate change mitigation**.
Of the 135 million tons of energy-related emissions, an estimated 61% are directly linked to Oil & Gas activities.

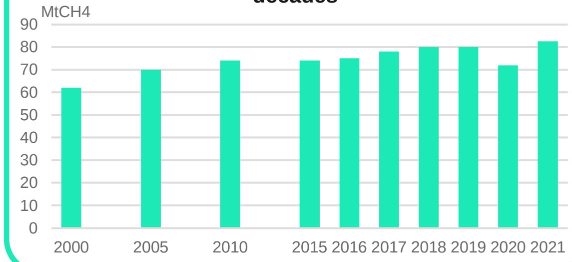
1. Context, issues and expectations

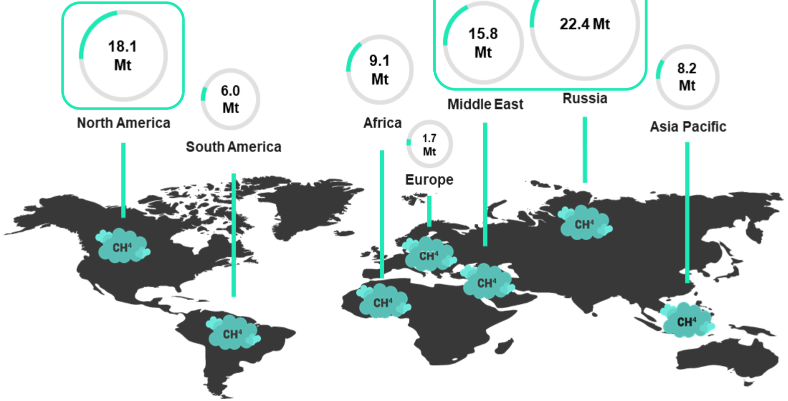
World view on methane emissions in upstream Oil & Gas

The O&G industry is 2nd place for methane emissions



O&G emissions are steadily increasing over 2 decades





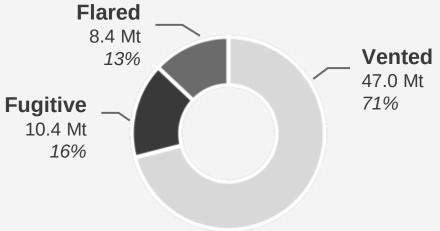
Oil and Gas Methane Emissions by geography

- A wide disparity can be observed between regions.
- 70% of the emissions are concentrated in the 3 highlighted areas above.
- The intensity of methane emissions varies significantly across countries and extraction points.

Upstream vs Downstream

- Upstream contributes to 80% of the oil & gas industry emissions.
- Methane emissions in downstream are mainly fugitive and dispersed throughout the network.
- Upstream emissions are located on extraction spots and are mostly due to intentional releases.

Upstream emission sources



The Oil & Gas industry will play a crucial part in reducing global methane emissions.
To tackle this challenge, the industry should **focus on the upstream sector, and invest in innovative technologies**.

Source : IEA Methane Tracker 2021

1. Context, issues and expectations

The approach to reduce Methane emissions

FIND

Data will be collected using one (or more) of the employed measurement technologies in order to detect Methane releases.

PROCESS

Data will be uploaded (cloud or other tech) and processed in order to quantify the severity of the leak. The data will be shared and displayed with the client at this stage.

FIX

A company that specializes in fixing methane leaks will be retained.

IMPROVE

Data detection and processing will continually improve (AI, IoT) to reduce the client's turnaround time.

This **approach to methane mitigation is a well-known standard in the industry**.
Nevertheless, the technologies and market solutions are focusing on three steps: FIND, PROCESS and IMPROVE

1. Context, issues and expectations
Benchmark deliverables

According to the IEA, almost ¾ **of methane emissions in the Oil & Gas sector could be reduced with existing technology***, and close to half at zero net cost. Major oil companies that are aiming for ambitious methane reduction targets will have to invest in measurement, data processing, and CH4-reducing technologies.

Oil & Gas companies will need to invest in integrated paths of technologies to mitigate CH4 leaks

Detection and Measurement (FIND)

- **Sensors mounted to infrastructure close to the identified source of emissions**
- **Drone surveillance with data capture**
- **Satellite detection**

Data Processing (PROCESS)

- **IoT**
- **Decision making tools**
- **Production and monitoring software**
- **Big data and Cloud**

Process improvement (IMPROVE)

- **AI to improve the process and data**
- **Reporting tools**
- **Dashboard to ease data analysis**

Our study will present a selection of technologies (standard and innovative) that will aid Oil & Gas stakeholders to **improve their efficiency in reducing methane emissions** in three steps.

*Source : *IEA Report 2021 - Curtailing methane emissions from fossil fuel operations*

Methane reduction technologies

2. Methane reduction technologies

Comparative criteria selected for the benchmark

In this benchmark, we compare the different technologies available in the market which can help Oil & Gas stakeholders reduce their methane emissions, and the operation models related to it (outsourcing or purchasing). To structure our analysis, we decided to evaluate methane detection and data processing technologies based on the criteria below:

Criterion	Description
Installation cost - CAPEX	The initial cost of purchasing and implementing the solution (settlement, training, insurance).
Track record	The impact of the solution based on its current use worldwide among Oil & Gas stakeholders.
Running cost - OPEX	The operational cost of using the solution (labor cost, licenses, power supply, renting resources).
Implementation time	The time required to make the first use of the solution. This field varies significantly with the location.
Maturity	The level of maturity of the solution based on its release date and the improvement made.

By using these criteria, we can have a clear and neutral comparison between the different technologies to support decision-making

2. Methane reduction technologies

Solutions across the value chain of Methane mitigation

FIND
Detection and measurement technologies

1. Laser Absorption Spectrometer (LAS)
2. Acoustic Leak Imaging camera (ALI)
3. Optical Gas Imaging camera (OGI)
4. Imaging interferometry (Glint Mode)
5. Inspection services

PROCESS
Technologies that process the data

6. Monitoring software
7. Production management software

IMPROVE
Advanced technologies that improve the process

8. Autonomous AI software

Technology

Service provider

2. Methane reduction technologies

Comparative chart of Methane detection technologies

				Outsourcing	
Technologies	1 Laser Absorption Spectroscopy (LAS)	2 Acoustic Leak Imaging camera (ALI)	3 Optical Gas Imaging camera (OGI)	4 Imaging Interferometry (Glint Mode)	5 Inspection Surveys on ground or aerial
Brand	**Aeris Technologies, LinkedAll**	**Distran Switzerland**	**FLIR (France Infra Rouge), Optical Gas Imaging**	**GHGSat**	**ABB, Pergam-Suisse AG, Kairos Aerospace (plane only)**
Installation cost – CAPEX	Medium	Medium	Medium	N/A (service provider)	N/A (service provider)
Running Cost - OPEX	Medium	Medium	Medium	High	Low
Maturity	Medium	Medium	High	Low	Medium
Track record	Established	Established	Standard	Prototype	Established
Implementation Time	Intermediate	Intermediate	Intermediate	Slow	Fast

Cost: low < 100k < Medium < 500k < High | **Maturity**: low < 5 year < Medium < 10 years < High | **Track record**: Standard < Established < Prototype

Implementation Time: Fast < days < Intermediate < years < slow

2. Methane reduction technologies

Comparative chart of Methane data processing and process improvement technologies

Technologies	6 Monitoring software	7 Production management software	8 Autonomous AI software	
Brand	**Viper Imaging**	**Schlumberger**	**Kelvin Inc.**	**C3IoT**
Installation cost – CAPEX	Low	Medium	High	High
Running Cost - OPEX	Low	Medium	Medium	High
Maturity	High	Medium	Medium	Medium
Track record	Standard	Established	Established ~ Prototype	Prototype
Implementation Time	Fast	Intermediate	Intermediate	Slow

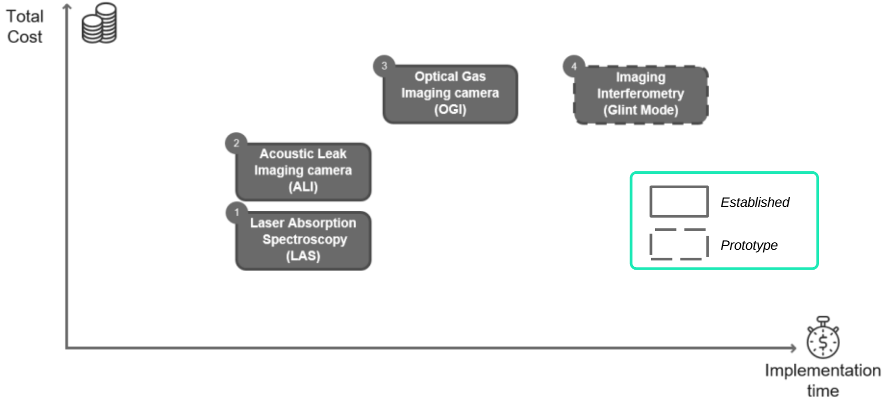
Cost: low < 100k < Medium < 500k < High | **Maturity**: low < 5 year < Medium < 10 years < High | **Track record**: Standard < Established < Prototype

Implementation Time: Fast < days < Intermediate < years < slow

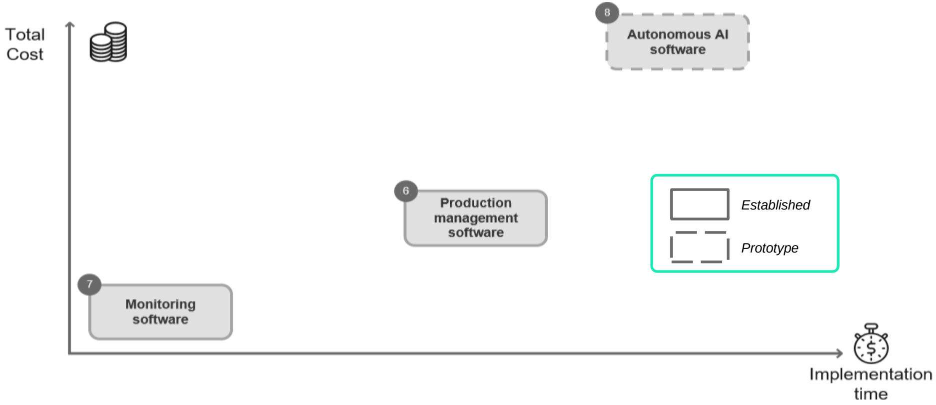
2. Methane reduction technologies

Market cost and implementation time of competitive solutions

Overview of measurement and detection technologies:



Overview of data processing and process improvement technologies:



All these technologies have been technically and economically described and compared in this part of the study.
To push further, we match the tech to use cases encountered by Oil & Gas stakeholders.

Main use cases related to tackling methane emissions

3. Main use cases

Focus on specific criteria to match client needs

To answer real client needs and specific use cases, we needed to complete our first analysis with more client-oriented criteria. The criteria below enrich the study and add the extra information required to make clear choices for every use case.

Generic criteria for detection and data technologies:

Area to inspect / Data volume	Refers to the total surface area to inspect and the amount of data related to it. Augments with the surface but also with the leaks to detect being smaller.
Allowable implementation time	Refers to the time allowable by the client for implementing the solution (detection/measurement or data processing).
Resources available	Refers to the financial resources (CAPEX & OPEX) the client can dedicate to tackling methane emissions.

Specific criteria for measurement & detection technologies:

Allowable inspection duration	Refers to the duration allowable by the client for the leak detection process. The higher the indicator, the more time can be spent inspecting installations.

Specific criteria for data technologies:

Process optimization available	Refers to what can be optimized in the data processes. The higher the indicator, the more space there is for optimization.

Applying this methodology provides the information to **identify the appropriate technology and operating model for each client use case**.

3. Main use cases: detection and measurement

Use case #1: short-term detection of large to small onshore leaks

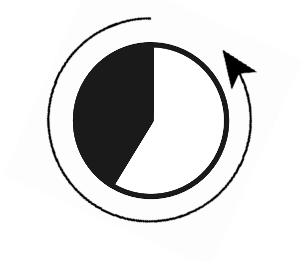
- One or several fields have leaks that need to be identified precisely or an inspection is required to audit the installations.
- A **punctual short-term solution** is needed to make installations analyzed safe at a limited cost.

Area to inspect

Allowable implementation time

Resources available

Allowable inspection duration



Most relevant technology:

Inspection services

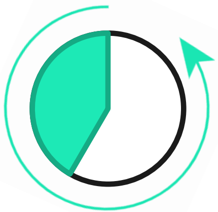
3. Main use cases: detection and measurement

Use case #2: mid-term detection of large to medium onshore leaks

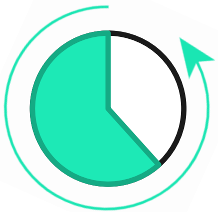
- For one or several fields, the company's objective is to build an internalized mid-term LDAR strategy to **reduce the environmental impact** as well as the costs related to the **larger leaks in priority**.

Area to inspect

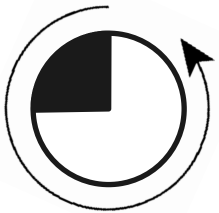
Allowable implementation time



Resources available



Allowable inspection duration



Most relevant technology:

LAS, ALI or OGI
Drone devices

3. Main use cases: detection and measurement

Use case #3: long-term detection of large to small onshore leaks

- For one or several fields, the company's objective is to build an internalized long-term LDAR strategy to **minimize the environmental impact** as well as the costs related to **all type of leaks, small to large.**

Area to inspect | **Allowable implementation time** | **Resources available** | **Allowable inspection duration**

Most relevant technology:

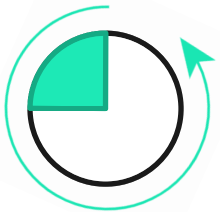
LAS, ALI or OGI Handheld devices

3. Main use cases: detection and measurement

Use case #4: detection of large onshore and offshore leaks at a company scale

- For a global company, the objective is to identify the main leaks to prioritize the **actions with the most impact**.
- The detection needs to be done in short order **at a world scale,** onshore and offshore, **prioritizing the larger leaks** to quickly give an overview of the situation.

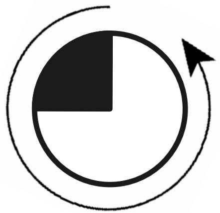
Area to inspect



Allowable implementation time

Resources available

Allowable inspection duration



Most relevant technology:

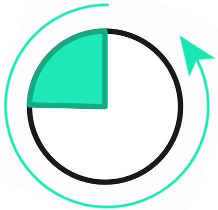
Imaging Interferometry

3. Main use cases: data processing and process improvement

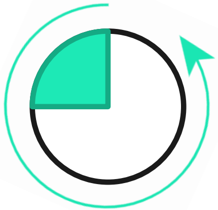
Use case #1: data visualization and aggregation for one field

- For one field, the operating team wants to **visualize and aggregate data** from their methane detection technology.

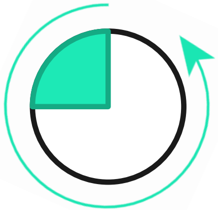
Area to inspect / Data volume



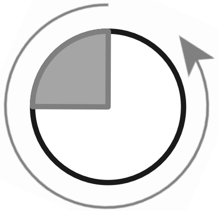
Allowable implementation time



Resources available



Processes optimization available



Most relevant technology:

Monitoring software

3. Main use cases: data processing and process improvement

Use case #2: data and processes automatization for one field

- For one field, the operating team wants to **automate the management of the processes** and the implementation of solutions.

Area to inspect / Data volume | **Allowable implementation time** | **Resources available** | **Processes optimization available**

Most relevant technology:

Production management software

3. Main use cases data: processing and process improvement

Use case #3: integration and processing the data at a company scale

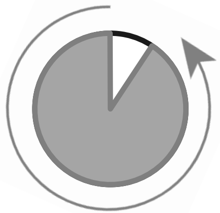
- For a company, the management team wants to **collect data, automate processes and solutions, forecast maintenance,** and avoid leaks.

Area to inspect / Data volume

Allowable implementation time

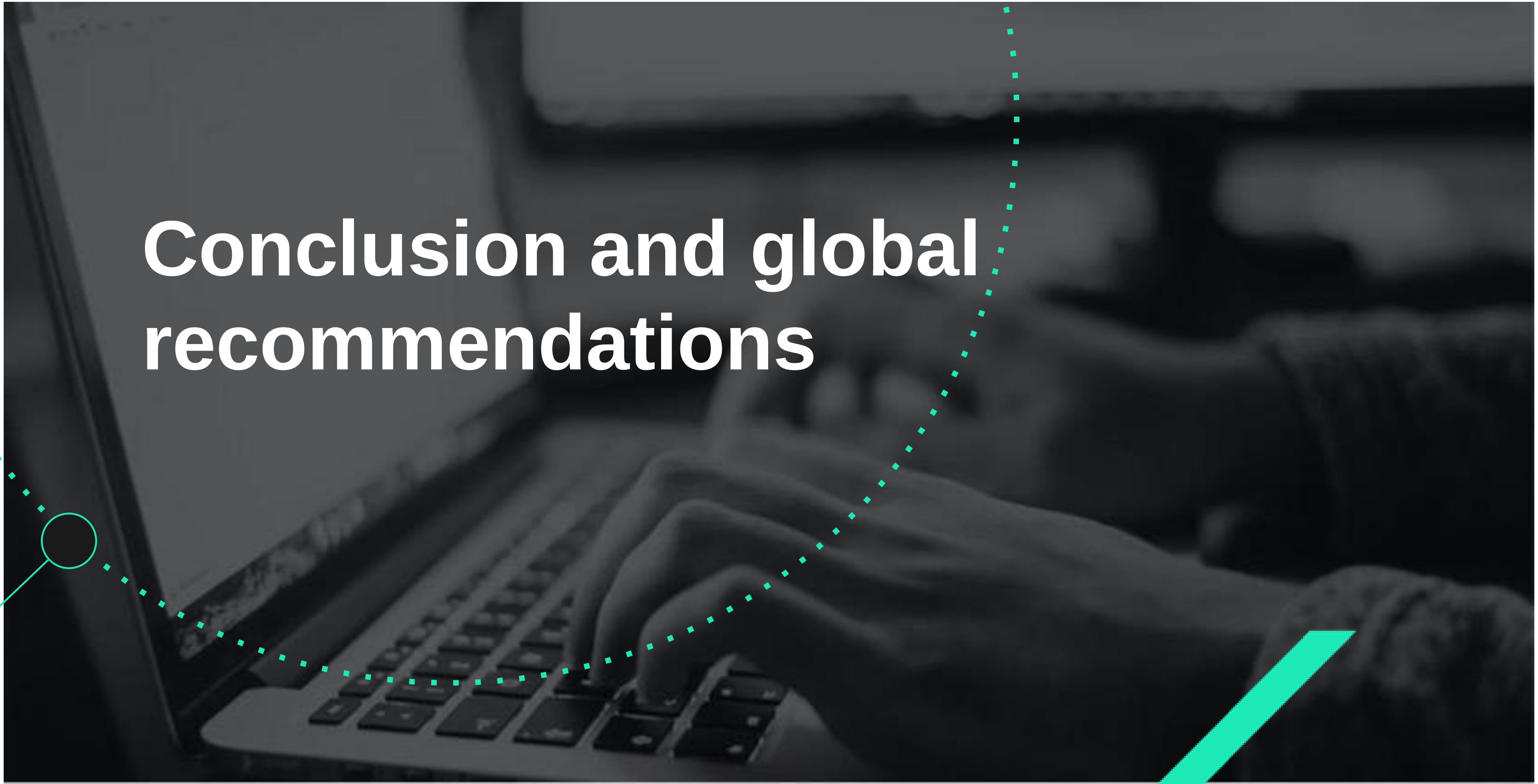
Resources available

Processes optimization available



Most relevant technology:

Autonomous AI software



Conclusion and global recommendations

4. Global recommendations to tackle Methane emissions

For a local oil and gas producer with few fields

- The main objective is to have a **detailed view of each field**, from large leaks to smaller ones.
- To **identify the leaks at the lowest cost,** we recommend the purchase of LAS handheld devices and the training of employees for every field. This solution can be completed with **punctual inspection survey services**.
- To **visualize the emissions from leaks**, the main tool would be monitoring software which could be paired with a production management software to **autonomize the process management**.

Area to inspect / data volume | **Allowable implementation time** | **Resources available** | **Allowable inspection duration** | **Processes optimization available**

Most relevant solution: **Laser Absorption Spectroscopy (LAS)** + **Inspection survey services** + **Monitoring software** + **Autonomous AI software**

4. Global recommendations to tackle Methane emissions

For a global oil and gas producer with many fields

- The main objective is to clearly **identify the largest leaks to prioritize actions**.
- The use of Imaging Interferometry will provide a global vision of all the fields, combined with ALI/OGI devices, handheld and on drones, will provide a **360° vision of the methane leaks.**
- Due to the large amount of data, an autonomous AI software will be required to identify and spread the best practices. It will also help **forecast maintenance and automation processes and solutions**.

Area to inspect / data volume | **Allowable implementation time** | **Resources available** | **Allowable inspection duration** | **Processes optimization available**

Most relevant solution:

Acoustic Leak Imaging cameras (ALI) + **Optical Gas Imaging cameras (OGI)** + **Imaging Interferometry (Glint Mode)** + **Autonomous AI software**

Acknowledgments and contacts

Contacts

Jean-Baptiste HECQUET
Senior Manager Energy & Environment
jean-baptiste.hecquet@sia-partners.com

Armand DE CHOLET
Supervising Senior Consultant Energy & Environment
armand.decholet@sia-partners.com

Authors

Simon Coma | **Pierre Yves Perrin** | **Mouhamad Kadri** | **Thomas Le Franc**

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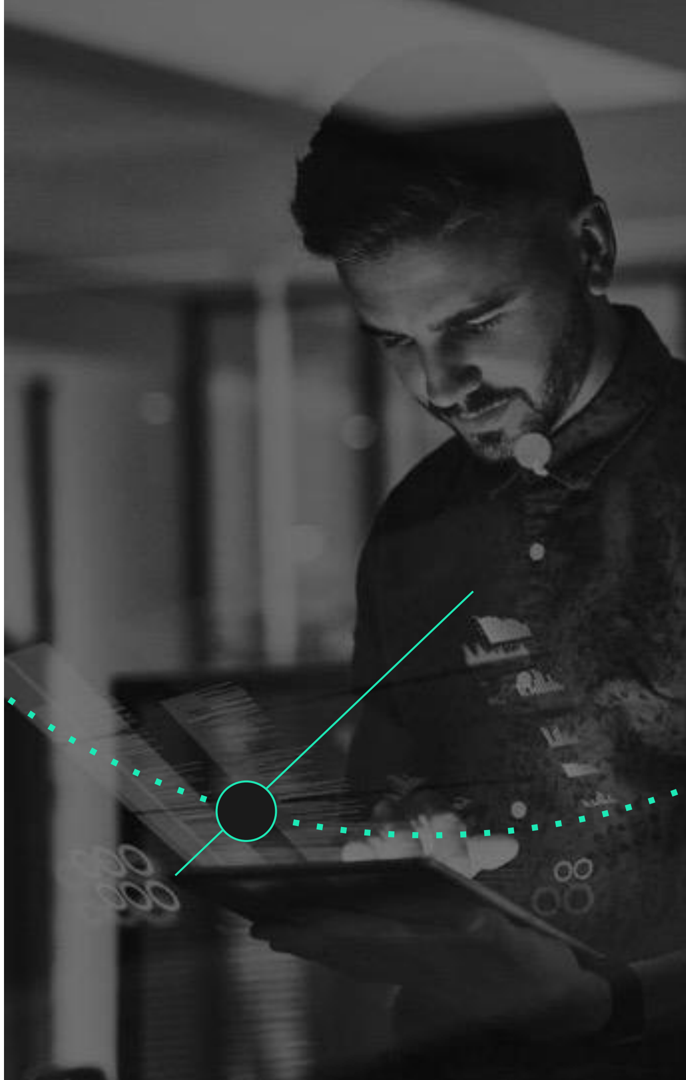
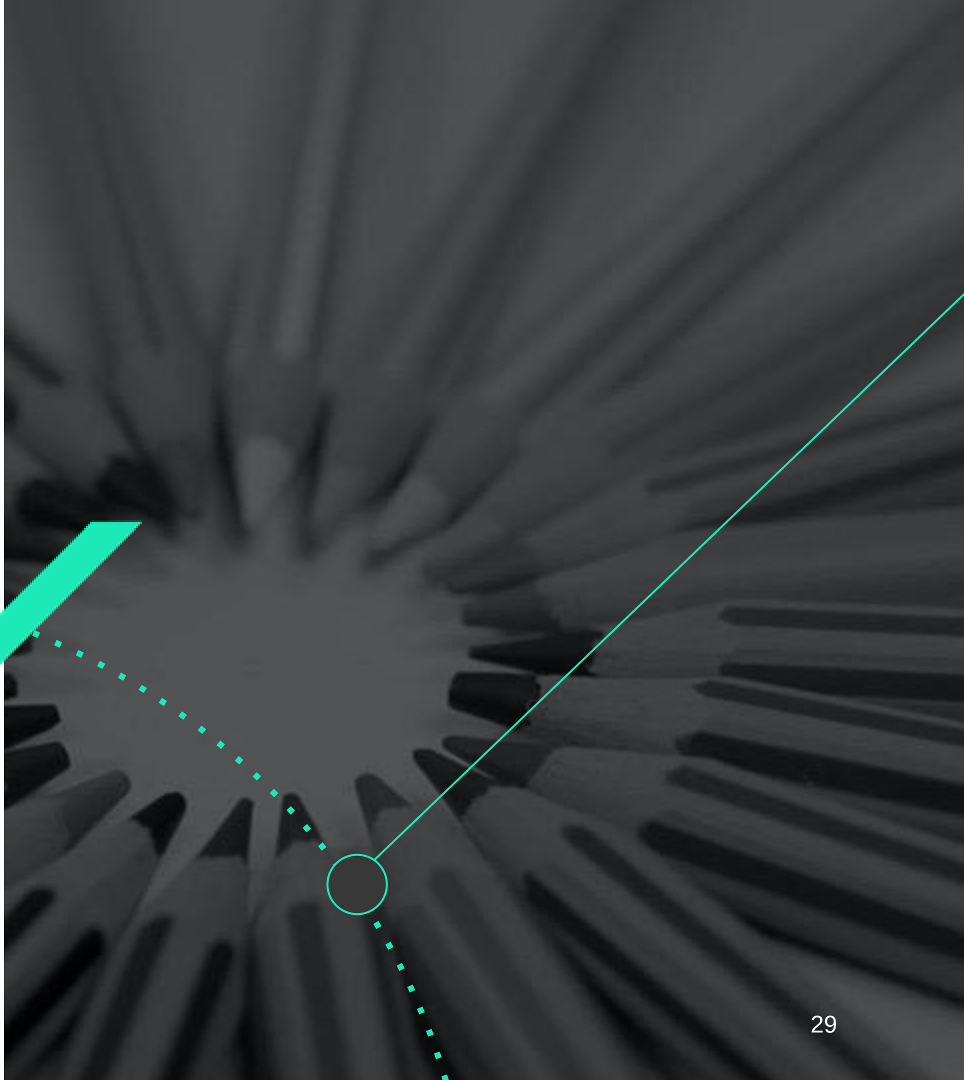


Appendices



1 Laser Absorption Spectroscopy (LAS) – handheld or aerial device

A diode-infrared laser which frequency is specifically absorbed by methane (spectrometry technology). As the laser beam from the device passes through a gas plume and is reflected to the camera, it will detect if methane is present in the beam path by comparing the strength of the outgoing and reflected beams.

Advantages

- **Mature technology**
- **Light handheld unit, aerial possibility**
- **Immediate detection of methane only**
- **Performs well in all climate conditions**

Disadvantages

- **Detection from short distance between 30-150m max**
- **Different angles are required to identify the leak point**
- **Needs a background surface to operate => no open fields**
- **Cannot operate through clouds**

- CAPEX: device’s purchase, between $10,000 and $50,000 for handheld device and ~$70,000 for drone technology
- OPEX: labor cost for the device operator
- Possibility of 100’s of components / hour for handheld device and x3 with drone technology (depending on flight time limit)

Source : https://heathus.com/assets/uploads/RMLD-CS_122.pdf, https://www.linkedall.com/product/ailf-u10/, https://gasleaksensors.com/products/gas-trac-lz-50-laser-methane-gas-leak-detector/

1 Laser Absorption Spectroscopy (LAS) – handheld or aerial Device

Technical Data

- Sensitivity: 5 ppm·m
- Methane detection only, no false alarm
- Time response: <0,1s
- Handheld device: ~8 hours battery, recharge time 3h-5h
- For drone: max 30 min - 1h flight time
- Real-Time data and Bluetooth/WIFI connections
- Graphical user interface and color camera and display

Product examples

RMLD-CS

- Hetek Solutions Inc
- TDLAS
- ~$15,000

GAS•TRAC LZ-30/50

- Sensit
- TDLAS
- ~$13,000

U10 Drone-mounted Laser

- LinkedAll and AiLF
- TDLAS
- ~$70,000

A very mature technology used by most in Oil & Gas as their first mean to detect small and located leaks.

Source : https://heathus.com/assets/uploads/RMLD-CS_122.pdf, https://www.linkedall.com/product/ailf-u10/, https://gasleaksensors.com/products/gas-trac-lz-50-laser-methane-gas-leak-detector/

1 Laser Absorption Spectroscopy (LAS) – Aeris Technologies

A diode-infrared laser which frequency is specifically absorbed by methane (spectrometry technology). As the laser beam from the device passes through a gas plume and is reflected to the camera, it will detect if methane is present in the beam path by comparing the strength of the outgoing and reflected beams.

Advantages

- **Autonomous once installed**
- **Locates and quantifies methane emissions**
- **Provides real time information**

Disadvantages

- **Requires sampling ports throughout client grid**
- **Requires battery changes (6-hour battery limit)**
- **Limited onboard memory (32 GB)**

Economical Data

- CAPEX: device's purchase, between $3,000 - $10,000 per year, per unit – half the price of comparable systems and 10X smaller, lighter.
- OPEX: labor cost for the device operator

Source : Scherer, J. J. (2022). Photonics and the Evolution of Ultrasensitive Gas Analyzers: Past, Present, and Future [PowerPoint slides]. *https://epic-assoc.com/wp-content/uploads/2021/12/Jim-Scherer-Aeris-Technologies.pdf*

1 Laser Absorption Spectroscopy (LAS) – Aeris Technologies

Technical Data

This system can be implemented on drones, handheld, or permanently fixed for continuous data. It is offered in 3 configurations:

1. MIRA PICO Series - most robust
2. MIRA Ultra Series - offers same capabilities as PICO with temperature stabilized optical core.
3. MIRA Strato Series: Drone – offers the same capabilities as PICO but smaller and lighter

Currently the only sensor with 1s resolution at 1ppb/s sensitivity. Measures in the middle infrared spectrum, meaning it's ability to detect methane is much better than competitors since it has stronger absorption.

Track records

- Currently employed in 7 countries, including USA, Canada, Europe, and China.

A very mature technology used by most in Oil & Gas as their first mean to detect small and located leaks.

2 Acoustic Leak Imaging camera (ALI) – Handheld or Aerial Device

Acoustic leak detectors capture the ultrasound signal of pressurized gas escaping a valve plug or gate that is not tightly sealed. These detectors come in both a «gun» style that detects leaks from a distance, or «stethoscope» style that detects internal leaks through a valve plug or gate.

Advantages

- **Easy-to-use, working comfort**
- **Time-saving**
- **Mature technology**

Disadvantages

- **Use with a drone not mature enough for now**
- **Detects all types of gas leaks, not only methane**
- **Not as useful for smaller leaks or low-pressure gas**

Economical Data

- Camera: between $35 000 and $67 000
- Drone: around $10 000-$15 000 for a drone, possibilities of packages around $84 000
- Possibilities of quantification software around $35 000
- OPEX: high labor costs

Source : Interview of Florian Perrodin, Co-Founder of Distran, global leader in ultrasonic camera manufacturing

2 Acoustic Leak Imaging camera (ALI) – handheld or aerial device

Technical Data

- Detection threshold : 1 L/h from 1m, 40L/h from 20m
- Working distance : 0.3 – 100 m
- Acoustic angle of view : 180° (half space)
- 124 microphones
- Rechargeable Li-ion battery
- Dimensions : 273 x 170 x 125 mm
- Weight: 980g

Track records

GE Oil & Gas

- Standard procedure since 2014
- Used in several countries worldwide

TotalEnergies

- Units deployed overseas
- Both use of visualization and quantification tools

A reliable technology able to detect a large range of leaks

Source : Distran Product, https://distran.swiss/en/ultra-pro/

3 Optical Gas Imaging camera (OGI) – handheld or aerial Device

Hydrocarbon emissions absorb infrared (IR) light at a certain wavelength and an IR camera uses this characteristic to detect the presence of hydrocarbon gas emissions from equipment at an oil and gas facility. OGI cameras can be used with handheld units or outfitted with a drone or an aircraft.

Advantages

- **Relatively low-cost**
- **Mature technology**
- **It can be outfitted with a drone, used by hand or used for continuous monitoring**

Disadvantages

- **Climate conditions affect the detection efficiency (temperature, wind, humidity)**
- **Darkness can be a limitation (but cameras can be equipped with lamps)**

- Camera: between $30 000 and $150 000
- Drone: around $10 000-$15 000 for a drone
- Possibilities of quantification software around $35 000
- OPEX: high labor costs
- Continuous monitoring on a fixed station or remote operations enabled (drones, aircraft)

Source : Interview of Vincent Chéret, Sales Manager at France Infra Rouge, leader company in thermography solutions

3 Optical Gas Imaging camera (OGI) – handheld or aerial device

Technical Data

- Absorption within 2 micrometers (detection of about 15 VOC gas)
- Rechargeable Li-ion battery
- Temperature of functioning : -20°C to 50°C
- Enable to scan area in real time, capable of 100s of components/hour
- Airplanes can identify a leak source within a range of about 500 meters, can survey dozens of facilities in a day

Track records

The Environmental Partnership
- Coalition of 80 Oil & Gas companies
- LDAR programs
- Since 2019

Chevron
- Autonomous drones for oil field monitoring

Shell
- Use of continuous monitoring
- Project Quanta3 started in 2017

The most precise camera device to detect the smaller leaks

Source : FLIR product, https://www.flir.com/instruments/optical-gas-imaging/
LinkedAll product, https://www.linkedall.com/product/ogi-640/

4 Imaging Interferometry – GHGsat

GHGsat Incorporation has developed a patented imaging interferometer which merges multiple sources of light to create an interference pattern. The analysis of this interference pattern reveals the presence and quantity of methane emitted. This technology can be implemented on aircrafts or on satellites to detect methane emissions from space.

Advantages

- **Effortlessly detect emissions at a world scale**
- **Measures methane and carbon dioxide**

Disadvantages

- **Can only detect large leaks, not small leaks**
- **Longer implementation time than other solutions**
- **More expensive long-term solution because of the service providing system**

Economical Data

No data available

Source : GHGsat website, https://www.ghgsat.com/en/technology/

4 Imaging Interferometry – GHGsat

Technical Data

- ❑ 6 satellites equipped with the technology are currently orbiting the planet
- ❑ Satellites orbit the earth in 90 minutes
- ❑ Operates at an altitude of 500 kms in high-resolution

Track records

- ❑ Controlled methane release in partnership with TotalEnergies in 2019
- ❑ In 2021, extension of the partnership with TotalEnergies for measuring the emissions from 6 offshore oil & gas platforms
- ❑ In Q4 2021, 143 MTCO2eq of methane emissions detected from 47 different countries

The most relevant solution to obtain regular reports about the larger leaks at a world scale

Source : GHGsat website, https://www.ghgsat.com/en/technology/

5 Inspection Services – Example of Kairos Aerospace

A diode-infrared laser which frequency is specifically absorbed by methane (spectrometry technology). As the laser beam from the device passes through a gas plume and is reflected to the camera, it will detect if methane is present in the beam path by comparing the strength of the outgoing and reflected beams.

Advantages

- **Not significantly affected by degradation**
- **Immunity to electromagnetic interference**
- **Large survey area**

Disadvantages

- **High operating costs in large settings**
- **Requires sunlight for spectrometer**
- **Can only detect large leaks, not small leaks**

Economical Data

- Flat rate of $100 per well for inspection and $1000 per well (on average) for repair.
- Planes are rented close to client's operations in order to reduce operating costs.
- Detection equipment is mounted to the strut of the wing.

Source : Ceraweek by S&P Global. (n.d.). https://ondemand.ceraweek.com/detail/video/6021450577001/kairos-aerospace-an-ogci-portfolio-company

5 Inspection Services – Example of Kairos Aerospace

Technical Data

- ❑ 12.1M tonnes of Carbon Dioxide equivalent (CO_2e) mitigated in 2021
- ❑ Operates at an altitude of 3000 feet and can cover 150 square miles per day

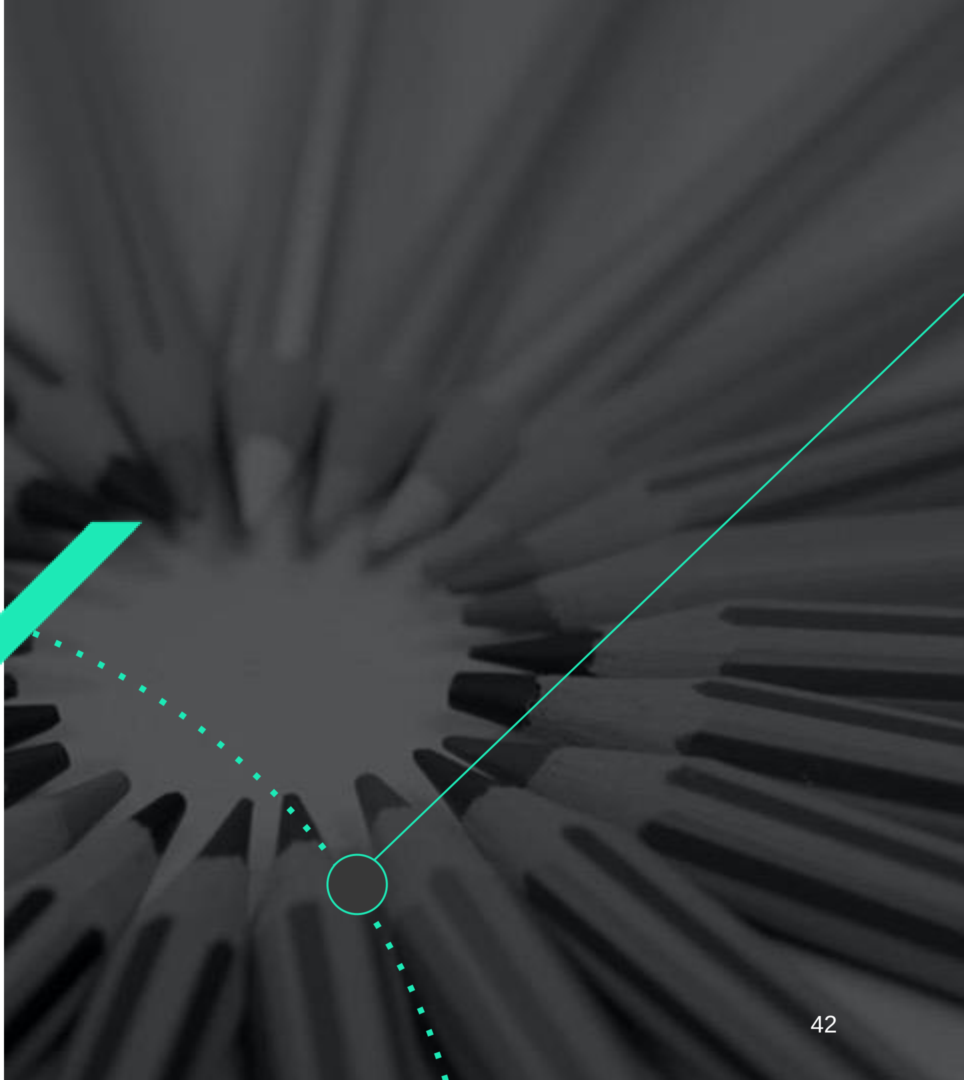
Track records

- ❑ Kairos Aerospace is currently proactively scanning upstream oil operations in order to have the data ready if client's request their services
- ❑ In 2021, Kairos Aerospace flew 13 regions in the United States and 4 internationally

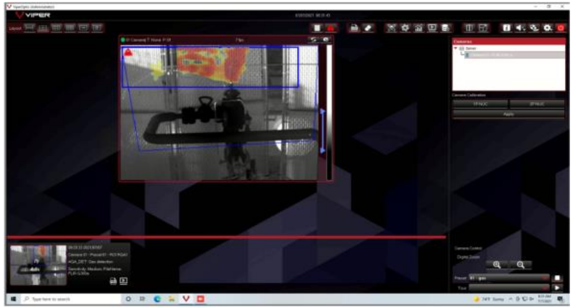
A quick and easy way to have an overview of the larger leaks

Source : Ceraweek by S&P Global. (n.d.). https://ondemand.ceraweek.com/detail/video/6021450577001/kairos-aerospace-an-ogci-portfolio-company

Data driven & digitalization technologies



6 ViperVision Software



Viper systems utilize OGI (Optical Gas Imaging) cameras and integrated ViperOptic software to detect and quantify hundreds of industrial gases. ViperOptic offers multiple capabilities from a single software platform.

Advantages

- **All-in-one solution: camera and software**
- **Modular and adaptive sensor: Fixed and portable OGI cameras**
- **Enhanced leak: ViperOptic software colorizes the gas**
- **Quantitative leak: ViperOptic quantifies the mass flow rate of the leak.**
- **Monitoring and recording videos**
- **Multiple gas type detection**

Disadvantages

- **Software needing Viper Camera's**
- **Data only gathered with OGI cameras**

Economical Data

- Total Cost: From $40 000 to $100 000 with a camera. The software license is included with the camera
- Clients: Exxon, BP, ENI, Oil field in the US, gas field in Italy

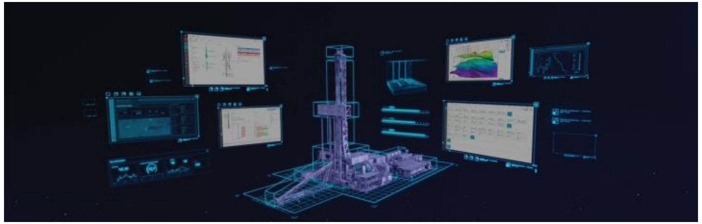
Data used

- Gas detection
- Gas quantification
- Surveillance
- Flame detection
- Spill detection

Source : Viper Imaging Sales Manager interview and documents

7 Process live data - enriched performance service

Process live data - enriched performance service provides a fully integrated detection and remediation solution. It is specifically designed to help operators manage GHG emissions and optimize production networks' overall economic performance and process facilities from the point source to the enterprise level. The service employs a data-driven approach to GHG emission management by leveraging a combination of Intelligent Internet of Things (IIoT) hardware, edge computing, and cloud-based applications



Advantages

- **End-to-end service, the service is a multifaceted offering for uptime assurance, process optimization, and greenhouse gas (GHG) control. It integrates digitally enabled equipment, collaboration with OEM experts, and maintenance to enhance asset life cycle management.**
- **Live monitoring on a secure cloud-based data environment for real-time monitoring**
- **Process modeling facilitates comprehensive emissions analysis, which enables rapid identification and mitigation processes**

Disadvantages

- **Complete solution from hardware (sensor) to software**
- **Cloud computing solution needed**

Source : https://www.slb.com/well-production/midstream/process-live-data-enriched-performance-service

Economical Data

No data available

Data used

- Any type of sensors (multipoint gas composition, flow rate, temperature, pressure, etc.)

Source : https://www.slb.com/well-production/midstream/process-live-data-enriched-performance-service

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Kelvin IA

AI-enabled solution to monitor and remotely manage production operations.

Advantages

- **Full-scale solution: process optimization, GHG control, maintenance optimization.**
- **Adaptive solution: Kelvin IA accepts all kinds of sensors and data. It can be integrated into all systems and platforms.**
- **Easy scale-up.**
- **Machine learning from human input.**
- **Entire process simulation allowing to visualize carbon emission and test operational change.**

Disadvantages

- **Cloud computing solution needed.**
- **Integration with client data and system.**
- **Operation time needed to learn from the employee in the field.**

Economical Data

- Total Cost: from $150 000 to $1.5 M depending on the scale and industrialization of the solution
- Clients: BP, Santos, funded by the Oil and Gas Climate Initiative

Data used

- Any type of sensors, all the data available
- Offer expertise to assist the sensor development if necessary
- Solution very effective for venting and improving on flaring

Source : KELVIN Inc. President of Sales interview and documents

7
8

C3 IoT

C3 IoT delivers a comprehensive platform as a service for the rapid design, development, and deployment of the largest-scale big data, predictive analytics, AI, and IoT applications. C3 IoT also provides a family of SaaS products developed with and operating on its PaaS, including predictive maintenance, sensor network health, supply chain optimization, and energy management.

Advantages

- **Full-scale solution: process optimization, GHG control, maintenance optimization**
- **Accept all kinds of sensors**
- **Machine learning and cloud computing**

Disadvantages

- **Cloud computing solution needed**
- **Integration with client data and system**
- **Optimization and maintenance focus**

Economical Data

- Total Cost: No data available
- Clients: Shell

Data used

- Any type of sensors, all the data available

Source : https://c3.ai/