LEAKSENSE

Central Case Project 2018

Vol. I

Executive Summary

Table of Contents

List of figures

List of tables

1 Introduction

1.1 Motivation

Current leak detection services fail to detect leaks fast enough to prevent an oil spill from becoming an environmental and financial disaster. For example, from 2002 to 2017, 527 hazardous leaks were detected in a pipeline network of a single oil operator in the USA. This translates to an oil leak occurring approximately every two weeks.[1]

Overall, 19 out of 20 oil leaks remain undetected until they become large spills with associated clean-up costs of over $500 million,[2] excluding further possible related fines, lawsuits and loss of reputation.[3] This makes the inability of the current inspection methods very costly for the customer. Finally, it is a global issue since worldwide, there are more than 10 million kilometres of oil and gas pipelines.[4]

The oil industry is in dire need of a service that can increase the speed and reliability of pipeline leak detection on a global scale. LeakSense provides this service, as further described in this summary.

1.2 Value proposition

LeakSense's mission is to provide a unique and cost-effective solution allowing leak detection and geo-localisation of leaks covering oil pipeline transportation networks.

LeakSense offers value-added services for leak detection in oil pipeline networks. Target customers are oil operators and insurance companies interested in reducing commodity losses and aiming to comply with various existing or upcoming environmental regulations. LeakSense will provide continuous global monitoring of the pipeline infrastructure. It includes periodic early leak detection warnings and issues alerts in case of leak occurrence.

[1] Based on Greenpeace.org available at https://www.greenpeace.org/usa/reports/oil-and-water/

[2] Based on Financial Post available at https://business.financialpost.com/news/u-s-residents-take-stock-of-enbridge-oil-spill-one-year-later

[3] Based on PR Watch available at https://www.prwatch.org/news/2014/02/12401/keystone-pipelies-exposed-sticky-oil-leaks-billion-dollar-spills-and-human-health

[4] Based on Geospatialworld available at https://www.geospatialworld.net/blogs/can-drones-power-offshore-oil-and-gas-operations/

Customers will be attracted through direct contracts or through partnerships with specialised industry entities (alliance partners) already operating on the market and offering solutions based on the conventional (non-space) technology. The leak detection will be provided globally for complete pipeline networks. This extensive coverage is achieved by analysing satellite imagery available from open and commercial sources as well as acquired with a proprietary infrared sensor developed in-house by the LeakSense company.

The following figure shows a business canvas of LeakSense, which highlights key elements of the proposed service.

1.3 Proposal

This Volume I provides a concise summary of market need, proposed technical solution, service delivery strategy and financial performance of the LeakSense business.

The technical proposal is detailed in Volume II and in applicable documents. The detailed business plan and financial analysis are provided in Volume III.

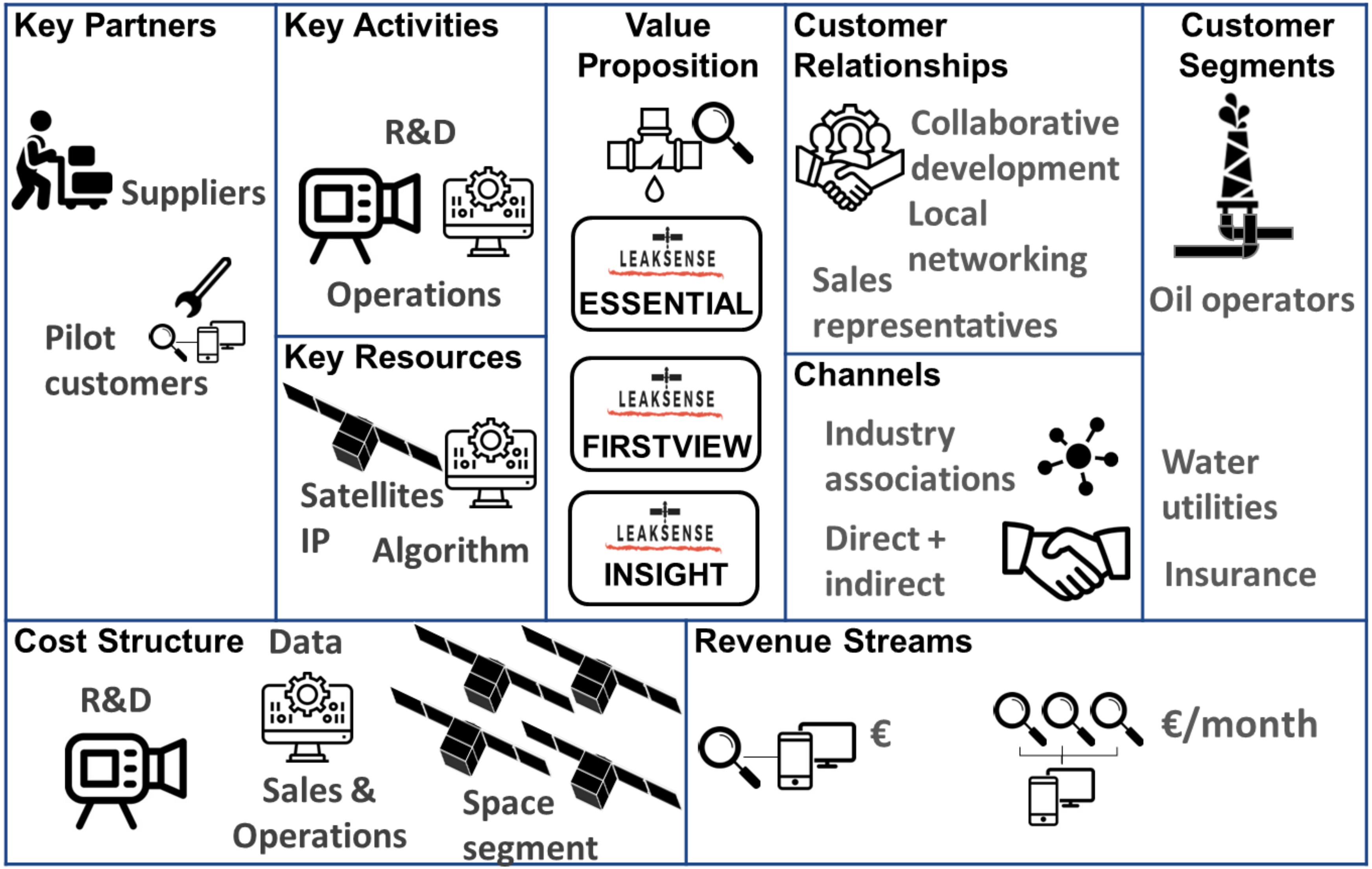

Figure 1-1 LeakSense business canvas

2 Market need

Oil pipeline leak detection is an annual $3 billion to $4 billion market, for which the desired spatial scale, sensitivity and revisit time for leak detection can currently not be delivered with current Earth observation systems.

2.1 Oil industry

The oil industry is required to conduct proper handling and storage of chemical and asset management. The oil industry is often addressed together with the gas industry, and many of the researched reports refer to the oil and gas sector.

Currently, it is estimated that the industry spends 32 billion € per year on pipeline monitoring (incl. leak detection and other aspects).

The oil industry, however, suffers from continuing spillages within the pipeline network. Between 1986-2013 there have been nearly 8,000 oil and gas pipeline incidents in the U.S. alone, releasing 76,000 barrels of oil per year, resulting in more than 500 deaths, 2,300 injuries and nearly $7 billion in damage, according to the Center for Biological Diversity (based on data released by U.S. Pipeline and Hazardous Materials Safety Administration).[5]

Safety, high availability, and reliability are key requirements for pipeline management systems and the supporting infrastructure. Nevertheless, globally **oil is still by far the most commonly spilled hydrocarbon**, followed by natural gas and gasoline. The main causes of failure are identified as impact damage due to **3rd party interference (i.e. theft, sabotage), ground movement, corrosion, fatigue, and operator error.**[6]

[5] Based onhttps://www.alerian.com/education/energy-value-chain/ and http://www.ukopa.co.uk/wp-content/uploads/2013/03/UKOPA-13-028.pdf

[6] Based on: Delliot 2019 Oil, Gas, and Chemicals Industry Outlook; Visiongain, “Big Data in Oil & Gas Market 2015-2025”, September, 2015 and Technavio, “Global Big Data in Oil and Gas Sector Set to Grow at a CAGR of 31% by 2020”, December, 2015

This spillage occurrence is a growing concern because oil and gas infrastructure keep expanding globally – up to 7% a year over the last 15 years. According to the Pipeline & Gas Journal's 2017 Worldwide Construction Report, approximately 134,000 km of new pipelines are planned or currently under construction worldwide.[7] However planning, permitting, and constructing infrastructure is often litigated by opposing groups because of the adverse environmental and social impacts in case of spillage which can cause hundreds of millions in damages and liability claims.

Therefore, the ability to have consistent pipeline monitoring aimed at timely detection of interferences and their provenance for attribution and potential use in litigation is extremely valuable. To solve this issue **the oil companies are dedicated to innovations. The entire industry spent $3.5 billion in 2015 on big data-related projects, with projected annual growth of 31% by 2020.**[8] This includes artificial intelligence, analytics, robotics, IoT and blockchain - all to increase efficiency, productivity, reliability, and predictability of operations.[9] Still patrolling and maintenance of pipelines integrity is a huge task that is currently done by walking/driving along the pipeline or aerial surveillance (which is expensive and conducted ad hoc). Here satellite imagery offers large scale analysis and persistent monitoring with the potential to mitigate the vulnerability to third-party interference, faster identification of damage across networks and more rapid response in case of accidents.[10]

2.2 Regulators

The oil and gas sector is **highly regulated** - mostly because of the environmental implications of improper oil and gas storage or transportation.

The European Commission Scientific Committee on Health, Environmental and Emerging Risks (SCHEER) has recently (December 2018) assessed public health risks resulting from onshore oil and gas exploration and extraction activities taking place on a commercial scale in the EU.[11] The conclusion of the Committee report reiterated that mining and the hydrocarbons industry entail

---

[7] Pipeline & Gas Journal's 2017 Worldwide Construction Report https://pgjonline.com/magazine/2017/january-2017-vol-244-no-1/features/pgj-s-2017-worldwide-pipeline-construction-report

[8] Based on Delliot 2019 Oil, Gas, and Chemicals Industry Outlook.

[9] Based on Delliot 2019 Oil, Gas, and Chemicals Industry Outlook, Visiongain, "Big Data in Oil & Gas Market 2015-2025", September, 2015, Technavio, "Global Big Data in Oil and Gas Sector Set to Grow at a CAGR of 31% by 2020", December, 2015.

[10] UKOPA Recommendations for the Inspection and Maintenance of Buried Pipelines, 2012 available at http://www.ukopa.co.uk/wp-content/uploads/2013/03/UKOPA-13-028.pdf

[11] European Commission, Does on shore exploitation pose health risks, https://ec.europa.eu/health/sites/health/files/scientific_committees/docs/citizens_oil_gas_en.pdf

significant risks to the environment and populations. Also, it was concluded that there is currently "insufficient" quantitative information available on the exposure pathways and associated levels. Moreover, according to the report, there is limited scientific monitoring of both the environment and social risks near established onshore oil and gas exploration and exploitation sites in the EU. Currently most of the risk exposure studies are done in-house by the industry, however, they result in complicated and fragmented risk maps without standardised risk management procedures. To bridge the knowledge the EC recommendations calls for the development of the first centralised and harmonised inventory of all oil and gas exploration and exploitation sites in the EU, conducting analytical and modelling studies to identify, quantify and characterise societal and environmental exposure to hazards, and carrying out quantitative risk assessment studies.

Also in the United States, the government is increasingly committed to updating the U.S Transportation Department pipeline safety programs run by the national Pipeline and Hazardous Materials Safety Administration (PHMSA). In particular a new type of legislation has been introduced in 2019 with the objective to modernize PHMSA's incident and construction data collection, and establish a voluntary safety information-sharing program and acknowledging that remote sensing will play an important future role for leak detection, facility inspections and right of way monitoring for identifying potential risk and determining regulatory compliance.[12]

Given these existing or upcoming regulations trends, oil and gas regulators have a lot to benefit from better data and data transparency and creating a common operating picture with the regulators.

2.3 Insurance industry

Operating within the oil and gas infrastructure is very risky. For example, the total damage from oil loss in Russian refineries – which are one of the biggest producers of oil and gas commodities in the world – amounting to $1.5 billion in the 2011-2016 period including the cost of repairing infrastructure and in the lost commodity.[13]

The total loss associated with environmental risks amounts to $500 million in the period 2009 – 2015 globally.[14] This is why the operators are subject to obligatory environmental insurance programmes

[12] Robert Smith, U.S. DoT, PHMSA, Remote Sensing and Reliability of Gas and Electrical Infrastructure Systems

[13] Deloitte, Global Insurance Broking: Oil and Gas Industry, available at https://www2.deloitte.com/content/dam/Deloitte/ru/Documents/financial-services/global-insurance-broking-oil-and-gas-industry-en.pdf

[14] Ibid.

as well as re-insurance products (reinsurance is insurance that is purchased by an insurance company).[15]

This requirement is directly related to the complexity of managing the risk profiles of the companies exposed to damage as well as the potential scale of the loss in case of catastrophic events.

One of the key products prepared by the insurance is the insurance claim documentation which needs to be under strict compliance concerning the reporting obligations outlined in various national registrations. In this case what is key is the availability of the up-to-date and reliable risk profiles which are used to assess the probability of the occurrence of the insured event, and to evaluate the claimed damage. The insurers are interested in having such accurate information to price their premiums in a competitive way (or conversely to have better control over the pay-out of claims and liabilities). The oil companies must also have robust risk management procedures as well as risk mitigation measures in place to enter an insurance contract.

These requirements create a definite need for robust surveys and asset inspections. The survey of the assets, refineries, terminals and oil rigs is, in fact, at the core of any risk management program of the insurance industry. Typically, based on the surveys conducted by on-site inspections a risk management report is prepared to estimate the maximum probable loss. However, automation of asset assessment and risk valuation as well as claims management using of sensor technology can greatly enhance the efficiency of this process. Remote sensing is particularly considered useful by insurers to support the process of the definition of the areas affected by a catastrophic event (such as oil spill/leak) and to identify and classify losses. The independent observations as a data source can allow for attribution of damage or reveal the characteristics of the event to determine if it is in line with the insurance policy is of high value to the insurers. The availability of pre- and post-loss data will provide more effective claims information and has also a potential to prevent cases of fraud and the submission of duplicate claims.[16]

---

[15] Ibid.

[16] MunichRe, The Future of Claims Management, available at https://www.munichre.com/site/touch-publications/get/documents_E-1134202369/mr/assetpool.shared/Documents/5_Touch/_Publications/09052_SSP_2017_en.pdf

2.4 Additional markets

The leaks from distribution networks are considered a major issue not only for the oil industry but are also affecting all water utilities worldwide. Treated water which is put into the distribution network and not billed is known as Non-Revenue Water (NRW). This NRW is on average around 30% globally and half of it has its origin in leaks.[17]

Water infrastructure expands steadily with increased populations and urbanization, especially in low- and middle-income countries. The water network can consist of thousands of kilometres of pipes of different diameters which transport the water from reservoirs, usually far away from the cities, to local tanks and the final user. Today, environmental sustainability **(water conservation)** is playing an increasingly important role however **widespread in-situ metering and monitoring is not yet reality** around the world, in particular for the remote and rural areas where metering is not pervasive. In particular, managing upstream losses and addressing the challenges of large diameter pipes is a problem. The water utilities are therefore interested in options for developing low-cost solutions to cover the whole water network and in technologies that can improve the scenarios of managing the losses in more effective ways.[18]

Finally, technologies that manage to achieve soil moisture detection for water leak detection can also be applied in other water conservation markets such as water productivity assessment and irrigation management.

2.5 Target market

Oil pipelines must operate 24 hours a day and 365 days a year, and, as such, any interruptions of operations can result either in loss of commodity or damage to the environment. LeakSense target market is oil leak detection.

According to the U.S. Dept. of Transportation's Pipeline and Hazardous Materials Safety Administration, as well as Deloitte Consulting, the global oil and gas industry spends $36 billion a year monitoring nearly 10 million kilometres of pipelines. This includes installation of the Supervisory Control and Data Acquisition (SCADA) systems, deployment of the sensor networks monitoring pressure, temperature and other key data from thousands of points with various technology domains

---

[17] Bluefield Research Water World https://www.waterworld.com/articles/print/volume-33/issue-12/features/eight-water-trends-to-watch-in-2018.html

[18] The IBNET Water Supply and Sanitation Blue Book 2014

(flow meters, fibre optic, pressure sensors, etc.), IT infrastructure scheduled maintenance tasks, as well as regular inspections. The size of the addressable market in oil leak detection is conservatively estimated globally at $3 to 4 billion a year and this figure is mainly driven by the costs of inspections carried out on a large scale and often across provinces or countries in order to detect and prevent in-service damage, degradation, or defects which can lead to failures.[19]

Geographical distribution

The United States is the world's top oil producer (620 Million ton (Mt)) followed by Saudi Arabia (560 Mt), the Russian Federation (548 Mt), Canada (242 Mt) and Iran (229 Mt).[20] Most of the pipeline routes are as a result in North America (United States, Canada), Russia and the Middle East. Europe imports around 87% of its crude oil and oil products from abroad largely from Russia, Iran, Saudi Arabia, and Kazakhstan.[21]

In the United States, there are 3,500,000 km of oil pipelines and 480,000 km of gas pipelines, operated by hundreds of companies.[22] In Europe there are nearly 37,500 km such pipelines, transporting some 720 million cubic meters per year of crude oil and oil products operated by 76 companies.[23] In Canada, there is more than 840,000 km of pipelines across the country operated by approximately 10 biggest companies.[24]

In these three regions data on the locations of the pipes is also most easily accessible as they are often made public to satisfy public concern and need for transparency and safety of operations. There are also stringent regulations in place in these countries to ensure the safety of crude oil transportation. These are therefore the target geographies for the LeakSense initial operations and market development.

---

[19] Market Watch, Leak Detection Market available at https://www.marketwatch.com/press-release/leak-detection-market-to-touch-us-338-billion-by-2022-2018-11-11

[20] International Energy Agency, Oil Information Overview, available at https://webstore.iea.org/oil-information-2018

[21] EuroStat, Oil and Petroleum Products available at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Oil_and_petroleum_products_-_a_statistical_overview&oldid=404136

[22] John-Isaac Clark, Decreasing Costs of Pipeline Monitoring With Geospatial Big Data, Digital Globe Blog available at https://platform.digitalglobe.com/decreasing-costs-pipeline-monitoring-geospatial-big-data/

[23] Concave 2018 Report, Performance of European Corss Country Oil Piplines available at https://www.concawe.eu/wp-content/uploads/Performance-of-European-cross-country-oil-pipelines-Statistical-summary-of-reported-spillages-in-2017-and-since-1971.pdf

[24] Canadian Petroleum Industry https://en.wikipedia.org/wiki/Canadian_petroleum_companies

3 Proposed system

LeakSense's proprietary system includes dedicated satellites optimized for oil leak detection, global coverage and rapid response time.

3.1 Overview

The LeakSense system will detect leaks with infrared measurements acquired from a constellation of satellites. The space-based monitoring of leakages has been selected to offer an advantage over the established aircraft- and helicopter-based monitoring. The advantages of space-based monitoring are consistent data (e.g. constant illumination conditions and viewing angles) as well as global coverage. For space-based monitoring, the initial cost is relatively high, but the operational cost can compensate this to achieve a competitive price compared to existing leak detection methods.

The LeakSense system has the following characteristics:

- Coverage of >90% of the networks globally.
- Able to detect oil leaks with a delay of fewer than 2 weeks for ongoing coverage.
- Able to geolocate oil leaks with an accuracy of a diameter of 500 (specified for high-density locations and can improve for other areas).
- Mission lifetime of at least 8 years.
- Ready for full operation 3.2 years after the start of the program.

The LeakSense system, visualized in the following figure, is based on a leak detection through direct measurement and is composed of a Space Segment and Ground and User Segment. The system is described in the subsequent sections.

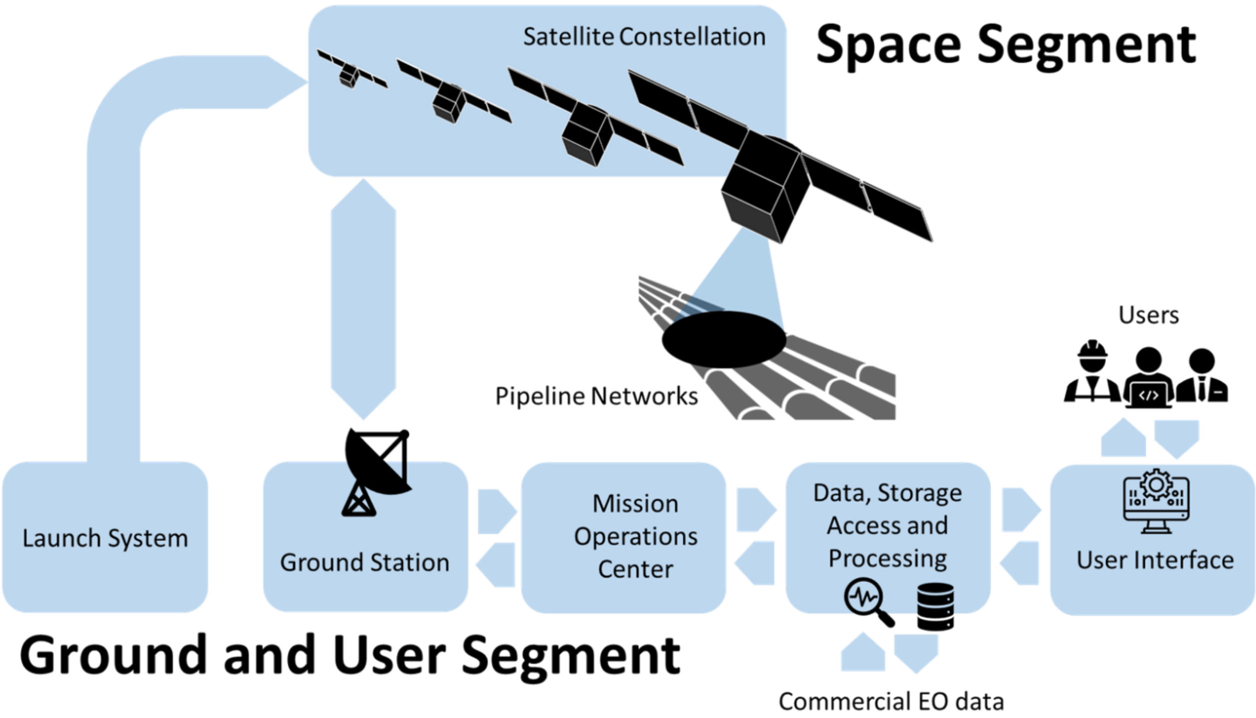

Figure 3-1 Concept of operations for LeakSense system

3.2 Leak detection strategy

The majority of the oil pipelines are buried, and any leaks typically propagate to the surface by saturating the soil. The presence of oil in surface soil can be directly detected by observing a change in short-wave and mid-wave infrared (SWIR/MWIR) reflectance. This method of oil detection with a short-wave infrared sensor has been demonstrated in a set of field trials.[25]

For LeakSense six thermo-optical bands are selected, as listed in the following table. The short-wave infrared (SWIR) bands 3, 4 and 5, included in the following figure, are used for direct detection of oil and are similar to the bands demonstrated in the field trials. To improve the detection reliability, particularly to better differentiate between water and oil-saturated soils, an additional mid-wave infrared (MWIR) band 6 is added to LeakSense system. The use of this additional band is a unique capability of LeakSense system.

[25] S. Asadzadeh, C.R. de Souza Filho / Remote Sensing of Environment 173 (2016) 162–173 concerning the use of SWIR bands for direct detection of oil

Table 3-1 LeakSense sensor thermo-optical bands

	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6
	Near infrared		Short wave and mid wave infrared			
Spectral range [nm]	850 - 880	945 - 975	1635 – 1665	1715 - 1745	2335 - 2365	3395 - 3425
Spectral resolution [nm]	10	10	10	10	10	10
Use	NDVI and vapour correction		Hydrocarbon (HC) detection			

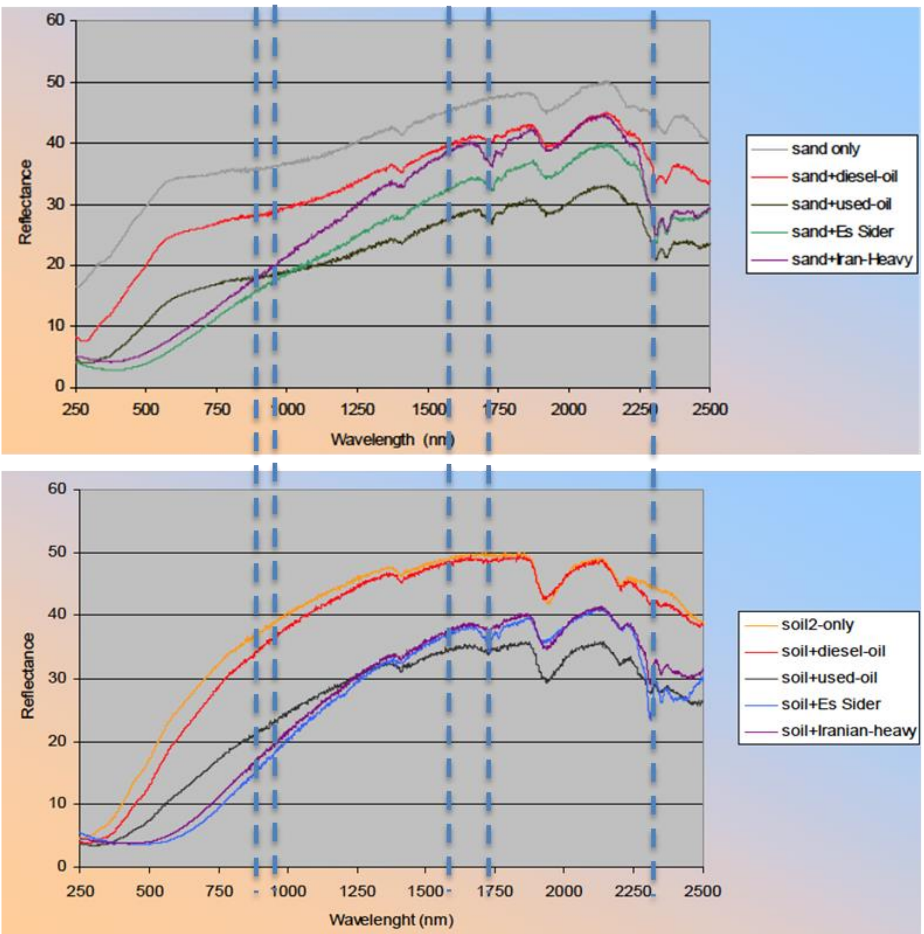

Figure 3-2 Spectral characteristics of dry soil and oil impacted soil[26], and selected bands 1 to 5

Oil leaks can also be detected by detecting the deterioration of the affected vegetation. The change in the status of vegetation can be observed with LeakSense near-infrared (NIR) bands 1 and 2,

[26] Hyperspectral Analysis of Oil and Oil-Impacted Soilsfor Remote Sensing Purposes. G. Andreoli et al. European Commision, Joint Research Centre

which provide an additional method for the detection of leaks in areas with dense vegetation. These two bands are also used for water vapour corrections applied in the data processing.

The LeakSense sensor is based on a commercially available detector and optical filters, and a classical 3-mirror optics. Time Delay Integration is considered. The key characteristics of the sensor are defined in the following table.

Table 3-2 Key characteristics of the LeakSense sensor

Sensor characteristic at nominal orbit		
Ground resolution along track (nadir)	40	m
Ground resolution across track (nadir)	40	m
Swath width (nadir)	20.5	km
Pixel encoding	8	bit

3.3 Data processing

The content of the LeakSense services includes the deployment of processing tools to provide advanced leak detection by providing spectral reflectance of saturated soils (for oil leak detection), as well as a range of data products (indexes), using the sensors belonging to the company as well as other available Earth observation data. Additional analytic products will also include basic land use (LU) characteristics for object detection and classifications as a core part of the value chain, as well as potential infrastructure stability products that can be developed on demand.

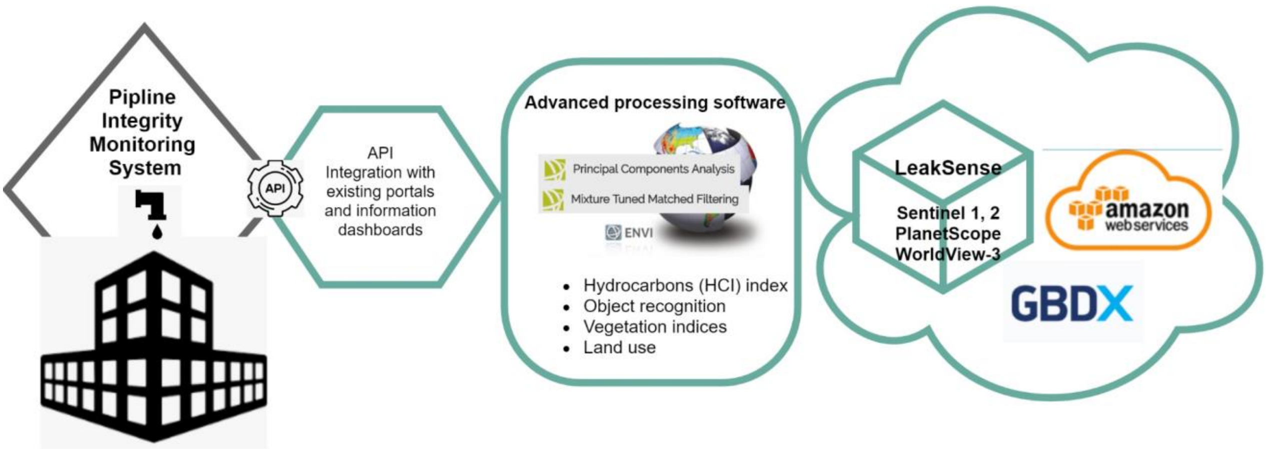

Figure 3-3 Data processing approach for LeakSense

3.4 Space segment

The space segment includes a satellite constellation with identical satellites. The baseline size of the constellation is 4 satellites and can be scaled with the business needs. The system can be upgraded by adding additional satellites, providing either more passes over the ground or different observed wavelengths, or both, resulting in a faster leak detection speed or increasing the reliability of the measurement.

The 4 satellites are equally spaced in the operational orbit defined in the following table. The orbit has been selected for consistent solar illumination conditions and for a local time suitable for observations with short- and mid-wave infrared sensors.

Table 3-3 LeakSense satellite orbit

Orbit type	Sun-Synchronous Orbit (SSO)	
Altitude	523	km
Inclination	97.49°	deg
Eccentricity	0	-
Local Time at Ascending Node (LTAN)	14:00	-
Orbit period	95.10	min
Repeating ground track period	14	days
Equatorial (max.) swath width	23.56°	deg

Each satellite carries a single short- and mid-wave infrared sensor on a dedicated payload deck, as depicted in the following figure. The satellite platform is 3-axis stabilized, with the attitude control system is based on star-trackers and reaction wheels. The satellite includes standard monopropellant hydrazine propulsion for in-orbit manoeuvring (incl. launch orbit correction and de-orbit) and momentum management. High-speed payload data downlink capability is provided by the Ka-band subsystem, while the platform telemetry and telecommand use the S-band subsystem. The electrical power is provided by a combination of deployable solar arrays and onboard batteries.

To reduce satellite cost and to reduce the development time, satellite modularity can be implemented. Payload, communications and integrated power/propulsion subsystems have been identified as the most promising candidates for modularity.

The key characteristics of the satellite are included in the following table. The satellite performance and capabilities are comparable to those available from commercial providers and therefore considered feasible with a low-cost solution.

Table 3-4 Key characteristics of LeakSense satellite

LeakSense satellite characteristics		
Satellite dry mass (incl. payload)	543	kg
Payload mass	100	kg
Propellant mass	86	kg
Delta-V	366	m/s
Satellite Orbit Average Power (OAP)	522	W
Absolute Pointing Error	0.05	°
Absolute Pointing Knowledge	0.004	°
Maximum slew rate	0.2	°/s
Downlink data-rate	275	Mbps

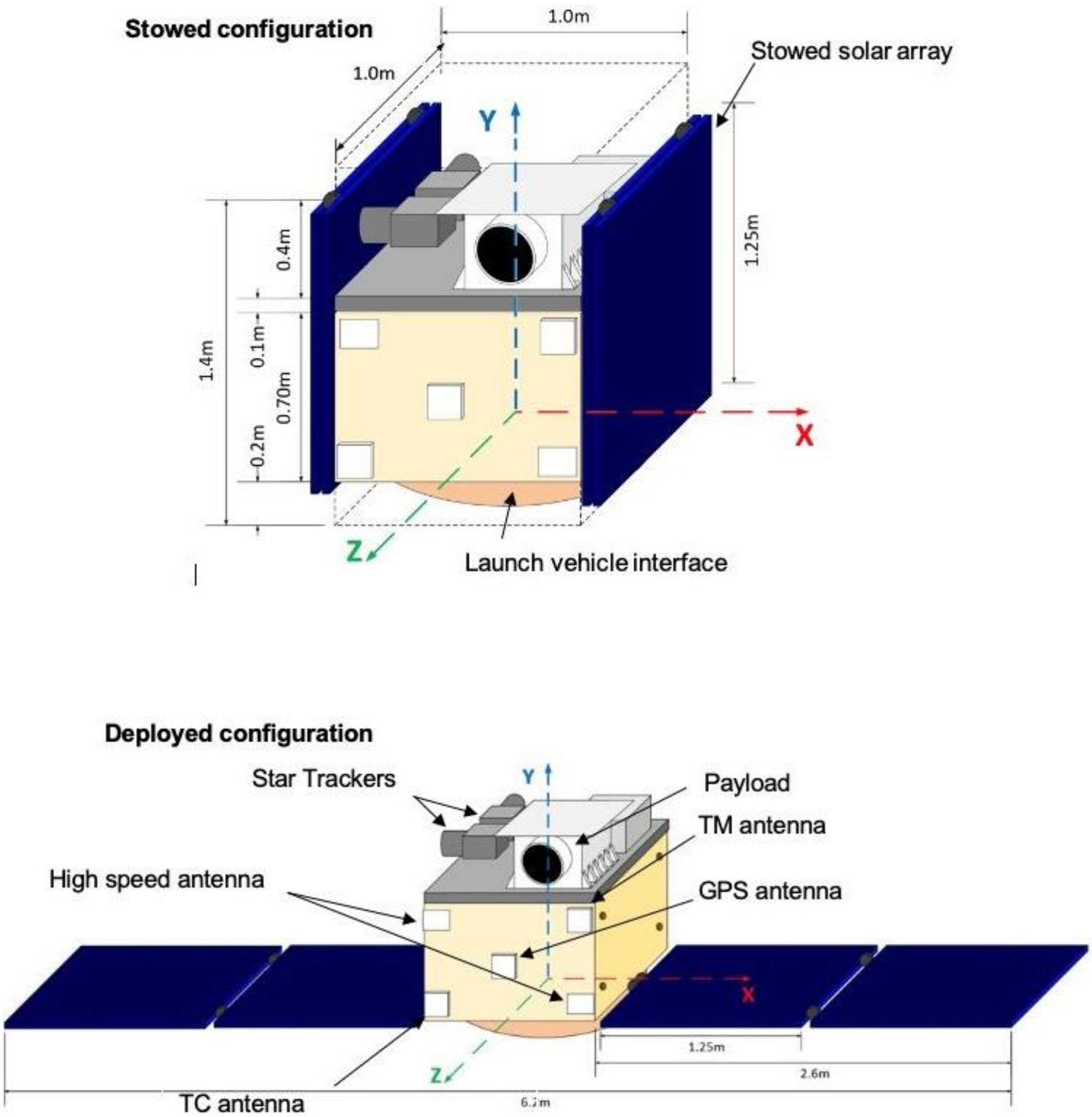

Figure 3-4 LeakSense satellite concept

3.5 Modularity assessment

The initial assessment has shown that two subsystems have turned out to be the most promising candidates for a modular design. Implementing modularity for more systems will increase the overhead from the interfaces while not adding considerable value. Therefore, the final proposal for modular architecture is shown in the following table.

Table 3-5 Modular Baseline Options

Rank	Subsystem	Justification
1	Instrument	Modular approach is baseline
3	Communications	Modular approach is baseline
2	Power / Propulsion	Electrical Propulsion is presented as alternative
5	AOCS	No Modularity
4	Data Handling	No Modularity
6	Thermal	No Modularity
7	Structure	No Modularity

It needs to be mentioned that exchanging a module can also lead to considerable updates on the non-hardware aspects of the system. Most obviously, new hardware will also require an adaptation of the driver-software in the interfacing subsystems. If functionality is changed or operating sequences are modified, the mission manager software must also be adapted. Changed commanding capabilities or modified data points will furthermore lead to an adaptation of the Mission Database (MDB). Updates in the operational sequence of a new component can even lead to a modification in the operating timeline of a complete spacecraft (e.g. a new instrument requiring a calibration sequence prior to measurement, different pointing or stability requirements, etc.). Therefore, it is highly recommended to implement the software components for each individual module in a modular way itself to improve qualification and integration into the overall system. Still, the effort to integrate a new module into the complete system can be considerable and will have to be taken into account for the estimation of the overall benefits.

3.6 Ground and User segment

The Ground and User Segment focuses on delivering the service to the users by obtaining and processing the data collected by the Space Segment. The data processing and user interface will be operated on rented infrastructure and resources (cloud storage and computing).

Control of the satellite will be performed from a Mission Operations Centre, with a dedicated operations team. The operations team will communicate with the Space segment through commercially available Ground Station networks. For the proposal, the KSAT ground network is assumed, with Svalbard Ground Station as the baseline.

The launch system used for deployment of the Space segment is included in the Ground segment because it is considered a supporting element to the Space segment. Launch service will be procured from a commercial provider. The satellite is compatible with a launch on VEGA, Soyuz, Mini-PSLV, and PSLV.

The LeakSense User Interface will allow the Customer to directly browse, discover, order and evaluate the services. The Customers will be able to open their accounts via this interface and enable in-situ data provisioning via Advanced Programmatic Interfaces (APIs) (via own servers) for value-added analytics. In other words, the common interface will have the capability to interconnect with external marketplaces via the implementation of front-end APIs to discover and integrate external data. An example of the selected delivery platform, adopted by the oil and gas industry, is shown in section 4.

3.7 Development approach and risks

To have a direct influence on the high-quality infrared measurement the satellite will be owned and operated by LeakSense. The payload and the data processing algorithms will be developed in-house to have control over key technology and proprietary data. The satellite platform, as well as integration, will be subcontracted to a commercial satellite provider.

The development risks are managed through the implementation of mitigating measures. The top risks are described in the following table, and the mitigation effort is already considered in the LeakSense development plan.

Table 3-6 Top development risks and mitigation measures

Risk Title	Risk Description	Mitigation and retirement implementation
Selected technology not able to meet mission requirements	Data is not usable to detect oil leaks	i) Early development of breadboard models, to be able to conduct verification tests.
		ii) Collaborate with laboratories researching this technology to confirm the feasibility
Acquired data not usable due to space segment performance	Noise level of data too high due to platform and payload performance	i) Development of breadboard models to conduct verification tests
		ii) Investigate the performance of commercially available platforms
		iii) Investigate other EO mission payload requirements for a feasibility study
Algorithm development	The algorithm is not able to perform to systems requirements	i) Use existing EO data in combination with known oil leaks to verify the algorithm.
		ii) Use data from breadboard verification tests to tune the algorithms.
Requirement changes	Customer induced requirements changes late in the project	Early iterations with the customers and pilot projects

4 Delivering the solution

LeakSense delivers user-oriented services with an early entry on the market and agile deployment approach.

The objective of LeakSense is to develop innovative sensing and analytic capability - currently not available on the market - addressing priority interests of three target demand sectors: oil industry, regulators and insurance industry.

4.1 Integration with users

The LeakSense satellite Earth Observation solution will allow for direct detection of onshore infrastructure leaks. The proposed satellite system will be coupled with Information and Communication Technology (ICT) infrastructure prepared for on-line LeakSense data processing and designed to improve the operational processes and information systems (such as operations response systems, logistics management systems, business intelligence, or environmental monitoring, etc.) of the customers.

In the oil sector, Supervisory Control and Data Acquisition (SCADA) systems are currently used for handling user data and to develop analytics. The majority of pipeline owners continue to operate their data management solutions via the in-house data-centers. LeakSense will enhance this data and operating environment by providing additional analytics offered as a Managed Application (external to the user systems and as a part of the existing operating portal) or integrated application (integrated with the user system).

The objective here is to use the combined analytics environment which can be provided as an online platform where clients will be able to access LeakSense services as well as integrate their data (i.e. contained in the SCADA system) into the analysis – i.e. by providing a map of the network topology to be monitored for leaks, access to their in situ data streams (i.e. sensor network) and provide feedback on the alerts issued by the LeakSense company.

Integration with the user segment will require that the customer information system is:

- Web-based.
- Capable of out-of-the-box integration with other applications.
- Flexible to quickly adapt to new products, programs, and services.
- Capable of handling geo-data.

Concerning the user interface, the Oil and Gas Earth Observation Response Portal (OGEO-ReP) has been selected as the most optimal way of integrating LeakSense services into operational practices of the oil industry.

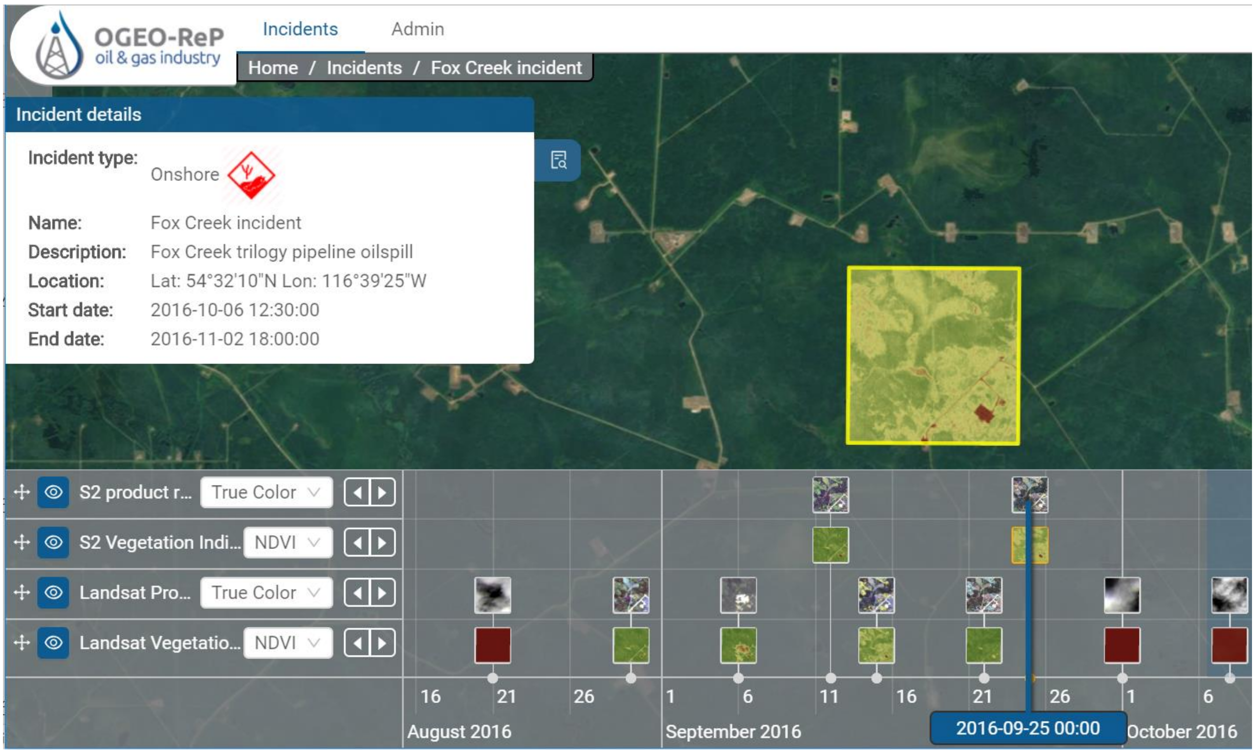

Figure 4-1 Image from the OGEO Portal[27]

The OGEO-ReP portal has been designed following the recommendations and requirements of the IOGP – International Association of Oil and Gas Producers. IOGP is the biggest oil industry association in the world developed to support works on behalf of the

[27] developed under the project financed by the European Space Agency "Oil and Gas Earth Observation Response Portal" and created by a consortium led by CGI together with CLS, Hatfield Consultants and ERM as part of the ESA contract "Expand Demand Oil and Gas".

world's oil & gas exploration and production companies to promote safe, responsible, and sustainable operations. IOGP's Global Industry Response Group (GIRG) has been established in 2010 after the DeepWater Horizon accident to better respond to risks and spill events. OGEO offers a development environment to build and offer services with direct access to tens of customers. This makes it a natural entry point for information delivery.

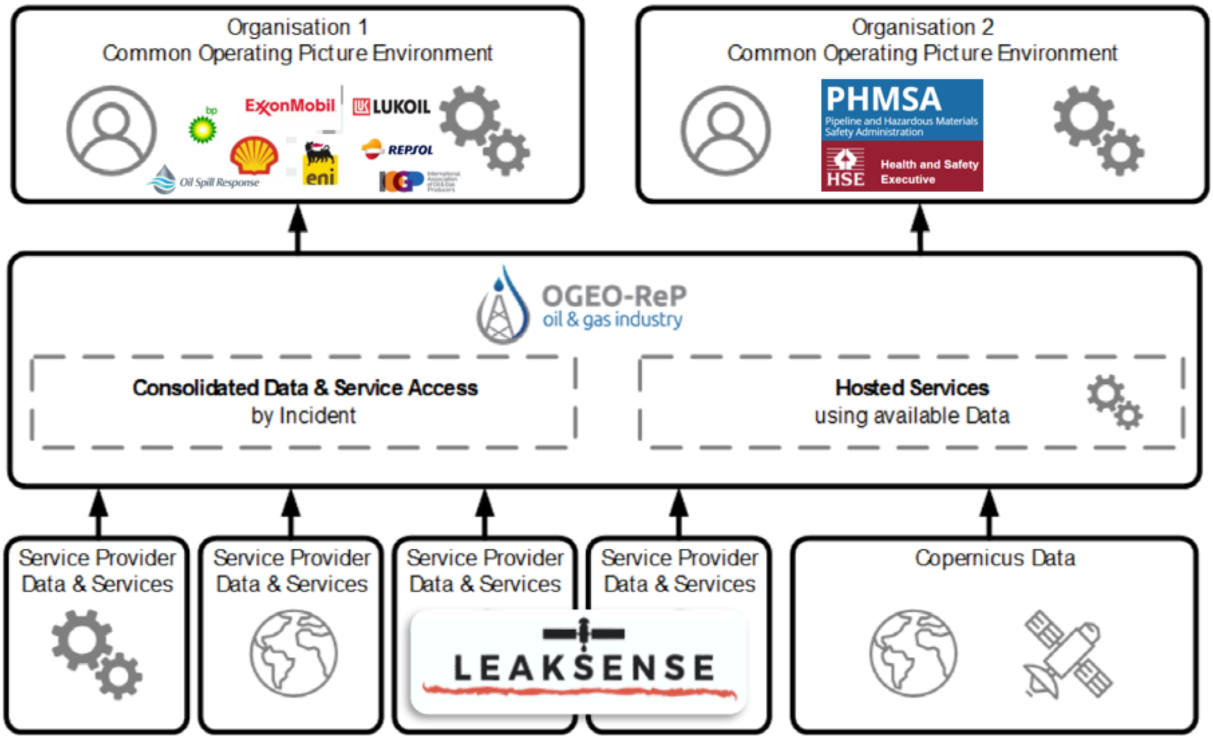

Figure 4-2 OGEO-ReP Portal service delivery architecture

4.2 Services portfolio

LeakSense will offer leak detection as a service. Three service levels are currently planned, as described in the following table.

The **LeakSense Essential** service level is a minimum viable product and provides a single scan of the network to identify any leaks. This service is intended as a trial for pilot projects and customers, and the first use is free. The objective is to allow the customers to evaluate the value of the service, provide customer's feedback to LeakSense development team and trial integration with customer's infrastructure. This service is also a viable option for customers who want to assess their network only occasionally (e.g. four times a year), where the consecutive scans are quoted at a normal market price.

The **LeakSense FirstView** is the subscription type service, where the customer's network is being periodically monitored for leaks. The revisit (scan) frequency depends on the availability of the commercial Earth observation data. Customers may choose a normal tasking priority, where the frequency of revisits is based on already available data, or match choose an option to task commercial EO providers for dedicated data. This service is intended as a first full commercial version of the service, providing steady revenue.

The **LeakSense Insight** service is fully available once the LeakSense satellites are in orbit. This service is similar to FirstView; however, with assured and more frequent revisit time. The pricing of this service scales with the revisit time – lower the revisit time higher the price.

Table 4-1 LeakSense service portfolio

	LEAKSENSE ESSENTIAL	LEAKSENSE FIRSTVIEW	LEAKSENSE INSIGHT
Coverage	Predefined geographical coverage	Predefined geographical coverage	Entire network
Revisit period	single scan	2 – 4 weeks	less than 3.5 days
Tasking priority	Normal, predefined tasking request	Normal to High (if tasking is commercially available)	Assured, guaranteed tasking
Primary data source	Commercially available data or LeakSense data	Commercially available data (open, free and commercial)	LeakSense data
Price (oil)	500k€ single payment (Free for first time users)	800k€ per month	800k€ to 1'600k€ per month, depending on revisit requested
Deployment timeline	With every new version of FirstView and Insight	Q1 2021	Q3 2023

4.3 Deployment strategy

The service development and deployment are planned for three phases, depicted in the following figure. **Phase 1** focuses on the development of the algorithms and user interfaces needed for FirstView. This activity is based on the commercially available Earth observation data. In addition, during this phase, the sensor technology is de-risked by performing engineering and field tests.

Phase 2 focuses on the development and deployment of the first satellite with LeakSense sensor. Also, the algorithms are further developed, such that shortly after the launch of the satellite, LeakSense Insight service can be offered, at least with a 14-day revisit time.

Finally, during **Phase 3** the satellite system is expanded and fully exploited. As a baseline 3 additional satellites are deployed, bringing the revisit time to down 3.5 days. This allows LeakSense to provide the full scope of Insight services. Depending on the market growth, additional satellites may be deployed in this phase to improve reliability and revisit time.

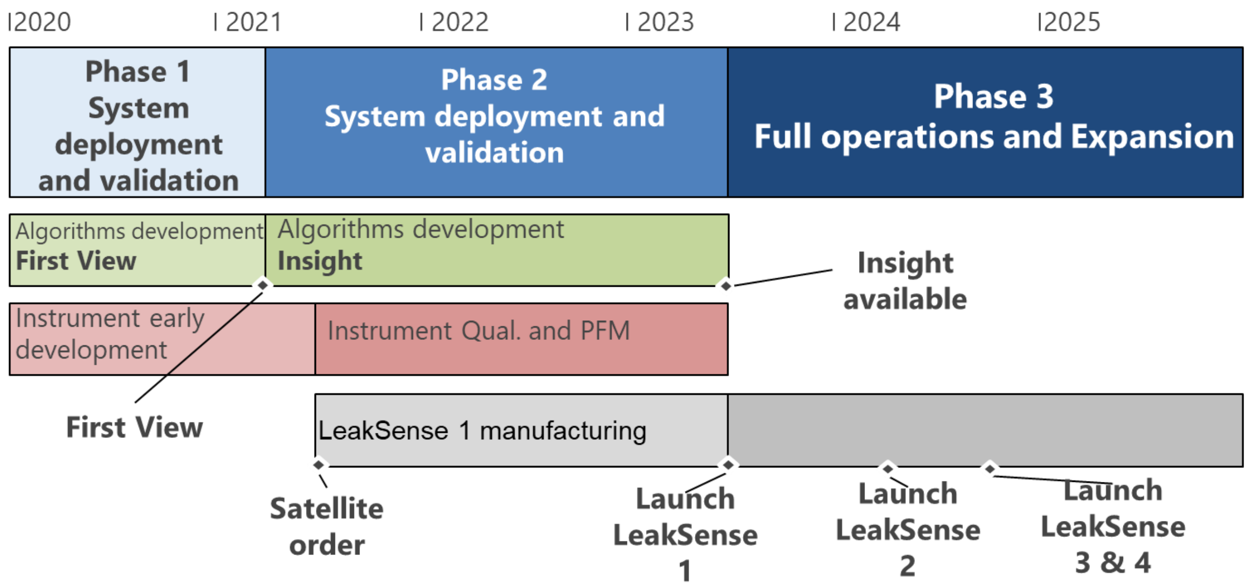

Figure 4-3 LeakSense deployment timeline

5 Financial analysis

LeakSense is profitable with scalable revenue and cost structure.

The sections below explain the main outcome of the financial analysis for a business case based on a constellation of four satellites, including the sales forecast, the cost structure of the system, the analysis of the financial viability, the funding needs and the growth opportunities.

LeakSense will be registered as a limited liability company in Germany (GmbH) to benefit from stable political and economic conditions for the investment and a highly skilled workforce.

The financial analysis includes the German corporate income tax rate (30%), social security contributions (22%) and the depreciation of assets based on German accounting standards.

5.1 Sales Forecast

	Target Customers	
Market	**Oil**	**Water**
Europe	15	808
North America	16	681
South America	-	
Middle East		-
East Asia	7	149
South Asia		27
Insurance Companies	20	
Total	**58**	**1,665**

Figure 5-1 Target customers

LeakSense will be able to provide services to oil and water companies in the main markets worldwide. Although the capability is global and any customer can be attended, the sales forecast is based on a limited part of the market shown in Figure 5-1.

The product availability is described in Section 4.3. The first basic oil and water services (LeakSense Essential and FirstView) will generate a small revenue while the first satellite is in production. Once the first LeakSense satellite is in flight, the sales will increase thanks to an optimised service (LeakSense Insight) to meet customer needs. As the revisit time is more frequent with constellation deployment, the value of the product will also increase, allowing to increase the market share. Once the constellation is

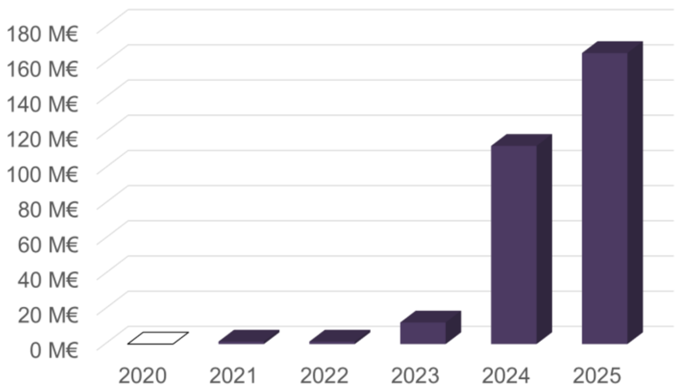

Figure 5-2 Annual Revenues

fully deployed, the estimated annual revenues reach 165 M€, as shown in Figure 5-2.

5.2 Cost Structure

The main assets of LeakSense will be the leak detection algorithm and the space segment. The algorithms are non-recurring costs whose development shall start as soon as the company is established, in the year 2020. These algorithms are the key to differentiate LeakSense from its competitors and, consequently, it is considered that the development remains within the company. The associated cost can be split into labour and direct costs for software licenses. The development is directly linked to the product availability and it spans during phases 1 and 2 (see section 4.3 for further details and timeline). The cost involved reaches 0.86 M€ and includes the creation of a reference database for oils and soils, as shown in Figure 5-3.

As described in section 3, the detection of hydrocarbons from space will require the use of a specialised sensing instrument on board of the satellite. The instrument development is the largest non-recurring cost. The early development, from breadboard to engineering model, will start in 2020 and will last for up to 18 months. The objective of this is mitigating the financial risk linked to technical feasibility before the large investments in phases 2 and 3. The development of technology reaches 20.2 M€, as shown in Figure 5-3.

Cost Breakdown	Recurrence type	Cost [k€]
Service		
Software	**NRC**	**865**
Algorithm development	NRC	615
Hydrocarbon Data base	NRC	250
Products	**RC per year**	**1 460**
LeakSense Essential	RC per year	347
LeakSense First View	RC per year	453
LeakSense Insight	RC per year	660
Space segment		
Technology development	NRC	20 180
Flight Model	RC per sat	54 684
Ground segment	**RC per year**	**765**
SUM NRC		**21 045**
SUM RC per satellite		**54 684**
SUM RC per year operations		**2 225**

Figure 5-3 Cost breakdown

The space segment is completed with the satellite and its launch. The cost considered is based on a commercial satellite platform, a flight model of the instrument and the launch service based on current market values for a launched payload of our class. The total cost of these three recurring cost elements for the first satellite is 54.7 M€.

Note that all elements under Space segment in Figure 5-3 include a 30% margin for uncertainty.

The recurring cost shown in Figure 5-3 includes the resources needed in terms of labour, procurement of external data and server costs. The total for all three products is 1.5 M€ per year.

The last cost in Figure 5-3 is the ground segment, which will be based on externally contracted ground stations and a LeakSense's control centre. The cost of this approach is 0.8 M€ per satellite and per year.

	cost	hours	cost	hours	cost	hours	cost	hours
Software	**100%**	**100%**	1%	37%	1%	8%	-	5%
Products	**100%**	**100%**	72%	67%	28%	33%	10%	13%
Space segment	-	-	**100%**	**100%**	68%	29%	60%	26%
Technology development	-	-	**100%**	**100%**	10%	-	5%	-
Mission	-	-	**100%**	**100%**	90%	90%	80%	80%
Ground segment	-	-	**100%**	**100%**	98%	50%	88%	25%

Figure 5-4 Recurring cost for constellations with respect to first satellite

As the size of LeakSense's constellation grows, the cost of recurring satellites and launches reduces thanks to bulk procurement and a recurrence of instruments and satellite design and testing. Figure 5-4 shows how much of the first satellite cost is considered for the following satellites in the constellation as it grows until 4 satellites.

The distribution of the costs per year in terms of operational expenses (OPEX) and capital expenses (CAPEX) described in the paragraphs above is shown in Figure 5-5 and Figure 5-6. Note that the largest investments in CAPEX are in years 2022 to 2024 due to the deployment of the space segment of LeakSense. There is no need for further investment from the year 2025. OPEX runs for all periods analysed.

Capital expenses		2020	2021	2022	2023	2024	2025
CAPEX	**[k€]**	**140**	**9**	**27,950**	**95,590**	**68,307**	**6**
Technical facilities and machines	**[k€]**	**-**	**-**	**27,800**	**95,550**	**68,250**	**-**
Space segment		**-**	**-**	**27,300**	**95,550**	**68,250**	**-**
Sensors(s)	[k€]	-	-	4,550	15,925	11,375	-
Satellite(s)	[k€]	-	-	13,000	45,500	32,500	-
Launch of satellites	[k€]	-	-	9,750	34,125	24,375	-
Technical Facilities	[k€]	**-**	**-**	**500**	**-**	**-**	**-**
Other equipment, factory and office equipment	**[k€]**	**140**	**9**	**150**	**40**	**57**	**6**

Figure 5-5 LeakSense capital expenses

Operating expenses	FY	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
OPEX	**[k€]**	**2,376**	**19,008**	**16,546**	**10,308**	**14,314**	**15,781**	**15,781**	**15,781**	**15,781**	**15,781**
Cost of material	**[k€]**	**519**	**12,798**	**10,670**	**2,746**	**2,568**	**3,108**	**3,108**	**3,108**	**3,108**	**3,108**
Goods	[k€]	-	-	-	-	-	-	-	-	-	-
Raw materials and supplies	[k€]	-	-	-	-	-	-	-	-	-	-
Expenses for purchased goods and services	[k€]	519	12,798	10,670	2,746	2,568	3,108	3,108	3,108	3,108	3,108
Personnel expenses	**[k€]**	**1,433**	**1,923**	**1,866**	**2,724**	**3,945**	**4,074**	**4,074**	**4,074**	**4,074**	**4,074**
Salaries and wages	[k€]	1,092	1,453	1,411	2,057	2,976	3,073	3,073	3,073	3,073	3,073
Social security contributions	[k€]	240	320	310	452	655	676	676	676	676	676
Other operating expenses	**[k€]**	**424**	**4,288**	**4,010**	**4,838**	**7,801**	**8,599**	**8,599**	**8,599**	**8,599**	**8,599**

Figure 5-6 LeakSense operating expenses

5.3 Viability of the Business Case

The resulting cash flow is shown in Figure 5-7. During the first years until the LeakSense satellites are deployed, the cash flow is negative due to the large CAPEX investment. This will be balanced by funding rounds, discussed in 5.4. The cumulative cash flow, including the funding needs, will grow at a steady rate once the constellation is deployed.

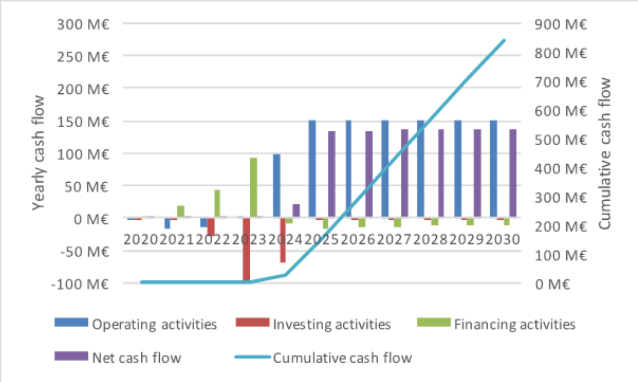

Figure 5-7 LeakSense cash flow

The total revenue is driven by the growth of sales described in 5.1. It shows a slow increase until 2023 and a faster and steady from 2024 when the constellation is deployed. The earnings before income and taxes (EBIT) show that LeakSense will break-even during 2023, as seen in Figure 5-8.

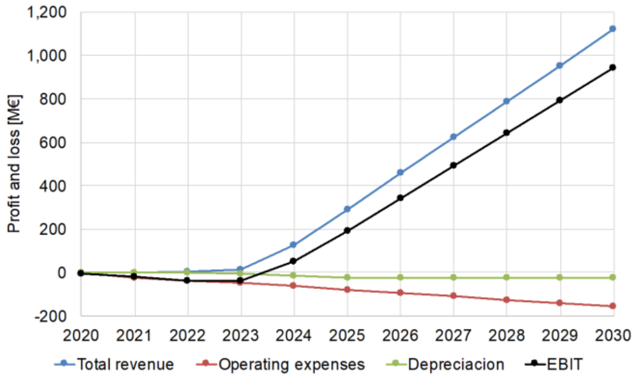

Figure 5-8 Revenue and time to profit

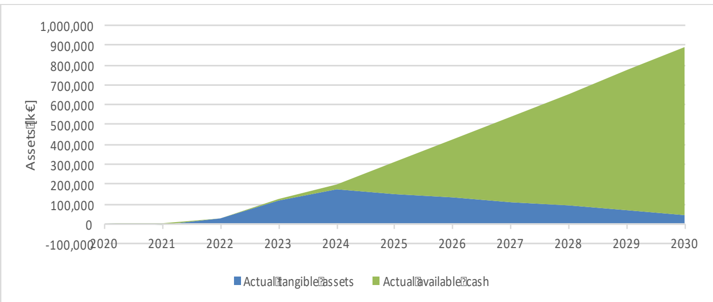

Figure 5-9 LeakSense assets

The first asset of the company will be the algorithm even if its valuation is not linked to any market value in the financial analysis. Then, the main tangible assets are the satellites which will grow as long as the constellation is deployed. The lifetime of the satellite determines their depreciation. At this stage, the replacement of LeakSense satellites is not included in the analysis. However, Figure 5-9 shows the company's ability to finance the original constellation with own cash resources.

5.4 Funding Needs

The company will start with an initial contribution from the founders and grants obtained from European institutions which already have funding programs for start-ups in the space sector. The main ones identified are the European Space Agency (ESA) and Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR). LeakSense estimates that initial investors and sponsors could contribute with 0.7 M€.

Source	Contribution
Founder's Investment	100.000 €
Development Grants	600.000 €
Venture Capital	35.200.000 €
Bank Loans	89.500.000 €

Figure 5-10 Funding needs

Funding Round	IRR	Multiple
Initial Investment	74,9 %	-
A – 2020	35,5 %	10
B – 2021	35,9 %	8
C – 2022	45,9 %	6
D - 2023	63,6 %	5

Figure 5-11 Internal Rate of Return (IRR) and multiple per funding round

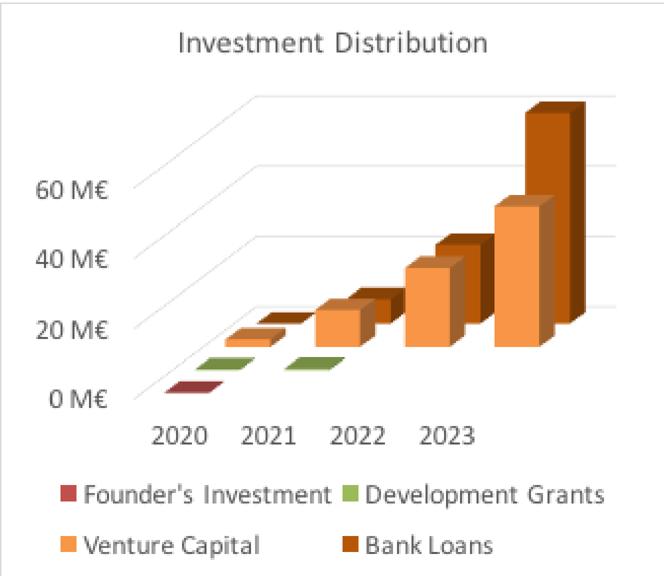

Figure 5-12 Funding needs distribution

The main funding sources are venture capital and bank loans. A total of four funding rounds are estimated between 2020 and 2023. The first rounds will require the support of venture capital. As the company grows and revenue increases, the source will shift to bank loans to maintain the percentage of shares of the investors. The distribution between venture capital and bank loans is shown in Figure 5-10. The internal rate of return for each funding round is shown in Figure 5-11.

There are four milestones for the development of LeakSense which are exit gate opportunities for the investors. They are (1) the development of the basic algorithm for leak detection, (2) the first stage of the instrument development (at which the satellite order is placed), (3) the demonstration in orbit after the first satellite launch (ability to capture customers) and (4) the decision to grow the constellation to the third and fourth satellite.

5.5 Growth Opportunities

	Oil		
Revisit time	Price	Customer Share	Revenue
[days]	[€]	[%]	[€ p.a.]
	0.5 M€	2%	**0.6 M€**
14.00	10.6 M€	3%	**18.4 M€**
7.00	12.7 M€	5%	**36.8 M€**
3.50	19.0 M€	10%	**105.5 M€**
1.75	25.3 M€	15%	214.2 M€
1.17	29.0 M€	25%	421.2 M€
0.88	31.7 M€	40%	735.0 M€

Figure 5-13 Revisit time based company growth

LeakSense brings solutions to the actual problems of the oil industry. The baseline considers three products with revisit as short as 3.5 days. However, if the customers need even more frequent monitoring of their distribution networks, LeakSense can satisfy this need by increasing the number of satellites in the constellation. This will offer additional products resulting in revenue increase (see Figure 5-13). Section 5.3 shows the cash flow and profit and loss projections of LeakSense, which predict a large availability of cash. Additional satellites can be funded from revenues or fresh investment. However, increasing the constellation size increases the value of the products for the customers (i.e. improved revisit time, reduction of false detections).

It should be noted that our business can help to create new markets for oil distribution networks. There are multiple areas which do not allow the deployment of pipelines because of the potential impact not detected leaks could have on the environment and the difficulty to detect these leaks. LeakSense can contribute to increasing the detection capability and reliability to defend a case in front of regulatory bodies. The reaction time and reliability are directly linked to the constellation size, additional algorithms to be developed and the complexity of the final leak detection product.

6 Conclusion

LeakSense is a value-added service for the detection of leaks in oil distribution networks. The service addresses the industry's need for reliable and timely detection of leaks, that cannot be met by the current Earth observation systems. The target market for LeakSense is estimated at $3-4 billion per year.

The oil leak detection is based on a demonstrated technology, augmented with additional capabilities for increased reliability. Oil detection sensors, developed by LeakSense with this technology, are deployed in a small constellation of small satellites. The system is optimized for detection of oil and high revisit, providing a unique competitive advantage, despite use of proven technology and commercial solutions.

In-house developed, proprietary, algorithms allow LeakSense to detect leaks with the Earth observation data acquired from satellites. The initial service can be offered in 2021 based on commercially available Earth observation data, allowing fast entry on the market and early feedback from the customers. Once LeakSense's own sensors and satellites are deployed in 2023, the services can be expanded providing higher value to the customers and revenue growth to LeakSense.

LeakSense is a profitable investment opportunity. First revenues are projected within the first 1.5 years, and the break-even point within the first 4 years. The revenues scale with successive deployment steps, and a conservative estimate of annual revenue is 160 million €, corresponding to 5% of the target market. This revenue can be scaled with market demand, which is expected to grow once the LeakSense system is operational. All investment into LeakSense can be repaid with significant profit. LeakSense is looking to engage with investors looking to take stake in a unique, scalable and focused business.