Deliverable 5.6

Report on the available technologies and sensors that can be utilized in the new system and on business model on incentives for monitoring and enforcement

Project no.	636329
Project acronym:	EfficienSea2
	EFFICIENSEA2 – efficient, safe and sustainable traffic at sea
Funding scheme:	Innovation Action (IA)
Start date of project:	1 May 2015
End date of project:	30 April 2018
Duration:	36 months

Due date of deliverable:	1 March 2016
Actual submission date:	29 January 2016
Organisation in charge of deliverable:	Partner 25, Litehauz

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

Document status

Authors

Name	Organisation
Frank Stuer-Lauridsen	Litehauz
Frey G. Callesen	Litehauz
Peter Pedersen	Gatehouse
Jeppe Skovbakke Juhl	BIMCO
Peter Krog-Meyer	DMA

Document History

Version	Date	Initials	Description
00-A	05.10.2015	FSL/FGC	Draft contents
01-B	30.11.2015		
01-C	03.12.2015	All	Draft content with contributions
1.0 Final	26.02.2016	FSL/FGC	Final report

Review

Name	Organisation
Kate Schrøder Jensen	Alfa Laval

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

Table of Contents

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

Executive Summary

The primary objective for this EfficienSea2 work package is to develop new emission monitoring concepts to be used by both shipowners and authorities. The goal is use continuous emission monitoring systems to deliver data for port state control purposes and optionally for public access. The study reports on existing monitoring systems and barriers for specification of a ship-to-shore reporting and presentation system for sulphur compliance in shipping.

The EU sulphur directive and the existing IMO SECA areas in the North Sea and Baltic Sea sets a scene for 0.1% S in SECAs and EU ports and 0.5% in EU member states EEZ in 2020. Currently, two paths exist for shipping to comply: fuel switch to low sulphur fuels, including LNG and other alternative fuels, or installing exhaust gas cleaning devices, i.e. scrubbers.

Currently automated or real time monitoring system for detecting sulphur content of fuel are emerging, but may not yet be a mature technology. The present post-delivery laboratory based mechanism is not applicable for SOx emissions monitoring. The focus of the current study is on utilising the continuous emission monitoring system installed on most scrubbers for developing the voluntary compliance monitoring system.

A number of commercial brands of scrubber systems are marketed with a range of sensors installed for the monitoring of SO2 and CO2. Despite the differences in technologies of their sensors there appear to be no barriers for storage of data in transmissible formats onboard.

Transmission to shore of large data sets may be costly if satellite connections are to be used. The estimated isolated data volumes may be as low as 10 MB per vessel over 18 months and should not in it self amount to a barrier for a voluntary data exchange system.

Currently, a short sea shipping company DFDS, that operates a number of European RO-PAX and RO-RO lines, is testing their own system for public display of the SOx emissions. Based on their experience and the study's preliminary findings there are several issues that need to be resolved.

In the EfficiencSea2 process and/or in the relevant international forums the following issues need to be appropriately defined for use in port state control:

- is the shipowner's onshore office or a central data hub to be used for data repository and storage?
- If data are more detailed than required by PSC, how to reduce?
- what is the criteria for exceeding, i.e. be non-compliant
- If shipowners responsibility to store data, how to access for PSC?
- How to ensure tamper-proof data if data are to be real time displayed?
- Which standards are to be used for data submission and naming of data entities

Certain issues are specifically related to the optional public access to analysed data:

- Should data be reduced (5 min to hourly?) to reflect criteria for non-compliance?
- How to display emergencies, distress, downtime etc, i.e. involuntary non-compliance?

The study is currently in the process of specifying the data transmission flow, storage, analysis and display based on selected key parameter values. Certain of these parameters will concomitantly require adjustment or confirmation from relevant organisations.

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

Introduction

The introduction of sulphur emissions reduction in shipping has led to both global targets from the International Maritime Organization and to the establishment of regional Sulfur Emissions Control Areas (SECAs) e.g. the North Sea and Baltic Sea SECAs both covering EU member states water and governed by the EU Sulphur Directive. Port and Coastal states have an obligation to survey and inspect vessels for their compliance with the international and national law, and while new regulation by default increases the administrative burden and the cost to the industry, it is the ambition of many entrepreneurs in the field of performance monitoring that this can be completely automated, thus reducing or eliminating the hassle of operating highly sophisticated equipment and leaving the record-keeping and reporting to electronic systems.

In the sister activity in work package 5 on “Development of a new common port database concept and structure” it is said that “Good nautical and commercial port information is the foundation for efficient and safe port calls”. The same can be said of the environmental monitoring data which, in the future, will form an increasingly larger part of the data exchange with maritime and port authorities. This work package activity and report focus on improving the exchange of information with authorities, and possibly public stakeholders by enhancing the automatic flow of information sea-to-shore. .Standardised templates and reporting forms will ensure an efficient exchange of data by streamlining the information flow and allow the information to be used as a basis for Port State Control purposes. This will reduce the administrative burden of updates to shore. This will help the shipping industry to remain competitive compared to other modes of transport.

A challenge to the information exchange regarding environmental performance data is the “business model” for a voluntary mechanism, as the benefits potentially reaped may hold different attraction for the range of shipping operating under the sulphur reduction emission schemes.

Objectives

The work in WP5.3 covers new emission monitoring concepts to be used by both shipowners and authorities. The starting case is SOx emissions in the Baltic Sea Region and the initial thinking is to use onboard sensor data for compliance monitoring. The project has evaluated possible incentive structures that could counteract the economic incentive of non-compliance due to the lower cost of undesirable fuels. A new effective solution will help level the competitive playing field of shipping companies.

It is assumed that continuous monitoring will encourage shipowners to fully comply with emission regulations compared to a setup with relatively rare occasional inspections. For the righteous shipping line, automated and continuous emission reporting will contribute to fairer competition, by making fuel/emission fraud more difficult.

The work covered

This report provides information primarily on the Subtasks 5.3.1 *Incentives and enforcement* and 5.3.3 *Mapping of sensor technologies and monitoring networks*. There are two more deliverables due at the final phase of the project:

“This project has received funding from the *European Union’s Horizon 2020 research and innovation programme* under grant agreement No 636329”.

- D5.7 Report on online land-based system tests and ship-based tests (M30) will report on Subtask 5.3.2 Definition of sensor and monitoring concepts and Subtask 5.3.4 Field testing, demonstration and evaluation.
- D5.8 Working prototype of online sensor with cloud-based algorithm (M35), which will report on the final parts of Subtask 5.3.4 and on Subtask 5.3.5 Recommendations.

LITEHAUZ is lead on WP5.3 with input from:

- Gatehouse
  - assist in service development, service and client side – web-based
- BIMCO
  - user involvement, ship-owners perspective
- Danish Maritime Authority (DMA)
  - assist with service development, servicer side with Maritime Cloud usage and client side on web based platform
- DANELEC
  - will liaise from WP2, task 2.4 on integrating sensor data collection

Subtask 5.3.1 Incentives and enforcement

A business model allowing for voluntary participation in a reporting mechanism to ports and authorities will provide an incentive through reduced PSC inspections when data are accessible in advance of entry into the EEZ/ports. Issues, such as data ownership, data access, encryption, confidentially, reliability and other typical challenges of cloud based data analysis are included.

Subtask 5.3.2 Definition of sensor and monitoring concepts

Identification of the current status of existing SOx measurement technologies is part of the initiating work on defining sensor and monitoring concepts. Evaluation and identification of available monitoring technologies will lead to a conceptual design of an emission control system, including design of software that can collect, analyse and transmit data to the cloud, where emissions are measured and geocoded in SECA (Sulphur Emission Control Area) zones. When using exhaust gas cleaning systems, sulphur oxide (SOx) emissions must be logged by the equipment and made available for inspection. It is suggested that such an approach is enhanced with an automatic emission report sent from the ship or the equipment supplier on a regular basis. Documenting emissions during all trips and in all sea areas gives the authorities an ability to map the precise geospatial emission.

The standards applicable in sensor technologies and the possible proxies feasible for monitoring will be assessed in light of the 2015 introduction of new sulphur reductions for shipping in European SECAs. Also, the use of scrubbers when operating on HFO or the use of MGO to reduce sulphur emissions can be monitored (automated or manually) and the results stored onboard or in a central data repository.

Subtask 5.3.3 Mapping of sensor technologies and monitoring networks

Monitoring of sulphur related performance indicators in shipping is still under development, but early stage sensor technologies are commercially available for stack emissions and for oil sulphur content. However, the sampling mechanisms, the detector standardization, the data transfer formats and data management are still in transition phases.

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

Based on our existing software architecture, it is the plan to develop the data transfer and storage framework in open source code and supply a display platform with near real time emission data (for scrubber sensors) and recalculated voyage emission data for fuel switch users (subject to reporting).

Subtask 5.3.4 Field testing, demonstration and evaluation

Field tests will be carried out on land-based lab/full-scale facilities as well as on the ships where the monitoring device has been installed. During the tests, the monitoring efficiency, data transfer and analysis will be demonstrated and evaluated. The system will be tested, demonstrated and evaluated on board a vessel.

Subtask 5.3.5 Recommendations

The system will allow shipowners and PSC authorities to screen the volunteers for sulphur regulatory compliance. The recommendations for the framework to be applied will be presented. The data submission and analysis mechanisms will be prepared for and may (in future applications) be developed for emission data of many more pollutants and for correlation of the performance indicators of the ship, primarily speed, load, fuel consumption, etc., but may also include geoposition as well as hydrological and meteorological parameters. This unique collection of data will facilitate data mining, pattern recognition algorithms and the options for other business models through subscriptions.

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

D5.6 Incentives and Enforcement

The current regime of regulation and enforcement

MARPOL – international regulations:

On 1 January 2015, new requirements on the sulphur content of ships' fuels took effect. They are laid down in Annex VI of the IMO MARPOL Convention.

The new regulations mean that ships operating within Sulphur Emission Control Areas (SECAs) must use fuels with a maximum sulphur content of 0.10% – down from the previous 1% limit – or adopt alternative solutions resulting in an equivalent effect. The SECA's are:

- The Baltic Sea area (as defined in MARPOL Annex I, regulation 1.11.2).
- The North Sea area (as defined in MARPOL Annex V, regulation 1.14.6).
- The North American area (as described by the coordinates provided in Appendix VII to MARPOL Annex VI).
- The United States Caribbean Sea area (as described by the coordinates provided in Appendix VII to MARPOL Annex VI).

From 2020 or 2025 a 0.5 % sulphur limit is expected to be introduced for all non-SECA waters. The exact date of entry for this limit depends on fuel availability and is to be decided in 2018.

EU – regional regulation:

For EU waters and ports, slightly different rules apply which are laid down in Directive 1999/32/EC as amended by Directive 2005/33/EC.

- Inside the EU-SECAs the MARPOL- and EU-sulphur limits of 0.1 % are the same
- Ships at quay in any EU ports (SECA or non-SECA) must also comply with the 0.1 % limit
- From 2020 ships in non-SECA EU waters including the respective countries' EEZ must use fuels with a maximum sulphur content of 0.5 %.

Enforcement

Compliance with the sulphur regulation is associated with considerable cost for shipowners leading to a call for robust enforcement of the rules from all sides. Various stakeholders have a role in this:

- **Port States** perform Port State Control and/or MARPOL inspections in their ports which is the main tool for verifying compliance. This is mainly done by checking bunker-related documents and jounals as well as relevant certificates. The document control is in some countries extended to also include an analysis of the fuel on board (either the MARPOL sample from the deliverer or an extracted sample of the fuel in use).
- **Flag states** are expected to encourage ships under their flag to comply with the rules and can apply sanctions for non-compliance as is the case with any regulation. Motivation for robust enforcement is considered less of a certainty for Flag States since they may be able to gain a competitive advantage over other Flag States by 'going easy' on ships under their flag.

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

- **Coastal States** have a less direct role at the moment, since the primary control and any sanctioning is currently handled by the relevant authorities in ports – not in open sea. However, some countries are using remote sensing technologies (i.e. 'sniffers' or optical sensors) to monitor parts of their national waters as a method for detecting potentially non-compliant ships.
- **Companies** cannot enforce regulation per se, but may still have a role in contributing to ensuring high levels of compliance. This includes voluntarily delivering data on own emissions to relevant authorities.

Current use and sharing of data

Port-, Flag-, and Coastal States generate data on compliance that are useful for their own targeting and potentially prosecution of non-compliant ships. The effect of such data increase rapidly if they are shared among authorities in different states as this will allow authorities to have a 'bigger picture' of who is compliant.

- Data on the results from inspections, including sulphur content analyses, are stored by Port State authorities in each country. For Paris MoU members, results of PSC are recorded in the joint database THETIS. EU-countries further have the option to store inspection data in sulphur control in the shared EU database THETIS-S. In all cases, the data stored in national or shared databases on inspections is of value to the enforcement in all states – not just the data owning state.
- Data from remote sensing is currently being used to indicate non-compliance and thus to help targeting those ships for inspection in national ports. Again, this data is valuable to other States as they too can use it for targeting their own inspections – however such data sharing is currently based on informal bilateral networks and has to be handled manually on a case by case basis.
- For ships that comply with the sulphur rules through the use of 'scrubbers' that include continuous monitoring of emissions (CEM), there will be a record of emissions available for authorities to check during inspections. Had this data, however, been more universally accessible by having the ship automatically broadcast its emissions data from the scrubbers to relevant authorities, then that ship could avoid being targeted for sulphur inspection saving time and resources for both itself and Port State authorities.
- For EU countries, a linkage is needed between the THETIS-S database, which will eventually be used for targeting ships for control and the potential collection of CEM data under the EfficienSea2 WP 5.3.1. Data on inspections are currently entered manually into THETIS-S following inspections. CEM- or other data would have to be uploaded through some form of automation, which would require an agreement with EMSA (sanctioned by the EU Member States) to develop THETIS-S further as well as a policy on how those data would contribute to targeting or waiving sulphur control. In practice, THETIS-S would only need to contain data on which ships are voluntarily supplying CEM data and whether they are non-compliant. The CEM ships, which are compliant could then NOT be targeted for inspection by THETIS-S, while at the same time in the unlikely case that a CEM ship is non-compliant it would be targeted for inspection. Similar systems could probably be set up for non-EU countries with regard to their databases although individual agreements would have to be made.

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

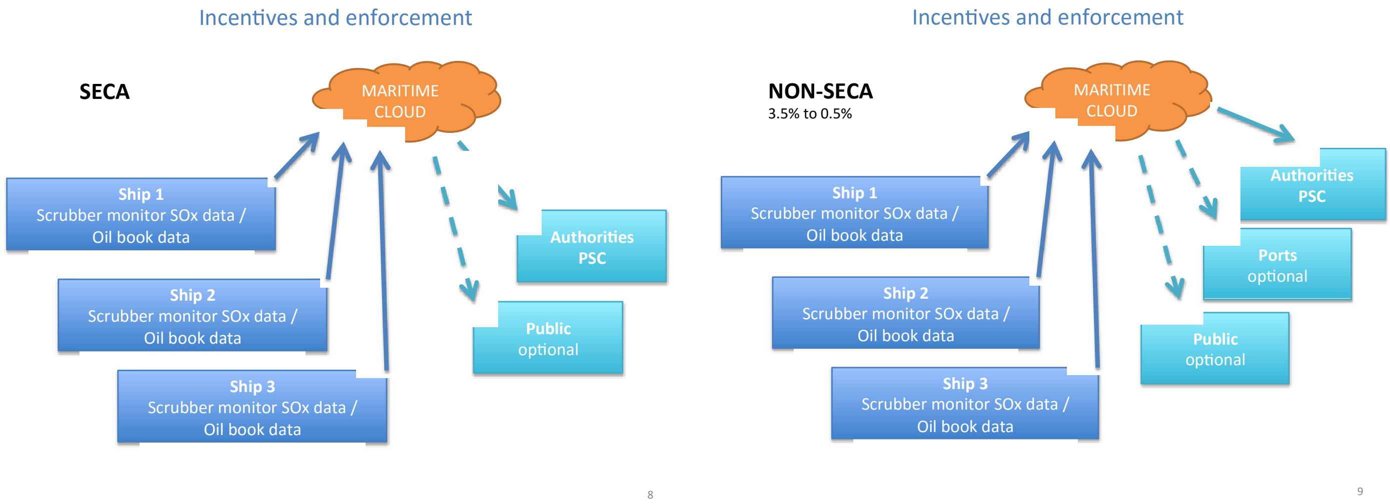

Figure 1 Incentives and enforcement in a SECA and non-SECA situation.

Incentives for voluntary submission of data to authorities

Voluntary submission of continuous emissions monitoring data would allow port state authorities to target non-compliant ships for sulphur inspection, and to NOT target compliant ships. This leads to the following possible incentives for shipowners:

- Less bureaucracy and waste of time for compliant ships and their crews as they will be less likely to be inspected[1].
- Improved business case for compliant ships, as any non-compliant ships will have a higher risk of getting caught, which mitigates the competitive advantage of willful non-compliance.
- Potential branding as a proven clean, compliant company.

It has to be noted, that sulphur inspections are handled differently in each Port State. Whether data provided voluntarily will be used and how they will be used is up to the relevant authority and the relevant national legislation. However, the incentives will be strong for Port States to use any available information that can lead to getting greater value form resources spent on sulphur control.

As mentioned above, in the EU, the sulphur inspection database THETIS-S is expected to be further developed in 2016 to include a targeting mechanism drawing on various types of data. Emissions data directly from ships would be an obvious source to include for calculating the ‘risk’ of a ship which would again lead to compliant ships not being inspected as often in ports.

Table 1 Cases for EU and global compliance reporting

	SECA	Non-SECA

[1] Sulphur inspections are in most countries part of a different regime from the PSC-system. Some countries conduct PSC and sulphur inspections in combination, while others divide these tasks. In the context of EfficienSea2 only sulphur inspections that ships would potentially be able to avoid by voluntarily submitting data are addressed.

“This project has received funding from the *European Union’s Horizon 2020 research and innovation programme* under grant agreement No 636329”.

EU (uploaded in advance and reported via THETIS-S?)	0.1%: Compliance leads to waiving PSC for sulphur	In ports 0.1%: Compliance leads to waiving PSC for sulphur EEZ 0.5%: Coastal states (for transit vessels no PSC)
Global	0.1%: Compliance leads to waiving PSC for sulphur	EEZ 0.5%: Coastal states (for transit vessels no PSC) In some ports 0.1% compliance reduces fees

Ports with existing incentive schemes

Emissions are significant sources of pollution and major public health costs, and both public debate and industry initiatives on how to curb these have led to the development of emissions reduction schemes in ports over the last few years. The International Association of Ports and Harbors promoted the development of the Environmental Ship Index (ESI), which evaluates the amount of nitrogen oxide (NOx) and sulphur oxide (SOx) that is released by a ship to provide an ESI Score. The ESI Score is often used by port authorities as an indication of the environmental performance of ocean going vessels.

A non-exhaustive list of major ports having some kind of award or incentive scheme for green operation of ships calling the ports.

- Port of Singapore: Green Port Program (only home flag vessels)
- Port of Tokyo: Green ship Incentive (using ESI)
- Port of New York & New Jersey: Clean Vessel Incentive (using ESI)
- Port of Los Angeles: ESI Program
- Port of Antwerp: Additional scrubber/LNG discount (on top of ESI)
- Port of Rotterdam: Green Award and ESI

Many European ports are already employing the ESI or other “green” assessment schemes in their port fee reduction, and EU ports are major contributors to the execution of World Ports Climate Initiative. A more detailed account of mechanisms to monitor and submit data to ports under the ESI programme is given in the section “How to present data for ports or third parties?”.

Business case to be limited to after 2020 scenario

As of 2020 the global limitations for content of sulphur in the fuel oil will be reduced to 0.5% from 3.5% (pending a 2018 review), while the current North Sea and the Baltics SECAs in EU and SECAs elsewhere will remain at 0.1% fuel oil sulphur content. In addition, the rest of EU have fuel oil sulphur content limit of 0.5%. These different regimes under SECA/EU water/global regulation may have different impacts on the business case depending on the trading patterns of potential participants. Obviously, in a voluntary scheme a shipowner’s motive for spending resources on participating in publishing emission data is highly dependent on the incentive(s). In 2020 regulations in EU limit fuel oil sulphur content to 0.1% in,

“This project has received funding from the *European Union’s Horizon 2020 research and innovation programme* under grant agreement No 636329”.

Furthermore, EU is implementing the MRV scheme under which ships operating in EU waters must report on CO_2 emission (fuel consumption)[2]. For ships entering European ports the MRV scheme dictates the start of CO_2 emissions reporting on the 1st of January 2018.

With this in mind it is challenging to produce a business case for reporting on SO_x, which incentivise shipowners to the effort put into reporting on SO_x or implementing Continuous Emissions Monitoring Systems (CEMS) for S.

As a way of dealing with the business case concerning SO_x reporting and monitoring a value proposition canvas has been developed, seen in Figure 2:

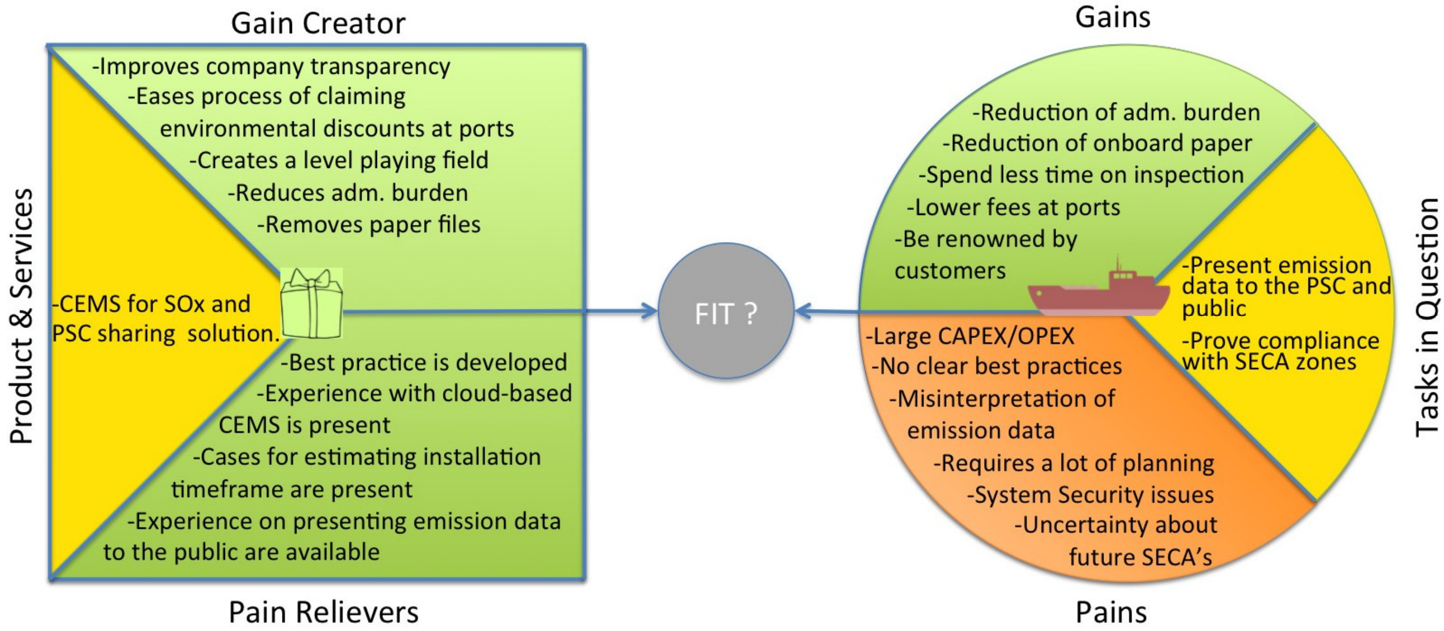

Figure 2: Value proposition canvas

- On the right side:
    - **Task in question**, describes the task need solving
    - **Gains**, which are the benefits the shipowner wants from a product that can solve the **Task in question**
    - **Pains**, describes the potential undesired outcomes and obstacles
- On the left side:
    - **Product & Service** tells what products are pushed to solve the **Tasks in question.**
    - **Gain Creator**, describes how the product can develop growth and gain in the buyer's company
    - **Pain Relievers**, describes what is in place to reduce potential **Pains**

The scope of the model is to see what issues and gains are present in terms of investing in a CEMS with a cloud solution or reporting SO_x emission to a centralized database through e.g. fuel switching time scheme.

The **pain** that is always present among shipowners is uncertainty. In this case the uncertainty is about the cost of buying/operating, installing and utilizing such systems. These issues are taken care of, as described in the model, during this report. Experience of current ongoing projects is presented; it's described how emission data can be utilized to the shipowner's advantage.

[2] Regulation (EU) 2015/757 of The European Parliament and the Council of 29 April 2015

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

The **gains** that the CEMS provide in terms of eliminating the need for PSC to inspect the ship for compliance with the SECA zones and the fact that the need for paper files is removed.

Considering a ship with a global operational profile with e.g. a scrubber, the CEMS may also ease the process of claim discounts in ports; in case these apply for ships producing emissions with lower sulphur equivalent than the 0.5% needed.

Incentives promoting public access to SO_x emission

To give a general idea of the issues regarding why all shipowners don't see a large incentive for implementing continuous emission monitoring systems with automatic data transfer aboard their ships, one might consider the following cases may be considered:

Shipowners with B2C relations inside ECA's

It is seen that the incentives are applicable to some extent for PAX, Ro-Ro and Ro-Pax vessels. This is mainly due to the short distance between the customers and the businesses using these services and the ships' owners and operators. As a general consideration, paying customers are reluctant to be affiliated with services that can have a negative impact on their social status, which being a polluter may have, and they will typically claim that they are already paying for a "clean" transportation service. Making emissions publically accessible is a way of providing transparency to these stakeholders; thereby assuring them nothing that could reflect negatively upon them.

Shipowners with B2B relations inside ECA's

Considering shipowners transporting bulk cargo like oil products, ore and grain, the "distance" to the end user of that product is typically quite far. To give an example, it would be near to impossibly for an end user to e.g. establish which crude oil carrier; delivered the crude oil for producing the gasoline filling the tank of an end user's car. This emphasizes the fact that the pressure for transparent emission data, will be very difficult for end users to push upon the shipowner as the correct recipient of this pressure is difficult to locate. The pressure instead would have to arise from the business using the transportation service.

The pressure towards more transparency may however come from relations/stakeholders closer to the shipowner. Some of these stakeholders, like AkzoNobel, Scania and Volkswagen, have joined the Clean Shipping Index (CSI). The index score is calculated on basis of the emission of SO_x, CO_2, NO_x, particulate matter, chemicals, waste and ballast water treatment. To handle a participating company's cargo the shipowner must report on the described topics. More than 2000 ships are already registered in their database. A more through explanation of rules for calculating the CSI can be found in the organization's publication CSI Guidance document 5.2[3]. As much as shipowners are moving towards reporting to the CSI database, the incentive for doing so is linked to getting more cargo, and not cargo which pays a higher premium.

The above system has much resemblance with the Oil Companies International Marine Forum[4], which handles vetting procedures for oil and product tankers, and publicizes reports of these. A vetting report rewarding a bad result, for the shipowner, causes cargo-owners to steer around this

[3] www.cleanshippingindex.com/wp-content/uploads/2015/10/Guidance-doc-CLEAN-SHIPPING-INDEX-5.2.pdf
[4] http://www.ocimf.org/

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

ship for a period of time, sometimes six months[5]. This is six months where the ship won't get chartered for transport of major oil companies.

In case a high SO_x score caused the same effect as a vetting review, deeming the ship unapproved. Becoming unqualified for transporting cargo for "anyone" could prove a very effective tool for controlling emissions, however this seems unrealistic.

Another possible incentive could be reduced port fees for ships with low SO_x emissions. However, as the sulphur emissions must comply with the S/ECA rules, being 0.1% sulphur in the fuel, this does not seem feasible unless ships are retrofitted to run on LNG or methanol.

The incentive for sharing emission data inside the S/ECA's seems rather weak, however some could be present. Reducing inspections aboard ships is one of these incentives, however as SO_x is the only measuring parameter, which is taken out of the equation the amount of time saved may not be that significant.

Shipowner with B2B relations outside ECA's

With non-SECA regulations limiting the fuel oil sulphur content to 3.5%. In this case it is possible for ports to provide incentives for shipsowners without the need for retrofitting the vessels for e.g. LNG. Examples of incentive concepts have been provided for switching to low sulphur fuels in non-SECA areas like Hong-Kong[6]. The incentive here would be lower port fees.

Table 2: Considerations regarding incentives

Approach	Drawback	Benefit	Incentive	Enforcement
SECA: Data to MA No PSC on S	Still PSC on all other issues Database to be financed (THETIS?)	Saving on time	Insufficient for shipowner?	Sufficient (link to THETIS-S)
SECA: Data to MA and Public web No PSC on S	Still PSC on all other issues Non- compliance exposure	Response to customer pressure (both B2B and C2B)	For PAX, Ro-Ro Other short sea? Container?	Sufficient
Data to MA also outside SECA but in EU	Possible reluctance from MAs to engage	Less admin burden	Insufficient for shipowner?	Sufficient

[5] http://www.standard-club.com/media/1557969/oil-major-vetting-and-approvals.pdf
[6] www.maritime-executive.com/article/hong-kong-wants-ship-emission-standards-now

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

Data also to ports w. fee red. outside SECA	Potential lack of confidentiality	Inclusion in port fee reduction outside SECA	Better, but probably still insufficient	PSC sufficient (?) Port sufficient
Data to MA and Public				

Draft outline of standard data storage and reporting

- To follow WP3 and other WP5 task results (S-100 etc)

The International Maritime Organization (IMO) has developed the S-100 framework for data formats used in the maritime domain. Hence, it is suggested to use the principles of S-100 for storage and reporting the measured data from SOx sensors.

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

Background on scrubbers

As of today two categorizes of scrubbers exits, more specific dry scrubbers and wet scrubbers. Dry scrubbers are typically used in power plants on-land, but a couple of dry scrubbers have been installed on ships. Mainly wet scrubbers are being installed on ships worldwide. Within the wet scrubber category there are 3 sub-categorizes. These are open loop, closed loop, and hybrid scrubber installations.

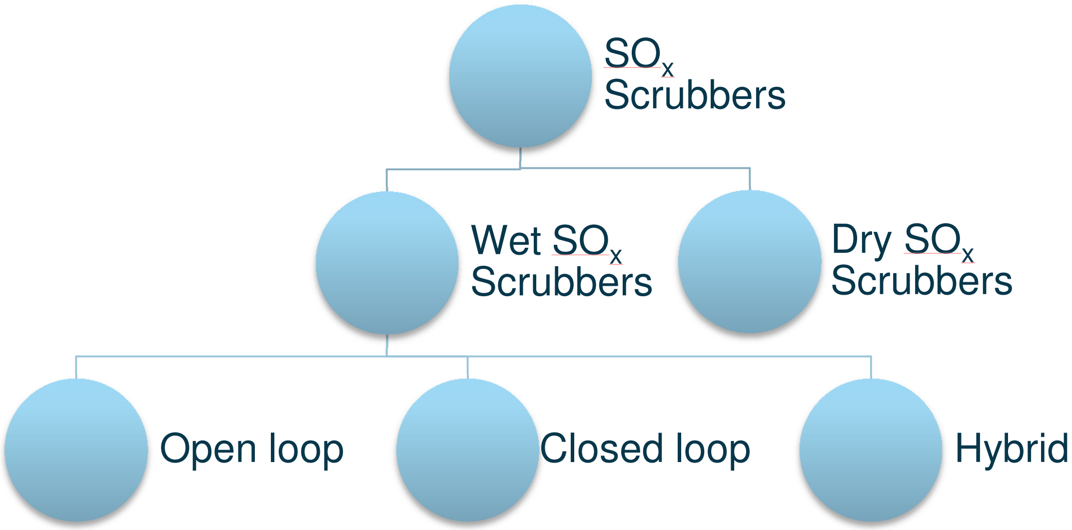

Figure 3: Overview of scrubber types

Dry scrubbers

The principle behind dry scrubbers is to lead the exhaust gas through a dry substance that will react with SO_x. The substance used is calcium hydroxide (lime) in the form of granules to maximize the surface to weight ratio. When the SO_x comes into contact with the granules the lime reacts and calcium sulfate (gypsum) is produced, which means the sulphur is bound in a solid state.

Lloyd's Register estimates that a scrubber using this technology would require lime at the rate of 10 kg/MWh·%S which means an engine running at 20 MW with 3.5% sulphur in the fuel would use about 17 tonnes per day. The spend lime has to be stored as well, meaning that a filled dry scrubber unit will weigh around 200 tonnes for a ship installed with a 20 MW engine output. The parasitic effect of a dry scrubbing unit is approximately 0.15-0.20% of the engine output being scrubbed, which is less than that of the wet scrubbing units.

Wet scrubbers

Wet scrubbers are the primary type of scrubbers being installed in ships today. Depending on the operational profile of the ship, alkalinity of the surrounding water and considerations about CAPEX and OPEX a shipowner decides on one of the below described wet scrubber systems. A ship which operates in high alkalinity waters at all times would most likely choose a open loop

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

scrubber, however if this ship also operates in shallow waters an open loop might require more frequent maintenance do to sediment build-up in filters.

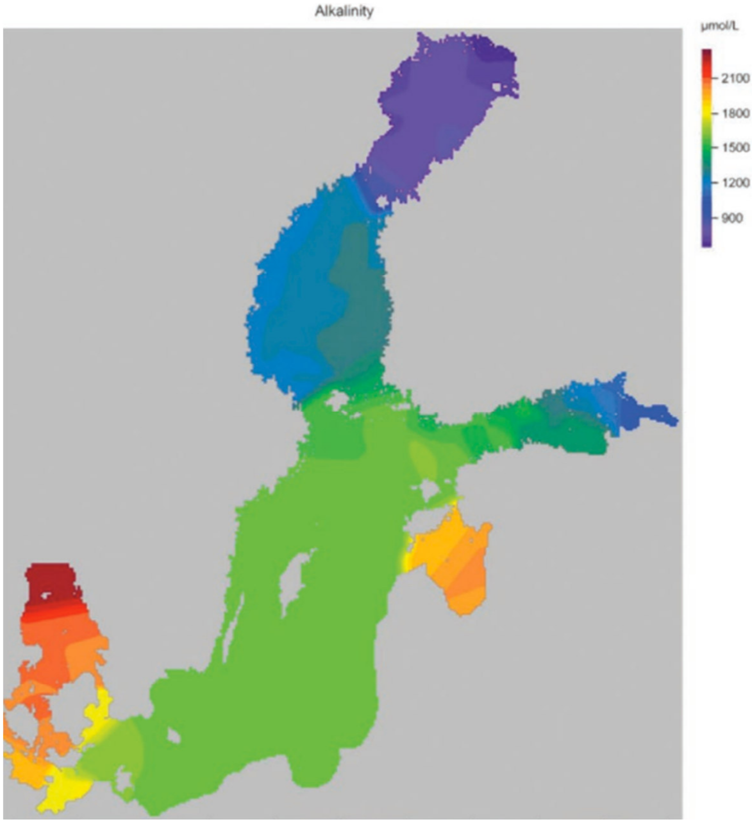

Figure 4: Example of alkalinity variations in the Baltic Sea[7]

Requirements to wash water discharge:

General for all wet scrubbing units is that not only SO_x is removed from the exhaust gas by the wash water, but also particulate matter (PM) and Polycyclic aromatic hydrocarbons (PAH)[8]. To limit the discharge of the above mentioned legislation doesn't allow ships to discharge wash-water with a turbidity greater than 25 FNU/NTU[9] and a PAHphe[10] greater than 50 $\mu g/L$. To achieve compliance with these rules, set out in MEPC 184(59), a water treatment system could be installed prior to the discharge installment. For closed-loop scrubber system a treatment systems like Alfa Laval PureSOx H2O would be appropriate. This uses high-speed centrifugal separators to lower the PM of the wash water, not much unlike fuel oil treatment plants. The open loop systems have higher flow rates, which makes hydrocyclone separation a well suited way of treating the water.

Open loop

The open loop scrubber system is the simplest of the possibilities available. This system utilizes the surrounding waters natural alkalinity, which enables it to wash out (buffer) SO_x from the exhaust gas. In practice this means that pumps draw water from a sea chest to the scrubber unit where the water "absorbs" the sulphur in the exhaust gas. Afterwards the wash water is pumped out into the ocean again. The open loop system requires a pumping capacity in the proximity of 45 m^3/MWh to induce compliance.

[7] White paper: Exhaust Gas Cleaning by Wärsila
[8] Except for system that removes PM before the exhaust gas is washed.
[9] FNU – formazin nephlometric units or NTU – nephlometric turbidity units
[10]

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

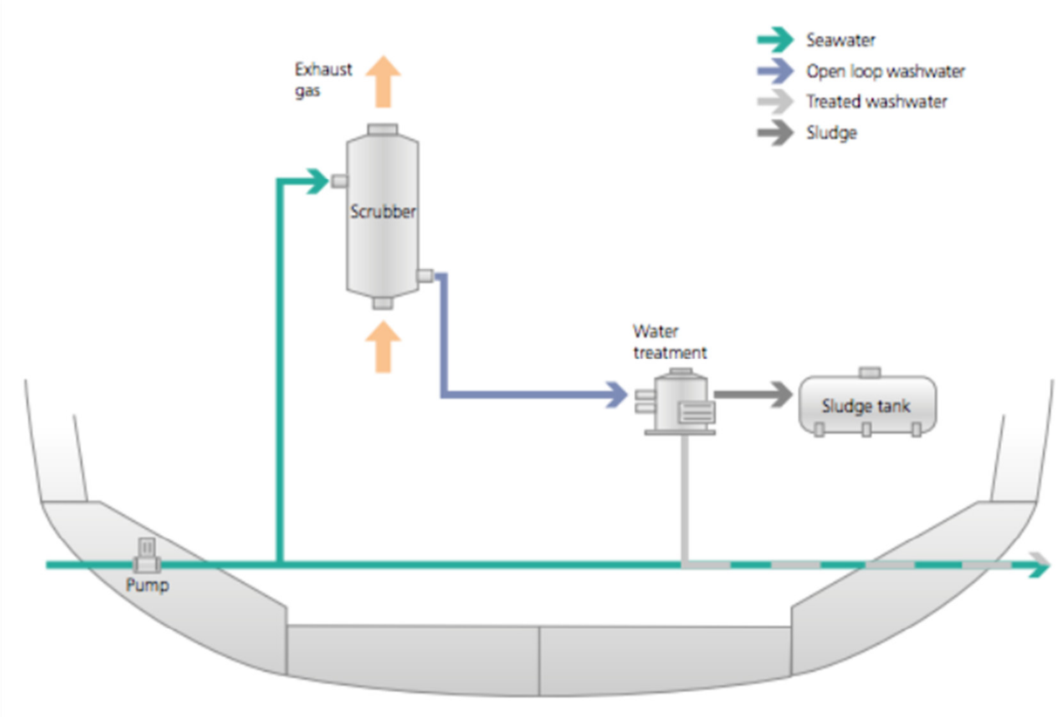

Figure 5: Process diagram of an open-loop scrubber installation[11]

Closed loop

The closed loop system is used in areas like the Great Lakes and the Gulf of Finland, where the alkalinity of the water isn't sufficient to buffer the SO_x in the exhaust gas. An alkalinity map of the Baltics and the Gulf of Finland can be seen in Figure 4. This system requires an alkaline substance to wash out the SO_x; usually sodium hydroxide is used. As the system is closed, the wash water is continuously recirculated, as seen in Figure 6. The circulation occurs within the area marked in red. This means a closed loop scrubber system will require more equipment and storage than the equivalent open loop system.

[11] Lloyd's Register Marine: Your options for emissions compliance

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

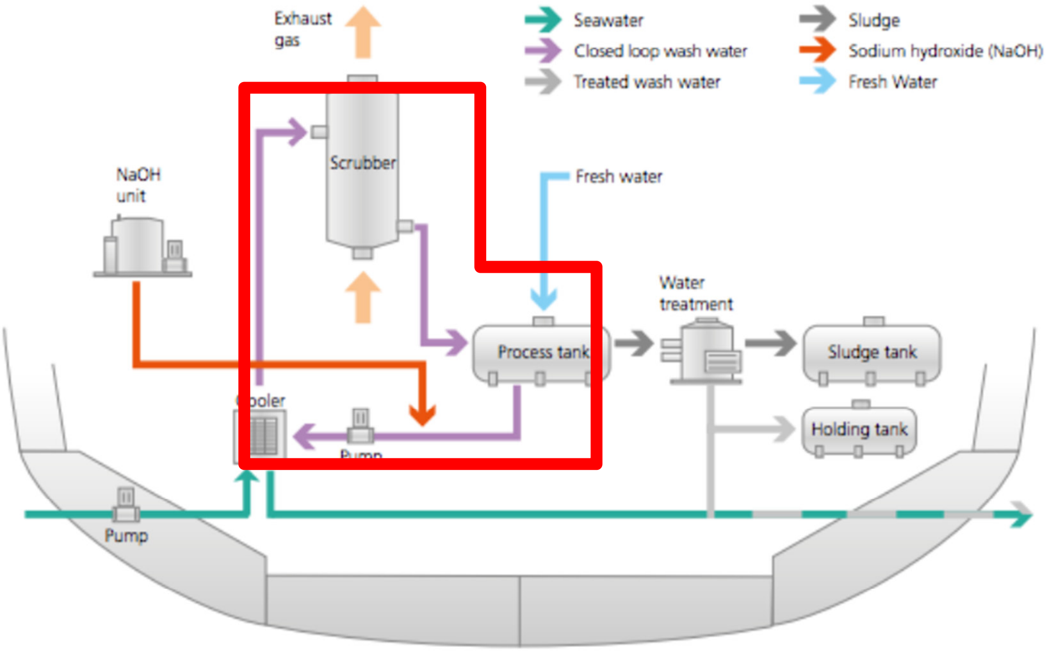

Figure 6: Process diagram of a closed-loop scrubber installation[12]

For instance a process tank, sodium hydroxide storage, cooling and several storage tanks are needed, meaning that the footprint of this kind of system will be larger than the equivalent open loop system. Depending on how long the ship is required to operate in zero-discharge condition, in ports or sensitive eco-systems, a holding tank must be dimensioned for this purpose. The discharge rate for a system working in closed loop would approximately be 0.1 m^3/MWh.

The parasitic effect of the closed loop system is smaller than that of the open loop system, being 0.5-1 % of the engine load. This is mainly because of the higher buffer capacity of the sodium hydroxide solution, which means a lower pumping capacity is required, around 20 m^3/MWh.

The consumption of Sodium hydroxide[13] solution is rated at approximately 6 L/MWh·%S, which again also needs to be stored, in amounts that are adequate for the entire voyage.

Hybrid scrubber system

Some ships have an operating profile, which makes it favorable to be able to both utilize open-loop scrubbing and closed-loop scrubbing. To accommodate these ships, hybrid scrubber systems have been developed. These system can utilizes both of the above mentioned technologies on-demand. This means it can switch to the most favorable scrubbing method in a given situation, whether this might be open or closed loop operation. However these systems require the pumping capacity of the open-loop system, capacity onboard so that the ship can perform scrubbing with zero-discharge and sodium hydroxide to be stored on-board.

Scrubber performance monitoring

The 2009 IMO Guidelines require that data recording devices are provided as part of any EGC system installation. The following details some of the basic system data that is to be monitored and recorded automatically[14]:

---

[12] Lloyd's Register Marine: Your options for emissions compliance
[13] Sodium hydroxide at 50% aqueous solution

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

- When the system is in use, time against Universal Coordinated Time (UTC), and vessel position by Global Navigational Satellite System (GNSS) position
- Washwater pressure and flow rate at the inlet connection
- Exhaust gas pressure before and pressure drop across the scrubber
- Engine or boiler load
- Exhaust temperature before and after the scrubber
- Exhaust gas SO_2 and CO_2 content
- Washwater pH, PAH and turbidity

The SO_2 and CO_2 recording device should be robust, tamper-proof and with read-only capability able to record at a rate of 0.0035 Hz. It should be capable of preparing reports and the data should be stored for a period of at least 18 months from the date of recording.

Type-approved scrubbers (scheme A) require a specific system technical manual, which must meet the requirements and be carried on board. Scheme B scrubbers do not require type approval; instead these systems are continuously monitored and it is the monitoring equipment fitted that must be approved by the administration. There has to be a scrubber record book or logging system, a record of daily checks on the monitoring system and each system also requires a technical manual in a specific format. An On-Board Monitoring Manual is also required for each scrubber and each ship must have an approved SOx Emissions Compliance Plan.

Statistics and data reduction

Sensors are typically capable of detecting and transmitting at much higher rates than required and many monitoring systems do store much larger data amounts than mandated by regulation. In some cases the detailed data are utilised onboard in various performance monitoring and management systems, so where the IMO guidelines set the minimum transfer rate a approx. every 5 minutes (0.0035 Hz), the performance monitoring onboard may be every 60 seconds or faster.

This may lead to a situation where the data submitted to land and/or stored for PSC purposes must undergo a data reduction. It does not appear that further requirements have yet been stipulated for the SO_2 and CO_2 monitoring apart from the 0.0035 Hz rate.

It is beyond the scope of this WP to establish such requirements, but it is also obviously a key requirement for a universal data submission protocol that such data are uniformly defined. Therefore a brief consideration of this issue is warranted and firstly it is clear that two issues are at hand:

1) Data are to confirm to PSC requirements

2) Data should be presented for PSC and ports/public

A number of other issues are also to be addressed in the EfficiencSea2 process and/or in the relevant international forums to be appropriately defined for use in port state control:

[14] From ABS (not dated) Exhaust Gas Scrubber Systems. Status and Guidance.

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

- is the shipowner’s onshore office or a central data hub to be used for data repository and storage?
- If data are more detailed than required by PSC, how to reduce?
- what is the criteria for exceeding, i.e. be non-compliant
- If shipowners responsibility to store data, how to access for PSC?
- How to ensure tamper-proof data if data are to be real time displayed?

Certain issues are specifically related to the optional public access to analysed data:

- Should data be reduced (5 min to hourly?) to reflect criteria for non-compliance?
- How to display emergencies, distress, downtime etc, i.e. involuntary non-compliance?

The study is currently in the process of specifying the data transmission flow, storage, analysis and display based on selected key parameter values. Certain of these parameters will require adjustment or confirmation from relevant organisations since the criteria for compliance are of paramount importance to all involved parties.

- If compliance is related to the vessel, and you have several scrubbers and sensors (main and auxiliary) installed, must all data be sent ashore and a separate algorithm calculate the combined perfomance and report compliance?
- If data are submitted at 0.0035 Hz but generated at higher rates, should algorithm onboard reduce to PSC requirements, and be based on average, median, 90% fractile or other?
- Once PSC acceptable data are generated, will PSC compliance criteria be single 0.0035 Hz exceedence, average 15 min (hourly, daily….), 90% fractile or other?
- Similar decision for public display must be taken regarding compliance/non-compliance processing.

The following represents more detailed issues regarding involuntary non-compliance that should be addressed as expressed from a shipowners viewpoint (by BIMCO):

Regulation 14.4.3 of MARPOL Annex VI establish the requirements for the Sulphur content of the fuel oil used on board. Current requirements states, that ships shall not exceed 0.10% while operating within emission control areas.

The 0.10% Sulphur limit in the fuel oil may be controlled by use of various systems measuring the content. The experiences gained onboard so far with regard to measurement of Sulphur and systems associated to the measurement process, shows, that there is a need for clarification of operational and legal responses to different types of malfunctions and transitory non-compliance in the systems. The below list is some few examples of such systems:

- Accidental break down of the system,
- Malfunction of the monitoring system only, which does not interfere with the performance of the system itself. This means that the systems may well be in compliance, but it cannot be proven to the full satisfaction the regulation,
- Non-compliance, caused by a breakdown of the system, leading to unacceptable levels of SO_2 in the exhaust gas and/or unacceptable levels of pH, turbidity and PAH in the wash-water discharge,
- A transitory non-compliance (for example due to engine load fluctuation),

“This project has received funding from the *European Union’s Horizon 2020 research and innovation programme* under grant agreement No 636329”.

- Possible non-compliance with the SOx emission limits during the running up and shut down of the system.

Clarifying example

In order to clarify the above list, BIMCO have established an example related to the use of an Exhaust Gas Cleaning (EGC) / Scrubber system.

Accidental break down of the EGCS

Like any machinery/system, accidental breakdown is possible and an EGC System is no different in this regard. A ship suffering such a breakdown should not be considered as being in immediate breach of the Regulations as the non-compliance would be unintentional. Regulation 3.1.2 of MARPOL Annex VI would still be applicable.

If possible, in particular considering navigational safety of the ship, the ship should changeover to compliant fuel. If the ship does not have compliant fuel or sufficient amount of compliant fuel on board, it needs to be clarified whether the ship should be allowed to complete the next planned leg of its voyage without deviation and then bunker compliant fuel. This would only be accepted when the ship has operated the ECGS in accordance with the system specifications.

Further, there is a need for clarification when it comes to redundancy of the auxiliary machineries and equipment, such as wash water pumps, dosing pump, control and monitoring devices etc., alternatively, ships to carry spare parts recommended by manufacturers. This is to avoid single point failure of that machinery and equipment.

Malfunction of the monitoring system only

Whether a Scheme A (parameter and emission checks) or a Scheme B (continuous monitoring) type of EGC System approval, a set of parameters should be monitored and recorded in the data recording and processing device as required by Guidelines for Exhaust Gas Cleaning Systems paragraph 7.2 These parameters are:

With discharge limits:

- SO2 / CO2 ratio (In the exhaust gas after EGC System)
- Wash water pH (at the EGC System inlet and over board discharge
- Wash water turbidity (at the EGC System inlet and over board discharge)
- Wash water PAH (at the EGC System inlet and over board discharge)

In addition the following parameters are recorded:

- Supply water pressure
- Supply water flow
- Supply water pH (EGC System inlet)
- Exhaust gas pressure (EGC unit)
- Exhaust gas pressure differential
- Exhaust gas temperature (EGC unit inlet)
- Exhaust gas temperature (EGC unit outlet)
- Combustion unit load

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

When running on a fuel oil with a constant Sulphur content, all parameters monitored according to the Guidelines (i.e. SO_2 / CO_2 ratio, wash water pH, etc.) will be in a certain interrelation, all depending on each other. If one of the parameters changes, some other(s) will necessarily also have to change.

This interrelation also works as an indicator of instrumentation malfunction; i.e. if a single sensor signal starts to drift, deviate or even falls out, the effect on the other parameters will tell whether the changes in signals are caused by sensor failure or if the EGC System itself shows a change in performance. If the other parameters are continuing at the normal levels, it is an indication that there is only an instrumentation malfunction, and there is no signal of non-compliance with regard to levels allowed in the exhaust gas emissions and the wash water discharge.

1) Instrumentation malfunction as such is not synonymous with non-compliance. If a malfunction occurs in the instrumentation for emission to air (SO_2/CO_2 ratio) or wash water discharge to sea (pH, PAHs (Polycyclic Aromatic Hydrocarbons), Turbidity), the ship could present alternative documentation for compliance. The documentation and actions could include (but is not limited to):
2) The recording of the data at the time of malfunction confirms that all other relevant data as recorded for the performance of the EGC System are showing values in line with values prior to the malfunction.
3) The fuel oil in use has a Sulphur content similar to or lower than the fuel being used at the time when the malfunction started
4) The vessel operator logs the malfunctioning of the monitoring equipment and advises its Flag Administration of the malfunction and the actions being taken to correct it.
5) The port State Administration should be notified before arrival if the monitoring equipment that has suffered a malfunction cannot be repaired /replaced.
6) The monitoring equipment that has suffered a malfunction is repaired /replaced as soon as practicable and the Flag Administration is advised once the system is returned to full operation.

It is expected, that if it can be demonstrated by daily spot checks or data recording that the EGCS has been in compliance, despite the malfunction of the equipment, such incidents should not be treated as a non-compliance issue. The ship should be required to repair the monitoring equipment as soon as possible.

<u>An EGCS suffers from transitory non-compliance</u>

If a ship has a certified EGC System installed on board which will, on occasion, exceed the SO_2/CO_2 ratio emission ceiling due to significant changes in engine load. For example a sudden, significant increase/decrease in power due to ship schedule adjustment or fluctuation of load due to weather and sea conditions. This data will be picked up by the continuous monitoring recording device suggesting the system is non-compliant.

Such fluctuations should be avoided to the greatest extent possible, but it is not technically feasible to entirely prevent transient breaches of the SO_2/CO_2 ratio under transient conditions. The system should not be considered to be non-compliant unless the issue is frequent and/or sustained.

<u>Possible non-compliance with the SOx emission limits during the start-up and shut-down</u>

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

It is reasonable to expect during the start-up and shut-down of an EGC System, that there may be a short period during which the SO2/CO2 emission ratio might exceed the applicable limit. This is a common issue with such systems and in our view it should not be considered as a breach of the requirements unless it represents a sustained period.

One way to address this issue is to require the EGCS manufacturer to establish in the operational manual the potential length of this period during which the SO2/CO2 emission ratio limit might exceed the standard ceiling before such a system is approved for compliance use on ship.

Shipowners preferred solution

Based on feedback from industry, these issues need to be addressed and clarified at IMO level, by developing separate guidance on the acceptance of sulphur data, in order to have a consistent enforcement among all port states and to provide certainty and operational clarity for the crews on board vessels.

A preferred solution may be similar to the paragraph 10.1.3.4 of the IMO Guidelines for Exhaust Gas Cleaning Systems, where it says that the continuous PAH (Polycyclic Aromatic Hydrocarbon) concentration limit may exceed the limit of 15-minute period in any 12-hour period (around 2%). This would allow for an abnormal start-up of the unit.

The IMO stakeholders, flag Administrations, Classification Societies and Industry should establish common transparent guidelines for acceptable stages of non-compliance, including the associated threshold limit value for exceeding the compliance level. The current 2% limit as set out in the IMO Guidelines for Exhaust Gas Cleaning Systems could very well form the basis.

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

Sensor types

SOx sensor technology can be split up into three groups *in-situ*, *extractive* and *cross-stack* sensors. These three groups of sensors work on different principles, measure at different ranges and have to be fitted in different locations of the exhaust stack.

These sensor technologies are offered by a range of companies in package deals or as turn-key application for continuous emission monitoring. The products presented in the below table have all been type approved by Class Societies. The type approvals are available at the Class Society's webhosted databases, however some type approvals are very brief in their description of operating principle.

Table 3: Type approved CEM sensors

Product Name	Company	Type Approved by	Reference
ShipCEMS	Norsk Analyse A/S	DNV-GL	A-13672
CT2100	Cascade technologies LTD	ABS	GL1919766
M1040/42	OPSIS AB	DNV-GL	A-13221
Emsys-iS	WR Systems	ABS	10-NN1875121-X
MARSIC200	Sick AG	DNV-GL	14097-15HH
Procal 2000	Procal	ABS	LC1983914-X1

The above type-approved systems utilize different sensor technologies, which offer different capabilities of the emission monitoring systems they are installed in. These sensor technologies are:

- Non-dispersive infrared spectroscopy (NDIR)
- Mid-Infrared absorption spectroscopy (Mid-IR)
- Differential Optical Absorption Spectroscopy (DOAS)

Non-dispersive infrared (NDIR) extractive:

This sensor technology is very well understood and is one of the technologies, which are referred to in MEPC Resolution 184(59) for measuring SO_2. The typical components in a gas analyzer based on NDIR technology are a:

- Infrared light source
- Sample chamber
- Light filter
- Infrared detector

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

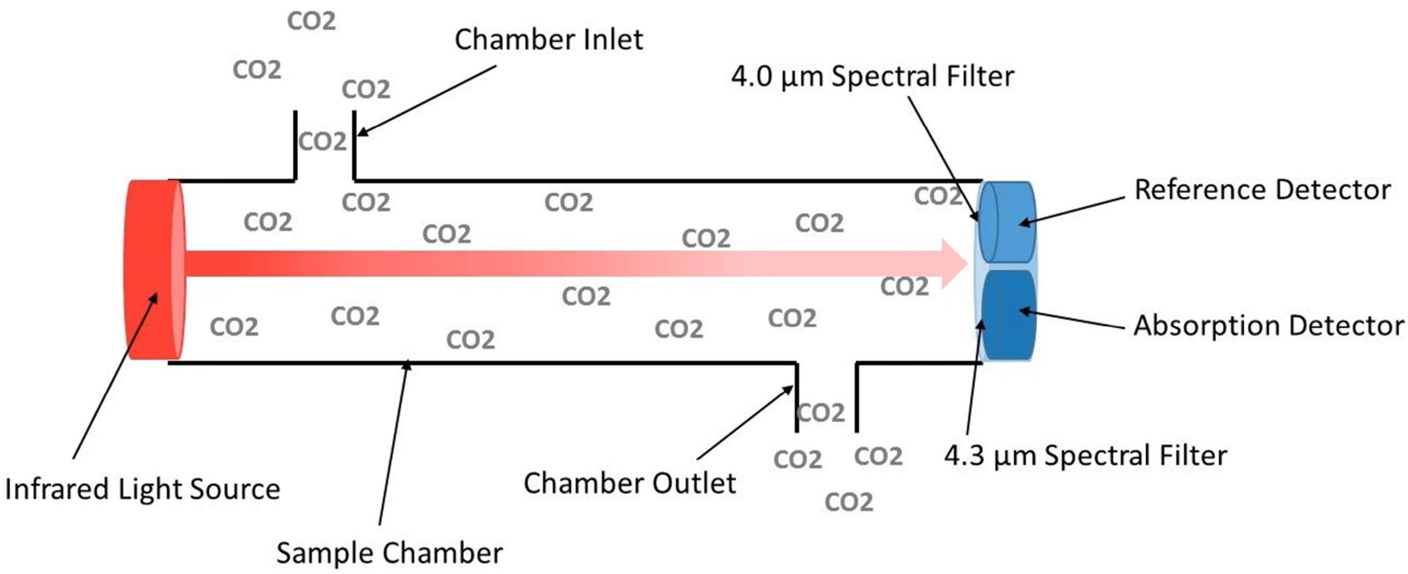

Figure 7: Principle of extractive NDIR spectrometer[15]

15

Working principle of NDIR gas analyzers:

The sample chamber is where the sample gas being analyzed is led through and exposed to the infrared light. The infrared light is a specific type called NDIR, which is an acronym for Non Dispersive Infrared. This means that the analyzing device emits a beam of infrared light, which does not disperse or scatters between the light source and the detector. Like many other gasses CO_2, SO_2 absorb infrared light at a specific wavelength. How much IR-light gets absorbed is proportional to the concentrations of CO_2 and SO_2 in the sample gas. Meaning that a reduced amount of light reaches the infrared sensor at the end of the sample chamber. To specifically measure the concentrations of e.g. SO_2 a filter that only allows light with the wavelength SO_2 absorbs is placed in front of the infrared light sensor.

To be able to determine the concentrations of SO_2 and CO_2 in the being analyzed a reference gas is needed; typically nitrogen is used. This reference gas is subjected to the same infrared light as the sample gas, at the same time. The amount of light absorbed by the nitrogen is measured on an reference infrared light detector. The absorbance measured in the sample and reference gas is compare and from this the concentration of SO_2 and CO_2 can be calculated.

As the environment in the stack is quite harsh due to the substances contained in the exhaust gas, issues may arise if improper materials are used in the CEMS. Calibration of the sensor is also necessary and proscribed in MEPC 184(59) that refers to the NO_x Technical Code (2008) for guidance. To combat this environment and make sure the measurements are accurate steps have been implemented:

- Extraction: The sample gas is extracted from the stack at high temperature and saturated with water vapor. To avoid build up of water in the sampling tubes, these are heated above the dew point temperature.
- *Water:* Specific for this technology is that the presence of water in the gas (wet gas) being analyzed may interfere with the results of the measurement of CO_2 concentrations; as they

[15] http://www.edaphic.com.au/knowledge-base/articles/gas-articles/ndir-explained/

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

are cross sensitive. Most systems solve this issue by drying the sample gas before the analysis is performed. Such a conditioning system can be seen in Figure 8 on the right. These show the product ShipCEMS produced by Norsk Analyse A/S.

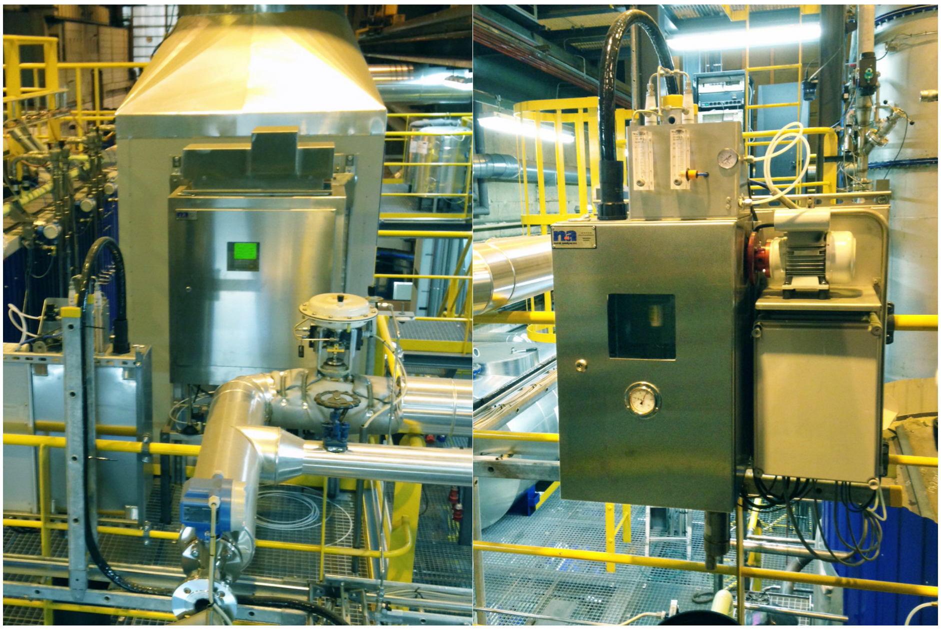

Figure 8: On the left a gas analyzer from Norsk Analyse A/S, on the right a gas conditioner also from Norsk Analyse A/S[16]

- Anti corrosive measure:
  - The sampling tubes need to be inert and temperature resilient, as they are heated, as described above, and transport the exhaust gas with a mix of corrosive substances. The material used in ShipCEMS's smapling tubes is PFA(perfluoroalkoxy)[17], a material quite similar to Teflon. It offers excellent chemical resistance and structural integrity at varying temperatures.
  - For housing cabinets and the extractive probe Stainless Steel 316 and 316L[18] are applied, as it offer high resistance to chemically challenging substances.
- Calibration and zero-span check: CEMS have calibration processes programmed into the software that controls the analysis. The calibration is performed automatically at set intervals or by manual interaction if e.g. suspicions of faulty sensor arise. The calibration process consumes calibration gas, however the volume consumed is quite small. Dansk Analyse A/S the reseller of ShipCEMS in Denmark suggested that a system like ShipCEMS would require replacement of calibration gas at 3-year intervals[19].

Table 4: Extractive CEMS

Name	Low SO_x range	Full SO_x range	Low CO_2 range	Full CO_2 range

16 www.shipcems.com
17 http://www.aetnaplastics.com/products/d/pfa
18 http://www.azom.com/article.aspx?ArticleID=2382
19 Interview of Dansk Analyse A/S

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

ShipCEMS	0-50 ppm	0-200 ppm	0-10 vol%	0-20 vol%
Marsic200	0-100 ppm	0-500 ppm	N/A	0-25 vol%

CEMS with NDIR sensor technology can be seen in the below table. Further more the range at which the sensors are able to measure is presented.

Midrange Infrared (MidIR) in-situ:

Midrange infrared technology is relatively new compared to NDIR technology. The principle behind this way of measuring concentrations of gasses is to produce infrared light at very specific wavelength. Depending on the producer this is achieved via different methods, being Enclosed Nichrome Filament or Quantum Cascade Laser (QCL).

The wavelength of the emitted light from the Nichrome Filament[20] can be controlled via the temperature that an electric current heats it to. This is used for emitting light that is absorbed by the gasses being measured. The QCL are very different from these. Typically, the materials the lasers are produced from determine the wavelength of the light the lasers emit. This has changed with the development of QCL technology. The wavelength of the light they emit is determined by the structure of the semiconducting material they are composed of[21].

The method for analyzing the concentrations of SO_2 and CO_2 is typically referred to as the dual-wavelength IR principle. This in-situ method relies on two impulses of infrared light. One impulse, which very specifically has a wavelength that is situated in the absorptions range of the gas being measured, and an IR light impulse with a wavelength very specifically outside any absorption range. These pulses of IR-light are emitted sequentially with a short time interval in between the pulses. The impulse inside the absorption range is to some degree absorbed due to the infrared properties of the gasses being measure, but also due to the particles that are present in the exhaust gas. The pulse outside the absorption range only looses intensity due to factors which are not related the concentrations of the gas which needs measuring. This therefore provides a reference that makes it possible to determine the concentration of the measured gas.

Below sensor products that utilize this technology and have been approved for marine appliances are listed:

Table 5: Mid-IR in-situ CEMS

Name	Low SO_x range	Full SO_x range	Full CO_2 range
Procal2000	0-100 ppm	0-1750 ppm	0-15 vol%
CT2100	N/A	0-1750 ppm	0-15 vol%

[20] Instrument Engineers' Handbook, Fourth Edition, Volume One: Process Measurement and Analysis by Bela G. Liptak
[21] http://www.daylightsolutions.com/technology/qcl_technology.htm

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

Emsys-iS	N/A	0-1750 ppm	0-10 vol%

The environment in which in-situ gas concentration measurements are performed cause some difficulties. Exhaust gas contains particulate matter, water vapor, aggressive components like SO_x and NOx. Furthermore as the sensor is placed in the exhaust stack, this is where calibration and zero-span gasses must be applied to make sure an in-situ product is giving accurate results. Producers have solved these issues in quite similar ways:

- *Water:* As the exhaust gas contains water vapor, water droplets (dew) could form on the measuring equipment and cause errors in the analysis. To make sure this doesn't happen the probe is fitted with heating elements, to keep the temperature above the dew point.
- *Particulate matter:* As seen in Figure 9 on the right Procal have solved this for their products whit a sintered metal filter place in the outer end of the probe. The exhaust gas can pass, whilst most of the PM cannot.
- *Anti-corrosive measures*: To ensure limited interaction between the materials in the sensor and e.g. the SO_x, calcium fluoride glass is used and the casing is made from stainless steel.
- Calibration and zero-span check: as regulations state in MEPC 184(59) a CEMS must have a self-validation system installed. In-situ applications have instrumental air and span gas installed. This is led through the sensor housing and into the probe, where the sensor sits. A scheme for automatic check of the sensor precision is typically part of the control unit's programming.

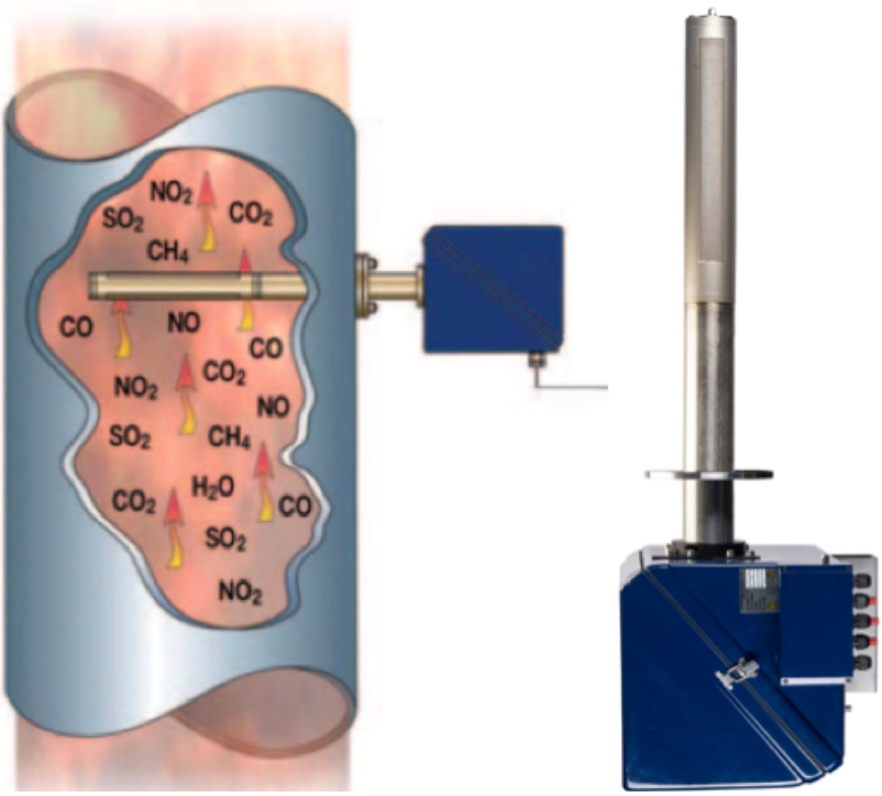

Figure 9: On the left placement of Procal2000 SOx sensor, on the right the Procal2000 sensor[22]

[22] www.procal.com/

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

Differential Optical Absorption Spectroscopy (DOAS) cross-stack analysis:

The DOAS principle is applied in numerous applications. For instance in analyzing concentration of trace gasses in the atmosphere. However, the principle can also be applied in much smaller scale like exhaust stacks.

Like the above-mentioned products this product also measures the absorption of light at different wavelengths. In this case light, produced by a high-pressure xenon lamp[23], is transmitted across the stack, resulting in some of the wavelengths being absorbed at a level that can be related to concentrations of SO_x and CO_2 in the exhaust gas. The emitted light minus the absorbed light is received in the other side of stack and transmitted via fiberoptical cable to the analyzing unit. The analyzing unit contains a spectrometer which first off all splits the light into narrow wavelengths via an optical grating. The narrow wavelengths are then analyzed to measure how much has been absorbed in the duct. This is related to known reference spectra that make it possible to calculate concentrations of various gasses in the exhaust gas. The principle is depicted in the below Figure 10.

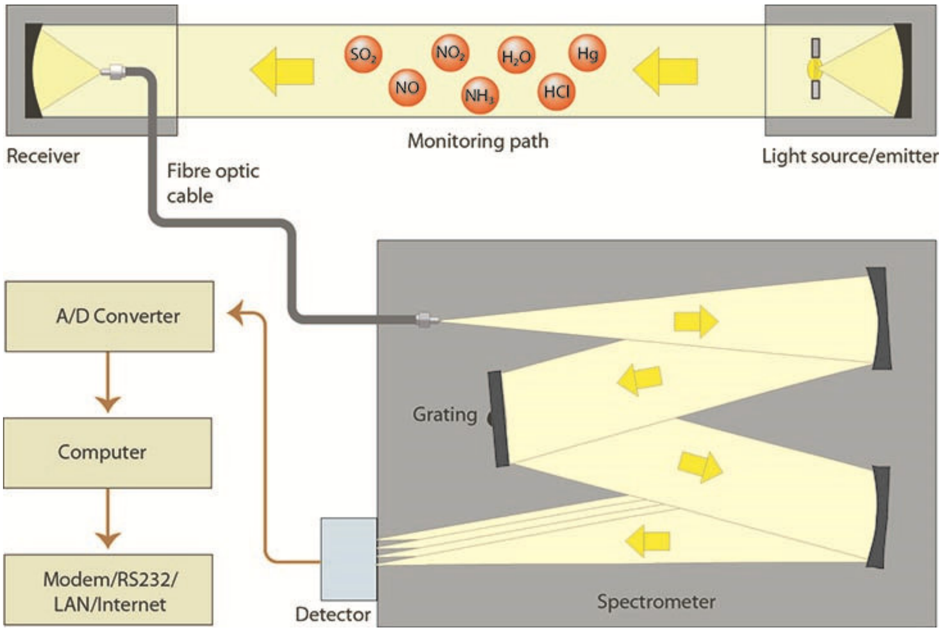

Figure 10: Diagram of the DOAS principle[24]

As of the moment the only approved cross-stack CEMS for marine appliances available is the OPSIS M800 with the following specification:

Table 6: DOAS CEMS

Name	Low SOx range	Full SOx range	Low CO2 range	Full CO2 range
OPSIS M800	0-50 ppm	0-10000 ppm	0-12 vol%	0-30 vol%

There are specific issues to consider when choosing a product like this:

- Sufficient space needs to be present on either side of the stack, as this type of product requires installations on both sides.

[23] http://opsis.se/Products/MonitoringMethods/UVDOASTechnique/tabid/1097/Default.aspx
[24] http://www.opsis.se/

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

- As fiberoptics are used for transporting the light to the analyzing unit, the analyzing cabinet can be placed anywhere on the ship as long as the cable can be drawn to it.
- One analyzing unit is typically capable of evaluating several stacks. The OPSIS M800 CEMS can handle up to 9 fiberoptic inputs. Meaning 9 stacks can be analyzed by one cabinet.

Table 7: Overview of the different CEMS addressed in this report

Product	Technology	Type of analysis	Normal range SO_2 & CO_2
Opsis M800	DOAS	In-situ, cross-stack	0-100 ppm 0-280 mg/Nm^3
Emsys-iS	MidIR, absorption spectroscopy	In-situ	0-1750 ppm 0-10 %
Procal 2000	MidIR absorption spectroscopy	In-situ	0-100 ppm 0-15 %
ShipCEMS	NDIR	Extractive	0-50 ppm 0-10 %
Marsic	NDIR	Extractive	0-100 ppm 0-25 %
CT2100	MidIR	In-situ	0-1750ppm 0-15 %

Oil quality and fuel switching:

A ship with no scrubber running on e.g. fuel oil containing 3.5% sulphur will need to switch to a fuel oil containing only 0.1% sulphur, when passing through a SECA zone. The process of switching fuel must be commenced prior to entering a SECA zone, with a margin that allows for enough time to flush the system of higher sulphur fuel, which could cause non-complaisance when entering the SECA zone. Also the fuel supply system needs time to gradually be lowered in temperature, so little fuel viscosity change occurs.

The date, time and place fuel switch over must be documented when entering and leaving an S/ECA zone, together with the volume of low sulphur fuel contained in the tanks aboard the ship[25].

Bunker Delivery Notes (BDN)

As of today the responsibility of measuring the fuel oil sulphur content is up to the deliverer of the fuel and not the recipient. The sulphur content of the delivered fuel oil is documented in the bunker delivery note. The information that must be stated in the BDN, is described in MARPOL VI appendix V:

- Name and IMO number of the receiving ship
- Port or Place if the bunker operation is performed offshore

[25] Fuel Switching Advisory Notice by ABS

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

- Name, address and telephone number of the fuel oil supplier
- Product names
- Quantity in metric tons
- Density at 15°C (kg/m^3) – tested in accordance with ISO 3675 or ISO 12185
- Sulphur content (% m/m) – tested in accordance with ISO 8754
- A declaration signed and certified by the fuel oil supplier's representative that the fuel oil supplied is in conformity with regulation 14(1) or (4)(a) and regulation 18(1) of Annex VI.

As stated MARPOL VI regulation 18(6) the BDN must be accompanied by a representative fuel oil sample. The sample must be sealed and signed by the supplier's representative and the master/officer in charge of the bunker operation. The sample must be kept under the ships control until the fuel oil is consumed or at least 12 months.

Controversy about these regulations

Rumors of shipowners who never bought Marine Gas Oil have been present since the SECA zone in Europe was implemented. One could argue that at pen and paper system cannot be considered tamper proof. This is also described in an article published by Ship & Bunker Oct. 2014[26], which state that some bunker suppliers deliver, falsified BDN. It's also described that only 0.1% of the ships in European ports are sampled for fuel compliance.

Considering the above an automated process for switching fuel and documenting the sulphur content of this fuel would diminish doubts about what grade fuel is being burned.

Fuel switch valve:

As described fuel oil change from e.g. HFO to MGO can cause a lot of damage to an engine if it is not performed correctly. HFO and MGO are typically delivered at 90°C and 35°C respectively, presented to the left in Figure 11. Solutions to automate this process exist, and can be supplied by Wärtsila, MAN Diesel & Turbo and probably also others. An example of an automated fuel change over system is LEMAG CONTROLmag supplied by MAN Diesel & Turbo in partnership with LEMAG LEHMANN & MICHELS, can be seen in Figure 11 to the right.

[26] www.shipandbunker.com/news/emea/754957-maersk-executive-explains-how-some-companies-are-cheating-eca-rules

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

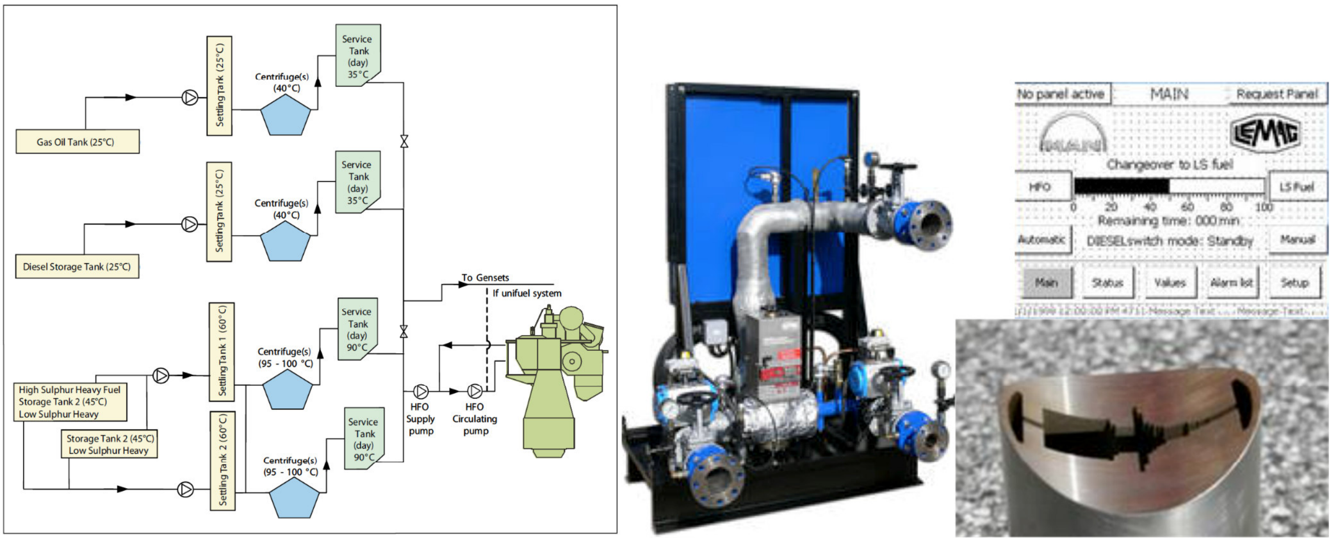

Figure 11: On the left, diagram of typical vessel fuel supply. On the right, fuel oil change over system by LEMAG[27]

Besides performing the fuel change over, the software included in the system provides tamper-proof logging of when and where the change over was performed.

Of course this does not remove the possibility of the fuel contained in the tank having higher sulphur content than allowed. This may however be solved by a continuous fuel oil sulphur contents analyzer.

Automatic sulphur analysis tool:

An example of a system that is able to continuously analyze sulphur content in fuel oil is described in a white paper published by NanoNord A/S – *Automatic sulphur analysis of fuel oils on marine vessels.* The described product is SULGUARD™. It may be worth to consider a product like this applied in future vessels, as proof of complacence with sulphur regulation. The systems is specifically built for marine use and applies X-ray fluorescence technology to analyze the sulphur content of the fuel oil, and have been shown to perform with accuracy similar to laboratories. Furthermore, the system already contains a tamper-free logging of GPS data and results from the sulphur concentration analysis, which it is programmed to perform at 15 min intervals. Besides the automatic analysis performed by the system, a manual analysis process is also possible. The ship's crew could use this while the bunkering process is performed, to evaluate whether the fuel oil being delivered has the promised sulphur content. This could proof desirable in the event of an inspection by PSC.

[27] www.lemag.de/dieselswitch.html

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

Figure 12: A fuel oil sulphur monitoring system, SULGUARD

The data collected and the transfer to shore

It is of paramount importance that an operational setup transfers data from ship to shore (and control from shore to ship) in a secure and tamper resistant way.

Scrubbers are complex machines with hundreds of sensors. Seen from a scrubber manufacturers point of view the development and optimization of the processes within the machine is ongoing. Also, condition based maintenance where parameters are measured continuously and evaluated centrally are an emerging technology and a way of servicing the customers. For both these reasons protocols shall be flexible and the amount of data transferred will vary. E.g. during a maintenance session additional sensors will be monitored to investigate the condition of the machine. These above considerations also account for the sampling frequency. In a trouble shooting session a higher sampling frequency could be valuable.

- The sensor data can be sent as an independent report with a frequency corresponding to the authorities' requirement. Another possibility that should be investigated further is to include the SOx measurements in the AIS message that the majority of vessels are obliged to transmit.

MONITORING NETWORK PART

How to present data for authorities

The required format and other conditions for supplying data to authorities will differ based on local legislation and specific IT infrastructure. General requirements would be:

- Data format: For authorities, the specific format required to meet their goals is different for each one. For most EU-countries, monitoring data could possibly be 'channeled' trough

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

THETIS-S to become part of a targeting mechanism in that system. This would require an agreement on data exchange with EMSA who hosts THETIS-S and agreement from the Member States.

- Data validity: It is necessary to establish standards within the E2 project organisation for the conditions under which CEM data can be considered trustworthy. If not, stakeholders will possibly be unable to use the data.
- Data security: Security measures would have to meet the strictest standard applied by any government or other stakeholder sharing its data on compliance. If not, those stakeholders will potentially be unable to submit and/or use data and gain the benefits of the E2 solution.
- Anonymity: The question of stakeholders' right to anonymity would have to be dealt with in the EfficienSea2 data governance work package. Formal authorities can generally share any data related to sulphur inspection and/or monitoring of ships emissions with other national and international authorities. On the other hand, inspection results and monitoring data would probably have to be anonymized before granting access to such data for stakeholders that are not authorities unless this is specifically warranted through legislation or binding agreements.
- Third parties acting on behalf of flag states: May or may not be able to benefit from the data in question. As usual access to government data would have to be granted formally by those governments.
- Other (non-data owning) authorities' access to data: A number of national authorities might be able to benefit from the information provided by CEM systems. An example would be environmental authorities in a country, which don't necessarily handle emissions control themselves. Their access to data should be handled by the data governance policy for E2.
- *[Are data submitted to one coastal/port state available for other coastal states in EU or in Paris MOU or other MOUs?]* Not necessarily. This would depend on the system being used to store the data. Inspection data in the PMoU database, THETIS, are visible to other PMoU member states. On the other hand, all EU member states can access sulphur inspection data in THETIS-S. The CEM data should ideally be available to all such organisations' members to achieve the greatest effect.

How to present data for ports or third parties?

As of today many ports have incentive schemes in order to encourage shipowners and operators to reduce the environmental impact of the ship. The incentive for being environmentally friendly is typically a discount on the port fee. A system used for determining whether a ship is eligible for a lower port fee is the ESI (Environmental Shipping Index); here emission data is shared with 3rd parties. This index has been developed by The International Association of Ports and Harbors (IAPH) environmental organ, which had an interest in promoting a reduction in CO_2, SO_x and NO_x. The way of calculating the index makes it possible to score anywhere from 0 to 100 points, where a score of 100 means that the ship produces no emissions at all and 0 is defined as being exactly compliant with reference values stated in IMO guidelines.

$$ESI_{score} = \frac{2 \cdot ESI\ NO_x + ESI\ SO_x + ESI\ CO_2 + OPS}{3.1}$$

The formula used for calculating the ESI, presented above, is a conjunction of sub-scores from how well the ship performs in terms of CO_2, SO_x, NO_x emission and bonus score if the ship has been fitted with a high voltage shore connection system (OPS – Onshore Power Supply). A

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

deeper explanation and calculation examples can be found on the Environmental Ship Index homepage[28]. At this website it is also possible to investigate which ports have implemented incentive scheme, to present how much can be saved in port fees some examples can be seen in the below

:

Table 8: Examples of ports with ESI-based incentives

Name of Port	Country	Required ESI	Incentive
Port of Tokyo	Japan	20-29.9 pts. 30-39.9 pts. ≥40.0 pts.	-30% in port charge[29] -40% in port charge -50% in port charge
Port of Los Angeles	United States	30-34 pts. 35-39 pts. ≥40 pts.	$ 750 per call[30] $ 1,000 per call $ 1,250 per call
Port of Antwerp	Belgium	>31 pts.	-10 % on tonnage dues[31]
Göteborg Hamn	Sweden	≥30 pts.	-10 % based on GT
Port of Amsterdam	Netherlands	≥20 pts. ≥31 pts.	(ESI-score/100)×"GT Reward" Above × 1.25

To obtain an ESI score a ship must report, on the ship's engine certificates, bunker fuel-information and CO_2 emission. This information entered via a secure web-based application. The information is stored in a database and the ESI score is calculated and presented to the public. When a ship wishes to use their ESI discounts, the ship informs the port of this upon it entering. From the publically available ESI score the port can determine how big of a discount the ship should be awarded with. If the port has doubts about the truthfulness of a ship's ESI score, the port can appoint an auditor to investigate the ship and report the score back to the administrators of the ESI database.

Presentation of emission data to the public:

There is a tendency among stakeholders for pushing towards more transparency in businesses, especially in regards to environmental issues[32]. Implementing a CEMS only provides the level of

---

28 Environmental Ship Index ESI website - http://esi.wpci.nl/
29 Port of Tokyo's webpage - www.tptc.co.jp/en
30 Port of LA webpage - www.portoflosangeles.org/
31 Port of Antwerp - www.portofantwerp.com/en
32 http://fairplay.ihs.com/commerce/article/4256771/dfds-regulation-chief%E2%80%99s-101-for-cop21-emission-targets

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

transparency the owner wants. If no proper way of communicating the data form the CEMS is implemented, then only the ones who inspect the ship will know that the emission levels are satisfactory. To make use of the data a public web-based system could be a way of offering the public an insight to the emission data, thus promoting transparency. How ever with a CEMS a lot of data is generated. Raw datasets will most definitely be of limited use to the general public. Most certainly this would lead to misinterpretation and a sense shipowners trying to bury something incriminating. This is why shipowners must be very considerate when choosing which data to present, how to present it and the interface of the platform that the data is presented on.

Experience from DFDS

An example of company that has dealt with these issues is DFDS. DFDS has acknowledged that environmental transparency is a competitive parameter, which the company wants to utilize. This has been deducted from being in close contact with their costumers who wished for more transparency about emissions. To accommodate this movement, DFDS have developed a system for transmitting, storing and presenting their emission data online.

Initially the system was supposed to only enable emission data to be stored for proof of compliance. Later on it was proposed that real-time presentation of emission data to the public could be a selling point to customers.

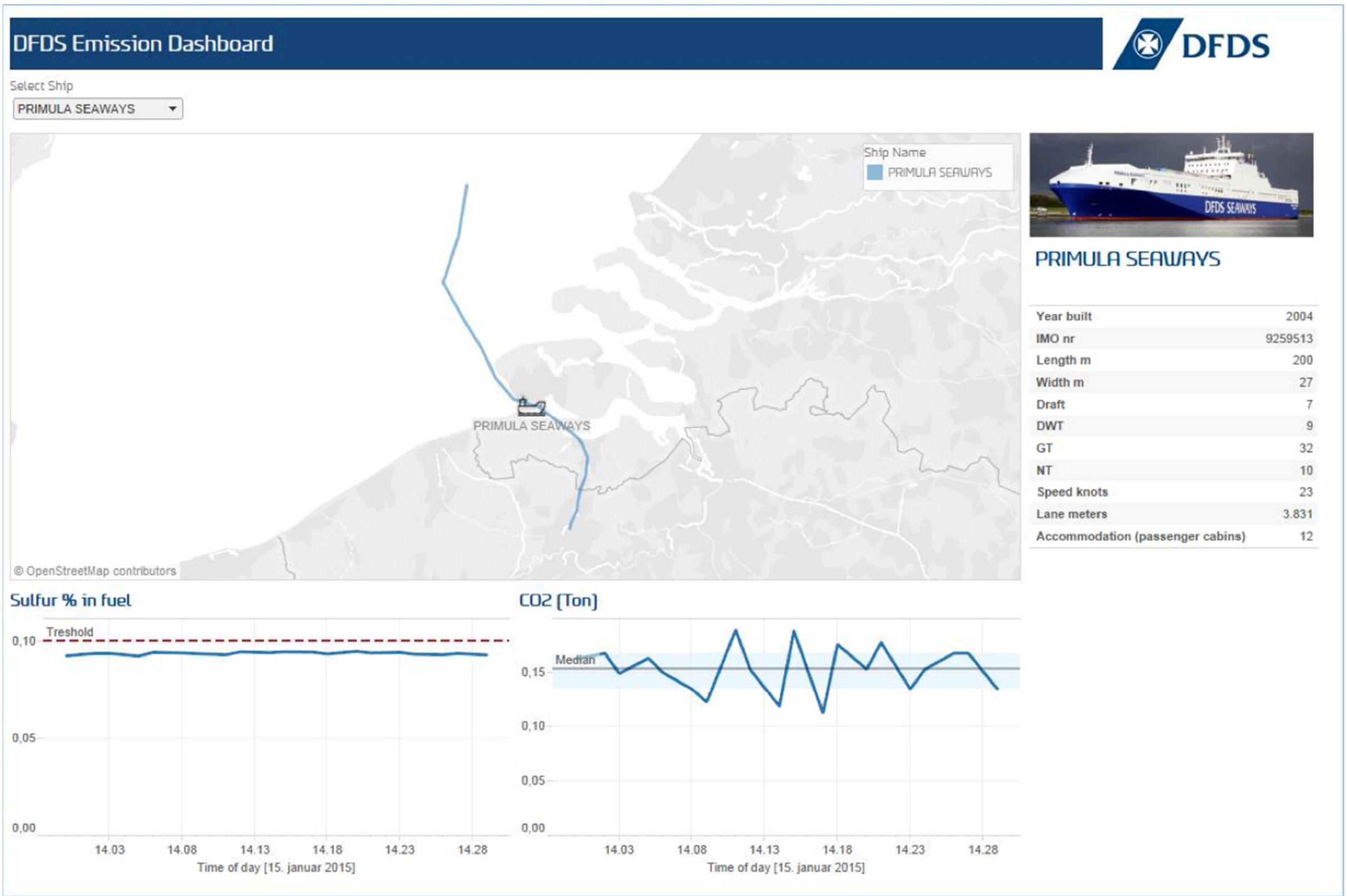

Figure 13: Example of dashboard from DFDS's CEMS with real-time analysis[33]

[33] Courtesy of DFDS A/S

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

The final product monitors emission concentrations in the stack aboard the ship and provides a live feed of this online. This is done in a graphic user interface (GUI) as depicted in Figure 13. The user interface provides the position of the ship, the current sulphur concentration equivalent and CO_2 emission. The above presented is just one of the possible ways for the public to gain access to DFDS's emission data. A mobile application is being developed too provide an in-hand possibility of monitoring a ship's sensor-recorded emissions. The transmission of emission data from the ships is planned to take place from all of DFDS's ships that have scrubbers installed. As these ships already have CEMS onboard to be compliant with EU's requirement for Scheme B approval of scrubbers, described in the guidelines of MEPC 184(59). Therefore transmission of data via VSAT systems doesn't require much extra hardware to be installed.

Cloud system

To understand how to dimension the storage capacity of the cloud for the emission data submitted by CEMS aboard ships, it is necessary determine average size and frequency of data submitted. As the rules for emission monitoring for scrubbers dictate:

- Sample frequency of 0.0035 Hz; meaning a sample every 4 min. 45 sec.
- The sample data must be stored for 18 months

Estimation of data size:

With the above in mind some general assumptions on the data transmitted and type of storage used it may be possible to give a reasonable estimate of storage capacity needed per ship participating.

Assumptions:

- MySQL or similar database management system is used
- The ship in question needs to transmit data from 1 sensors
- Linearity is assumed if more sensors are added

Table 9: the types of data and estimated sizes of them

○ Name:	○ Data Type:	○ Estimated Size per data sample:
○ **IMO no.**	○ Text	○ 11 Bytes
○ **Sampel ID**	○ Integer	○ 4 Bytes
○ **Date**	○ Date	○ 3 Bytes
○ **Time**	○ Time	○ 3 Bytes
○ **GPS**	○ Real, doulble	○ 8 Bytes pr. coordinate
○ **Speed**	○ Real, double	○ 8 Bytes
○ **Heading**	○ Integer	○ 4 Bytes
○ **Sensor**	○ Real, double	○ 8 Bytes

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 636329".

- The sizes of the different types of data are estimated from guidelines on storage size stated by MySQL[34].
- The IMO requires storage in the range of 11 bytes as it contains 9 text entities and the rule states the storage size equals: text length + 2 bytes.

Table 10: Estimate of storage required for one sensor

	IMO no.	Sample ID	Date	Time	GPS (lat,lng)	Speed	Heading	Sensor	Total
One sample [Bytes]	11	4	3	3	16	8	4	8	**57**
30 days [Mbytes]	0.10	0.04	0.03	0.03	0.15	0.07	0.04	0.07	**0.52**
18 months [Mbytes]	1.80	0.65	0.49	0.49	2.62	1.31	0.65	1.31	**9.33**

Experience from DFDS[35]:

As DFDS has already implemented a CEMS with which transmits emission data, as described in the previous section. Ideas for an IT-infrastructure can be drawn from their experience.

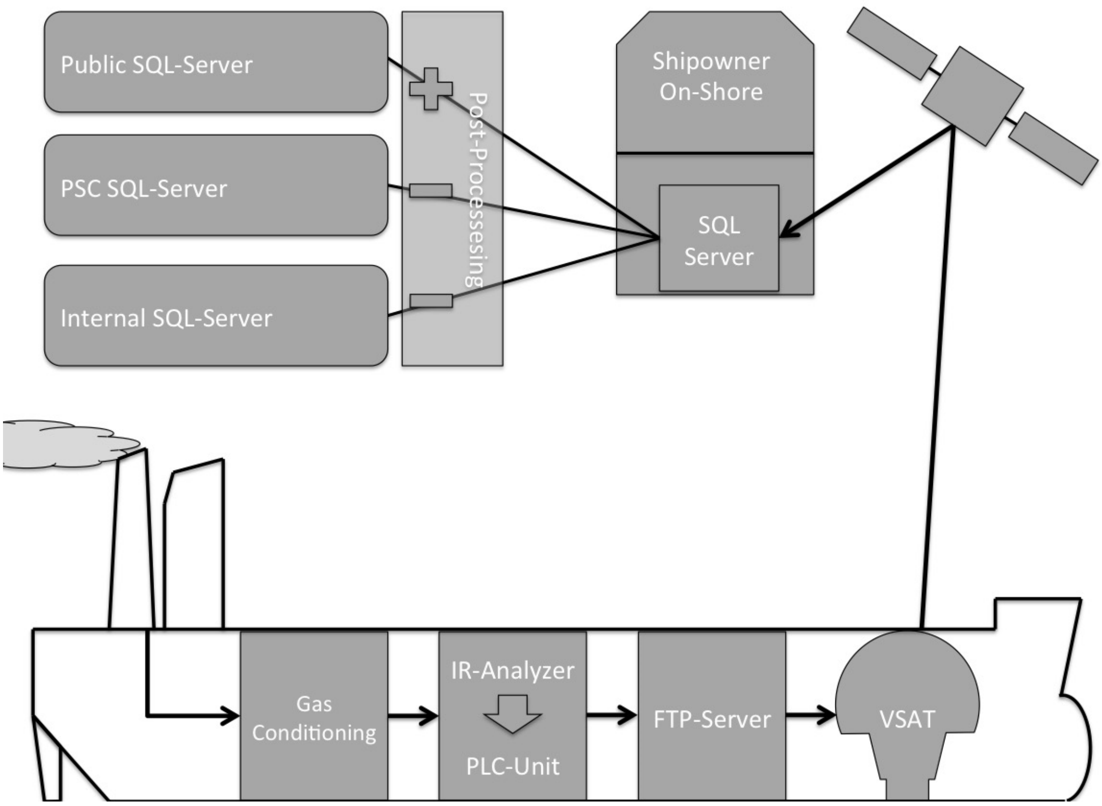

Figure 14: Flowchart of extractive CEMS with cloud solution

[34] mysql.com/doc/refman/5.0/en/storage-requirements.html
[35] Interview of Jimmi Bønnelycke IT Project Coordinator at DFDS A/S

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

The general idea is to gather data at the ship and transmit this to a recipient at shore. Some explanations of the flowchart presented in Figure 14:

- Fuel is burned in the combustion chambers of the engine. The exhaust gas from this process is extracted and conditioned so that the gas is dry. …
- The conditioned gas is analyzed via e.g. IR-light:
    - The sensor provides an analog signal which is interpreted by a PLC
    - The PLC receives GPS coordinates and joins them with the sensor data and a timestamp
- At set intervals the data is transmitted from the PLC to a FTP-server aboard the ship
    - The FTP buffers the data before transmitting via e.g. VSAT to an SQL-server ashore
- Relevant parts of the raw data is now either transmitted directly to appropriate recipients or post-process and then transmitted.
    - For PSC purposes the data must be in a non-tampered format
    - For Public presentation the format would need post processing, to reduce data. A moving average may be appropriate
    - The Internal should be saved in the original non-tampered format.

Ownership of the servers, meaning the hardware (infrastructure), needed to communicate the sensor data from the ship and store it may be best placed with either an authority or the shipowner; depending on the size of the fleet being monitored. It might not make much sense for a small shipowner to invest in all of the equipment need to achieve the above structure. Here sensor data may be sent to an authority and then be passed on to the shipowner.

As with any newly implemented integrated software solution some procedures need to be established around the continuous operation of it. Responsibility for how and when to take action on failed parts of the transmission process must be put in place. An example of such an issue would be if no data were received ashore. This would require action to be taken to insure no data is lost do to overwriting in the PLC-unit. To avoid loosing data, a member of the crew aboard the ship may have to physically interact with unit and save data to e.g. an USB-storage device. However, scenarios like this must be anticipated and an action plan must be implemented.

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".