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OGC Integrated Methane Sensor Web for Emissions Management Best Practice - Part I - Fugitive Emissions Management based on AER Directive 60

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i. Abstract

<Insert Abstract Text here>

ii. Keywords

The following are keywords to be used by search engines and document catalogues.

ogcdoc, OGC document, sensor web, methane emissions, Internet of Things, SensorThings, climate change

iii. Preface

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iv. Submitting organizations

The following organizations submitted this Document to the Open Geospatial Consortium (OGC):

SensorUp Inc., the University of Calgary, TC Energy, Fraunhofer IOSB

v. Submitters

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Hylke van der Schaaf	Fraunhofer IOSB

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- Cenovus Energy
- Canadian Natural Resources (CNRL)

- Alberta Innovates

Note: this does not imply a complete endorsement by these organizations.

Chapter 1. Scope

Methane (CH4) is one of the most potent greenhouse gases, and the comparative impact of methane is 25 times greater than CO2 over a 100-year period [IPCC 2007]. Methane is an invisible and odourless gas, and it is very labour intensive and time consuming in order to detect and repair the leaks. Current methane emission management solutions are fragmented and being developed without standards, ultimately leading to a complex network of incompatible sensing solutions that need to interrelate but are not possible. However there is no single methane sensing technology that can meet the accuracy, spatio-temporal resolution, and low-cost requirements. There is a need to interconnect the heterogeneous existing and emerging methane sensing technologies, ranging from satellites, drones, fixed-wing fly-overs, vehicle-based systems, continuous in-situ monitoring stations, to handheld Optical Gas Imaging (OGI) devices. An effective methane emissions management solution needs an integrated methane sensor web. OGC Sensor Web Enablement (SWE) provides the fundamental standard building blocks for the integrated methane sensor web.

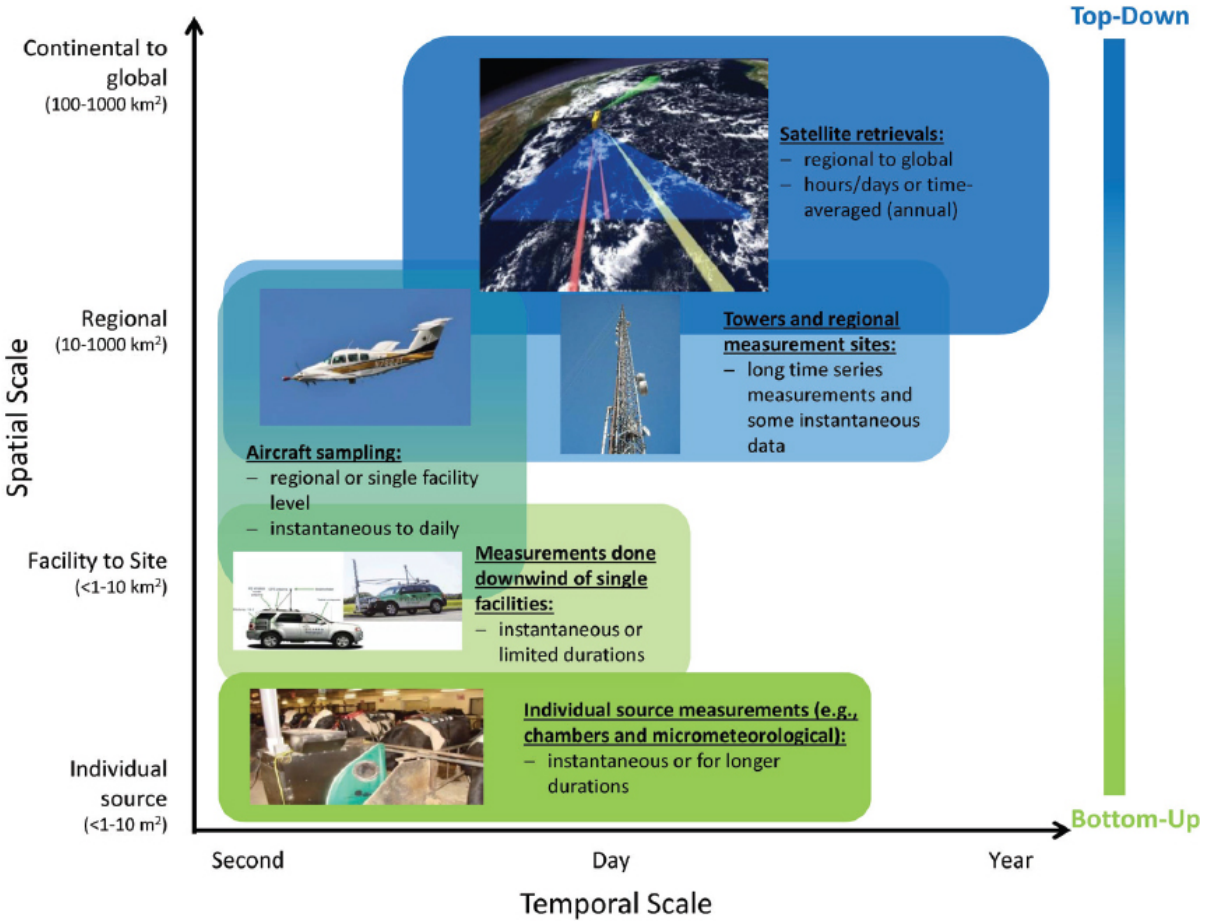

Figure 1. Examples of methane measurement platforms operating across a variety of spatial and temporal scales. [National Academies of Sciences, Engineering, and Medicine. 2018]

This OGC Best Practice (OGC BP) defines a SensorThings API for fugitive methane emissions management. Regulations play a critical role for methane emissions reduction, and how methane emissions are detected, repaired, and managed highly dependent on the local regulation. This OGC BP is designed based on the Alberta Energy Regulator's regulatory requirement for fugitive emissions management [AER Directive 60].

This OGC BP document provides a data model and API for the exchange of fugitive emissions observation data and the necessary metadata, both within and between different organizations. For

example, it can be used for leak detection and repair service providers to prepare and exchange fugitive emissions observation data with the oil and gas producers. Oil and gas producers can also use the OGC BP to exchange fugitive emissions data within the organization and with regulators.

Venting and combustion methane emissions are out of scope in this BP, and the development of BP for venting emissions and combustion emissions are on the roadmap.

1.1. Roadmap

This OGC BP is the first part of the OGC Integrated Methane Sensor Web for Emissions Management BPs. We plan to publish a series of OGC BPs for methane emissions management, ranging from the data sources (e.g., different types of sensing systems) to the data destinations (e.g., fugitive and venting emissions for regulatory reporting). The goal is to develop the building blocks for an integrated Methane Emissions Sensor Web, enabling seamless flows of observation data from SensorThings nodes with heterogeneous sensing sources (i.e., multiple disparate methane observation systems), to SensorThings nodes with analytics-ready data (i.e., a aggregated methane emissions datalake), and eventually to SensorThings nodes with compliance-ready data (i.e., data compliant to various regulatory organizations in different jurisdictions).

Figure below shows the roadmap of the different OGC BPs to be developed and their relationship.

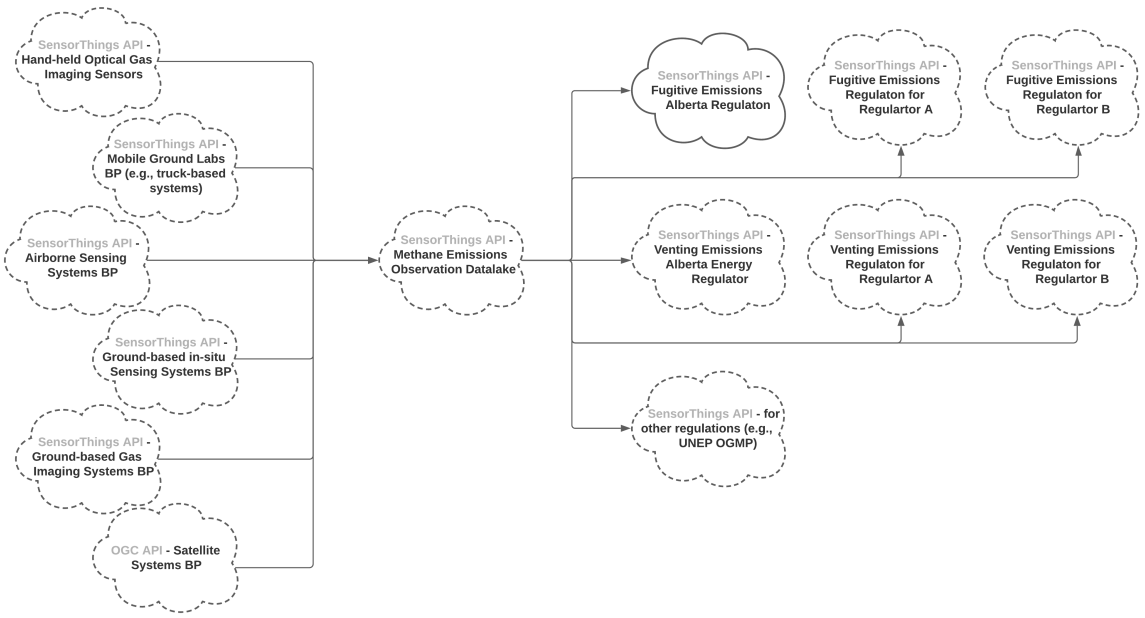

Figure 2. Methane Emissions Sensor Web Best Practice Roadmap

1.2. Design Goals

The OGC BP and its series have the following design goals:

1. Modular: the different parts a methane emissions management system can be separated and reassembled, with the benefit of flexibility, future-proof, and variety in use.
2. Simple: the design is concise, easily testable, easy to implement, and developer friendly.

3. Interoperable: whenever possible follows international open standards
4. Scalable: is able to grow in terms of number of sensors, types of sensors, and volume of data without sacrificing performances.

Chapter 2. Conformance

This OGC Best Practice (OGC BP) defines a SensorThings API for fugitive methane emissions management based on the Alberta Energy Regulator's regulatory requirement for fugitive emissions management AER Directive 60 2021-04.

Conformance with this OGC BP shall be checked using all the relevant tests specified in annex a (normative) of this document.

All requirement classes and conformance classes described in this document are owned by the document(s) identified.

The following table lists the requirement classes defined in this OGC BP.

NOTE The text in the *Requirements class id* and *Requirements* columns in the following table is the path fragment that, when appended to the URI: http://www.opengis.net/spec/imsw-fm-aer60/1.0, provides the URI that can be used to unambiguously identify the requirement and the conformance class.

Requirements class id	Requirements	Description
/req/datamodel/thing	• /req/datamodel/thing/properties • /req/datamodel/thing/relations	Thing entity
/req/datamodel/location	• /req/datamodel/location/properties • /req/datamodel/location/relations	Location entity

Requirements class id	Requirements	Description
/req/datamodel/datastream	• /req/datamodel/datastream/number-of-fugitive-emissions-properties • /req/datamodel/datastream/number-of-fugitive-emissions-relations • /req/datamodel/datastream/fugitive-emissions-volume-properties • /req/datamodel/datastream/fugitive-emissions-volume-relations • /req/datamodel/datastream/fugitive-emissions-mass-properties • /req/datamodel/datastream/fugitive-emissions-mass-relations	Datastream entity
/req/datamodel/observed-property	• /req/datamodel/observed-property/properties	ObservedProperty entity
/req/datamodel/observation	• /req/datamodel/observation/properties	Observation entity
/req/datamodel/feature-of-interest	• /req/datamodel/feature-of-interest/properties	FeatureOfInterest entity
/req/datamodel/sensor	• /req/datamodel/sensor/properties	Sensor entity

Chapter 3. References

The following normative documents contain provisions that, through reference in this text, constitute provisions of this document. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the normative document referred to applies.

Insert References here. If there are no references, state “There are no normative references”.

References are to follow the Springer LNCS style, with the exception that optional information may be appended to references: DOIs are added after the date and web resource references may include an access date at the end of the reference in parentheses. See examples from Springer and OGC below.

Smith, T.F., Waterman, M.S.: Identification of Common Molecular Subsequences. J. Mol. Biol. 147, 195–197 (1981)

May, P., Ehrlich, H.C., Steinke, T.: ZIB Structure Prediction Pipeline: Composing a Complex Biological Workflow through Web Services. In: Nagel, W.E., Walter, W.V., Lehner, W. (eds.) Euro-Par 2006. LNCS, vol. 4128, pp. 1148–1158. Springer, Heidelberg (2006)

Foster, I., Kesselman, C.: The Grid: Blueprint for a New Computing Infrastructure. Morgan Kaufmann, San Francisco (1999)

Czajkowski, K., Fitzgerald, S., Foster, I., Kesselman, C.: Grid Information Services for Distributed Resource Sharing. In: 10th IEEE International Symposium on High Performance Distributed Computing, pp. 181–184. IEEE Press, New York (2001)

NOTE

Foster, I., Kesselman, C., Nick, J., Tuecke, S.: The Physiology of the Grid: an Open Grid Services Architecture for Distributed Systems Integration. Technical report, Global Grid Forum (2002)

National Center for Biotechnology Information, http://www.ncbi.nlm.nih.gov

ISO / TC 211: ISO 19115-1:2014 Geographic information — Metadata — Part 1: Fundamentals (2014)

ISO / TC 211: ISO 19157:2013 Geographic information — Data quality (2013)

ISO / TC 211: ISO 19139:2007 Geographic information — Metadata — XML schema implementation (2007)

ISO / TC 211: ISO 19115-3: Geographic information — Metadata — Part 3: XML schemas (2016)

OGC: OGC 15-097 OGC Geospatial User Feedback Standard. Conceptual Model (2016)

OGC: OGC 12-019, OGC City Geography Markup Language (CityGML) Encoding Standard (2012)

OGC: OGC 14-005r3, OGC IndoorGML (2014)

Chapter 4. Terms and Definitions

This document uses the terms defined in Sub-clause 5.3 of [OGC 06-121r8], which is based on the ISO/IEC Directives, Part 2, Rules for the structure and drafting of International Standards. In particular, the word “shall” (not “must”) is the verb form used to indicate a requirement to be strictly followed to conform to this Best Practice.

For the purposes of this document, the following additional terms and definitions apply.

4.1. Abbreviations

AER Alberta Energy Regulator

API Application Programming Interface

ATS Alberta Township Survey

FEM-STA Fugitive Emissions Management - SensorThings API

FEMP Fugitive Emissions Management Program

GeoJSON Geographic JSON

IANA Internet Assigned Numbers Authority

ID Identity Document

JSON JavaScript Object Notation

LSD Legal Subdivisions

OGC Open Geospatial Consortium

STA SensorThings API

URI Uniform Resource Identifier

OGI Optical Gas Imaging

SWE Sensor Web Enablement

BP Best Practice

Chapter 5. Conventions

This sections provides details and examples for any conventions used in the document. Examples of conventions are symbols, abbreviations, use of XML schema, or special notes regarding how to read the document.

5.1. Identifiers

The normative provisions in this document are denoted by the URI

http://www.opengis.net/spec/imsw-fm-aer60/1.0

All requirements and conformance tests that appear in this document are denoted by partial URIs which are relative to this base.

Chapter 6. Methane Emissions

In the Fifth Assessment Report (AR5)[3], the IPCC estimates the GWP of methane to be 84 times over a period of 20 years and 28 times over a period of 100 years. Therefore, 1 tonne of emitted methane can be considered equivalent to 28 tonnes of emitted CO2 when looking at its warming impact over 100 years. The current atmospheric concentrations of CO2 and methane are about 400 ppm and 2 ppm, respectively. Thus, the concentration of methane is 200 times lower than that of CO2[4]. However, this small fraction of methane has a considerable warming potential which is equivalent to 2 × 28 = 56 ppm of CO2 over 100 years and 2 × 84 = 168 ppm of CO2 over 20 years. Therefore, even though methane is 200 times less concentrated than CO2, its warming potential is only about seven times lower than that of CO2 over a period of 100 years, and about 40 % of the CO2 warming potential over a period of 20 years. In another word, although methane's lifetime in the atmosphere is much shorter than CO2, methane is more efficient at trapping heat than CO2. Because methane is so potent, and because we have solutions to reduce its emissions, addressing methane is the fastest, most effective way to slow the rate of warming. Methane is produced by the breakdown of buried organic materials due to heat and pressure in the earth or by the decomposition of organic matter. Methane can be introduced into the atmosphere by either natural processes or human activities. Natural processes consist of the decay of plant material in wetlands, the leakage of gas from underground deposits, while human activates source of emissions embrace oil and gas industry, agriculture, and waste management. Wetlands including ponds, lakes, and rivers are responsible for about 30% of methane emissions to the atmosphere. Another 20% is produced by agriculture, due to a combination of livestock, waste management, and rice cultivation. Activities related to oil and gas production and coal extraction release an additional 30%. The remainder of methane emissions come from minor sources such as wildfire, biomass burning, permafrost, termites, dams, and the ocean. In Canada, Oil and Gas facilities are the largest industrial emitters of methane. They release 44% of total methane emissions. Upstream activities such as exploration, drilling, production, and field processing contribute close to 90% of methane emissions and account for 26% of Canada's total GHG emissions [5]. The Government of Canada has developed methane emissions regulatory frameworks to be applied in a target of achieving a 40 to 45% reduction in methane emissions from the upstream oil and gas industry by 2025. In the Oil and Gas Industry, methane emissions to the atmosphere are often organized as either vent gas or fugitive emissions. Vent gas emissions are intentional releases of methane, typically in a controlled manner, resulting from normal process conditions. On the other hand, fugitive emissions which also called 'leaks' are unintentional releases of methane from sources that should not be emitting such as broken valves or flanges.

Chapter 7. Methane Emissions Sensing Technologies

Methane emissions sensing technologies can be categorized by the methane sensor types or by the methane sensing platforms. Based on its sensing priciples, methane emssions sensors can be categorized into the following types: (1) optical sensors, (2) calorimetric sensors, (3) pyroelectric sensors, (4) semiconducting metal oxide sensors, and (5) electrochemical sensors. The following table summarize their advantages and disvantages. Aldhafeeri et al provides a comprehensive review of methane gas detection sensors, including the recent development and future perspectives [Aldhafeeri 2020].

Methane concentration measurements are mostly made with optical instruments, using either laser spectroscopy or imaging spectrometry [6]. Laser spectroscopy determines the concentration of target molecules by measuring the characteristic absorption of a mid- or near-infrared laser along a path length of meters to kilometers. Unlike laser-based instruments, imaging spectrometers measure spectral densities using pixel-based sensor elements. Imaging spectrometers generate a multi-pixel field of view measurement that captures column-integrated concentrations. Other sensor classes exist, such as ionization devices and differential absorption light detection and ranging [5]. These sensor classes are used different types of platforms. Five general platforms for detecting and screening fugitive emissions are handheld instruments, fixed sensors, a vehicle with mounted sensors, aerial vehicles, and satellites. In the following, we are going to introduce each platform.

7.1. Handheld Instruments

For many years the standard leak detection practice has been EPA method 21: Determination of Volatile Organic Carbon Leaks. EPA method 21 requires that components be surveyed using a method 21 compliant portable instrument that can measure the volatile organic carbon (VOC) concentration near each component with sufficient accuracy. Method 21 is still favored by some operators, but the use is declining as Gas-imaging cameras are more convenient. Gas-imaging cameras often referred to as optical gas-imaging (OGI) cameras, are a tool for detecting fugitive emission sources. These cameras provide images and video recordings of leaks that are invisible to the human eye. In recent years, OGI cameras have become the standard for LDAR because they generate easily communicable and intuitive results for reporting purposes, and are more efficient than Method 21, as they survey components remotely.

Figure 3. A field technican performs methane emission survey with an optical gas imaging camera [Zimmerle et al., 2020]

7.2. Fixed Sensors

Fixed sensors are deployed in high-risk areas and provide continuous readings of methane concentration. Optical methods are most common, including laser-based line-integration sensors, fixed concentration detectors, and camera installations. Continuous monitoring and the potential for automation make fixed sensors appealing, especially in dense infrastructure. As a screening tool, a distributed sensor network could identify fugitive emissions nearly instantaneously, preventing extended emissions events that remain undetected between mobile screening and conventional LDAR visits. As the only non-mobile technology class, fixed sensors might be best suited for facilities with high component density (e.g., gas plants, compressor stations, multi-well pads).

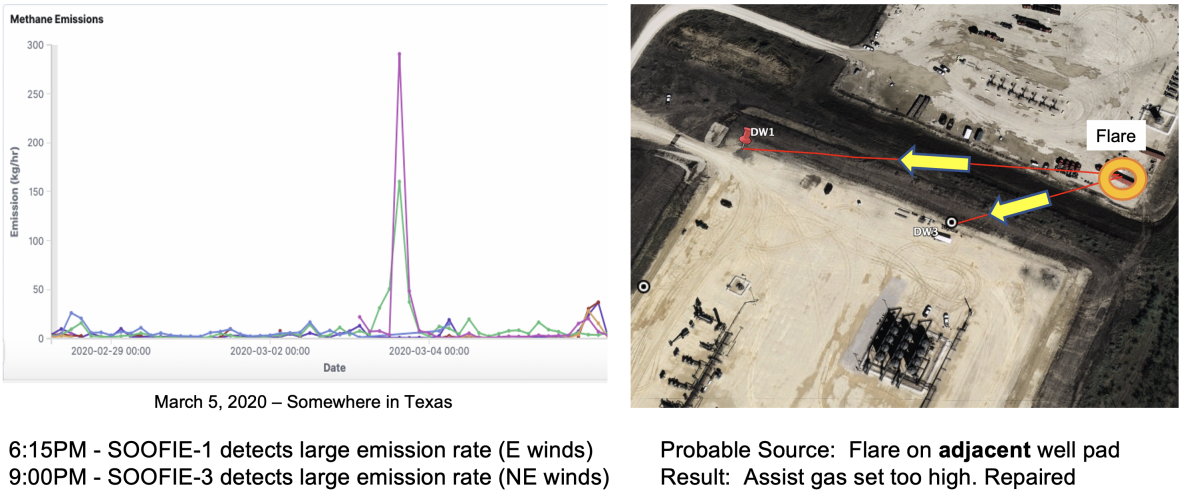

Figure 4. Example data of SOOFIE

7.3. Vehicle With Mounted Sensor

Vehicles equipped with methane sensors and anemometers to account for atmospheric conditions

can be used to detect methane emissions over a large area in a short amount of time. Data are tracked by location using a GPS, and methane concentrations and fluctuation rates can be calculated. This setup enables a survey approach called concentration mapping, which generates a map of methane concentrations along the vehicle path. Road accessibility can limit the use of these vehicles, and their sensors cannot differentiate between fugitive emissions and vent gas emissions.

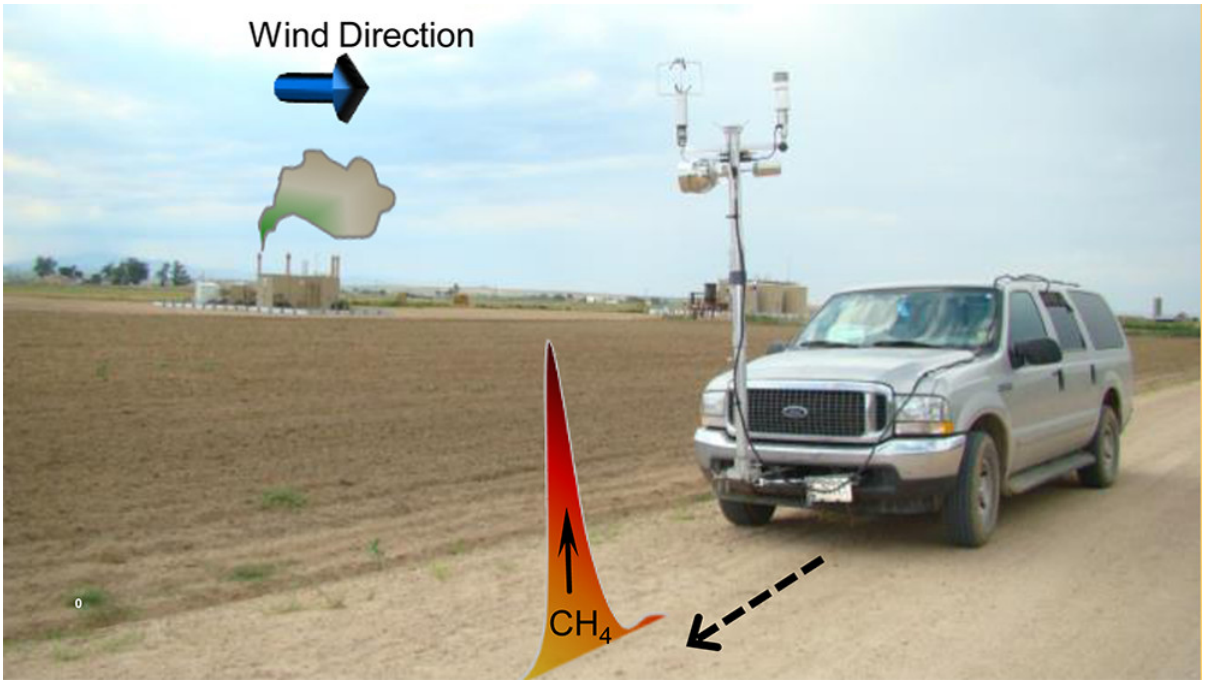

Figure 5. A methane measurement mobile ground lab system [Brantley, et al. 2014]

7.4. Aerial Vehicle

Aerial vehicles, such as piloted aircraft or unmanned aerial vehicles, mounted with a methane detection sensor can also be used to detect emissions over large areas in a short amount of time. Aerial vehicles may not be able to differentiate between fugitive emissions and vent gas emissions or be able to isolate the source of emission.

Figure 6. Example data of Bridger Photonics [Johnson, et al. 2021]

7.5. Satellites

Satellites that use optical imaging technologies, such as thermal and short-wave infrared sensors, can be used to detect emissions over large areas. Satellites provide low-resolution imagery, so they cannot be used to identify the source of the emission or low-level emissions, but because they can collect data frequently (daily or weekly), they can be used to identify abnormal or stochastic emission sources. These technologies encompass broad spatial and temporal scales of measurement. Therefore, different technologies and methods are suitable for different monitoring programs, and different data products can be expected. In Alberta, regulations released in December 2018 mandate screening for fugitive emissions using one of several methods. The next section of this discussion paper will use Directive 60 in Alberta, as an example of a methane fugitive emissions leak detection and repair program.

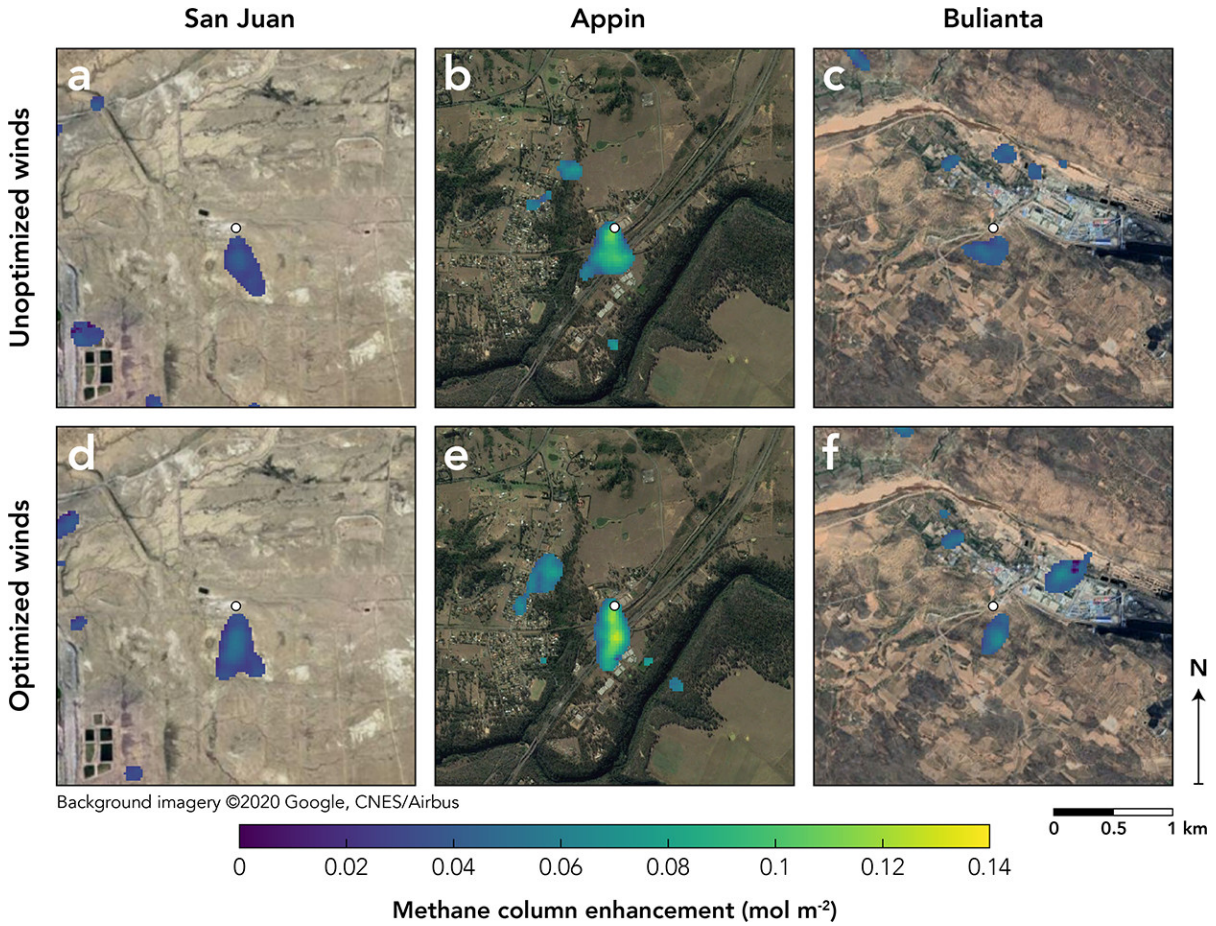

Figure 7. Example data of GHGSat [Varon et al., 2020]

7.6. Clauses not containing normative material sub-clause 2

Chapter 8. Fugitive Emissions Management SensorThings API Specification - Part I - AER Directive 60

This chapter describes the entities, their properties and values, and their relations for fugitive emissions reporting requirements based on AER Directive 60.

The SensorThings API Entities of this Best Practice are depicted in the following figure.

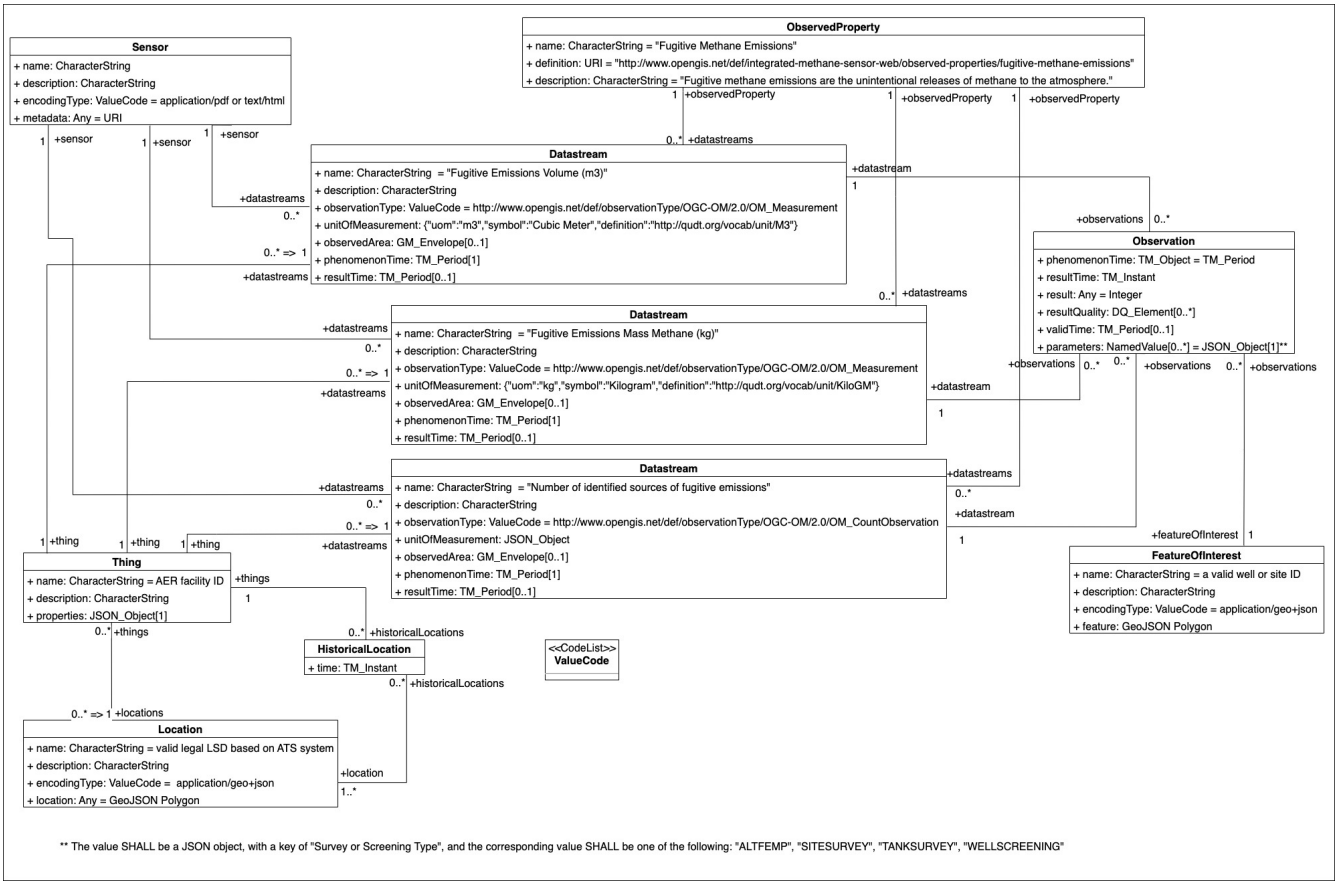

Figure 8. SensorThings API Entities for the Fugitive Emissions AER 60 Best Practice

8.1. Requirement Class: Thing

Requirements Class	
http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/thing	
Target type	JSON Object Instance
Dependency	http://www.opengis.net/spec/iot_sensing/1.1/req/datamodel/thing

Requirement 1	http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/thing/properties This requirement defines the mandatory properties of a *reporting facility* (as a Thing).
Requirement 2	http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/thing/relations This requirement defines the direct relation between the "Thing" entity and the "Location" and "Datastream" entities.

8.1.1. Requirement 1

This requirement defines the mandatory properties of a *reporting facility* (as a Thing).

Requirement 1	/req/datamodel/thing/properties The SensorThings SHALL have a “Thing” entity that has the properties with the corresponding value and multiplicity listed in Table 1.

Table 1. Properties of a reporting facility "Thing" entity

Name	Definition	Data types and values	Multiplicity and use
name	The facility ID of the *reporting facility*	Character string type, and the value shall be a valid AER facility ID	One
description	A short description of the facility	Character string type	One
properties	The well ID or site ID that is associated with the facility ID	A JSON object that has a key of "well or site id" and the corresponding value shall be a valid AER well ID or site ID	One

8.1.2. Requirement 2

This requirement defines the direct relation between the "Thing" entity and the "Location" and "Datastream" entities.

Requirement 2	/req/datamodel/thing/relations The “Thing” entity SHALL have the direct relation between the "Thing" entity and the entities listed in Table 2.

Table 2. Direct relation between a reporting facility "Thing" entity and other entity types

Entity type	Relation	Description
Location	One mandatory	A *reporting facility* "Thing" SHALL have one Location. Multiple *reporting facilities* "Thing" MAY be located at the same "Location".
Datastream	Three-to-many mandatory	A *reporting facility* "Thing" SHALL have three related Datastream entities, describing the *number-of-fugitive-emissions*, the *fugitive-emissions-volume*, and the *fugitive-emissions-mass* respectively. A *reporting facility* "Thing" MAY have additional "Datastreams".

8.2. Requirement Class: Location

Requirements Class	
http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/location	
Target type	JSON Object Instance
Dependency	http://www.opengis.net/spec/iot_sensing/1.1/req/datamodel/location
Requirement 3	http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/location/properties This requirement defines the mandatory properties of the "Location" entity of a *reporting facility*.

Requirement 4	http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/location/relations This requirement defines the direct relation between the "Location" entity and the "Thing" entity.

8.2.1. Requirement 3

This requirement defines the mandatory properties and relations of the "Location" of the *reporting facility*.

Requirement 3	/req/datamodel/location/properties The SensorThings SHALL have a "Location" entity that has the properties with the corresponding value and multiplicity listed in Table 3.

Table 3. Properties of a reporting facility Location entity

Name	**Definition**	**Data types and values**	**Multiplicity and use**
name	The *reporting facility's* legal description of the Legal Subdivision (LSD) according to the Alberta Township Survey (ATS) system	Character string type, and the value shall be a valid legal description of the LSD based on the ATS system	One
description	The description about the Location	Character string type	One
encodingType	The IANA media type for GeoJSON	Character string type, and the value shall be "application/geo+json"	One
location	The GeoJSON polygon [RFC7946] represents the area of the legal description LSD	A GeoJSON Polygon object, and the value of the GeoJSON Polygon coordinates shall be the boundary of the legal description LSD	One

8.2.2. Requirement 4

This requirement defines the direct relation between the "Location" entity and the "Thing" entity.

Requirement 4	/req/datamodel/location/relations The "Location" entity SHALL have the direct relation between the "Location" entity and the entities listed in Table 4.

Table 4. Direct relation between a reporting facility Location entity and the Thing entity

Entity type	**Relation**	**Description**
Thing	Many optional	Multiple *reporting facilities* "Thing" MAY be located at the same "Location". A Location MAY not have a *reporting facility* "Thing".

8.3. Requirement Class: Datastream

Requirements Class	
http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/datastream	
Target type	JSON Object Instance
Dependency	http://www.opengis.net/spec/iot_sensing/1.1/req/datamodel/datastream
Requirement 5	http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/datastream/number-of-fugitive-emissions-properties This requirement defines the mandatory properties of the *number-of-fugitive-emissions* "Datastream" entity of a *reporting facility* "Thing".
Requirement 6	http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/datastream/number-of-fugitive-emissions-relations This requirement defines the direct relation between the *number-of-fugitive-emissions* "Datastream" entity and the "Thing", "Sensor", "ObservedProperty", and "Observation" entity.
Requirement 7	http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/datastream/fugitive-emissions-volume-properties This requirement defines the mandatory properties of the *fugitive-emissions-volume* "Datastream" entity of a *reporting facility* "Thing".

Requirement 8	http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/datastream/fugitive-emissions-volume-relations This requirement defines the direct relation between the *fugitive-emissions-volume* "Datastream" entity and the "Thing", "Sensor", "ObservedProperty", and "Observation" entity.
Requirement 9	http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/datastream/fugitive-emissions-mass-properties This requirement defines the mandatory properties of the *fugitive-emissions-mass* "Datastream" entity of a *reporting facility* "Thing".
Requirement 10	http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/datastream/fugitive-emissions-mass-relations This requirement defines the direct relation between the *fugitive-emissions-mass* "Datastream" entity and the "Thing", "Sensor", "ObservedProperty", and "Observation" entity.

8.3.1. Requirement 5

This requirement defines the mandatory properties of the *number-of-fugitive-emissions* "Datastream" of the *reporting facility*.

Requirement 5	/req/datamodel/datastream/number-of-fugitive-emissions-properties The *reporting facility* "Thing" SHALL have a *number-of-fugitive-emissions* "Datastream" entity that has the properties with the corresponding value and multiplicity listed in Table 5.

Table 5. Properties of a number-of-fugitive-emissions Datastream entity

Name	Definition	Data types and values	Multiplicity and use
name	Number of identified sources of fugitive emissions	Character string type, and the value shall be "Number of identified sources of fugitive emissions"	One
description	A short description of the Datastream	Character string type	One

Name	Definition	Data types and values	Multiplicity and use
observationType	The observation type of the *number-of-fugitive-emissions* "Observation" is a ISO/OGC 19156 count observation	The value shall be compliant with OM_CountObservation	One
phenomenonTime	This "Datastream" SHOULD have a phenomenonTime, describes the temporal interval of the phenomenon times of all observations belonging to this Datastream	TM_Period (ISO 8601 Time Interval)	One

8.3.2. Requirement 6

This requirement defines the direct relation between the "Datastream" entity and other entity types.

Requirement 6	/req/datamodel/datastream/number-of-fugitive-emissions-relations The *number-of-fugitive-emissions* "Datastream" entities SHALL have the direct relation between the "Datastream" entity and the entities listed in Table 6.

Table 6. Direct relation between a number-of-fugitive-emissions Datastream entity and other entity types

Entity type	Relation	Description
Thing	One mandatory	Each *number-of-fugitive-emissions* "Datastream" SHALL have one and only one *reporting facility* "Thing". A *reporting facility* "Thing" SHALL have one and only one *number-of-fugitive-emissions* "Datastream".

Entity type	Relation	Description
Sensor	One mandatory	The "Observations" in a *number-of-fugitive-emissions* "Datastream" are performed by one "Sensor". One "Sensor" MAY be used by different Datastreams. **Note:** A "Sensor" in this best practice is an observation process describing the Fugitive Emissions Management Program (FEMP) that generates the observation result.
ObservedProperty	One mandatory	The "Observations" of a *number-of-fugitive-emissions* "Datastream" SHALL observe the methane fugitive emissions "ObservedProperty" as defined in Requirement 11.
Observation	Many optional	A *number-of-fugitive-emissions* "Datastream" has zero-to-many "Observations". One Observation SHALL occur in one-and-only-one "Datastream".

8.3.3. Requirement 7

This requirement defines the mandatory properties the *fugitive-emissions_volume* "Datastream" of the *reporting facility*.

Requirement 7	/req/datamodel/datastream/fugitive-emissions-volume-properties A *reporting facility* "Thing" SHALL have a *fugitive-emissions-volume* "Datastream" entity that has the properties with the corresponding value and multiplicity listed in Table 7.

Table 7. Properties of a fugitive-emissions-volume Datastream entity

Name	Definition	Data types and values	Multiplicity and use
name	The volume of fugitive emissions (`m3`)	Character string type, and the value shall be "Fugitive Emissions Volume (`m3`)"	One
description	A short description of the Datastream	Character string type	One
observationType	The observation type of the *fugitive-emissions-volume* "Observation" is a ISO/OGC 19156 measurement	The value shall be compliant with OM_Measurement	One
phenomenonTime	This "Datastream" SHOULD have a phenomenonTime, describes the temporal interval of the phenomenon times of all observations belonging to this Datastream	TM_Period (ISO 8601 Time Interval)	One
unitOfMeasurement	The unit of measurement of this Datastream is cubic meter	A SensorThings "unitOfMeasurement " JSON Object, with the following key-value pairs: `{"uom":"m3","symbol":"Cubic Meter","definition":"http://qudt.org/vocab/unit/M3"}`	One

8.3.4. Requirement 8

This requirement defines the direct relation between the *fugitive-emissions-volume* "Datastream" entity and other entity types.

Requirement 8	/req/datamodel/datastream/fugitive-emissions-volume-relations The *fugitive-emissions-volume* "Datastream" entity SHALL have the direct relation between the "Datastream" entity and the entities listed in Table 8.

Table 8. Direct relation between a fugitive-emissions-volume Datastream entity and other entity types

Entity type	**Relation**	**Description**
Thing	One mandatory	Each *fugitive-emissions-volume* "Datastream" SHALL have one and only one *reporting facility* "Thing". A *reporting facility* "Thing" SHALL have one and only one *fugitive-emissions-volume* "Datastream".
Sensor	One mandatory	The "Observations" in a *fugitive-emissions-volume* "Datastream" are performed by one "Sensor". One "Sensor" MAY be used by different Datastreams. **Note:** A "Sensor" in this best practice is an observation process describing the Fugitive Emissions Management Program (FEMP) that generates the observation result.
ObservedProperty	One mandatory	The "Observations" of a *fugitive-emissions-volume* "Datastream" SHALL observe the methane *fugitive-emissions*"ObservedProperty " as defined in Requirement 11.

Entity type	Relation	Description
Observation	Many optional	A *fugitive-emissions-volume* "Datastream" has zero-to-many "Observations". One Observation SHALL occur in one-and-only-one "Datastream".

8.3.5. Requirement 9

This requirement defines the mandatory properties of the *fugitive-emissions-mass* "Datastream" of the *reporting facility*.

Requirement 9	/req/datamodel/datastream/fugitive-emissions-mass-properties A *reporting facility* "Thing" SHALL have a *fugitive-emissions-mass* "Datastream" entity that has the properties with the corresponding value and multiplicity listed in Table 9.

Table 9. Properties of a fugitive-emissions-mass "Datastream" entity

Name	Definition	Data types and values	Multiplicity and use
name	The mass of fugitive emissions (kg)	Character string type, and the value shall be "Fugitive Emissions Mass Methane (kg)"	One
description	A short description of the Datastream	Character string type	One
observationType	The observation type of the *fugitive-emissions-mass* "Observation" is a ISO/OGC 19156 measurement	The value shall be compliant with OM_Measurement	One

Name	Definition	Data types and values	Multiplicity and use
phenomenonTime	This "Datastream" SHOULD have a phenomenonTime, describes the temporal interval of the phenomenon times of all observations belonging to this Datastream	TM_Period (ISO 8601 Time Interval)	One
unitOfMeasurement	The unit of measurement of this Datastream is kilogram	A SensorThings "unitOfMeasurement " JSON Object, with the following key-value pairs: `{"uom":"kg","symbol":"Kilogram","definition":"http://qudt.org/vocab/unit/KiloGM"}`	One

8.3.6. Requirement 10

This requirement defines the direct relation between the *fugitive-emissions-mass* "Datastream" entity and other entity types.

Requirement 10	/req/datamodel/datastream/fugitive-emissions-mass-relations The *fugitive-emissions-mass* "Datastream" entity SHALL have the direct relation between the "Datastream" entity and the entities listed in Table 10.

Table 10. Direct relation between a fugitive-emissions-mass "Datastream" entity and other entity types

Entity type	Relation	Description
Thing	One mandatory	Each *fugitive-emissions-mass* "Datastream" SHALL have one and only one *reporting facility* "Thing". A *reporting facility* "Thing" SHALL have one and only one *fugitive-emissions-mass* "Datastream".

Entity type	Relation	Description
Sensor	One mandatory	The "Observations" in a *fugitive-emissions-mass* "Datastream" are performed by one "Sensor". One "Sensor" MAY be used by different Datastreams. **Note:** A "Sensor" in this best practice is an observation process describing the Fugitive Emissions Management Program (FEMP) that generates the observation result.
ObservedProperty	One mandatory	The "Observations" of a *fugitive-emissions-mass* "Datastream" SHALL observe the methane *fugitive-emissions* "ObservedProperty" as defined in Requirement 11.
Observation	Many optional	A *fugitive-emissions-mass* "Datastream" has zero-to-many "Observations". One Observation SHALL occur in one-and-only-one "Datastream".

8.4. Requirement Class: ObservedProperty

Requirements Class	
http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/observed-property	
Target type	JSON Object Instance
Dependency	http://www.opengis.net/spec/iot_sensing/1.1/req/datamodel/observed-property
Requirement 11	http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/observed-property/properties

8.4.1. Requirement 11

This requirement defines the mandatory properties of the fugitive emissions "ObservedProperty".

Requirement 11	/req/datamodel/observed-property/properties The three mandatory "Datastream" entities (*i.e.*, *number-of-fugitive-emissions*, *fugitive-emissions-volume*, and *fugitive-emissions-mass*) SHALL have a related *fugitive-emissions* "ObservedProperty" entity that has properties with the corresponding value and multiplicity listed in Table 11.

Table 11. Properties of a fugitive emissions "ObservedProperty" entity

Name	**Definition**	**Data types and values**	**Multiplicity and use**
name	The term used in AER Directive 60 to describe fugitive emissions	Character string type, and the value shall be "Fugitive Methane Emissions"	One
description	A description about the ObservedProperty	The value shall be "Fugitive methane emissions are the unintentional releases of methane to the atmosphere."	One
definition	This property is the URI of the ObservedProperty definition. Dereferencing this URI SHOULD result in a representation of the definition of the ObservedProperty.	The value shall be "http://www.opengis.net/def/integrated-methane-sensor-web/observed-properties/fugitive-methane-emissions"	One

8.5. Requirement Class: Observation

Requirements Class	
http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/observation	
Target type	JSON Object Instance
Dependency	http://www.opengis.net/spec/iot_sensing/1.1/req/datamodel/observation
Requirement 12	http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/observation/properties

8.5.1. Requirement 12

This requirement defines the mandatory properties of the fugitive emissions "Observations".

Requirement 12	/req/datamodel/observation/properties The "Observations" of the three mandatory "Datastream" entity SHALL have properties with the corresponding value and multiplicity listed in Table 12.

Table 12. Properties of a number-of-fugitive-emissions Observation entity

Name	**Definition**	**data types and values**	**Multiplicity and use**
phenomenonTime	The time period of when the "Observation" happens.	TM_Period (ISO 8601 Time Interval)	One
result	The *number-of-fugitive-emissions*	Integer	One
parameters	Key-value pairs describing an event-specifc parameter.	The value SHALL be a JSON object, with a key of "Survey or Screening Type", and the corresponding value SHALL be one of the following: "ALTFEMP", "SITESURVEY", "TANKSURVEY", "WELLSCREENING"	One

8.6. Requirement Class: FeatureOfInterest

Requirements Class	
http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/feature-of-interest	
Target type	JSON Object Instance
Dependency	http://www.opengis.net/spec/iot_sensing/1.1/req/datamodel/feature-of-interest
Requirement 13	http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/feature-of-interest/properties
Requirement 14	http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/feature-of-interest/relations

8.6.1. Requirement 13

This requirement defines the mandatory properties of the "FeatureOfInterest" entity related to the "Observations" of the three mandatory "Datastreams." In the context of fugitive emissions, the "FeatureOfInterest" of fugitive emissions "Observation" is where the leaks occur. In AER Directive 60, the "FeatureOfInterest" is modelled as a site. In some cases, a *reporting facility* called "Thing" can have more than one site, such as wells, controlled tanks, process units, or wellhead [AER Manual015 Figure 1] and [AER Manual015 Figure 3]. The following figure describes the relationship between a *reporting facility* "Thing" and "FeaturesOfInterest."

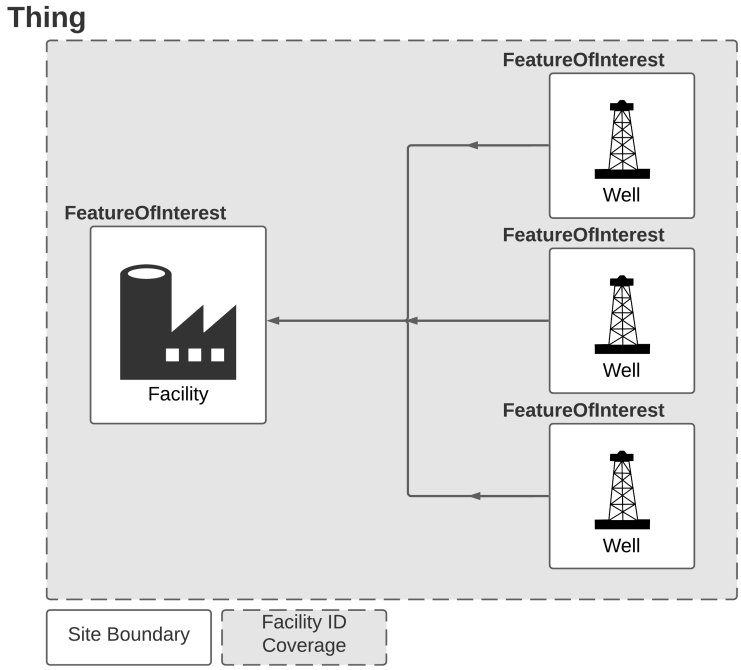

Figure 9. Thing and FeatureOfInterest Relationship

An Observation results in a value that is being assigned to a phenomenon. The phenomenon is a property of a feature, the latter being the FeatureOfInterest of the Observation [OGC and ISO 19156:2011]. In the context of this best practice, the FeatureOfInterest is the *site* and can be identified by the site's location. For example, the FeatureOfInterest of a wifi-connected thermostat can be the thermostat's location (*i.e.*, the living room where the thermostat is located). In the case of remote sensing, FeatureOfInterest can be the geographical area or volume that is being sensed.

Requirement 13	/req/datamodel/feature-of-interest/properties The "FeatureOfInterest" entity of the "Observations" of the three mandatory "Datastreams" SHALL have the properties with the corresponding value and multiplicity listed in Table 13.

Table 13. Properties of a FeatureOfInterest entity

Name	Definition	Data types and values	Multiplicity and use
name	The well ID or site ID that is associated with the facility ID	CharacterString, the value SHALL be a valid well or site ID	One
description	Site description	CharacterString	One
encodingType	The IANA media type for GeoJSON	Character string type, and the value shall be "application/geo+json"	One
feature	The GeoJSON polygon [RFC7946] represents the site boundary	A GeoJSON Polygon object, and the value of the GeoJSON Polygon coordinates shall be the boundary of the site or well	One

8.7. Requirement Class: Sensor

Requirements Class	
http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/sensor	
Target type	JSON Object Instance
Dependency	http://www.opengis.net/spec/iot_sensing/1.1/req/datamodel/sensor
Requirement 15	http://www.opengis.net/spec/imsw-fm-aer60/1.0/req/datamodel/sensor/properties

8.7.1. Requirement 14

This requirement defines the mandatory properties of the "Sensor" entity.

NOTE The "Sensor" entity in this best practice is not an instrument, but rather it SHALL be an observation process ISO/OGC 19156:2001 OM_Process described the Fugitive Emissions Management Program (FEMP) that generates the observation result.

Requirement 14	/req/datamodel/sensor/properties A "Sensor" in this best practice is an observation process describing the Fugitive Emissions Management Program (FEMP) that generates the observation result. The "Sensor" SHALL have the properties with the corresponding value and multiplicity listed in Table 14.

Table 14. Properties of a Sensor entity

Name	**Definition**	**Data types and values**	**Multiplicity and use**
name	Provides a label for the "Sensor" entity, and it should be the descriptive name of the FEMP that generates the fugitive emissions observation results	CharacterString	One
description	The description of the FEMP	CharacterString	One
encodingType	The encoding type of the metadata property.	Character string type, and the value shall be "application/pdf" or "text/html"	One
metadata	This value depends on the value of the encodingType. The value SHALL be a resolvable URI, linking to either a PDF document or an HTML page, describing the FEMP used to generate the fugitive emissions observation results.	The value SHALL be a resolvable URI.	One

Annex A: Conformance Class Abstract Test Suite (Normative)

This section contains the conformance classes for the OGC Integrated Methane Sensor Web for Emissions Management Best Practice - Part I - Fugitive Emissions Management based on AER Directive 60. The Fugitive Emissions Management (FEM) SensorThings API (STA) service needs to pass all the conformance tests defined in this section as well as the OGC SensorThings API Part 1: Sensing Version 1.1 Conformance Class Abstract Test Suit.

A.1. Conformance Class: FEM-STA Thing

Conformance Class	**/conf/datamodel/thing**	
Requirements	/req/datamodel/thing/properties /req/datamodel/thing/relations	
Dependency	http://www.opengis.net/spec/iot_sensing/1.1/conf/datamodel/thing	
Test 1	/conf/datamodel/thing/properties	
	Requirement	/req/datamodel/thing/properties
	Test purpose	Verify that the Thing entity has mandatory properties as defined in FEM-STA Specification.
	Test method	Inspect the entire JSON object of the Thing entity set to identify if each entity has the mandatory properties defined in the corresponding requirement. Pass if no errors are reported. Fail otherwise.
	Test type	Conformance

Test 2	/conf/datamodel/thing/relations	
	Requirement	/req/datamodel/thing/relations
	Test purpose	Verify that the Thing entity has mandatory relations as defined in FEM-STA Specification.
	Test method	Inspect the entire JSON object of each Thing entity set to identify if each entity has the mandatory relations defined in the corresponding requirement. Pass if no errors are reported. Fail otherwise.
	Test type	Conformance

A.2. Conformance Class: FEM-STA Location

Conformance Class	**/conf/datamodel/location**	
Requirements	/req/datamodel/location/properties /req/datamodel/location/relations	
Dependency	http://www.opengis.net/spec/iot_sensing/1.1/conf/datamodel/location	
Test 3	/conf/datamodel/location/properties	
	Requirement	/req/datamodel/location/properties
	Test purpose	Verify that the Location entity has the mandatory properties as defined in FEM-STA Specification.
	Test method	Inspect the full JSON object of the Location entity set to identify if each entity has the mandatory properties defined in the corresponding requirement. Pass if no errors are reported. Fail otherwise.
	Test type	Conformance

Test 4	/conf/datamodel/location/relations	
	Requirement	/req/datamodel/location/relations
	Test purpose	Verify that the Location entity has the mandatory relations as defined in FEM-STA Specification.
	Test method	Inspect the full JSON object of each Location entity set to identify if each entity has the mandatory relations defined in the corresponding requirement. Pass if no errors are reported. Fail otherwise.
	Test type	Conformance

A.3. Conformance Class: FEM-STA Datastream

Conformance Class	**/conf/datamodel/datastream**
Requirements	/req/datamodel/datastream/number-of-fugitive-emissions-properties /req/datamodel/datastream/number-of-fugitive-emissions-relations /req/datamodel/datastream/fugitive-emissions-volume-properties /req/datamodel/datastream/fugitive-emissions-volume-relations /req/datamodel/datastream/fugitive-emissions-mass-properties /req/datamodel/datastream/fugitive-emissions-mass-relations
Dependency	http://www.opengis.net/spec/iot_sensing/1.1/conf/datamodel/datastream

Test 5	/conf/datamodel/datastream/number-of-fugitive-emissions-properties	
	Requirement	/req/datamodel/datastream/number-of-fugitive-emissions-properties
	Test purpose	Verify that each *number-of-fugitive-emissions* Datastream entity has the mandatory properties as defined in FEM-STA Specification.
	Test method	Inspect the full JSON object of the *number-of-fugitive-emissions* Datastream entity set to identify if each entity has the mandatory properties defined in the corresponding requirement. Pass if no errors are reported. Fail otherwise.
	Test type	Conformance
Test 6	/conf/datamodel/datastream/number-of-fugitive-emissions-relations	
	Requirement	/req/datamodel/datastream/number-of-fugitive-emissions-relations
	Test purpose	Verify that each *number-of-fugitive-emissions* Datastream entity has the mandatory relations as defined in FEM-STA Specification.
	Test method	Inspect the full JSON object of each *number-of-fugitive-emissions* Datastream entity set to identify if each entity has the mandatory relations defined in the corresponding requirement. Pass if no errors are reported. Fail otherwise.
	Test type	Conformance

Test 7	/conf/datamodel/datastream/fugitive-emissions-volume-properties	
	Requirement	/req/datamodel/datastream/fugitive-emissions-volume-properties
	Test purpose	Verify that each *fugitive-emissions-volume* Datastream entity has the mandatory properties as defined in FEM-STA Specification.
	Test method	Inspect the full JSON object of the *fugitive-emissions-volume* Datastream entity set to identify if each entity has the mandatory properties defined in the corresponding requirement. Pass if no errors are reported. Fail otherwise.
	Test type	Conformance
Test 8	/conf/datamodel/datastream/fugitive-emissions-volume-relations	
	Requirement	/req/datamodel/datastream/fugitive-emissions-volume-relations
	Test purpose	Verify that each *fugitive-emissions-volume* Datastream entity has the mandatory relations as defined in FEM-STA Specification.
	Test method	Inspect the full JSON object of each *fugitive-emissions-volume* Datastream entity set to identify if each entity has the mandatory relations defined in the corresponding requirement. Pass if no errors are reported. Fail otherwise.
	Test type	Conformance

Test 9	/conf/datamodel/datastream/fugitive-emissions-mass-properties	
	Requirement	/req/datamodel/datastream/fugitive-emissions-mass-properties
	Test purpose	Verify that each *fugitive-emissions-mass* Datastream entity has the mandatory properties as defined in FEM-STA Specification.
	Test method	Inspect the full JSON object of the *fugitive-emissions-mass* Datastream entity set to identify if each entity has the mandatory properties defined in the corresponding requirement. Pass if no errors are reported. Fail otherwise.
	Test type	Conformance
Test 10	/conf/datamodel/datastream/fugitive-emissions-mass-relations	
	Requirement	/req/datamodel/datastream/fugitive-emissions-mass-relations
	Test purpose	Verify that each *fugitive-emissions-mass* Datastream entity has the mandatory relations as defined in FEM-STA Specification.
	Test method	Inspect the full JSON object of each *fugitive-emissions-mass* Datastream entity set to identify if each entity has the mandatory relations defined in the corresponding requirement. Pass if no errors are reported. Fail otherwise.
	Test type	Conformance

A.4. Conformance Class: FEM-STA ObservedProperty

Conformance Class	**/conf/datamodel/observed-property**
Requirements	/req/datamodel/observed-property/properties
Dependency	http://www.opengis.net/spec/iot_sensing/1.1/conf/datamodel/observed-property

Test 11	/conf/datamodel/observed-property/properties	
	Requirement	/req/datamodel/observed-property/properties
	Test purpose	Verify that the ObservedProperty entity has the mandatory properties as defined in FEM-STA Specification.
	Test method	Inspect the full JSON object of the ObservedProperty entity set to identify if each entity has the mandatory properties defined in the corresponding requirement. Pass if no errors are reported. Fail otherwise.
	Test type	Conformance

A.5. Conformance Class: FEM-STA Observation

Conformance Class	**/conf/datamodel/observation**	
Requirements	/req/datamodel/observation/properties	
Dependency	http://www.opengis.net/spec/iot_sensing/1.1/conf/datamodel/observation	
Test 12	/conf/datamodel/observation/properties	
	Requirement	/req/datamodel/observation/properties
	Test purpose	Verify that the Observation entity has the mandatory properties as defined in FEM-STA Specification.
	Test method	Inspect the full JSON object of the Observation entity set to identify if each entity has the mandatory properties defined in the corresponding requirement. Pass if no errors are reported. Fail otherwise.
	Test type	Conformance

A.6. Conformance Class: FEM-STA FeatureOfInterest

Conformance Class	**/conf/datamodel/feature-of-interest**

Requirements	/req/datamodel/feature-of-interest/properties /req/datamodel/feature-of-interest/relations	
Dependency	http://www.opengis.net/spec/iot_sensing/1.1/conf/datamodel/feature-of-interest	
Test 13	/conf/datamodel/feature-of-interest/properties	
	Requirement	/req/datamodel/feature-of-interest/properties
	Test purpose	Verify that the FeatureOfInterest entity has the mandatory properties as defined in FEM-STA Specification.
	Test method	Inspect the full JSON object of the FeatureOfInterest entity set to identify if each entity has the mandatory properties defined in the corresponding requirement. Pass if no errors are reported. Fail otherwise.
	Test type	Conformance
Test 14	/conf/datamodel/feature-of-interest/relations	
	Requirement	/req/datamodel/feature-of-interest/relations
	Test purpose	Verify that the FeatureOfInterest entity has the mandatory relations as defined in FEM-STA Specification.
	Test method	Inspect the full JSON object of each FeatureOfInterest entity set to identify if each entity has the mandatory relations defined in the corresponding requirement. Pass if no errors are reported. Fail otherwise.
	Test type	Conformance

A.7. Conformance Class: FEM-STA Sensor

Conformance Class	**/conf/datamodel/sensor**
Requirements	/req/datamodel/sensor/properties

Dependency	http://www.opengis.net/spec/iot_sensing/1.1/conf/datamodel/sensor	
Test 15	/conf/datamodel/sensor/properties	
	Requirement	/req/datamodel/sensor/properties
	Test purpose	Verify that the Sensor entity has the mandatory properties as defined in FEM-STA Specification.
	Test method	Inspect the full JSON object of the Sensor entity set to identify if each entity has the mandatory properties defined in the corresponding requirement. Pass if no errors are reported. Fail otherwise.
	Test type	Conformance

Annex B: Title ({Normative/Informative})

NOTE	Place other Annex material in sequential annexes beginning with "B" and leave final two annexes for the Revision History and Bibliography

Annex C: Revision History

Date	Release	Editor	Primary clauses modified	Description
2016-04-28	0.1	G. Editor	all	initial version

Annex D: Bibliography

NOTE

Example Bibliography (Delete this note).

The TC has approved Springer LNCS as the official document citation type.

Springer LNCS is widely used in technical and computer science journals and other publications

- For citations in the text please use square brackets and consecutive numbers: [1], [2], [3]

– Actual References:

[n] Journal: Author Surname, A.: Title. Publication Title. Volume number, Issue number, Pages Used (Year Published)

[n] Web: Author Surname, A.: Title, http://Website-Url

[1] OGC: OGC Testbed 12 Annex B: Architecture. (2015).