Development of a Consistent Methodology for Estimating Greenhouse Gas Emissions from Oil and Gas Industry Operations

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ABSTRACT

Understanding the sources and quantities of greenhouse gas (GHG) emissions is critical to developing an emissions inventory that accurately represents various oil and gas industry segment operations. To address this, the American Petroleum Institute (API) formed a Greenhouse Gas Emissions Methodology Working Group. The working group's objectives were to review, summarize and recommend methodologies for consistent estimation of GHG emissions from oil and gas industry facilities, including exploration and production through refining to product marketing. In a continued pursuit of consistent emission estimation methodologies for the oil and gas industry, the working group is meeting with other protocol development organizations to compare and reconcile different estimation techniques.

This paper discusses the process undertaken to compare methodologies used by member companies, national governmental bodies, and intergovernmental experts and to develop a compendium of emission estimation methodologies. It highlights technical, scope, and boundary considerations that play a key role in the final inventory calculations. It presents a general classification scheme for all oil and gas industry devices and operations, while identifying the parameters needed to generate robust estimates of emissions for each equipment category and industry segment. The paper also illustrates ways in which GHG emissions inventory data can be presented and summarizes some of the considerations in designing a GHG emissions inventory.

INTRODUCTION

The API *Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Gas Industry*[1] represents over a year long effort by API's Greenhouse Gas Emissions Methodology Working Group to screen, evaluate and document a range of calculation techniques and emission factors useful for developing GHG emission inventories. It is a compilation of recognized methodologies applicable to oil and gas industry operations. In the development process, API has reached out to its members, governmental, and non-governmental organizations to examine existing protocols, compile common methodologies and ensure broad peer-review of its efforts.

The Compendium development process consisted of the following:

- Assembling relevant emission factors for estimating GHG emissions from oil and gas industry activities, based on currently available public documents;
- Outlining detailed procedures for conversions between different measurement unit systems, with particular emphasis on implementing oil and gas industry standards;
- Describing the multitude of oil and gas industry operations—from exploration and production through refining to the marketing of products, as well as the transportation of crude oil, natural gas and petroleum products—and the associated emissions sources that should be considered;
- Developing emission inventory examples—based on selected facilities from the various industry segments—to demonstrate the broad applicability of the methodologies; and
- Outlining scope and boundary issues and providing suggestions on how to handle them in constructing an overall inventory.

TECHNICAL APPROACH

The methodologies outlined in the Compendium can be used to guide the estimation of GHG emissions for individual projects, entire facilities or company-wide inventories. The methodologies focus on carbon dioxide (CO_2) and methane (CH_4) emissions because these are potentially the most relevant GHG compounds for the oil and gas industry.

The Compendium groups CO_2 and CH_4 emissions from oil and gas industry operations into five categories: combustion devices, point sources, non-point sources, non-routine activities, and indirect emissions.

1) Combustion devices include both stationary sources, such as engines, boilers, heaters, and flares; and fleet-type transportation devices, such as trucks and ships, where these sources are essential to operations (i.e., material or personnel transportation). The CO_2 emissions from these sources can be calculated from the amount and type of fuel they consume. Methane emissions, resulting from incomplete fuel combustion, are also a function of the amount and type of fuel consumed, as well as the efficiency of the equipment.
2) Point sources include vents from oil and gas industry units, such as hydrogen plants and glycol dehydrators, that emit either CO_2 and/or CH_4. They also include other stationary devices such as storage tanks, loading racks and similar equipment. The rate of these emissions is a function of the unit throughput and can be estimated by engineering calculation or by using appropriate emission factors.
3) Non-point sources include fugitive emissions (equipment leaks), emissions from wastewater treatment facilities, and a variety of other emissions generated by waste handling.
4) Non-routine activities, associated with maintenance or emergency operations, also may generate GHG emissions. Their rates are not easily determined and have to be evaluated on a case-by-case basis, often using a combination of factors and engineering calculations.
5) Indirect emissions are defined as GHG emissions associated with oil and gas company operations, but physically occurring from sites or operations owned or operated by another organization. The Compendium specifically addresses purchased steam and electricity. Estimating these emissions requires input from the energy utility company or use of published emission factors based on average GHG emissions for energy generation in a given location or region.

Table 1 provides examples of the specific emission sources that are found in each category. The Compendium includes calculation and estimation techniques for determining CO_2 and CH_4 emissions from all of these sources.

COMPENDIUM CONSIDERATIONS

An emissions inventory is time dependent, reflecting conditions at the time the inventory is conducted. Given the dynamic nature of oil and gas industry operations, as well as the evolving state of international and domestic interest in GHG emissions, the Compendium strongly recommends careful documentation of all decisions to allow for future review and revisions as new information becomes available.

In addition, source applicability considerations and other boundary issues are often an integral part of the emissions inventory development process. Table 2 outlines some of the key considerations in designing a comprehensive emissions inventory and provides the recommended approaches adopted by the Compendium. While the Compendium addresses these issues, it recognizes that the actual application within a company and the decisions surrounding implementation are governed by company policies and specific needs.

Technical Considerations

The Compendium includes emission factors from different documents with various approaches to estimating emissions. In reviewing these documents, attention was focused on understanding the underlying assumptions used in developing the emission factors in order to combine data from multiple sources on a consistent basis using the reporting conventions selected for the Compendium.

Some of the key technical considerations used in developing the Compendium are outlined below:

1) Standard Gas Conditions - There are many different sets of reference conditions where "standard" often depends on the application, industry convention, or regional convention. To convert emissions data from a volume basis to a mass basis for a gas stream these standard conditions must be defined. Standard conditions used in the Compendium are the API standards widely used in commerce in the U.S - 14.7 psia and 60°F. This is equivalent to 379.3 standard cubic feet (scf)/lb-mole or 23,685 cm^3/g-mole.
2) Heating Value Specifications - Heating value describes the quantity of energy released when a fuel is completely combusted. Two conventions are often used which differ based on the phase (latent heat) of water in the combustion products. For higher heating value (HHV) or gross calorific value, water is in the liquid form; for lower heating value (LHV) or net calorific value, water is in the vapor form. The Compendium uses HHV to report fuel data in terms of energy and to convert between fuel volume and energy. This convention was chosen to be consistent with AP-42[2], which is widely used by the oil and gas industry in the U.S. and Canada. Other sources of GHG data, such as the Intergovernmental Panel on Climate Change (IPCC)[3], report fuel volumes and energy in terms of LHV.
3) Units - GHG emissions are typically reported in metric tonnes (1 metric tonne = 1000 kg = 2205 lbs). The format for units presented throughout the Compendium is to first preserve the units and original emission factor as cited in the referenced source. This enables the user to easily check for updates from the referenced sources. Then, each emission factor is also reported in a common unit basis of tonnes of CH_4 or CO_2 emissions per unit of activity, where the unit of activity is expressed in terms common to U.S. practices (gallons, barrels, standard cubic feet). Conversion factors are provided if other units are preferred.

Emissions Estimation Methodology

A number of techniques can be used to estimate emissions. The availability of data and a source's contribution to the overall inventory will generally determine the estimation approach selected.

Combustion sources generate a large majority of oil and gas industry CO_2 emissions but much smaller amounts of CH_4 emissions. Combustion emissions can be accurately determined from measurements of fuel use and its composition. For non-combustion CH_4 emissions, the use of emissions factors and engineering calculations yields acceptable results. Direct measurement can also be used, but it is costly and frequently yields little improvement on accuracy.

Where possible, the Compendium provides multiple estimating approaches for each category of emissions. These approaches are generally presented in terms of preferred and alternative approaches. Decision diagrams are provided to guide the user through the available options where the choice of one approach over another is driven by the data availability and required precision.

COMPARISON OF VARIOUS PROTOCOLS

As part of "road-testing" the Compendium, API has undertaken an initiative to compare the Compendium to other widely used GHG emission estimation protocols. Currently available protocols were compared on both a qualitative and quantitative basis. The protocols used for this comparison include:

- Canadian Association of Petroleum Producers (CAPP), *Global Climate Change Voluntary Challenge Guide*[4];
- Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC)[5];
- Exploration and Production Forum (E&P Forum), *Methods for Estimating Atmospheric Emissions from E&P Operations*[6];
- Intergovernmental Panel on Climate Change (IPCC), *Guidelines for National Greenhouse Gas Inventories*[3,7,8];
- Regional Association of Oil and Natural Gas Companies in Latin America and the Caribbean (ARPEL), *Atmospheric Emissions Inventories Methodologies in the Petroleum Industry*[9];
- UK Emissions Trading Scheme (UK ETS)[10];
- U.S. EPA, Emission Inventory Improvement Program (EIIP)[11]; and
- World Resources Institute/World Business Council for Sustainable Development (WRI/WBCSD), *The Greenhouse Gas Protocol*[12].

The selection of these protocols was governed by their comprehensiveness and the fact that they are most commonly referenced in other documents. Some of these protocols address only specific segments of the oil and gas industry, such as the E&P Forum document, which focuses on production operations. Other protocols concentrate on combustion sources and provide only CO_2 emission methodologies. The comparison effort addresses these differences and compares the Compendium to those sources addressed by the other protocol documents.

The qualitative review focussed on the following key points:

- Scope of the document relative to the oil and gas industry;
- Root source of emission factor data; and
- Additional or omitted emission sources compared to those identified in the API Compendium.

Table 3 summarizes the comparison of the protocols for each of these key points. In addition, Table 4 provides a checklist of sources included in each of the protocols. Review of this list provides a simple means of identifying inclusion or exclusion of key emission sources.

For the quantitative comparison, example facilities were used to provide a better understanding of the effect of differences noted in the qualitative comparison. Emissions were estimated using approaches described in each of the protocols for sources identified in six hypothetical facilities. These facilities were developed as part of the API Compendium document[1]. The facility types were:

- Onshore oil field with high CO_2 content ;
- Offshore oil and gas production platform;
- Natural gas processing facility;
- Production gathering compressor station;
- Marketing terminal; and
- Refinery.

The results of these comparisons demonstrate a wide variability in overall facility estimates, primarily based on different assumptions or data resources. For example, updates to CH_4 emission factors in AP-42[2] have resulted in significant changes in CH_4 emissions from some types or combustion equipment.

Two major factors in the varying CH_4 emission estimates for non-combustion sources are the actual sources included in the different protocols and the treatment of these sources in the emission factors. Some protocol documents base CH_4 emissions on either a single emission factor or a few broad categories, grouping multiple emission sources into one emission factor. This usually underestimates emissions due to the exclusion of some sources, such as production tank flashing losses. These compound emission factors could lead to inappropriate applications unless details on the mathematical derivation and the specific sources included are clearly documented. Regional differences and operating practices could also contribute to differences in emission estimates.

Generally, the CO_2 emission estimates show more agreement. However, some variability results from the use of average fuel-based or equipment-based emission factors, where both are typically developed from assumed, general fuel properties. Improved accuracy results from actual fuel properties and equipment-specific information where available.

CONCLUSIONS

Initial "road testing" of the API Compendium and special studies undertaken to compare it to other commonly used protocols reveals the following:

- API's *Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Gas Industry*[1] brings together all of the resources necessary to estimate GHG emissions from oil and gas industry operations.
- Multiple calculation methods are provided to allow for maximum use of available data. Decision diagrams are included, indicating preferred and alternative approaches, to guide the user in selecting among different emission estimation techniques.
- Although the focus is on oil and gas industry operations, the techniques presented, particularly for combustion and indirect emissions, have broader application to many other industries.
- Documentation of calculation methods and transparency of other assumptions is key. Many of the protocol documents reviewed lack the detail necessary to understand the derivation of emission factors, and allow for their appropriate application to other inventory scenarios.
- Quantitative inter-comparison among the various protocols enables a better understanding of the differences noted above in the qualitative comparison of GHG estimation methodologies.
- Combustion CO_2 emissions dominate most emission inventories for oil and gas operations. Variations in CO_2 emission estimates primarily result from differences between actual and generalized fuel properties.

- Estimation of CH_4 emissions depends largely on the extent of information available, including detailed knowledge of equipment types and efficiencies, operational practices and hours of operation.
- Improving the accuracy of CH_4 emission estimation is important for those operations in which CH_4 represents a significant portion of the total CO2-Equivalent emissions. However, it might not be essential for facilities primarily dominated by combustion or indirect emissions, where CH_4 tends to be more marginal.

As part of the one-year "road test" of the Compendium, API welcomes a continuing open exchange of information and a broad discussion of the methodologies presented. (To obtain a copy see: www.global.ihs.com). The API Greenhouse Gas Emissions Methodology Working Group is currently arranging discussions with other worldwide oil and gas industry organizations to compare various emission methodology differences. It is hoped that prior to finalizing the Compendium later in 2002, it will be possible to achieve better harmonization of protocols and enable improved global comparability of emission estimates.

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Table 1. Examples of CO_2 and CH_4 emission sources in each of the categories.

Category	Sources Include:
Combustion Devices	
Stationary Sources	Boilers, heaters, furnaces, reciprocating internal combustion engines and turbines, flares, incinerators and thermal/catalytic oxidizers
Mobile Sources	Barges, ships, railcars and trucks for material transport; planes/helicopters and other company vehicles
Point Sources	
Process Vents	Hydrogen plants, amine units, glycol dehydrators, regeneration of Fluid Catalytic Cracking Units and reformers, Flexicoker coke burn
Other Venting	Crude oil, condensate and petroleum product storage tanks, gas-driven pneumatic devices, chemical injection pumps, exploratory drilling, ship and barge loading/balasting/transit operations, product loading racks
Non-Point Sources	
Fugitive Emissions	Valve, pump and compressor seal leaks
Other Non-Point Sources	Wastewater treatment, surface impoundments
Non-Routine Activities	
Maintenance/Turnaround	Decoking of furnace tubes, vessel and gas compressor depressurizing, well and pipeline blowdowns, tank cleaning, painting
Other Releases	Pressure relief valves, emergency shutdown devices
Indirects	Off-site generation of steam and electricity for on-site power and heat

Table 2. Considerations for a GHG emissions inventory.

Issue	Recommendation
What compounds or emissions should be targeted?	Focus on carbon dioxide (CO_2) and methane (CH_4) first, assess other GHGs later if industry is a significant emitter.
What industry sectors should be included?	It is advisable to have a common framework for all sectors, from well-head to retail. Nonetheless, special attention is needed for specific operating practices and unique process units.
Should the inventory scope include all operations globally?	The methods compiled are universally applicable. Specific needs for local, national, regional, or global summaries should determine the inventory scope. In applying the methods globally, care should be taken to allow for regional differences in the definition of standard conditions and fuel properties.
Should the inventory account for emissions attributable to imported and/or exported steam and power?	The methodology allows for both approaches—emissions from directly operated devices along with indirect emissions associated with utility usage. If such emissions are included, separate, clearly labeled summaries should be used to differentiate between “direct” and “indirect” emissions to prevent double counting sources in national inventories.
Should the inventory account for emissions from joint ventures or other non-wholly owned enterprises?	Two parallel inventories could be developed, one based on “100% as operated” approach, while the second tracks the “equity share” in facilities and operations. The implementation of this recommendation should be based on individual company environmental, health, and safety (EH&S) policy.

Table 3. Summary of qualitative comparison of GHG emissions protocols.

Protocol/Boundaries	Combustion	Point	Non-Point	Non-Routine	Indirect
Canadian Voluntary Challenge Guide[4]					
Developed to support petroleum company submittals to Canada's Voluntary Challenge Registry. Non-combustion approaches are generally limited to upstream operations.	Combustion EFs based on AP-42 January 1995 Version[2]. Provides manufacturer specific EFs for IC engines. **Includes:** Fuel-based and equipment based EFs. **Does not include:** mobile sources and refinery specific EFs	**Includes:** CH_4 EFs for instrumentation venting, oil batteries (including flashing losses), tank working and breathing losses, and sour gas processing. **Does not include:** glycol dehydration, tank flashing, drilling, and downstream operations.	**Includes:** Component based fugitive EFs for vapor service in oil and gas production facilities. Comparable with Compendium **Does not include:** liquid service or downstream EFs.	Not addressed in this document.	**Includes:** CO_2 EFs for Canadian provinces. **Does not include:** steam imports/ exports
Canadian Industrial Energy End-Use Data and Analysis Centre[5]					
Cites Environment Canada 1992, with updates in 1999[13]. Provides EFs for CO_2 only.	**Includes:** Fuel based EFs and refinery specific EFs. **Does not include:** engines, turbines, heaters. Provides fuel energy data in terms of HHV from Statistics Canada.	Not addressed in this document.			Tracks energy associated with electricity and steam inputs and consumption but does not calculate associated emissions.
E&P Forum[6]					
Covers exploration and production operations only. Provides 5 Tiers of emission estimation approaches. Provides/combines EFs for different countries. Provides EFs for CO_2, CH_4, NOx, CO, and VOCs.	CO_2 and CH_4 emissions – Fuel consumed basis. Comparable to API Compendium with some unit conversions. **Includes:** Fuel-based and equipment based EFs. **Does not include:** refinery specific EFs	**Includes:** Working losses from tanks; loading losses. **Does not include:** tank flashing losses; pneumatic devices; chemical injection pumps; dehydrators by source.	**Includes:** Component based fugitive EFs for upstream operations. Comparable with Compendium. **Does not include:** downstream EFs.	**Includes:** Emissions = volume released × fraction vaporized **Does not include:** source specific EFs	Not included
EIIP[11]					
Developed for preparing state inventories. Provides EF methodologies for CO_2, CH_4, and N_2O relative to oil and gas industry operations.	The API Compendium references EIIP for CO_2 emissions from combustion fuel basis approach. **Includes:** CH_4 EFs on an equipment basis; consistent with the API Compendium; mobile source EFs on vehicle mile travel basis, which requires unit conversion for comparison to Compendium. **Does not include:** refinery specific EFs	**Includes:** Facility-wide CH_4 EFs, generally reported in terms of overall processes or operations. **Does not include:** source specific EFs	**Includes:** Facility-wide CH_4 EFs, generally reported in terms of overall processes or operations **Does not include:** source specific EFs	Included under roll up of point and non-point sources. **Does not include:** source specific EFs	Provides a US national average emission factor of 0.36 lb C/kW-hr of electricity generated for use with state net imports of electricity. **Does not include:** steam imports/ exports

EF = Emission Factor

Table 3. Continued

Protocol/Boundaries	Combustion	Point	Non-Point	Non-Routine	Indirect
IPCC Guidelines for National Inventories[3,8]					
Developed for preparing national inventories. Manual provides two calculations tiers and references another methodology as a 3rd tier Provides EFs for CO_2, CH_4, N_2O, NOx, CO, and NMVOC.	All energy data are expressed in terms of net calorific values. **Includes:** Tier 1 EFs in terms of kg per TJ of consumption fuel; Tier 2 EFs based on fuel type and equipment type. **Does not include:** Refinery specific EFs.	Tier 1 approach provides range of emission factors for three broad categories of emissions. Tier 2 provides mass balance equations for oil production, crude oil transportation and refining, and exploration and drilling losses. Tier 3 suggests source specific emission estimation. **Does not include:** source specific EFs			**Includes:** Equipment based, Tier 2 combustion emission factors for electricity and steam generation equipment. **Does not include:** import/ export issues.
Latin American/Caribbean Methodology Document[9]					
Provides EFs for CO_2, CH_4, NO_x, CO, SO_x, NMHC, BTEX, and particulates. Addresses emission methodologies by source for each industry sector. Covers exploration/drilling through product distribution and service stations.	Cites EPA (Stationary Internal Combustion Sources and External Combustion Sources; April 1993[14]) and CAPP (Guide to Voluntary Challenge, June 1995[15]). Provides fuel heating values in terms of gross and net. **Includes:** Combustion emission factors on an equipment basis for upstream and downstream operations **Does not include:** turbines and mobile sources	**Includes:** Detailed emission estimate methodologies for tanks and loading/ transit; pneumatic devices, chemical injection pumps, drilling, diesel storage, produced water, pipeline pigging, casing gas, and asphalt blowing.	**Includes:** Component based fugitive emission factors. Note: Gas plant EFs (from API 4615[16]) are currently shown for onshore fugitive sources.	**Includes:** Most upstream equipment/ process blowdowns, compressor starts, and surge tanks **Does not include:** Compressor blowdowns, well tests, well workovers, emergency releases, and refinery non-routine activities	Not addressed
UK Emissions Trading Scheme[10]					
Scope includes: On-site combustion of fossil fuels; On-site consumption of electricity generated on-site or off-site; and On-site consumption of heat or steam generated on-site or off-site.	**Includes:** CO_2 EFs for fuel-based energy generation ($kgCO_2$/kWh) and conversion factors for kWh/tonne, L/tonne, and kWh/L. **Does not include:** Equipment based EFs, or CH_4 emissions from combustion	Non-CO_2 process emissions are not included at this time. Participants wanting to report non-CO_2 emissions can notify DEFRA for approval of a protocol covering that source.			**Includes:** One EF for all electricity from the public supply network; methodology for treating imported or exported emissions from combined heat and power (CHP). **Does not include:** Regional or utility based EFs for electricity.
The Greenhouse Gas Protocol[12]					
Currently, does not address emissions specific to oil and natural gas industry operations.	**Includes:** CO_2 EFs from a number of sources in different unit conventions. Notes that the tool should not be used for gas flaring or gas fired IC engines. A separate calculation tool is provided for CO_2 emissions from mobile sources. **Does not include:** Equipment based EFs, or CH_4 emissions from combustion	Not addressed at this time for oil and natural gas industry operations.			**Includes:** Preferred approach based on supplier data or actual fuel and generation technology. Provides published EFs and country specific CO_2 EFs. Note that these EFs combine emissions due to heat and power. Provides two methods for estimating emissions from combined heat and power (CHP) plants.

Table 4. Protocol emission source comparison.

	API	CAPP	CIEEDAC	E&P Forum	IPCC	ARPEL	EIIP	WRI/ WBCSD and UK ETS
COMBUSTION SOURCES								
Fuel Basis	X		X	X	X		X	X
Equipment/Source Basis	X	X						
Boilers/Heaters	X	X		X	X	X	X	
Engines	X	X		X	X	X	X	
Turbines	X	X		X	X		X	
Flares	X	X		X	X	X	X	
Essential Mobile Sources	X	X		X	X		X	
Other (Refinery) Combustion Units	X		X			X		
POINT SOURCES								
Process Vents	X			X	X		X	
Gas Sweetening Processes	X	X			X			
Dehydration Processes	X					X		
Refining Processes	X							
Other Venting								
Tanks	X	X		X		X		
Pneumatic Devices	X	X				X		
Chemical Injection Pumps	X	X				X		
Exploratory Drilling	X					X		
Loading/Unloading/Transit	X			X		X		
NON-POINT SOURCES								
Fugitive Emissions					X		X	
Process Equipment Leaks (component basis)	X	X		X		X		
Fuel Gas System Leaks								
Other Non-point Sources	X							
NON-ROUTINE ACTIVITIES – Maintenance/Turnarounds								
Equipment/Process Blowdowns	X					X		
Well Workovers	X							
Compressor Starts	X					X		
Heater/Boiler Tube Decoking	X							
NON-ROUTINE ACTIVITIES – Other Releases								
Pressure Relief Valves (PRVs)	X							
Well Tests and Blowdowns (when not flared)	X							
Pipeline Leaks	X							
Surge Tanks	X					X		
Emergency Shutdown (ESD)/ Emergency Safety Blowdown (ESB)	X							
INDIRECTS								
Electricity Imports/Exports	X	X	X		X		X	X
Steam Imports/Exports	X		X				X	X

X indicates that the document provides an emission estimation approach for the associated source type.

CAPP includes review of Canada's Climate Change Voluntary Challenge and Registry Inc (VCR Inc.) *Registration Guide 1999*[17]; Environment Canada, *Canada's Greenhouse Gas Inventory 1990-1998*, Final Submission to the UNFCCC Secretariat, October 2000[18]; and Environment Canada, *Canada's Greenhouse Gas Inventory, 1997 Emissions and Removals with Trends*, April 1999.[19]

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