American
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SYNOPSIS REPORT

TOWARD A CONSISTENT METHODOLOGY FOR ESTIMATING GREENHOUSE GAS EMISSIONS FROM OIL AND NATURAL GAS INDUSTRY OPERATIONS

CLIMATE CHANGE

Toward a Consistent Methodology for Estimating Greenhouse Gas Emissions from Oil and Natural Gas Industry Operations

INTRODUCTION

Climate change is a major issue of international concern that is being addressed by companies throughout the oil and natural gas industry. While many questions remain about the linkage between human greenhouse gas (GHG) emissions and the climate system, many companies around the globe are already engaged in voluntary actions to limit their GHG emissions while investing heavily in new technologies.

The oil and natural gas industry is by its nature a global industry, operating in many markets and utilizing a variety of exchanges and trading apparatus in its daily dealings. With the increased attention to the potential value—and risk—associated with carbon emissions, there is a need for a coherent and harmonized methodology for estimating greenhouse gas emissions. This will assure that emission credit exchanges will be using the same "carbon currency" when taking credit for potential mitigation activities. In developing a global fungible market for emission credit exchanges, joint projects and other trading schemes—the consistency, credibility and verifiability of the methodology used to derive greenhouse gas emissions is vital.

A fundamental predicate for meaningful and appropriate actions is knowledge that begins with understanding the nature of relevant emission sources and quantity of emissions. When it comes to estimating and summarizing their GHG emissions many companies in the oil and gas industry find themselves faced with a wide array of guidance documents. National and international bodies lacking the needed information to fully describe industry operations have developed some of these documents concurrently without attempting to reconcile regional differences.

The goal of this document is to:

- Provide an overview of the API Compendium, its structure and its content;
- Describe the qualitative and quantitative differences identified when comparing the API Compendium to other guidelines and protocols; and
- Emphasize the importance of reconciling the differences for the Oil & Gas industry to ensure comparability of emissions estimation and understanding the impacts associated with actions taken.

API Activities

Developing an international greenhouse gas estimation methodology for the oil & gas sector is quite a formidable task. Such an approach needs to be simple yet comprehensive; flexible yet maintain a core structure; comparable yet adaptable to data on-hand; and transparent yet protective of confidential process information. Since participants are likely to be highly varied in regards to circumstances and objectives, the methodology needs to accommodate flexibility and simplicity. A systematic decision-making approach needs to be applied for selecting appropriate emissions estimating methods without compromising the comparability and transparency objectives.

To assist its members, and as a reference for other interested parties, API has developed a Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Gas Industry (April, 2001) that documents calculation techniques and emission factors available for developing GHG emissions inventories for oil and gas industry operations. These techniques cover the calculation or estimation of emissions from the full range of industry operations—from exploration and production through refining to the marketing of products—as well as the emissions from the transportation of crude oil, natural gas and petroleum products.

The Compendium currently focuses on estimating methane (CH_4) and carbon dioxide (CO_2) emissions in the oil and natural gas industries, as those are by far the most significant GHG associated with the industry's operations. Figure 1 provides a schematic depiction of the operations and emissions sources for the various industry sectors being addressed in the API Compendium.

In developing this compendium API reached out to sibling organizations and reviewed their guidance documents, along with emerging national and international protocols and internal company greenhouse gas emission estimation protocols. This report provides a brief overview of the API Compendium and details in the sections below qualitative and quantitative comparisons of emission estimation methods. The methods compared are drawn from the most current GHG protocols available from the oil and gas industry, governmental, and non-governmental organizations, and the quantitative comparisons are based on example facilities representing the various sectors of the industry.

API hopes to expand the global dialogue among oil & gas associations striving towards a consistent methodology framework for estimating GHG emissions from industry operations. It is API's goal to revise and finalize the Compendium in 2003, incorporating all the lessons learned from the qualitative and quantitative comparisons presented in the following sections. Attaining such a global consistency will ensure interregional comparability in estimating techniques and the eventual fungibility of emission reduction credits worldwide.

EMISSION INVENTORY PRACTICES

The design and harmonization of GHG inventorying and reporting practices include decisions on: Scope, Extent, Boundaries, and Threshold, as well as the technical issues of emission sources, estimating methods and data requirements.

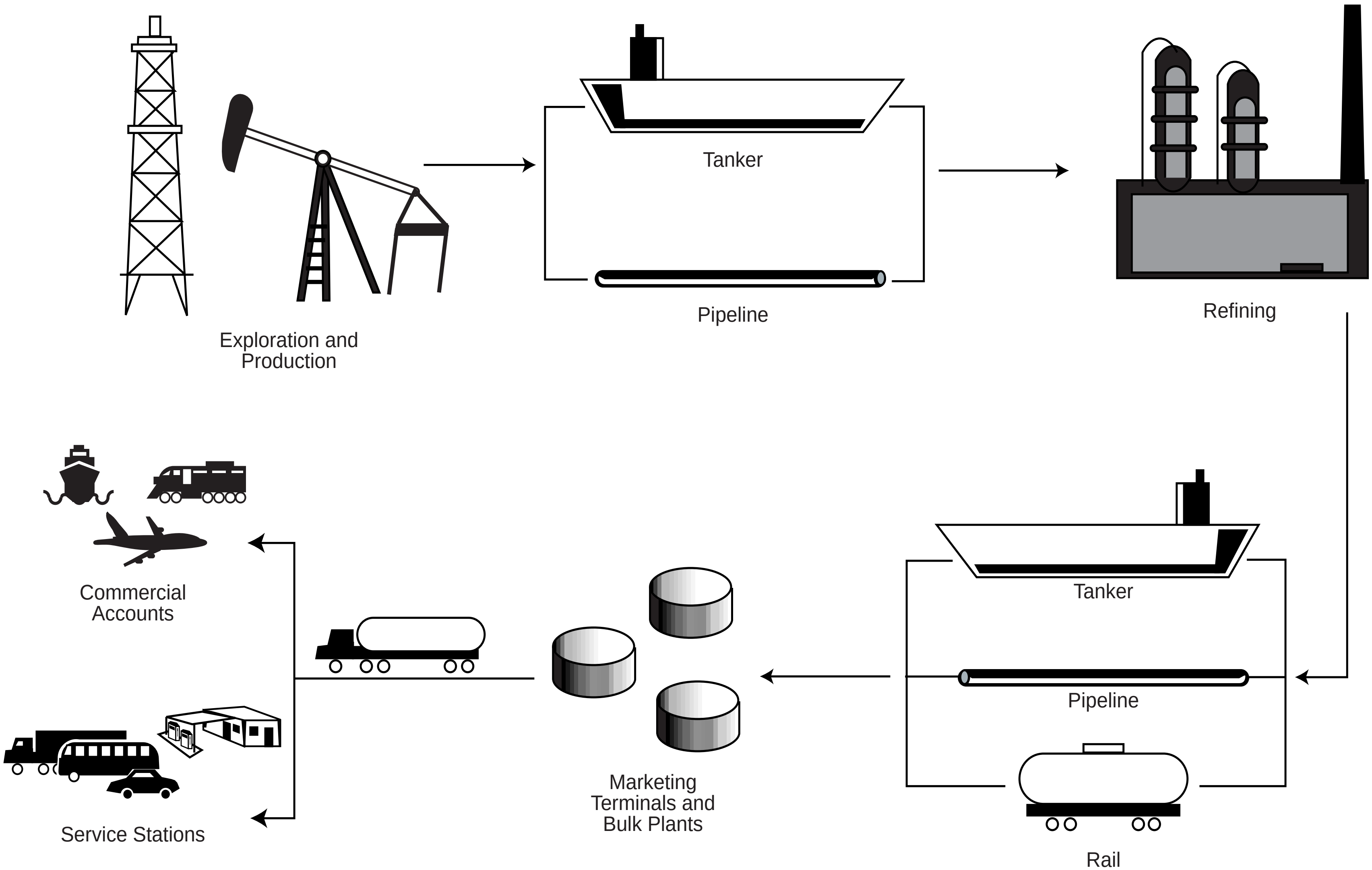


Figure 1—Major Emission Sources for an Integrated Oil Company

Figure 1—Oil and Gas Industry Schematic of GHG Emissions

In addition to the API Compendium efforts, a broad international coalition of businesses, non-governmental organizations (NGOs), government and inter-governmental organizations, have undertaken the task of developing internationally accepted accounting and reporting standard for GHGs. The initiative is operating under the umbrella of the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI) and has provided some guidance to help differentiate between Accounting Principles and Engineering Assessment of emissions.

To date several organizations such as the US EPA Climate Leaders, the Chicago Climate Exchange and the California Energy Commission have based their guidance documents on the general accounting principles elaborated in the WRI/WBCSD approach.

API has been collaborating with WRI in the compendium development process and has offered the methodology compendium as the Oil & Gas Industry Module for engineering estimates of emissions.

This section will describe the emerging global consensus on the basic elements (or modules) that make up a comprehensive GHG inventory. It will also provide greater detail on the basic structure and technical considerations that went into devising the API Compendium.

Elements of an Emissions Inventory

A key question in the design of any GHG emissions inventory is:

"*What Constitutes a Comprehensive GHG Inventory?*"

Figure 2 provides a schematic depiction of the possible components of a comprehensive inventory. The actual building blocks used to construct specific inventories may vary, as discussed below.

The API Methodology Compendium, as described below, includes a general discussion of scope and boundary yet it does not specify the inclusion or exclusion of any specific emission inventory components. It recognizes that the choice on how to structure specific inventories will be governed by local requirements and company policies. Moreover, it provides estimation methodologies for all potential emission sources, and recommends that in describing their inventories, companies clearly indicate their basis for the estimate and what sources/operations are included.

If companies elect to account for emissions from equity shares of non-operated facilities, contractor operations, and/or purchased or sold electricity and steam, it is recommended that those be exhibited as separate entries in any inventory presentation. Whichever approaches are used, the API Compendium strongly recommends thorough documentation and transparent presentation of data.

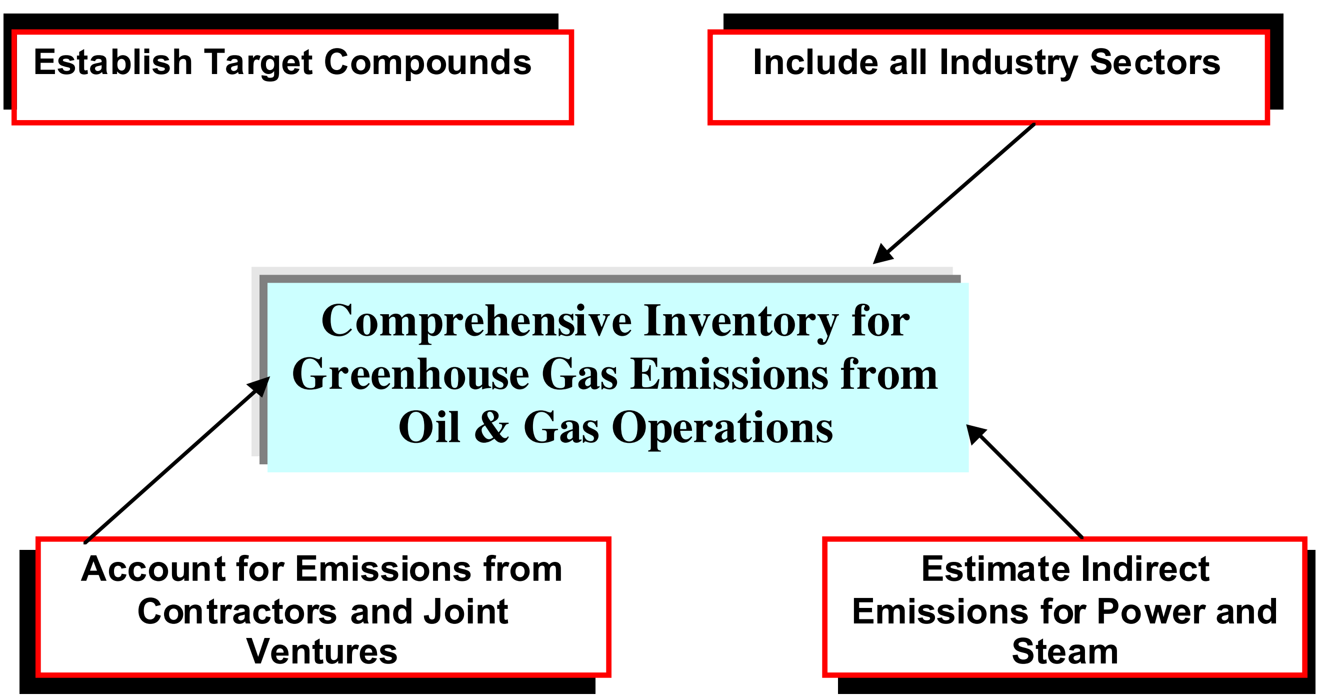


Figure 2—Elements of a Comprehensive Emissions Inventory

Table 1—Issues in Designing a GHG Emissions Inventory

Issue	***Recommended Framework:***
Greenhouse Gases to be Included in inventory	Of the six potential compounds, or classes thereof, specified in the Kyoto Protocol, only 2 are highly relevant to Oil and Gas industry operations. Primary emphasis should be on CO_2 and CH_4.
Industry Sectors and Thresholds	Companies in the Oil & Gas Industry have a wide range of operations in all sectors from Oil and Gas exploration and production to refining, marketing, product distribution and retail. This mix of businesses differs in size and complexity. Applicable thresholds should be defined to establish relevance to the inventory being developed.
Reporting Scope and Geographical Coverage	The multitude of national and regional GHG estimation and reporting protocols fosters inconsistency in reporting for global companies. Industry guidance is needed to minimize redundancy in calculations, while allowing for regional and industry sector summaries.
GHG Emissions from JVs, non-wholly owned business units, contractors, and outsourcing	A growing portion of the oil and gas industry is operated through joint ventures and other forms of ownership. Most emission reporting practices entail estimating 100% of "operated emissions". In addition, for global GHG assessments, companies might also need to account for the full spectrum of emissions on an "Equity Basis". This will entail including joint ventures and other business units.
Accounting for emissions attributable to Indirect sources, e.g. utilities usage	The oil & gas industry's ability to operate depends to a large extent on the availability of electrical power and steam. For a variety of economic and local siting considerations, these utilities might be either on-site or imported. Emissions associated with such utilities are viewed as an enabler of the process, and thus might be taken into account when constructing a comprehensive inventory. Where indirect emissions are included in the inventory, they should be clearly identified to differentiate from direct emissions.

The key issues to be considered in developing a greenhouse gas emissions inventory, along with a recommended framework for addressing them are provided in Table 1.

OVERVIEW OF API'S COMPENDIUM

There are many GHGs, but oil and gas industry operations are significant emitters of only two: carbon dioxide (CO_2) and methane (CH_4). The Compendium provides information on calculation and estimation techniques for both. It should be emphasized however that the Compendium is neither a standard nor a recommended practice for the development of emission inventories for these gases. It sets out a systematic approach for classifying potential emission sources, includes a choice of methods for calculating emissions, and provides decision-trees to help navigate among methods.

The API Compendium is divided into five sections:

- *Section 1*—Highlights the Compendium's scope and organization and provides examples of the types of GHG emission sources that should be considered in developing an inventory.
- *Section 2*—Describes the segments of the oil and gas industry that should be considered in developing a GHG emissions inventory and provides a comprehensive list of potential emission sources for each of these segments.
- *Section 3*—Discusses in general terms the calculation techniques used in developing an inventory and outlines technical considerations that are essential for consistent application of the various methods.
- *Section 4*—Presents the specific methods that can be used for estimating emissions and developing an inventory. It comprises the bulk of the Compendium.
- *Section 5*—Presents case studies using the methodologies presented in Section 4 to develop illustrative inventories for example oil and gas industry facilities.

The Compendium also includes a tabulation of emission and conversion factors used in GHG inventory calculations, additional information on emission inventory calculation techniques not commonly used in the oil and gas industry, and a glossary of terms used in discussing emissions inventories. GHG emissions are typically reported in metric tons—tonnes—of emissions, and appropriate factors for summarizing equivalent CO_2 emissions are also provided.

Important features of the API Compendium include a systematic approach to classifying all the industry sources into five major groupings and explicit description of all the technical considerations associated with unit conversions and data summation.

Classification of Sources

The Compendium groups oil and gas industry GHG emission sources into five categories: combustion devices, point sources, non-point sources, non-routine activities, and indirect emissions. Methane and CO_2 emissions can result from sources within each of these categories as outlined below:

- *Combustion devices* include both stationary sources, such as engines, burners, heaters, and flares; and fleet-type transportation devices, such as trucks and ships, where these sources are essential to operations (i.e. products or personnel transportation).
- *Point sources* are part of normal operations, with releases occurring through stacks, vents, ducts, or other confined streams. They include hydrogen plants and glycol dehydrator vents along with venting from storage tanks and loading racks.
- *Non-point sources* include primarily CH_4 emissions from equipment leaks (fugitive emissions), wastewater treatment facilities, and other sources that are part of waste handling.
- *Non-routine activities* associated with maintenance or emergency operations may also generate GHG emissions.
- *Indirect emissions* include emissions associated with company operations but physically occurring elsewhere. The Compendium specifically addresses purchased steam and electricity.

Technical Considerations

The Compendium includes emission factors from different documents with various approaches to estimating emissions. In harmonizing the methodology a consistent set of units and conversion factors were used, as detailed briefly below:

- *Standard Gas Conditions*—"Standard" often depends on the application or industry convention. The API Compendium uses API standards—widely used in commerce in the U.S —14.7 psia and 60°F [equivalent to 379.3 standard cubic feet (scf)/lb-mole or 23,685 cm3/g-mole].
- Heating Value Specifications—The quantity of energy released when fuel is completely combusted is its heating value. It is used for converting between fuel volume and energy. The Compendium uses the higher heating value (HHV, or gross calorific value) consistent with AP-42 (EPA, 2000), as widely used by industry in the U.S. and Canada. Other sources of GHG data, such as IPCC (IPCC, 1997), report fuel volumes and energy in terms of lower heating value (LHV or net calorific value).
- *Units*—GHG emissions are typically reported in metric tons (or tonnes) where 1 metric ton = 1000 kg = 2205 lbs. Each emission factor is provided in the original format from its referenced source along with a derived factor using a common unit basis of tonnes of CH_4 or CO_2. Emission factors presented in the Compendium are reported in terms of units commonly used in the U.S. oil and gas industry (gallons, barrels, standard cubic feet). However, the methods presented in the Compendium are applicable worldwide and conversion factors are provided if other units are preferred.

The methods and technical approach presented in the Compendium are applicable worldwide and might be broadly used by other industries with similar source categories. In particular, the sections on Combustion sources and associated emissions are generic and could be used in most industrial and commercial combustion operations. It should be noted that conversion factors are presented throughout the API Compendium for the most commonly used data unit conventions. As the Compendium gains increased global recognition, API will review the conversion factors and identify additions to enable consistent summation and reporting of emission inventory data. This is one enhancement planned for the next release of the Compendium in 2003.

COMPARISON OF PROTOCOLS

The comparison of the various emissions estimation protocols entail three levels of review:

1. The scope and content of the document relative to the oil and gas industry in order to identify existing methodology gaps for specific devices or industry operations;
2. The root sources of the emission factors used for estimating GHGs to ensure that they are current and transparent in their development; and
3. The resultant facility-wide emissions, using the six case studies previously described in detail in the API Compendium, as a basis for the quantitative comparison.

Each of these three topics is discussed in greater detail below and is accompanied by illustrative tables and graphs.

Scope and Content

The following documents were reviewed on a qualitative basis to examine differences between their emission estimation approaches and those provided in the API Compendium.

- Australian Greenhouse Office (AGO), *Workbook for Fuel Combustion Activities* (AGO, 1999);
- Australian Petroleum Production and Exploration Association (APPEA), *Greenhouse Challenge Report* (APPEA, 2000);
- Canadian Association of Petroleum Producers (CAPP), *Global Climate Change Voluntary Challenge Guide* (CAPP, 2000);
- Canadian Industrial Energy End-Use Data and Analysis Center (CIEEDAC) memorandum on "Guide for the Consumption of Energy Survey" (CIEEDAC, 2000);
- Environmental Protection Agency (EPA) Emission Inventory Improvement Program (EIIP, 1999);
- Exploration and Production Forum (E&P Forum) *Methods for Estimating Atmospheric Emissions from E&P Operations* (E&P Forum, 1994);
- Gas Technology Institute (GTI), GRI-GJGCalc'Version 1.0 (GRI, 1999);

- Intergovernmental Panel on Climate Change (IPCC), *Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997; UNECE/EMEP, 1999; IPCC, 2001);
- Regional Association of Oil and Natural Gas Companies in Latin America and the Caribbean (ARPEL), *Atmospheric Emissions Inventories Methodologies in the Petroleum Industry* (ARPEL, 1998);
- UK Emissions Trading Scheme (DEFRA, 2001); and
- World Resources Institute and World Business Council for Sustainable Development, *The Greenhouse Gas Protocol* (WRI/WBCSD, 2001).

Figures 3a and 3b depict the variability in addressing the different emission sources in the eleven protocols listed above. Table 2 goes into greater detail summarizing the results of comparing the protocols for scope, root data sources, details used in developing emission factors along with an overall assessment on how they compare with the API Compendium Pilot Version published in April 2001.

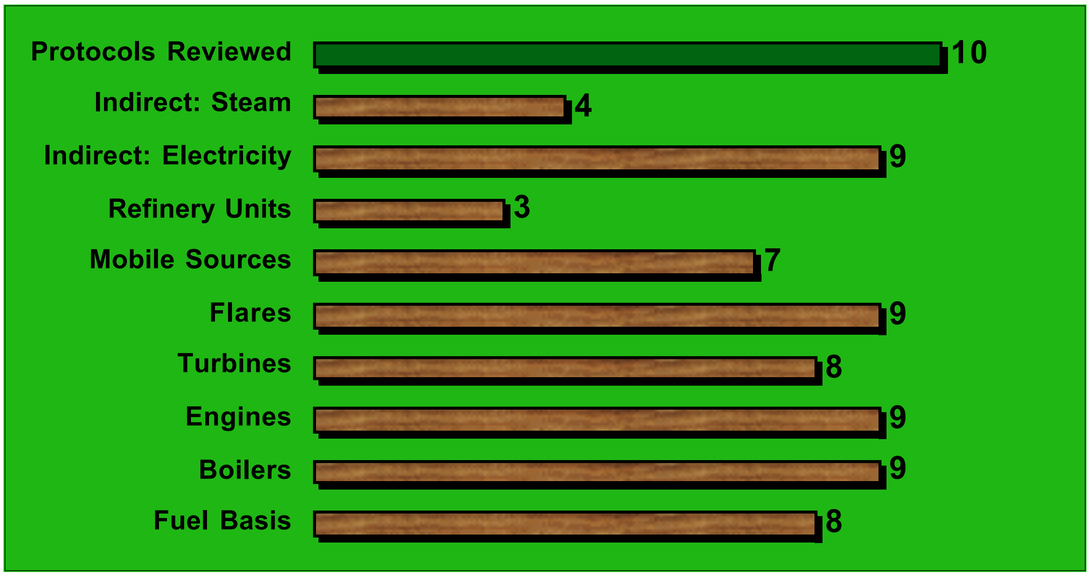


Figure 3a—Protocols Addressing Combustion Sources

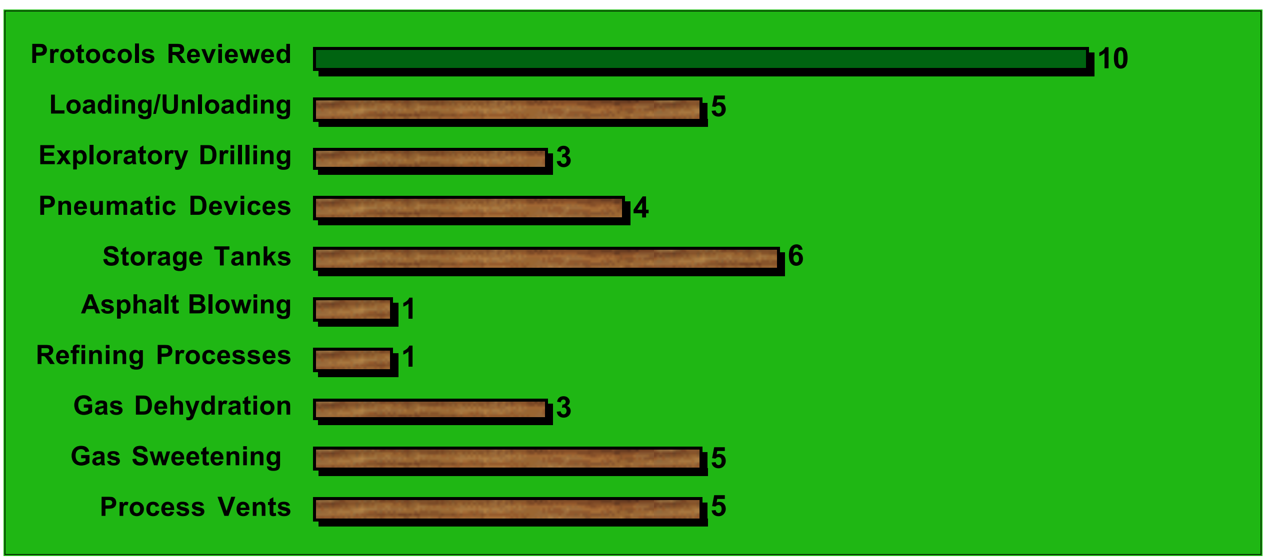


Figure 3b—Protocols Addressing Point Sources

Table 2—Qualitative Comparison of Regional GHG Inventory Guidance

Protocol (Publication Date)	Scope	Root Data Source(s)	Other Details	Overall Comparison to API Compendium
Australian Greenhouse Challenge Report (APPEA, 2000)	Covers exploration and production operations, and transport/ loading.	Cites E&P Forum (1994) for emission factors.	Emission factor units are not defined.	Difficult to compare without details on emission factor basis.
Australian Greenhouse Office (AGO, 1999)	Workbooks 1.1 and 2.1 address sources relevant to oil/gas industry.	Combustion emissions are based on IPCC approach. 1994 version of document provided approaches for non-combustion emissions based on E&P Forum and IPCC, 1996. Current version reports national inventory results.	Expresses energy data in terms of gross calorific value (HHV). IPCC factors are converted to HHV basis using Australian heating values.	Combustion emissions are consistent with API Compendium fuel based approach. Non-combustion emissions are reported in tonnes/yr with no published details on emission factor basis.
Canadian Industrial Energy End-Use Data and Analysis Center (CIEEDAC)	Addresses refinery CO_2 combustion emissions only.	Default emission factors cite Environment Canada, 1992 with updates in 1995.	Fuel data reported in HHV. Provides means to record electricity and steam transfers, but does not calculate emissions.	Comparable only for combustion emission sources in refineries.
Canadian Voluntary Challenge Guide (CAPP, 2000)	Developed to support petroleum company submittals to Canada's Voluntary Challenge Registry.	Equipment based combustion emission factors cite EPA AP-42, 1995. Manufacturer data provided for IC engines. Non-combustion emission factors are generally based on Canadian-specific measurement programs (Picard, 1999).	Expresses energy data in terms of HHV.	General combustion sources are outdated. Non-combustion sources are generally comparable to API Compendium.
E&P Forum's *Methods for Estimating Atmospheric Emissions from E&P Operations* September 1994.	Covers exploration and production operations, and gas processing.	For combustion, generally cites EPA AP-42, 1986 or E&P Forum internal data. For fugitives, cites API "Fugitive Hydrocarbon Emissions from Oil and Gas Production Operations" 1993. Provides limited venting data.	Provides methodologies for five calculation tiers. Emission factors provided in Tiers 2, 3, and 4 are most comparable to API Compendium. Provides data for multiple countries.	Generally outdated with respect to US data.
GRI-GHGCalc™ Version 1.0 (GTI, 1999)	Covers natural gas production, processing, transmission, storage, distribution, and electrical usage.	Non-combustion emission factors derived primarily from GRI/EPA methane study (GRI/EPA, 1996). Combustion sources based on EPA AP-42 (Supplement E, 1999). Indirects based on DOE and Canadian data (DOE, 1997; Neitzert, 1999)	Provides three calculation tiers that vary in the level of input data required and relative accuracy of estimated results.	Tier 2 and 3 combustion approaches and indirect approaches are comparable with API Compendium. Tier 3 non-combustion factors are generally consistent with API Compendium for natural gas operations.

Table 2—Qualitative Comparison of Regional GHG Inventory Guidance

Protocol (Publication Date)	Scope	Root Data Source(s)	Other Details	Overall Comparison to API Compendium
IPCC's Guidelines for National Greenhouse Gas Inventories (IPCC, 1997). Non-combustion emissions are updated in IPCC uncertainty document (IPCC, 2001).	Energy chapter covers sources relevant to oil/gas industry. Oil refining is not included in the uncertainty document.	For combustion, equipment based approach cites EPA AP-42 (1995). Fuel based approach uses International Energy Association (IEA) Statistics. IPCC, 2001 provides non-combustion emission factor ranges for broad source categories citing CAPP, 1999; GRI/EPA, 1996; and EPA, 1999.	All energy data are expressed in net calorific values (i.e., lower heating value, LHV) converted from a higher heating value (HHV) basis.	Equipment based combustion sources are outdated. Fuel based approach is consistent with API Compendium. Vented/fugitive emission factors are not source specific and generally reported in terms of overall processes or operations.
Latin American /Caribbean Methodology Document (ARPEL, 1998)	Covers exploration/ drilling, production, processing, refining, product distribution, and service stations. Also includes marine terminals and road construction vehicles.	Combustion sources cite EPA (Stationary Internal Combustion Sources and External Combustion Sources, April 1993) and CAPP (Guide to Voluntary Challenge, June 1995). Fugitive EFs cite API 4615 and API 4612. Tank emissions cite API 2517, API 2518, API 2519 and API Technical Data Book.	Provides good descriptions of industry activities. Expresses fuel energy data in terms of HHV and LHV.	Generally comparable to API Compendium in terms of specific sources included. Combustion emissions are generally comparable to API Compendium equipment based approach, though may be outdated. Many of the emission factor sources are outdated or derived from Canadian data.
U.S. EPA, Emission Inventory Improvement Program (EIIP, 1999)	Volume VIII, Chapters 1, 3, and 14; and Volume II Chapter 10 address sources relevant to oil/gas industry.	Provides fuel based combustion emission factors citing EIA, 1996 and EPA AP-42 (1995). Non-combustion emission factors rolled up to broad operational factors cite IPCC, 1997 and GRI/EPA, 1996.	Energy data associated with CO_2 emissions are expressed in gross calorific values (HHV). Energy data associated with CH_4 emissions are expressed in net calorific values (LHV).	Combustion EFs consistent with the API Compendium approaches. Non-combustion EFs are not source specific and generally reported in terms of overall processes or operations. Several of the more detailed emission calculation approaches were incorporated into the API Compendium.
The GHG Protocol (WRI/WBCSD, 2001).	Currently does not address emissions specific to oil/gas operations. Provides CO_2 emission factors for combustion and indirect sources.	Provides fuel based CO_2 emission factors from a number of different sources and in different unit conventions. HHV factors cite EIA, 2001.	Specifically addresses emissions from combined heat and power processes.	Combustion emissions are consistent with API Compendium fuel based approach.
UK Emission Trading Scheme (DEFRA, 2001)	Includes on-site combustion of fossil fuels and on-site consumption of electricity, heat and steam.	Provides combustion emission factors for CO_2 based on energy generation and input basis. Cites DEFRA environmental reporting guidelines.	Provides methodology for treating imported or exported emissions from CHP. Expresses energy data in terms of LHV.	Combustion emissions are comparable to API Compendium fuel based approach, but fuel types vary somewhat.

Emission Factors Comparison

Combustion devices are significant sources of emissions for Oil & Gas industry operations, and appropriate CO_2 emission factors are necessary for estimating emissions from these sources. This section compares the emission factors tabulated in several of the protocol documents on a quantitative basis to demonstrate potential numeric differences resulting from the various data sources. The analysis below focuses on highlighting similarities and differences in fuel based CO_2 combustion emission factors for several of the protocols

The API Compendium specifies the energy content of combustion fuels in terms of their 'Higher Heating Values' (HHV). This convention was chosen to be consistent with AP-42 (EPA, 1995 and subsequent updates). This is also sometimes referred to as 'Gross Calorific Value'—rather than HHV—and is the convention most commonly used in the U.S. and Canada. Other protocol documents, especially those outside of North America, utilize fuel data in terms of 'Lower Heating Values' (LHV), also referred to as 'Net Calorific Value'.

Table 3 tabulates CO_2 emission factors for fuel combustion from several protocol documents. It lists the reviewed emission factors alongside those recommended in the API Compendium. All of the emission factors presented are provided in HHV, or have been converted to a HHV basis, to allow a valid evaluation of potential differences.

> In reviewing several of the referenced protocols, it was determined that some of them do not explicitly specify the convention used for the fuel heating value.
>
> This provides an opportunity for erroneous application of emission factors, which *may result in a 5% – 10% error in the calculated emissions.*

There are some significant differences in the fuel-based CO_2 emission factors in Table 3, as shown in the Variability (%) column. The variability value indicates the spread between the highest and the lowest value reviewed, normalized to the median of the value distribution. Approximately half of the fuel types show over 5% difference as compared to the average emission factors. The most significant differences seem to be associated with combustion of refinery fuel gas and petroleum coke. There does not seem to be any consistent bias, some of the emission factors are lower while others are higher than those presented in the API Compendium.

These comparisons highlight the importance of obtaining fuel specific data (e.g. composition, heating value, density, etc.) in order to obtain quality results. Published emission factors should be applied carefully to ensure their applicability due to potentially significant variances in the properties of the actual fuels combusted.

Another parameter to consider when using CO_2 emission factors for combustion devices is the fractional conversion of carbon in the fuel to CO_2 (sometimes referred to as the fraction oxidized). Two general conventions are in common use: one assumes that all of the carbon is oxidized during the combustion process and emitted as CO_2, while the other presumes a fractional conversion for different fuel types (generally, 99.5% for natural gas and 99% for petroleum fuels and coal). The API Compendium and the WRI/WBCSD use the first approach, assuming total conversion for all combustion sources, with the exception of flares. The second approach is the one used by the IPCC and the U.S. EPA EIIP.

COMPARISONS OF CASE STUDY EXAMPLES

Several of the protocols described above were used for a quantitative comparison of the resultant emissions estimated for the six case studies examples that were detailed in the API Compendium. The protocols used for this quantitative comparison with the API Compendium results are those issued by: ARPEL, EIIP, E&P Forum, CAPP, CIEEDAC, IPCC, and WRI. These protocols were selected because they provide unique emission estimation approaches and are the ones cited most frequently in the other protocols reviewed above.

In reviewing the data obtained from these comparisons, it should be noted that:

- E&P Forum provides emission-estimating techniques for exploration and production operations only, while CIEEDAC only applies to refineries. Therefore, these protocols are used in the numeric comparison only in those examples that pertain to the specific industry sector.
- Voluntary Challenge and Registry Inc. (VCR Inc.) Registration Guide 1999 emission factors were used to fill in any gaps where emission factors were not provided in CAPP's Voluntary Challenge Guide (CAPP, 2000).
- WRI provides only CO_2 emission estimation guidance for combustion sources, stating that CH_4 emissions are relatively insignificant from most stationary sources. WRI also cautions against the use of their emission factors for gas-fired stationary internal combustion engines and for flares.

All the case study examples are summarized in terms of key differences noted in comparing results. In order to highlight significant results from these examples, graphical presentations are also provided for a couple of the comparisons.

> **I. Onshore Oil Field with High CO_2 Content**
>
> Facility Description—This hypothetical facility consists of 320 producing wells with a production rate of 6,100 barrels per day (bbl/day) of oil and 30 million standard cubic feet per day (scf/day) of natural gas.

Comparative Results

- Flares make up the majority of CH_4 emissions from combustion sources. Using the E&P Forum protocol results in the highest CH_4 estimated emissions (455.9 tonnes/yr), based on 95% destruction efficiency in the flare, with residual methane from the 5% that is ultimately not combusted. EIIP, CAPP, and IPCC each cite 98% combustion efficiency for the flares, consistent with the API Compen-

Table 3—Comparison of CO_2 Emission Factors for Fuel Combustion: Common Industry Fuel Types

Variability (%)	Fuel Types	Metric Tons of CO_2 / MMBTU (HHV)					
		API CO2 Emission Factor[1]	AGO Workbook 1.1 (Table 4)	IPCC Volume 3 (Table 1-1)	DEFRA, Protocol A1	WRI/ WBCSD[2]	CIEEDAC
3.6	Aviation Gas	0.0692	0.0717		0.0703	0.0693	
14.4	Bitumen	0.0810	0.0851	0.0808	0.0879	0.0931	
35.2	Coke (Coke Oven/Gas Coke)	0.1085	0.1260	0.1083	0.0879	0.1083	0.0893
5.4	Crude Oil	0.0743		0.0734	0.0703		
6.4	Distillate Fuel	0.0732	0.0718		0.0703	0.0732	0.0750
11.9	Electric Utility Coal	0.0994	0.0966		0.0879		
—	Ethanol	0.0700					
—	Flexi-Coker/ Low Btu Gas	0.113					
1.4	Gas/Diesel Oil	0.0742	0.0735	0.0742	0.0732	0.0732	
2.8	Jet Fuel	0.0723	0.0717		0.0703	0.0709	
4.4	Kerosene/Aviation Kerosene	0.0723	0.0735	0.0716	0.0703	0.0724	
3.8	Lignite	0.0976		0.1013		0.0977	
2.7	LPG	0.0629	0.0626	0.0632	0.0615	0.0631	
2.9	Butane	0.0668					0.0649
5.3	Ethane	0.0597		0.0617	0.0586		
11.6	Propane	0.0704				0.0631	0.0632
2.8	Misc. Petroleum Products and Crude	0.0721	0.0723		0.0703		
2.5	Motor Gasoline	0.0712		0.0694	0.0703	0.0710	
9.7	Naphtha (<104°F)	0.0665	0.0696	0.0734	0.0761		
0.0	Nat Gas Liquids	0.0632		0.0632			
6.8	Natural Gas	0.0531	0.0542	0.0532	0.0556	0.0531	0.0520
7.3	Other Bituminous Coal	0.0931		0.0947	0.0879	0.0931	
0.3	Other Oil (>104°F)	0.0732		0.0734			
—	Pentanes Plus	0.0669					
37.3	Petroleum Coke	0.102	0.1260	0.1010	0.0879	0.1021	0.0987
26.4	Refinery Fuel Gas	0.057	0.0718		0.0586		0.0566
11.0	Residual Fuel	0.0788	0.0718	0.0775	0.0703	0.0789	
—	Special Naphtha	0.0728					
—	Still Gas	0.0642					
8.9	Sub-bituminous Coal	0.0963		0.0962	0.0879	0.0965	
—	Unfinished Oils	0.0742					

Notes:
[1]Primarily taken from EIIP, 1999.
[2]Cites heating value and other fuel property conversion factors from EIA, *Annual Energy Review*, and U.S. Department of Energy, 2000.

dium. ARPEL recommends 98% combustion efficiency for steam-assisted flares and 95% combustion efficiency for non-steam assisted flares.

- For CO_2 combustion emissions, E&P Forum and ARPEL result in slightly higher estimates than the other protocols, even though both use lower combustion efficiencies than in the other documents. Overall, the CO2 combustion emissions range from a low of 41,100 tonnes/yr for the API Compendium to a maximum of 50,400 tonnes/yr using E&P Forum.
- Point source CH_4 and CO_2 emissions for the API Compendium are higher than the other protocols. The API Compendium quantifies emissions by source type, while the other protocols provide fewer source classifications or combine emissions into one general emission factor.
- The Compendium, CAPP, and ARPEL include flashing losses from production tanks, although the API Compendium estimate is approximately 3 times larger than the emission estimate from CAPP and ARPEL. Flashing losses based on the Compendium approach are 1852 tonnes CH_4/yr, while the CAPP estimate is 575 tonnes CH_4/yr, and the ARPEL estimate is 585 tonnes CH_4/yr. E&P Forum has very low point source emissions (0.1 tonnes/yr) because flashing loss emissions are not presented.
- Non-point source CH_4 and CO_2 emissions differ for several of the protocols that provide emission factors for fugitive components, since each document seems to cite a different source of information: The API Compendium emission factors are based on the 1995 EPA protocol document (EPA, 1995); the E&P Forum fugitives estimates are based on API Publication 4589 (API, 1993); CAPP fugitive factors are based on CPA (Vol. II, 1992) which lacks emission factors for several component types that are part of the facility; and ARPEL is based on API Publication 4615 (API, 1995).
- Fugitive emissions based on component counts are highest for CAPP and lowest for E&P Forum. EIIP and IPCC do not provide fugitive component based factors, but rather offer emission factors based on facility throughput (heat or volume basis). Application of IPCC's facility-wide fugitive factor results in the highest emissions for all the protocols evaluated.
- Non-routine CH_4 and CO_2 emissions are only quantified by the Compendium and ARPEL. The Compendium estimate is higher than ARPEL because it includes vessel blow-downs, compressor starts, oil well workovers, and PRV releases, while of these source types ARPEL only quantifies compressor starts.

Figure 4 presents graphically the results for CO_2 and CH_4 emissions estimates for the example facility when using the methodologies provided in the various protocol documents.

Comparative Results

- Methane combustion emissions for this facility are relatively small. E&P Forum has the highest CH_4 combustion emissions (17.8 tonnes/yr) while ARPEL has the lowest (0.24 tonnes/yr). As with the Onshore Oil Field case study, the primary reason for the noted differences is the variation in flare emission factors.
- The CO_2 combustion emissions are relatively similar for all protocols, even though different references are cited. ARPEL seems to take a different approach and excludes CO_2 emission factors for support boats or helicopters. Several of the protocols provide fuel based CO_2 combustion factors, while ARPEL only includes equipment-based factors.
- Point source CH_4 emissions are much higher (by a factor of two) for the API Compendium as compared to the other protocols. This is primarily a result of significantly higher crude flashing losses. CAPP and ARPEL also report tank flashing loss emissions, but their emission estimates are approximately $^1/_2$ of the value estimated from the Compendium. EIIP provides only a single non-combustion CH_4 emission factor specific to offshore platforms. IPCC combines point and non-point emissions into one factor for gas production and two separate factors for oil production.
- Only IPCC and ARPEL provide CO_2 emission factors for point sources. IPCC's factor is based on a roll-up of all vented sources while ARPEL provides a CO_2 factor for flashing losses. IPCC includes non-point CO_2 emissions in their facility gas production factor, and provides a separate CO_2 non-point emission factor for oil production.
- Fugitive emissions based on component counts are highest using the API Compendium emission factors and lowest using E&P Forum's factors. Similar to the Onshore Oil Field case study, EIIP and IPCC provide facility-based (platform or volume basis) rather than component-based fugitive emission factors. Application of IPCC's facility-wide fugitive factor results in the highest non-point emissions for all the protocols investigated.
- The API Compendium is the only protocol that provides emission factors specifically for non-routine sources included in the example cases. These emissions are relatively small (4.9 tonnes/year) for the offshore facility studied.
- EIIP's combined point source CH_4 emission factor appears to include non-routine sources because it references the GRI/EPA methane study (Harrison, et al., 1996) that included non-routine sources.

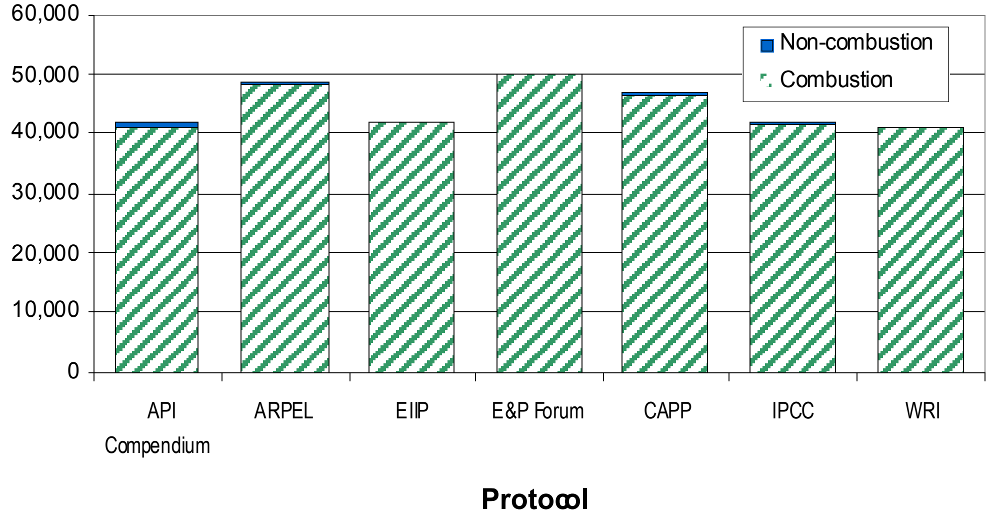
II. Offshore Oil and Gas Platform

Facility Description—This facility consists of 72 wells with a production rate of 150,000 bbl/day of oil emulsion, 36,000 bbl/day of dry crude, and 12 million scf/day of natural gas.

Comparative Results

- Methane combustion emissions range from a low of 6.5 tonnes/yr for ARPEL to 200.4 tonnes/yr for CAPP. The ARPEL emissions are lower than the other protocols due

CO_2 Emissions (tonnes/yr)



CH_4 Emissions (tonnes/yr)

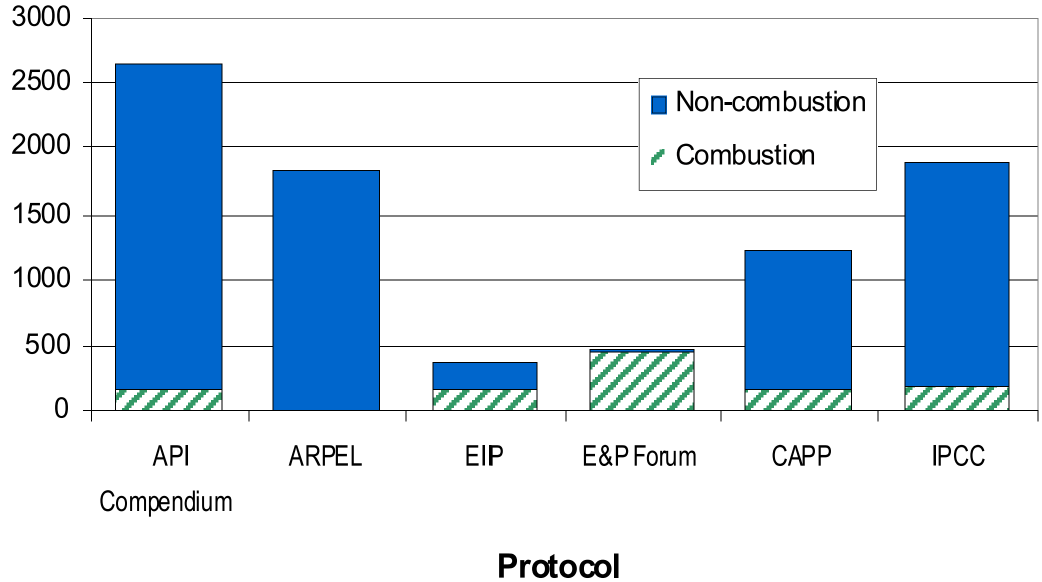


Figure 4—Comparative Emissions Estimate—Onshore Oil Production Facility

III. Natural Gas Processing Facility

Facility Description—This plant processes 800 million scf/day of sour gas with sulfur content of 1.13% (as H_2S).

to the exclusion of turbine emission factors and differences in the flare combustion efficiency.

- The CO_2 combustion emissions are consistently in the 470,000 to 510,000-tonnes/yr ranges for all protocols except ARPEL, which is estimated at 234,500 tonnes/yr. Here also, the ARPEL estimate is low because it does not include emissions from turbines, which contribute 239,000 to 274,000 tonnes/yr, based on the other protocols.
- For point sources, CH_4 emissions vary mainly due to the emission sources that were considered by each protocol. Both the API Compendium and ARPEL include an emission factor for dehydrator vents, and produce comparable results (ARPEL is 9% higher). CAPP does not include any point source CH_4 emission factors for processing.
- EIIP presents a single emission factor that includes both point and non-point sources. IPCC provides a general CH_4 factor for processing fugitives, but it is not clear from their description whether point sources are included in this factor.
- The API Compendium, IPCC, and CAPP present emission factors/estimation approaches for CO_2 emissions from sour gas processing (the API Compendium approach is based on CAPP). The IPCC approach is based on an emission factor rather than the CAPP material balance approach, which accounts for the specific CO_2 concentrations in the sour and processed gas streams at the facility. Emissions estimated following the IPCC method are almost twice as large as those using the CAPP methods. Documentation of the IPCC method is not sufficient to enable a determination of the causes for this large difference.
- ARPEL is the only protocol that provides a CO_2 emission factor for glycol dehydrators. From their text, however, it is not clear how the CO_2 factor was derived to determine if it is an omission from the other protocols.
- For non-point CH_4 emissions, only the API Compendium and ARPEL provide fugitive component emissions factors. ARPEL cites API 4615 (API, 1995), which is also the source of emission factors used in the Compendium for this example.
- EIIP provides a single CH_4 emission factor for point and non-point sources, while IPCC provides a general CH_4 emission factor thought to combine both non-point and point sources. The emission factors provided by EIIP and IPCC result in lower emissions compared to the summed source estimates using the API or ARPEL approaches.
- IPCC presents a general CO_2 emission factor for fugitive sources, referencing a 1999 CAPP report on Canadian upstream Oil & Gas operations and the GRI/EPA study (Harrison, et al., 1996). There is not enough documentation for the IPCC approach to enable one to determine how this factor was derived and whether vented sources are included.
- For non-routine emissions, the API Compendium uses a general emission factor for these maintenance activities, resulting in 77.9 tonnes CH_4/yr. ARPEL provides a source specific emission factor for compressor starts that results in 0.04 tonnes CH_4/yr. EIIP's general point source CH_4 emission factor appears to include non-routine sources because it is based on emissions from the GRI/EPA Methane Study (Harrison, 1996) that quantified non-routine sources. However, the EIIP CH_4 emissions are only one-half as large as the sum for non-combustion emissions from ARPEL and the API Compendium.

IV. Production Gathering Compressor Station

Facility Description—This facility is comprised of a 3400-hp compressor station with four reciprocating compressors and 80 miles of gathering pipeline.

Comparative Results

- Methane combustion emissions vary from a low of 1.5 tonnes/yr using EIIP and IPCC to a maximum of 101 tonnes/yr using ARPEL. EIIP, CAPP and IPCC are based on the 1995 version of AP-42. The API Compendium on the July 2000 version (Supp. F) and ARPEL on the April 1993 version.
- The E&P Forum document references internal data as the source of their emission factors.
- Carbon dioxide emissions from combustion sources are relatively similar for all protocols, ranging from 11,020 tonnes CO_2/yr using CAPP to 13,399 tonnes CO_2/yr using WRI.
- Pneumatic devices are the only point source specified for this facility. Emission estimates for the pneumatic devices using the API Compendium and CAPP are comparable (96.7 tonnes CH_4/yr for the API Compendium versus 92.2 tonnes CH_4/yr for CAPP), although the two protocols rely on different references for their emission factors.
- EIIP provides a single rolled-up emission factor for this facility that presumably includes both point and non-point sources. Use of this factor results in estimated emissions of 29.6 tonnes CH_4/yr, much lower than the pneumatic device emissions estimated using the other protocols.
- The pneumatic device emissions estimated using the factors presented in ARPEL are 325.5 tonnes CH_4/yr for this facility, which might be demonstrating some discrepancy in unit conversion or the throughput basis (volume vs. mass). However, since details on these conversions are lacking, it is not possible to ascertain the reason for the large difference noted.
- Non-point CH_4 emissions for this facility consist of fugitive emission components estimated on a component basis for all protocols except EIIP, which provides a rolled-up emission factor. Each protocol cites a different

source for the fugitive emission factors, resulting in a range of estimated non-point emissions from 12.6 tonnes CH_4/yr using E&P Forum to 29.0 tonnes CH_4/yr using the API Compendium.

- Specific non-routine emissions are only quantified in the API Compendium and ARPEL. EIIP's rolled-up point source CH_4 emission factor appears to include non-routine sources because it is based on emissions from the GRI/EPA methane study that included non-routine sources. The API Compendium includes pipeline blow downs, compressor starts and blow downs, PRV releases, and pipeline leaks, resulting in a higher emission estimate than ARPEL, which includes only compressor starts and pipeline venting.
- The ARPEL pipeline-venting emissions are unique in the sense that they include an emission factor for line depressurizing and pigging, as well an emission factor for "pull backs" or venting associated with water removal. However, the pipeline-venting factor in ARPEL is based on the number of wells rather than pipeline miles, requiring knowledge of the number of wells in order to be able to use this factor.

V. Marketing Terminal

Facility Description—This marketing terminal has a loading rack capacity of 300 million gallons per year throughput. The loading rack is equipped with a propane fueled vapor combustors to control volatile hydrocarbon emissions.

Comparative Results

- Combustion emissions result primarily from diesel-fueled fire pump engines and other mobile sources (heavy duty diesel trucks). Methane combustion emissions are very low for this facility with emissions in the range of 0.12 to 0.15 tonnes/yr for all protocols except ARPEL, which results in estimated emissions of less than 0.01 tonnes CH_4/yr. The reason that the ARPEL estimate is about 90% lower than the others is due to the fact that it does not include the emissions of the diesel trucks.
- CAPP is the only protocol that provides a CH_4 emission factor for propane combustion, though the emissions are negligibly small (less than 0.001 tonnes/yr for this example).
- Carbon dioxide combustion emissions for the WRI/WBCSD Protocol are very comparable to the API Compendium estimates, with both resulting in higher estimated emissions when compared to other protocols, due to the inclusion of CO_2 emissions from the combustion of the gasoline fuel loading vapors (contributing 2,070 tonnes CO_2/yr).
- The API Compendium and the WRI/WBCSD Protocol also include vapor combustor emissions from diesel and jet fuel loading.
- The vapor combustor emission estimation approach presented by the API Compendium relies on fuel carbon contents expressed as weight fractions and the WRI/WBCSD Protocol references this API method in its stationary combustion tool.
- None of the protocols provide emissions guidance for CH_4 or CO_2 emissions for point, non-point, or non-routine emissions for marketing terminals due to the insignificant quantities of CH_4 and CO_2 in refined liquid products.

VI. Refinery

Facility Description—The refinery in this example has a crude throughput of 250,000 bbl/day, designed primarily to produce transportation fuels.

Comparative Results

- Inclusion of coke burn-off rates during catalyst regeneration is a major contributor to the overall CO_2 emissions from refineries, however it appears to have been overlooked by many of the protocols reviewed. Methane combustion emissions are all much lower than CO_2 but they vary considerably when using the different protocols. Values obtained are ranging from a low of 113 tonnes CH_4/yr for EIIP and IPCC to 633 tonnes CH_4/yr for CAPP. As noted earlier, WRI and CIEEDC do not provide CH_4 emissions guidance for refineries.
- The CO_2 combustion emissions for the refinery case study are relatively consistent among the protocols investigated, ranging from a low of 2,664,000 tonnes/yr for ARPEL to a maximum of 3,022,000 for the CIEEDAC.
- The ARPEL estimate is lower since it lacks a specific emission factor for CO_2 emissions from turbines, and 3 turbines are included in the refinery example studied.
- Three of the protocols (EIIP, CAPP, and IPCC) do not provide information on how to estimate CO_2 from refinery flares. These protocols provide information for upstream or processing flares, but not refinery flares.
- ARPEL and CIEEDAC are the only protocols that provide emission factors for the combustion of refinery fuel gas in boilers and heaters. The other protocols provide only natural gas emission factors that were used for the emissions comparison.
- No CH_4 emissions are estimated for point sources for any of the protocols except IPCC and EIIP, with EIIP citing the IPCC emission factors. IPCC provides a CH_4 factor for crude oil tanks in refining and a rolled-up general refining factor that presumably includes both point and non-point sources. Using these factors results in emissions of 477 tonnes CH_4/yr with a slightly higher value for EIIP due to round off in unit conversions.
- The API Compendium and CIEEDAC are the only protocols that provide an approach to estimate the catalytic cracker regeneration vent CO_2 emissions, using the coke burn rate. This source results in 1,973,000 tonnes CO_2/yr using the API approach and 1,478,000 tonnes CO_2/yr using the CIEEDAC emission factor. The API method

includes an estimate of the coke carbon content while the CIEEDAC approach uses a simple emission factor that does not vary with the coke carbon content.

- ARPEL provides CH_4 emission factors in terms of unit feed rate for catalytic cracker regeneration vents based on mode of operation. A range of emissions can be estimated using the petroleum coke heating values from the API Compendium, with emissions varying from 11,400 tonnes CH_4/yr for conventional burn, to 4,760 tonnes CH_4/yr for partial CO burn, and becoming negligible for the full CO burn. Thus, this emission source warrants additional attention where full CO burn is not used.
- None of the protocols provide an approach for estimating fugitive emission factors on a component basis specifically for CH_4. While refinery hydrocarbon fugitive emission factors are available in the literature, the CH_4 content of the streams is typically assumed to be negligible for non-fuel gas components. Although fuel gas components may contain CH_4, associated component counts are not typically available and are not given for this example.
- None of the protocols provide a specific method to estimate non-routine emissions (except possibly IPCC and EIIP, which present a refining rolled-up emission factor that may include non-routine emissions). Following the US practice, the API Compendium states that non-routine emission sources are generally routed to the fuel gas system or to flares, and thus would be included in the overall estimate of combustion emissions.

Figure 5 presents the estimated emissions from the example refinery when the various protocol documents are applied to the same set of sources and devices.

CONCLUSIONS

The main conclusion from this review of greenhouse gas emission estimation protocols is that differences in the resultant emissions inventory could be significant, in some cases, depending on the approach used to calculate emissions, and the assumptions governing the choice of sources, fuels and operating practices.

Therefore, 'transparency' is a key issue, as many of the protocol documents do not provide enough detail to understand the derivation of the emission factors. Careful documentation of the underlying conditions and assumptions is necessary to ensure proper implementation of the guidance provided by the protocols.

Quantitative comparisons, in which the application of the protocols was demonstrated for a range of industry example facilities, enables a better understanding of differences noted in a mere qualitative assessment. Primary contributors to the differences observed both in the qualitative and quantitative comparisons among the various protocols can be attributed to:

a. Omission of some emission source types from several of the protocols,

b. Differences in emission factors recommended, due to the sources included or the information cited, and

c. Hierarchy of the different "tiers" or levels of emission factors – where some of the protocols lump several emission sources into one emission factor.

Next Steps

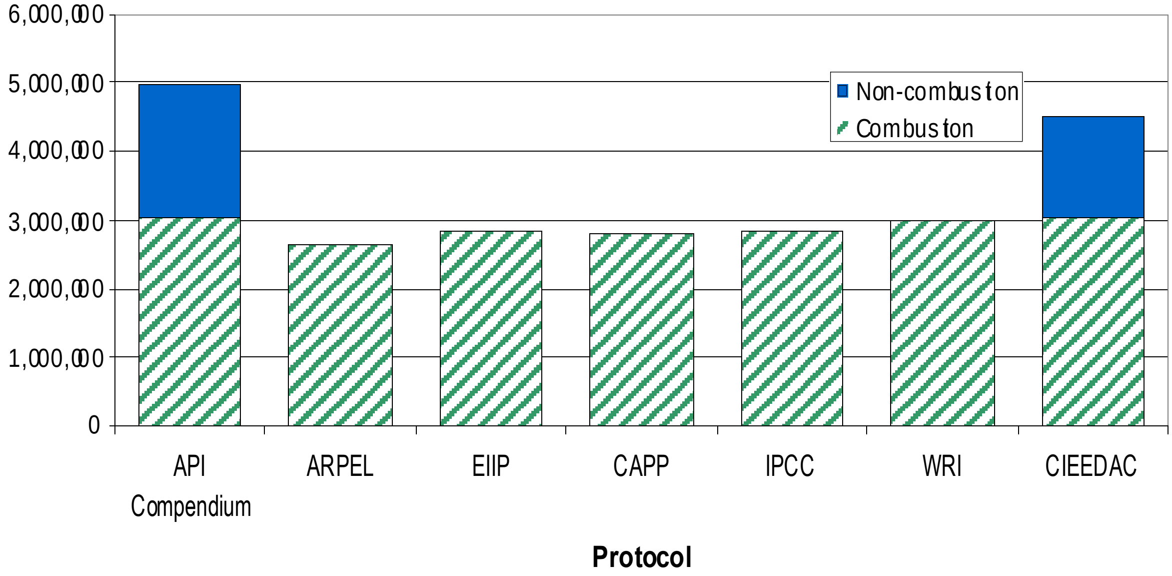
API and its members will continue to work over the next few years to refine and promote globally a common methodology for estimating emissions within the industry.

This outreach effort will include closer collaboration with petroleum industry associations in different regions of the world in order to achieve better harmonization of protocols and enable improved global comparability of emission estimates for Oil & Gas Industry sources and operations.

Key Findings

- General fuel based emission factors provided in the protocol documents include assumed "average" fuel properties that are often not documented. Use of fuel specific data eliminates the potential for variability.
- Combustion emissions are presented on either a higher heating value basis (HHV) or a lower heating value (LHV) basis. Some of the protocols do not clearly indicate which basis is used and the reader must delve deeply into the text to find the basis.
- Using a single emission factor to represent a compilation of sources generally underestimates emissions due to the exclusion of some sources. Thus, basing an inventory on the summation of source specific emission factors clearly shows which source types are included.
- Methane emissions are not included in many of the protocols.
- Use of turbines is increasing and will therefore necessitate specific emission factors for turbine combustion emissions, to obtain an accurate emissions estimate.
- Flashing losses from production tanks could be significant for a variety of exploration and production facilities and need to be included in sectors' protocols.
- A myriad of devices such as pneumatic devices and chemical injection pump emissions are addressed differently by various protocols.
- Only a few of the protocols reviewed include the dehydrator vent emissions that are associated with the drying of natural gas during production or transmission.
- Indirect emissions from electricity cogeneration, its usage or steam imports and exports are included in most – but not all – the protocols.
- Significant variation in CH4 emissions from combustion sources occurs due to different versions of U.S. EPA's AP-42.

CO_2 Emissions (tones/yr)



CH_4 Emissions (tones/yr)

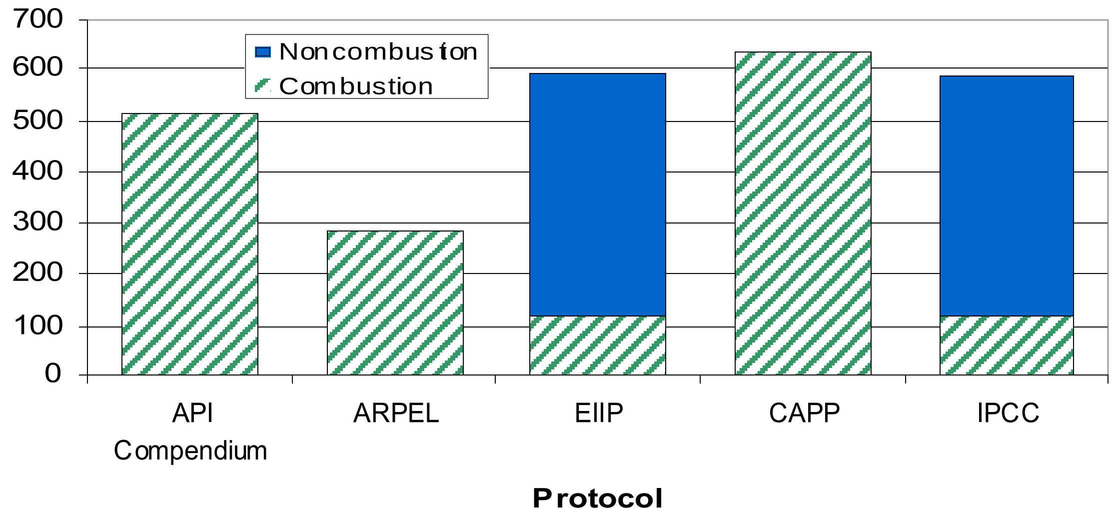


Figure 5—Comparative Emissions Estimate—Large Complex Refinery

ACKNOWLEDGEMENTS

Theresa Shires, Graham Harris and Chris Loughran of URS Corporation compiled the API Methodology Compendium and also conducted both the qualitative and quantitative comparisons of the listed protocols and case study examples.

The work was coordinated and supervised by API's Greenhouse Gas Emissions Methodology Work Group, chaired by Susan Nordrum of ChevronTexaco, with participation of representatives of BP, ChevronTexaco, ConocoPhillips, ExxonMobil, Marathon, Murphy Oil, and Shell.

Karin Ritter, Regulatory and Scientific Affairs Department along with Robert Greco and Russell Jones of the Global Climate Team provided API staff support.

Dr. Miriam Lev-On of The LEVON Group, LLC, drafted this synopsis.

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