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METHANE AND CARBON DIOXIDE EMISSION ESTIMATES FROM U.S. PETROLEUM SOURCES

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Methane and Carbon Dioxide Emission Estimates From U.S. Petroleum Sources

Health and Environmental Sciences Department

API PUBLICATION NUMBER 4645

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EXECUTIVE SUMMARY

The United States Environmental Protection Agency (EPA) and others have previously estimated United States emissions of greenhouse gases, including the contribution from the United States petroleum industry. This has led the United States petroleum industry to conduct this more refined estimate of its emissions of carbon dioxide (CO₂) and methane (CH₄) for the base year of 1990 and to project those emissions to the year 2000.

This study consisted of four tasks:

1. Comparison of emission estimation methodologies from published sources;
2. Estimation of year 1990 industry emissions using the Intergovernmental Panel on Climate Change (IPCC) methodology to the extent possible as well as data from other sources as necessary;
3. Selection of a methodology for projecting emissions to the year 2000; and
4. Estimation of emissions for the year 2000.

Tasks 1 and 2 were based upon reviews of existing greenhouse gas inventory literature, and Tasks 3 and 4 were based upon review and use of available published data showing activity and emission projections. Emission estimates for a given time period are calculated by multiplying an emission factor (e.g., units of mass emissions per volume throughput) by an activity rate (e.g., units of volume throughput per time period).

API previously estimated global emissions of carbon dioxide and methane from petroleum sources in reports issued in 1991-1992. This report updates those estimates for the exploration and production, crude transportation, refining, and product transportation segments of the United States petroleum industry. The approach used

in this study represents the best available approach for the level of emissions and activity data that is publicly available. This approach is preferable to the United Nation's IPCC methodology for calculating national estimates of greenhouse gas emissions for two reasons:

- 1) It is specific to the petroleum industry; and
- 2) It includes some source categories which are omitted in the IPCC methodology.

RESULTS

Existing greenhouse gas emissions literature was reviewed, examining the following key parameters: boundaries, detail level, representativeness, comprehensiveness, data quality, and practicality. None of the existing studies reviewed were found to be ideal for estimating emission rates for the U.S. petroleum industry, but a best estimate approach was developed using the IPCC methodology as a basis with supplemental estimates from the other studies examined. Methods for estimating (year 1990) and projecting (year 2000) activity factors for the petroleum industry were developed based on the literature. Projected changes to emission factors resulting from implementation of proposed regulations as well as energy efficiency improvements were also identified.

Table ES-1 presents the estimated and projected methane and CO₂ emissions from the U.S. petroleum industry. The total year 1990 emissions of CO₂ from petroleum production through product transport are 284 million tons, which compares reasonably well with the estimate in the previous API report of 300 million tons. The differences can be attributed to updated activity factors for the production and transportation industry segments, and to accounting for actual refinery utilization in determining the year 1990 refinery activity factors. The CH₄ emissions of 0.848 million tons for 1990 may be contrasted with an estimate of 0.392 million tons in the previous API study. The difference in the methane estimates can be attributed to the inclusion of production tank emissions and the use of updated activity factors in this study.

Table ES-1. Estimated and Projected Emissions of Greenhouse Gases from the Petroleum Industry (Million Tons per Year).

	Year 1990	Year 2000	Change
Carbon Dioxide	284	288	1.4%
Methane	0.848	0.609	-28%

Total carbon dioxide emissions are projected to increase slightly from 284 million tons in 1990 to 288 million tons in the year 2000. Emissions of CO₂ are projected to decrease in the crude transport segment, but increase slightly in the other industry segments. Projected annual emissions of methane show a reduction of 0.239 million tons over the period. This reduction occurs primarily in the exploration and production segment due to reductions in both the emission factors and the activity factor (amount of crude produced).

The Global Warming Potentials (GWP) recommended by the IPCC and developed by other studies allow scientists to compare the ability of each greenhouse gas to trap heat in the atmosphere relative to other gases. The 100 year GWP for carbon dioxide is 1 and for methane it is 24.5. This means that each ton of methane has about 25 times more global warming impact than a ton of carbon dioxide. When adjusted for GWP, Table ES-2 shows that greenhouse gas emissions (CO₂ and CH₄) from the U.S. petroleum industry will decrease by 0.6% from 1990 to 2000.

Table ES-2. Estimated and Projected GWP-Adjusted Emissions of Greenhouse Gases from the Petroleum Industry (Million Tons per Year).

	GWP	1990 Emissions	1990 GWP Adjusted Emissions	2000 Emissions	2000 GWP Adjusted Emissions	% Change (from 1990 to 2000)
Carbon dioxide	1	284	284	288	288	1.4%
Methane	24.5	0.848	20.8	0.609	14.9	-28%
Total			305		303	-0.6%

SENSITIVITY ANALYSIS

Most of the emission factors used in this study were developed from limited samples of emission measurements. This study's estimate could be further refined in the future if more detailed data become available. No such estimates exist today, although an ongoing study by the U.S. EPA Office of Research and Development (ORD), "*Methane Emissions from the Petroleum Industry*," may provide that detail for methane in the near future.

General sensitivity examinations were conducted to examine key sources of emissions. For CO₂, the top four emission sources are: drilling, refinery thermal processes, refinery atmospheric separation, and catalytic hydrorefining. The activity factors for these categories are expected to be fairly constant over the ten year period examined in this study, and the emission factors from these sources are known with a reasonable level of certainty. Therefore, the CO₂ estimates in this study do not appear to be very sensitive to the assumptions made.

The general sensitivity examination for methane revealed that the largest single emission source is production tanks and the second largest is production "fugitives, maintenance, and venting & flaring." These two sources dwarf the emission estimates for the other industry segments. Regarding the sensitivity examination:

- The emission estimate is not performed on an equipment level of detail and therefore has some inherent uncertainties.
- The activity factor for these sources is production rate which is somewhat uncertain for the year 2000.
- There is considerable uncertainty as to the absolute level of the methane emission factors for sources in these categories, but it is expected that these factors will remain flat or decline over the period due to measures being undertaken by the industry. As a result, the trend in methane emissions will be flat to declining from 1990-2000.

Therefore, the absolute level of estimates of methane emissions for 1990 and 2000 are more uncertain than the carbon dioxide estimates; nevertheless, the trend in methane emissions is downward from the 1990 levels.

As indicated in Table ES-2, the CO₂ emissions dominate the GWP-adjusted emissions from the U.S. petroleum industry. Therefore, the total estimates of greenhouse gas emissions from the petroleum industry are not likely to be very sensitive to the assumptions made, despite the greater uncertainty in the methane emissions.

CONCLUSIONS

The estimated emissions resulting from this study showed that current estimates of greenhouse gas emissions from the United States petroleum industry are reasonably consistent with previous estimates and that little change is expected in these emissions from 1990 to 2000.

Section 1

INTRODUCTION

The objective of this project is to revise and update the methodology and inventory for methane (CH₄) and carbon dioxide (CO₂) emissions from the United States petroleum industry. API had previously estimated global emissions of methane and carbon dioxide from petroleum sources in reports issued in 1991-1992 (Radian 1991; Radian 1992). This project focuses on emissions from the United States and updates the estimates for the production of crude through the transport of refinery products.

This effort has been divided into four tasks:

- Task 1: Comparison of Methodologies—This task compares the attributes of available methodologies and the relative applicability to emissions from the U.S. petroleum industry (see Section 2).
- Task 2: 1990 Emission Estimate—To the extent possible, the methodology outlined by the Intergovernmental Panel on Climate Change (IPCC) is used in this task to update the previous methane and carbon dioxide emission estimates for the year 1990 (see Section 3). Data from other sources are used as necessary.
- Task 3: Selection of Methodology for Projecting Emissions—This task reviews methods for projecting U.S. petroleum industry emissions to the year 2000 and recommends an approach (see Section 4).
- Task 4: Estimation of Emissions for the Year 2000—Based on recommendations outlined in Task 3, this task computes methane and carbon dioxide emission estimates for the year 2000 (see Section 5).

PETROLEUM INDUSTRY BOUNDARY DEFINITION

Boundaries define what is considered the "petroleum industry" and can exclude certain equipment that is not directly related to the petroleum industry. Boundaries must be

established for the petroleum industry that are technically reasonable, and that match the boundaries used by other accepted U.S. studies such as the GRI/EPA methane emissions study for the natural gas industry (Radian, 1996).

The petroleum industry can be broken into distinct segments so that data from existing reports can be compared on a consistent basis, and so that segments excluded by certain reports become more readily apparent. Based upon examination of existing emission estimates, the following four segments provide the most consistent approach:

- 1) Production (exploration/extraction)—This includes all well and surface production equipment, including storage tanks associated with domestic crude production;
- 2) Crude transportation—This includes all truck, marine, rail, and pipeline transportation of crude, including imported crude;
- 3) Refining—This includes crude storage tanks, all refinery units, and finished product tanks;
- 4) Product transportation—This includes all transport of refinery products by truck, marine, rail, and pipelines.

Figure 1-1 shows a simplified conceptual diagram of these industry segments.

Because oil and gas can be produced from the same well, the production segment presents some interesting boundary issues, where some equipment may be related solely to natural gas production, and therefore may not be part of the petroleum industry. Figure 1-2 shows the production sector boundary definitions as defined in the GRI/EPA methane emissions study (Radian, 1996a). The GRI/EPA study of methane emissions from the natural gas industry deals with the production boundary issue on an equipment level detail. Although the GRI/EPA report specified the natural gas industry boundaries, by inference all items outside of the gas industry boundaries are petroleum industry equipment. Experts from API member companies participated in determining

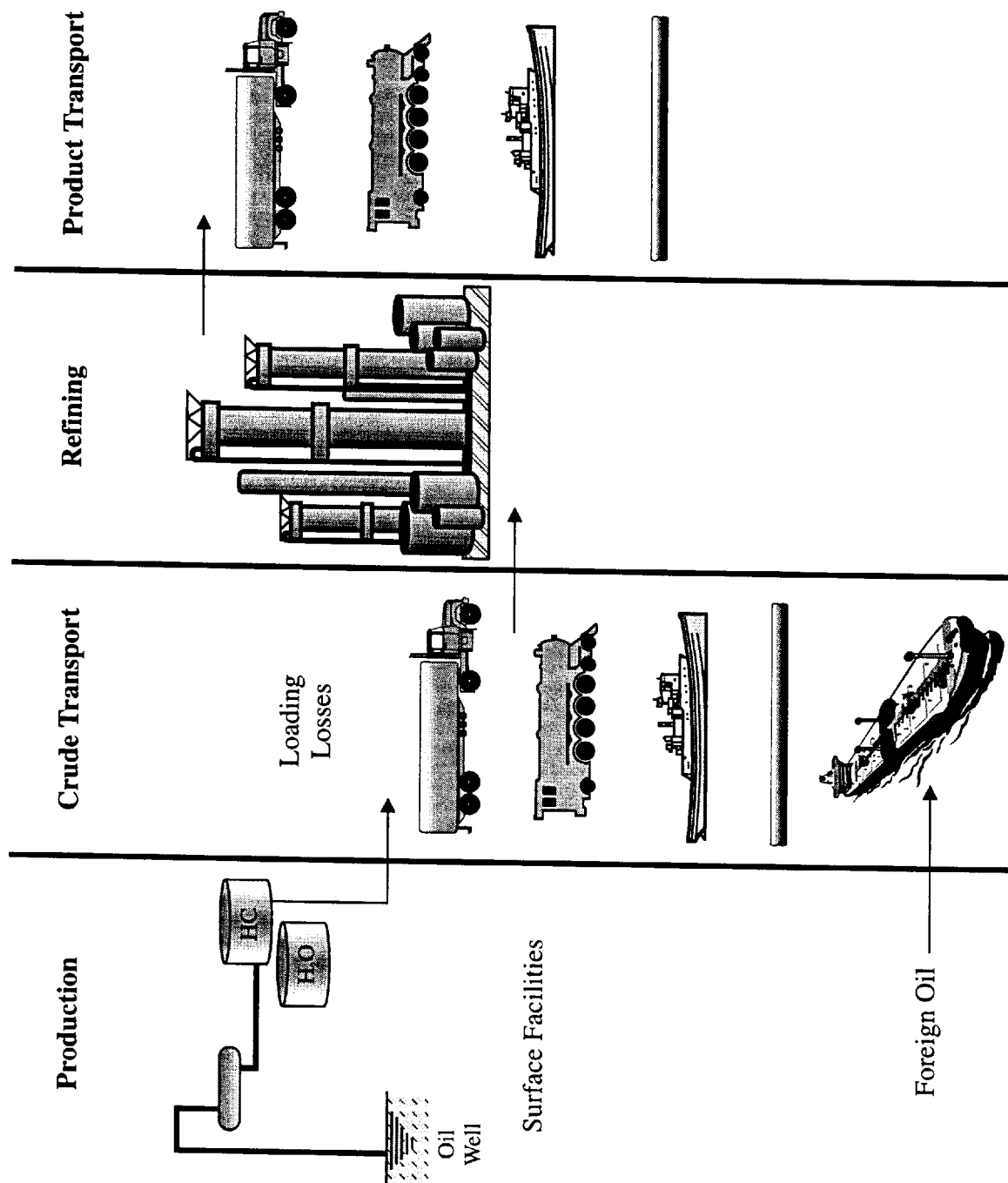
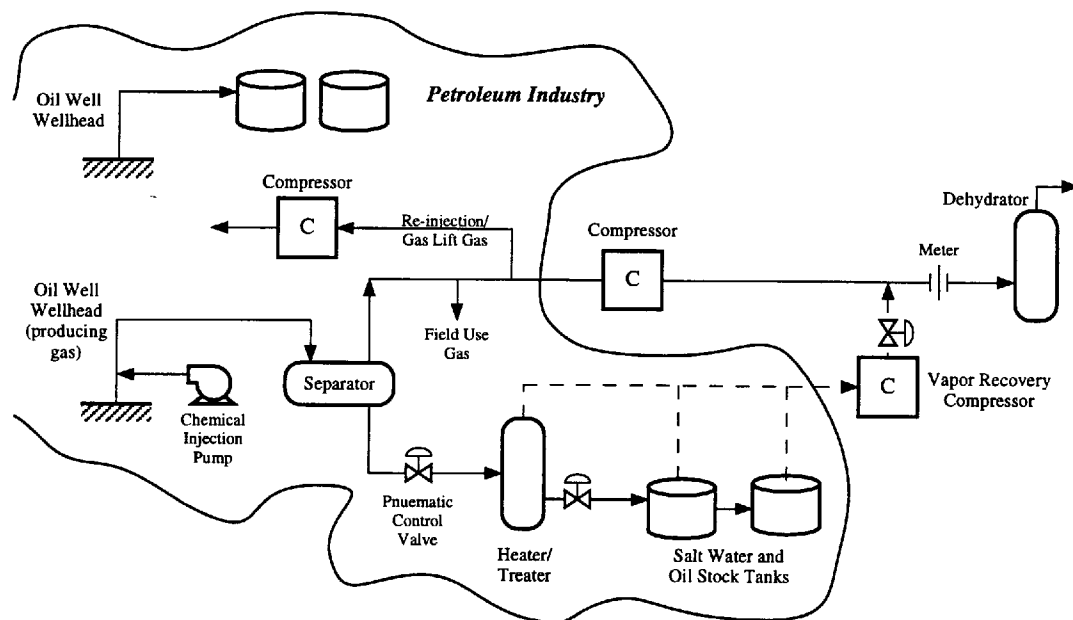


Figure 1-1. Petroleum Industry Segments.

Oil Wells



Gas Wells

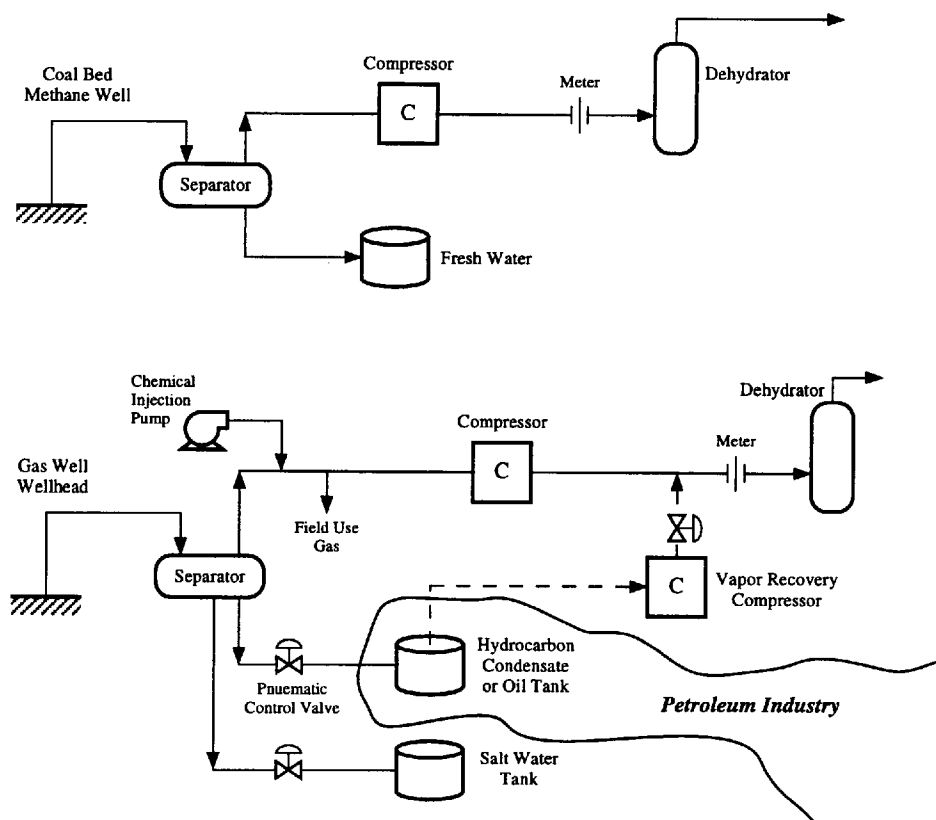


Figure 1-2. Industry Boundaries.

the boundary definition used in the GRI/EPA report. Therefore this report recommends the production boundaries shown in Figure 1-2.

All downstream equipment in crude transportation are included within the petroleum industry boundaries.

Refining includes all refinery equipment and tanks (crude and product tanks).

Aromatics and isomerization processes in refineries are also included. However, the refinery boundary excludes the downstream chemical plant operations such as steam cracking ethylene plants, plastic/rubber operations, etc., even though these operations may sometimes be integrated within a refinery complex. The refinery boundaries are consistent with those used by *The Oil and Gas Journal* for reporting refining activities (Thrash, 1991).

Product transport includes all refinery fuel products, but similar to the refining segment, it excludes chemical plant products.

Section 2

COMPARISON OF METHODOLOGIES

The strengths and weaknesses of various recommended methodologies for estimating methane and carbon dioxide emissions from the petroleum industry are compared in this section. This effort centers on the comparison of other, more recent methodologies and inventories to the earlier API reports on greenhouse gas emissions:

API Global Emissions of Methane from Petroleum Sources (Radian, 1991).

API Global Emissions of Carbon Dioxide from Petroleum Sources (Radian, 1992).

The scope of the methodology comparison was limited to evaluation of the following four sets of reports:

EPA Office of Air and Radiation Reports:

- a) *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA, 1994).
- b) *Anthropogenic Methane Emissions in the U.S., Report To Congress* (EPA, 1993a).
- c) *Options for Reducing Methane Emissions Internationally, Report To Congress*, (EPA, 1993b).

IPCC: *Guidelines for National Greenhouse Gas Inventories*, Volumes 1 through 3 (IPCC, 1995).

E&P Forum: *Methods for Estimating Atmospheric Emissions from E&P Operations* (E&P 1994).

GRI/EPA: *Methane Emissions from the Natural Gas Industry* Multiple reports (Radian, 1996).

In the following portions of this text, the eight reports listed above will be referred by the following names: API CH₄ report, API CO₂ report, EPA Greenhouse report (a), EPA RTC (b,c), IPCC report, E&P Forum report, and GRI/EPA reports, respectively.

STANDARD APPROACH

Most of the reports reviewed calculate total emissions using a standard approach that employs activity factors (AF's) and emission factors (EF's) in the following manner:

$$\text{Emissions} = \text{AF} \times \text{EF} \quad \text{Equation (2-1)}$$

where:

Emissions	=	total annual emissions for a specific source reported as a volume or mass per year;
AF	=	activity factor, which is an equipment or unit population or level of activity; and
EF	=	emission factor, which is the emission rate per equipment or emission rate per activity.

The evaluation of methodologies involved examination of both the emission factor and activity factor sources. The sources listed above were reviewed and key elements from each source were compared.

LITERATURE REVIEW

The literature review for this API project was limited to the eight reports listed previously. Some literature search data were available from a concurrent project, however, very few of these sources produced overall methodology data. API directed that the reports listed in the original proposal should be the main focus for this evaluation (API CO₂ report, API CH₄ report, EPA reports, IPCC report, E&P Forum report, and GRI/EPA reports). In a few instances, other reports were evaluated for specific equipment source references; these reports are mentioned in the following sections.

KEY ELEMENT COMPARISON/RANKING

The methodology analysis culminated in a comparison of key elements or parameters. These key elements are: boundaries, detail level, representativeness, comprehensiveness, data quality, and practicality:

- | | | |
|----|----------------------------|---|
| 1) | Boundaries: | What equipment, especially in the field production area, is included or excluded from the petroleum sector? |
| 2) | Detail Level: | At what level were the emission calculations made (i.e., individual equipment emission factors, or single factors for an entire segment)? |
| 3) | Representativeness: | Were data generated specifically for the U.S. petroleum industry or extrapolated from other industries? |
| 4) | Comprehensiveness: | Did the study include all significant emission sources? |
| 5) | Data Quality : | What was the quality of the data used in the study (i.e., test results or engineering judgement)? |
| 6) | Practicality: | Can the technique be applied by industry, considering current data limitations? |

The criteria established for each of these ranking parameters is described in the following subsections.

Boundaries

The boundary (i.e., emission sources relative to the U.S. petroleum industry) adopted by the report being evaluated was compared against the selected API petroleum industry boundary as discussed in Section 1. Most of the reports, with the exception of the GRI/EPA reports, did not estimate emissions on an equipment level so distinct industry boundaries could not be utilized. This is an issue for the production segment particularly, where some of the references report emissions that combine both oil and

natural gas industry sources. For example, the IPCC report provides only one methane emission estimate for production, which is based on both oil and gas production activities; no method of separating oil emissions from natural gas is provided.

Detail Level

Detail level refers to the extent at which the calculations were made, such that the more detail involved, the better the approach (more representative of the industry, better quality data, etc.). For example, the E&P Forum report states that calculations can be made in one of five increasingly accurate levels of detail:

- Tier 1: Preliminary regional estimate;
- Tier 2: Emission factor based on fuel consumption and quantity of gas vented and flared;
- Tier 3: Application of emission factors to generic pieces of equipment;
- Tier 4: Application of equipment specific emission factors and operational data such as load variations; and
- Tier 5: Emission data derived from direct measurement.

However, many of these levels of detail are redundant or apply only to a specific site emission estimate, rather than a national estimate. For example, Tier 5 is not possible for a national estimate because it is unrealistic to directly measure emissions from every piece of equipment. Therefore, the Tier 5 approach would have to be combined with Tier 3 to extrapolate measurements from representative pieces of equipment to a national emission estimate.

The following tiers will be used for this API evaluation of the detail level of national estimates:

- Tier 1: Emission data from other reports of unknown quality;
- Tier 2: Approximate industry wide estimates;

- Tier 3: Unit/Operation specific emission factors; and
- Tier 4: Equipment specific emission factors.

Most reports did not define the detail level at which the values were calculated. However, the detail level can be subjectively determined by review of the report. Table 2-1 shows the emission estimate for each industry segment covered by the reports and the detail level estimated by this analysis. Further breakdown of report detail is discussed in the following sections and shown in Tables 2-2 through 2-11. Please refer to the reports reviewed for details on the sources and calculation techniques used.

Table 2-1. Comparison of Report Detail Levels and Emission Estimates by Industry Segment.

Report(s)	Production		Transportation		Refining		Product Transportation	
	CH ₄	CO ₂	CH ₄	CO ₂	CH ₄	CO ₂	CH ₄	CO ₂
API CO ₂		Tier 3 83 MM tons		Tier 3 10 MM tons		Tier 3 197 MM tons		Tier 3 10 MM tons
API CH ₄	Tier 2 217 k tons		Tier 3 16 k tons		Tier 3,4 97 k tons			
EPA Greenhouse	Tier 2 279 k tons	Tier 2 7 MM tons	Tier 1 7 k tons		Tier 1 13 k tons			
EPA RTC	Tier 2 25 k tons (533) a		Tier 2 7 k tons		Tier 2 14 k tons			
IPCC	b		b		b			
E&P Forum	Tier 1 57 k tons	Tier 1 82 MM tons c	b	b				
GRI/EPA	Tier 4 d							

Notes:

Units for carbon dioxide emissions are in million tons carbon dioxide (MM tons) and methane emissions are in thousand tons methane (k tons). Blank cells indicate no estimate.

- a Methane emissions for production would be as high as 533,000 tons if the "venting and flaring" emissions estimated by the RTC were included.
- b Indicates areas where the report offered emission factors at the unit (Tier 3) or equipment (Tier 4) detail level, but did not provide corresponding activity factors to develop an emission rate estimate.
- c Emission estimate based on total production of oil and gas.
- d Indicates that the report did not calculate a U.S. inventory for the petroleum industry, but has applicable emission factors.

MM tons = 10⁶ tons
k tons = 10³ tons

Table 2-2. 1990 CO₂ Emissions Summary from API: Global Emissions of Carbon Dioxide from Petroleum Sources.

API CO ₂ Emissions Summary		CO ₂ EF	CO ₂	CO ₂ AF	AF units	CO ₂ tons	Subtotal CO ₂ tons	EF Quality	Emission Factor Basis and Activity Factor Basis (where known)
1. Exploration/Extraction Drilling Extraction Venting & Flaring Losses 2. Crude Handling	Drilling	2887.43	ton/drilled well	27,837	wells drilled	80,377,389	82,534,246	good	combustion equipment (power gen. & other engines)- (Radian, 1989)
	Extraction	3.5	ton/well	616,245	active wells	2,158,858		incomplete	combustion equipment (power gen. & other engines)- (Radian, 1989)
	Venting & Flaring	0	ton/scf	9,800E+10	cubic ft	0		poor	DOE Energy Information Administration - Venting & Flaring
	Truck Transport	1.1E-05	ton/Bbl mile	1,100E+10	Bbl mile	125,939	10,475,509	good	Fuel type and efficiency, Bbl mile from Transportation in America
	Marine Transport	1.3E-06	ton/Bbl mile	2,631E+12	Bbl mile	3,289,250		good	Fuel type and efficiency, Bbl mile from Transportation in America
	Rail Transport	6E-06	ton/Bbl mile	5,170E+09	Bbl mile	31,020		good	Fuel type and efficiency, Bbl mile from Transportation in America
	Pipeline	3E-06	ton/Bbl mile	2,343E+12	Bbl mile	7,029,300		good	Pump station EF (Radian, 1976) Bbl mile from Transportation in America
	3. Refining *	3.7E-05	ton/Bbl	4,951,742,570	Bbl	183,214	196,843,493	unknown	Radian 1980 established tons CO ₂ /barrel total refinery capacity
	Flaring	0.008349	ton/Bbl	4,951,742,570	Bbl	41,339,623		good	Heating req. per unit (Radian, 1980), fuels profile
	Equipment Leaks	0.082649	ton/Bbl	719,926,000	Bbl	59,500,804		good	Capacity from Oil and Gas Journal
4. Product transport	-Atm Sep	0.0167	ton/Bbl	1,412,721,550	Bbl	2,358,539		good	"
	-Thermal processes	0.025045	ton/Bbl	880,015,000	Bbl	22,039,976		good	"
	-cat hydrotreating	0.030054	ton/Bbl	414,338,875	Bbl	12,452,333		good	"
	-Alkyl	0.018645	ton/Bbl	893,885	Bbl	16,666		good	"
	-Hydrogen	0.008349	ton/Bbl	2,573,076,625	Bbl	21,481,330		good	"
	-Vacuum Sep	0.008349	ton/Bbl	2,066,982,225	Bbl	17,256,201		good	"
	-Cat cracking	0.016697	ton/Bbl	442,631,850	Bbl	7,390,403		good	"
	-Cat hydrocracking	0.006626	ton/Bbl	2,604,384,500	Bbl	1,630,605		good	"
	-Cat hydrotreating	0.028384	ton/Bbl	286,858,975	Bbl	8,142,205		good	"
	-Arom/Isom	0.01357	ton/Bbl	87,727,750	Bbl	1,190,422		good	"
5. Other	-Lubes	0.006345	ton/Bbl	264,863,710	Bbl	1,680,560		good	"
	-Asphalt	0.006652	ton/Bbl	27,153,445	Bbl	180,611		good	"
	-Cokes	0	ton/Bbl	4,951,700,000	Bbl	0		-	Not considered a source for CO ₂
	Tanks	1E-05	ton/Bbl mile	2,365E+11	Bbl mile	2,412,708	9,683,752	good	Average specific gravity of 6 products, fuel type and efficiency
	Truck Transport	1.1E-06	ton/Bbl mile	1,100E+12	Bbl mile	1,210,000		good	Bbl mile from Transportation in America
	Marine Transport	5.3E-06	ton/Bbl mile	9,048E+10	Bbl mile	479,544		good	"
	Rail Transport	3.1E-06	ton/Bbl mile	1,830E+12	Bbl mile	5,581,500		good	"
	Pipeline								
	Total						300	10 ⁶ tons CO ₂	
							5,160	Bscf CO ₂	

* Note: Previous API report (Radian, 1991) cited 182,538,000 tons CO₂ for refining, but this number was based on emission factors (EFs) with one significant figure. When the more detailed EFs are used (more significant figures), the number shown in this table results.

* Number of wells was incorrectly reported in 1992 API Methane report as 61,234. The correct value is shown here.
 ** V&F emissions were reported in the 1992 API report, but not included in industry total. V&F emissions are included in the total shown here.

Table 2-4. 1990 CO₂ Emissions Summary for EPA: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1993.

EPA Inventory of Greenhouse Gas Emissions and Sinks: 1990-1993						
CO ₂ Emissions Summary						
1. Exploration/Extraction	CO ₂ EF	EF units *	CO ₂ AF	AF units	10 ⁶ tons CO ₂	Subtotals CO ₂ 10 ⁶ tons
Flared	525	g C/m ³	3.41E+09	m ³	7.2	7
2. Crude Handling Losses						
3. Refining						
4. Product Transport						
Total						7 10 ⁶ tons CO ₂ 125 Bscf CO ₂

* Flared units of g C/m³ = grams of Carbon equivalent per cubic meter.

Table 2-5. 1990 CH₄ Emissions Summary for EPA: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1993.

EPA Inventory of Greenhouse Gas Emissions and Sinks: 1990-1993						
CH ₄ Emissions Summary						
1. Exploration/Extraction	CH ₄ EF	CH ₄ EF units *	CH ₄ AF	AF units	1000 tonnes CH ₄ (metric tonnes)	Subtotals CH ₄ (US tons)
Fugitive	14.26681	g/GJ			253.0	278,884
Routine Maintenance	1.255772	g/GJ				
Venting and Flaring	0.002816	g/GJ				
2. Crude Handling Losses	13.00822	g/GJ			6.0	6,614
3. Refining-fugitives	0.4	g/GJ			12.0	13,228
4. Product Transport						0
Total						298,726 tons CH ₄ 14.2 Bscf CH ₄

* Units of g/GJ = grams of CH₄ emissions per 10e9 Joules
Units of tonnes (metric tons) = 1000 kg

Table 2-6. 1990 CH₄ Emissions Summary for EPA Report to Congress: Anthropogenic Methane Emissions in the United States: Estimates for 1990.

EPA Report to Congress CH ₄ Emissions Summary		CH ₄ EF	CH ₄ EF units	CH ₄ AF	AF units	CH ₄ tons	Subtotals CH ₄ tons	EF Quality	Emission Factor Basis and Activity Factor Basis (where known)
1. Exploration/Extraction* Fugitive Maintenance V&F 2. Crude Handling Losses Marine Transport 3. Refining Equipment Leaks Vents of Waste Gas Maintenance Tanks 4. Product Transport		72 0.15 4-20%	kg/well kg/well of V&F total	309,155 309,155 167,519	oil wells not mktng gas oil wells not mktng gas million scf	24,514 51	24,566	Incomplete	PSI Basis, Wellhead only, seps at oil wells marketing gas ignored
								Incomplete	PSI Basis (Tilkicioglu, 1989)
							6,718	very poor	Radian 1991, Barnes&Edmund 1990
						6,718	13,546	Incomplete reasonable	PSI Basis (Tilkicioglu, 1989)
						0		Incomplete	PSI Basis (Tilkicioglu, 1989)
Total						11,454		Incomplete	PSI Basis (Tilkicioglu, 1989) and (Radian, 1980)
						0		-	PSI Basis (Tilkicioglu, 1989)
						2,093		reasonable	PSI Basis (Tilkicioglu, 1989)
Total							44,830	tons CH ₄ *	Not considered a source of CH ₄ emissions
							2.1	Bscf CH ₄	

Note:

* Excluded "Venting and Flaring" emissions which were calculated by the RTC to be 101,872 - 508,810 tons CH₄

Table 2-7. CH₄ Emissions Summary for IPCC (No Base Year Specified): Greenhouse Gas Inventory Reference Manual.

IPCC Greenhouse Gas Inventory - Reference Manual (Vol. 3) CH ₄ Emission Summary						
	CH ₄ EF	CH ₄ EF units	CH ₄ AF	AF units	Subtotals CH ₄	EF Quality
1. Production	7664	kg/PJ prod.				incomplete
2. Crude Handling Losses	745	kg/PJ of oil tankered				reasonable
Marine Transport	0.2	g/kg fuel				reasonable
Rail Transport	0.2	g/kg fuel				incomplete
3. Refining	90-1400	kg/PJ refined				incomplete
Storage Tanks	20-260	kg/PJ refined				incomplete
4. Product Transport						tons CH ₄
Total						Bscf CH ₄

Table 2-8. CO₂ Emissions Summary for IPCC (No Base Year Specified): Greenhouse Gas Inventory Reference Manual.

IPCC Greenhouse Gas Inventory - Reference Manual (Vol. 3) CO ₂ Emission Summary						
	CO ₂ EF	CO ₂ EF units	CO ₂ AF	AF units	Subtotals CO ₂	EF Quality
1. Exploration/Extraction						No emission estimates provided for this segment.
2. Crude Handling Losses						"
3. Refining						"
4. Product Transport						"
Total						tons CH ₄ Bscf CH ₄

Table 2-9. CH₄ Emissions Summary for E&P Forum (No Base Year Specified): Methods for Estimating Atmospheric Emissions from E&P Operations.

E&P Forum	CH ₄ EF	EF units *	CH ₄ AF	AF units	Subtotals CH ₄	EF Quality	Emission Factor Basis and Activity Factor Basis (where known)
CH ₄ Emissions Summary							
Tiers 2 and 3:							
1. Production							
Diesel combustion	0.00014	tonnes/tonne burned				unknown	E&P Forum internal data
Turbines	0.0008	tonnes/tonne burned				unknown	E&P Forum internal data
Engines	0.00014	tonnes/tonne burned				unknown	E&P Forum internal data
Boilers/heaters	7.8E-06	tonnes/tonne burned				unknown	E&P Forum internal data
Gas combustion	0.00042	tonnes/tonne burned				unknown	E&P Forum internal data
Turbines	0.00042	tonnes/tonne burned				unknown	E&P Forum internal data
Engines	0.017	tonnes/tonne burned				unknown	E&P Forum internal data
Boilers/heaters	4.3E-05	tonnes/tonne burned				unknown	E&P Forum internal data
Flaring	0.035	tonnes/tonne burned				unknown	No source listed
Gas	0.00033	tonnes/tonne burned				unknown	OLF Environmental Programme, "Emissions to Air" (Dec. 1991)
Venting Emissions	0.7	tonnes/tonne vented				unknown	Based on gas composition of 70% CH ₄
Storage Tanks							
Fixed roof	2E-07	tonnes/tonne throughput				incomplete	US EPA AP-42 (1986), E&P Forum Internal Data
External floating roof	1.5E-07	tonnes/tonne throughput				incomplete	US EPA AP-42 (1986), E&P Forum Internal Data
Internal floating roof	4E-08	tonnes/tonne throughput				incomplete	Laveman, "Evaporation Loss from Storage Tanks," Chicago Bridge and Iron Co. (1991)
2. Transportation							
Air	8.7E-05	tonne/tonne fuel				reasonable	OECD/OECD, IPCC, "Estimation of Greenhouse Gas Emissions and Sinks" (1991)
Sea	0.00027	tonne/tonne fuel				reasonable	Lloyd's Register, "Marine Exhaust Emissions Programme" (1991)
Land	0.00023	tonne/tonne fuel				reasonable	OECD/OECD, IPCC, "Estimation of Greenhouse Gas Emissions and Sinks" (1991)
Crude Loading Operations							
Rail, tank cars, and trucks	5.8E-05	tonne/tonne crude				unknown	E&P Forum Internal Data
Ship loading	1.7E-05	tonne/tonne crude				unknown	E&P Forum Internal Data
3. Refining							
4. Product Transport							
Tier 1 Total							Not covered
Production, oil	0.000143	tonne/tonne produced	364,292,000	tonnes oil produced	51,984 tonnes CH ₄		API "Global Emissions of Methane from Petroleum Sources" (1992)
					57,303 tons CH ₄		
					2.7 Bscf CH ₄		

* tonnes = metric tonne = 1000 kg

Tier 1 Note:

Production, oil and gas

0.00385

tonnes/tonne oil & gas

922,000,000

tonnes oil & gas prod

3,549,700 tonnes CH₄

US EPA "Estimation of Greenhouse Gas Emissions and Sinks" (1993)

3,912,869 tons CH₄



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Table 2-10. CO₂ Emissions Summary for E&P Forum (No Base Year Specified): *Methods for Estimating Atmospheric Emissions from E&P Operations*

E&P Forum CO ₂ Emissions Summary	CO ₂ EF	CO ₂ EF units *	CO ₂ AF	AF units	Subtotals CO ₂	EF Quality	Emission Factor Basis and Activity Factor Basis (where known)
Tiers 2 and 3							
1. Production	3.2 tonnes/tonne burned					reasonable	US EPA AP-42 (1986)
Diesel combustion	3.2 tonnes/tonne burned					reasonable	US EPA AP-42 (1986)
Turbines	3.2 tonnes/tonne burned					reasonable	US EPA AP-42 (1986)
Engines	3.2 tonnes/tonne burned					reasonable	US EPA AP-42 (1986)
Boilers/heaters	2.75 tonnes/tonne burned					reasonable	US EPA AP-42 (1986)
Gas combustion							
Flaring	2.65 tonnes/tonne burned					unknown	Source not listed
Gas	3.04 tonnes/tonne burned					unknown	OLF Environmental Programme, "Emissions to Air" (Dec. 1991)
Liquid							
2. Transportation	3.2 tonnes/tonne fuel					reasonable	OECD/OECD, IPCC, "Estimation of Greenhouse Gas Emissions and Sinks" (1991)
Air	3.2 tonnes/tonne fuel					reasonable	Lloyd's Register, "Marine Exhaust Emissions Programme" (1991)
Sea	3.2 tonnes/tonne fuel					reasonable	OECD/OECD, IPCC, "Estimation of Greenhouse Gas Emissions and Sinks" (1991)
Land	na						
Crude Loading Operations							
3. Refining							
4. Product Transport							Not covered
Tier 1 Total:	0.081 tonnes/tonne oil & gas produced		9.22E+08	tonnes oil & gas produced	74.70 10 ⁶ tonnes CO ₂ 82.34 10 ⁶ tons CO ₂ 1418.5 Bscf CO ₂		API "Global Emissions of CO ₂ from Petroleum Sources" (1991)
1. Production, oil and gas							

* tonnes = metric tonne = 1000 kg

Table 2-11. 1992 CH₄ Emissions Summary for GRI/EPA Study: Methane Emissions from the Natural Gas Industry (Multiple Reports).

GRI/EPA Methane Emissions Project CH ₄ Emissions Summary as applicable to Oil Industry*		CH ₄ EF	EF units	CH ₄ AF	AF units	CH ₄ tons	Subtotals CH ₄ tons	EF Quality	Emission Factor Basis (and Activity Factor Basis where known)
1. Exploration/Extraction									
A. Fugitives									
oil wellheads (no gas)		17.44	scfd/well	393,235	oil wellheads (no gas)	145		+/- 24%	Preliminary data from gas industry - for sites with gas and oil production
oil wellheads (miking gas)		36.4	scfd/well	208,962	oil wellheads (miking gas)	161		+/- 33%	Preliminary data from gas industry - for sites with gas and oil production
separators		122	scfd/sep	20,896	separators	54		+/- 30%	Gas industry data. AF based on one separator per well.
sales areas		40.55	scfd/s.a.		oil sales areas	0			Star Environmental, API Report 4615
pipelines		56.4	scfd/mile	50,000	miles of pipelines	60		+/- 97%	Data from 14 sites
B. Venting									
pneumatics		308	scfd/device		pneumatic devices			+/- 55%	Measurements, site, and manufacturer data. Update 10/95
CIP's		439	scfd/CIP		CIPs			+/- 91%	Measurements, site, and manufacturer data
unmarketed gas (vented)									Sources were considered from gas industry perspective, but no emission estimate was calculated
H/T vents				600,000	tanks				"
oil tanks									"
condensate tanks									
C. Combustion									
gas lift compressors		0.24	scf/HP-hr		HP-hrs			+/- 5%	TRANSDAT model and SwRI data
gas powered pump engines		0.24	scf/HP-hr		HP-hrs			+/- 5%	TRANSDAT model and SwRI data
burners									Sources were considered from gas industry perspective, but no emission estimate was calculated
drilling		0.375	scfd/vessel					+/- 67%	Data from 12 sites
D. Maintenance									
E. Upsets									
emergency shutdown		256,888	scfy/platform						Gas industry data
pressure relief valve lift		34	scfy/PRV						Gas industry data
2. Crude Handling Losses		Not covered							Not covered
3. Refining		Not covered							Not covered
4. Product Transport		Not covered							Not covered
Total									
								tons CH ₄	
								Bscf CH ₄	

Note: * The focus of the GRI/EPA Methane Emissions project was the natural gas industry. Activity and emission factors were not developed specifically for the oil industry, but some values are applicable to both. Those that were available are shown here.

Data Quality

Data quality is a function of the detail level (described previously), as well as the basis for the emission factors. Emission factors can be determined from tenuous broad brush estimates, reasonable data-based estimates, or field emission measurements. Tables 2-12 and 2-13 show a matrix of data quality for emission factors and activity factors that range from worst to best. The matrix is based upon a scale of increasing detail level and a scale of better emission/activity factor basis. In these tables "worst" indicates that the emission factor or activity factor estimate is generally applied to the entire industry with poor or incomplete background information to support the estimates. The term "best" indicates that scientifically valid equipment level measurements were performed for the emission factor and the equipment level activity factor is based on a documented nationally tracked source. For both tables, "unknown" indicates that no documentation was provided for a particular emission factor or activity factor, so a ranking could not be estimated.

The matrix scale for data quality was used where possible to subjectively rank the data quality of the emission factor data for each of the reports. The results of this analysis are shown in Tables 2-2 through 2-11. The column labeled "EF Quality" gives a subjective ranking of the data quality based upon the matrix shown in Table 2-12. For the GRI/EPA methane emissions project, 90% confidence bounds for the emission factor terms were calculated to provide an accuracy estimate. These values are listed in the "EF Quality" column for this report.

Data quality also depends on the source for the data. Figure 2-1 shows the approximate lineage for the data for each of the major reports being considered by this analysis. As shown in this diagram, the reports are inter-connected and rely on much of the same information.