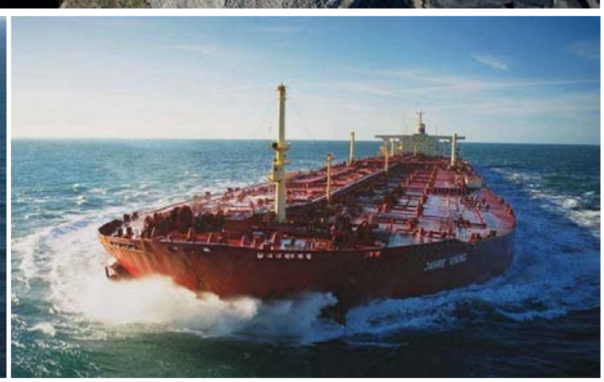
Carbon Majors:
Accounting for carbon and methane emissions 1854-2010
Methods & Results Report









By Richard Heede

Climate Mitigation Services

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Climate Mitigation Services

Principal Investigator: Richard Heede
heede@climatemitigation.com
1626 Gateway Road
Snowmass, CO 81654 USA
970-927-9511 office
970-343-0707 mobile

Dedicated to my friend and mentor Peter Roderick

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Climate Justice Programme
Sydney
www.climatejustice.org
Project coordinator: Keely Boom, Executive Director CJP, keely@climatejustice.org.au
&
Greenpeace International
Amsterdam
www.greenpeace.org
Project coordinator: Martina Krueger, martina.krueger@greenpeace.org

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Note on units: International SI units are used throughout, except where reporting is in bbl of oil, cubic feet of natural gas, or (short) tons of coal. Emissions of methane are expressed in CH_4 or in CO_2-equivalent terms (CO_2e; SAR: 100-y, 21xCO_2).



Cover: Standard Oil "octopus" Udo Keppler, 1904; flaring in Nigeria, World Bank 2011; bituminous coal; coal train, Wyoming; Mountaintop removal, Kayford WV, Vivian Stockman, 2003; platform off Qatar; Jahre Viking ULCC tanker (now dismantled).
Above: Sunset over Iraqi petroleum flares; Kuwait oil fires, 1990s; Melting globe.

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Accounting for carbon and methane emissions 1854-2010

Abstract. Analysis of historic data on fossil fuel extracted by 83 of the world's largest oil, gas, and coal producing entities and CO_2 produced by the 7 largest cement entities provided the basis for estimating emissions of carbon dioxide (CO_2) and methane (CH_4) attributable to these carbon fuel and cement producers. Annual production data typically reach back to 1920 or earlier for major oil and coal companies, and later for state-owned oil companies in Algeria, Libya, Angola, Nigeria, China, Norway, Brazil, Persian Gulf states, Venezuela, and other chiefly OPEC member countries. Production data for nation-states supplant investor-owned companies in centralized economies, e.g., Soviet and Polish coal production. The entities include 50 investor-owned and 31 state-owned entities, and 9 current and former nation-states. The amount of carbon extracted is calculated for each entity, by fuel type and year, and emission of CO_2 from produced & marketed fuels is estimated after accounting for non-energy uses. Additional direct emissions — chiefly from companies' own operations, such as venting of CO_2 in gas processing, natural gas flaring, use of own fuels, and fugitive methane from coalmines and oil and gas operations — are also estimated.

Total emissions of 914 billion tonnes of carbon dioxide equivalent ($GtCO_2e$) are traced to the fuels and cement produced by the 90 Carbon Major Entities (CMEs) based on production data from as early as 1854 to 2010. Emissions include 815 $GtCO_2$ from the combustion of produced & marketed hydrocarbon fuels, 13 $GtCO_2$ from cement production, 6 $GtCO_2$ from natural gas flaring, 5 $GtCO_2$ vented from natural gas, 7 $GtCO_2$ from entities' own fuel use, and 68 $GtCO_2e$ from methane. The Carbon Dioxide Information and Analysis Center (CDIAC) emissions database for fossil fuel CO_2, flaring, and cement production from 1751 to 2010 totals 1,323 $GtCO_2$, and 1,450 $GtCO_2e$ with methane emissions. This project has quantified emissions equivalent to 63 percent of CDIAC's global emissions since 1751. Of emissions attributed to CMEs, half have occurred since 1986.

Overall uncertainty is ±10 percent. The quality and completeness of production data varies, entities have differing operating characteristics and produce fuels with variable carbon content from differing geologic formations and geographic regions, reporting on methane emissions is often opaque, coalmine depth and rank of produced coals is often not reported, CO_2 vented from raw natural gas and variable flaring practices means that uncertainties for individual entities are often higher — typically in the ±10-15 percent range. In aggregate, the sum of all entity emissions is at or below global emissions of both CO_2 and methane. Emission factors are based on internationally recognized sources such as the IPCC, World Bank, U.S. EPA, and the European Commission, as well as data from producers, energy engineers, and professional associations.

1. Introduction

This project was undertaken to trace the origin of anthropogenic carbon dioxide (CO_2) and methane to the world's largest extant producers of carbon fuels and cement. The primary driver of climate change is not current emissions, but cumulative (historic) emissions. This project quantifies and traces for the first time the lion's share of cumulative global CO_2 and methane emissions since the industrial revolution began to the largest multinational and state-owned *producers* of crude oil, natural gas, coal, and cement. These fuels, used as intended by billions of consumers, has lead to the most rapid increase in atmospheric CO_2 of the last 3 million years and the highest concentration of CO_2 of the last 800,000 years.[1]

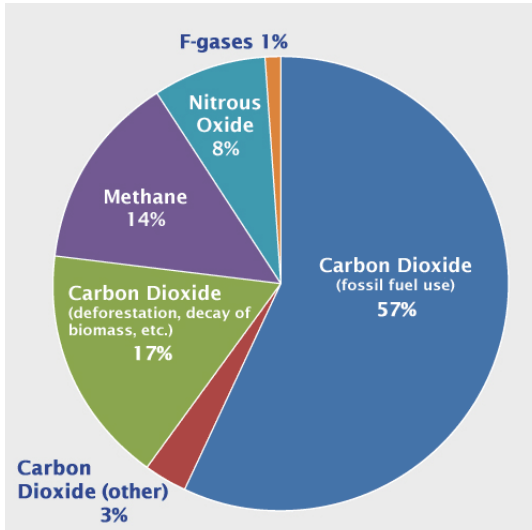
The atmosphere has a mass of 5.14×10^{15} tonnes, of which CO_2 constitutes 398.6 parts per million (ppm) (and briefly reached 400 parts per million in May 2013).[2] One ppm of CO_2 corresponds to 2.13 billion tonnes carbon (GtC), and the mass of atmospheric carbon is 852 GtC, rising by about 4 GtC per year. The CO_2 level at the dawn of the industrial revolution

[1] Luthi, D., M. Le Floch, B. Bereiter, T. Blunier, J.-M. Barnola, U. Siegenthaler, D. Raynaud, J. Jouzel, H. Fischer, K. Kawamura, & T.F. Stocker (2008) High-resolution CO_2 concentration record 800,000 years before present, *Nature*, vol. 453:379-382.

[2] Scripps Institution of Oceanography (2013) Atmospheric CO_2 concentrations (ppm) derived from in situ air measurements at Mauna Loa, Observatory, Hawaii. Data for June 2013. www.co2now.org Trenberth, K. E., & C. J. Guillemot (1994), The total mass of the atmosphere, *J. Geophys. Res.*, 99(D11), 23079–23088, doi:10.1029/94JD02043.

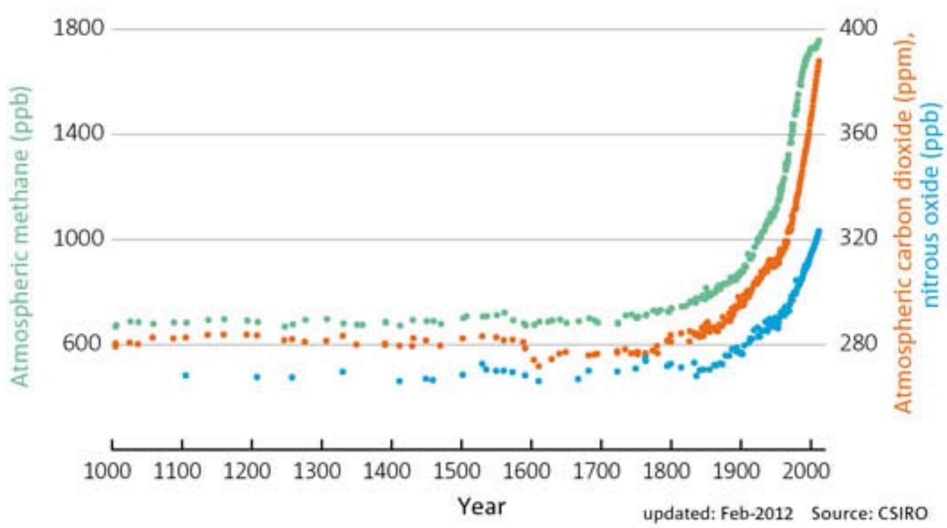
was 278 ppm, or 592 GtC. The rapid rise in carbon dioxide is the result of human alteration of the carbon cycle through land-use and deforestation over the last several millennia and, more significantly, from the mining and combustion of geologic deposits of fossil fuels since the invention of the steam engine in the late 18th Century when fossil fuel use began in earnest (Figures 1 and 2).[3] In fact, the majority of the net rise of 260 GtC in atmospheric carbon is from the consumption of fossil fuels.

Figure 1. Global greenhouse gas emissions by gas, 2005.



IPCC (2007) *Fourth Assessment Report*: Synthesis Report, Figure 2.1.

Figure 2. Concentrations of CO_2, CH_4, and N_2O 1000 to 2010 AD.



CSIRO (2012) *State of the Climate 2012*.

The natural flows of carbon dioxide (CO_2) through the biosphere and ocean are much larger than humanity's contribution of industrial and land use emissions that gradually increase atmospheric concentration of CO_2 and other greenhouse gases (GHGs) that are warming

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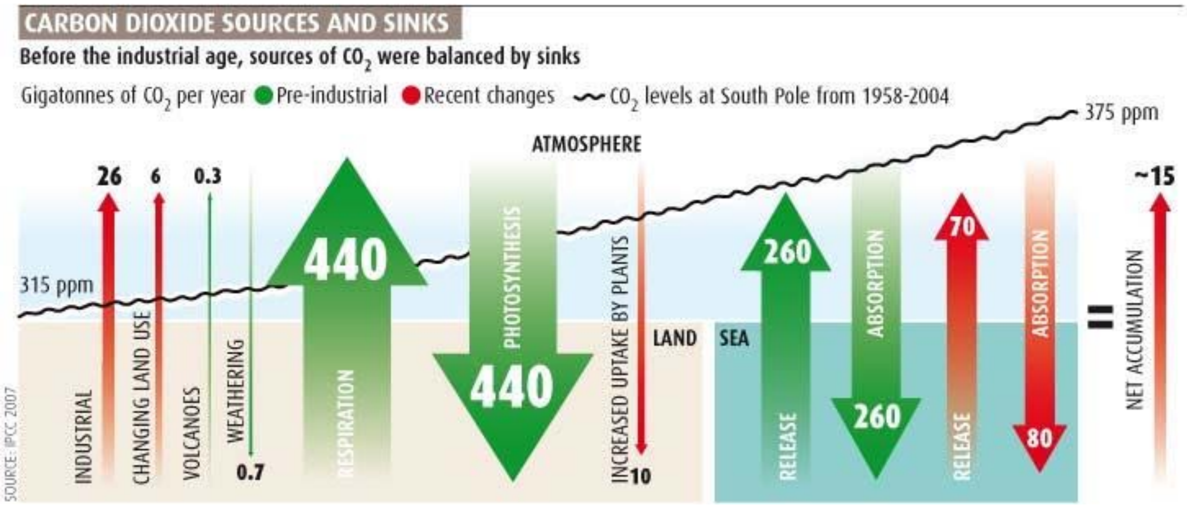
3 Carbon emissions from land use and deforestation account for 17% of total greenhouse gas emissions, or 22% of total CO_2 emissions. IPCC (2007) *Fourth Assessment Report*, Synthesis Rpt, Figure 2.1. Also see Raupach, 2011.

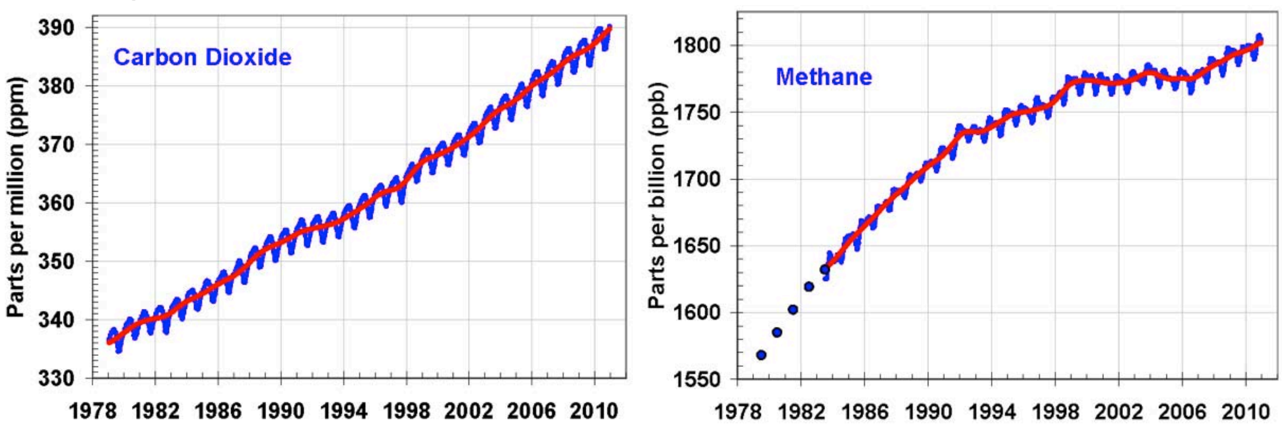
the earth's atmosphere and oceans (Figure 3). The bulk of emissions are of recent vintage: *one-half* of cumulative global emissions of industrial CO_2 from fossil fuel combustion and cement manufacturing since 1751 have occurred since 1984, that is, in the last 26 years of the 260-year anthropocene (Figure 4; also see Figure 2 and Figure 8).

Figure 3. Carbon dioxide sources and sinks



IPCC, 2007.

Figure 4. Atmospheric concentration of carbon dioxide and methane 1978-2010.



Butler, James (2011) *The NOAA Annual Greenhouse Gas Index,* NOAA Earth System Research Laboratory, Boulder, CO.

This era of human alteration of the atmosphere was termed the *anthropocene* by Eugene Stoermer and popularized by Paul Crutzen. By the 1890s, when Svante Arrhenius did his pioneering work estimating the global warming from a doubling of atmospheric CO_2 content, it was inconceivable to him that fossil fuel use would ever reach the scale required for such a doubling. The world is on the verge of achieving the inconceivable. Significant changes to the world's agricultural productivity, hydrology, desertification, extreme weather, droughts, heat waves, species extinctions, and rising seas are already detected and attributed to human use of nature's abundant stores of carbon fuels.

Great economic expansion and the general rise in comfort, shelter, food, and clothing have flowed from human ingenuity, in large measure driven by ubiquitous use of convenient, storable, transportable, and powerful carbon fuels. Some of the greatest technological achievements continue to be found in the extraordinary ways in which carbon fuels are brought to the surface from increasingly remote and hostile environments. The world's most massive ground and marine vehicles and facilities are built to find, extract, process, and transport our fuels and derivative petrochemical products to billions of consumers. The extraction, delivery, and final combustion of carbon fuels in one billion vehicles, millions of buildings, and tens of thousands of aircraft and ships has relieved the world of much human drudgery, helped feed the hungry, and made the average citizen richer and far more comfortable than in centuries past.

The world burns hydrocarbon fuels in massive quantities (equivalent to 12.6 km^3 of oil per year, or 430 m^3 (370 t) of oil per second), to heat buildings, for industrial processes, and to power pistons and turbines to move vehicles, aircraft, and power plants.[4] We know where the products of combustion end up: in the atmosphere as waste heat, water vapor, carbon dioxide, and other contaminants. Where does the carbon come from? Who provides these fuels to the global market? These are the questions this project seeks to answer.

The project

The primary objective is to quantify and trace historic and cumulative emissions of carbon dioxide and methane to the largest extant fossil fuel and cement producers. This project focuses on the industrial carbon fuels and cement manufacturing, and details the annual and cumulative contribution of each of the largest 90 producers from as early as 1854 (but typically later) to 2010. National greenhouse gas (GHG) inventories estimate aggregate emissions of the six "Kyoto gases,"[5] chiefly from fuel consumption, process emissions, fugitive methane, and land-use changes. This project's focus is to trace emissions back to the corporate producers of the lion's share of the world's carbon fuels and cement.

Current production of fossil fuels by multinational and state energy enterprises is well known, as are the historic emissions of the world's 196 nations. This project is a first attempt at aggregating historic data by carbon producing entities. The work is unique in converting production of all fossil fuels into the carbon content and resulting emissions of carbon dioxide upon the combustion of marketed fuels, and in tracing emissions to the primary producing entities.

We quantify the annual production of carbon fuels, subtract fuels used for non-energy purposes (carbon stored in products rather than oxidized), consider the carbon content of each fuel type produced, and trace final emissions of carbon dioxide to each producing entity, regardless of the final end-user of the carbon fuels. In addition, we estimate direct emissions from flaring and venting of carbon dioxide, emission from each entity's own fuel use, and fugitive emissions of methane from entity operations.

The Carbon Majors project followed the publication of Friends of the Earth International (2004) *Exxon's Climate Footprint: The Contribution of ExxonMobil to Climate Change Since 1882* based on Heede (2003) *ExxonMobil Corporation: Emissions Inventory 1882-2002: Methods & Results*, a project under the auspices of the Climate Justice Programme, London.

[4] Based on 2010 global emissions of industrial carbon dioxide (33,486 $MtCO_2$ (CDIAC)), converted to oil equivalent at 0.375 m^3 of oil per tCO_2. This calculation is based on 423.85 kg CO_2 per bbl, and excludes non-energy uses.

[5] Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6). In this project we include only industrial sources of CO_2 and CH_4.

No starting year was set for fossil fuel production; this is determined by the availability of production data for each entity. The earliest data are for 1854 (Westmoreland Coal). The largest multinational oil companies were established prior to World War I, and most state-owned oil companies were formed in the 1970s.[6] Production data are often unavailable for the early years of an entity's existence, but most production data are relatively complete from the 1930s forward. According to the global emissions database maintained by the Carbon Dioxide Information Analysis Center (CDIAC), of cumulative emissions over the 1751-2010 period, only 0.4 percent had been emitted by 1854, 3.4 percent by 1900, and 10.4 percent by 1930.[7] (See Figure 8 for global emissions 1810-2010.)

A threshold for inclusion in this study was set at the production of ≥8 million tonnes of carbon (MtC) in a recent year. While some entities are below this threshold — coal mining operations by large oil companies, for example, or companies whose production met the threshold in 2005 (when this project started) but has since declined, or a smaller company acquired by a larger one — the rule still applies in order to have a manageable number of total entities. The total number of entities also varies through mergers and acquisitions.

A variety of enterprise ownership and governance structures are included:

- Investor-owned fossil fuel and cement producers (chiefly multinational corporations, e.g., BP, Chevron, Xstrata, Peabody, Hess, Lafarge, and BHP Billiton);
- Privately-held producers (e.g., Murray Energy Corp., a U.S. coal mine operator);
- Government-owned enterprises (state-owned oil producers such as StatOil, Petrobras, Pemex, and the many National Oil Companies in Africa, the Middle East, and Asia);
- Current or former centrally planned economies with limited non-government producers, such as the Former Soviet Union (FSU) for coal, oil, and natural gas until the dissolution of the USSR in 1991, and coal-producing nations such as Kazakhstan and Poland.

2. The procedure and methodology: an overview

The procedure starts with company or entity net fossil fuel production data from publicly available sources, estimation of the carbon content of each fuel type, deduction for non-energy uses of produced fuels (which determines carbon storage rates but also accounts for *emissions* from non-energy uses, such as short-term oxidation of lubricants, waxes, petrochemicals, and other petroleum products), and emission factors for each fuel, for each entity, and for every year for which production data have been found.

A threshold of ≥8 MtC/year was established for entity production. Company production data was gathered from publicly available sources (annual reports in the collections of public and academic libraries, filings with the U.S. Securities and Exchange Commission, compilations in published literature, and company histories [8,9,10,11,12,13]), entered on excel

[6] Standard Oil 1870; BP (Anglo Persian Oil Company, in 1909, as a subsidiary of Burmah Oil); Royal Dutch Shell 1907; Chevron (as the Texas Fuel Company in 1901, Texaco, and Pacific Coast Oil Company as Standard Oil of California, Socal); Gulf Oil and Mobil (Socony –Vacuum Oil Company) were established in 1911 upon the Supreme Court dissolution of Standard Oil Trust; Gulf Oil in 1907; ENI in 1926 (as AGIP); Pemex in 1938. For more information on the "wave of nationalization" in the 1970s and early 1980s, see: Victor, David G., David Hults, & Mark Thurber (2012), Figure 20.2.

[7] Marland, Gregg, T. A. Boden, & R. J. Andres (2011) "Global, Regional, and National CO_2 Emissions." In *Trends: A Compendium of Data on Global Change*, Carbon Dioxide Information Analysis Center, Oak Ridge Nat. Lab., U.S. DOE.

[8] Bamberg, James H. (1994) *The History of British Petroleum: The Anglo-Iranian Years, 1929-1954*.

worksheets, and carefully annotated with data sources, units, information on net or gross production, and caveats, limitations, data gaps, and ambiguities. The available fossil fuel production datasets are sought from the earliest dates available; for some entities this extends to the establishment of the company (in the 1890s or 1900s for the oil majors). The production records are not always complete from the early years of an entity's existence — either from missing data early in the entity's history or gaps in production data (the latter are interpolated, the former are not estimated).[14]

We applied emission factors derived from IPCC default (Tier 1) values on combustion emissions for each fuel and rank of coal and modified by deducting net non-energy uses of each fuel in order to estimate the emissions traced to the production of carbon fuels by each entity for each year and fuel type.[15] Every entity's cumulative emissions from each fuel type are linked to a summary worksheet, in which four additional emission sources are estimated: vented CO_2 from natural gas processing, CO_2 from gas flaring, CO_2 from own fuel use, and fugitive CO_2 and methane (CH_4) from oil and gas operations and coal mining.[16]

The results are compared to CDIAC estimates of annual and cumulative carbon dioxide and methane emissions by from as early as 1751 (in the case of coal) to 2010.[17]

Global emissions from cement production are 2.4 percent of cumulative CO_2 emissions 1751-2010, and have risen to 4.9 percent of 2010 emissions. Emissions of CO_2 from the calcining of limestone ($CaCO_3$) into cement clinker are estimated for 7 cement producers.

Readers are encouraged to review the detailed discussion of the methodology in Annex B.

3. The accounting protocol and rules (in brief)

The procedure employed in this project starts with company (or entity) net fossil fuel production data from published sources, estimation of the carbon content of each fuel type, subtraction for non-energy uses of produced fuels and feedstocks, emission factors for each fuel, for each entity, for each and every year for which production data has been found. This is conceptually straightforward, but is complex in practice.

Carbon Major entities were initially selected in 2005-2006 from a combination of sources, such as *Oil & Gas Journal*, Energy Intelligence *Top 100 Oil*, National Mining Association coal mining data, and EIA International Energy Statistics for extant companies that meet the ≥8 MtC/yr threshold. Some entities have since been added, while others were absorbed through mergers or acquisitions.

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[9] Gibb, George Sweet, & Evelyn H. Knowlton (1956) *History of Standard Oil Company (NJ), 1911-1927: The Resurgent Years.*

[10] Hidy, Ralph, & Muriel Hidy (1956) *Pioneering in Big Business: History of Standard Oil Co, 1882-1911*.

[11] Howarth, Stephen (1997) *A Century in Oil: The Shell Transport & Trading Co 1897-1997*.

[12] Yergin, Daniel (1991) *The Prize: The Epic Quest for Oil, Money, and Power*.

[13] Giddens, Paul H. (1955) *Standard Oil Company (Indiana): Oil Pioneer of the Middle West*.

[14] Reporting of production data did not become common practice until the laws that established the U.S. Securities and Exchange Commission and corporate reporting standards were passed by the U.S. Congress in 1933 and 1934.

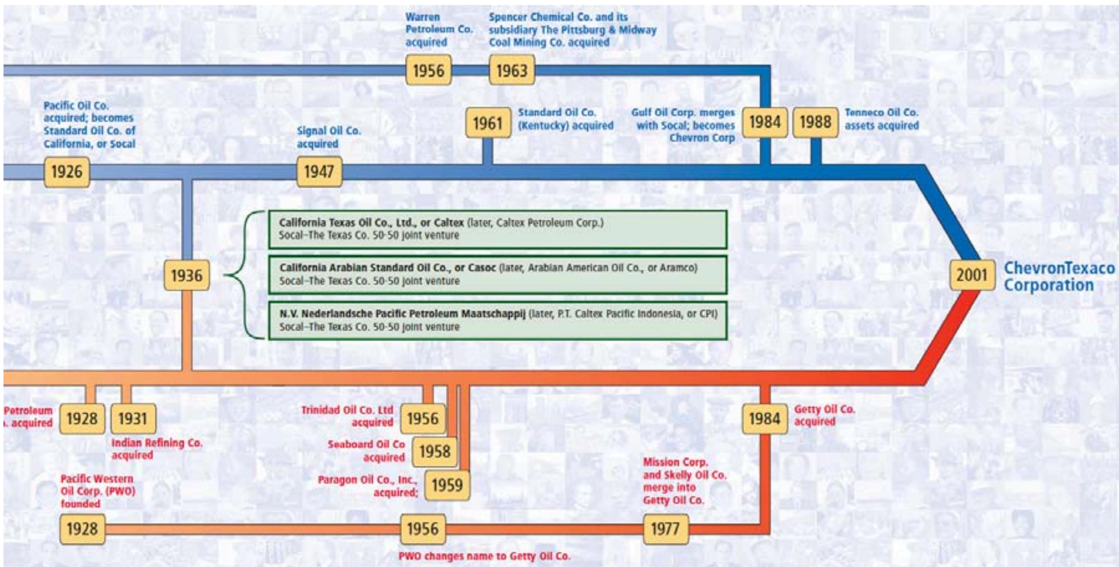
[15] Intergovernmental Panel on Climate Change (2006) 2006 *IPCC Guidelines for National Greenhouse Gas Inventories*: Volume 2: Energy, Geneva; www.ipcc-nggip.iges.or.jp/public/2006gl

[16] Intergovernmental Panel on Climate Change (2006) Volume 2: Energy, Chapter 4: Fugitive Emissions, Geneva.

[17] Annual and cumulative CO_2 emissions traced to the 90 carbon major entities are compared to the CDIAC database (Marland, Boden, & Andres, 2011); attributed methane emissions are compared to global estimates by Stern & Kaufmann (1998) and European Commission's Joint Research Centre (2011) *Global Emissions EDGAR v4.2: Methane Emissions*.

Mergers and acquisitions are tracked; acquired assets are attributed to the extant company (e.g., Chevron is attributed Texaco's production and emissions legacy, as well as previously acquired Gulf Oil, Mission, Skelly, Unocal, Getty Oil). Divestitures and disposition of assets are also accounted for; production from divested assets is reflected in subsequent annual reports. Nationalized or expropriated assets are also tracked insofar as equity production is accurately reported by multinational oil companies. Net equity or "working interest" production data are used. It was common practice in the 1960s and 1970s to only report gross production, in which cases net production is estimated from a "net-to-gross ratio."

Figure 5. Chevron and Texaco mergers and acquisitions, detail 1926-2001.



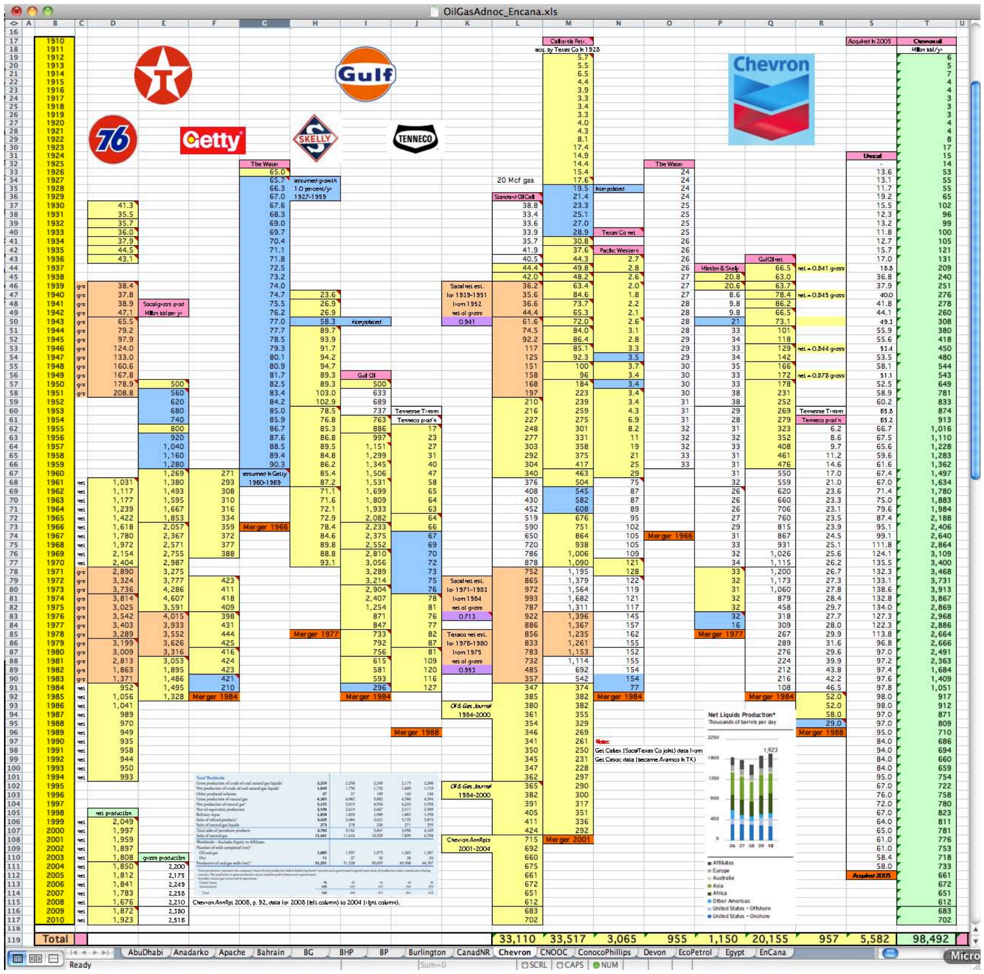
Courtesy Chevron.com. See Annex E.

Carbon dioxide emissions from cement production are estimated by a proportion (rising from 54 percent in 1990 to 67 percent in 2010) of gross emissions reported by the major cement companies to the Cement Sustainability Initiative.[18] The attributed proportion of gross emissions estimates the process emissions of the CO_2 emitted from high-temperature calcining of limestone ($CaCO_3 \rightarrow CaO + CO_2$) into clinker, or Portland cement, thus *excluding* emissions from fuel and electricity inputs (to avoid double-counting of fuels already accounted for by carbon major entities (CMEs) or other primary producers).

Attribution of emissions to cement producers differs from emissions traced to fossil fuel producers. In the latter, emissions are traced back to original extractors and providers of carbon fuels; as such they are not the consumers of the fuels and thus *not* the final emitters (except for direct emissions). In the case of cement, emissions are traced to the entity that processes limestone into cement rather than to the limestone extractors. Cement entities are usually opaque on whether they own the limestone quarries or they procure it from independent mining companies. Both carbon fuel and cement companies provide products to the global market that emit CO_2 in their conversion to marketable products (comparable to an oil company's flaring emissions); the major difference is that carbon fuel producers sell products that are themselves sources of additional carbon dioxide emissions.

[18] World Business Council for Sustainable Development Cement Sustainability Initiative (2011) *CO_2 and Energy Accounting and Reporting Standard for the Cement Industry*, www.wbcsdcement.org, May11, 76 pp

Figure 6. Chevron and its predecessors' production of oil and NGLs, 1912-2010 (detail).



Carbon Majors worksheet on Chevron and its mergers & acquisitions. See Annex D for the full PDF of the worksheet.

4. Uncertainties (in brief)

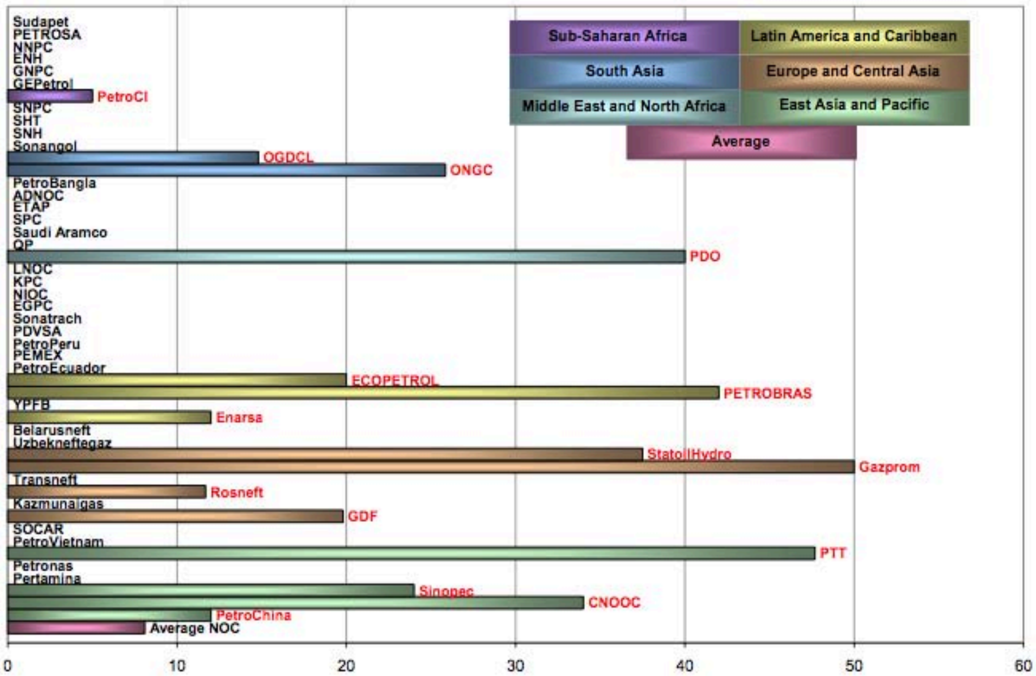
The core idea of attributing industrial emissions of CO_2 and methane to fossil fuel and cement producers is simple. While industrial emissions of CO_2 and methane attributed to *nations* based on the *consumption* of fossil fuels and cement manufacture is already well-known within a relatively narrow uncertainty range,[19] this project is the first attempt at attributing emissions to carbon *producers* and therefore involve greater uncertainties.

Uncertainties, data gaps, ambiguities, choice of methodologies, poor or non-existent reporting of fuel production by Carbon Major Entities (CMEs), potential double-counting, and missing data complicate the actual work. Estimated uncertainty for the cumulative sum of entities is ±10 percent, although it can be higher for individual entities, since production data is more complete in recent decades, and emission factors for coal combustion and methane are globally conservative but vary for individual coal companies. Uncertainties are fully discussed in Annex B (Methodology), and an overview is offered here.

[19] The Global Carbon Project, for example, cites uncertainty for fuel combustion estimates as ±5 percent for one standard deviation (IPCC "likely" range). Global Carbon Project (2012) *Global Carbon Budget 2012*, www.globalcarbonproject.org.

We seek reliable and publicly available production data, preferably self-reported by the producers. There are data gaps (which are interpolated) in the historic records for some entities; for many entities we do not have production data back to the establishment of the company (this results in minor cases of under-reporting, since early production is usually dwarfed by decades of company expansion). We have corrected the known over-reporting that occurs when oil majors report only gross production (common in the 1950s to 1970s) by applying a "net-to-gross" ratio to the years of reported gross production.[20]

Figure 7. National Oil Companies with Partial Private Ownership.



Percent Private Ownership. Source: World Bank, 2008, Figure 4.

The greatest source of uncertainty is with respect to production by state-owned oil and gas companies (such as Saudi Aramco, National Iranian, Petroleos de Venezuela, Sonangol). While we have largely succeeded in reporting net production by multinational oil companies operating in these countries, there is greater uncertainty regarding production reported by the National Oil Companies — reporting which either erroneously includes production transferred to (and reported by) their international operating partners or appears to report total national production as their own. The production reported in *Oil & Gas Journal* is the primary source for the state-owned companies that do not report production data, or only rarely do so. We have eliminated much of the potential double-counting through a review of the available literature on equity production and production-sharing agreements and made downward revisions to production reported by state-owned oil and gas companies, or, in some cases, the production reported by *Oil & Gas Journal* in its annual OGJ100 review of international companies.[21] Uncertainties remain, however, and

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[20] See Annex B: Methodology, section 3: Uncertainties / Production data. Net production data is preferred, since gross production usually includes production due a joint venture or a production-sharing partner or a state resource owner.

[21] Victor, David G., David Hults, & Mark Thurber, eds, (2012) *Oil and Governance: State-Owned Enterprises and the World Energy Supply*. Marcel, Valerie (2006) *Oil Titans: National Oil Companies in the Middle East*. Aissaoui, Ali (2001) *Algeria: The Political Economy of Oil and Gas*. Ariweriokuma, Soala (2009) *The Political Economy of Oil and Gas in Africa: The Case*

state-owned producers are encouraged to provide complete records of equity production for each year of its corporate history. Figure 7 shows ownership shares in many of the state-owned oil and gas companies detailed in this analysis.[22]

The emissions associated with entity use of their own produced fuels are included as an additional emission source for oil and gas producers (coal producers are excluded, since data on entity use of produced coal is not available and is likely negligible). Company use of its own fuels include field use of produced natural gas for compressors, or similar uses on offshore production platforms or at refineries and processing facilities, pipelines, and for on-site power generation. Each entity's use of own fuels is highly variable; we estimate average own energy use equal to 5.9 percent of emissions from market natural gas.[23] See the methodology discussion in Annex B for details.

Non-energy uses introduce another set of uncertainties. No two oil producers refine the same proportion of petrochemical precursors (such as ethylene), lubricants, waxes, road oil, and other non-energy products that effectively store carbon. (We do account for *net* carbon storage by crediting combustion of plastics, tires, lubricants, greases, and volatiles back to the emissions column.) Natural gas and coal are also used for non-energy products. Non-energy uses vary by season, geography of production, oil gravity, where it is shipped and refined, and innumerable other variables that cannot be fully reflected in a single global non-energy factor. Furthermore, petrochemical use has expanded at differing rates around the globe and from decade to decade. Like other global emission databases (such as CDIAC's), we have to apply one consistent and constant factor for non-energy uses for each fuel type, and while the factor may be reasonably accurate globally, it may not reflect the disposition of each entity's oil and gas products.

Oil produced and stored in Strategic Petroleum Reserves starting in 1971, chiefly in OECD nations and China, is not accounted for. This omission is minor, since total stored volumes in 2010 amounted to 4.1 billion bbl, or 0.42 percent of the 976 billion bbl produced globally between 1971 and 2010. Furthermore, the crude oil will be refined and marketed once the oil is released from the reserves, so it is merely a delay in emissions.

Emission factors, largely based on IPCC values, are assigned an uncertainty range of ±5 percent, although in practice — particularly for coal producers that do not report coal rank, quality, or heating values — the uncertainty is higher: a company's reported production of "thermal coal" can range in carbon content from sub-bituminous to bituminous coal, suggesting an uncertainty range of ±15 percent in emissions per tonne of coal production. Most producers, backed by our research on coal rank in operating regions of several companies, fall in a narrower uncertainty range. The coal emission factor applied to carbon major coal producers is, on average, 4.4 percent higher than the average coal emission

of Nigeria. World Bank (2008, & 2008b) *A Citizen's Guide to National Oil Companies*, Technical Report, and Data Directory. Baker Institute (2007) *The Changing Role of National Oil Companies in International Energy Markets*, Rice University. Grayson, Leslie (1981) *National Oil Companies*.

[22] World Bank (2008) *A Citizen's Guide to National Oil Companies, Part A: Technical Report*, World Bank, Washington, & Center for Energy Economics, Bureau of Economic Geology Jackson School of Geosciences University of Texas, Austin.

[23] We analyzed own energy use reported by eleven company data submissions to the Carbon Disclosure Project. Scope 1 "combustion" emissions are assumed to represent own fuel use, typically 47 percent petroleum products and 53 percent natural gas. Estimated own fuel emissions ranged from 5.1 percent to 17.0 percent of emissions from sold products (Hess and ENI, respectively) and average 11.3 percent (weighted). We adjust this downward by allocating only own use of natural gas (excluding own use of petroleum products, the carbon for which is fully allocated); the final emission factor is 59.24 $kgCO_2/tCO_2$ from product combustion, or 5.92 percent.

factor calculated from CDIAC results over 1980 to 2010. This provides some assurance that our estimates are reasonable, given the highly variable coal ranks and ambiguous reporting by many entities in this analysis.

Estimates of emissions from vented CO_2, flared natural gas, and fugitive CO_2 and methane from oil and gas operations and coal mines (mining and post-mining) are based on peer-reviewed sources — primarily IPCC default values (except for methane from oil and gas operations where U.S. EPA methane rates are used; see Annex B for discussion) — and are reasonable globally, but with higher uncertainty for individual producers. For example, we derive the coal methane factor by averaging methane rates (IPCC default values) from developing and developed countries, combining mining and post-mining, and weighting the factors for underground and surface coal production in 2005 (60 percent underground, 40 percent opencast).[24] This yields a reasonable global factor, but underestimates methane emissions for underground operators and vice-versa for opencast operators.[25] For example, a coal operator with underground (UG) mines will have a methane emission rate of 13.7 kg CH_4/tonne of coal mined (using the average IPCC factor for UG mines, although each mine's "gassiness" will vary) and will be attributed a methane emissions rate of 7.30 kg CH_4/t coal mined, an underestimate of 46.7 percent. This reduces total emissions attributed to this operator — the sum of CO_2 from coal combustion and methane leakage — by 6.8 percent.

5. Emission factors for combustion of crude oil, natural gas, & coal, and ancillary emissions of carbon dioxide & methane

The emission factors applied to each entity's production of crude oil and natural gas liquids (NGLs), natural gas, and coal, after accounting for net non-energy uses, are listed in Table 1. The factors are based on IPCC values, except for natural gas, which is based on EPA factors.

Table 1. Emissions factors for combustion of crude oil & NGLs, natural gas, and coal

Energy source	Carbon kg C/unit	Carbon dioxide kg CO_2/unit
Crude oil & NGLs	101.4 kgC/bbl	371.4 kgCO_2/bbl
Natural gas	14.6 kgC/kcf	53.4 kgCO_2/kcf
Lignite	328.4 kgC/tonne	1,203.5 kgCO_2/tonne
Subbituminous	495.2 kgC/tonne	1,814.4 kgCO_2/tonne
Bituminous	665.6 kgC/tonne	2,439.0 kgCO_2/tonne
Anthracite	715.6 kgC/tonne	2,621.9 kgCO_2/tonne
"Metallurgical coal"	727.6 kgC/tonne	2,665.9 kgCO_2/tonne
"Thermal coal"	581.1 kgC/tonne	2,129.3 kgCO_2/tonne

Crude oil: prior to non-energy deduction & adjustment for NGLs: 115.7 kgC/bbl, 423.8 kgCO_2/bbl;
Gas: prior to non-energy deduction: 14.86 kgC/kcf, or 54.44 kgCO_2/kcf; (kcf = thousand cubic feet).

Emissions from flaring and vented carbon dioxide and from fugitive and vented methane from oil and gas operations and coal mining are shown in Table 2. This analysis uses a global warming potential for methane of 21 x CO_2, 100-year time horizon (per IPCC *Second*

[24] World Coal Institute (2005) *The Coal Resources: A Comprehensive Overview of Coal*, London, worldcoal.org

[25] Underground mines emit methane at 18 m^3 per tonne, on average, compared to 1.2 m^3/t for opencast (surface) mines. This is primarily a function of coal seam depth. IPCC (2006) *Guidelines*, Volume 2, chapter 4: fugitive emissions.

Assessment Report).[26] The basic unit is $kgCO_2e$ per tonne of CO_2 ($kgCO_2e/tCO_2$) released from combustion of petroleum, natural gas, and coal, and the total column shows additional emissions per tCO_2 for each fuel type, and easily converted to percent. Additional emissions from venting and flaring and methane are 6.02 percent for petroleum, 23.8 percent for natural gas, and 8.47 percent for coal. These factors include deductions for non-energy uses of each carbon fuel, but exclude the factor for entities' use of own fuel.

Table 2. Emission factors for vented, flared, and fugitive carbon dioxide & methane

Entity	Combustion $kgCO_2/tCO_2$	Flaring $kgCO_2/tCO_2$	Vented $kgCO_2/tCO_2$	Methane $kgCH_4/tCO_2$	Methane $kgCO_2e/tCO_2$	Total $kgCO_2e/tCO_2$
Crude oil & NGLs	1,000	15.94	3.83	1.92	40.39	1,060.2
Natural gas	1,000	1.74	28.53	9.88	207.44	1,237.7
Coal	1,000	ne	ne	4.03	84.73	1,084.7

ne: not estimated; see text for discussion. GWP factors on the 100-year time horizon, per IPCC *SAR*. The natural gas EF excludes emissions from "own fuel use" of 59.24 kg CO_2/tCO_2 (natural gas only).

The derivation and context for the above factors are discussed in Annex B: Methodology, section 4: Emission factors, non-energy use, ancillary emissions of CO_2 and CH_4, own fuel use and emissions, and cement protocol.

6. Results: all Carbon Major Entities, and by source

This project quantifies and traces emissions resulting from production of crude oil & NGLs, natural gas, and coal to 83 of the world's largest fossil fuel entities from as early as 1854 through 2010. Emissions from cement manufacture by seven entities are also estimated.

A cumulative total of 914 billion metric tonnes of carbon dioxide equivalent ($GtCO_2e$) is attributed to 90 producing entities from the combustion of produced and marketed carbon fuels (815 $GtCO_2$), cement production (13 $GtCO_2$), vented CO_2 (5 $GtCO_2$), flaring (6 $GtCO_2$), own fuel use (7 $GtCO_2$), and fugitive methane from oil, natural gas, and coal production (68 $GtCO_2$). The emissions traced to these "Carbon Major" entities represent 63.4 percent of global industrial CO_2 emissions from fossil fuel combustion, flaring, and cement over the period from 1751 to 2010 (63.0 percent of CO_2 and methane).[27] That is to say, nearly two-thirds of global industrial CO_2 emissions since the industrial revolution can be traced to fuels and cement produced by only 90 specific entities. This analysis includes nine current and former nation-states in which investor-owned or state-owned enterprises have not been established or play a minor historical or quantitative role, chiefly in the coal sector (e.g., Former Soviet Union, Poland, North Korea). We first present cumulative results for all 90 entities, followed by results for investor-owned companies (IOCs), state-owned entities (SOEs), and current and former nation-states in Chapter 7.

Table 3 compares the results for all 90 carbon major entities to global historic industrial emissions of CO_2 and methane from 1751 to 2010 (CDIAC global data).

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[26] Intergovernmental Panel on Climate Change (1996) *Climate Change 1995, Second Assessment Rpt, The Science of Climate Change*, IPCC Working Group I, Cambridge Univ. Press. See Table 4, p. 22.

[27] Marland, Gregg, T. A. Boden, & R. J. Andres (2011). Cumulative emissions of carbon dioxide from fossil fuel combustion, flaring, and cement 1751-2010 total 1,336 $GtCO_2$, of which Carbon Majors total 846.6 $GtCO_2$, or 63.4 percent. The fraction is slightly lower for the sum of CO_2 & methane: Global 1,450 $GtCO_2e$, of which carbon majors 914 $GtCO_2e$ (63.04 percent).

Table 3. All Carbon Majors and global emissions of CO_2 and methane, 1751-2010

Source	Carbon Majors $GtCO_2e$	Global 1751-2010 * $GtCO_2e$	Carbon Majors % of global
Oil & NGLs	365.7	472.0	77.5%
Natural gas	120.1	176.1	68.2%
Coal	329.6	642.5	51.3%
Cement	13.2	32.5	40.6%
Flaring	6.0	12.6	47.9%
Vented CO_2	4.8	na	na
Own fuel use	7.1	na	na
Fugitive methane	67.6	114.6	59.0%
Sum	914.3	1,450.3	63.0%

* Global CO_2 combustion data from CDIAC; methane from Stern & Kaufmann and European Commission JRC data.

Figure 8 charts and compares annual emissions of carbon dioxide attributed to all Carbon Major entities to global emissions from 1810 to 2010. Table 4 shows the cumulative emissions attributed to Carbon Majors entities, in $GtCO_2e$ and percent by source.

Figure 8. Carbon Majors and global industrial CO_2 emissions 1810-2010

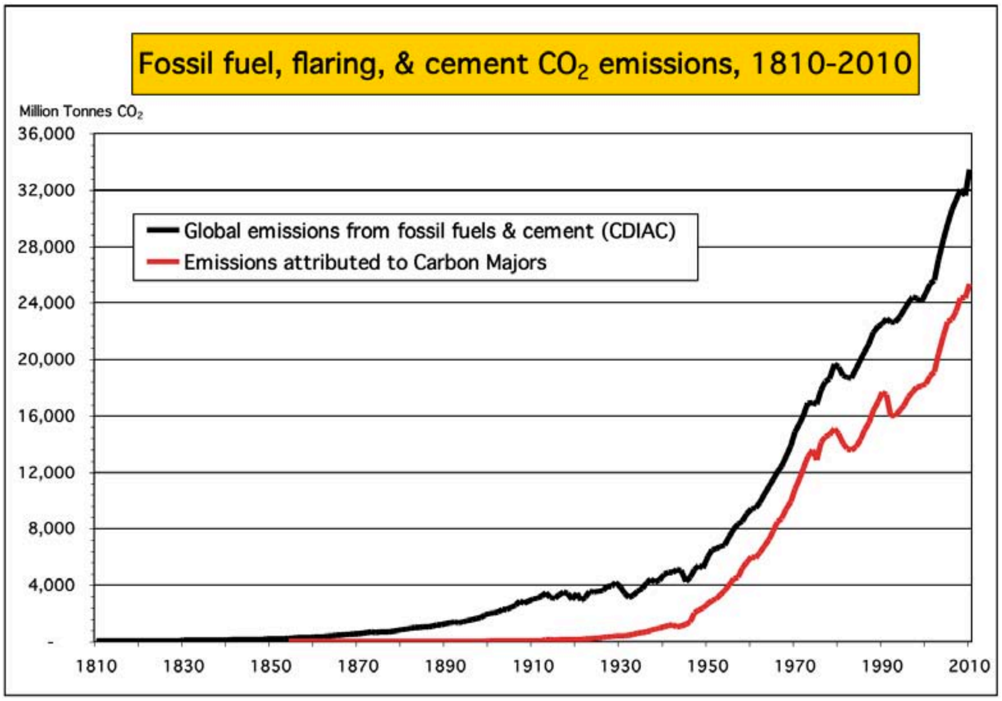


Table 4. Carbon Majors cumulative totals, by source

Combustion	Entities #	Total emissions $GtCO_2e$	Share of CME total Percent
Oil & NGLs	55	365.7	40.00%
Natural gas	56	120.1	13.14%
Coal	36	329.6	36.05%
Flaring	56	6.0	0.66%
Own fuel use	56	7.1	0.78%
Cement	7	13.2	1.45%
Vented CO_2	54	4.8	0.53%
Fugitive methane	83	67.6	7.40%
Total	90	914.3	100.0%
CDIAC global emissions 1751-2010		1,450.3	
Carbon Majors of global emissions (CDIAC)		63.04 percent	

Net of non-energy uses, these emissions are attributed to the producers of 985 billion bbl of crude oil and NGLs (of which the carbon in ~80 billion bbl has been stored through non-energy uses), 2,248 trillion cubic feet (Tcf) of natural gas (63,653 billion cubic meters (Bcm)), and 163 billion tonnes of various ranks of coal.

Figures 9 & 10 illustrate how this project's results differ from CDIAC's totals by source. This project quantifies 77.5 percent of global historic emissions from crude oil, 68.2 percent of natural gas, 51.3 percent of coal, 40.6 percent of cement, 47.9 percent of flaring, and 59.0 percent of fugitive methane (compared to CDIAC/JRC). The emissions attributed to Carbon Majors based on data from 1854 or later are equivalent to 63.0 percent of estimated global industrial emissions of carbon dioxide and methane over the period 1751 to 2010.

Figure 9. Global industrial CO_2 emissions 1900-2010, by source

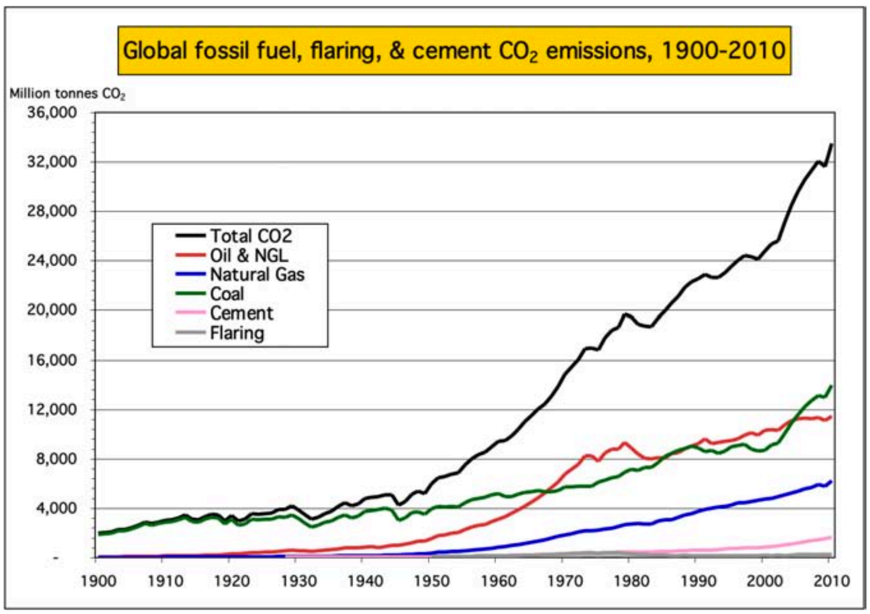
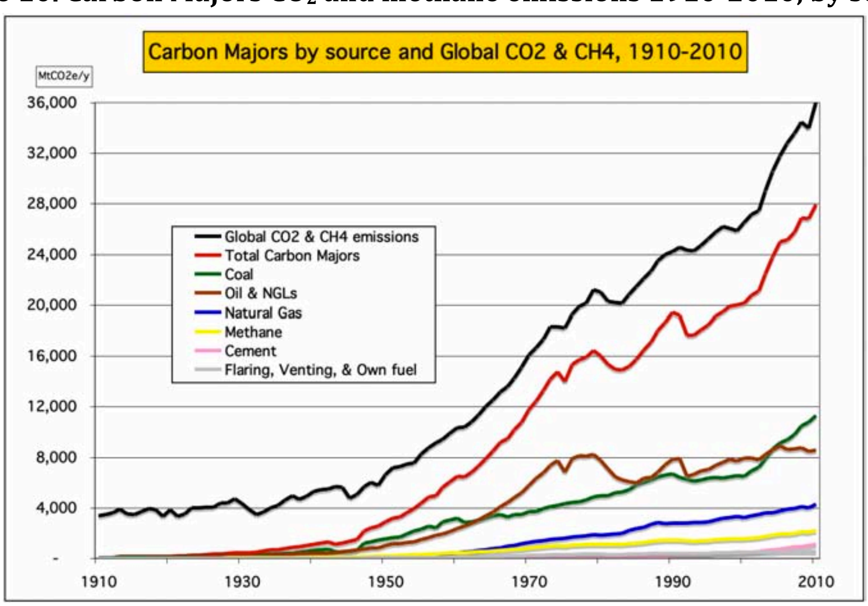
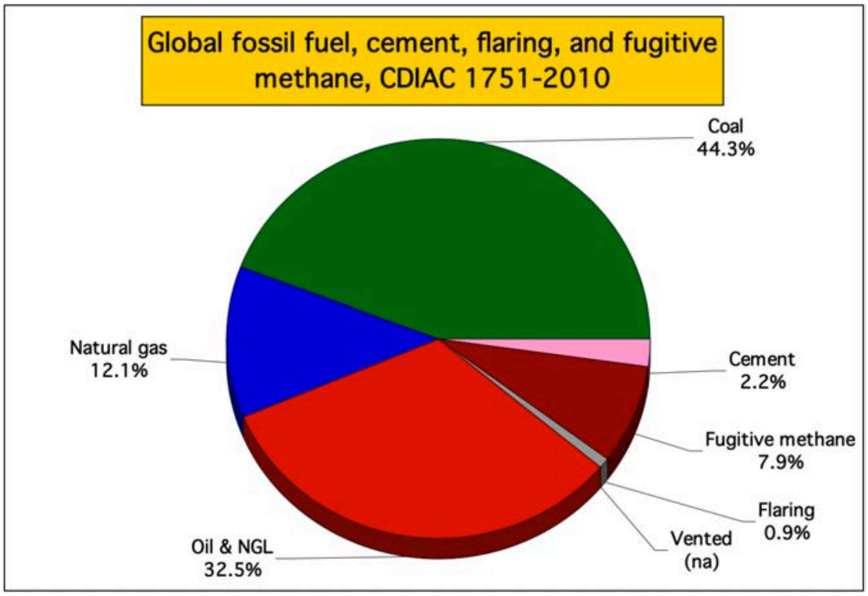


Figure 10. Carbon Majors CO_2 and methane emissions 1910-2010, by source



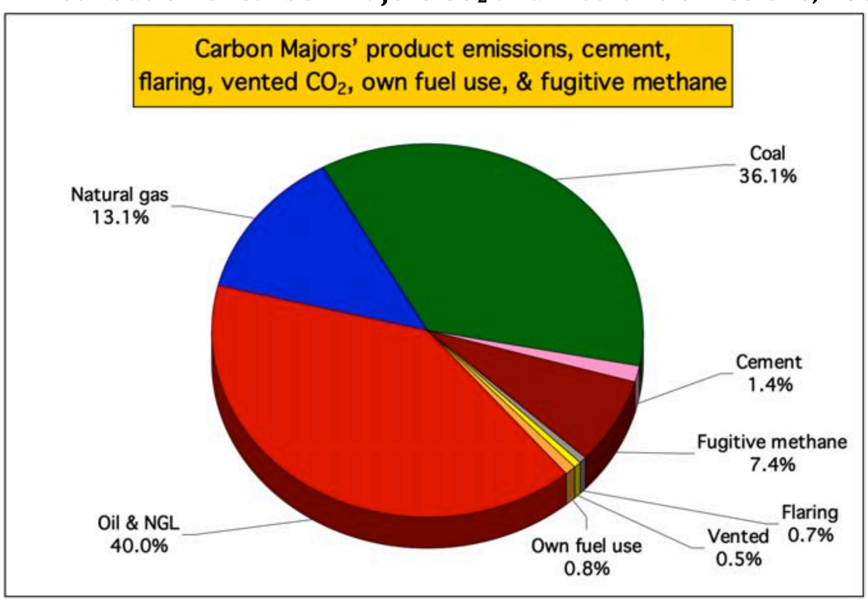
Figures 11 and 12 compare the combined results for the 90 carbon major entities to CDIAC cumulative estimates by fossil fuel combustion, cement emissions, vented CO_2, flaring, and fugitive methane in percentage by source.

Figure 11. Distribution of global industrial CO_2 and methane emissions, 1751-2010



CDIAC data.

Figure 12. Distribution of Carbon Majors CO_2 and methane emissions, 1854-2010



FOSSIL FUEL PRODUCTION & EMISSIONS: CRUDE OIL AND NATURAL GAS LIQUIDS (NGLS)

This project has documented a cumulative total of 984.7 billion bbl of oil & NGL production from 55 entities, ranging in size from OMV (501 million bbl) to Saudi Aramco (108 billion bbl). Non-energy uses took an estimated 8.02 percent of production out of the potential emissions column for use as feedstocks for petrochemicals, lubricants, road oils, waxes, and similar uses, after accounting for short-term re-emission to the atmosphere. The final emission factor is 371.4 kg CO_2 per bbl (Table 1).

Oil & NGL emissions from fuel combustion total 365.7 GtCO_2. CDIAC's estimate of historic emissions from combustion of liquids from 1870 to 2010 total 128.8 GtC, or 472.0 GtCO_2; this project has therefore documented emissions from oil and NGL combustion equivalent to 77.5 percent of the cumulative total from liquids (CDIAC). Carbon dioxide from flaring, vented and fugitive CO_2, and fugitive methane adds 22.0 GtCO_2e. This project has quantified and traced a total of 387.7 GtCO_2e to Carbon Major petroleum producers, 350.1 GtCO_2e of which are attributed to all investor-owned and state-owned oil companies (Table 5).

Table 5. Top Twenty investor- & state-owned oil & NGL producers and attributed emissions

Entity	Data set anno	Oil & NGL prod million bbl	Emissions MtCO_2
1. Saudi Aramco, Saudi Arabia	1938-2010	108,050	40,133
2. Chevron, USA	1912-2010	98,492	36,583
3. ExxonMobil, USA	1884-2010	79,658	29,587
4. BP, UK	1913-2010	69,684	25,883
5. National Iranian	1928-2010	63,130	23,448
6. Royal Dutch Shell, The Netherlands	1892-2010	56,962	21,157
7. Pemex, Mexico	1938-2010	39,797	14,782
8. Petroleos de Venezuela	1960-2010	34,118	12,673
9. Kuwait Petroleum	1946-2010	25,095	9,321
10. ConocoPhillips, USA	1924-2010	24,961	9,271
11. Total, France	1934-2010	23,683	8,796
12. PetroChina	1988-2010	22,527	8,367
13. Abu Dhabi National Oil	1962-2010	20,352	7,559
14. Iraq National Oil	1960-2010	17,680	6,567
15. Libya National Oil	1961-2010	15,561	5,780
16. Nigerian National	1959-2010	15,023	5,580
17. Pertamina, Indonesia	1958-2010	13,241	4,918
18. Petrobras, Brazil	1960-2010	12,879	4,784
19. Sonatrach, Algeria	1959-2010	12,026	4,467
20. Lukoil, Russian Federation	1996-2010	9,023	3,352
All other IOC & SOE oil & NGL producers		136,264	50,612
Sum all IOC & SOE producers		889,182	330,267
Vented CO_2			1,266
Flaring CO_2			5,266
Fugitive methane (CO_2e)			13,341
Total			**350,139**

Emissions attributed to each entity are for combustion of oil products, and exclude additional CO_2 & methane.

Fossil fuel production & emissions: Natural Gas

This project has documented the cumulative production of 2,248 trillion cubic feet (Tcf) of natural gas (63,653 Bcm) of 56 entities, ranging in size from CONSOL (0.68 Tcf, for coalbed methane recovery) to Gazprom (438 Tcf). Non-energy uses removed an estimated 1.86 percent of production out of the emissions column for petrochemicals and fertilizer manufacture, once short-term re-emission to the atmosphere for non-energy uses were accounted for. The emission factor is 53.43 kgCO_2 per 1,000 cubic feet (kcf) (Table 1).

Emissions from the combustion of natural gas total 120.1 $GtCO_2$. The CDIAC estimate for natural gas emissions over the period from 1885 to 2010 totals 48.0 GtC, or 176.1 $GtCO_2$; this project has documented emissions from natural gas combustion equivalent to 68.2 percent of the total estimated by CDIAC. Additional CO_2 from flaring, vented CO_2, entity use of its own natural gas, and fugitive methane from natural gas systems adds 35.7 $GtCO_2e$. Emissions quantified and attributed to natural gas producers total 155.8 $GtCO_2e$, of which 132.5 $GtCO_2e$ is traced to all investor-owned and state-owned oil companies (Table 6).

Table 6. Top Twenty investor- & state-owned natural gas producers & attributed emissions

Entity	Data set anno	Natural gas prod billion cf (Bcf)	Emissions $MtCO_2$
1. Gazprom, Russian Federation	1989-2010	437,606	23,383
2. ExxonMobil, USA	1900-2010	200,228	10,699
3. Chevron, USA	1935-2010	158,420	8,465
4. Royal Dutch Shell, The Netherlands	1930-2010	120,068	6,416
5. BP, UK	1932-2010	106,799	5,707
6. ConocoPhillips, USA	1926-2010	101,538	5,426
7. Sonatrach, Algeria	1961-2010	65,327	3,491
8. Pemex, Mexico	1959-2010	62,824	3,357
9. National Iranian	1956-2010	60,965	3,258
10. Saudi Aramco, Saudi Arabia	1955-2010	50,289	2,687
11. Petroleos de Venezuela	1960-2010	39,282	2,099
12. Total, France	1972-2010	37,309	1,994
13. ENI, Italy	1950-2010	36,679	1,960
14. Petronas, Malaysia	1974-2010	34,971	1,869
15. Anadarko, USA	1945-2010	27,604	1,465
16. PetroChina	1988-2010	24,433	1,306
17. Abu Dhabi NOC	1962-2010	23,926	1,278
18. Pertamina, Indonesia	1958-2010	23,319	1,246
19. Statoil, Norway	1977-2010	19,079	1,019
20. Repsol, Spain	1987-2010	18,377	982
All other IOC & SOE natural gas producers		262,474	14,025
Sum all IOC & SOE producers		1,912,213	102,176
Vented CO_2			2,915
Flaring CO_2			177
Own fuel use			6,053
Fugitive methane (CO_2e)			21,196
Total			**132,518**

Emissions attributed to each entity are for combustion of natural gas, and exclude additional CO_2 & methane.

Note: Multinational companies were, historically, more interested in producing oil, not natural gas, and the gas was pipelined to processing plants or (more often) flared, re-injected to maintain reservoir pressures, or, in many cases, simply vented. Many state-owned entities did not report natural gas production (in which case we used the U.S. EIA international production statistics for each producing country on the assumption that none or little of the gas was exported).[28] Now that natural gas is increasingly monetized as LNG or exported by pipeline, far less natural gas is flared. Flaring from oil production in 2010 totaled 4,734 Bcf (134 Bcm) — down 15 percent since 2007 — of which 26 percent is from Russia, 11 percent from Nigeria, 8 percent from Iran, and 1.6 percent from the USA.[29]

[28] U.S. Energy Information Administration (2013) *Country Studies*, U.S. DOE, www.eia.gov/countries

[29] World Bank (2011) Gas flaring from gas associated with oil production; 2006-2010, go.worldbank.org/D03ET1BVD0

FOSSIL FUEL PRODUCTION & EMISSIONS: COAL

This project documented the cumulative production of 162.7 billion tonnes (Gt) of 36 entities, ranging in size from Anadarko/Kerr-McGee (0.30 Gt) to Coal India (8.1 Gt). Non-energy uses took an estimated 0.02 percent of production out of the emissions column for coking coal (accounting for the carbon in steel-making), carbon fibers, and other industrial uses. The *average* emission factor is 2.025 kg CO_2 per kg coal — but ranges from a low of 1.203 kg CO_2/kg for lignite producers (e.g., Luminant, North American Coal) to 2.439 kg CO_2/kg for bituminous coal producers (e.g., Sasol, UK Coal, and Murray Coal) and 2.665 kg CO_2/kg for metallurgical coal (e.g., BHP-Billiton, Xstrata).

Table 7. Investor-owned & state-owned coal producers and attributed emissions

Entity	Data set anno	Coal prod million tonnes (Mt)	Emissions $MtCO_2$
1. British Coal Corp., UK	1947-1994	7,275	17,742
2. Coal India, India	1973-2010	8,052	14,282
3. Peabody Energy, USA	1945-2010	5,341	11,461
4. CONSOL Energy, USA	1864-2010	3,454	8,342
5. Anglo American, UK	1909-2010	2,963	6,676
6. RWE, Germany	1965-2010	4,717	6,309
7. Rio Tinto, Australia	1961-2010	2,697	5,495
8. Arch Coal, USA	1973-2010	2,550	5,428
9. BHP-Billiton, Australia	1955-2010	2,345	5,355
10. Sasol, South Africa	1953-2010	1,329	3,241
11. Xstrata, Switzerland	1998-2010	828	2,049
12. Massey Energy, USA	1981-2010	811	2,027
13. Alpha Natural Resources, USA	1998-2010	879	1,981
14. Singareni Collieries, India	1947-2010	978	1,735
15. Occidental, USA	1945-1992	688	1,725
16. Cyprus Amax, USA	1969-1998	1,084	1,611
17. Westmoreland Coal, USA	1854-2010	878	1,411
18. ExxonMobil, USA	1970-2002	619	1,317
19. Chevron Mining (& Midway), USA	1965-2010	504	1,229
20. Kiewit Mining Group, USA	1944-2010	671	1,194
21. North American Coal, USA	1950-2010	905	1,088
22. Ruhrkohle AG, Germany	1989-2003	631	1,049
23. Luminant, USA	1977-2010	804	967
24. BP Coal, The Netherlands	1960-1989	431	918
25. Murray Coal, USA	1988-2010	301	734
26. UK Coal, UK	1995-2010	300	732
27. Kerr McGee (Anadarko), USA	1979-1996	299	636
Sum all IOC & SOE coal producers		52,333	106,736
Vented CO_2			na
Flaring CO_2			na
Fugitive methane (CO_2e)			9,043
Total			**115,779**

Emissions attributed for coal combustion, and exclude methane; see Table 22 for nation-states.

Emissions traced to the Carbon Major coal entities total 329.6 $GtCO_2$. The CDIAC estimate for coal emissions from 1751 to 2010 totals 175.4 GtC, or 642.5 $GtCO_2$; this project has documented emissions from coal combustion equivalent to 51.3 percent of the global cumulative total estimated by CDIAC. Methane emissions from vented or fugitive methane comprise 7.8 percent of total coal emissions (27.9 $GtCO_2e$ of 357.5 $GtCO_2e$). (Table 7.) The 24 investor-owned coal companies are attributed 79.2 $GtCO_2e$, and the three state-owned coal companies (one of which, British Coal Corporation, is no longer extant) are attributed 36.6 $GtCO_2e$. Coal production and emissions traced to the nine nation-states total 241.8 $GtCO_2e$, and thus makes up the bulk of attributed coal emissions.[30]

As noted in the Methodology Annex, this project tracks rank or heating values of produced coal companies when reported. Carbon content factors (IPCC data) are applied in order to estimate final emissions traced to each company's coal production. Background research on the coal quality or rank for non-reporting companies in coal regions in which the companies operated was conducted to elucidate the carbon content of coal mined.

CEMENT PRODUCTION & EMISSIONS

This project has attributed a total of 13.2 $GtCO_2$ of industrial process emissions to seven cement entities, ranging from Taiheiyo Cement (0.40 $GtCO_2$) to Lafarge (1.0 $GtCO_2$). The *average* emission factor is 0.540 kg CO_2 per kg cementitious product. The CDIAC estimate of cement emissions over the period from 1928 to 2010 totals 8.88 GtC, or 32.5 $GtCO_2$; this project has therefore documented emissions from cement manufacturing equivalent to 40.6 percent of the cumulative total estimated by CDIAC.[31] Process emissions from the calcining of limestone totaling 4.1 $GtCO_2$ have been traced to the six investor-owned cement producers, for which have data for 1990 to 2010, except for Taiheiyo (from 1975), even though all of these companies were founded prior to World War One.

Table 8. The six investor-owned cement producers and attributed emissions

Entity	Data set anno	Gross emissions $GtCO_2$	Process emissions $GtCO_2$
1. Lafarge, France	1990-2010	1.73	1.04
2. Holcim, Switzerland	1990-2010	1.66	1.01
3. HeidelbergCement, Germany	1990-2010	0.98	0.59
4. Cemex, Mexico	1990-2010	0.91	0.55
5. Italcimenti	1990-2010	0.77	0.46
6. Taiheiyo	1975-2010	0.69	0.40
Total		**6.75**	**4.06**

See Table 23 for China's cement emissions.

The cement industry is dominated by local and smaller companies, and only six global companies meet the threshold of <8 MtC/yr. Cement companies typically report production *capacity* rather than actual production. This is the reason we derive net process emissions from company-reported gross emissions of CO_2. (Note: gross emissions of CO_2 include fuel and electricity inputs; these emissions are *excluded* from our calculations.) We quantify net industrial process emissions of CO_2 from the heating of calcium carbonate ($CaCO_3$) in cement kilns, a process that releases CO_2 to the atmosphere.

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[30] Former Soviet Union, China, Poland, Russia, Czechoslovakia, Kazakhstan, Ukraine, North Korea, and Czech Republic.

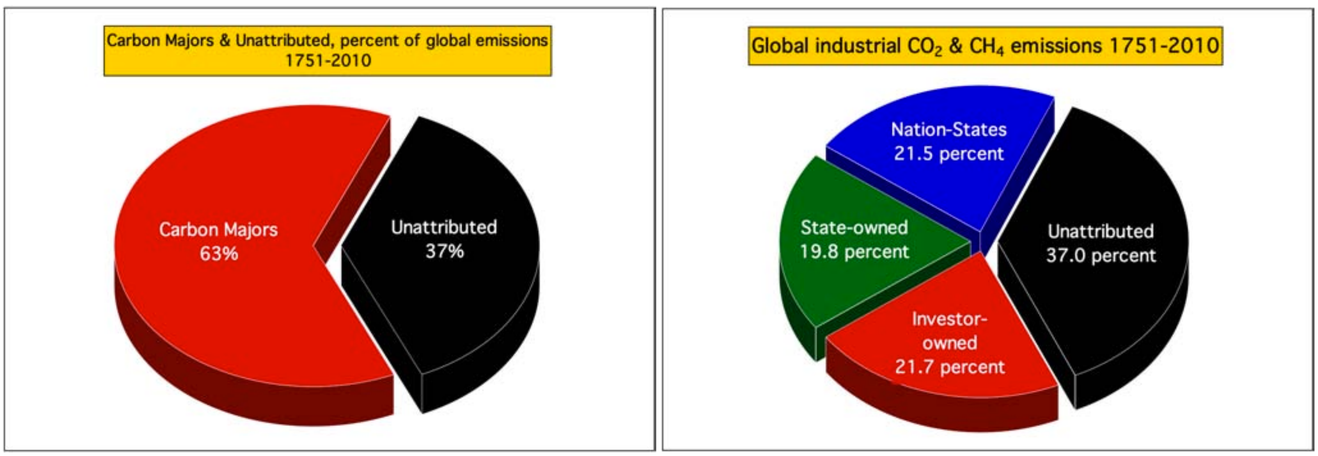
[31] A factor of 0.50 kg CO_2 per kg cementitious was used for China, which was based on CDIAC and U.S. Bureau of Mines data: CDIAC emission estimation protocol asserts that "CO_2 production (in metric tons of C) = 0.136 metric tons of C per tonne cement * quantity of cement produced." 0.136 tC * 3.667 CO_2/C = 0.499 tCO_2 per tonne of cement produced; round to 0.5, or 2 tonnes cement production per tCO_2. Mole calculation: (12.01 g C/mole $CaCO_3$ ÷ 56.08 g CaO/mole $CaCO_3$) * 0.635 g CaO/g cement = 0.136 g C/g cement. Boden, Marland, & Andres (1995).

China's cement emissions are calculated differently than the methodology used for the six investor-owned companies. For China, which produced 53.9 percent of world cement in 2010, we use cement production data from the U.S. Bureau of Mines and apply the CDIAC CO_2 coefficient (0.50 tCO_2/t cement).[32] See Annex B for details on the cement methodology.

SUMMARY OF ALL CARBON MAJORS

Figure 13 illustrates the share of global cumulative emissions (1,450 $GtCO_2e$) contributed by Carbon Major entities (914 $GtCO_2e$). The black triangle represents the proportion not accounted for by the Carbon Majors project, which are companies no longer extant, and the thousands of existing oil, natural gas, and coal companies that do not meet the 8 MtC threshold for inclusion in this project, and the excluded nation-states (e.g., Tajikistan and Vietnam), and the hundreds of companies that are no longer in business (such as early coal companies) and whose assets were not acquired by the companies included in this analysis.

Figures 13 & 14. Historic emissions attributed to Carbon Majors & unattributed, and by category



Of cumulative emissions traced to Carbon Majors, 21.7 percent (315 $GtCO_2e$) is traced to investor-owned companies, 19.8 percent (288 $GtCO_2e$) to state-owned entities, and 21.5 percent (312 $GtCO_2e$) to nation-states (Figure 14).

Global emissions of industrial sources of carbon dioxide and methane totaled 36 billion tonnes CO_2e ($GtCO_2e$) in 2010, or 1,142 tCO_2e per second, equivalent to filling the volume of the United Nations building in New York City *twice*, per second.[33,34] The 90 Carbon Major entities contributed 27.95 $GtCO_2e$ in 2010, or 886 tCO_2e per second. Of the 2010 emission rate attributed to Carbon Major entities:

- 7,628 $MtCO_2e$ (242 tCO_2e/sec, 27.3%) is attributed to investor-owned companies,
- 10,818 $MtCO_2e$ (343 tCO_2e/sec, 38.7%) is attributed to state-owned companies, and
- 9,500 $MtCO_2e$ (301 tCO_2e/sec, 34.0%) is attributed to nation-states.

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32 Marland, Gregg, & Ralph Rotty (1984) Carbon dioxide emissions from fossil fuels: a procedure for estimation and results for 1950-1982, *Tellus*, vol. 36b:232-261.

33 In 2010, fossil fuels contributed 31.6 $MtCO_2$, cement 1.6 $MtCO_2$, flaring 0.3 $MtCO_2$, and fugitive methane ~2.5 $MtCO_2e$.

34 Based on work by Carbon Visuals in the UK, updated from their use of CDIAC-based emissions rate of 957 $MtCO_2$ (fuels, cement, and flaring) in 2006: 6.9 UNs in four seconds, updated to the 2010 rate of 1,142 tCO_2/sec, or 1.9 UNs/sec.

7. Results: investor-owned, state-owned, and nation-states

This project has quantified and traced cumulative emissions totaling 914.3 $GtCO_2e$ to the 90 Carbon Major entities included in this analysis. This is equivalent to 63.04 percent of the CDIAC estimate of cumulative industrial emissions from 1751 to 2010, including methane emissions associated with coal mining and natural gas.[35] CDIAC industrial emissions from oil, natural gas, coal, cement, flaring, and fugitive methane totals 1,450.3 $GtCO_2e$. (CDIAC includes a small factor for vented CO_2 in its natural gas estimates.) Emissions attributed to all Carbon Major investor-owned and state-owned entities are shown in Table 9. Table 10 compares all investor-owned and state-owned entities' emissions to global industrial CO_2 and methane emissions for the anthropocene from 1751 to 2010.

Table 9. Investor-owned & state-owned entities' cumulative emissions, by source

COMBUSTION	Entities **#**	IOC & SOE emissions **$GtCO_2e$**	Share of total **Percent**
Oil & NGLs	54	330.27	54.82%
Natural gas	55	102.18	16.96%
Coal	27	106.74	17.72%
Flaring	54	5.44	0.90%
Own fuel use	55	6.05	1.00%
Cement	6	4.05	0.67%
Vented CO_2	55	4.18	0.69%
Fugitive methane	81	43.58	7.23%
Total	81	602.49	100.00%
Global emissions 1751-2010 (CDIAC)		1,450.33	
IOCs & SOEs of global emissions		41.54 percent	

Table 10 Investor-owned & state-owned entities' and global cumulative emissions, by source

SOURCE	IOCs & SOEs **$GtCO_2e$**	Global 1751-2010 * **$GtCO_2e$**	IOCs & SOEs **% of global**
Oil & NGLs	330.3	472.0	70.0%
Natural gas	102.2	176.1	58.0%
Coal	106.7	642.5	16.6%
Cement	4.1	32.5	12.5%
Flaring	5.4	12.6	43.2%
Vented CO_2	4.2	na	na
Own fuel use	6.1	na	na
Fugitive methane	43.6	114.6	38.0%
Sum	602.5	1,450.3	41.5%

Global CO_2 combustion data from CDIAC; methane from Stern & Kaufmann & European Commission JRC data.

The emissions attributed to the twenty largest (in terms of cumulative historic emissions of CO_2 and methane) investor-owned and state-owned fossil fuel companies are shown in Table 11. These entities have been attributed cumulative emissions totaling 428 $GtCO_2e$, or 29.5 percent of the global total from 1751 to 2010. The largest twelve investor-owned companies alone contributed 242 $GtCO_2e$, and equivalent to 16.7 percent of the global historic emissions through 2010. See Table 12 for the complete list of entities.

Figure 15 shows cumulative emissions attributed to the twenty largest investor- and state-owned entities quantified in this project, excluding nation-state entities.

[35] CDIAC (Stern & Kaufmann, 1998) estimated methane emissions from 1860 to 1994; we used EDGAR data from 1994 to 2010 (European Commission, Joint Research Centre, 2011).

Table 11. Top Twenty investor-owned & state-owned entities' 2010 & cumulative emissions

Entity	2010 emissions $MtCO_2e$	Cumulative $MtCO_2e$	Percent of global 1751-2010
1. Chevron, USA	423	51,096	3.52%
2. ExxonMobil, USA	655	46,672	3.22%
3. Saudi Aramco, Saudi Arabia	1,550	46,033	3.17%
4. BP, UK	554	35,837	2.47%
5. Gazprom, Russian Federation	1,371	32,136	2.22%
6. Royal Dutch/Shell, Netherlands	478	30,751	2.12%
7. National Iranian Oil Company	867	29,084	2.01%
8. Pemex, Mexico	602	20,025	1.38%
9. ConocoPhillips, USA	359	16,866	1.16%
10. Petroleos de Venezuela	485	16,157	1.11%
11. Coal India	830	15,493	1.07%
12. Peabody Energy, USA	519	12,432	0.86%
13. Total, France	398	11,911	0.82%
14. PetroChina, China	614	10,564	0.73%
15. Kuwait Petroleum Corp.	323	10,503	0.73%
16. Abu Dhabi NOC, UAE	387	9,672	0.67%
17. Sonatrach, Algeria	386	9,263	0.64%
18. Consol Energy, Inc., USA	160	9,096	0.63%
19. BHP-Billiton, Australia	320	7,606	0.52%
20. Anglo American	242	7,242	0.50%
Top 20 IOCs & SEOs	**11,523**	**428,439**	**29.54%**
Top 40 IOCs & SEOs		**546,767**	**37.70%**
All 81 IOCs & SEOs	**18,524**	**602,491**	**41.54%**
Total 90 Carbon Majors	**27,946**	**914,251**	**63.04%**

Right column compares each entity's cumulative emissions to CDIAC's global industrial emissions 1751-2010. The totals above combine attributed emissions from crude oil & NGL, natural gas, and coal combustion of marketed products, plus ancillary emissions from venting, flaring, own fuel use, and fugitive CO_2 and CH_4.

Figure 15. Top Twenty Carbon Majors, investor and state-owned entities

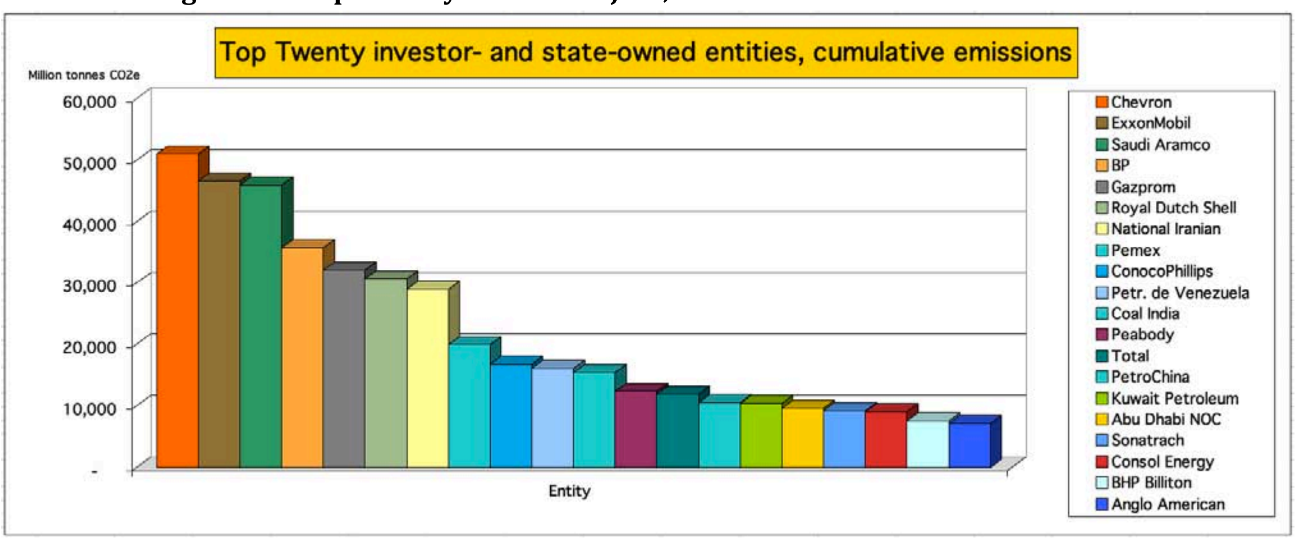


Table 12 shows all of the eighty-one investor-owned and state-owned entities' cumulative contribution of carbon dioxide and methane from product combustion, flaring, vented CO_2, own fuel use, and fugitive methane as a percentage of global industrial CO_2 & CH_4 emissions 1751-2010 (CDIAC). Table 13 provides the same data for the nine nation-states.

Table 12. All 81 investor- & state-owned carbon & cement entities and cumulative emissions

	Entity	Products (fuel, cement) $GtCO_2$	Flaring, own fuel, vented CO_2 $GtCO_2$	Fugitive methane $GtCO_2e$	Total emissions $GtCO_2e$	Percent of global 1751-2010
1.	ChevronTexaco, USA	46.28	1.48	3.34	**51.10**	**3.52%**
2.	ExxonMobil, USA	41.60	1.54	3.53	**46.67**	**3.21%**
3.	Saudi Aramco, Saudi Arabia	42.82	1.03	2.18	**46.03**	**3.17%**
4.	BP, UK	32.51	1.02	2.31	**35.84**	**2.47%**
5.	Gazprom, Russian Federation	25.09	2.13	4.92	**32.14**	**2.22%**
6.	Royal Dutch Shell, The Netherlands	27.57	0.99	2.19	**30.75**	**2.12%**
7.	National Iranian Oil Company	26.71	0.76	1.62	**29.08**	**2.01%**
8.	Pemex, Mexico	18.14	0.59	1.29	**20.03**	**1.38%**
9.	British Coal Corporation, UK *	17.74	0.00	1.50	**19.25**	**1.33%**
10.	ConocoPhillips, USA	14.70	0.67	1.50	**16.87**	**1.16%**
11.	Petroleos de Venezuela	14.77	0.44	0.95	**16.16**	**1.11%**
12.	Coal India	14.28	0.00	1.21	**15.49**	**1.07%**
13.	Peabody Energy, USA	11.46	0.00	0.97	**12.43**	**0.86%**
14.	Total, France	10.79	0.35	0.77	**11.91**	**0.82%**
15.	PetroChina, China	9.67	0.28	0.61	**10.56**	**0.73%**
16.	Kuwait Petroleum Corp.	9.80	0.23	0.48	**10.50**	**0.72%**
17.	Abu Dhabi NOC, UAE	8.84	0.26	0.57	**9.67**	**0.67%**
18.	Sonatrach, Algeria	7.96	0.40	0.91	**9.26**	**0.64%**
19.	Consol Energy, Inc., USA	8.38	0.00	0.71	**9.10**	**0.63%**
20.	BHP Billiton, Australia	6.97	0.06	0.58	**7.61**	**0.52%**
21.	Anglo American, UK	6.68	0.00	0.57	**7.24**	**0.50%**
22.	Iraq National Oil Company	6.70	0.14	0.29	**7.14**	**0.49%**
23.	RWE, Germany	6.31	0.00	0.54	**6.84**	**0.47%**
24.	Pertamina, Indonesia	6.16	0.21	0.46	**6.83**	**0.47%**
25.	Libya National Oil Corp.	6.22	0.15	0.32	**6.69**	**0.46%**
26.	Nigerian National Petroleum	6.06	0.15	0.33	**6.54**	**0.45%**
27.	Petrobras, Brazil	5.49	0.16	0.34	**5.99**	**0.41%**
28.	ENI, Italy	5.20	0.24	0.54	**5.97**	**0.41%**
29.	Rio Tinto, UK	5.50	0.00	0.47	**5.96**	**0.41%**
30.	Arch Coal, USA	5.43	0.00	0.46	**5.89**	**0.41%**
31.	Petronas, Malaysia	4.56	0.22	0.50	**5.27**	**0.36%**
32.	Anadarko, USA	4.56	0.18	0.46	**5.20**	**0.36%**
33.	Occidental, USA	4.63	0.09	0.34	**5.06**	**0.35%**
34.	Statoil, Norway	3.89	0.15	0.33	**4.37**	**0.30%**
35.	Oil & Gas Corporation, India	3.71	0.14	0.31	**4.16**	**0.29%**
36.	Lukoil, Russian Federation	3.60	0.09	0.19	**3.87**	**0.27%**
37.	Sasol, South Africa	3.24	0.00	0.27	**3.52**	**0.24%**
38.	Qatar Petroleum	3.00	0.13	0.29	**3.41**	**0.24%**
39.	Repsol, Spain	2.96	0.13	0.29	**3.38**	**0.23%**
40.	Marathon, USA	2.64	0.11	0.24	**2.99**	**0.21%**
41.	Yukos, Russian Federation *	2.69	0.06	0.12	**2.86**	**0.20%**
42.	Egyptian General Petroleum	2.48	0.09	0.20	**2.77**	**0.19%**
43.	Rosneft, Russian Federation	2.50	0.07	0.15	**2.72**	**0.19%**
44.	Petroleum Development Oman	2.40	0.08	0.18	**2.66**	**0.18%**
45.	Hess, USA	2.09	0.08	0.19	**2.36**	**0.16%**
46.	Xstrata, Switzerland	2.05	0.00	0.17	**2.22**	**0.15%**
47.	Massey Energy, USA	2.03	0.00	0.17	**2.20**	**0.15%**
48.	Alpha Natural Resources, USA	1.98	0.00	0.17	**2.15**	**0.15%**
49.	Singareni Collieries, India	1.74	0.00	0.15	**1.88**	**0.13%**

50. Ecopetrol, Colombia	1.66	0.05	0.10	**1.81**	**0.12%**
51. Sonangol, Angola	1.69	0.03	0.07	**1.79**	**0.12%**
52. Cyprus Amax, USA *	1.61	0.00	0.14	**1.75**	**0.12%**
53. EnCana, Canada	1.40	0.09	0.20	**1.69**	**0.12%**
54. Devon Energy, USA	1.41	0.08	0.19	**1.69**	**0.12%**
55. BG Group, UK	1.24	0.09	0.21	**1.54**	**0.11%**
56. Sinopec, China	1.41	0.04	0.08	**1.53**	**0.11%**
57. Westmoreland Mining, USA	1.41	0.00	0.12	**1.53**	**0.11%**
58. Suncor, Canada	1.24	0.05	0.11	**1.41**	**0.10%**
59. Syrian Petroleum	1.29	0.04	0.08	**1.40**	**0.10%**
60. Kiewit Mining, USA	1.19	0.00	0.10	**1.29**	**0.09%**
61. North American Coal, USA	1.09	0.00	0.09	**1.18**	**0.08%**
62. RAG, Germany	1.05	0.00	0.09	**1.14**	**0.08%**
63. China National Offshore Oil Co.	1.03	0.03	0.06	**1.12**	**0.08%**
64. Luminant, USA	0.97	0.00	0.08	**1.05**	**0.07%**
65. Lafarge, France	1.04	0.00	0.00	**1.04**	**0.07%**
66. Holcim, Switzerland	1.01	0.00	0.00	**1.01**	**0.07%**
67. Canadian Natural Resources	0.83	0.04	0.09	**0.96**	**0.07%**
68. Apache, USA	0.81	0.04	0.10	**0.95**	**0.07%**
69. Bahrain Petroleum	0.78	0.05	0.11	**0.93**	**0.06%**
70. Talisman, Canada	0.79	0.04	0.09	**0.92**	**0.06%**
71. Murray Coal, USA	0.73	0.00	0.06	**0.80**	**0.05%**
72. UK Coal, UK	0.73	0.00	0.06	**0.79**	**0.05%**
73. Husky Energy, Canada	0.59	0.02	0.05	**0.66**	**0.05%**
74. Nexen, Canada **	0.59	0.02	0.04	**0.65**	**0.04%**
75. HeidelbergCement, Germany	0.59	0.00	0.00	**0.59**	**0.04%**
76. Cemex, Mexico	0.55	0.00	0.00	**0.55**	**0.04%**
77. Polish Oil & Gas	0.42	0.02	0.03	**0.47**	**0.03%**
78. Italcimenti, Italy	0.46	0.00	0.00	**0.46**	**0.03%**
79. Murphy Oil, USA	0.37	0.02	0.03	**0.42**	**0.03%**
80. Taiheiyo, Japan	0.40	0.00	0.00	**0.40**	**0.03%**
81. OMV Group, Austria	0.30	0.01	0.03	**0.35**	**0.02%**
Total IOC & SOE producers	**543.23**	**15.68**	**43.58**	**602.49**	**41.54%**
Total CDIAC, 1751-2010	**1,323.09**	**na**	**114.65**	**1,450.33**	
Percent this study of CDIAC	**41.06%**	**na**	**38.01%**	**41.54%**	

This table includes each entity's estimated emissions from fuel combustion (net of non-energy uses), flaring, own fuel use, and ancillary emissions of CO_2 and CH_4 (in CO_2e units). Emissions from cement manufacturing are listed under product emissions, but are vented process emissions from the calcination of calcium carbonate. * not extant; production and emission quantified for these entities but not attributed to extant entities. ** Nexen was acquired by CNOOC in 2012.

Table 13. 2010 and cumulative emissions of Nation-State producers

Entity	Products (fuel, cement) $GtCO_2$	Flaring, own fuel, vented CO_2 $GtCO_2$	Fugitive methane $GtCO_2e$	Total emissions $GtCO_2e$	Percent of global 1751-2010
1. Former Soviet Union (oil, gas, coal)	116.88	2.31	10.53	**129.72**	**8.94%**
2. China (coal and cement)	115.11	0.00	8.98	**124.09**	**8.56%**
3. Poland (coal)	24.66	0.00	2.09	**26.75**	**1.84%**
4. Russian Federation (coal)	10.36	0.00	0.88	**11.24**	**0.78%**
5. Czechoslovakia (coal)	6.77	0.00	0.57	**7.35**	**0.51%**
6. Kazakhstan (coal)	4.09	0.00	0.35	**4.44**	**0.31%**
7. Ukraine (coal)	3.11	0.00	0.26	**3.37**	**0.23%**
8. North Korea (coal)	2.58	0.00	0.22	**2.80**	**0.19%**
9. Czech Republic & Slovakia (coal)	1.84	0.00	0.16	**2.00**	**0.14%**
Total	**285.42**	**2.31**	**24.04**	**311.76**	**21.50%**

INVESTOR-OWNED ENTITIES

Investor-owned companies are attributed 314.8 $GtCO_2e$, or 21.7 percent of cumulative global industrial emissions of CO_2 and methane since 1751 (Table 14, Figure 16). Table 14 shows 2010 and cumulative emissions of CO_2 and methane attributed to each of the 50 investor-owned companies.

Table 14. 2010 and cumulative emissions of all investor-owned carbon producers

Entity	2010 emissions $MtCO_2e$	Cumulative $MtCO_2e$	% cumulative global, 1751-2010
1. Chevron, USA	423	51,096	3.52%
2. ExxonMobil, USA	655	46,672	3.22%
3. BP, UK	554	35,837	2.47%
4. Royal Dutch Shell, Netherlands	478	30,751	2.12%
5. ConocoPhillips, USA	359	16,866	1.16%
6. Peabody Energy, USA	519	12,432	0.86%
7. Total, France	398	11,911	0.82%
8. Consol Energy, Inc., USA	160	9,096	0.63%
9. BHP Billiton, Australia	320	7,606	0.52%
10. Anglo American, UK	242	7,242	0.50%
11. RWE, Germany	148	6,843	0.47%
12. ENI, Italy	258	5,973	0.41%
13. Rio Tinto, UK	161	5,961	0.41%
14. Arch Coal, USA	341	5,888	0.41%
15. Anadarko, USA	96	5,195	0.36%
16. Occidental, USA	109	5,063	0.35%
17. Lukoil, Russian Federation	322	3,873	0.27%
18. Sasol, South Africa	113	3,515	0.24%
19. Repsol, Spain	126	3,381	0.23%
20. Marathon, USA	59	2,985	0.21%
21. Yukos, Russian Federation *	-	2,858	0.20%
22. Hess, USA	61	2,364	0.16%
23. Xstrata, Switzerland	214	2,223	0.15%
24. Massey Energy, USA	91	2,199	0.15%
25. Alpha Natural Resources, USA	182	2,149	0.15%
26. Cyprus Amax, USA *	-	1,748	0.12%
27. EnCana, Canada	84	1,695	0.12%
28. Devon Energy, USA	93	1,690	0.12%
29. BG Group, UK	97	1,543	0.11%
30. Westmoreland Mining, USA	46	1,530	0.11%
31. Suncor, Canada	89	1,407	0.10%
32. Kiewit Mining, USA	59	1,295	0.09%
33. North American Coal, USA	40	1,181	0.08%
34. Ruhrkohle AG, Germany	-	1,138	0.08%
35. Luminant, USA	33	1,049	0.07%
36. Lafarge, France	61	1,044	0.07%
37. Holcim, Switzerland	62	1,008	0.07%
38. Canadian Natural Resources	93	958	0.07%
39. Apache, USA	97	951	0.07%
40. Talisman, Canada	62	925	0.06%
41. Murray Coal, USA	59	796	0.05%
42. UK Coal, UK	19	794	0.05%
43. Husky Energy, Canada	42	665	0.05%
44. Nexen, Canada	36	651	0.04%
45. HeidelbergCement, Germany	31	587	0.04%
46. Cemex, Mexico	27	551	0.04%
47. Italcimenti, Italy	24	463	0.03%
48. Murphy Oil, USA	27	418	0.03%
49. Taiheiyo, Japan	10	402	0.03%
50. OMV Group, Austria	45	346	0.02%
Total:	**7,628**	**314,811**	**21.71%**

Right column compares each entity's cumulative emissions to CDIAC's global emissions 1751-2010.
* not extant; production and emission quantified for these entities but not attributed to extant entities.

Table 15. Investor-owned and global industrial emissions of CO_2 and methane, by source

Source	IOCs 1854-2010 $GtCO_2e$	CDIAC 1751-2010 * $GtCO_2e$	Carbon Majors % of global
Oil & NGLs	156.8	472.0	33.2%
Natural gas	50.4	176.1	28.6%
Coal	73.0	642.5	11.4%
Cement	4.1	32.5	12.5%
Flaring	2.6	12.6	20.5%
Vented CO_2	2.0	na	na
Own fuel use	3.0	na	na
Fugitive methane	23.0	114.6	20.0
Sum	314.8	1,450.3	21.7%

Global CO_2 combustion data is from CDIAC; methane is from Stern & Kaufmann and European Commission JRC data.

State-owned entities

State-owned companies are attributed 287.7 $GtCO_2e$, or 19.8 percent of cumulative global industrial emissions of CO_2 and methane since 1751 (Table 17, Figure 16). Table 16 lists all 31 state-owned companies and the 2010 and cumulative emissions traced to each entity compared to global emissions since 1751 (CDIAC data).

Table 16. 2010 and cumulative emissions of all state-owned carbon producers

Entity	2010 emissions $MtCO_2e$	Cumulative $MtCO_2e$	% cumulative global, 1751-2010
1. Saudi Aramco, Saudi Arabia	1,550	46,033	3.17%
2. Gazprom, Russian Federation	1,371	32,136	2.22%
3. National Iranian Oil Company	867	29,084	2.01%
4. Pemex, Mexico	602	20,025	1.38%
5. British Coal, UK *	-	19,245	1.33%
6. Petroleos de Venezuela	485	16,157	1.11%
7. Coal India	830	15,493	1.07%
8. PetroChina, China	614	10,564	0.73%
9. Kuwait Petroleum Corp.	322	10,503	0.72%
10. Abu Dhabi NOC, UAE	387	9,672	0.67%
11. Sonatrach, Algeria	386	9,263	0.64%
12. Iraq National Oil Company	220	7,137	0.49%
13. Pertamina, Indonesia	64	6,830	0.47%
14. Libya National Oil Corp.	219	6,693	0.46%
15. Nigerian National Petroleum	270	6,540	0.45%
16. Petrobras, Brazil	356	5,991	0.41%
17. Petronas, Malaysia	260	5,274	0.36%
18. Statoil, Norway	243	4,367	0.30%
19. Oil & Gas Corporation, India	164	4,163	0.29%
20. Qatar Petroleum	271	3,410	0.23%
21. Egyptian General Petroleum	129	2,768	0.19%
22. Rosneft, Russian Federation	364	2,723	0.19%
23. Petroleum Development Oman	124	2,663	0.18%
24. Singareni Collieries, India	99	1,882	0.13%
25. Ecopetrol, Colombia	89	1,809	0.12%
26. Sonangol, Angola	147	1,794	0.12%
27. Sinopec, China	160	1,532	0.11%
28. Syrian Petroleum	48	1,402	0.10%
29. China National Offshore Oil Co.	130	1,123	0.08%
30. Bahrain Petroleum	36	931	0.06%
31. Polish Oil & Gas, Poland	12	473	0.03%
Total:	**10,818**	**287,680**	**19.84%**

* not extant; production and emission quantified for these entities but not attributed to extant entities.

Table 17. State-owned entity emissions and global emissions of CO_2 and methane, by source

Source	SOEs 1854-2010 $GtCO_2e$	CDIAC 1751-2010 * $GtCO_2e$	Carbon Majors % of global
Oil & NGLs	173.4	472.0	36.7%
Natural gas	51.8	176.1	29.4%
Coal	33.8	642.5	5.3%
Cement	0	32.5	0.0%
Flaring	2.9	12.6	22.7%
Vented CO_2	2.1	na	na
Own fuel use	3.1	na	na
Fugitive methane	20.6	114.6	18.0%
Sum	287.7	1,450.3	19.8%

Global CO_2 combustion data is from CDIAC; methane is from Stern & Kaufmann and European Commission JRC data.

Nation-state entities

Nation-states are attributed 311.8 $GtCO_2e$, or 21.5 percent of cumulative global industrial emissions of CO_2 and methane since 1751 (Table 18, Figure 16). Table 19 shows the nine Carbon Major nation-state (former and current) producers of oil and NGLs, natural gas, coal, and cement for 2010 and cumulatively.

Table 18. Nation-state and global industrial emissions of CO_2 and methane, by source

Source	Nation-states $GtCO_2e$	CDIAC 1751-2010 * $GtCO_2e$	Carbon Majors % of global
Oil & NGLs	35.5	472.0	7.5%
Natural gas	17.9	176.1	10.2%
Coal	222.9	642.5	34.7%
Cement	9.1	32.5	28.1%
Flaring	0.6	12.6	4.7%
Vented CO_2	0.6	na	na
Own fuel use	1.1	na	na
Fugitive methane	24.0	114.6	21.0%
Sum	311.8	1,450.3	21.5%

Global CO_2 combustion data is from CDIAC; methane is from Stern & Kaufmann and European Commission JRC data.

Table 19. 2010 and cumulative emissions of all nation-state carbon producers

Entity	2010 emissions $MtCO_2e$	Cumulative $MtCO_2e$	% cumulative global, 1751-2010
1. Former Soviet Union (coal, oil, gas)	na	129,717	8.94%
2. China (coal and cement)	7,898	124,089	8.56%
3. Poland (coal)	294	26,750	1.84%
4. Russian Federation (coal)	695	11,243	0.78%
5. Czechoslovakia (coal)	na	7,347	0.51%
6. Kazakhstan (coal)	287	4,442	0.31%
7. Ukraine (coal)	145	3,370	0.23%
8. North Korea (coal)	88	2,802	0.19%
9. Czech Republic (coal)	92	2,000	0.14%
Total:	**9,500**	**311,760**	**21.50%**

"Nation-states" are centrally planned economies, current and former, and do not include state-owned entities (SOEs).

Tables 20 and 21 lists the 2010 and cumulative emissions traced to the single nation-state producer of crude oil & NGLs and natural gas included in our assessment (Former Soviet Union, FSU); note that Gazprom succeeds FSU starting in 1989; note also that China's nation-state production of oil & NGLs and natural gas are not included in favor of including only the production by China's state-owned oil and gas companies PetroChina, CNOOC, and Sinopec. Table 22 lists the nation-state coal producers, years of data coverage, cumulative coal production (Mt), and cumulative emissions attributed to these nine nation-states. Table 23 shows the single nation-state cement producer included in the Carbon Majors study — China — and total attributed emissions from the calcining of limestone.

Table 20. Nation-state oil & NGL producers and attributed emissions

Entity	Data set anno	Crude oil & NGL billion bbl	Emissions $MtCO_2e$
Former Soviet Union	1949-1991	95,475	35,462
Vented CO_2			136
Flaring CO_2			565
Own fuel use			na
Fugitive methane (CO_2e)			1,432
Total			**37,596**

Table 21. Nation-state natural gas producers and attributed emissions

Entity	Data set anno	Natural gas billion cf (Bcf)	Emissions $MtCO_2e$
Former Soviet Union	1960-1988	335,678	17,937
Vented CO_2			512
Flaring CO_2			31
Own fuel use			1,063
Fugitive methane (CO_2e)			3,721
Total			**23,263**

Table 22. Nation-state coal producers and attributed emissions

Entity	Data set anno	Coal production million tonnes (Mt)	Emissions $MtCO_2e$
1. China, PRC	1945-2010	54,476	105,961
2. Former Soviet Union	1900-1991	29,051	63,480
3. Poland	1913-2010	11,959	24,661
4. Russian Federation	1992-2010	5,027	10,365
5. Czechoslovakia	1938-1992	4,460	6,773
6. Kazakhstan	1992-2010	1,715	4,095
7. Ukraine	1992-2010	1,266	3,107
8. North Korea	1980-2010	1,199	2,543
9. Czech Republic + Slovakia	1993-2010	1,250	1,844
Sum all nation-states	1900-2010	110,403	222,868
Vented CO_2			na
Flaring CO_2			na
Fugitive methane (CO_2e)			18,883
Total			**241,751**

Table 23. Nation-state cement producer and attributed emissions

Entity	Data set anno	Gross emissions $GtCO_2$	Process emissions $GtCO_2$
China, PRC	1928-2010	na	9.15

China's cement production 1928-2010 totals 18.30 billion tonnes (U.S. Bureau of Mines).

Summary of Investor-Owned, State-Owned, and Nation-State entities

The relative contributions of investor-owned, state-owned, and nation-state entities have varied over the years. The state-owned companies rose prominently after the oil embargo in 1973 and the subsequent rise of nationalization of oil and natural gas resources in the Persian Gulf, North Africa, and elsewhere in the mid-1970s.[36]

The transformation of Gazprom into a state-owned company in 1989 and the dissolution of the Soviet Union in 1991 are the main reasons for the decline in emissions traced to nation-states, whereas the rapid rise in the 2000s is largely due to China's expanding coal and cement emissions, Figure 16. The top ten companies are shown in Figure 17.

Figure 16. Investor-owned, state-owned, and nation-state emissions, 1910-2010

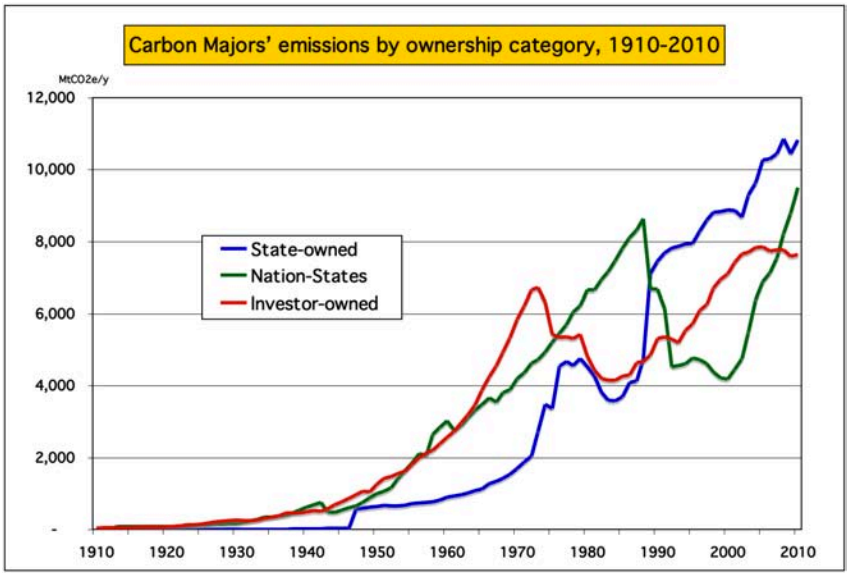
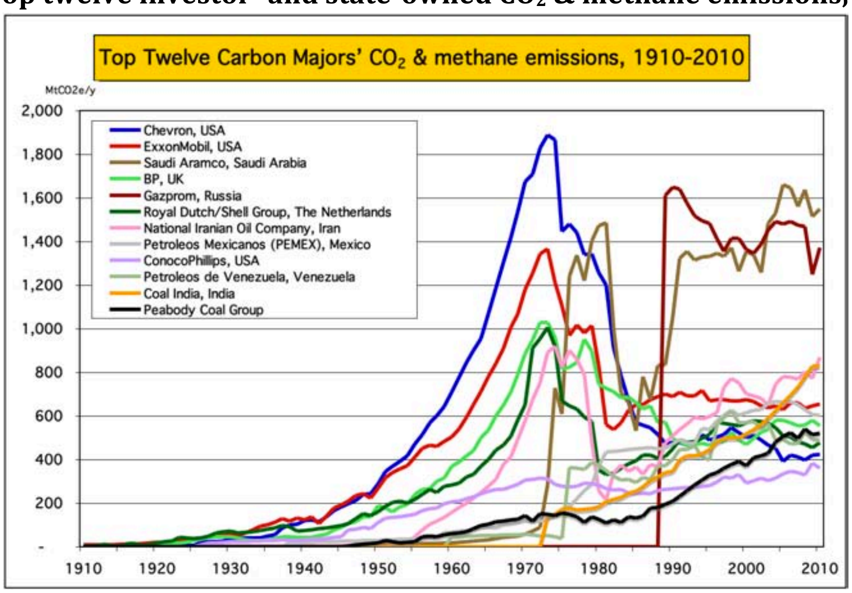


Figure 17. Top twelve investor- and state-owned CO_2 & methane emissions, 1910-2010



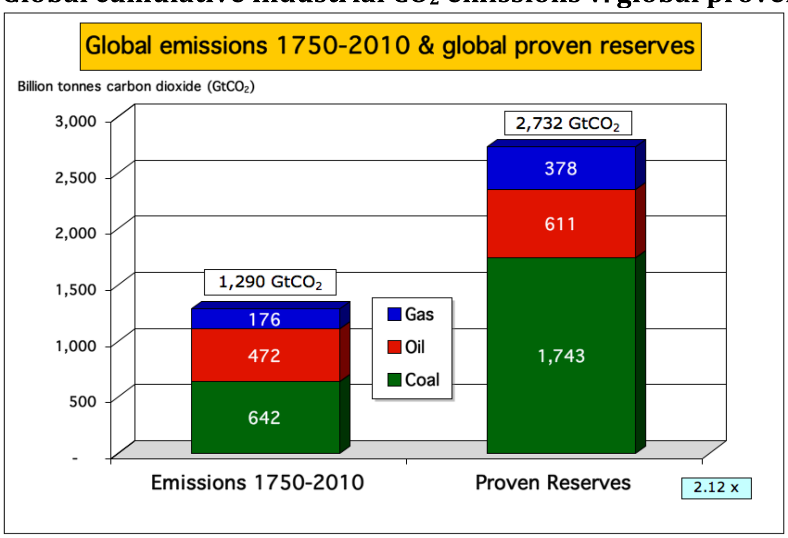
[36] See Victor, David G., David Hults, & Mark Thurber, eds, (2012) and Marcel, Valerie (2006) for discussion.

8. A note on fossil fuel reserves.

Proven recoverable reserves of oil, natural gas, and coal reported and carried on the books of investor-owned (and state-owned) Carbon Major entities have not been quantified. The subject of proven fossil fuel reserves is of importance to investors, regulators, companies' capital investments and strategic planning, and their critical and closely watched reserve-to-production ratios, but it is beyond the scope of this project to detail reported reserves.[37]

A few general observations can be made, however. In 2010 this author estimated potential emissions of total world proven fossil fuel reserves based on 2009 data for published by BP, *Oil & Gas Journal*, and the U.S. Energy Information Administration.[38] In my analysis I accounted for non-energy uses of each fuel (based on Carbon Major methodologies), and estimated that world proven reserves equated to 2,585 $GtCO_2$ of potential emissions. (Note: the fraction of petroleum used for non-energy uses may rise over the next several decades, reducing actual emissions.) World reserve estimates, especially unconventional petroleum (oil sands, tight shales) and natural gas, are increasing. A recent re-estimation of proven reserves suggests a ten percent increase over the last three years to 2,824 $GtCO_2$, based on 2012 data.[39] Some observers (e.g., Heinberg, Simmons) urge a cautious interpretation of published reserve estimates from the perspective of technological constraints, reserve-inflation, opaque reporting, and limited market access.[40] Ultimately recoverable carbon resources range from 4,000 GtC (14,670 $GtCO_2$) to nearly 16,000 GtC (58,570 $GtCO_2$).[41]

Figure 18. Global cumulative industrial CO_2 emissions v. global proven reserves



Climate Mitigation Services. CDIAC data for fuel combustion totals 1,290 $GtCO_2e$ (excludes cement and flaring).

[37] Grantham, Jeremy (2012) Be persuasive. Be brave. Be arrested (if necessary), *Nature*, vol. 491, 14Nov12. Also see International Energy Agency (2012b) *World Energy Outlook 2012*, Nov, Paris, www.iea.org, 660 pp.

[38] Heede, Richard (2010) *Carbon In Context*, American Renewable Energy conference, Aspen, CO, August.

[39] Calculations by Heede, from BP (2012) *BP Statistical Review of World Energy June*, www.bp.com/statisticalreview. *Oil & Gas Journal* (2012) "Global oil production up in 2012 as reserves estimates rise again," 3Dec2012. Energy Information Administration (2012) *International Energy Outlook 2011*.

[40] Heinberg, Richard (2009) *Blackout: Coal, Climate, and the Last Energy Crisis*. Simmons, Matthew R. (2005) *Twilight in the Desert: The Coming Saudi Oil Shock and the World Economy*. Energy Watch Group (2007) *Coal: Resources and Future Production,* by Werner Zittel & Jorg Schindler, Ludwig Bolkow Systemtechnik, www.energywatchgroup.org.

[41] Low estimate (4,004 GtC): Heede, H. R. (1983) *A World Geography of Recoverable Carbon Resources in the Context of Possible Climate Change*, National Center for Atmospheric Research, Boulder, NCAR-CT-72, 136 pp. High est (15,970 GtC): German Advisory Council on Global Change (2011) *World in Transition - A Social Contract for Sustainability,* Table 4.1-3.

Figure 18 compares the potential emissions embodied in proven recoverable reserves to the cumulative emissions from global fossil fuel combustion from the beginning of the industrial revolution through 2010: proven reserves (accounting for non-energy carbon storage) are 2.1 times larger than all historic emissions to date.

A recent report by the CarbonTracker Initiative estimated the carbon content and potential emissions of the proven reserves of the largest 100 oil and natural gas and largest 100 coal companies listed on world stock exchanges.[42] While there is a significant overlap between the Carbon Tracker entities and those included in the Carbon Major analysis, not all holders of significant reserves are also large annual producers, and some entities do not meet this project's threshold of ≥8 MtC/yr. Carbon Tracker also estimated potential emissions from total world reserves — i.e., adding proven reserves held by state-owned companies and by nation-states totaling 2,795 $GtCO_2$ (including the top 200 investor-owned companies). The Carbon Tracker analysis did *not* account for non-energy uses.

9. A note on future research.

The Carbon Major analysis has been a thorough, eight-year investigation of the carbon dioxide and methane emissions traceable to an identified set of 90 of the world's largest producers of crude oil and NGLs, natural gas, coal, and cement. The methodology and the results have been peer-reviewed by several experts with knowledge of GHG inventories, fossil fuel production, non-energy uses, fugitive emissions, and international and national inventory protocols. Nonetheless, the statements in this report, as well as the methodology, the implementation of the methodology, the error detection protocols, and the final results are all by the author, and any oversights and errors are solely the author's. The analysis has been thoroughly vetted, and numerous sources of uncertainty, data incompleteness and data quality have been noted throughout. My high degree of confidence in the methodology and the results notwithstanding, there are several ways in which the methodology and results can be improved. Certainly, the fossil fuel and cement companies themselves — whose self-reported data is preferably used — can help correct any errors or oversights in reporting, interpretation, or completeness. My colleagues and I look forward to working with industry to improve the analysis and results in future editions of the work.

A few specific areas for future work that have been beyond the scope of the present analysis or can be improved upon with additional research are listed:

- Uses of natural gas for non-energy uses, and on the final net carbon storage factor and short-term re-emission to the atmosphere;
- Regional coal-related methane emission rates, based on monitored methane generation and ventilation rates, by both underground and open-cast mines. These are specific to each mine and often varies from year to year;
- Non-energy uses of petroleum products, natural gas, and coal. First, with a view to revising the factors that are derived and applied in this analysis, and, second, the possibility of using a dynamic set of factors that reflect each year's (or decade's) variable non-energy uses. This, too, will vary for each entity, ownership of refineries and chemical plants, variable demand, exports, petroleum grades produced, etc.;

[42] Carbon Tracker (2011) *Unburnable Carbon: Are the World's financial markets carrying a carbon bubble?,* 36 pp. The report estimated "potential emissions" totaling 745 $GtCO_2$ by investor-owned entities. www.carbontracker.org.

- Full disclosure of equity or working interest production by state-owned oil and natural gas companies, particularly in the early 1970s when a number of states acquired or seized the assets of multinational companies operating within their national borders and offshore concessions;
- The oil, gas, and coal entities for which there are gaps in reported production, and (more importantly), complete time-series from the establishment of each entity, including each entity's mergers, acquisitions, and divestments;
- Additional research on China's coal-mining industry may reveal data on investor-owned (or partially state-owned) mining companies such as China Coal Energy Company and others. The China National Coal Association shows current production data and company listings for several dozen entities, but we have been unable to gather historic data and verify the ownership structure of Chinese coal entities — many of which are reportedly operated and/or directed by provincial governments. Hence, this project has aggregated all coal production under the nation-state, and future research may disaggregate production to investor- or state-owned entities;
- Further research on the creation of investor-owned, quasi-state-owned, and state-owned enterprises in centrally-planned economies may reveal, in China and in other nations, additional entities warranting inclusion in future editions of this work;
- Collect and analyze reported of proven recoverable reserves of crude oil, NGLs, natural gas, shale gas, oil sands, and coal for investor-owned companies; similar data for state-owned companies are typically not publicly available.

Investor-owned and state-owned oil, natural gas, and coal companies — as has been noted throughout the report — can be more forthcoming, complete, and transparent in their reporting of production and Scope 1 and 3 emissions. Specifically, companies can:

- Provide complete reporting on equity production, disposition of refined petroleum products, own uses of petroleum and natural gas in company operations (including pipelines, power generation, co-generation, etc);
- Separately report annual production of crude oil and natural gas liquids (NGLs);
- Provide complete information on methane emissions by source and fuel (including their coal operations);
- Coal companies can be far more complete and informative regarding methane generation in their coalmines and the quantities and rates of vented methane, or captured and utilized or flared methane (where applicable), from both underground and opencast mines, by mine location, and as typical rates per tonne of coal mined;
- Coal operators can also be far more informative, in most cases, regarding heating values, carbon content, and coal rank mined from each mine or operating region;
- Greater disclosure by producers on cement production (in addition to production capacity), and full disclosure on industrial process emissions per tonne or per year, including additional information on production and emissions prior to 1990;
- Complete reporting of carbon content of produced and/or marketed fuels, heating values, carbon content, and so forth. Unlike current reporting to Carbon Disclosure Project (which only some companies do), reporting on carbon contained in products sold, including an adjustment for likely disposition of gases and liquids to non-energy uses (as has been done in this analysis);
- Complete reporting on carbon dioxide vented from field gas separators or natural gas processing plants, and additional information on entrained CO_2 fractions by field or geographic region;
- Additional reporting on projects to capture and sequester carbon, methane capture and utilization, and efforts to reduce other GHG not included in this analysis, such as nitrous oxide and other greenhouse gases.

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Annex A

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Annex B: Methodology

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Annex B: Methodology

This section details the methodologies and procedures used in the Carbon Majors project to quantify emissions of carbon dioxide and methane traceable to the supply chains for oil and natural gas liquids, natural gas, coal, and industrial cement — including the combustion of the hydrocarbon products delivered to the global economy — from as early as 1854 to 2010 by 90 of the world's largest fossil fuel and cement producing entities.

The overall process and methodology is reviewed in Section 1, the accounting protocol is reviewed in Section 2, followed by a discussion of the uncertainties and limitations of the work and results in Section 3. Section 4 examines the emission factors applied to each entity's fuel production data in order to estimate final emissions, discusses how emission factors and non-energy uses are derived, and details the derivation of factors for the estimation of CO_2 vented in gas processing, CO_2 from entities' use of own fuels, CO_2 from flaring, and methane emissions from coal mining and natural gas and petroleum systems.

Pertinent tables from the portfolio of excel worksheets, where the real methodology work is done, are included as figures below as guides to the work flow and where to locate the core tables; these are often too low-resolution in small format, and readers are encouraged to peruse the core tables attached as PDF worksheets in Annex D. The worksheets contain additional tables that provide context, come from other sources, or otherwise support the final calculations; all tables are numbered to guide readers to the final calculations.

1. The procedure and methodology: an overview

The procedure starts with company or entity net fossil fuel production data published in publicly available sources (typically annual reports), estimation of the carbon content of each fuel type, subtraction for non-energy uses of produced fuels (which determine carbon storage rates but also accounts for *emissions* from non-energy uses, such as short-term oxidation of lubricants, petrochemicals, and petroleum products), and emission factors for each fuel, for each entity, and for every year for which production data has been found.

In sequence, the steps are as follows:

- Identify the fossil fuel and cement production entities meeting the ≥8 MtC/year threshold;[43]
- Create worksheet templates for coal, oil, natural gas, and cement entities;
- Gather company annual reports, company histories, SEC filings, ministry bulletins or operation reviews, entity website datasets on production (e.g., National Iranian Oil Company), and data from U.S. Energy Information Administration, International Energy Agency, the United Nations Statistics Division, and similar sources. Phone calls or emails directly to producers were occasionally made in search for missing data (e.g., Sasol);

[43] This was originally done when the project commenced in 2005 and accomplished by surveying annual compilations of entity production statistics from *Oil & Gas Journal's* OGJ100 and OGJ150, Energy Intelligence Group, National Mining Association, World Coal Association, World Business Council for Sustainable Development's Cement Sustainability Initiative, *World Cement*, and other sources. Some entities have since merged (e.g., XTO by ExxonMobil), and others added.

- A cadre of graduate students and colleagues searched business library collections in Sydney, Johannesburg, London, Cambridge (Harvard), Boulder, and Berkeley. A British MP provided data on British Coal. Phone calls to other libraries were made, including Rice University, University of Tulsa, *Oil & Gas Journal*, and special collections in search of data. We made frequent use of *Oil & Gas Journal's* annual "OGJ150/100" issue — particularly for National Oil Companies (NOCs) that do not publish oil and natural gas production data;
- Enter production data in a dedicated worksheet for each entity, noting data sources, units, incomplete reporting, and uncertainties;
- While historically complete production records were sought for investor-owned fossil fuel producers, the research is not complete in every instance, corporate reporting to share-holders is often incomplete or non-existent prior to the U.S. Securities Acts of 1933 and 1934 (establishing the SEC and requiring quarterly and annual reporting of financial and operational information, as well as a "management discussion and analysis");
- Data sources were carefully documented in cell notes to each worksheet. Data ambiguities (long or short tons or metric tonnes), net vs gross production, data gaps (e.g., non-reporting of natural gas production, common prior to 1930), unavailable annual reports, uncertainties (e.g., rank of coal mined), calculation methodologies, and similar issues related to the data are noted;
- Data gaps, typically from missing annual reports, are noted; such gaps are interpolated. Some "gaps" are the result of incomplete library collections,[44] e.g., we do not have natural gas production for Phillips Petroleum (acquired by Conoco) prior to 1937, in which cases interpolation has no role and the data set remains incomplete;
- Non-energy uses of petroleum (but also coal and natural gas) were analyzed to derive reasonable carbon storage factors covering variability in petrochemical, asphalt, lubricants, waxes, coking coal, and other non-combustive uses of produced and refined hydrocarbons. Such uses vary by season, geography, oil gravity, contaminants, refinery operations, and demand for ethylene, bitumen, etc. Non-energy uses also vary by year and decade (clearly important for this century-long assessment), and by place of production and source of demand. The invention and development of synthetic materials based on petrochemicals accelerated in the 1920s and 1930s (chiefly in the U.S. and Germany), but recent growing demand in Asia affects the final non-energy factors;[45]
- A single factor for net non-energy uses is applied to each producer regardless of the disposition of their crude oil to their own refineries or sold to independent refiners, and is held constant across time. This tends to underestimate emissions in the early decades (from a higher net carbon storage factor), it is consistent with international practice (e.g., the fossil fuel estimation protocol and emission database published by Oak Ridge National Laboratory's Carbon Dioxide Information Analysis Center [CDIAC]). Lower emissions in the early decades are roughly balanced by overestimation of emissions in the later decades when non-energy uses are likely higher than the applied net storage factor;
- Net non-energy uses account for final emissions of carbon dioxide in cases where a portion of the diverted hydrocarbons are emitted to the atmosphere over the short term, such as combusted lubricants, waxes, and petrochemical products, or plastics burned in waste-to-energy plants, or tires used in cement kilns;
- The storage of crude oil in strategic petroleum reserves, chiefly held in OECD countries and China, is ignored, since the stored oil will be released and combusted at some point. Total storage is 4.1 billion bbl, of which 2.7 billion bbl is held by private industry and 1.4 billion

[44] Most library collections of company annual reports are not catalogued.

[45] Synthetic materials use expanded a hundred-fold between 1950 and 1979 (Flavin, 1980). Petrochemical materials have largely supplanted plastics derived from organic polymers such as collagen, rubber, and cellulose.

bbl stored in government-owned facilities. The largest reserve — the U.S. Strategic Petroleum Reserve — held 0.727 billion bbl at year-end 2010;[46]

- Final emissions also depend on type of fuel, and while emission factors for oil and natural gas are fairly consistent across time and geography, emissions from coal combustion are highly sensitive to coal rank. Emphasis was therefore placed on noting coal quality for all the producers that specify coal rank. Research on coal quality and rank was conducted for Colombia, South Africa, Russia, Ukraine, USA, Australia, India, and China. For example, if a U.S. coal producer does not specify coal rank, but operates mines in Wyoming and Colorado, it is assumed that sub-bituminous coal was produced. In cases where producers only specified "thermal coal" production, the average carbon-content of coal intended for raising steam in industrial or utility boilers is applied;
- IPCC *Guidelines,* United Nations, International Energy Agency energy statistics, and most fuel consumption data used for national inventories express fuel consumption in energy content (TJ or QBtu). Oil, natural gas, and coal companies, however, report production in commodity units of barrels, cubic feet, and tonnes, respectively, and this project's protocol derives and applies emission factors on the basis of commodity units, carbon content, oxidation rates (now 100 percent, per revised IPCC guidelines), and non-energy uses;[47]
- All entity fuel production worksheets are dynamically linked to fuel summary worksheets (SumOil, SumGas, and SumCoal.xls). A second summary sheet for each fuel converts production data (by entity, year, and quantity) into estimated emissions by applying the final emission factor for each fuel. A single emission factor is applied to oil and natural gas production. For coal production, however, differing factors (derived from IPCC default carbon content factors) are applied for each rank of coal produced by each entity;
- Each fuel summary worksheet sums the emissions attributed to all Carbon Majors by year as well as historic totals, and these annual and historic sums are compared to global emissions by fuel as estimated by CDIAC for 1751-2010;
- Finally, total emissions from the fuels and cement produced by the 90 entities are linked to a summary sheet (SumRanking), in which four additional emission sources are applied:
    - carbon dioxide from flaring at oil and gas operations, processing plants, refineries, storage tanks, and other upstream and midstream facilities;
    - CO_2 vented from natural gas processing plants [removal of CO_2 from raw ("sour") natural gas, sulfur, and other contaminants];
    - fugitive methane from coal mines, oil production and storage, and gas production, processing, and transportation systems; and
    - CO_2 emissions from petroleum companies' use of their own fuel, chiefly of natural gas prior to their reported "gas available for sale."
- Once final sums for each entity are calculated, the worksheet is sorted by total carbon dioxide and methane emissions, resulting in a ranking of the 90 carbon major entities. The proportion of each entity's contribution to total anthropogenic industrial emissions is calculated from CDIAC's database of total industrial emissions 1751-2010;
- The many summary worksheets drive all the charts and graphics. Examples: total emissions of identified entities compared to global industrial CO_2 1751-2010, annual emissions by fuel type, pie charts of cumulative emissions by fuel, or emissions since 1990 (or any other year of interest). Another worksheet lists every Carbon Major entity's emissions of CO_2 and CH_4 gas by year from 1854 (or later) to 2010.

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[46] Energy Information Administration (2013) *Annual Energy Review*, Table 5.17 Strategic Petroleum Reserve, 1971-2011.

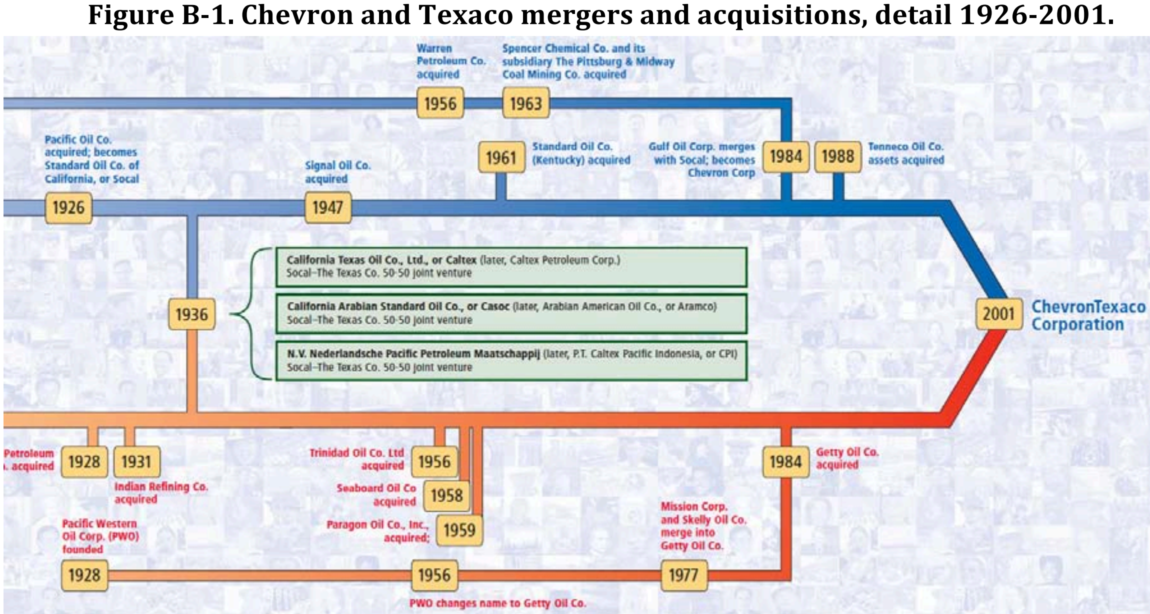
[47] Intergovernmental Panel on Climate Change (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories:* Volume 2: Energy, Geneva; www.ipcc-nggip.iges.or.jp/public/2006gl

2. The accounting protocol and rules

The procedure employed in this project starts with company (or entity) net fossil fuel production data from published sources, typically annual reports, estimation of the carbon content of each fuel type, subtraction for non-energy uses of produced fuels and feedstocks, emission factors for each fuel, for each entity, for each and every year for which production data has been found. This is conceptually straightforward, but is complex in practice.

1. Selection of fossil fuel producing entities was originally made in 2005 on the basis of production data on oil, natural gas, and coal from published sources (such as *Oil & Gas Journal*, Energy Intelligence *Top 100 Oil*, National Mining Association coal mining data, and EIA International Energy Statistics) for extant companies.
    a. New entities meeting the threshold were added as new information came to light, such as the addition of XTO (later acquired by ExxonMobil in 2009), OMV Group, and SunCor (merged with PetroCanada in 2009);
    b. New entities may be added in the future if production histories become available, such as for Severstal, Mechel OAO, and Raspadskaya in the Russian Federation;
    c. Coal and cement production in China is attributed to the nation-state. While there are numerous semi-autonomous coal-mining entities operating in China, many are under the control of provincial governments, their ownership structure is unclear, and their "incorporation" of recent vintage. Future editions of this project may disaggregate production to these coal and cement producers if data is available.
2. Mergers and acquisitions are tracked. Historic production of merged or acquired companies are attributed to the extant company. For example, Mission and Skelly Oil merged with Getty in 1977, Texaco acquired Getty in 1984, Gulf Oil merged with SoCal to become Chevron in 1984, Texaco and Chevron merged in 2001, and Chevron acquired Unocal in 2005. To the extent we have production data for these prior entities, all production is attributed to Chevron. We report production data for the acquired or merged entities on the worksheet for the extant company, and add their production to, in this case, Chevron's summary column. See Figure B-1.

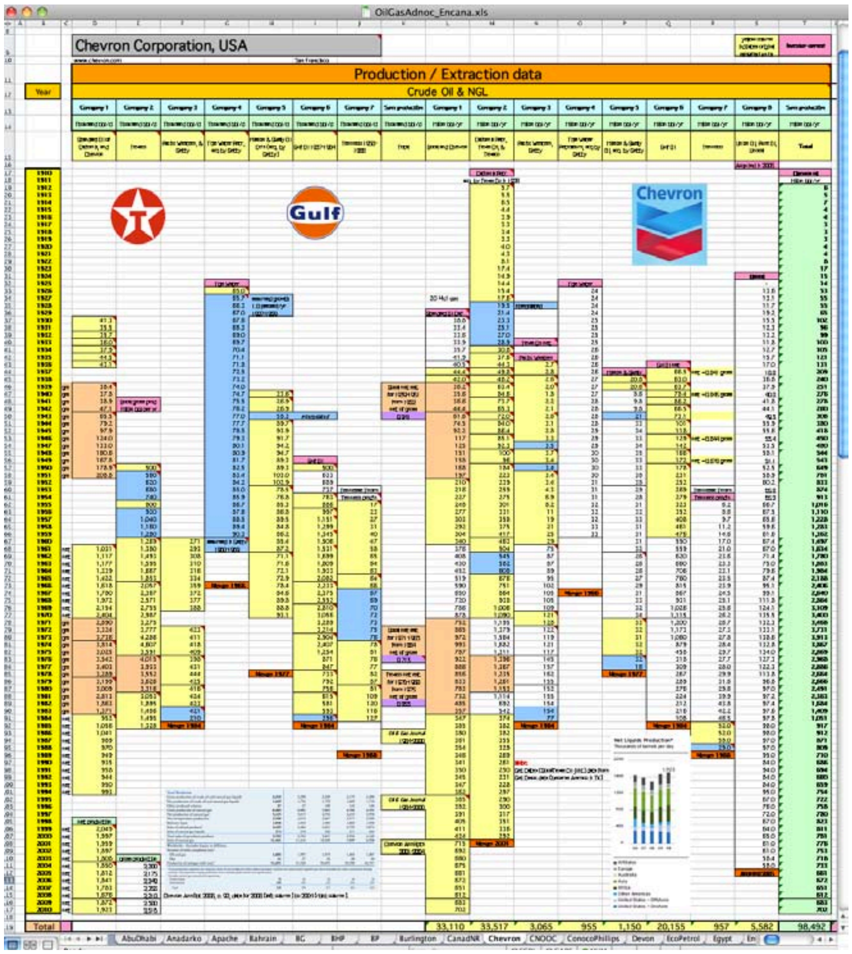
Figure B-1. Chevron and Texaco mergers and acquisitions, detail 1926-2001.



Courtesy Chevron.com.

3. Divestitures and disposition of assets: unlike acquisitions (in which production data for the acquisition is not retroactively added to company-reported production in annual reports), if a company divests producing assets or companies, the *subsequent* annual reports will reflect the disposition of production assets.

Figure B-2. Chevron and its predecessors' production of oil & NLGs 1912-2010.



Carbon Majors worksheet on Chevron and its mergers and acquisitions. See Annex D for full PDF.

4. Nationalization or expropriation of assets: Several nations have nationalized oil and natural gas production assets previously owned by companies such as Texaco, Socal, Exxon (Esso), Mobil, Anglo-Persian (now BP), and Shell. Mexico nationalized its oil industry in 1938, Iran in 1951, Brazil in 1953, Iraq in 1961, Egypt in 1962, and Indonesia in 1963, followed by Libya, Algeria, and Saudi Arabia. However, the multinational companies operating in these countries — whether through concessions, production-sharing agreements, or joint-ventures — typically report equity production quantities, not total production from the operated fields. Equity production is attributed to the multinational operating companies. A recent example is the attempted expropriation of Argentina-based YPF, a quasi-independent operating subsidiary for Repsol's South American assets.[48]

[48] President Kirchner of Argentina initiated an expropriation process for 51 percent of YPF shares in April 2012. BBC, "Argentina to expropriate Repsol oil subsidiary YPF," www.bbc.co.uk/news/business-17732910

5. Break-ups: the Supreme Court broke up the Standard Oil Trust in 1911 into entities we recognize today: Standard Oil ("SO") became Esso and, later, Exxon; Standard Oil Company of New York [SOCONY] merged with Vacuum Oil Company in 1931, named Mobil 1966, and merged with Exxon in 1999.[49] The Ohio Oil Company became Marathon Oil and survives today. Atlantic Refining Company merged with Richfield in 1966 and absorbed Sinclair in the 1969 (later divesting some assets); ARCO was acquired by BP America in 2000 (except for ARCO Alaska, which was acquired by Phillips Petroleum, now ConocoPhillips).

Figure B-3. Standard Oil Trust descendants' tree.

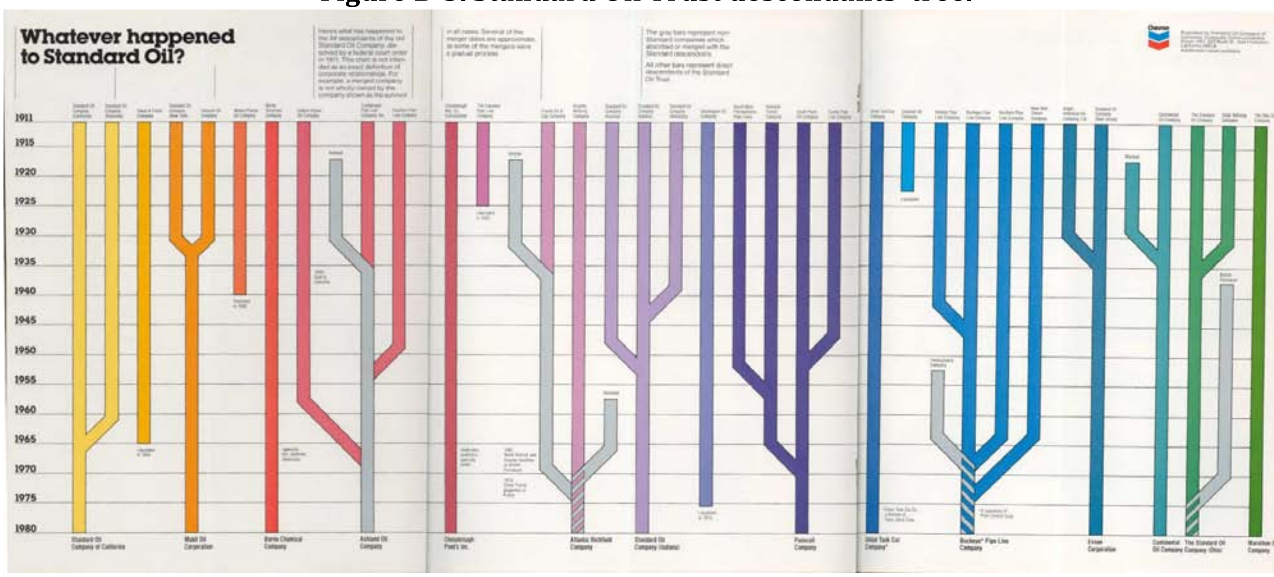


Chart published by Standard Oil Company of California (SOCAL), ~1982, prior to several subsequent mergers.

6. Equity production: multinational oil and gas companies report equity production as net production, that is, production from assets either wholly or partially owned, equity–share for joint projects (even if operated and produced by another company), shared-production contracts, and so forth.

7. Net production: This project reports company net production of crude oil and NGLs (except in cases where only gross production is reported, a common practice in the 1960s and early 1970s. For example, Standard Oil of New Jersey only reports gross production from 1962 through 1976).[50] For natural gas, "gas available for sale" is the typical metric in annual reports, though many pre-1980 reports showed net production (the difference is roughly that gas available for sale excludes company use of natural gas for its operations, petrochemical, and processing plants). For coal production, data is typically net production (excluding unmarketable production), but some companies report "sold tonnes."[51] These variables are documented in cell notes to fuel production worksheets.

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49 ExxonMobil is attributed Standard Oil's oil production from 1882 to 1911.

50 It is recognized that reporting gross production overestimates emissions; this project does estimates net production in cases where only gross production is reported by applying a "net of gross" percentage; e.g., Standard Oil of New Jersey reported net as ~0.87 of gross 1956-1961; see discussion below. Producers are encouraged to provide net production data to correct the record.

51 Sold production can include minor purchases from other producers, though rarely quantified.

a. State-owned oil and gas companies typically report total production, not net production due the state, or equity share. This poses a potential double-counting problem—namely that oil is reported both as overseas equity production by multinational oil and gas companies *and* production by the state-owned oil and gas companies. Reporting quality is variable; National Iranian Oil Company, for example, offers no data on total production, and data is taken from *Oil & Gas Journal* "OGJ100" reports for 1986-2010, national production from EIA and CIA estimates for 1973-1985, and Iranian Oil Operating Companies for 1928-1972.[52] The Nigerian National Petroleum Company is one of the few state-owned companies that report on its production quotas alongside production-sharing with its multinational operators. StatOil and Petrobras are among the SOEs that do report equity production;

b. It is unclear — for those state-owned entities that report production (e.g., Saudi Aramco, Pertamina, Petroleum Oman) — whether production data nets out production allocated to production-sharing partners. Overall, reporting by state-owned companies is poor, unclear, and incomplete. Publication of net production by state-owned oil and gas companies will help resolve such ambiguities and, in some cases, reduce the production and emissions attributed to state-owned entities;

c. This potential source of over-reporting has been minimized by analyzing available information regarding dates of nationalization, asset purchase agreements, asset seizures, and the approximate national production attributable to the investor-owned companies and the state-owned companies, respectively. The contractual details are not publicly available, but numerous sources have been consulted in order to minimize production reported by both entities.[53,54,55]

8. Coal production is typically reported in physical units, and converted to tonnes. This project tracks rank of coal mined, if available. If neither coal rank nor heating value is specified, then the average carbon content of "thermal coal" is applied.

   a. In countries where independent coal production companies do not operate — centrally planned economies such as China, Former Soviet Union, Ukraine, and Kazakhstan — total national coal production by coal rank, using EIA International Energy Statistics, U.S. Bureau of Mines, United Nations, and national statistics is reported.

9. Gaps in production data reporting are interpolated. For BHP Billiton, for example, annual reports covering 1996-1999 were not found, and the gap is interpolated. Numerous such data gaps exist, and are all noted on entity production worksheets as well as on the summary production worksheets (SumOil, SumGas, SumCoal);

10. Emissions of carbon dioxide from cement production are process-emissions from the calcining of limestone and thus *excludes* CO_2 from energy inputs. Most cement producers report production *capacity* rather than annual cement production. This project is thus limited to estimating process emissions for the six largest global cement producers based on data reported to WBCSD's Cement Sustainability Initiative. The estimation protocol is discussed in Section 4: Methodological Details.

[52] Iranian Oil Operating Companies, Annual Review for years 1928-1972, crude oil production tables; no natural gas data. Reports courtesy Univ. of Exeter's Arab World Documentation Unit, www.ex.ac.uk/awdu

[53] Victor, David G., David Hults, & Mark Thurber, eds, (2011) *Oil and Governance: State-Owned Enterprises and the World Energy Supply*, Cambridge University Press, 1,034 pp.

[54] Marcel, Valerie (2006) *Oil Titans: National Oil Companies in the Middle East*, Chatham House, London, Brookings Institution Press, Washington, 322 pp.

[55] World Bank (2008b) *A Citizen's Guide to National Oil Companies, Part B: Data Directory*, World Bank, and Center for Energy Economics, Bureau of Economic Geology Jackson School of Geosciences University of Texas, Austin, 764 pp.

3. Uncertainties

The core idea of tracing and attributing supply chain emissions of CO_2 and methane to the fossil fuel and cement producers is simple. The execution of the work, however, is complex. The industrial emissions of CO_2 and methane attributed to *nations* is based on the *consumption* of fossil fuels and cement manufacture and is already well-known within a relatively narrow uncertainty range.[56] The present analysis is the first attempt to attribute emissions to primary carbon *producers* and involves greater uncertainties.[57,58] Unlike CDIAC estimates, which are based on United Nations consumption statistics and are expressed in heating values (and readily-derived units of carbon per TJ), this project relies on physical units reported by multi-national producers that have a broader range of carbon contents and emission factors — particularly for coal.

Uncertainties, data gaps, ambiguities, choices of methodologies, poor or non-existent reporting of fuel production by CMEs, potential double-counting, and missing data complicate the actual work. The specifics are discussed in cell notes to worksheets, in the sections below, and in Table B-2 at the end of this section.

- Production data:
    - Uncertainties include revised and updated production figures in subsequent annual reports; such revisions are typically minor, and we make a concerted effort to reflect the revised data in entity production worksheets;
    - This project has tracked most significant mergers & acquisitions (prior production and emissions are attributed the to the acquiring entity); the uncertainty arises from missing the acquisition of minor companies or production assets, and not, therefore, adding all of the historic carbon production from acquired assets. This tends to under-estimate total attributed emissions, and is likely below 5 percent;
    - Occasionally the reporting units are ambiguous (short tons, long tons, Imperial tons, or metric tonnes). Final reporting is consistently in metric tonnes;[59]
    - While an omission rather than an uncertainty, it is not always possible to track production back to an entity's incorporation (e.g., missing Phillips Petroleum natural gas production prior to 1937, then 265 Bcf; Phillips was established 1917). These missing data thus underestimate actual attributable production, but insofar as production in early years is small compared to later production, the effect is relatively small; in the case of Phillips gas production, the company's oil production from 1927 to 1936 is only 1.19 percent of total production 1927 to 2010 and the picture is probably similar for the missing data on natural gas production;
    - Some companies report only gross production and not net production. Many multi-national companies — particularly in the late 1950s to early 1970s — reported only gross production in their annual reports. (Net deducts royalty production and partner's (or host government's) share of joint-venture production). This depends

[56] The Global Carbon Project, for example, cites uncertainty for fuel combustion estimates as ±5 percent for one standard deviation (IPCC "likely" range). Global Carbon Project (2012) *Global Carbon Budget 2012*, www.globalcarbonproject.org.

[57] While international climate negotiations focus on national emissions in 1990 and reduction commitments by 2012, alternative schemes of burden-sharing based on national or regional emissions since 1890 or 1900 have also been discussed, such as the "Brazilian proposal," which also include emissions from land-use, and allocate responsibility based on historic contribution to temperature rise. Pongratz & Caldeira extend the estimates of CO_2 emissions from land-use to the millennium scale. See den Elzen et al 2005, MATCH 2008, Raupach 2011, Shindell et al 2009, and Hoehne & Blok 2005.

[58] The CDIAC global emissions database is based on United Nations statistics for 1950-2010. See Marland & Rotty (1984) for discussion of uncertainties for CDIAC's national fossil fuel and cement emissions.

[59] For example, BHP reports coal production in Imperial tons (2,240 lb = 1,016.047 kg) through 1974, and metric tonnes thereafter, following Australia's Metric Conversion Act (1971).

on the specifics of production-sharing agreements and their scale relative to fully-owned production assets. These uncertainties tend to overestimate production from small to as high as 30 percent for those years (though more typically in the 6 to 15 percent range). Most companies report net equity production for most years and are considered accurate. Exxon (then Standard Oil of New Jersey, aka "Esso") reported net production in the 1930s, 1950-1962, and 1977-2010, but only gross production for 1940-1947 and 1962-1976. In 1961, for example, when Exxon reported both net and gross, net was 87 percent of gross (gross exceed net by 14.9 percent).[60] Other international oil companies report similar percentages during years of reporting both gross and net production. The effect of this historic over-reporting by Exxon and other companies is on the order of +5 percent;

- Each company's reporting has been adjusted by applying a "net-to-gross" ratio for those companies and years for which only gross production is reported. This is done for each company that reported only gross production, and resulted in lowering attributed oil production by several billion bbl;[61]
- The greatest source of uncertainty is with respect to production by state-owned oil and gas companies (e.g., Saudi Aramco, National Iranian, Petroleos de Venezuela, Sonangol). National oil companies appear to often report total *national* production on their national territory and territorial waters and thus may include production transferred to their international operating partners. Such unclear, incomplete, or ambiguous reporting is common among state-owned oil and gas companies;
- Available sources were used to adjust each state-owned oil and gas company's self-attributed production downwards by reducing total national production to a percentage of national production owned by each state (e.g., 60 percent for Kuwait Petroleum and Saudi Aramco). These adjustments reduced attributed production and potential double-counting by several billion bbl. The available information does not remove all uncertainties regarding the net equity oil production of state-owned companies and their international partners. Producers are encouraged to correct errors and provide accurate and comprehensive data on equity production;[62]
- Figure B-4 shows state-owned oil companies (called National Oil Companies by the World Bank and other analysts) production as a share of total national production within its territory and territorial waters. Statoil, for example, produces less than half of Norway's crude oil (even though it has extensive international production assets), whereas Egyptian General Petroleum (EGPC) produces nearly twice as much oil as Egypt's total oil production (although several international partners operate in Egypt, including Hess). This, however, does little to resolve uncertainties around equity production by state-owned oil and gas companies; also see Figure 7 in the main text.[63]

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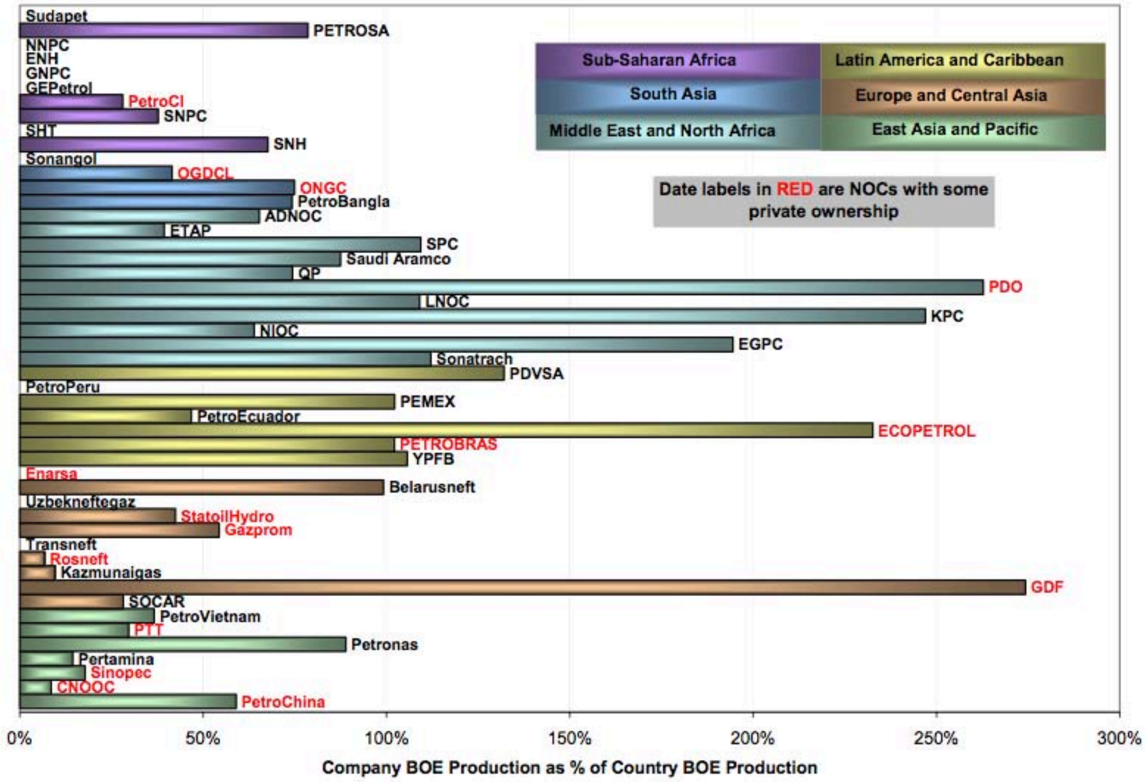
[60] Crude oil production for 1960-61 from SONJ Annual report for 1961, p. 30. This reports on both net and gross production. 1961 Gross: 2,744 kbbl/d, Net: 2,386 kbbl/d; Net is 0.870 of gross.

[61] For example, Exxon: net of gross for Exxon 1940-1947 and 1962-1976 based on average net of gross 1950-1961 (0.870. Also Mobil 1952-1967 and 1975-1980 based on net of gross 1968-1971 (0.855). Reduces XOM's attributed production by 5,074 Mbbl (from 84,732 Mbbl to 79,658 Mbbl), a reduction of 5.99 percent.;
Chevron net of gross 1984 (0.713) applied to Socal gross 1971-1983. Texaco net of gross 1975(0.953) applied to 1976-1980. Gulf and other acquired companies appear to report net production. Total change for Chevron: minus 4,433 Mbbl (from 102,925 Mbbl to 98,492 Mbbl), a reduction of 4.31 percent;
Royal Dutch Shell net of gross factor ave. 1954-1966 is 87.3 percent and is applied to gross 1967-1979, reduces attributed production by 2,680 Mbbl (from 59,642 to 56,962 Mbbl), or 4.5 percent;
Conoco and Phillips seem to both report net production for all years; no net of gross adjustment.

[62] Victor et al. (2011), Marcel (2006), and World Bank (2008, 2008b). See also Ariweriokuma, Soala (2009), Aissaoui, Ali (2001), and Grayson, Leslie (1981).

[63] World Bank (2008) *A Citizen's Guide to National Oil Companies, Part A: Technical Report*, World Bank, Washington, & Center for Energy Economics, Bureau of Economic Geology Jackson School of Geosciences University of Texas, Austin.

Figure B-4. National Oil Company oil production as share of total country production.



Company BOE Production as % of Country BOE Production. Source: World Bank, 2008, Figure 5.

- Use of own fuels:
    - This study estimates energy consumption and emissions from the petroleum industry's use of its own fuels at a rate of 5.9 percent of natural gas production, considerably less than the 9.5 to 10 percent of *combined* oil and natural gas production for the oil and gas supply chain estimated by the International Petroleum Industry Environmental Conservation Association;[64]
    - This includes field use of produced natural gas for compressors, or similar uses on offshore production platforms or at refineries and processing facilities, pipelines, on-site power generation, and chemical plants. Entity production data — especially for natural gas — is for marketed gas or "gas available for sale" — and the gas usage estimated here for own fuel use is truly a source of additional emissions;
    - While the industry also uses liquid petroleum products in equipment, construction, refineries, tankers, crude and LNG carriers, all of this carbon is already included from production through combustion, whereas there is a significant gap between total production of natural gas and "gas available for sale;"
    - The coal industry is a large user of energy in mining operations, but nearly all such energy is purchased petroleum and purchased electricity — carbon, in other words, that is accounted for by Carbon Majors or other entities not included in this study. No additional energy or emissions are added to coal companies from own fuel use;
    - We analyzed Scope 1 emission sources reported by eleven oil and gas company GHG inventories submitted to the Carbon Disclosure Project (CDP). These include BP, Chevron, ConocoPhillips, ENI, ExxonMobil, Hess, Pemex, Petrobras, Royal Dutch Shell, Statoil, and Total. This analysis, based on self-reported data to CDP, indicates

[64] IPIECA (2007) *Saving Energy in the Oil and Gas Industry*, IPIECA, London, 17 pp.

Scope 1 emissions that average 17.9 percent of emissions from the combustion of marketed products, or, in CDP terminology, "use of sold products;"[65]

  - The average additional factor for the eleven companies analyzed is 5.9 percent of natural "gas available for sale," since oil and gas companies produce more gas than is marketed (gas used for re-pressuring reservoirs, flared, or used in company operations). This 5.9 percent factor is used to estimate energy use and emissions in addition to company-reported "gas available for sale" and is applied to all producers of natural gas;
  - Cement manufacturers use large amounts of fossil fuel inputs (as well as alternative fuels such as biomass, refuse, and tires). However, this project quantifies *process* emissions from the calcining of limestone, and thus excludes emissions from fuel and electricity inputs that are accounted for by primary carbon producers.

- Non-energy uses:
  - Globally, the non-energy use factors are derived from official sources (e.g., IPCC, IEA, UN, CDIAC, EIA, EPA, International Network of Non-Energy Use & CO_2 Emissions (NEU-CO_2), and other protocols for estimating non-energy uses and carbon sequestration rates). Non-energy factors for each individual entity clearly differ, and differ by season, by refinery and feedstock production, each entity's ethylene and petrochemical precursors, petrochemical demand, where the oil is produced, where it is shipped, to whom crude oil is sold, the gravity of the oil, and innumerable variables that cannot be fully reflected in a single global non-energy factor. Furthermore, petrochemical use has expanded at differing rates around the globe and from decade to decade;
  - The non-energy use factor estimated and applied in this project — based on U.S. Energy Information Administration and Environmental Protection Agency data — is well within the range of other recent protocols. However, this factor likely *over*-estimates non-energy use (and thus *under*estimates final CO_2 emissions) for the first half of global production prior to 1984, and is neutral or slightly *under*estimates net non-energy uses (and thus *over*estimates final CO_2 emissions) from 1984 to 2010. The result is reasonable for the full breadth of historic production and emissions. If a more recent dataset is chosen, such as 1990-2010, then the results likely over-estimate emissions, since non-energy uses are higher in recent years than reflected in the non-energy factor. Note: the non-energy factor is applied to every producer, regardless of actual disposition of their crude oil, NGLs, and natural gas;
  - The non-energy use factors account for short-term re-emission to the atmosphere, not merely the total diversion of carbon fuels to non-fuel uses. Long-term storage of carbon as well as short-term emissions for liquids, natural gas, and coal used for non-energy purposes Is accounted for. Examples: lubricants (9 percent storage, 91 percent emitted), asphalt and road oil (100 percent storage), liquefied petroleum gases, naphthas, and pentanes plus used for petrochemicals (59 percent storage, 41 percent emitted), and natural gas (59 percent storage, 41 percent emitted);[66]

[65] We analyzed Scope 1 "combustion" emissions (assumed to represent own fuel use) reported by ten oil and gas company submissions to the Carbon Disclosure Project. Own fuel uses average 46.7 percent petroleum products and 53.3 percent natural gas, excluding purchased heat and electricity (IPIECA, 2007). Royal Dutch Shell (10.2 percent), Hess (5.1 percent), BP (11.1 percent), Exxon Mobil (14.0 percent), Conoco (15.1 percent), Statoil (6.0 percent), Petrobras (12.3 percent), Chevron (7.6 percent), Total (8.2 percent), and ENI (17.0 percent); the ten-company average is 11.3 percent. We adjust this downward by allocating only own use of natural gas (excluding own use of petroleum products, the carbon for which is fully allocated); the final emission factor is 59.24 $kgCO_2/tCO_2$ from product combustion, or 5.92 percent. Reported total Scope 1 emissions, which include flaring and venting and methane, average 17.9 percent of product emissions.

[66] The U.S. EPA is currently reviewing the quantities and sequestration rates for natural gas non-fuel uses, and the carbon storage rates and quantities are likely to be lowered. Lacking the new data, we have not adjusted the sequestration rate calculated for and applied in this project. Future editions of this work will review and possibly revise these factors.

- U.S. EPA relies on EIA data for non-energy uses of carbon feedstocks. The resulting average net storage rates for each fuel are applied to carbon majors. As mentioned above, fuel production entities differ in their refinery operations and their final disposition of products, and non-energy uses have expanded over recent decades;[67]
- It is known, therefore, that application of U.S.-derived net non-energy use factors will not accurately reflect net non-energy use in, say, Qatar, China, Brazil, or Nigeria. However, it is necessary to apply a single factor, and the applied factor is well-documented, reasonable, and globally applicable;
- See section #4, Non-Energy Uses of oil, natural gas, and coal for details.

- Emission factors (EF):
  - The emissions factors applied to fossil fuel production are taken from international and U.S. sources (IPCC, IEA, United Nations, EIA, EPA, CDIAC). IPCC factors are preferred and used when available;
  - IPCC factors are checked against comparable EPA factors (EPA prepares and submits the annual U.S. national emission inventory following IPCC *Guidelines*);[68]
  - The IPCC guidance does not, however, provide heating values for physical quantities of fossil fuels (typically in units of kgC/GJ, or carbon per unit of heat content), and other sources have to be used in order to complete the emission factors;
  - The methodology is chiefly Tier 1 insofar as IPCC default factors are used. Developing a Tier 2 or 3 inventory is impracticable, given that complete data is not available from the producing entities regarding, for example, specific coal rank or each entity's refinery operations and production of non-energy products;
  - For crude oil the IPCC's default values of 42.30 GJ/t and 20.00 kgC/GJ are used and, when converted to carbon content per bbl, is 115.67 kgC/bbl. Next the co-reporting of crude oil and NGLs is accounted for (NGLs are lighter; see bullet below), which reduces the carbon content of liquids to 110.2 kgC/bbl. Accounting for non-energy uses of 8.02 percent reduces this to an effective EF of 101.40 kgC/bbl;
  - Most oil companies aggregate crude oil and natural gas liquids (NGLs) in reporting statistics. Inasmuch as NGLs are lighter (such as ethane C_2H_6, propane C_3H_8, and butane C_4H_{10}) than the complex crude oils, the emission factors for NGLs are lower than for crude oils. Since the quantities or proportions of NGLs are often not reported in company liquids production data, an emission factor for crude plus NGL liquids production is calculated. This adjustment lowers the combined crude and NGL emission factor by 4.73 percent (from 115.7 kgC to 110.2 kgC/bbl);
  - For natural gas the IPCC default value of 15.30 kgC/GJ,[69] (14.50 kgC/million Btu) was initially used, times 1.105GJ/kcf (thousand cubic feet) — derived from the United Nations Statistical Division heating value per cubic meter (39.021 MJ/m³).[70]

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[67] A historic analysis of petroleum non-energy uses is not available; however, the US EPA/EIA data covers 1980-2010. In 1980, the storage rate (net non-energy use factor) was 8.70 percent in 1980, 9.5 percent in 1990, 10.1 percent in 2000, and 8.4 percent in 2010. Petroleum non-energy uses in the United States in 2010 totaled potential emissions of 302 $MtCO_2$, or 12.8 percent of actual petroleum emissions of 2,351 $MtCO_2$. This rate (prior to adjusting for short-term re-emissions of combustion) is comparable to United Nations global data, which suggests a global average gross petroleum non-energy use of 14.8 percent; United Nations *Energy Statistics Yearbook, 2009*, Table 25: Production of non-energy products from refineries (524.3 Mt) and Table 26: Production of energy products from refineries (3,224 Mt); 524.3 Mt is 14.8 percent of the sum of the two components.

[68] Intergovernmental Panel on Climate Change (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories: Volume 2: Energy,* Geneva; www.ipcc-nggip.iges.or.jp/public/2006gl

[69] The IPCC default value for natural gas is 15.3 kgC/GJ (ranges from 14.8 to 15.9 kgC/GJ). IPCC *Guidelines 2006*, volume 2: Energy, chapter 1: Introduction, Table 1.3.

[70] United Nations (2012) *Energy Statistics Yearbook 2009*, UN Statistics Division, Jun12; chapter on natural gas, Table V, puts "Standard Heat Value" at 39,021 kJ/m³ ("net calorific value"); unstats.un.org/unsd/energy/yearbook/default.htm.

This leads to an emission factor of 16.91 gC/cf (61.95 gCO_2/cf) prior to deducting non-energy uses; 16.59 gC/cf and 60.80 gCO_2/cf after deducting non-energy uses;

- However, this emission factor is unreasonably high compared to that computed from CDIAC data (CDIAC global gas emissions 1980-2010 / EIA gas production 1980-2010) equal to 52.70 gCO_2/cf;[71]
- Consequently, the IPCC/UN-derived factor was replaced with a factor based on U.S. EPA and U.S. EIA factors: 14.46 kgC/million Btu (HHV) times 1.028 million Btu per 1,000 cf (kcf) = 14.86 kgC/kcf. Adjust for net non-fuel uses of natural gas and the final factor is 14.58 kgC/kcf, and 53.43 $kgCO_2$/kcf;[72]
- This emission factor is 13.3 percent lower than the IPCC/UN factor described above, and reduced emissions attributed to natural gas producers by the same percentage;
- Coal factors are based on IPCC default values by coal rank, and varies from 328.4 kgC/tonne for lignite to 715.6 kgC/t for anthracite. See Table B-1 & Section 4 for details;
- The factors are based on international reporting standards, but their application gives rise to uncertainties. The coal producers — whether multinational companies such as Xstrata or centrally planned economies such as China — often do not report data on coal quality and rank, which clearly affects the resulting emissions of carbon dioxide;
- The IPCC *Guidelines* do not offer an emission factor for "thermal coal," a common unit used by coal production companies instead of the more precise and useful coal ranking such as bituminous, or lignite, or GJ per tonne. The average of IPPC emission factors for bituminous and sub-bituminous coal is calculated. One reviewer recommended the use of a weighted factor for coal types consumed in electric utility and industrial boilers; however, such disposition data has not been found;

Table B-1. Final combustion emissions factors (after accounting for net non-energy uses)

Energy source	Carbon tC/unit	Carbon dioxide tCO_2/unit
Crude oil & NGLs	101.4 kgC/bbl	371.4 $kgCO_2$/bbl
Natural gas	14.6 kgC/kcf	53.4 $kgCO_2$/kcf
Lignite	328.4 kgC/tonne	1,203.5 $kgCO_2$/t
Subbituminous	495.2 kgC/t	1,814.4 $kgCO_2$/t
Bituminous	665.6 kgC/t	2,439.0 $kgCO_2$/t
Anthracite	715.6 kgC/t	2,621.9 $kgCO_2$/t
"Metallurgical coal"	727.6 kgC/t	2,665.9 $kgCO_2$/t
"Thermal coal"	581.1 kgC/t	2,129.3 $kgCO_2$/t

Crude oil: prior to non-energy deduction & adjustment for NGLs: 115.7 kgC/bbl, 423.8 $kgCO_2$/bbl;
Gas: prior to non-energy deduction: 14.86 kgC/kcf ,or 54.44 $kgCO_2$/kcf; (kcf = thousand cubic feet).

- Ancillary emissions of CO_2 and CH_4:
  - Methane emissions are increasingly reported by multinational oil & gas producers, though infrequently by coal producers. Emission rates vary widely by company, region, even specific fields, and for coal from underground or surface (opencast)

[71] This is a comparison that hides a number of variables, such as non-energy uses, production vs consumption of natural gas, UN consumption data (on which CDIAC emission estimates are made) vs EIA's, etc.

[72] U.S. Environmental Protection Agency (2012b) *Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990 – 2010,* Annex 2: Methodology for Estimating CO_2 Emissions from Fossil Fuel Combustion, Table A-42: Carbon Content Coefficients for Natural Gas (Tg Carbon/QBtu), page A-64; U.S. Energy Information Administration (2013) *Annual Energy Review 2011*, Table A-4: Approximate Heat Content of Natural Gas 1949-2011; Dry Natural Gas Production averages 1,027.6 Btu/scf.

mines (underground mines emit methane at ~15 times the rate of surface mines, per tonne mined, according to the IPCC *Guidelines*);[73]

- The source emission factors for methane and carbon dioxide are, in most cases, taken from the IPCC *Guidelines*. The only instances in which the IPCC default methane emission rates are not used are for oil and natural gas methane emissions;
- The reason for not using IPCC values for methane emissions from oil and natural gas systems is the counter-intuitive IPCC result, once all the various CH_4 rates for fugitives, venting, and flaring, averaged for developing and developed country rates, average of low and high ranges (or unitary values), the IPCC default values are far higher for petroleum than for natural gas systems. For petroleum the IPCC default value works out to be 10.1 $kgCH_4/tCO_2$ emitted from petroleum combustion, which is equivalent to 3.93 kg CH_4 per bbl (Table B-5). This value is 5.5 times the U.S. EPA methane emission rate for petroleum systems. Conversely, the IPCC methane rate from natural gas systems is 3.71 $kgCH_4/tCO_2$ emitted from natural gas combustion compared to the EPA value of 9.88 $kgCH_4/tCO_2$ (Table B-8);
- Estimates of methane leakage from natural gas and petroleum systems are being revised by the U.S. EPA, and the factors may underestimate actual CH_4 emissions;[74]
- The methane emission rates from petroleum and natural gas are based on U.S. EPA (2012), which was the latest version available during the final quantification phase for this project.[75] In the inventory released in April 2013 the agency revised downward the U.S. methane emissions from natural gas systems by an average of 20.2 percent.[76] These adjusted rates are disputed, according to monitoring data. Future editions of this work may therefore use revised methane emission rates;[77]
- Methane emissions from coal mining are in line with IPCC and EPA values (4.03 $kgCH_4/tCO_2$ and 3.90 $kgCH_4/tCO_2$, respectively), and the IPCC factor is applied. The IPCC values for underground and surface mining methane rates (13.7 $kgCH_4/tCO_2$, and 0.87 $kgCH_4/tCO_2$, respectively) are adjusted by weighting for world coal production at 60 percent underground and 40 percent surface mining;[78]
- The companies whose reports of Scope 1 emissions were submitted to the Carbon Disclosure Project and analyzed for this project all reported methane emission rates far lower than global methane data indicate as the average emission rate. The ten companies (all but Pemex) that provided methane data average 0.53 $kgCH_4/tCO_2$ from the combustion of each entities' combined oil and gas products, whereas the global historic average for oil and gas sector is 3.89 kg CH_4/tCO_2. The emission rates applied here are based on EPA methane factors and corroborated by EDGAR data;[79]

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[73] Underground mines emit methane at 18 m^3 per tonne, on average, compared to 1.2 m^3/t for opencast (surface) mines. This is primarily a function of coal seam depth. Since surface-mined coal is generally of lower rank and heating value, thus lower CO_2 emissions per tonne, the ratio is lower per unit of emissions.

[74] Harvey (2012) *Leaking Profits*, NRDC. U.S. EPA estimates of methane from natural gas systems have risen from 220 Bcf in 1990 to 791 Bcf in 2010 — far outstripping the gain in U.S. production (17.8 Tcf in 1990 to 21.6 Tcf in 2010).

[75] U.S. Environmental Protection Agency (2012) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010*, April12.

[76] U.S. EPA (2013) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011*, 505 pp., April. Ch. 10: Recalculations and Improvements: "Updates were made to two key sources in the expert review draft: liquids unloading, and completions with hydraulic fracturing and workovers with hydraulic fracturing (refracturing). … Overall, these changes resulted in an average annual decrease of 41.6 Tg CO_2 Eq. (20.2 percent) in CH_4 emissions from Natural Gas Systems for the period 1990 through 2010."

[77] See Wigley, Tom M. L. (2011) Coal to gas: the influence of methane leakage, *Climatic Change Letters*, online 26Aug11; Ingraffea, Anthony R. (2013) Gangplank to a Warm Future, *New York Times* Op-Ed, 28 July 2013; and Watson, Theresa L., & Stefan Bachu (2009) Evaluation of the Potential for Gas and CO_2 Leakage Along Wellbores, *SPE Drilling & Completion*, vol. 24(1):115-126. SPE-106817-PA.

[78] World Coal Institute (2005) *The Coal Resources: A Comprehensive Overview of Coal*, London, 44 pp.

[79] U.S. Environmental Protection Agency (2012) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010*, 481 pp., April, + annexes. epa.gov/climatechange/emissions/usinventoryreport.html; and:

- Oil and gas companies' monitoring systems and methane estimation protocols are typically rigorous, third-party verified, and comprehensive.[80] Entities' actual methane emissions vary with operational circumstances, mix of oil and gas production, safety requirements, management priorities, and other variables. It's likely that companies analyzed are leading efforts to reduce methane emissions. The performance variability is, however, strikingly high and one-*seventh* the global average historic rate for combined oil and gas system methane emissions;[81]
- The applied methane emission rates are conservative compared to CDIAC (Stern & Kaufmann, 1998) and EDGAR energy-related methane emissions. This study attributes 67.6 GtCO_2e of methane to all entities, whereas the combined CDIAC & EDGAR data estimates total methane from 1860 to 2010 of 5.46 TgCH_4, equal to 114.6 MtCO_2e (at IPCC's GWP of 21*CO_2, per SAR). Thus, this study attributes 59.0 percent of global energy-related methane compared to 63.9 percent of fossil fuel emissions (including flaring, venting, and own fuel use);
- Carbon dioxide is vented from production platforms and gas processing plants, as well as from ubiquitous flaring at upstream and mid-stream facilities. In particular, carbon dioxide is common in raw natural gas and is typically removed (and vented) to meet market specifications. The CO_2 entrained in produced gas varies from negligible to as high as 20 percent or more (though this is more common with Coal Bed Methane), varies strongly by field, and thus by company. A few companies are field-testing CO_2 sequestration (e.g., StatOil's *Sleipner* and Snøvhit platforms in the North Sea and Barents / Norwegian Sea, respectively);
- We applied the average default IPCC CO_2 flaring rates for oil (15.94 kg CO_2/tCO_2, or 5.92 kg CO_2/bbl), which is in the range between the EPA, World Bank, and CDIAC values (Table B-3); flaring rates from natural gas are 1.74 kg CO_2/tCO_2 (Table B-6);
- IPCC default values for venting from petroleum systems are used (3.83 kg CO_2/tCO_2, or 1.42 kg CO_2/bbl) (Table B-4);
- Emissions of carbon dioxide from coal mines is ignored in the IPCC *Guidelines*.[82] This study also excludes CO_2 released from coal, even though U.S data suggests CO_2 liberation rates of 2.6 kg CO_2/tonne of coal mined, or 1.23 kg CO_2/tCO_2 from combustion of "average" coal. CO_2 liberated from coal mining is thus a small source of 0.12 percent and is ignored in this analysis.[83]

European Commission's Joint Research Centre (2011) *Global Emissions EDGAR v4.2: Methane Emissions*, Emission Database for Global Atmospheric Research (EDGAR), Nov11; edgar.jrc.ec.europa.eu/overview.php?v=42

[80] Significant direct monitoring of methane emissions is not typical, given the tens of thousands of methane point sources large companies possess. Protocols depend, for the most part, on equipment counts and emissions rates (gCH_4/hr) for Kimray pumps, storage tanks, pipeline seals, and so forth.
See American Petroleum Institute (2011), Canadian Association of Petroleum Producers (2003), International Petroleum Industry Environmental Conservation Association (2003) for oil and gas emission inventory protocols.

[81] The entities reported rates varying by a factor of ten — from 0.15 [Statoil] to 1.51 [ENI] kgCH_4/tCO_2—emitted from the combustion of oil and gas products. The global average methane rate for combined oil and gas is 3.89 kgCH_4/tCO_2.

[82] "Low temperature oxidation: Oxidation of coal when it is exposed to the atmosphere by coal mining releases CO_2. This source will usually be insignificant when compared with the total emissions from gassy underground coal mines. Consequently, no methods are provided to estimate it. Where there are significant emissions of CO_2 in addition to methane in the seam gas, these should be reported on a mine-specific basis." IPCC *2006 Guidelines*, vol. 2, chapter 4: Fugitive emissions; Surface mining: fugitive methane, Section 4.1.3 Underground coal mines, page 4.10.

[83] We estimate a rate of 2.62 kg CO_2 per tonne of coal mined, which equals 0.123 percent, or 1.23 kg CO_2/tCO_2 from coal combustion. Sources: Lyons, Paul C. (1996) *Coalbed methane potential in the Appalachian states of Pennsylvania, West Virginia, Maryland, Ohio, Virginia, Kentucky, and Tennessee--An overview*, USGS Open-File Report 96-735. Cites CO_2 content ranging from 0.5 to 10 percent. U.S. Environmental Protection Agency (2012) *Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010*, Table 3-30. U.S. Energy Information Administration (2011) *Annual Coal Report*, Tables 1 and 3. U.S. Environmental Protection Agency (2008b) *Upgrading Drained Coal Mine Methane to Pipeline Quality: A Report on the Commercial Status of System Suppliers*, Coalbed Methane Outreach Program, US EPA. Table 2 shows CMM N and CO_2 in IL, VA, PA, WV, AL ranging in CO_2 1% to 5%. U.S Dept of Energy (2009) *Capture and Use of Coal Mine Ventilation Air Methane,* Deborah A. Kosmack, U.S. DOE & CONSOL Energy Inc. Table 1. Gas Chromatography Analysis of Gas Samples Taken During Vent Capacity Tests: Methane: 40-44%, N: 50-53%, CO_2: 3.6-4.1%.

TABLE OF UNCERTAINTIES AND EXCLUDED EMISSIONS

Given the numerous variables applied to ninety entities with widely differing production histories, geographies, and geologic provinces of producing different fuels with variable carbon contents and highly variable (and poorly reported) direct emissions of vented CO_2, flaring, own fuel use, and fugitive or vented methane, it is not practicable to provide a bottom-up calculated estimate of uncertainty for each and every entity. Whereas as the Global Carbon Project estimates an uncertainty of ±5 percent for combustion emissions,[84] this analysis conservatively estimates an uncertainty of ±10 percent for the overall historic emissions attributed to Carbon Major entities.

As noted in Table B-2, most comparisons to international and global historic emissions (such as CDIAC and JRC) and emission factors support the conclusion that the factors and thus the attributed emissions are reasonable and typically at or below comparable international factors for combustion emissions, non-energy uses, and additional direct sources such as vented CO_2, flaring, own fuel use, and methane. The characteristics of each of the Carbon Major entities and the variable reliability and completeness of fossil fuel production data also means that individual entities may have higher uncertainty ranges, often in the ±15 percent range. See Section 3 for details.

Table B-2. Summary of uncertainties, excluded emissions, and alternative calculations

Overall results		
1.	The Global Carbon Project cites uncertainty for fuel combustion estimates as ±5 percent (one standard deviation); if applied to this project's total combustion of 833,430 $MtCO_2$ then:	±41,672 $MtCO_2$
2.	Other estimated uncertainty ranges include IPCC Tier 1 methodology for methane from natural gas systems, for which uncertainties range from ±17 % (flaring in processing, developing countries) to ±97 % (fugitive methane, production, developing countries). Fugitive methane in developed countries range from ±72 % (production) to ±76 % (transmission). This uncertainty is globally minor, but pertinent to companies:	"not applicable" (na)
3.	IPCC Tier 1 methodology for methane from crude oil range from ±16 % (vented, developing countries) to ±88 % (fugitives, refining). This uncertainty is globally minor, but pertinent to individual companies:	na
4.	IPCC Tier 1 methodology for CO_2 from natural gas range from ±15 % (flared, processing, developing countries) to ±93 % (fugitives, processing, developed countries). The all-important vented CO_2 from processing plants is not even assigned an uncertainty range (default factor). This uncertainty is globally minor, but pertinent to individual companies:	na
5.	For methane from coal mining, the uncertainties range from ±39 % (underground) to ±67% (opencast). This uncertainty is globally minor, but pertinent to individual companies:	na
6.	Potential double-counting of multinational equity production within national boundaries of oil & gas-producing with national production reported by state-owned companies has been minimized, and full disclosure of equity production can help resolve the remaining production uncertainties that remain.	na
Data (missing, gaps, etc)		
7.	Investor-owned company reporting of gross rather than net oil and gas production ~1960-1970. This has been corrected in all cases where producers specify gross vs net.	na
8.	Missing production datasets (eg Phillips natgas prior to 1937, StatOil prior to 1984, Total prior to 1933). Since early production pales in quantity produced, the undercount is probably quite small;	"not estimable" (ne)
Non-Energy Uses		
9.	If the Natural Gas carbon storage rate is lowered by 1 percent (from 1.711 percent to 0.711 percent), the attributed emissions will increase from 120,113 to 120,725 $MtCO_2$: undercount of:	-612 $MtCO_2$

[84] The Global Carbon Project cites uncertainty for fuel combustion estimates as ±5 percent for one standard deviation (IPCC "likely" range). Global Carbon Project (2012) *Global Carbon Budget 2012*, www.globalcarbonproject.org

10. The non-energy uses of petroleum have risen over the last 100 years. This analysis is globally reasonable. If, hypothetically, net C storage is currently not 8.02 percent but 9.02 percent, then 2010 oil emissions will increase by 1.09 percent, or +98 MtCO2. Hypothetical: na

11. If the EIA non-energy rate (ave 1995-2010) of 0.023 % rather than the EPA-derived rate of 0.016 % is applied, coal emissions would decrease from 329,604 to 329,579 MtCO_2; overcount +25 MtCO_2

Emission factors (combustion)

12. This study oil combustion factor (371.4 kgCO2/bbl) vs computed CDIAC EF (382.7 kgCO2/bbl) underestimates emissions by -3.032 percent * 365,729 MtCO_2 = undercount of: -11,088 MtCO_2

13. This study gas combustion factor (53.43 kgCO_2/kcf) vs computed CDIAC EF (52.70 kgCO_2/kcf) overestimates emissions by +1.376 percent * 120,113 MtCO_2 = overcount of: +1,653 MtCO_2

14. This study coal combustion factor (1,995 kgCO_2/tonne) vs computed CDIAC EF (1,907 kgCO_2/t) overestimates emissions by +4.409 percent * 329,604 MtCO_2 = overcount of: +14,533 MtCO_2

15. If we had used the IPCC/UN natural gas emission factor (60.80 kgCO_2/kcf) rather than the U.S. EPA/EIA factor applied (53.43 80 kgCO_2/kcf), the attributed natural gas emissions would have been 13.79 % higher, to 136,681 MtCO_2, instead of 120,113 MtCO_2: undercount of: -16,568 MtCO_2

16. Coal rank uncertainty: e.g., if "thermal" is used in place of bit or sub-bit, then bituminous (2.439 tCO_2/t) / thermal (2.129 tCO_2/t), or 1.1456, and thermal (2.129 tCO_2/t) / sub-bituminous (1,814 tCO_2/t) or 1.1736, or average of ±15.96 percent. This uncertainty is globally minor, but pertinent to individual coal companies: na

Emission factors (methane, CO_2 flaring venting own fuel use)

17. CO_2 from venting (sour gas CO_2 removal). Globally reasonable, but will vary for each gas producer. na

18. We account for 58.98% of methane 1860-2010 compared to 63.95% of all CO_2 sources but cement; "truing up": (67,616 MtCO_2e) * (1 – (63.95/58.98)) = undercount of: -5,705 MtCO_2e

19. CM accounts for 47.93 percent of CO_2 from flaring vs 74.97 percent combined oil and natural gas flaring of 6,040 MtCO_2 * (1 – (74.97/47.93) = undercount of: -3,407 MtCO_2

20. Coal-mining fugitive and vented methane emission factor: overestimates CH_4 emissions for surface operators and underestimates emissions for underground operators. The net result globally reasonable: ~0 MtCO_2e

21. Use of IPCC/UN natural gas emission factor increased gas emissions by ~5.7 percent, or +7,856 MtCO_2; na

22. Use of IPCC/UN crude oil emission factor decreased oil emissions by ~0.3 percent, or -1,239 MtCO_2; na

23. Conservative estimate of oil and natural gas producers' use of own fuels: 5.924 % of natural gas CO_2, vs. IPIECA: 9.5 to 10 % of combined oil and gas supply chain, say 8.0 % of oil plus gas (365,729 MtCO_2 + 120,113 MtCO_2) * 0.08 = 38,867 MtCO_2; minus the estimated 7,115 MtCO_2: or undercount of: -31,752 MtCO_2

24. Isotopic value of CO_2 (3.664191) vs short-hand 3.67: -0.159 % * 839,520 MtCO_2 = undercount of: -1,342 MtCO_2

Exclusions

25. Oil diverted to SPRs (4.1 billion bbl in global SPRs, private + govt storage; 1971-2010 total production of 985 billion bbl, or SPR = 0.42 %); 4.1 billion bbl equiv to overcount of: +1,523 MtCO_2

26. CO_2 vented from coal mining is excluded. CMS estimates factor of 2.62 kg CO_2/tonne coal; CMEs coal production 1854-2010 of 162.7 billion tonnes; * 2.62 kg CO_2/t = undercount of: -427 MtCO_2.

27. Methane and nitrous oxide emissions from fuel combustion are *not* estimated, insofar as these sources are end-user technology dependent and not inherently related to the chemistry of the fuel burned. An analysis of EPA CO_2, CH_4, and N_2O combustion-related emission rates (by CMS, background for EPA Emission Factor Hub[85]), CH_4 and N_2O added 0.71 to 0.78 percent to CO_2 from coal combustion, 0.10 percent for natural gas, and 0.33 to 0.38 percent for petroleum products. Estimated exclusion: na

28. Emissions from oil well fires, Gulf War 1, 1991; see CDIAC "Kuwait oil fires": 0.123 MtC oil plus 0.007 MtC gas flaring, total 0.130 MtC, or 0.478 MtCO_2; global CO_2 emissions from all sources in 1991: 22,861 MtCO_2, of which Kuwaiti oil fires is 0.0021 percent. Estimated exclusion: -0.478 MtCO_2

29. CH_4 from venting; offshore platforms often vent rather than flare for safety reasons; CMS has not evaluated the prevalence of this practice in the industry, onshore or offshore; Estimated exclusion: ne

30. Well blow-outs (e.g., Hess, 1985); upset conditions, and similar large-scale methane releases. Numerous, occasionally large and durable, others regular and small, and happen to every producer of associated and non-associated natural gas. No one, to our knowledge, tracks this information. Estimated exclusion: ne

[85] U.S. Environmental Protection Agency (2011b) *Emission Factors for Greenhouse Gas Inventories*, Center for Corporate Climate Leadership, epa.gov/climateleaders/ guidance/ghg-emissions.html

Most of the alternative calculation methods, factors, uncertainties, and excluded sources listed in Table B-2 indicate undercounts and reinforce our conclusion that the factors and methods used in this analysis are reasonable and at or below international factors and protocols. However, these are not additive (some are annual or periodic or cover years or decades, others are cumulative, some are uncertainty ranges, others are simply alternative calculation options), and the individual components cannot be summed.

4. Methodological details: emission factors, non-energy use, ancillary emissions of CO_2 and CH_4, and cement protocol.

In order to estimate final emissions to the atmosphere from data on fossil fuel production we first need to account for the proportion of each fuel that is diverted from combustion uses. While most marketed fuels enter the combustion supply chain — whether bituminous coal en route to power plants or liquid fuels sold to car, truck, and aircraft operators, or natural gas distributed via pipeline to industry and homeowners — hydrocarbons are also useful for a variety of non-energy purposes, such as steel, petrochemicals, and fertilizers.[86]

Liquid hydrocarbons are highly prized for the variety of precursor and final petrochemical products. The methodology must also account for the proportion of each fuel's non-energy uses that are oxidized to CO_2 within the short-term such as burning plastics in landfills or lubricants that either get combusted during use or are recycled after use and burned in a utility boiler. The proportion of the hydrocarbon inputs that is stored in durable products must be estimated for each non-energy use. Second, the carbon in each fuel type must be applied in order to estimate emissions of CO_2 from the combustion process (full oxidation is assumed in the IPCC 2006 *Guidance*). Third, additional sources of CO_2 from fossil fuel production and processing must be estimated, such as venting of CO_2 entrained in raw natural gas (and must be removed to meet market specifications), CO_2 from flared natural gas, or CO_2 from flaring and entity use of its own fuels. Fourth, fugitive methane from petroleum, natural gas, and coal production, processing, storage, and transportation must also be quantified.

Each section below describes these factors in the following order:

1. Non-energy uses;
2. Carbon content / fuel combustion emission factor;
3. Ancillary emissions of CO_2;
4. Ancillary emissions of CH_4.

Crude Oil & NGLs

This project has quantified the production of 985 billion barrels of crude oil and natural gas liquids (NGLs) by 55 investor-owned and state-owned entities from as early as 1884 (ExxonMobil, then Standard Oil) to 2010. Once non-energy uses for petroleum liquids are accounted for, and the carbon content and emission factor are applied to each entity's production, the carbon dioxide attributable to each entity is estimated.

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[86] Petrochemicals are used in myriad products. One relatively minor example: the world produced ~2.7 billion car and truck tires in 2011. Freedonia Group (2012) *World Tires: Industry Study with Forecasts for 2015 & 2020*, Cleveland, freedoniagroup.com/ brochure/28xx/2860smwe.pdf. Passenger car tires weigh ~10 kg, light duty truck tires ~16 kg, and large truck tires ~50 kg. If we assume that the average tire weighs 12 kg (accounting for smaller tires in non-OECD countries), and that 55 percent of the average tire is composed of synthetic rubber and carbon black, then the mass of petrochemicals in world tire production is 18 Mt. (Tire weights from Dept. of Ecology, State of Washington, Waste Tires; ecy.wa.gov/programs/swfa/tires/). World petroleum production totaled 30.87 billion bbl in 2010, or 4.23 billion tonnes, of which tires account for 0.43 percent. U.S. automobiles incorporate 275 kg of plastics, fluids, and lubricants, excluding gasoline, or 18 percent of the average vehicle's weight of 1,540 kg. Davis, Stacy, Susan Diegel, & Robert Boundy (2008) *Transportation Energy Data Book*, 27th, Table 4.14: Average materials consumption for a domestic car, 2004.

Three additional factors are added to cumulative emissions for each entity: CO_2 from flared associated gas, vented CO_2, and fugitive emissions of methane (CH_4) from crude oil & NGL production, transportation, refining, storage, and distribution. The methodology for each factor is detailed below.

NON-ENERGY USES.

Crude oil, petroleum products, and natural gas liquids are valuable feedstocks for a vast array of non-energy uses ranging from plastics and waxes and road oil to lubricants.

The methodology of the Carbon Majors project is based on US EPA and US EIA data on non-energy uses and accounts for short-term combustion of non-energy products 1980-2010. The appended worksheet "Non-fuel uses EPA TBtu" shows the details by non-energy use:

Road oil: 1980-2010 average non-energy use of 1.12 QBtu, at 20.55 MtC/QBtu, with carbon content of 22.99 MtC (= 84.29 $MtCO_2$), of which zero percent is emitted (i.e., 100 percent stored in macadam), and thus an average annual storage of 84.29 $MtCO_2$;

Liquefied petroleum gases: non-energy use of 1.34 QBtu * 17.06 MtC/QBtu = 22.85 MtC carbon content (83.17 $MtCO_2$) * 59 percent sequestration rate = 49.43 $MtCO_2$ stored;

Pentanes Plus: non-energy use of 0.16 QBtu * 19.10 MtC/QBtu = 2.59 MtC carbon content (9.50 $MtCO_2$) * 59 percent storage rate = 5.60 $MtCO_2$ stored;

Lubricants: non-energy use of 0.33 QBtu * 20.25 MtC/QBtu = 6.67 MtC carbon content (24.46 $MtCO_2$) * 9 percent storage rate = 2.20 $MtCO_2$ stored;

Petrochemical feedstocks: non-energy use of 1.18 QBtu * 19.35 MtC/QBtu = 22.92 MtC carbon content (84.05 $MtCO_2$) * 62.5 percent storage rate = 52.53 $MtCO_2$ stored;

Petroleum coke: non-energy use of 0.13 QBtu * 27.93 MtC/QBtu = 3.72 MtC carbon content (13.64 $MtCO_2$) * 30 percent storage rate = 4.10 $MtCO_2$ sequestered;

Special naphthas: non-energy use of 0.10 QBtu * 19.73 MtC/QBtu = 2.04 MtC carbon content (7.48 $MtCO_2$) * 59 percent storage rate = 4.41 $MtCO_2$ stored;

Other: non-energy use of 0.23 QBtu * 20.23 MtC/QBtu = 4.70 MtC carbon content (17.23 $MtCO_2$) * 73 percent storage rate = 12.49 $MtCO_2$ stored;

Total petroleum: average annual non-energy use of 4.57 QBtu * (variable carbon content) = 88.47 MtC carbon content (324.41 $MtCO_2$) * (variable storage rates) = 215.05 $MtCO_2$ stored, and an average storage rate of 66.29 percent for non-fuel uses, and 109.36 $MtCO_2$ (33.71 percent) re-emitted to the atmosphere annually.

Non-energy use of crude oil and NGLs, averaged over 1980-2010, totals 4.57 QBtu/y, with a carbon content of 88.47 $MtCO_2$ (potential emissions of 324.4 $MtCO_2$ if combusted), of which 109.36 $MtCO_2$ is re-emitted over the short term, and 215.5 $MtCO_2$ is stored in long-term storage (asphalt, plastics, and tires), for an average storage rate of 66.3 percent.

In order to calculate an overall sequestration rate we compare non-energy storage to oil and NGL *emissions* over 1980 to 2010, which averages 2,298 $MtCO_2$ per year; the average non-energy storage rate is thus 9.34 percent (215.5 $MtCO_2$/2,298 $MtCO_2$).[87]

This result is averaged with Oak Ridge National Laboratory's Carbon Dioxide Information Analysis Center non-energy factor of 6.7 percent,[88] which CDIAC applies to all liquids

[87] This has ranged from a low of 7.99 percent in 1982 to a high of 10.9 percent in 1999, and 8.40 percent in 2010. See the "Non-Energy Uses Oil" worksheet.

consumption data from 1870 to 2010. The average of these two factors is 8.018 percent, which is applied to all crude oil & NGL production data sets, each year, for each entity.

Fig. B-5. Petroleum products non-energy uses and net carbon storage worksheet

	Petroleum Products																					
	Petroleum coke					Special Naphthas					Other ¹					Total Non-energy Use				Total petroleum emissions	Non-energy emissions rate Percent of total emissions	Non-energy storage rate Percent of total emissions
	Non-energy use	Carbon Coefficent	Carbon Content	Quant emitted 70%	Quant stored 30%	Non-energy use	Carbon Coefficent	Carbon Content	Quantity emitted 41%	Quantity stored 59%	Non-energy use	Carbon Coefficent	Carbon Content	Quantity emitted 27.5%	Quantity stored 73%	Non-energy use	Carbon Content	Quantity emitted	Quantity stored			
	QBtu	MtC/QBtu	MtC	MtCO2	MtCO2	QBtu	MtC/QBtu	MtC	MtCO2	MtCO2	QBtu	MtC/QBtu	MtC	MtCO2	MtCO2	QBtu	MtC	MtCO2	MtCO2	MtCO2	Percent	Percent
Year	EIA	EPA	calculated	calculated	calculated	EIA	EPA	calculated	calculated	calculated	EIA	EPA	calculated	calculated	calculated	EIA	calculated	calculated	calculated	EIA	calculated	calculated
1980	0.14	27.93	3.91	10.04	4.30	0.19	19.73	3.75	5.64	8.11	0.34	20.23	6.88	6.94	18.29	4.19	82	104	198	2,272	4.59%	8.70%
1981	0.17	27.93	4.75	12.19	5.22	0.14	19.73	2.76	4.15	5.98	0.31	20.23	6.27	6.32	16.67	3.77	74	98	175	2,122	4.60%	8.24%
1982	0.14	27.93	3.91	10.04	4.30	0.13	19.73	2.56	3.86	5.55	0.28	20.23	5.66	5.71	15.06	3.44	67	86	161	2,011	4.29%	7.99%
1983	0.06	27.93	1.68	4.30	1.84	0.16	19.73	3.16	4.75	6.83	0.26	20.23	5.26	5.30	13.98	3.44	67	81	163	1,995	4.08%	8.18%
1984	0.09	27.93	2.51	6.45	2.77	0.21	19.73	4.14	6.23	8.96	0.24	20.23	4.86	4.90	12.91	3.59	70	86	171	2,053	4.19%	8.33%
1985	0.09	27.93	2.51	6.45	2.77	0.16	19.73	3.16	4.75	6.83	0.24	20.23	4.86	4.90	12.91	3.62	71	84	174	2,035	4.15%	8.57%
1986	0.08	27.93	2.23	5.73	2.46	0.13	19.73	2.56	3.86	5.55	0.22	20.23	4.45	4.49	11.83	3.71	72	84	181	2,125	3.97%	8.51%
1987	0.14	27.93	3.91	10.04	4.30	0.14	19.73	2.76	4.15	5.98	0.21	20.23	4.25	4.28	11.29	4.06	79	97	193	2,152	4.52%	8.98%
1988	0.15	27.93	4.19	10.75	4.61	0.11	19.73	2.17	3.26	4.69	0.23	20.23	4.65	4.69	12.37	4.15	81	99	198	2,246	4.40%	8.81%
1989	0.14	27.93	3.91	10.04	4.30	0.11	19.73	2.17	3.26	4.69	0.23	20.23	4.65	4.69	12.37	4.15	81	100	196	2,246	4.44%	8.73%
1990	0.12	27.93	3.35	8.60	3.69	0.11	19.73	2.17	3.26	4.69	0.23	20.23	4.65	4.69	12.37	4.37	85	103	208	2,187	4.72%	9.50%
1991	0.11	27.93	3.07	7.89	3.38	0.09	19.73	1.78	2.67	3.84	0.26	20.23	5.26	5.30	13.98	4.42	85	104	208	2,134	4.89%	9.75%
1992	0.17	27.93	4.75	12.19	5.22	0.10	19.73	1.97	2.97	4.27	0.21	20.23	4.25	4.28	11.29	4.56	88	111	213	2,180	5.10%	9.77%
1993	0.08	27.93	2.23	5.73	2.46	0.10	19.73	1.97	2.97	4.27	0.20	20.23	4.05	4.08	10.76	4.72	91	111	222	2,184	5.08%	10.16%
1994	0.08	27.93	2.23	5.73	2.46	0.08	19.73	1.58	2.37	3.41	0.20	20.23	4.05	4.08	10.76	4.94	95	116	231	2,221	5.24%	10.39%
1995	0.08	27.93	2.23	5.73	2.46	0.07	19.73	1.38	2.08	2.99	0.20	20.23	4.05	4.08	10.76	4.97	95	117	232	2,207	5.30%	10.51%
1996	0.09	27.93	2.51	6.45	2.77	0.07	19.73	1.38	2.08	2.99	0.20	20.23	4.05	4.08	10.76	5.05	97	119	235	2,290	5.20%	10.27%
1997	0.04	27.93	1.12	2.87	1.23	0.07	19.73	1.38	2.08	2.99	0.20	20.23	4.05	4.08	10.76	5.24	100	121	245	2,313	5.24%	10.60%
1998	0.15	27.93	4.19	10.75	4.61	0.11	19.73	2.17	3.26	4.69	0.23	20.23	4.65	4.69	12.37	5.45	105	131	253	2,358	5.56%	10.75%
1999	0.22	27.93	6.14	15.77	6.76	0.15	19.73	2.96	4.45	6.40	0.22	20.23	4.45	4.49	11.83	5.68	110	139	264	2,417	5.75%	10.90%
2000	0.10	27.93	2.79	7.17	3.07	0.10	19.73	1.97	2.97	4.27	0.22	20.23	4.45	4.49	11.83	5.32	102	125	249	2,461	5.08%	10.13%
2001	0.17	27.93	4.75	12.19	5.22	0.08	19.73	1.58	2.37	3.41	0.23	20.23	4.65	4.69	12.37	5.02	97	119	237	2,473	4.83%	9.57%
2002	0.15	27.93	4.19	10.75	4.61	0.10	19.73	1.97	2.97	4.27	0.22	20.23	4.45	4.49	11.83	5.09	98	121	239	2,472	4.88%	9.68%
2003	0.12	27.93	3.35	8.60	3.69	0.08	19.73	1.58	2.37	3.41	0.21	20.23	4.25	4.28	11.29	5.02	97	117	237	2,518	4.65%	9.42%
2004	0.22	27.93	6.14	15.77	6.76	0.05	19.73	0.99	1.48	2.13	0.20	20.23	4.05	4.08	10.76	5.41	105	130	255	2,609	4.97%	9.78%
2005	0.19	27.93	5.31	13.62	5.84	0.06	19.73	1.18	1.78	2.56	0.20	20.23	4.05	4.08	10.76	5.19	101	122	247	2,628	4.65%	9.40%
2006	0.21	27.93	5.86	15.05	6.45	0.07	19.73	1.38	2.08	2.99	0.24	20.23	4.86	4.90	12.91	5.14	100	120	245	2,603	4.63%	9.42%
2007	0.20	27.93	5.59	14.34	6.14	0.08	19.73	1.58	2.37	3.41	0.24	20.23	4.86	4.90	12.91	5.06	98	122	237	2,603	4.69%	9.12%
2008	0.23	27.93	6.42	16.49	7.07	0.08	19.73	1.58	2.37	3.41	0.24	20.23	4.86	4.90	12.91	4.59	89	115	212	2,444	4.71%	8.67%
2009	0.13	27.93	3.72	9.55	4.09	0.04	19.73	0.87	1.31	1.89	0.24	20.23	4.86	4.90	12.91	4.12	79	101	189	2,320	4.34%	8.16%
2010	0.07	27.93	1.95	5.02	2.15	0.03	19.73	0.59	0.89	1.28	0.25	20.23	5.06	5.10	13.45	4.33	82	104	197	2,351	4.43%	8.40%
average	0.13		3.72	9.56	4.10	0.10		2.04	3.07	4.41	0.23		4.70	4.74	12.49	4.57	88.47	109.36	215.05			
% of total	2.9%		4.2%	8.7%	1.9%	2.3%		2.3%	2.8%	2.1%	5.1%		5.3%	4.3%	5.8%	100.0%	100.0%	100.0%	100.0%	2,298	4.75%	

Average storage rate 1980-2010 for non-energy uses of petroleum (USA)	9.335%
Carbon storage rate in CDIAC’s global emissions database 1751-2010	6.700%
Average of CDIAC & US liquids average 1980-2010 carbon storage rate; applied to Carbon Major Entities’ production	8.018%

linked to Oil Emissions Factor Calc

See Annex D for PDF of “Non-Energy Uses Oil” worksheet for details.

Caveat: Non-energy uses — particularly petrochemical feedstocks — have increased sharply since plastics came into use starting in the 1920s. Hence we are overestimating sequestration (i.e., underestimating oil & NGL emissions) prior to ~1980. On the other hand, half of all emissions have occurred since 1984, and the storage rate of 8.02 percent is fairly accurate for the bulk of cumulative petroleum emissions. Each oil producer refines petrochemical and other non-energy products in varying proportions, and each refiner varies the percentage from season to season, refinery to refinery, and year to year; some refiners produce a smaller percentage of non-energy products than others.

CARBON CONTENT.

The carbon content of crude oils varies by geography, gravity, and the mixture of complex hydrocarbons present in the world’s oils. It is beyond the scope of this project to estimate a producer’s emissions from marketed petroleum products based on the quantity of products sold (data is not available) or on the carbon content of each entity’s production sources. A reasonable general factor must be applied to every barrel.

[88] CDIAC’s 6.7 percent for non-fuel uses; CDIAC adds 1.5 percent “passes through burners unoxidized or is otherwise spilled,” excluded here, following IPCC (2006) *Guidelines* default 100 percent oxidation rates (a shift from 1996 Guidance, in which default oxidation rates were 0.98 for coal, 0.99 for oil products, and 0.995 for gas (IPCC, 1996, table 1-6).

- This project adopts the IPCC default value of 20.00 kgC/GJ, and 5.78 GJ/bbl — the latter calculated from IPCC's default value of 42.3 TJ/Gg times average specific gravity of 0.86 (United Nations, 2009), which converts to 7.314 bbl/t and thus 5.78 GJ/bbl — the result of which is a factor of 115.67 kgC/bbl, or 423.85 kgCO_2/bbl if fully oxidized.[89,90]
- This project uses isotopic values for carbon and oxygen, for which the CO_2/C conversion factor is 3.664191, rather than the conventional shorthand of 3.67.[91]
- Potential emissions per bbl of crude oil attributed to producers must account for non-energy uses — described above — at an average net sequestration rate of 8.02 percent. This reduces attributed oil emissions from 423.85 kg CO_2/bbl to 389.87 kg CO_2/bbl.
- This factor is applied to entity crude oil and NGL production in order to estimate final emissions attributable to Carbon Majors' liquids production.

Figure B-6. Carbon content in crude oil & NGLs

Table 1	Petroleum & Natural Gas Liquids				
		KgC/GJ	GJ/bbl	Kg carbon per bbl	Kg CO2 per bbl
Step 1:	Carbon in extracted oil	20.00	5.78	115.67	423.85
Step 2:	Adjust for natural gas liquids (NGLs) in reported production	100 percent	4.729%	110.20	403.80
Step 3:	Inputs of own fuels to production, transportation, & processing	(applied in SummaryRanking.xls)		110.20	403.80
Step 4:	Vented carbon dioxide, oil operations	(applied in SummaryRanking.xls)		110.20	403.80
Step 5:	Fugitive, leaked, or vented methane	(applied in SummaryRanking.xls)		110.20	403.80
Step 6:	Flaring at oil operations	(applied in SummaryRanking.xls)		110.20	403.80
Step 7:	Adjust for net carbon sequestered through non-fuel uses of oil	timated in "non-energy uses" workshe	8.018%	101.37	371.43
Step 8:	Oxidation factor	100 percent		101.37	371.43
Step 9:	Convert step 8 factor to CO2e emissions per million barrels	Million tonnes Carbon and CO2 per million barrels:		0.1014	0.3714

See Annex D for PDF of "Oil Emissions Factor Calc" worksheet for details.

Caveat: Crude oil producers nearly always also produce associated natural gas, as well as non-associated natural gas, both of which typically contain natural gas liquids (NGLs). NGLs have lower emission factors per bbl than do crude oils (on the order of 40 percent lower), since NGLs are lighter and have higher hydrogen to carbon ratios. Most producers, however, aggregate crude oil and NGL production data, and the emission factor has been lowered in order to account for the estimated 8.16 percent of crude oil and NGL combined being the lighter NGL fractions. This adjustment lowers the combined crude and NGL emission factor by 4.73 percent (from 115.7 kgC to 110.2 kgC/bbl).[92]

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[89] The IPCC default value for crude oil is 20.0 kgC/GJ (ranges from 19.4 to 20.6 kgC/GJ). IPCC *Guidelines 2006* Volume 2: Energy, chapter 1: Introduction, Table 1.3. Net calorific value of crude oil at 42.3 TJ/Gg (range from 40.1 to 44.8 TJ/Gg), IPCC *2006 Guidelines,* vol 2, ch. 1: Introduction, Table 1.2. Oil's gravity varies from 0.724 in Indonesia to 0.961 in Surinam; we use the value of 0.86 ("unspecified" oil) from United Nations (2012) *Energy Statistics Yearbook, 2009*, Appendix.

[90] We have shifted to the IPCC/UN carbon content factors at the recommendation of reviewers. My previous use of U.S. EPA factors was based on consistency in the calculation of kgC/bbl; the IPCC approach is based on carbon content per unit of heat content (kgC/GJ) and required applying factors from other sources, such as the UN value of specific oil gravity. The IPCC/UN methodology gives a value of 115.67 kgC/bbl as discussed above, whereas the EPA/IEA methodology gives 117.33 kgC/bbl. The IPCC-derived factor is 1.42 percent lower. Environmental Protection Agency (2011) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009*, Annex 2: Methodology and Data for Estimating CO_2 Emissions from Fossil Fuel Combustion, Table A-34: Annually Variable C Content Coefficients by Year (TgC/QBtu), shows US crude oils from 1990 through 2009 with values ranging from 20.15 to 20.31 TgC/QBtu (= kgC per million Btu). The EPA/EIA calculation was 20.23 kgC/million Btu times 5.80 million Btu/bbl (EIA's default factor), or 117.33 kgC/bbl.

[91] C = 12.0107 + O = 15.9994 x 2 = 44.0095/12.0107 = 3.664191. This is 99.84 percent of the typical 3.67 value.

[92] Natural gas liquids are lighter than crude oil and have lower emission factors per unit volume (we focus here on EF on the basis of volume, rather than energy content, because oil and gas producers report production in bbl). The emission factor for butane (276.36 kgCO_2/bbl), ethane (181.44 kgCO_2/bbl), propane (234.78 kgCO_2/bbl), and natural gasoline

ANCILLARY EMISSIONS OF CO_2: FLARING.

Flaring rates are calculated on the basis of IPCC default values, averaging values for oil production in developing and developed countries (40.5 and 34.0 $kgCO_2/m^3$ of oil production, respectively), thus 37.25 $kgCO_2/m^3$ of oil production. The combustion of one cubic meter of oil emits 2,336 $kgCO_2$, and the effective flaring rate for petroleum is 1.594 percent, or 15.94 $kgCO_2/tCO_2$ from oil combustion. See tables 5 through 8 in the "Flaring and Venting" worksheet for details on the IPCC flaring default values and the conversion to flaring rates. Figure 6 below summarizes IPCC crude oil flaring default factors (as well as fugitive plus vented CO_2 from petroleum); also see Table 2 below.

The data from the World Bank's Global Gas Flaring Reduction Initiative for 2006-2010, based on satellite measurements, averages 149 Bcm of flared gas per year (5,248 Bcf/yr),[93] which results in an average flaring rate of 32.61 $kgCO_2/tCO_2$ from oil combustion, or 2.68 percent. Data in billion cubic meters (Bcm) of flared gas is converted to Bcf, from which estimated resulting CO_2 emissions are calculated, and are compared to CO_2 emissions from oil combustion (using CDIAC oil emissions data) in order to estimate the equivalent *flaring rate* in kg CO_2 from flaring as a percent of CO_2 from oil combustion.

Figure B-7. IPCC Tier 1 petroleum-system vented, fugitive, and flared CO_2 worksheet

Table 7	Summary of IPCC CO2 rates for crude oil		
	Source	kg CO2/t CO2	kg CO2/bbl
	Fugitives	0.65	0.24
	Venting	3.18	1.18
	Flaring	15.94	5.92
	Total	19.78	7.35
	Fugitive + venting	3.83	1.42
	Flaring	15.94	5.92
	Total	19.78	7.35

See Annex D for PDF of "Flaring & Venting" worksheet Tables 5. 6, and 7 for details.

Table B-3. Petroleum-system flaring rates, per tCO_2 from oil combustion and per bbl

	$kgCO_2/tCO_2$	kg CO_2/bbl
World Bank, average 2006-2010	32.61	12.11
U.S. EPA, average 1990-2010	12.20	4.76
CDIAC, average 1950-2010	26.70	9.92
IPCC Tier 1 values	**15.94**	5.92

Note: the metric for kg CO_2 per bbl assumes that all flared gas is associated with petroleum production, and is calculated using an oil combustion factor (including non-energy uses) of 0.3714 tCO_2 per bbl.
See Ancillary workbook, "Flaring & Venting" worksheet, Tables 12 (CDIAC)), Table 18 (World Bank), Table 7 (IPCC).

The result, shown in Fig. 7 (and in the appended PDF of the "Flaring & Venting" worksheet), is 15.94 kg CO_2 from flaring per tonne CO_2 from petroleum combustion, or 1.594 percent. This factor is applied to each crude oil & NGL producing entity's cumulative emissions, and consequently raises the attributed emissions by 1.594 percent for each entity.

(308.70 $kgCO_2$/bbl) averages to 250.32 kg CO_2/gallon. Crude oil's emission factor is 431.76 kg CO_2/gallon; the unweighted average NGL emission factor is thus 42 percent lower than crude oil. (data: U.S. Environmental Protection Agency (2011b) *Emission Factors for Greenhouse Gas Inventories*, epa.gov/climateleaders/ guidance/ghg-emissions.html); EIA world production data for 1980-2012 show that Natural Gas Plant Liquids (NGPLs) comprise an average of 8.16 percent of total crude oil, lease condensate, and NGPLs for 1980-2012.
The formula for the adjustment to crude oil emission factor (115.67 kgC/bbl) is as follows: 0.0816 * (1-0.42044), which lowers the emission factor for combined crude oil and NGL to 110.20 kgC/bbl, or 403.80 $kgCO_2$/bbl.

[93] World Bank (2012) *Estimated Flared Volumes from Satellite Data, 2006-2010*, World Bank Global Gas Flaring Reduction, web data: http://go.worldbank.org/D03ET1BVD0.

ANCILLARY EMISSIONS OF CO_2: PETROLEUM-SYSTEM VENTED CO_2.

The IPCC Tier 1 values for vented and fugitive CO_2 from petroleum systems are computed and applied to carbon major entities. These rates, as for flaring above, average IPCC emission factors for developing and developed countries; the factor for vented & fugitive CO_2 emissions is 3.83 kg CO_2/tCO_2 (3.18 kg CO_2/tCO_2 & 0.65 kg CO_2/tCO_2, respectively) from the combustion of the produced crude oil. The IPCC Tier 1 value is considerably higher than the venting rate calculated from the EPA methodology and data for the U.S., also shown in Table 3.[94] The IPCC factor — 3.83 kgCO_2/tCO_2 from petroleum combustion — is applied to cumulative petroleum emissions attributed to each oil producing entity.

Table B-4. Petroleum-system vented CO_2 rates per tCO_2 from oil combustion & per bbl

	kgCO_2/tCO_2	kg CO_2/bbl
U.S. EPA, average 1990-2010	0.43	0.16
IPCC Tier 1 values	**3.83**	1.42

Note: the metric for kg CO_2 per bbl assumes that all flared gas is associated with petroleum production, and is calculated using an oil combustion factor (including non-energy uses) of 0.3714 tCO_2 per bbl. See Ancillary workbook, "Flaring & Venting" worksheet, Table 25 (EPA), Table 7 & 8 (IPCC).

Figure B-8. Petroleum-system flaring and venting rate final IPCC Tier 1 factors

Summary of Oil & Natural Gas Flaring and Venting rates			
CO2: Flaring		CO2: Venting	CO2: Venting
Flaring: Oil	Flaring: Gas	CO2 Venting: Oil	CO2 Venting: Gas
flaring: Oil	flaring: Gas	(includes fugitives)	(includes fugitives)
kg CO2/tCO2	kg CO2/tCO2	kg CO2/tCO2	kg CO2/tCO2
15.94	1.74	3.833	28.53

See Annex D for PDF of "Flaring & Venting" worksheet Tables 5 through 8 for details (above: Table 8).

ANCILLARY EMISSIONS OF CH_4.

Methane emissions from petroleum systems are based on U.S. data from EPA.[95] Emission sources include pneumatic device venting, tank venting, combustion and process upsets, miscellaneous venting and fugitives, wellhead fugitives, crude oil transport, and refining. U.S. emissions totaled 1,478 GgCH_4 in 2010. We use EPA data for 1990, 1995, 2000, and 2006-2010, as shown in the screenshot of EPA (2012) Annex 3, Table A-141:

Figure B-9. U.S. data on methane emissions from petroleum systems

Table A-141: Summary of CH_4 Emissions from Petroleum Systems (Gg)

Activity	1990	1995	2000	2006	2007	2008	2009	2010
Production Field Operations	**1,653**	**1,557**	**1,467**	**1,365**	**1,396**	**1,404**	**1,437**	**1,455**
Pneumatic device venting	489	463	428	396	398	416	419	420
Tank venting	250	226	214	188	192	182	206	214
Combustion & process upsets	88	82	76	71	72	75	94	97
Misc. venting & fugitives	799	762	726	692	714	706	693	700
Wellhead fugitives	26	25	22	17	20	24	24	24
Crude Oil Transportation	**7**	**6**	**5**	**5**	**5**	**5**	**5**	**5**
Refining	**18**	**18**	**19**	**19**	**19**	**19**	**18**	**19**
Total	**1,677**	**1,581**	**1,492**	**1,389**	**1,420**	**1,427**	**1,460**	**1,478**

Note: Totals may not sum due to independent rounding.

EPA (2012) *U.S. Inventory for 2010*, Table A-141: Summary of CH_4 Emissions from Petroleum Systems (Gg). See Ancillary workbook, "Flaring & Venting" worksheet, Table 30 (EPA), and Tables below.

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[94] EPA (2012) *U.S. Inventory for 2010*, Annex 3, Table A-144: Summary of CO_2 Emissions from Petroleum Systems (Gg CO_2)

[95] U.S. Environmental Protection Agency (2012) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010*, 481 pp., April, + annexes. epa.gov/climatechange/emissions/usinventoryreport.html

The IPCC Tier 1 values are not used because the computed rates are not in agreement with either the EDGAR or the U.S. EPA rates (Table B-5), and counter-intuitively attribute far higher methane emission rates to petroleum systems than to natural gas systems. Nor are oil and gas company methane estimates of much use since companies do not disaggregate emissions from oil and gas operations. However, the oil and gas companies whose emission estimates are submitted to the Carbon Disclosure Project show far lower rates, overall — in fact only 11.4 percent of the rates applied here, namely 0.53 kg CH_4/tCO_2 compared to the 4.62 kg CH_4/tCO_2 used here, averaged over *combined* oil and gas combustion emissions. The reasons for this are not clear: either the ten companies analyzed have lowered their methane emissions dramatically (strongly out-performing the oil and gas sector), or are not fully estimating their methane emissions.[96] Or the EPA-derived methane emission factors are erroneous; these, however, are backed up by EDGAR, IPCC, and other sources.

In order to calculate a methane emission *rate* we divide CH_4 emissions by CO_2 emissions from combustion of U.S. oil production for the same years (multiplied by this project's emissions factor for oil & NGLs, which accounts for non-energy uses of petroleum: 0.3714 tCO_2/bbl) to derive a methane emission rate ranging from 1.68 $kgCH_4/tCO_2$ in 1990 to 2.13 $kgCH_4/tCO_2$ in 2008.[97] The weighted average of 1.92 $kgCH_4/tCO_2$ is applied to each entity's cumulative emissions attributed to its crude oil & NGL production.

Table B-5. Petroleum-system methane leakage rates per tCO_2 from oil combustion & per bbl

	$kgCH_4/tCO_2$	$kgCH_4$/bbl
U.S. EPA, average 1990-2010	**1.92**	0.71
EDGAR, global average 1970-2008[98]	1.73	0.64
IPCC Tier 1 values	10.58	3.93

Note: the metric for kg CH_4 is based on methane emissions associated with petroleum production and refining, and is calculated using an oil combustion factor (including non-energy uses) of 0.3714 tCO_2 per bbl. See Ancillary workbook, "Flaring & Venting" worksheet, Table 5 (IPCC), Table 30 (EPA), and "General Non-CO2 data" Table 2 (rows 324-382; EDGAR data 1980-2008).

Figure B-10. Worksheet on methane emissions from petroleum systems

Table 30	US methane emissions & rates from Petroleum Systems					
Gg = million kg	Oil production	CH4 emissions	Methane rate	Oil emissions	Methane rate	
	million bbl	million kg CH4	kg CH4/bbl	MtCO2	kg CH4/tCO2	
	Crude & NGPL	EPA Table A-141	calculated	calculated	calculated	
1990	2,685	1,677	0.62	997	1.68	
1995	2,394	1,581	0.66	889	1.78	
2000	2,125	1,492	0.70	789	1.89	
2006	1,862	1,389	0.75	692	2.01	
2007	1,848	1,420	0.77	687	2.07	
2008	1,807	1,427	0.79	671	2.13	
2009	1,957	1,460	0.75	727	2.01	
2010	2,012	1,478	0.73	747	1.98	
Average	2,086	1,491	0.72	775	1.94	
	EIA data	EPA data				
Totals	16,690	11,924		6,199		
	Weighted average		0.71		1.924	kg CH4/tCO2
					Source for Final CH4 Table 6	

See appended PDF of "Oil & Gas ancillary CH4" worksheet Table 30 for details.

[96] Hess, BP, Shell, ExxonMobil, Statoil, Petrobras, ConocoPhillips, Statoil, Total, ENI SpA, Pemex, and Chevron submissions to the CDP were analyzed. See "Entity CDP Scopes 1-3" worksheet in "AncillaryCH4&CO2.xls" workbook for details.

[97] A methane emission rate per bbl of oil produced in the United States, by year, is calculated in Fig. 9 (middle column), averaging 0.72 $kgCH_4$/bbl. This project does not apply the factor to oil production but to oil *emissions* attributed to each producing entity, hence the need for the $kgCH_4/tCO_2$ factor.

[98] Computed from EDGAR methane emissions 1970-2008 attributed to oil production and refineries. Methane emissions have risen from 59.7 $TgCH_4$ in 1970 to 121.5 $TgCH_4$ in 2008, of which, on average, 39.6 percent is from natural gas, 36.1 percent from coal, 19.0 percent from oil, and 5.2 percent from "energy manufacturing and transformation." European Commission's Joint Rsrch Centre (2011) *Global Emissions EDGAR v4.2: Methane Emissions*, Nov11.

Figure B-11. Summary of methane leakage rates from petroleum systems

Final Oil & Natural Gas methane rates			
Methane			
Crude oil & NGLs	Natural gas	Oil & Gas Prod'n	Percent
kg CH4/t CO2	kg CH4/t CO2	kg CH4/t CO2	
1.92	9.88		

See appended PDF of "Oil & Gas ancillary CH4" worksheet Table 6 for details.

Figure B-11 shows the final methane emission factors calculated for this project, for both petroleum and natural gas systems. The actual worksheet links each pertinent cell to the final entity summary worksheets (SumRanking.xls), and any revisions will automatically flow through to sums and charts.

Natural Gas

This project has quantified the extraction of 2,248 trillion cubic feet (Tcf) of natural gas production by 54 entities from 1900 (for ExxonMobil, then Standard Oil) to 2010. Once non-energy uses for natural gas are accounted for, and the carbon content and emission factor is applied to each entity's production (generally *marketed* production), we estimate emissions of carbon dioxide attributable to each entity. Three additional factors are added to cumulative emissions for each entity: CO_2 from flared natural gas, CO_2 vented as process emissions (especially sour gas removal: CO_2 and hydrogen sulfide), and routine and fugitive emissions of methane from natural gas operations, processing, transportation, and storage. We add one additional factor pertinent to natural gas only: estimated entity use of own fuel.[99] The methodology for each factor is detailed below.

NON-ENERGY USES.

Non-energy use of natural gas is predominantly for the production of ammonia for fertilizer production and industrial uses such as formaldehyde production from methanol.

> **Non-energy use of natural gas:** 1980-2010 average non-energy use of 0.61 QBtu, at 14.45 MtC/QBtu, with carbon content of 8.80 MtC (potential emissions of 32.27 $MtCO_2$), of which 41 percent is emitted, or 13.24 $MtCO_2$, and 59 percent stored, or average storage of 19.05 $MtCO_2$.[100]

In order to calculate a net sequestration rate for natural gas non-energy use, we divide the quantity stored by total emissions from the combustion of natural gas in the U.S. for each year 1980-2010. The average quantity stored is 19.05 $MtCO_2$, divided by average natural

[99] Estimated for natural gas only insofar as the industry produces more natural gas than is "available for sale," and while many producers re-inject produced gas into its producing oil fields in order to maintain reservoir pressures, all oil and gas producers consume a lot of natural gas in field operations, power generation, refineries, chemical plants, pipelines, etc.

[100] These calculations are based on Energy Information Administration (2011) *Annual Energy Review, 2010,* Table 1.15: Fossil Fuel Consumption for Nonfuel Use Estimates, 1980-2010 and U.S. EPA (2012) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2010*, Annex 4: IPCC Reference Approach for Estimating CO_2 Emissions from Fossil Fuel Combustion, Table A-256: 2010 Non-Energy Carbon Stored in Products. Perry Lindstrom (personal communication, 27Sep12) of the EIA informs me that non-fuel uses of natural gas and the net storage rates are being reviewed and will likely be revised downward. The effect is that net storage quantities and rates — calculated at 1.711 percent of natural gas production — probably overestimate storage and thus underestimate emissions attributed to natural gas production. If the storage rate is lowered by 1 percentage point (from 1.711 percent to 0.711 percent), the emissions attributed to carbon majors will increase by 612 $MtCO_2$ (from 120,113 to 120,725 $MtCO_2$), or +0.051 percent.

gas emissions of 1,108 $MtCO_2$. Over the 31-year EPA and EPA data set on natural gas non-energy uses, the net storage rate is 1.711 percent per annum.

Figure B-12. Non-energy uses and net carbon storage worksheet for natural gas

	Natural Gas							
	Non-energy use	Carbon Coefficent	Carbon Content	Quant emitted 41.0%	Quantity stored 59.0%	Total natural gas emissions	Non-energy emission rate Percent of total emissions	Non-energy storage rate Percent of total emissions
	QBtu	MtC/QBtu	MtC	MtCO2	MtCO2	MtCO2	Percent	Percent
	EIA	EPA	calculated	calculated	calculated	EIA	calculated	calculated
1980	0.65	14.45	9.39	14.12	20.32	1,063	1.33%	1.91%
1981	0.48	14.45	6.94	10.43	15.01	1,036	1.01%	1.45%
1982	0.41	14.45	5.92	8.91	12.82	963	0.92%	1.33%
1983	0.40	14.45	5.78	8.69	12.51	901	0.96%	1.39%
1984	0.45	14.45	6.50	9.78	14.07	962	1.02%	1.46%
1985	0.52	14.45	7.51	11.30	16.26	926	1.22%	1.76%
1986	0.44	14.45	6.36	9.56	13.76	866	1.10%	1.59%
1987	0.49	14.45	7.08	10.65	15.32	920	1.16%	1.67%
1988	0.57	14.45	8.24	12.38	17.82	962	1.29%	1.85%
1989	0.50	14.45	7.23	10.86	15.63	1,022	1.06%	1.53%
1990	0.56	14.45	8.09	12.17	17.51	1,025	1.19%	1.71%
1991	0.59	14.45	8.53	12.82	18.45	1,047	1.22%	1.76%
1992	0.62	14.45	8.96	13.47	19.39	1,082	1.25%	1.79%
1993	0.64	14.46	9.25	13.91	20.02	1,110	1.25%	1.80%
1994	0.69	14.46	9.98	15.00	21.58	1,134	1.32%	1.90%
1995	0.69	14.46	9.98	15.00	21.59	1,184	1.27%	1.82%
1996	0.70	14.46	10.12	15.22	21.90	1,205	1.26%	1.82%
1997	0.72	14.46	10.41	15.65	22.52	1,211	1.29%	1.86%
1998	0.79	14.44	11.41	17.15	24.68	1,189	1.44%	2.08%
1999	0.77	14.46	11.13	16.74	24.09	1,192	1.40%	2.02%
2000	0.74	14.47	10.71	16.10	23.17	1,241	1.30%	1.87%
2001	0.64	14.46	9.25	13.91	20.02	1,187	1.17%	1.69%
2002	0.68	14.46	9.83	14.78	21.27	1,229	1.20%	1.73%
2003	0.63	14.44	9.10	13.68	19.68	1,191	1.15%	1.65%
2004	0.62	14.46	8.97	13.48	19.40	1,194	1.13%	1.62%
2005	0.65	14.46	9.40	14.13	20.34	1,175	1.20%	1.73%
2006	0.64	14.46	9.25	13.91	20.02	1,157	1.20%	1.73%
2007	0.68	14.46	9.83	14.78	21.27	1,235	1.20%	1.72%
2008	0.66	14.46	9.54	14.35	20.65	1,243	1.15%	1.66%
2009	0.62	14.46	8.97	13.48	19.40	1,218	1.11%	1.59%
2010	0.64	14.46	9.25	13.91	20.02	1,285	1.08%	1.56%
	EPA non-energy use in 2009 of 0.366 Qbtu and 0.222 Qbtu in 2010.							
averages:	0.61	14.45	8.80	13.24	19.05	1,108	1.19%	1.71%
simple 31-yr average								
Average carbon storage rate 1980-2010 for non-energy uses of natural gas (USA)								1.711%
Carbon storage rate in CDIAC's global emissions database 1751-2010								2.000%
Average of CDIAC & US average 1980-2010 carbon storage rate								1.856%
							linked to "Gas Emissions Factor Calc"	

See appended PDF of "Non-energy uses" in SumGas.pdf workbook for details.

The net storage rate is averaged with the datum adopted by CDIAC, which uses a 98 percent emission rate and thus a 2 percent carbon storage rate (although in CDIAC's case, 0.5 percent is for incomplete combustion, which, per IPCC 2006 *Guidance*, is set at zero). The average of the 1.711 percent used here and CDIAC's 2.0 percent is 1.856 percent. This rate is used to calculate the effective carbon dioxide emission factor for natural gas.

CARBON CONTENT.

The carbon content of natural gas per unit of volume is calculated on the basis of U.S. EPA and U.S. EIA factors: 14.46 kgC/million Btu (HHV) times 1.028 million Btu per 1,000 cubic feet (kcf) (HHV) = 14.86 kgC/kcf. Adjusted for net non-fuel uses of natural gas and the final factor is 14.58 kgC/kcf, and 53.43 $kgCO_2$/kcf.[101,102] See Table B-12 for details.

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[101] U.S. Environmental Protection Agency (2012b) *Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990 – 2010,* Annex 2: Methodology for Estimating CO_2 Emissions from Fossil Fuel Combustion, Table A-42: Carbon Content Coefficients for Natural Gas (Tg Carbon/QBtu), page A-64; U.S. Energy Information Administration (2013) *Annual Energy Review 2011*, Table A-4: Heat Content of Natural Gas 1949-2011; Dry Natural Gas Production averages 1,027.6 Btu/scf.

Figure B-13. Carbon content in natural gas and final combustion emission factor

Table 1	Natural Gas				
		Kg carbon per Million Btu	Million Btu per 1,000 cf	Kg carbon per 1,000 cf	Kg CO2 per 1,000 cf
		kgC/million Btu (HHV)	(HHV) million Btu/kcf	kgC/kcf	kgCO2/kcf
Step 1:	Carbon in produced natural gas (net production)	14.46	1.028	14.86	54.44
Step 2:	Energy inputs to gas extraction, transport, processing, & delivery	(applied in SummaryRanking.xls)		14.86	54.44
Step 3:	Vented carbon dioxide, gas operations	(applied in SummaryRanking.xls)		14.86	54.44
Step 4:	Direct venting of methane (intentional & fugitive), gas ops	(applied in SummaryRanking.xls)		14.86	54.44
Step 5:	Flaring of natural gas, gas operations	(applied in SummaryRanking.xls)		14.86	54.44
Step 6:	Adjust for carbon sequestered through non-energy uses of gas	estimated in "non-energy uses"	0.98144	14.58	53.43
Step 7:	Adjust for oxidation rate	100 percent	1.00000	14.58	53.43
Step 8:	Convert step 7 factor to emissions per billion cubic feet (Bcf)	Million tonnes Carbon and CO2 per billion cf (Bcf)		0.01458	0.05343

See appended PDF of "Gas Emissions Factor Calc" in SumGas.pdf workbook for details.

ANCILLARY EMISSIONS OF CO_2: CO_2 REMOVAL FROM PRODUCED GAS.

Carbon dioxide commonly occurs in natural gas and is typically removed in order to meet pipeline heating value requirements. Removal of "sour gas," i.e., carbon dioxide, is done at natural gas processing plants. CO_2 content in raw gas various widely from field to field around the world, and tends to be higher in unconventional gas fields. Total CO_2 content in U.S. natural gas averages 3.45 percent, but 4.83 percent in unconventional gas (and up to 18 percent in coal bed methane production), and 3.41 percent in conventional gas, shown in Figure 13.[103] Note that the U.S. data on CO_2 *content* in natural gas shows higher rates than the EPA vented CO_2 from natural gas processing plants, which suggests that not all CO_2 is removed from natural gas, since the average venting rate shown in Table 5 is 2.33 percent. Indeed, the carbon dioxide content of marketed pipeline quality natural gas is a maximum of 2.0 percent.[104]

Figure B-14. CO_2 content in U.S. natural gas by region and well type

Table A-133: U.S. Production Sector CO_2 Content in Natural Gas by NEMS Region and Natural Gas Well Type

	U.S. Region						
Well Types	North East	Midcontinent	Gulf Coast	South West	Rocky Mountain	West Coast	Lower-48 States
Conventional	0.92%	0.79%	2.17%	3.81%	7.95%	0.16%	3.41%
Non-conventional*	7.42%	0.31%	0.23%	NA	0.64%	NA	4.83%
All types	3.04%	0.79%	2.17%	3.81%	7.58%	0.16%	3.45%

Source: GRI-01/0136 GTI's Gas Resource Database: Unconventional Natural Gas and Gas Composition Databases. Second Edition. August, 2001

*In GTI, this refers to shale, coal bed methane, and tight geologic formations. The Inventory defines un-conventional wells that those that are hydraulically fractured.

EPA (2012) U.S. Inventory for 2010, Annex 3, Table A-133. Original data GRI 2001.

102 It would have been preferable to use IPCC or other international data to derive the carbon content of natural gas on a volumetric bases, but United Nations (2012) *Energy Statistics Yearbook 2009*, UN Statistics Division, Jun12, "Standard Heat Value" (net calorific value) at 39,021 kJ/m³, which is unreasonably high and skewed the emission factor to a value of 16.91 kgC/kcf (61.9 $kgCO_2$/kcf), and to 16.59 kgC/kcf (60.8 $kgCO_2$/kcf) after accounting for non-energy uses. These IPCC/UN values are ~13.8 percent higher than the U.S. EPA/EIA emission factor applied to natural gas production here.

103 Gas Research Institute (2001) *Gas Resource Database: Unconventional Natural Gas and Gas Composition Databases*, 2nd edition; cited in EPA (2012) *Inventory 2010*, Annex 3, Table A-133: "U.S. Production Sector CO_2 Content in Natural Gas by NEMS Region and Natural Gas Well Type." Note: shale gas production has increased from less than 1%in 2000 to 23% of total U.S. production in 2010, and is projected to reach 34% in 2020. EIA (2012) *Annual Energy Outlook*, table 19, page 62.

104 American Petroleum Institute (2009) *Compendium of Greenhouse Gas emissions Methodologies for the Oil & Gas Industry*, Aug09, 807 pp. Appendix E, Table E-4.

CO_2 content in world natural producing areas are poorly characterized, and this study calculates a CO_2 emission rate from IPCC Tier 1 default factors for vented CO_2 and fugitive CO_2 (of which fugitive CO_2 is a very small fraction). The majority of vented and fugitive emissions are from processing, with smaller amounts from production, transmission, and storage. The factors vary from 0.040 kg CO_2/m^3 in developed countries and 0.0675 kg CO_2/m^3 in developing countries; the average (0.0538 kg CO_2/m^3) converts to 28.53 kg CO_2/tCO_2 from the combustion of natural gas, and shown in Figure 14 and Table 5 below. This rate equates to an additional 2.85 percent of CO_2 emissions from gas production, and is applied to cumulative natural gas production for each Carbon Majors producing entity.

Figure B-15. Vented CO_2 emissions from natural gas processing plants

Summary of Ancillary Flaring and Venting factors			
CO2: Flaring		CO2: Venting	CO2: Venting
Flaring: Oil	Flaring: Gas	CO2 Venting: Oil	CO2 Venting: Gas
flaring: Oil	flaring: Gas	(includes fugitives)	(includes fugitives)
kg CO2/tCO2	kg CO2/tCO2	kg CO2/tCO2	kg CO2/tCO2
15.94	1.74	3.833	28.53

See appended PDF of "Flaring & Venting" in AncillaryCH4&CO2.pdf, tables 3 and 8 for details.

Table B-6. Estimates of vented & fugitive CO_2 emissions from natural gas systems

	$kgCO_2/tCO_2$	kg CO_2/Bcf
U.S. EPA, average 1990-2010	23.34	
IPCC Tier 1 values	**28.53**	1,525

See appended PDF of "Flaring & Venting" in AncillaryCH4&CO2.pdf, tables 1, 2, 3, 4, and 8 for details.

ANCILLARY EMISSIONS OF CO_2: FLARING

The IPCC Tier 1 emissions factor for flaring from natural gas systems is applied, averaging developed and developing countries, chiefly from processing, condensate transport, and gas storage. The average factor is 0.00328 kg CO_2/m^3, which converts to 1.74 kg CO_2 of flaring per tonne of CO_2 from natural gas combustion, or 93 gCO_2/cf of burned natural gas. See tables 1 and 2 in "Flaring & Venting" worksheet for details of the computations. Also see Figure 14 above and Table 6 below for summary flaring factors.

Table B-7. Estimates of flaring CO_2 emissions from natural gas systems

	$kgCO_2/tCO_2$	kg CO_2/Bcf
U.S. EPA, average 1990-2010	na	
IPCC Tier 1 values	**1.74**	93

See appended PDF of "Flaring & Venting" in AncillaryCH4&CO2.pdf, tables 1, 2, 3, 4, and 8 for details.

ANCILLARY EMISSIONS OF CH_4.

Methane is emitted from the production through delivery of natural gas. Global estimates for 2008 total 52 $MtCH_4$. Principal sources are well workovers, pneumatic device vents, field separation equipment, and compressor stations; in some countries (e.g., Russian Federation) pipeline leakage is a significant source. The Carbon Majors study excludes methane emissions from natural gas distribution pipelines, since emissions to fossil fuel producers are attributed (not distributors, gas utilities, or consumers). The IPCC Tier 1 rates are too low (whereas the IPCC Tier 1 values for methane from petroleum systems are too high) compared to other sources.

Figure B-16. Worksheet on methane emissions from natural gas systems, EPA data

Table 32	Calculation of natural gas system methane rates				
	U.S. natural gas production, EIA data	Estimated CO2 emissions from U.S. natural gas prodn	Methane emission rate (excluding distribution CH4)	Methane emission rate (excl. distrib.	Methane emission rate (excl. distrib.
	Bcf/yr	MtCO2/yr	kg CH4/tCO2	g CH4/cf	Percent
1990	17,810	952	7.81	0.417	2.17%
1992	17,840	953	7.95	0.425	2.20%
1995	18,599	994	8.17	0.437	2.27%
2000	19,182	1,025	9.14	0.488	2.54%
2006	18,504	989	11.06	0.591	3.07%
2007	19,266	1,029	11.32	0.605	3.14%
2008	20,286	1,084	11.11	0.594	3.08%
2009	20,580	1,100	11.14	0.596	3.09%
2010	21,577	1,153	10.64	0.569	2.95%
Total 1990-2010	173,644	9,278	88.35		
average	19,294	1,031	9.82	0.5278	2.72%
	Weighted average of 1990-2010		9.88		1.54%
			Linked to Table 6		Bradbury et al 2013

See the appended PDF of "Oil & Gas ancillary CH4" worksheet Table 32 for details.

Table B-8. Natural gas-system vented & fugitive methane rates, per tCO_2 from gas combust'n

	$kgCH_4/tCO_2$	tCH_4/Bcf
U.S. EPA, weighted average 1990-2010	**9.88**	531
EDGAR, global average 1970-2008[105]	8.98	482
IPCC Tier 1 values	4.22	225

Note: the metric for kg CH_4 is based on methane emissions associated with natural gas production and processing. See appended PDF of "Oil & Gas ancillary CH4" worksheet Tables 1, 2, 6, 31, and (particularly) Table 32 for details.

Figure B-17. Summary table of vented and fugitive methane from natural gas systems

Final Oil & Natural Gas methane rates			
Methane			
Crude oil & NGLs	Natural gas	Oil & Gas Prod'n	Percent
kg CH4/t CO2	kg CH4/t CO2	kg CH4/t CO2	
1.92	9.88		

See appended PDF of "Oil & Gas ancillary CH4" worksheet Table 6 for details.

Instead the methane emission rate is based on U.S. EPA data for the United States 1990-2010. Production stage emissions (67 percent of the total), processing plants (9 percent), and natural gas transportation and storage (24 percent) are included, but distribution emissions are not.[106] The EPA-derived rate is 531 tCH_4/Bcf of gas production, and 9.88 kg CH_4/tCO_2 from natural gas combustion. (Note: this is prior to the growth of hydraulic fracturing gas production from tight shale formations, which reportedly has higher methane emission rates than conventional gas production.)[107] Applying the standard GWP factor for methane of 21 * CO_2, per IPCC's *Second Assessment Report*, yields a natural gas methane rate (9.88 * 21) of 207.4 kg CO_2e/tCO_2 from natural gas combustion, equivalent to an adder of 20.7 percent above gas combustion and applied to all natural gas producers.

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[105] Computed from EDGAR methane emissions 1970-2008 from natural gas systems. According to this database, global energy-related methane emissions have risen from 59.7 $TgCH_4$ in 1970 to 121.5 $TgCH_4$ in 2008, including 52.1 $TgCH_4$ from natural gas systems. European Commission's Joint Research Centre (2011) *Global Emissions EDGAR v4.2: Methane Emissions*, Emission Database for Global Atmospheric Research, Nov11; edgar.jrc.ec.europa.eu/overview.php?v=42. This data is from the "General Non-CO2 data" worksheet in the "AncillaryCH4&CO2.xls" workbook.

[106] The percentages are from the EPA estimates (2012) of U.S. gas-system emissions, since the EDGAR global data does not provide a breakdown of natural gas methane emissions by source.

[107] Howarth, Robert W., Renee Santoro, & Anthony Ingraffea (2011) Methane and the greenhouse-gas footprint of natural gas from shale formations, A Letter, *Climatic Change*, vol. 106:679-690. See also: Ingraffea, Anthony (2013) Gangplank to a Warm Future, *New York Times* Op-Ed, 28 July 2013; Wigley, Tom M. L. (2011) Coal to Gas: The Influence of Methane Leakage, *Climate Change Letters*, vol. 108:601-608; and Allen et al. (2013) *Proc. Natl. Acad. Sciences*, online 16Sep13.

Analysis of EPA's methane emissions for the United States — 9.88 kg CH_4/tCO_2 (207.4 kg CO_2e/tCO_2) from gas production and processing relative to CO_2 emissions from gas combustion — is in good agreement with the EDGAR data set, which averages 8.98 kg CH_4/tCO_2 from 1970 to 2008.[108]

Coal

This project has traced the production of 162,736 million tonnes of coal production to the Carbon Major entities and estimated cumulative emissions 329.6 $GtCO_2$ from combustion of the produced coal. Once non-energy uses for coal are accounted for, and the carbon content and emission factor is applied to each entity's production, the emissions of carbon dioxide attributable to each entity are estimated. One additional emission source is added to each entity: vented and fugitive emissions of methane from coal mining operations, the majority of which are from underground mines that are ventilated for safety reasons. Underground coal deposits contain higher proportions of methane embedded in the coal seams (methane content typically increases with coal seam depth), whereas in surface coal deposits much of the trapped CH_4 has been liberated over the eons.

NON-ENERGY USES.

Non-energy use of coal is predominantly for carbonization to make metallurgical coke for steel manufacturing, but also smaller industrial uses such as coal tars (for aromatic chemicals), synthesis gas for chemical uses, activated carbon, filters, soaps, and carbon fibers. The IPCC (2006) provides guidance on non-energy calculations and quantitative estimates, as well as storage factors, but provides insufficient data useful for estimating emission and sequestration *rates*, and we instead base our estimates on EPA (2012).[109]

> **Non-energy use of coal:** 1980-2010 average non-energy use of 0.029 QBtu, at 26.05 MtC/QBtu, with carbon content of 0.76 MtC (potential emissions of 2.80 $MtCO_2$), of which 90 percent is emitted, or 2.52 $MtCO_2$, and 10 percent stored, or an average annual storage of 0.28 $MtCO_2$. Note: the smaller component of coal's non-energy uses — industrial applications — has a higher storage factor of 59 percent, compared to 10 percent for coking coal.[110]

This results in average 1980-2010 storage rate of 0.016 percent relative to the CO_2 emissions from coal combustion.[111] Song & Schobert (1996b) suggest a higher carbon storage rate (based on 0.78 QBtu of non-energy coal use in 1992),[112] compared to EPA's use

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108 European Commission's Joint Research Centre (2011) *Emission Database for Global Atmospheric Research* (EDGAR), edgar.jrc.ec.europa.eu/overview.php?v=42. We elect to not use the EDGAR data, and its calculated methane emission rate, due to incomplete boundary definition of what is included in natural gas system emissions. *Factsheet - Energy: Fugitive emissions* (1B) at: edgar.jrc.ec.europa.eu/factsheet_1b.php.

109 U.S. EPA (2012) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2010*, Table A-32: Unadjusted Non-Energy Fuel Consumption, and Table 3-21: 2010 Adjusted Non-Energy Use Fossil Fuel Consumption, Storage, and Emissions. These tables are reproduced in the attached "Non-energy uses" worksheet in the PDF of the SumCoal.xls workbook.

110 We do not adjust the overall storage rate, since the EPA's use of EIA's data appears to ignore industrial uses when it comes to estimating final emissions from non-energy uses. If we were to make this adjustment it would double the overall storage rate. However, we only have 2010 data to work with, and given the variability and dominance of coking coal uses, we cannot justify making this adjustment.

111 CMS analysis of the EIA data (unadjusted by the EPA) suggests a sequestration rate of 0.077 percent over the 31-yr period 1980-2010. However, since the EPA is the lead agency for providing national inventories to the IPCC, we use the EPA-derived result in the Carbon Majors project.

112 Song, Chunsan, & Harold Schobert (1996b) *Non-Fuel Uses of Coals and Synthesis of Chemicals and Materials*, Fuel Science Program, Pennsylvania State University, University Park, PA.

of EIA's datum of 0.04 QBtu in the same year. Song and Schobert do not provide enough data on emissions and storage or the multi-year data necessary to calculate long-term trends and carbon storage rates.[113] The rate calculation adopted here may be low, but the factor from the most applicable data is applied. Rates may be revised at a later date.

Figure B-18. Calculation of non-energy use rate for coal

	Coal								
	Alternative Non-energy use	Non-energy use	Carbon Coefficent	Carbon Content	Quant emitted 90.00%	Quantity stored 10.00%	coal emissions	Non-energy emission rate Percent of total emissions	Non-energy storage rate Percent of total emissions
	QBtu	QBtu	MtC/QBtu	MtC	MtCO2	MtCO2	MtCO2	Percent	Percent
						done			
	EPA	EIA	EPA	calculated	calculated	calculated	EIA	calculated	calculated
		done	done	done	done	done	done	done	done
1980		0.08	25.96	2.08	6.85	0.76	1,436	0.48%	0.053%
1981		0.07	25.96	1.82	6.00	0.67	1,485	0.40%	0.045%
1982		0.04	25.96	1.04	3.43	0.38	1,433	0.24%	0.027%
1983		0.04	25.96	1.04	3.43	0.38	1,488	0.23%	0.026%
1984		0.05	25.96	1.30	4.28	0.48	1,598	0.27%	0.030%
1985		0.03	25.96	0.78	2.57	0.29	1,638	0.16%	0.017%
1986		0.02	25.96	0.52	1.71	0.19	1,617	0.11%	0.012%
1987		0.03	25.96	0.78	2.57	0.29	1,691	0.15%	0.017%
1988		0.02	25.96	0.52	1.71	0.19	1,775	0.10%	0.011%
1989		0.02	25.96	0.52	1.71	0.19	1,795	0.10%	0.011%
1990	0.0082	0.02	25.96	0.52	1.71	0.19	1,821	0.09%	0.010%
1991		0.02	25.96	0.52	1.71	0.19	1,807	0.09%	0.011%
1992		0.04	25.95	1.04	3.43	0.38	1,822	0.19%	0.021%
1993		0.03	25.95	0.78	2.57	0.29	1,882	0.14%	0.015%
1994		0.03	25.94	0.78	2.57	0.29	1,893	0.14%	0.015%
1995	0.0491	0.03	25.93	0.78	2.57	0.29	1,913	0.13%	0.015%
1996	0.0355	0.03	25.93	0.78	2.57	0.29	1,995	0.13%	0.014%
1997	0.0112	0.03	25.93	0.78	2.57	0.29	2,040	0.13%	0.014%
1998	0.0213	0.03	25.95	0.78	2.57	0.29	2,064	0.12%	0.014%
1999	0.0512	0.03	25.98	0.78	2.57	0.29	2,062	0.12%	0.014%
2000	0.0660	0.03	26.00	0.78	2.57	0.29	2,155	0.12%	0.013%
2001	0.0361	0.02	26.00	0.52	1.72	0.19	2,088	0.08%	0.009%
2002	0.0523	0.02	26.05	0.52	1.72	0.19	2,095	0.08%	0.009%
2003	0.0638	0.02	26.09	0.52	1.72	0.19	2,136	0.08%	0.009%
2004	0.1797	0.02	26.10	0.52	1.72	0.19	2,160	0.08%	0.009%
2005	0.0924	0.02	26.09	0.52	1.72	0.19	2,182	0.08%	0.009%
2006	0.0748	0.02	26.04	0.52	1.72	0.19	2,147	0.08%	0.009%
2007	0.0142	0.02	26.05	0.52	1.72	0.19	2,172	0.08%	0.009%
2008	0.0410	0.02	26.05	0.52	1.72	0.19	2,139	0.08%	0.009%
2009	0.0183	0.01	26.05	0.26	0.86	0.10	1,876	0.05%	0.005%
2010	0.0768	0.02	26.05	0.52	1.72	0.19	1,985	0.09%	0.010%
		0.0294	25.9885	0.7626	2.5167	0.2796	1,884	0.14%	
		Average storage rate 1980-2010 for non-energy uses of coal (USA)							0.016%
									linked to EF worksheet

See the appended PDF of "Non-energy uses" in SumCoal.pdf for details.

CARBON CONTENT.

The carbon content of coal on a mass basis is far more varied and complex than for crude oil and natural gas, and varies from 32.8 percent for lignite to 71.6 percent for anthracite based on computations of IPCC default values for coal types.[114] Potential emissions from the combustion of produced coals is reduced from non-energy uses of coal (0.016 percent, hence the 0.9998 shown in the non-energy uses column in Figure 19).

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113 In the EIA data cited by EPA (2012) Table A-32, non-energy use of industrial coking coal ranged from zero to 168 TBtu/y (1997 and 2004, respectively); industrial other coal was in a narrower range (8 to 12 TBtu/y).

114 IPCC (2006) *Guidelines for National GHG Inventories*, Volume 2: Energy, Introduction, Table 1.3: Default Values of Carbon Content (in kgC/GJ), page 21. IPCC does not list "average utility coal," which this study uses as a default value for coal producers that show coal production as either "thermal coal" or does not specify coal rank. CMS estimates this value by averaging bituminous and sub-bituminous coal.

The adjusted coal coefficient for each coal type is shown in red in Fig. 18, and ranges from 1.20 tCO_2 per tonne lignite to 2.62 tCO_2 per tonne anthracite. These factors are applied to the quantities of coal produced by each entity, for each year.

While it is preferable to base calculations on carbon content per unit of heating value (such kgC/MJ), as CDIAC does, using United Nations coal consumption data, this project is constrained by coal producers' (chiefly investor-owned) tendency to report production in metric tonnes or short tons — and typically to *not* report heating values or energy content of produced coals, though some companies do (e.g., Murray Energy: bituminous, though heating values are not provided, and Anglo American). More often, producers will report generic coal rank, such as "thermal" and "coking coal" (Anglo American [with heating values of South African production ranging from 4,470 to 7,400 kcal/kg], Coal India [coking and non-coking], North American Coal [lignite]).[115] Others provide a mixed record; Peabody, for example, provided data on mine type (surface or open cast), type of coal (steam, pulverized, or metallurgical), and heating values of coal produced at each of the company's forty domestic and international mines in its 2006 annual report.[116] These details were deleted from the 2010 report, except for generic coal type (e.g., thermal or metallurgical).

Figure B-19. Carbon content and emission factors for coal types

Carbon Majors applies IPCC-derived coefficients in "Coal Emissions" worksheet

Calculation of Coal Coefficients by Coal Rank (IPCC default values)

(prior to adjusting for oxidation and non-fuel uses)					Non-energy uses	Adjusted	Not including methane,
IPCC default value	IPCC values	calculation		3.664191 CO2/C	(100% oxidation)	Coal Coefficient	included elsewhere
GJ/tonne	kgC/GJ	kgC/tonne	Percent C	Tonne CO2/tonne	adjustment factor	tonne CO2/tonne coal	
11.90	27.60	328.44	32.8%	1.2035	0.9998	1.2033	Lignite
18.90	26.20	495.18	49.5%	1.8144	0.9998	1.8141	Sub-bituminous
25.80	25.80	665.64	66.6%	2.4390	0.9998	2.4386	Bituminous
26.70	26.80	715.56	71.6%	2.6219	0.9998	2.6215	Anthracite
28.20	25.80	727.56	72.8%	2.6659	0.9998	2.6655	Metallurgical coal
22.35	26.00	581.10	58.1%	2.1293	0.9998	2.1289	Thermal coal

thermal coal is assumed to be the average of bituminous and sub-bituminous — linked to "Coal Emissions" worksheet, column "FT" (2010)

IPCC does not specify average boiler fuel default value, and figure may be revised

See appended PDF of "Coal C Coefficients" in SumCoal.pdf workbook for details.

Given these constraints, we are forced into a carbon estimation protocol with fairly broad uncertainties. "Thermal coal," for example, can range from lignite in India and Germany to high-carbon bituminous mined in New South Wales, Appalachia, and Correjon (Colombia), and with carbon content ranging from ~30 to ~70 percent and an emission factor ranging from ~1.2 to ~2.4 tCO_2/tonne coal. We have attempted to narrow the uncertainties by researching coal quality in regions of interest and where producers provide inadequate information on coal rank or heating values, such as Luminant (lignite, Texas) or Coal India (lignite and sub-bituminous). Producers are encouraged to correct errors and provide complete information on coals mined, heating values for each mine wholly or partially owned, and provide the kind of estimates made here with partial information.

The carbon content and CO_2 emission estimation protocol is as follows:

- Research annual reports, SEC filings, company histories, and website information on annual coal production;

[115] Several entities provide little guidance on rank or heating value of produced coals, e.g., Massey Energy
[116] See the Coal extraction worksheet for details.

- Note, to the extent reported by each entity, coal rank and heating values; the ranking is typically generic categories such as "thermal" or "steam" and "metallurgical" or "coking" coal, or "hard coal;"
- List additional information on specific coal rank and heating values for each mine or production asset, if published by the company;[117]
- Categorize coal production by coal rank where company data allows it, or research typical coal ranks of important producing regions and assign likely rank;
- If a coal operator has listed coal rank for, say, the last twenty years but did not do so in earlier annual reports, we apply the same ranks to previous production;
- The percentage of production by rank is calculated for each entity. Peabody's production, for example, is 96.9 percent "thermal" (for which we use the average of bituminous and sub-bituminous coal) and 3.1 percent metallurgical; Xstrata is 84.4 percent bituminous and 15.6 percent metallurgical; Coal India is 6.6 percent lignite and 93.4 percent sub-bituminous; Sasol is 100 percent bituminous;
- This distribution of production by rank allows us to calculate probable emissions by each producer's customers, since we have accounted for non-energy uses in the emission coefficients worksheet (Figures 17 and 18);
- Thus, for each entity, we multiply coal production for each year by the percentage of each rank of coal and the emission factor for each rank of coal. As an example, BHP Billiton's 2010 production totaled 104 million tonnes, of which 71.1 percent was "energy coal" (categorized as "thermal" coal) and 28.9 percent "metallurgical coal:"

  *104 Mt coal * 0.711 * 2.129 tCO_2/tonne coal + 104 Mt coal * 0.289 * 2.665 tCO_2/tonne coal;*
  Total BHP emissions, 2010: 236 MtCO_2; average BHP emission factor is 2.284 tCO_2/t.

- The distribution of coal types is based on the number of years such data is reported, and this distribution is applied to each entity's entire production history;

ANCILLARY EMISSIONS OF CO_2.

While small quantities of carbon in coals is oxidized into CO_2, trapped, and liberated during mining and post-mining operations, such emissions are considered negligible, this study (as well as IPCC and EPA) excludes this emission source.[118] U.S data suggests CO_2 liberation rates of ~2.6 kg CO_2/tonne of coal mined, or ~1.2 kg CO_2/tCO_2 from coal combustion. CO_2 liberated from coal mining is thus a small source of ~0.12 percent.[119] Given the paucity of

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[117] While heating values are documented on the production worksheets, we have not applied them: no producer has provided sufficient data for all its operations over its mining history to make such an approach feasible; and the work of making use of differing heating values for each of its 40 mines provided by Peabody Energy for 2006, for example, is beyond the scope of this project. Where heating values are provided they are used to inform the classification of coal rank.

[118] "Low temperature oxidation: Oxidation of coal when it is exposed to the atmosphere by coal mining releases CO_2. This source will usually be insignificant when compared with the total emissions from gassy underground coal mines. Consequently, no methods are provided to estimate it. Where there are significant emissions of CO_2 in addition to methane in the seam gas, these should be reported on a mine-specific basis." IPCC *2006 Guidelines*, vol. 2, chapter 4: Fugitive emissions; Surface mining: fugitive methane, Section 4.1.3 Underground coal mines, page 4.10.

[119] We estimate a rate of 2.493 kg CO_2 per tonne of coal mined, which equals 0.123 percent, or 1.23 kg CO_2/tCO_2 from coal combustion. Sources: Lyons, Paul C. (1996) *Coalbed methane potential in the Appalachian states of Pennsylvania, West Virginia, Maryland, Ohio, Virginia, Kentucky, and Tennessee--An overview*, USGS Open-File Report 96-735. Cites CO_2 content ranging from 0.5 to 10 percent. U.S. Environmental Protection Agency (2012) *Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010*, Table 3-30. U.S. Energy Information Administration (2011) *Annual Coal Report*, Tables 1 and 3. U.S. Environmental Protection Agency (2008b) *Upgrading Drained Coal Mine Methane to Pipeline Quality: A Report on the Commercial Status of System Suppliers*, Coalbed Methane Outreach Program, US EPA. Table 2 shows CMM N and CO_2 in IL, VA, PA, WV, AL ranging in CO_2 1% to 5%. U.S Dept of Energy (2009) *Capture and Use of Coal Mine Ventilation Air*

global and U.S. data, and the lack of IPCC protocols in its guidance documents for coal-mine vented CO_2, we do not include an estimate of this source in the Carbon Majors project.

ANCILLARY EMISSIONS OF CH_4.

Most coals contain methane embedded in pore spaces (along with minor amounts of CO_2, ethanes, and nitrogen) that are released during mining or in post-mining treatment. The methodology is based on estimates of global CH_4 emissions from coal mining; a methane release *rate* per tonne mined and per tonne CO_2 from coal combustion is calculated.

Figure B-20. IPCC Tier 1 values for coal methane emission rates

Table 2	kg CH4 per tonne coal mined		
	Low	Average	High
Underground mining	kg CH4/t mined	kg CH4/t mined	kg CH4/t mined
Mining	6.70	12.06	16.75
Post-mining	0.60	1.68	2.68
Total	7.30	13.74	19.43
Surface mining			
Mining	0.20	0.80	1.34
Post-mining	-	0.07	0.13
Total	0.20	0.87	1.47
UG/SF	36.33	15.77	13.18

See appended PDF of "Coal ancillary CH4" in AncillaryCH4&CO2.pdf workbook for details.

Figure B-21. IPCC Tier 1 factors and derivation of average coal methane emission rate

	Table 6	kg CH4/ t coal mined converted to kg CH4/t CO2			
		Low	Average	High	
	Combined mining	kg CH4/t CO2 comb.	kg CH4/t (or tCO2)	kg CH4/tonne	
	Underground	7.30	13.74	19.43	kg CH4/t mined
	Surface	0.20	0.87	1.47	kg CH4/t mined
	Total	7.50	14.61	20.90	kg CH4/t mined
	Average	3.75	7.30	10.45	kg CH4/t mined
	Coal combustion EF	2.13	2.13	2.13	tCO2 emitted/t coal combusted
	Methane rate, CH4	1.76	3.43	4.91	kg CH4/tCO2 from combusted coal
	Methane rate, CO2e	37.01	72.04	103.10	kg CO2e/tCO2 from combusted coal
Adjusted for mining method.	Methane rate, adjustec	2.10	4.03	5.75	kg CH4/tCO2 from combusted coal
Adjusted for mining method.	Methane rate, adjustec	44.02	84.73	120.81	kg CO2e/tCO2 from combusted coal
		linked to summary table 9, and thereto SumRanking.xls			

See appended PDF of "Coal ancillary CH4" in AncillaryCH4&CO2.pdf workbook for details.

Figure B-22. Final coal methane rates

Final coal mining methane rates		
Methane		
	Coal mining emissions	
kg CH4/t coal	kg CH4/t CO2	kg CO2e/t CO2
8.59	4.03	84.73

See Table 9 in the appended PDF of "Coal ancillary CH4" in AncillaryCH4&CO2.pdf workbook for details.

The IPCC Tier 1 emission factors are applied to coal entities in this study, starting with IPCC emission rates (in units of m^3 of methane per tonne of coal mined) for underground and open cast mining and post-mining, using "average" factors, converting to an emission rate of kg CH_4 per tonne of CO_2 emission from coal combustion (using an emission factor of

Methane, Deborah A. Kosmack, U.S. DOE & CONSOL Energy Inc. Table 1. Gas Chromatography Analysis of Gas Samples Taken During Vent Capacity Tests: Methane: 40-44%, N: 50-53%, CO_2: 3.6-4.1%.

2.129 tCO_2/t coal), and, finally, adjusting for ~60 percent of world coal mined underground and ~40 percent open cast.[120] The final factor — 4.03 kg CH_4/tCO_2 from coal combustion — is applied to each coal entity's annual coal extraction and marketing.

Table B-9. Calculated coal-mining methane rates: other expert sources and this study.

Source	Tg CH_4	kg CH_4/tonne coal	kg CH_4/tCO_2
Kirchgessner, 1993	45.6	9.47	4.84
CIAB, 1994	26.0	5.36	2.74
Fung et al, 1991	39.0	8.80	4.50
Boyer et al, 1990	53.5	11.53	5.89
Cicerone & Oremland, 1988	35.0	7.89	4.04
Crutzen, 1987	37.0	8.35	4.27
Stern & Kaufmann, 1996	63.6	10.54	5.56
IPCC, tier 1 calculation, *underground only*[121]		13.74	6.45
IPCC, tier 1 calculation, *opencast only*		0.87	0.41
IPCC, tier 1 calculation, *60% UG, 40% OC*		8.59	4.03
European Commission, EDGAR, 2008	46.7	6.85	3.56
European Commission, EDGAR, 1970-2008	29.8	6.86	3.64
EPA, 2011 (global)		4.29	2.24
EPA, 2012 (USA, underground)		8.09	3.37
EPA, 2012 (USA, surface)		1.08	0.60
EPA, 2012 (USA, all coal)		3.39	1.68
This study[122]	**~56.2**	**8.59**	**4.03**

See appended "Coal ancillary CH4" in AncillaryCH4&CO2.pdf workbook Tables 4, 8, and 10-13 for details.

The final methane emission factor of 4.03 kg CH_4 is in the mid-range of the estimates by other sources listed in the above table. (Calculations of methane rates by CMS.) This factor is applied to all coal production entities in this study; the resulting estimate of attributed *cumulative* methane emissions totals 1,330 $MtCH_4$ (equal to 27,926 $MtCO_2e$ at IPCC *Second Assessment Report's* GWP value of 21 * CO_2).

Since cumulative combustion emissions of all coal entities is 329,604 $MtCO_2$, the methane emissions add 8.47 percent to emissions of carbon dioxide from coal combustion. This is in line with the EDGAR adder, the average of 1970-2008 is 7.49 percent. The EDGAR methane emission rates show a decline from 8.4 kg CH_4/tonne in 1970 to 6.9 kg CH_4/t in 2008.[123]

The IPCC-based methodology does not account for variable methane content and liberation rates, capture of methane (for flaring or utilization, rather than venting to the atmosphere), open cast vs underground rates, and other factors for which producers, by and large, do not provide the information required. Consequently, methane emissions attributed to surface operators will be over-estimates, and, vice-versa, underground operators will be attributed lower methane emissions.

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[120] World Coal Institute (2005) *The Coal Resources: A Comprehensive Overview of Coal*, London, 44 pp. The trade group changed its name to World Coal Association in 2010.

[121] "This is the density of CH_4 and converts volume of CH_4 to mass of CH_4. The density is taken at 20° C and 1 atmosphere pressure and has a value of 0.67 * 10^{-6} Gg/m^3." IPCC *Guidelines 2006*, vol. 2: Energy, ch. 4: Fugitive Emissions, page 4.12. The procedure for underground mines is 18.0 m^3/t (plus 2.5 m^3/t for post-mining); thus 20.5 m^3/t * 0.67 * 10^{-6} Gg/m^3 (0.67 kg CH_4/m^3) equals 13.74 kg CH_4/t.

[122] The global coal methane emissions implied by this study's emission rate of 4.03 $kgCH_4/tCO_2$ from coal combustion (13,950 $MtCO_2$ in 2010) totals 56.2 $TgCH_4$. No global methane estimates are available for comparison that is also based on the rapid rise of coal production in 2009 and 2010, especially in China.

[123] European Commission's Joint Research Centre (2011) *Global Emissions EDGAR v4.2: Methane Emissions*, Nov11; edgar.jrc.ec.europa.eu/overview.php?v=42; the complete EDGAR methane data are reproduced in the "General Non-CO2 data" worksheet, rows 324 to 380, in AncillaryCH4&CO2.pdf

About one-fifth of methane liberated from U.S. coal mines in 2010 was recovered and used (943 $TgCH_4$ of 4,401 $TgCH_4$ total, or 21.4 percent), though this usage rate has increased from 6.2 percent in 1990, according to the U.S. EPA data in the figure below.[124] China, the world's largest coal mining methane emitter (~14.3 $TgCH_4$ in 2010, at a rate of ~4.3 $kgCH_4$/t of coal production), captured and used 17 percent of its coal mine methane.[125] Globally, 22 percent of coal methane is being recovered and used.[126]

Figure B-23. US sources and disposition of coal-mine methane 1990-2010

Table 3-28: CH_4 Emissions from Coal Mining (Tg CO_2 Eq.)

Activity	1990		2005	2006	2007	2008	2009	2010
UG Mining	62.3		34.9	34.9	35.7	44.9	49.6	51.6
Liberated	67.9		50.2	50.2	50.9	60.5	66.1	71.4
Recovered & Used	(5.6)		(15.2)	(18.8)	(15.2)	(16.3)	(16.6)	(19.6)
Surface Mining	12.0		13.3	14.0	13.8	14.3	12.9	13.1
Post-Mining (UG)	7.7		6.4	6.3	6.1	6.1	5.6	5.7
Post-Mining (Surface)	2.0		2.2	2.3	2.2	2.3	2.1	2.1
Total	**84.1**		**56.8**	**56.8**	**57.8**	**66.9**	**70.1**	**72.6**

Note: Totals may not sum due to independent rounding. Parentheses indicate negative values.

Table 3-29: CH_4 Emissions from Coal Mining (Gg)

Activity	1990		2005	2006	2007	2008	2009	2010
UG Mining	2,968		1,663	1,693	1,698	2,102	2,360	2,459
Liberated	3,234		2,389	2,588	2,422	2,881	3,149	3,402
Recovered & Used	(266)		(726)	(895)	(724)	(779)	(789)	(943)
Surface Mining	573.6		633.1	668.0	658.9	680.5	614.2	626.2
Post-Mining (UG)	368.3		305.9	298.5	289.6	292.0	266.7	270.2
Post-Mining (Surface)	93.2		102.9	108.5	107.1	110.6	99.8	101.8
Total	**4,003**		**2,705**	**2,768**	**2,754**	**3,186**	**3,340**	**3,458**

Note: Totals may not sum due to independent rounding. Parentheses indicate negative values.

See appended PDF of "Coal ancillary CH4" in AncillaryCH4&CO2.pdf workbook for details.

Cement

This project includes industrial emissions from cement manufacturing. World production of cement in 2010 totaled 3.3 billion tonnes, more than half (1.78 billion tonnes) of it in China. Emissions of carbon dioxide from cement manufacture includes the CO_2 released from the high-temperature processing of limestone (calcium carbonate, $CaCO_3$) into clinker, the cementitious product that makes up portland cement. This calcining process releases 0.498 to 0.540 tCO_2/t clinker. Emissions from energy inputs such as electricity for motors and fuel inputs such as coal, petroleum coke, natural gas, tires, plastics, and other waste products or biomass used to heat the rotary kilns to ~1,400 °C are *excluded*. The inventory methodology is based on limestone inputs and a careful calculation of calcining CO_2 emissions, including kiln dust, and either excluding or including emissions from energy inputs, depending on whether gross CO_2 are sought (such as by WBCSD Cement Sustainability Initiative and its members) or industrial CO_2 from limestone decarbonation (such as

124 EPA (2012) *Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010*, Tables 3-28 and 3-29.

125 Global Methane Initiative (2010) *Coal Mine Methane Country Profiles*, China.

126 73.6 $MtCO_2e$ (3.50 $MtCH_4$) of total emissions of 329 $MtCO_2e$ (15.67 Mt CH_4). This may be inaccurate, since some "CMM" projects may be from coal-bed methane projects, and comparing 2005 emissions to more recent annual CMM utilization. Global Methane Initiative (2010) *Coal Mine Methane Country Profiles*, Tables 3 and 4.

by CDIAC). This project estimates only process emissions from calcining and excludes emissions from fuel and electricity inputs (which are accounted for primary production already included in carbon major's fuel production).

METHODOLOGY.

The cement producers[127] included in Carbon Majors by and large do *not* report cement production data, which are needed to use the IPCC and national inventory approaches. A search of each company's annual reports and/or sustainability reports reveals reporting of cement production *capacity* rather than actual cement production. We devised another method to estimate each company's calcining emissions.

Figure B-24. Cementitious product emission factors.

0.5071	IPCC 1996
tCO2/t cementitious product	
0.4987	CDIAC emission factor
0.5400	WBCSD Sustainabile Cement Initiative - general cement EF
0.5196	WBCSD GNR suggests 60 percent process emissions of
	global average of 866 kg CO2 per tonne of clinker
0.5203	IPCC tier 1 approach, IPCC 2006
0.5196	truing up to CDIAC process emission factor

See appended PDF of "Process Emissions" in SumCement.pdf workbook for details.

The largest cement manufacturers participate in and report gross emissions to the WBCSD Cement Sustainability Initiative; they typically also report gross emissions in their annual sustainability reports.[128] The process emission estimates are based on each entity's reported gross emissions of CO_2 — that is, both emissions of CO_2 from calcining and emissions of CO_2 from energy inputs — and then estimate the fraction of the total from calcination of limestone. Inasmuch as the industry has made good progress in improving the efficiency of the industrial process (thus lowering the energy input per tonne of clinker) *and* increased the non-fossil fuel energy inputs, this change is accounted for by gradually increasing the proportion of calcination of total emissions from 1990 to 2010 (Figure 25).

The methodology is as follows:

- Multiply each cement entity's gross CO_2 emissions by the CSI default emission factor of 525 kgCO_2/tonne of clinker * 80 percent (the clinker content of cementitious product) — which thus equals a cementitious product emission factor of 420 kgCO_2/tonne;[129]
- The cementitious product emission factor of 420 kgCO_2/t is divided by the reported overall "net emission rate" of CSI members, which declined from 758 kgCO_2/t in

[127] Cemex, Heidelberg, Holcim, Italcementi, Lafarge, & Taiheiyo. China's cement production & emissions are also included.
[128] World Business Council for Sustainable Development Cement Sustainability Initiative (2009) *Cement Industry Energy and CO_2 Performance: 'Getting the Numbers Right'*, 44 pp., www.wbcsdcement.org.
[129] Based on WBCSD Cement Sustainability Initiative protocol (2011) default factor of 525 kg CO_2/tonne clinker times an industry average of approximately 80 percent clinker in cementitious product (due to substitute and additional materials such as gypsum, fly ash, etc), CMS estimates 420 kg CO_2 per tonne of cementitious product is attributable to the calcining process ($CaCO_3$ ---> CaO + CO_2) (525 * 0.8 = 420). Cement Sustainability Initiative (2011) *CO_2 and Energy Accounting and Reporting Standard for the Cement Industry*, 76 pp. www.wbcsdcement.org/pdf/tf1_co2%20protocol%20v3.pdf.

1990 to 625 kg CO_2/t in 2010; the resulting percentages increased from 55.7 percent in 1990 to 66.4 percent in 2010 (see table below, right column);[130]

- The percentage series is linked from table 3 in the "Cement Industry data" worksheet to row 18 of the "Process emissions" worksheet in SumCement;
- Each cement manufacturer's gross emissions by year ("Gross emissions" worksheet) is multiplied by the process emissions percentage for each year 1990 to 2010, the result of comprises estimated CO_2 emissions from processing limestone into cement in the "Process emissions" worksheet.

Figure B-25. Derivation of percentages for calcining emissions of gross emissions

Table 3	WBCSD GNR participants data					Estimated
Year	Thermal efficiency MJ/tonne clinker	Net emission rate kg CO2/tonne	Gross emission rate kg CO2/tonne	Production Mt cementitious	Net emissions Mt CO2	calcining emissions percent of net
		kg CO2e per tonne cementitious product				420 kg CO2/t
		(column "X")				(420/column "X")
						(net emission rate)
1990	4,260	754	759	529	400	55.7%
1991		749	754	interpolated		56.0%
1992		745	750	interpolated		56.4%
1993		740	745	interpolated		56.7%
1994		736	741	interpolated		57.1%
1995		731	736	interpolated		57.5%
1996		726	731	interpolated		57.8%
1997		722	727	interpolated		58.2%
1998		717	722	interpolated		58.6%
1999		713	718	interpolated		58.9%
2000	3,760	708	713	627	448	59.3%
2001		703	708	interpolated		59.7%
2002		699	704	interpolated		60.1%
2003		694	699	interpolated		60.5%
2004		690	695	interpolated		60.9%
2005	3,680	685	690	766	518	61.3%
2006	3,670	659	675	835	555	63.7%
2007	3,670	651	668	890	584	64.5%
2008	3,650	638	657	877	568	65.8%
2009	3,580	627	646	803	510	67.0%
2010	3,580	633	655			66.4%

Column marked "X" is divided into 420 kg CO_2/t to yield percentages in right-hand column.
See appended PDF of "Cement industry data" in SumCement.pdf workbook for details.

The cumulative result is that 13.2 $GtCO_2$ is attributed to the six cement manufacturers plus China. Of this total, 4.0 $GtCO_2$ is attributed to the six investor-owned cement companies from 1990 to 2010.

CHINA'S CEMENT EMISSIONS.

China's emissions are calculated differently, inasmuch cement production data are available (unlike for the entities discussed above) from U.S. Bureau of Mines production data for China 1928-2010. CDIAC uses this approach, and simply multiplies cement production by 0.500.[131]

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[130] The CSI "net emission rate" excludes emissions from non-fossil fuel energy inputs.

[131] To quote from Boden et al (1995): "This conversion factor was obtained by dividing the molar mass of carbon by the molar mass of calcium oxide and multiplying this quotient by the average fraction of calcium oxide contained in cement: (12.01 g C/mole $CaCO_3$ ÷ 56.08 g CaO /mole $CaCO_3$) * 0.635 g CaO /g cement = 0.136 g C /g cement. The consensus that 63.5% of the typical cement in the world is composed of calcium oxide is based on the opinions of experts consulted in the field, as well as inspection of composition data by type and country (Griffin 1987)." The formula: (12.01/56.08) * 0.635 * 3.667 = 0.4987, rounded up to 0.500. Boden, T. A., G. Marland, & R. J. Andres (1995) *Estimates of Global, Regional, &*

China's cement emissions totals 9.2 $GtCO_2$, though from a longer time series (1928-2010) than the six investor-owned cement companies.[132]

Caveats:

- Cement producers typically do not publish cement production statistics;
- The most comprehensive data is that submitted to the WBCSD CSI database (often also published in entity sustainability reports), but which typically only state gross and net CO_2 emissions for 1990 and 2000-2010;[133] 1991-1999 are interpolated, which introduces varying errors for each manufacturer, though not likely large;
- A uniform percentage factor is applied to each entity's gross CO_2 emissions in order to estimate calcining emissions: each company's fraction will likely differ;
- Technical progress in lowering the fossil carbon energy inputs to cement making is accounted for, which each cement producer has amply demonstrated in their performance data, though at somewhat differing rates, whereas the methodology adopted in this analysis conflates this improvement to one factor applied to all entities equally, albeit improving gradually over time.

Figure B-26. Process emission estimates for cement entities

2000s												Sum to 2010	
2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010		Million tonnes CO2	Cement process emissions
59.3%	59.7%	60.1%	60.5%	60.9%	61.3%	63.7%	64.5%	65.8%	67.0%	66.4%			Process emissions as percent of Gross CO2
24	24	24	27	30	31	34	35	32	27	27	y	551	Cemex
298	330	362	430	484	533	617	679	692	806	890	y	9,150	China, PRC
25	24	22	24	26	26	29	34	35	30	31	y	587	HeidelbergCement
46	48	51	53	55	58	61	64	64	60	62	y	1,008	Holcim
20	20	20	20	21	25	28	29	28	24	24	y	463	Italcementi
47	48	49	48	51	53	59	62	68	62	61	y	1,044	Lafarge
11	11	11	10	10	10	11	10	10	9	10	y	402	Taiheiyo
470	504	537	613	678	735	838	914	930	1,017	1,106	y	13,205	Emissions from identified cement prod'n (MtCO2)
128	138	147	167	185	201	229	249	254	278	302	y	3,604	Carbon in identified cement prod'n (MtC)
828	868	923	1,011	1,092	1,173	1,301	1,400	1,414	1,509	1,638	y	32,519	CDIAC cement emissions (Million tonnes of CO2) 1929-2010
226	237	252	276	298	320	355	382	386	412	447	y	8,875	CDIAC cement emissions (Million tonnes of carbon)
56.8%	58.0%	58.2%	60.6%	62.1%	62.7%	64.4%	65.3%	65.7%	67.4%	67.5%	y	40.6%	Percent of cumulative CDIAC cement emissions
Total emissions from identified cement production through 2010 (million tonnes CO2)												13,205	

See Annex D for PDF of "Process emissions" in SumCement.pdf workbook for details.

National Annual CO_2 Emissions from Fossil-Fuel Burning, Hydraulic Cement Production, and Gas Flaring: 1950-1992, cdiac.ornl.gov/epubs/ndp/ndp030/ndp0301.htm#co2man

132 Based on U.S. Bureau of Minerals (1933-) *Minerals Yearbook*. Data is corroborated by CDIAC data for China 1928-2008.

133 The WBCSD terminology is unclear. Their "gross emissions" account for total direct CO_2 emissions and differs from "net emissions" in terms of alternative fossil fuels, biomass inputs, emissions reduction credits, and alternative raw material inputs — and includes calcining emissions. See Cement Sustainability Initiative (2011) page 25 for definitions. This study uses the term "process emissions" to include only the CO_2 emitted from the calcination of limestone in cement production, inasmuch as we need to exclude emissions from electricity and fuel inputs, which are accounted for by primary carbon producers. The WBCSD provides little data on calcining emissions.

Table B-10. Summary of combustion, flaring, venting, & fugitive emissions

Crude oil & NGLs		
Cumulative production:	984.7 billion bbl	(108.5 GtC)
Non-energy uses	8.02 %	(79 Gbbl, 8.7 GtC stored)
Emission factor:	0.3714 tCO_2/bbl	(0.0507 tCO_2/t)
Fuel combustion:	365.73 $GtCO_2$	94.32 %
Flared CO_2:	5.83 $GtCO_2$	1.50 %
Vented CO_2:	1.40 $GtCO_2$	0.36 %
Methane:	14.77 $GtCO_2e$	3.81 %
Total:	387.74 $GtCO_2e$	100.00 %
Natural gas		
Cumulative production:	2,247.9 Tcf	(64,653 Bcm, 33.4 GtC)
Non-energy uses	1.86 %	(0.62 GtC stored)
Emission factor:	0.0534 $MtCO_2$/Bcf	(1.887 $MtCO_2$/Bcm)
Fuel combustion:	120.11 $GtCO_2$	77.10 %
Flared CO_2:	0.21 $GtCO_2$	0.13 %
Vented CO_2:	3.43 $GtCO_2$	2.20 %
Methane:	24.92 $GtCO_2e$	15.99 %
Own fuel use	7.12 $GtCO_2$	4.57 %
Total:	155.78 $GtCO_2e$	100.00 %
Coal		
Cumulative production:	162.74 billion tonnes (Gt)	
Non-energy uses	0.016 %	(0.01 GtC stored)
Emission factor: Lignite	1.203 tCO_2/tonne	0.3284 tC/t
Subbituminous	1.814 tCO_2/tonne	0.4952 tC/t
Bituminous	2.439 tCO_2/tonne	0.6656 tC/t
Anthracite	2.622 tCO_2/tonne	0.7156 tC/t
"Metallurgical"	2.665 tCO_2/tonne	0.7276 tC/t
"Thermal"	2.129 tCO_2/tonne	0.5811 tC/t
Fuel combustion:	329.60 $GtCO_2$	92.19 %
Flared CO_2: [134]	na	
Vented CO_2:	na	
Methane:	27.93 $GtCO_2e$	7.81 %
Total:	357.53 $GtCO_2e$	100.00 %
Cement		
Cumulative production:	~24.4 billion tonnes (Gt)	
Emission factor:	~0.54 tCO_2/tonne cement	
$CaCO_3$ calcining:	13.21 $GtCO_2$	100.00 %
Total:	13.21 $GtCO_2e$	100.00 %
All Carbon Majors		
Oil & NGLs	365.73 $GtCO_2$	40.00 %
Natural gas	120.11 $GtCO_2$	13.14 %
Coal	329.60 $GtCO_2$	36.05 %
Total combustion	815.45 $GtCO_2$	89.19 %
Cement	13.21 $GtCO_2$	1.44 %
Vented CO_2	4.83 $GtCO_2$	0.53 %
Flaring	6.04 $GtCO_2$	0.66 %
Own fuel use	7.12 $GtCO_2$	0.78 %
Methane	67.62 $GtCO_2e$	7.40 %
Total Carbon Majors	914.25 $GtCO_2e$	100.00 %

[134] Ventilation (CH_4 and CO_2 and contaminant) gases from underground coalmines are typically *not* flared.

Summary of flaring, venting, and fugitive emission factors

Emission from flaring, fugitive, and vented carbon dioxide and from fugitive and vented methane from oil and gas operations and coal mining are shown in table 9. Since the basis is $kgCO_2e$ per tonne CO_2 released from combustion of petroleum, natural gas, and coal, the total column shows additional emissions per tCO_2, easily converted to percent. That is, additional emissions from venting and flaring and methane are 6.02 percent for petroleum, 23.77 percent for natural gas, and 8.47 percent for coal.

Table B-11. Emission factors for vented, flared, and fugitive carbon dioxide and methane

Entity	Combustion $kgCO_2/tCO_2$	Flaring $kgCO_2/tCO_2$	Vented $kgCO_2/tCO_2$	Methane $kgCH_4/tCO_2$	Methane $kgCO_2e/tCO_2$	Total $kgCO_2e/tCO_2$
Crude oil & NGLs	1,000	15.94	3.83	1.92	40.39	1,060.2
Natural gas	1,000	1.74	28.53	9.88	207.44	1,237.7
Coal	1,000	ne	ne	4.03	84.73	1,084.7

ne: not estimated; see text for discussion. Excludes own fuel use of 59.24 kg CO_2/tCO_2 (natural gas only).

Table 1 is repeated below for easy comparison with Table B-11 above:

Table B-12. Final combustion emissions factors

Energy source	Carbon kg C/unit	Carbon dioxide kg CO_2/unit
Crude oil & NGLs	101.4 kgC/bbl	371.4 $kgCO_2$/bbl
Natural gas	14.6 kgC/kcf	53.4 $kgCO_2$/kcf
Lignite	328.4 kgC/tonne	1,203.5 $kgCO_2$/t
Subbituminous	495.2 kgC/t	1,814.4 $kgCO_2$/t
Bituminous	665.6 kgC/t	2,439.0 $kgCO_2$/t
Anthracite	715.6 kgC/t	2,621.9 $kgCO_2$/t
"Metallurgical coal"	727.6 kgC/t	2,665.9 $kgCO_2$/t
"Thermal coal"	581.1 kgC/t	2,129.3 $kgCO_2$/t

Crude oil: prior to non-energy deduction & adjustment for NGLs: 115.7 kgC/bbl, 423.8 $kgCO_2$/bbl;
Gas: prior to non-energy deduction: 14.86 kgC/kcf ,or 54.44 $kgCO_2$/kcf; (kcf = thousand cubic feet).

Figure B-27. IPCC 2006 *Guidelines*, overview of emission source categories

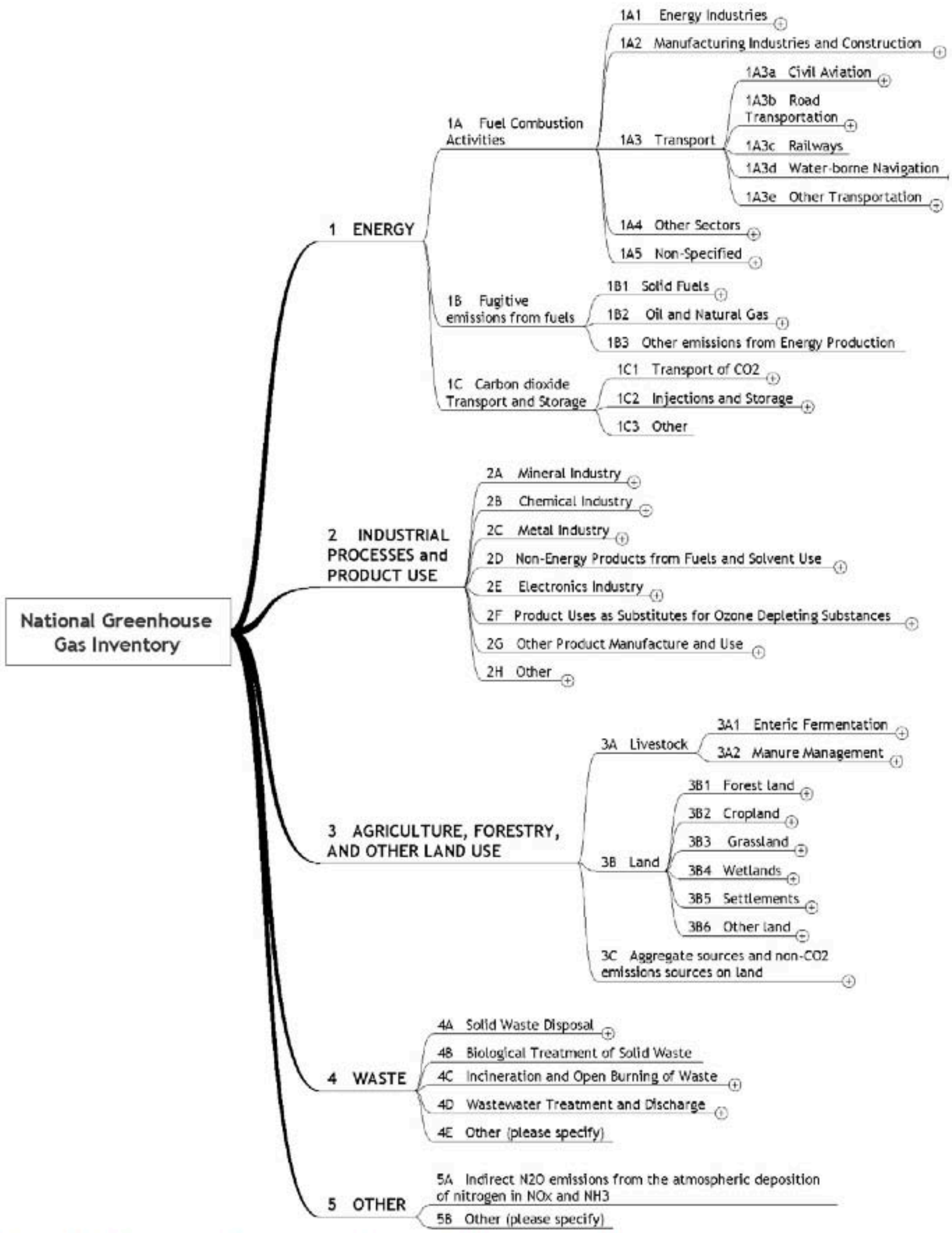

Figure 1 Main Categories of Emissions by Sources and Removals by Sinks

Intergovernmental Panel on Climate Change (2006) *Draft 2006 IPCC Guidelines for National Greenhouse Gas Inventories*: Overview Chapter, 12 pp.; www.ipcc.ch/meetings/session25/doc4a4b/doc4a.pdf.

Figure B-28. IPCC 2006 *Guidelines*, overview decision tree and tiers

The *IPCC 2006 Guidelines* generally provide advice on estimation methods at three levels of detail, from tier 1 (the default method) to tier 3 (the most detailed method). The advice consists of mathematical specification of the methods, information on emission factors or other parameters to use in generating the estimates, and sources of activity data to estimate the overall level of net emissions (emission by sources minus removals by sinks). Properly implemented, all tiers are intended to provide unbiased estimates, and accuracy and precision should, in general, improve from tier 1 to tier 3. The provision of different tiers enables inventory compilers to use methods consistent with their resources and to focus their efforts on those categories of emissions and removals that contribute most significantly to national emission totals and trends.

The *IPCC 2006 Guidelines* apply the tiered approach by means of *decision trees (*see the example in Figure 2). A decision tree guides selection of the tier to use for estimating the category under consideration, given national circumstances. National circumstances include the availability of required data, and contribution made by the category to total national emissions and to the trend in emissions over time. The most important categories, in terms of total national emissions, and the trend are called *key categories*[13]. Decision trees generally require tier 2 or tier 3 methods for *key categories*. The *IPCC 2006 Guidelines* provide for exceptions to this, where evidence demonstrates that the expense of data collection would significantly jeopardize the resources available for estimating other *key categories*.

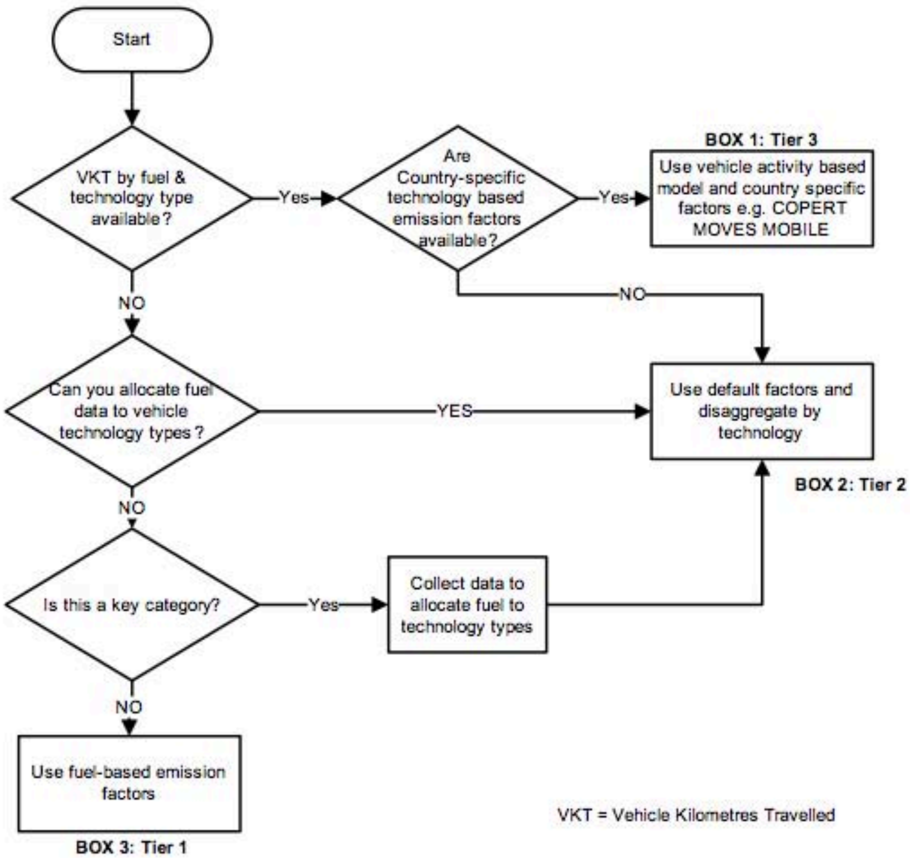

Figure 2 Example Decision Tree (for CH_4 and N_2O from Road Transport)

Annex C

List of entity worksheets

OIL & NGL & NATURAL GAS PRODUCERS	ANNO	# OF PAGES
Abu Dhabi NOC, UAE	1962-2010	6
Anadarko, USA	1945-2010	4
Apache, USA	1985-2010	2
Bahrain Petroleum	1975-2010	4
BG Group, UK	1963-2010	2
BHP Billiton, Australia	1970-2010	4
BP, UK	1913-2010	10
Canadian Natural Resources	1988-2010	2
ChevronTexaco, USA	1912-2010	10
China National Offshore Oil Co.	1988-2010	2
ConocoPhillips, USA	1924-2010	10
Devon Energy, USA	1988-2010	4
Ecopetrol, Colombia	1987-2010	4
Egyptian General Petroleum	1959-2010	4
EnCana, Canada	1987-2010	2
ENI, Italy, 1950-2010	1950-2010	4
ExxonMobil, USA	1882-2010	14
Former Soviet Union (oil, gas, coal)	1949-1991	4
Gazprom, Russian Federation	1989-2010	6
Hess, USA	1958-2010	4
Husky Energy, Canada	1988-2010	2
Iraq National Oil Company	1960-2010	4
Kerr-McGee (see Anadarko)	1945-2005	2
Kuwait Petroleum Corp.	1946-2010	6
Libya National Oil Corp.	1961-2010	4
Lukoil, Russian Federation	1996-2010	4
Marathon, USA	1938-2010	4
Murphy Oil, USA	1983-2010	4
National Iranian Oil Company	1928-2010	4
Nexen, Canada	1959-2010	4
Nigerian National Petroleum	1987-2010	6
NorskHydro (see Statoil)	1987-2006	2
Occidental, USA	1958-2010	4
Oil & Natural Gas Corporation, India	1959-2010	6
OMV Group, Austria	1997-2010	2
Pemex, Mexico	1938-2010	4
Pertamina, Indonesia	1959-2010	6
Petrobras, Brazil	1954-2010	4
PetroChina, China	1988-2010	8
Petroleos de Venezuela	1960-2010	6
Petroleum Development Oman	1967-2010	6
Petronas Malaysia	1959-2010	6
Polish Oil & Gas, Poland	1998-2010	2
Qatar Petroleum	1959-2010	4
Repsol, Spain	1964-2010	4
Rosneft, Russian Federation	1998-2010	4
Royal Dutch/Shell Group, Netherlands	1892-2010	10
Saudi Aramco, Saudi Arabia	1938-2010	8
Sibneft, Russian Fed. (see Gazprom)	1998-2004	0
Sinopec, China	1999-2010	4
Sonangol, Angola	1959-2010	4

Sonatrach, Algeria	1964-2010	4
Statoil, Norway	1984-2010	6
Suncor, Canada	1987-2010	4
Syrian Petroleum	1968-2010	4
Talisman, Canada	1992-2010	2
Total, France	1934-2010	4
Unocal, USA (see Chevron)	1926-2004	4
XTO, USA (see ExxonMobil)	1994-2009	2
Yukos, Russian Fed. (see Rosneft)	1990-2005	2

Coal Producers	**Anno**	**# of pages**
Alpha Natural Resources, USA	1999-2010	2
Anglo American, UK	1909-2010	6
Arch Coal, USA	1973-2010	2
BHP Billiton, Australia	1955-2010	4
BP, UK (see BP oil & gas)	1960-2003	0
British Coal Corporation, UK	1947-1994	2
China (coal and cement)	1945-2010	6
China Coal Energy (included in China)	2005-2010	2
Coal India	1973-2010	6
Consol Energy, Inc., USA	1864-2010	4
Cyprus Minerals, USA	1969-1998	2
Czech Republic (coal)	1993-2010	4
Czechoslovakia (coal; see Czech Republic)	1938-1992	0
ExxonMobil, USA	1970-2002	2
Former Soviet Union (oil, gas, coal)	1900-1991	4
Kazakhstan (coal)	1992-2010	4
Kiewit Mining, USA	1944-2010	2
Luminant, USA	1977-2010	2
Massey Energy, USA	1981-2010	4
Murray Energy, USA	1988-2010	2
North American Coal, USA	1950-2010	2
North Korea (coal)	1980-2010	4
Occidental, USA (Island Creek Coal)	1945-1992	2
Peabody Energy, USA	1945-2010	4
Pittsburgh & Midway (to Chevron), USA	1965-2010	2
Poland (coal)	1913-2010	4
RAG, Germany	1989-2003	4
Rio Tinto, UK	1961-2010	4
Royal Dutch Shell (see Anglo American)	1979-1999	2
Russian Federation (coal)	1992-2010	4
RWE, Germany	1965-2010	2
Sasol, South Africa	1953-2010	2
Singareni Collieries, India	1947-2010	4
UK Coal, UK	1995-2010	2
Ukraine (coal)	1992-2010	4
Westmoreland Mining, USA	1854-2010	4
Xstrata, Switzerland	1998-2010	2

Cement Producers	**Anno**	**# of pages**
Cemex, Mexico	1990-2010	4
China (cement)	1928-2010	4
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Holcim, Switzerland	1990-2010	4
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World cement 2009, US 1900-2009	1900-2009	2

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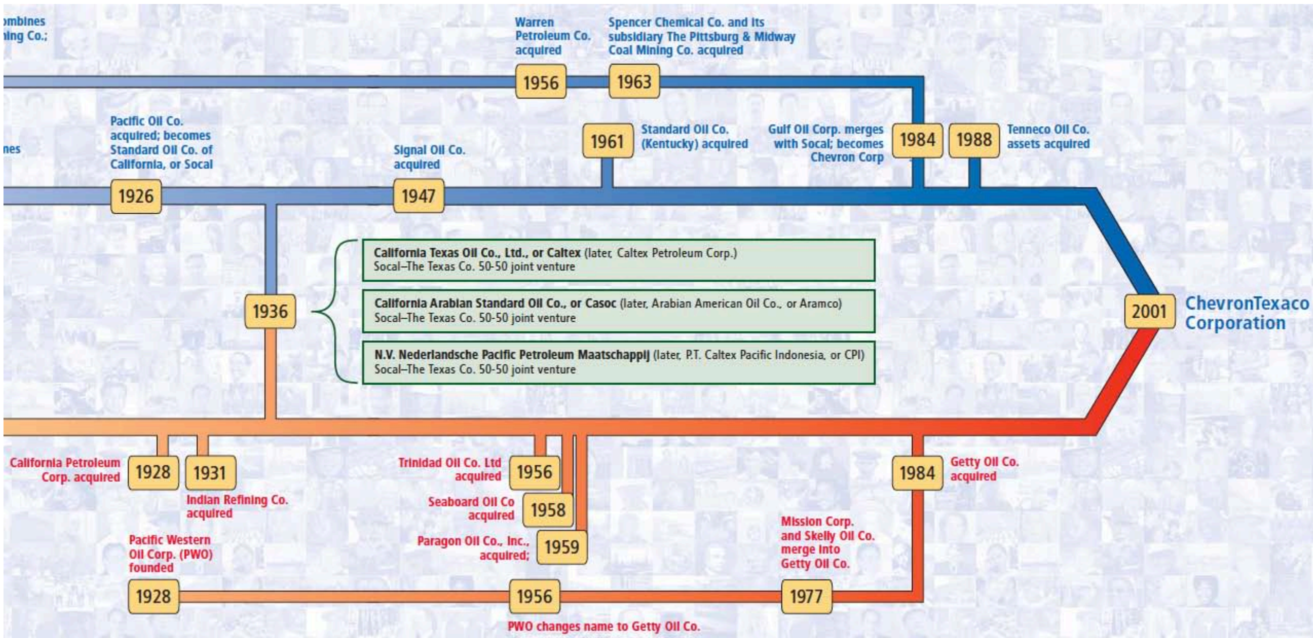
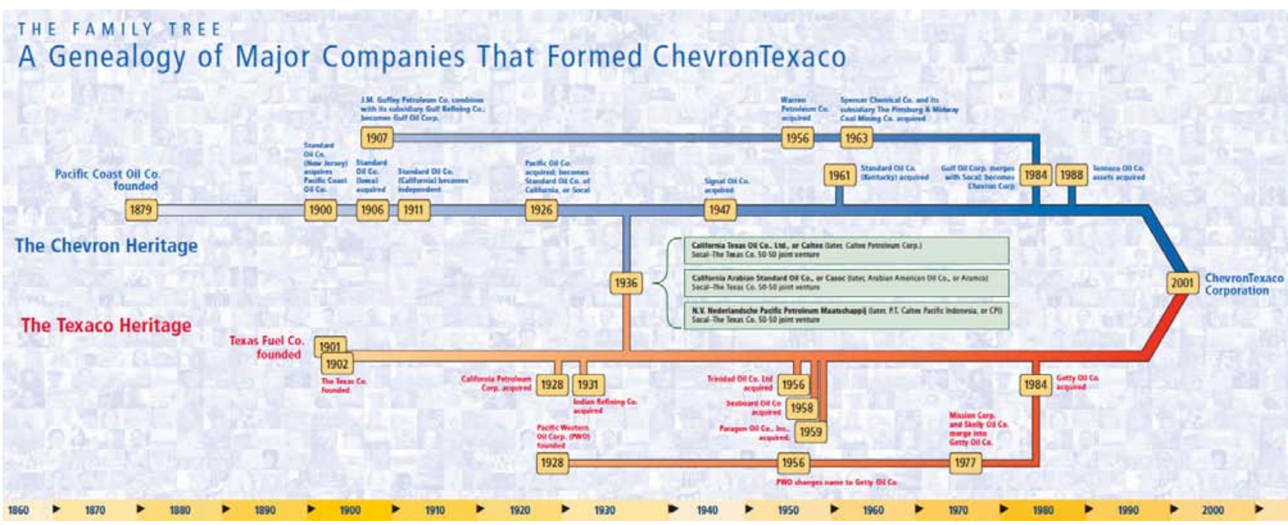
TOTAL ENTITY & SUMMARY WORKSHEETS	**674**

Annex E

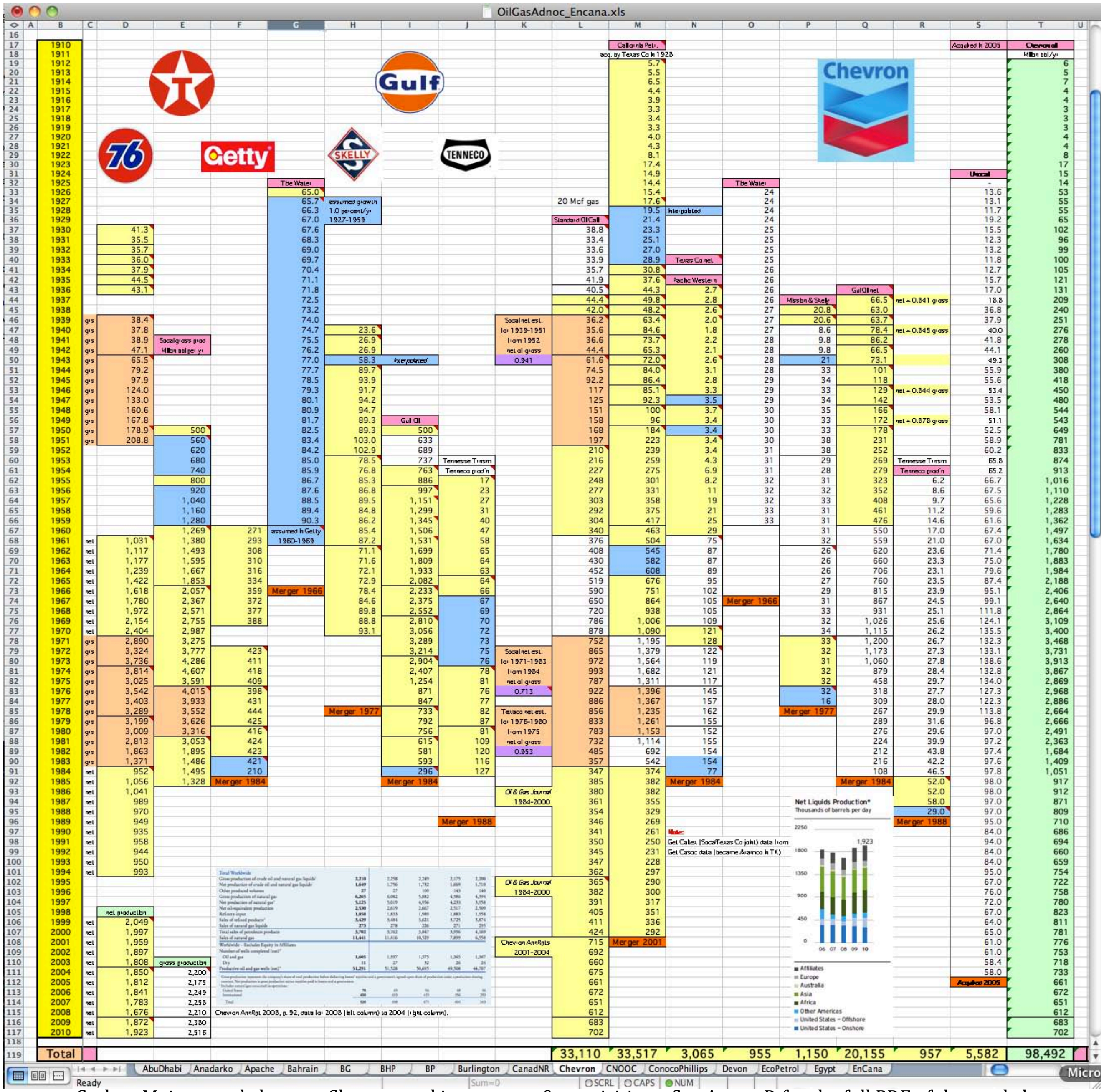
Other materials

CHEVRONTEXACO FAMILY TREE (SEE TEXT, FIGURE 5 AND FIGURE B-1).





CHEVRONTEXACO FAMILY TREE (SEE TEXT, FIGURE 6 AND FIGURE B-2).



Carbon Majors worksheet on Chevron and its mergers & acquisitions. See Annex D for the full PDF of the worksheet.