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U.S. Greenhouse Gas Emission Bottlenecks: Prioritization of Targets for Climate Liability

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Abstract: Due to market failures that allow uncompensated negative externalities from burning fossil fuels, there has been a growing call for climate change-related litigation targeting polluting companies. To determine the most intensive carbon dioxide (CO_2)-emitting facilities in order prioritize liability for climate lawsuits, and risk mitigation strategies for identified companies as well as their insurers and investors, two methods are compared: (1) the conventional point-source method and (2) the proposed bottleneck method, which considers all emissions that a facility enables rather than only what it emits. Results indicate that the top ten CO_2 emission bottlenecks in the U.S. are predominantly oil (47%) and natural gas (44%) pipelines. Compared to traditional point-source emissions methods, this study has demonstrated that a comprehensive bottleneck calculation is more effective. By employing an all-inclusive approach to calculating a polluting entity's CO_2 emissions, legal actions may be more accurately focused on major polluters, and these companies may preemptively mitigate their pollution to curb vulnerability to litigation and risk. The bottleneck methodology reveals the discrete link in the chain of the fossil-fuel lifecycle that is responsible for the largest amount of emissions, enabling informed climate change mitigation and risk management efforts.

Keywords: energy policy; greenhouse gas liability; climate change liability; risk analysis; risk management; climate governance; climate change; corporate environmental responsibility; climate lawsuits; carbon dioxide emissions

1. Introduction

Global greenhouse gas (GHG) emissions and global atmospheric carbon dioxide (CO_2) concentration continue to increase because of fossil fuel combustion despite repeated warnings about the resultant "dangerous" climate change from climate scientists [1,2]. Anthropogenic global climate destabilization is scientifically established with a 95% confidence [3] as are the detrimental repercussions on our environment, social, and economic systems [4,5]. The impacts of anthropogenic climate change include, but are not limited to: (i) increased temperatures and the resultant heat waves, which cause thousands of human deaths [6–8], (ii) increased rate of crop failures [9,10], which worsens the existing socially-constructed global hunger and starvation [11–13], (iii) electric grid failures and power outages [14,15], (iv) droughts [16–18], (v) increased fire severity and frequency [19–21], and (vi) sea level rise and the resultant submersion of low-lying coastal and shoreline erosion [22,23], saltwater intrusion [23,24], storm damage to coast lines and exacerbated flood risks [25–28].

The negative externalities of burning fossil fuels represent a market failure that has seen a growing call to be rectified using litigation in part because of the political interference from the companies that profit from polluting [29–41]. Emissions liability is a business risk [31,32,36,39,40]. Most work in this area focuses on quantifying the harm done by polluters in order to compensate the people, businesses [35], or governments [34,38,41] that have been or will be harmed in the future [29,30,33,37]. Authors argue that the victims that are losing the most due to climate change should be put in top priority for compensation [34]. Similarly, targets for litigation are chosen based on who did the wrong or benefited from it. For example, Farber [37] has shown that both Americans' ancestors and those currently living in U.S. are responsible for past GHG emissions resulting in climate change due to the current profit they enjoy from having developed with uncontrolled emissions. However, what is less clear is how climate related litigation should be strategically advanced if the goal of the litigation is to prevent future harm by shutting down current GHG emitters rather than simply compensating existing victims.

How should environmental organizations and others trying to protect people and the planet decide who are the most critical polluters to target for climate-related lawsuits? For example, an enormous amount of attention and effort has been focused on stopping the Keystone XL Pipeline [42–45], but would the magnitude of the emissions associated with this pipeline warrant the effort- or should lawsuits be focused elsewhere? In order to answer these questions quantitatively, this article presents an open and transparent methodology for prioritizing climate lawsuits based on an individual facility's ability to act as a bottleneck for GHG emissions.

2. Materials and Methods

In order to make this method reproducible while still being reliable, only publically-available data was used. This included data from two U.S. Government Databases: (i) Environmental Protection Agency (EPA) Facility Level Information on GHG Tool (FLIGHT) [46], and (ii) Energy Information Administration (EIA) Coal Data Browser [47] and Liquids Pipeline Projects Database [48], and supplemental data regarding oil pipelines from Enbridge's Energy Infrastructure Assets Report [49]. To determine the most intensive carbon-emitting facilities in order to prioritize liability for climate lawsuits two methods were used and compared: (1) the conventional point source method and (2) the proposed bottleneck method:

2.1. *Methodology for Computing Point-Source CO_2 Emissions*

(1) GHG emitters were catalogued as one of eight sub-classes divided both by fossil fuel source (coal, oil—petroleum and natural gas) and lifecycle entity (extraction, transport, end use/product sale) as shown in Table 1.

(2) The FLIGHT database [46] was filtered to isolate fuel type and to identify entities producing the highest level of CO_2 emissions, delimiting the data to the ten largest facilities per sub-class. Of the eight sub-classes, point-source data for six sub-classes were explicitly available through the FLIGHT tool. Coal extraction and oil transport point-source emissions data are not provided. The values for these processes are dwarfed by the emissions from burning the fossil fuels and are thus considered negligible and not included here.

(3) Checked top emitting facilities on their public website, identified headquarter location, and confirmed magnitude of enterprise.

2.2. *Methodology for Computing CO_2 Emission Bottlenecks*

(1) GHG emitters were catalogued as one of eight sub-classes divided both by fossil fuel source (coal, oil-petroleum and natural gas) and lifecycle entity (extraction, transport, end use/product sale) as shown in Table 1.

(2) The FLIGHT database [46] was filtered to isolate fuel type and to identify entities producing the highest level of CO_2 emissions, delimiting the data to the 10 largest facilities per sub-class. In order to explicitly report resource throughput for each facility for calculation of bottleneck potential:

    (a) Coal extraction data were derived from the EIA Coal Data Browser [47].

(b) Oil and natural gas wells annual production values were derived from the GHG Summary Report provided for each top-emitting facility through the FLIGHT tool [46].

(c) Oil pipeline and refinery capacity data were derived from the Liquids Pipeline Projects Database provided by EIA [49], Enbridge's Energy Infrastructure Assets Report [49], and each facility's corporate website.

(d) Natural gas pipeline capacity and power plant data were derived from the GHG Summary Report provided for each top-emitting facility through the FLIGHT tool [46].

(3) The EPA GHG Equivalencies Calculator was used to calculate bottleneck emissions per facility, deriving potential annual CO_2 emissions based on conversion from resource capacity. Considering that the resource capacity of power plant facilities (coal and natural gas) inherently reflect its emitting capacity, bottleneck emissions are assumed to be equivalent to point-source emissions for these two end-uses.

(a) Point-source CO_2 emission data per facility is provided directly by the FLIGHT tool [46].

(4) Top emitting facilities were confirmed using information on their public website, identified headquarter location, and confirmed magnitude of enterprise.

Figures 1–3 explain the steps that were used to convert each facility's resource capacity to potential emissions to determine the magnitude of the bottleneck for coal, oil and natural gas, respectively [50–53]. The full explanation and equations can be found in Appendix A.1: Methods [50–53].

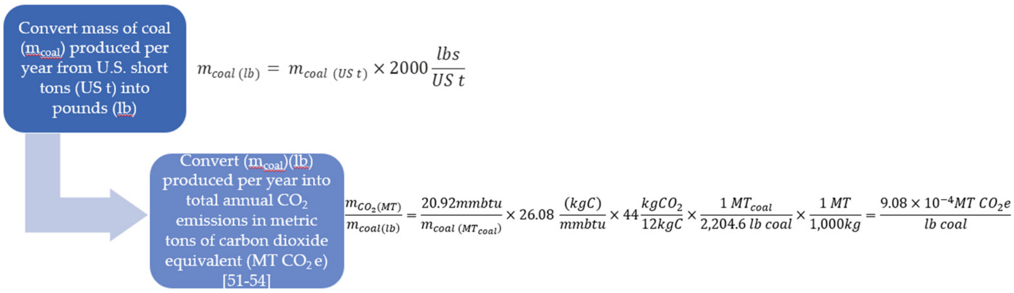

Figure 1. Stepwise process used to calculate potential annual CO_2 emissions (MT CO_2 e) of a coal facility.

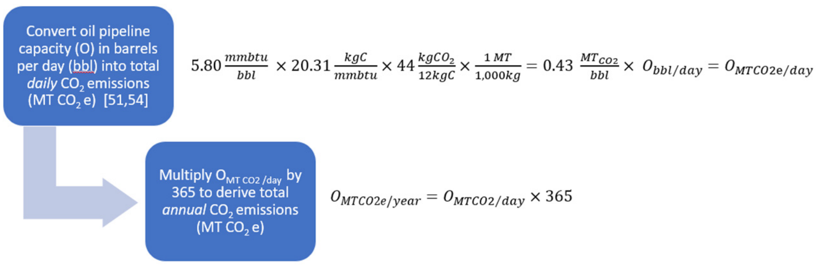

Figure 2. Stepwise process used to calculate potential annual CO_2 emissions (MT CO_2 e) of an oil facility.

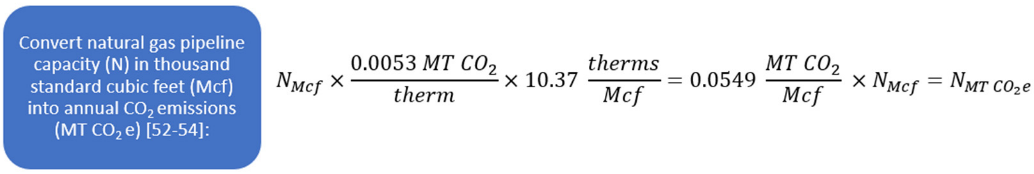

Figure 3. Equation used to calculate potential annual CO_2 emissions (MT CO_2 e) of a natural gas facility.

It should be pointed out that the EPA GHG Equivalencies Calculator warns that due to rounding, calculations performed using the above equations may not return exact results.

Table 1. The eight classes of GHG emitting entities evaluated.

Type of Entity	Fossil Fuel		
	Coal	Oil	Natural Gas
Resource Extraction	Underground and Strip Mines	Wells	Wells/Pumping Stations
Transport	N/A *	Shipping/Pipelines	Shipping/Pipelines
End Use/Product Sale	Power Plants	Processing/Refineries	Power Plants

* For coal industry calculations, transportation between extraction and end-use is not included due to lack of public access to data.

3. Results

3.1. Point-Source Carbon Emissions

Discrete point-source emissions data for six of the eight sub-classes were provided by EPA's FLIGHT tool [46]. Coal extraction and oil pipeline point-source emissions data were not provided and were thus ignored as is common in conventional studies of fossil fuel emissions.

Assessing an entity's pollution liability based solely on point-source emissions is inadequate as it does not take into account the ability of that entity to enable further emissions beyond those which originate on-site. Attempting to strategically reduce CO_2 emissions, this study argues that a comprehensive calculation of an entity's entire bottleneck capacity, or resource throughput, is obligatory to reflect its true magnitude. To demonstrate the distinguishing importance between point-source and bottleneck calculations, all point-source data are provided in Figures 4–9 (The numerical values are shown in Tables for all chart-based Figures in Appendix A.2) for comparison against the bottleneck emissions.

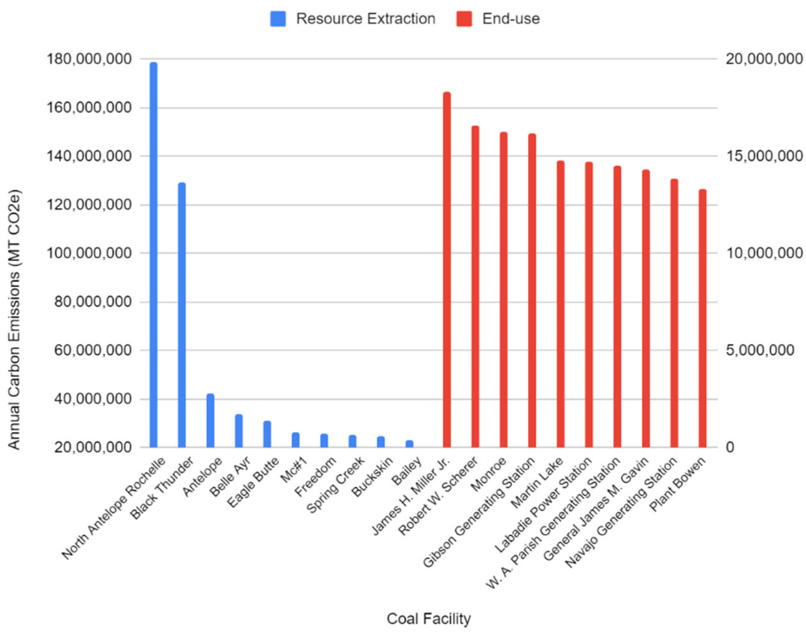

Figure 4. Top CO_2 Emission Point-Sources of the Coal Industry for Resource Extraction and End-use.

The highest emitting coal extraction facility (North Antelope Rochelle Mine) directly and indirectly produces approximately 9.8 times more MT CO_2e per year than the leading coal-fired power plant (James H. Miller Jr.). When comparing between resource extraction and end-use sectors, 78% of the total coal industry emissions can be attributed to bottlenecks in coal mining. The bottleneck calculations for coal extraction facilities are based on the assumption that all of the coal mined from a facility will eventually be combusted for end-use. Thus, the annual pounds of coal produced per year by each coal extraction facility was directly converted into MT CO_2e per year to reflect the fact that the extraction of coal is the fundamental activity that eventually leads to coal combustion and CO_2 emissions. The end-use calculations (for both coal and natural gas) are directly provided by the EPA database [46] and solely reflect the point-source pollution emitted at the power plant location, which is considered equivalent to a facility's bottleneck capacity. In comparison, the former calculation is inclusive of all downstream emissions, whereas the latter is a discrete determination of annual MT CO_2e emitted by a single activity.

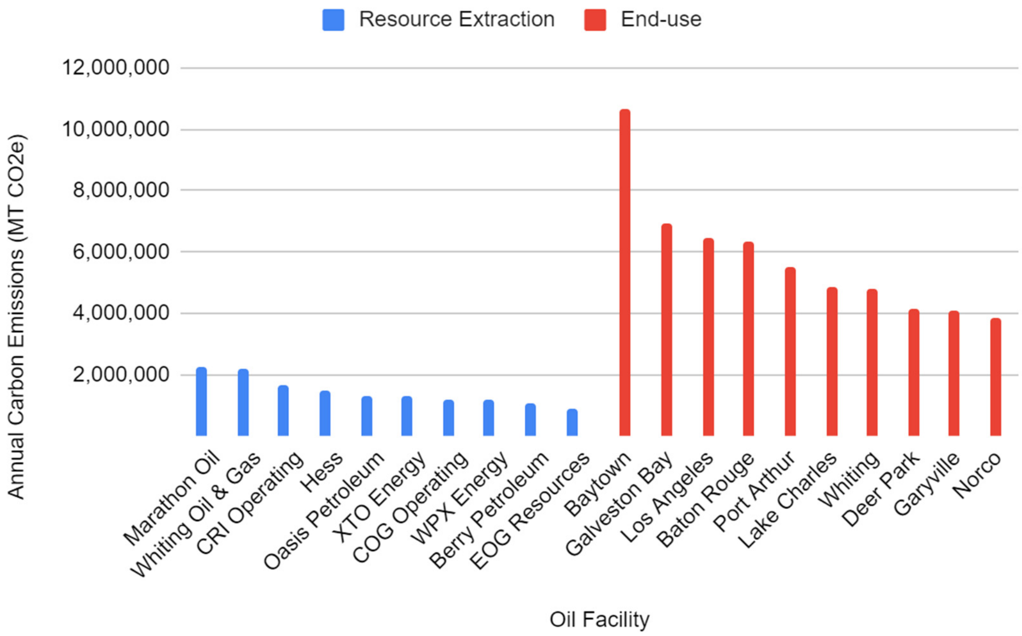

Figure 5. Top CO_2 Emission Point-Sources of the Oil Industry for Resource Extraction and End-use.

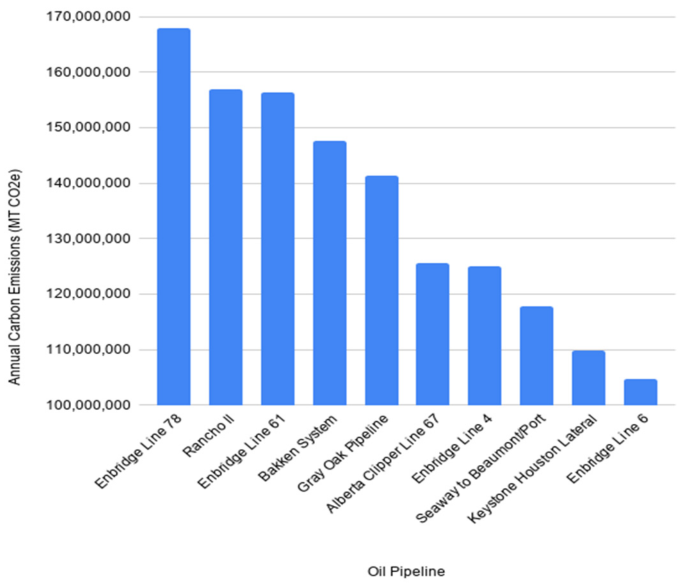

Figure 6. Top CO_2 Emission Point-Sources of the Oil Industry for Transport.

For coal industry calculations, transportation between extraction and end-use is not included. This activity was deliberately omitted to eschew the lack of distinct and transparent data sources. Coal shipping information is provided by the EIA Coal Data Browser [47] and Liquids Pipeline Projects Database [48] yet it is presented in such a way that does not lend itself to definitive calculation of transportation dynamics and CO_2 emissions. The origin of coal is made anonymous, and the final destinations of the product exceed more than ten facilities per origin, which effectively complicates the ability to follow the resource from its extraction to its end-use with clarity and confidence. Consequently, the complexity of the coal transportation system, characterized by numerous railway routes and ambiguous data, has precluded its incorporation into this study although the many routes redundant transportation routes and modes indicate it is unlikely to represent a bottleneck.

Comparing point-source emissions with bottleneck calculations for oil, it is evident that consideration of an entity's capacity to act as an emissions bottleneck considerably changes the legal landscape. For example, oil extraction annually produces 14,505,900 MT CO_2e point-source emissions, whereas annual *bottleneck* emissions total 198,162,321 MT CO_2e–clearly demonstrating that point-source calculations only represent a trivial amount (7% in the case of oil extraction) of the true capacity of an entity to directly and indirectly generate GHG emissions.

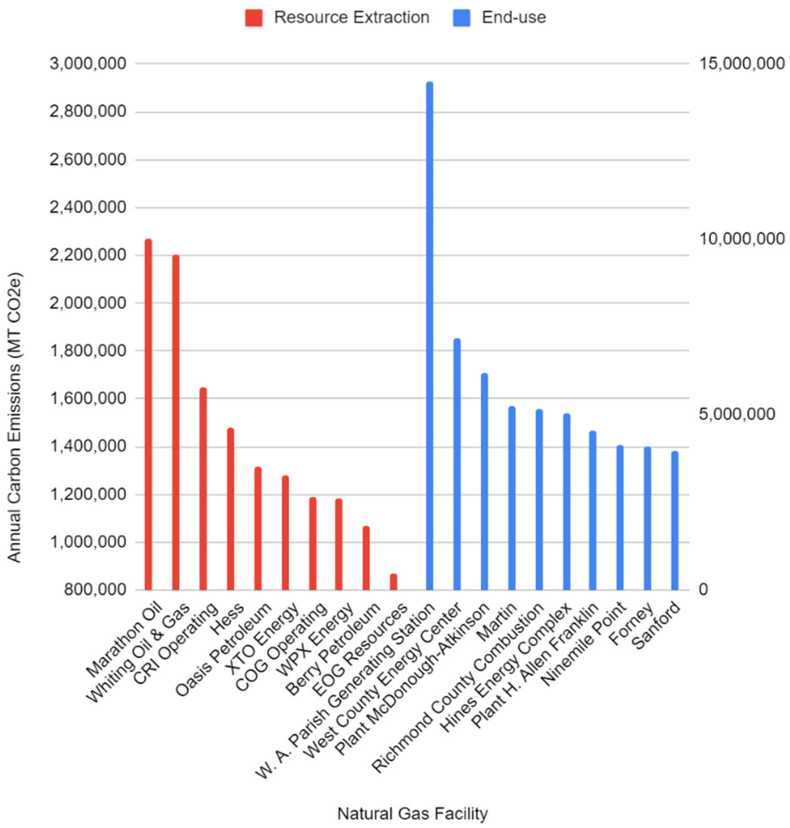

Figure 7. Top CO_2 Emission Point-Sources of the Natural Gas Industry for Resource Extraction and End-use.

Traditionally, point-source emissions calculations are used for the purpose of establishing legal liability. To further demonstrate the inadequacy of point-source emissions calculations to establish true pollution liability, a comparison between natural gas transportation values is warranted. Annually, natural gas onshore transmission results in 1,986,594 MT CO_2e as point-source emissions, and 1,287,506,052 MT CO_2e as bottleneck emissions: demonstrating that this bottleneck calculation accounts for 35 times more emissions than does the simple point-source method. This major discrepancy in emissions diverts attention away from natural gas pipelines as responsible polluting entities, foregoing the opportunity to hold these actors accountable for their true contribution to atmospheric GHG concentration if bottleneck potential is overlooked.

Overall, burning natural gas results in the fewest CO_2 emissions when compared to burning petroleum or coal products to generate an equivalent amount of energy [54]. However, natural gas is mainly composed of methane (CH_4), a significantly more potent greenhouse gas whose comparative ability to trap radiation is 25 times greater than CO_2 [55]. While CO_2 emissions are the focus of this study, natural gas production is considered the largest anthropogenic source of CH_4 and a source of other harmful atmospheric pollutants [54,56]. Figure 7 indicates that the end-use of natural gas at power plants generates 78% of point-source CO_2 emissions of the entire industry (60, 060, 762 MT CO_2 e). This finding draws negative attention to the end-use of the product, yet in the United Sates, natural gas is often retrieved using a precarious process known as hydraulic fracturing in which water, sand, and chemicals are forced down wells at high pressure [57]. The resulting environmental decimation [54,58] and impact on drinking water resources [59,60] of this high-risk endeavor permits the extraction of natural gas to be considered an enormous threat to human health, similarly to CO_2 emissions.

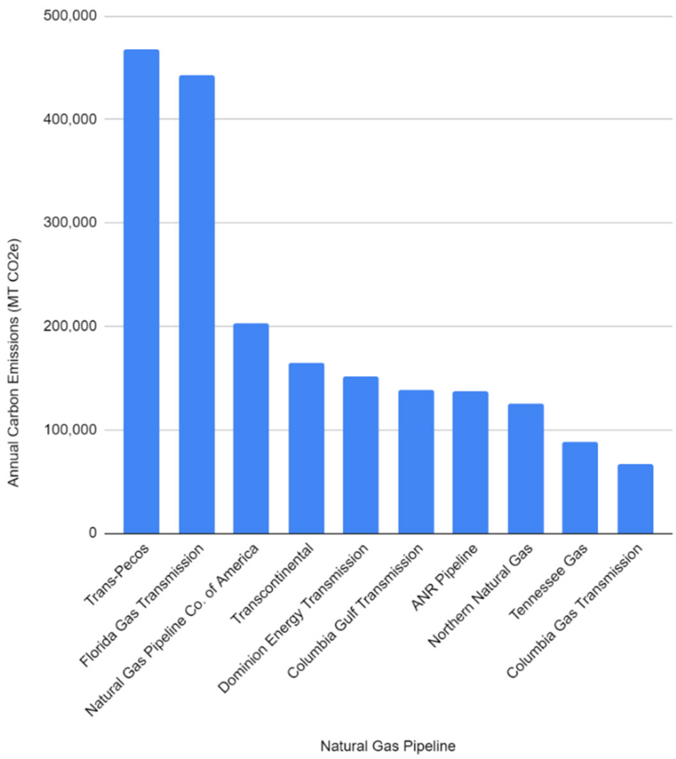

Figure 8. Top CO_2 Emission Point-Sources of the Natural Gas Industry for Transport.

Finally, the overall top ten carbon dioxide emission points sources for all fossil fuels is quantified in Figure 9 and mapped in Figure 10. Mapping is important in this context as it provides information about legal jurisdiction for climate related lawsuits.

According to point-source emissions calculations provided by the EPA, oil transportation entities occupy eight out of ten positions on the overall top ten CO_2 emitters across all fossil-fuel industries list (Figure 9) and the remaining two entities are coal mines. There is a notable disparity between the top 10 point-source and bottlenecks emitters, further illustrating the justified rationale for relying upon bottleneck capacity rather than point-source emissions to establish accurate legal liability for polluting entities. The top three CO_2 emissions bottlenecks (natural gas pipelines) do not rank at all on the list of top ten point-source emitters, demonstrating that a comprehensive emissions calculation is better able to capture polluting entities that otherwise may have been overlooked using traditional methods.

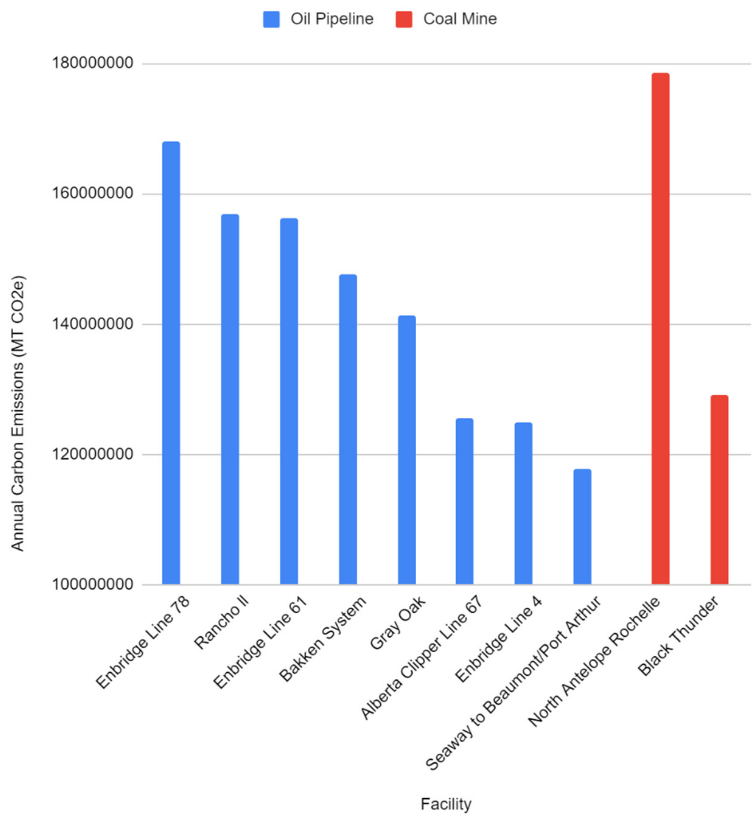

Figure 9. Overall Top 10 CO_2 Emission Point-Sources Across All Fossil-Fuel Industries in U.S.

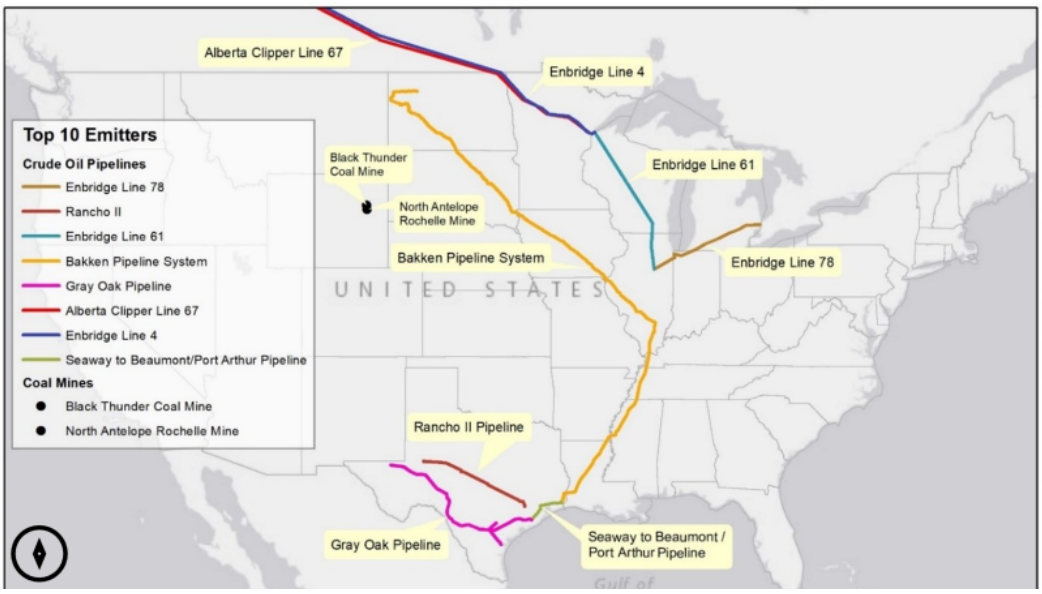

Figure 10. Map of Overall Top 10 CO_2 Point-Source Emitters Across All Fossil-Fuel Industries in the United States (Generating using OpenStreetMap).

3.2. CO_2 Emission Bottlenecks

The comprehensive calculation of bottleneck emissions includes all potential emissions for a given resource extraction, transportation or end use. Embedding all down-stream emissions within the calculation for resource extraction, for example, is justified as all subsequent emissions can be attributed to the initial acquisition of the resource through this bottleneck. The common methodology employed by the U.S. EPA and other environmental organizations is to evaluate an activity's point-source emissions. Relatively simplistic point-source calculations miss the total potential emissions as they ignore the responsibility for the enabled emissions. By calculating an entity's entire resource throughput, it is possible to evaluate the magnitude of its role as a bottleneck for CO_2 emissions. The objective of this work is to identify which entities of the fossil-fuel industry act as CO_2 emission bottlenecks and are thus the most likely to be targeted for GHG emissions lawsuits. The top CO_2 bottlenecks are shown for coal in Figure 11 and mapped in Figure 12. Similarly, the bottleneck results for oil are shown in Figures 13–16.

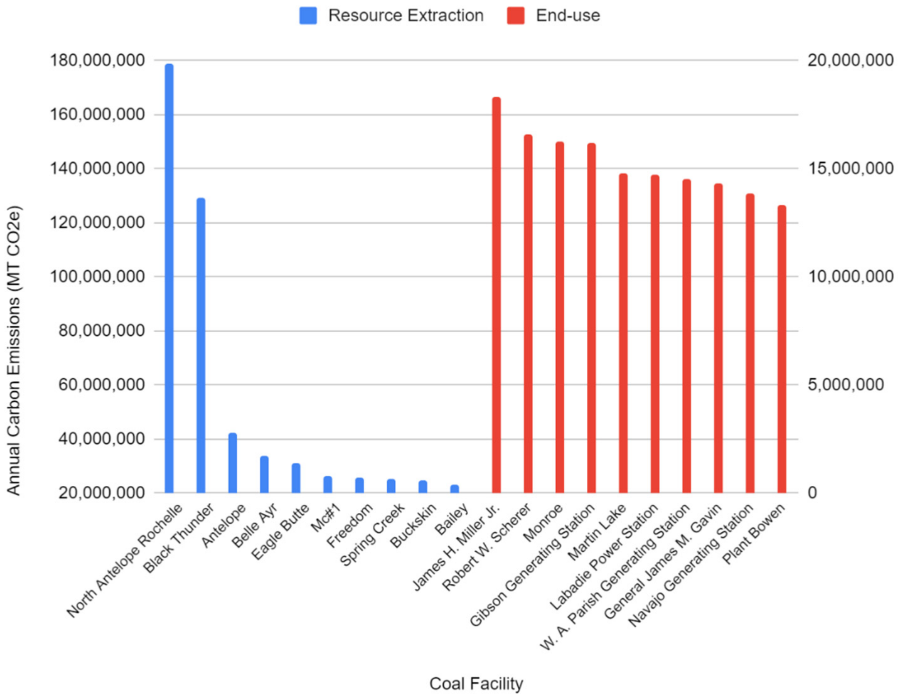

Figure 11. Top CO_2 Bottlenecks of the Coal Industry for Resource Extraction and End-use.

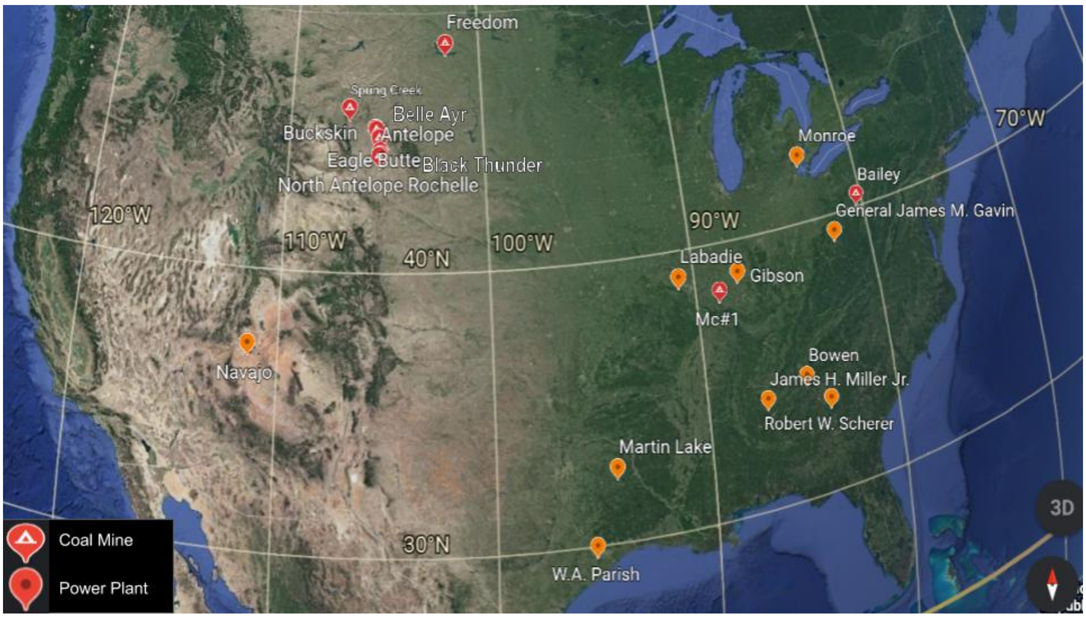

Figure 12. Map of Top CO_2 Emission Bottlenecks- Coal Extraction and Power Plants in the United States (Generating using Google Earth).

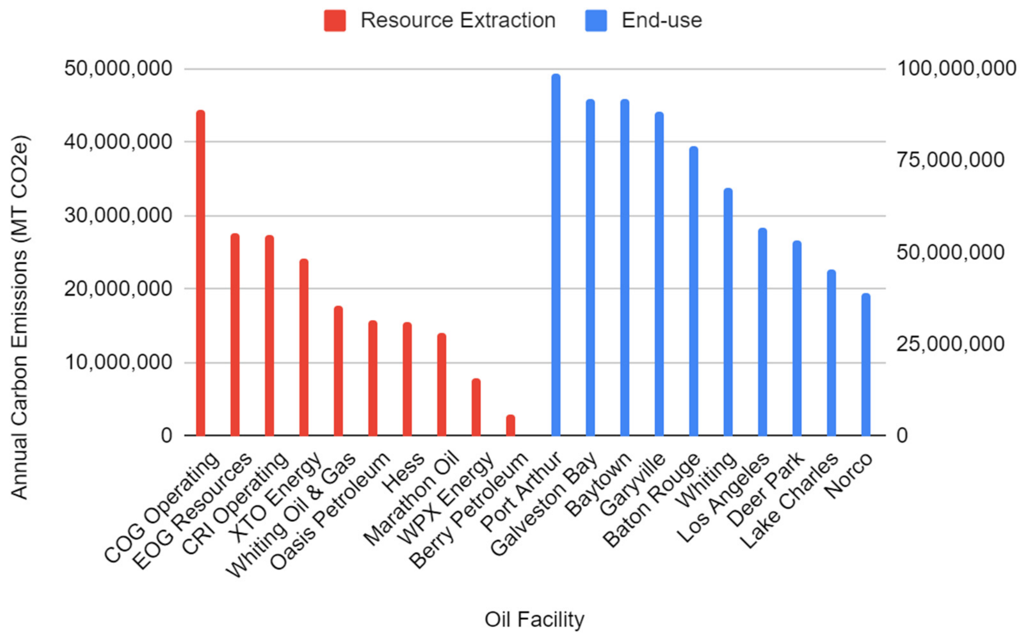

Figure 13. Top CO_2 Bottlenecks of the Oil Industry for Resource Extraction and End-use.

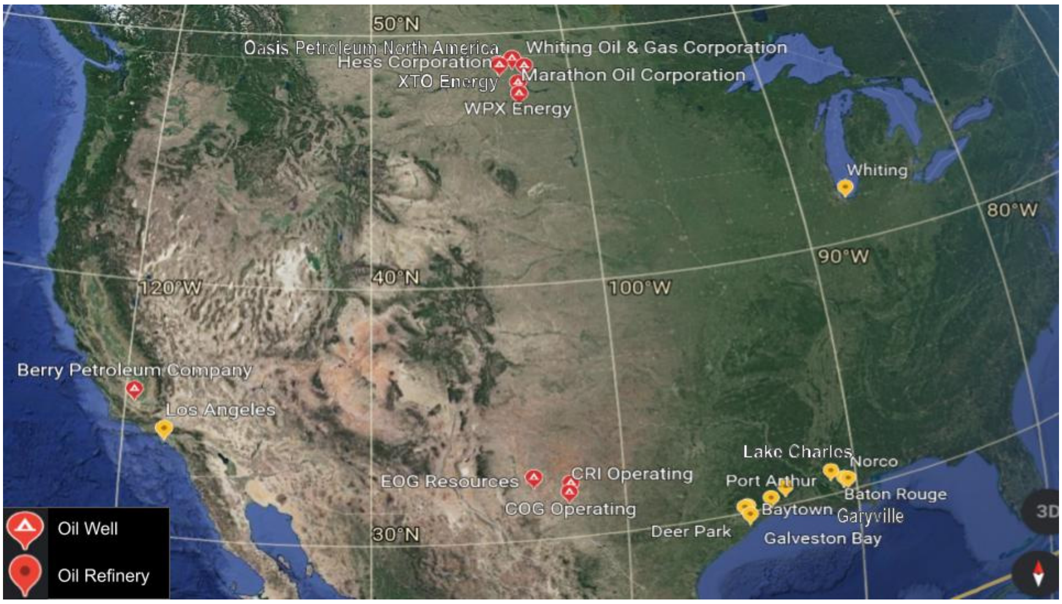

Figure 14. Map of Top CO_2 Emission Bottlenecks- Oil Extraction & Refining Facilities in the United States (Generating using Google Earth).

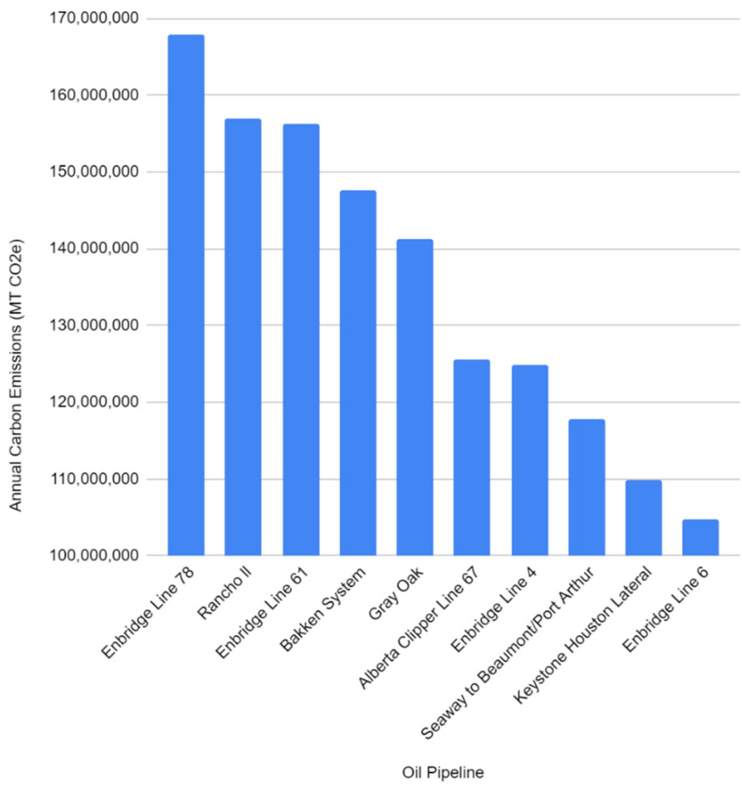

Figure 15. Top CO_2 Bottlenecks of the Oil Industry for Transport.

Figure 16. Map of Top CO_2 Emission Bottlenecks- Oil Pipelines in the United States (Generating using OpenStreetMap).

Using the bottleneck calculation logic previously discussed, a direct conversion from fuel capacity to potential emissions was calculated for all three of the oil industry sub-classes. This approach considers an oil well, pipeline or refinery's capacity to represent the eventual CO_2 emissions associated with the quantity of fuel being handled by each facility.

The bottlenecks for natural gas are shown in Figures 17–20.

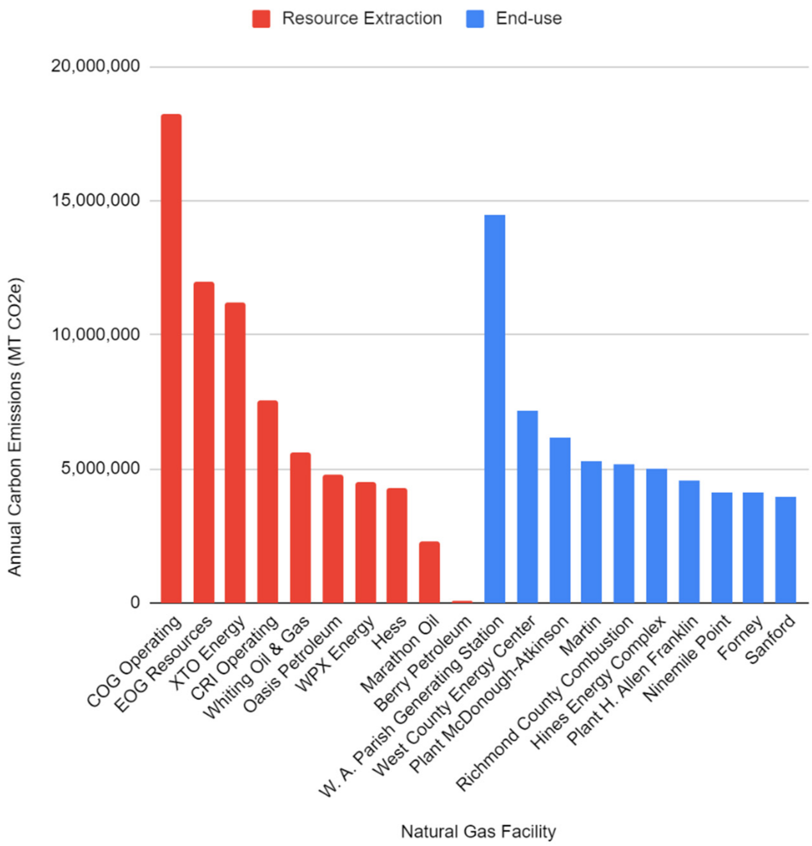

Figure 17. Top CO_2 Bottlenecks of the Natural Gas Industry for Resource Extraction and End-use.

Figure 15 indicates that oil transportation is a substantial bottleneck for CO_2 emissions- being responsible for 58% of the oil industry's total bottleneck emissions. The oil distribution infrastructure in the U.S. operates at such a magnitude that it enables large amounts of fuel to move from inception to termination, directly and indirectly resulting in extensive CO_2 emissions (1,242,898,050 MT CO_2 e annually).

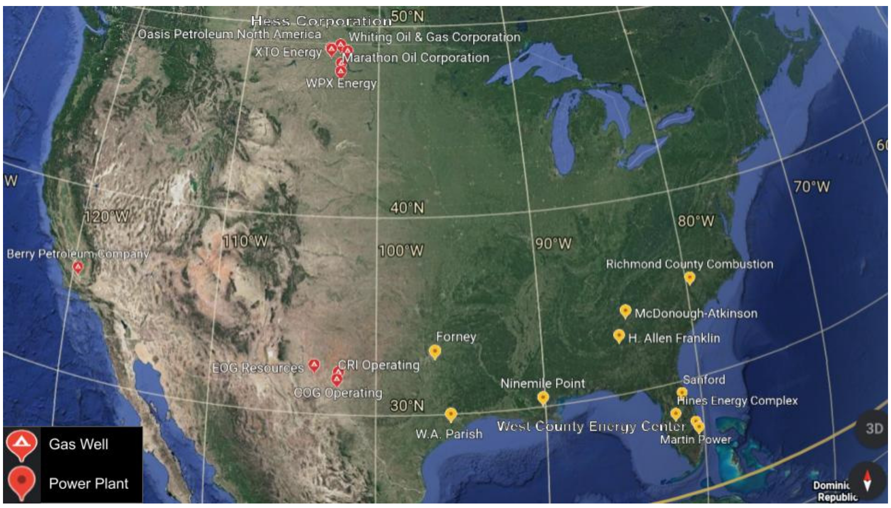

Figure 18. Map of Top 20 CO_2 Emission Bottlenecks- Natural Gas Extraction Facilities & Power Plants in the United States (Generating using Google Earth).

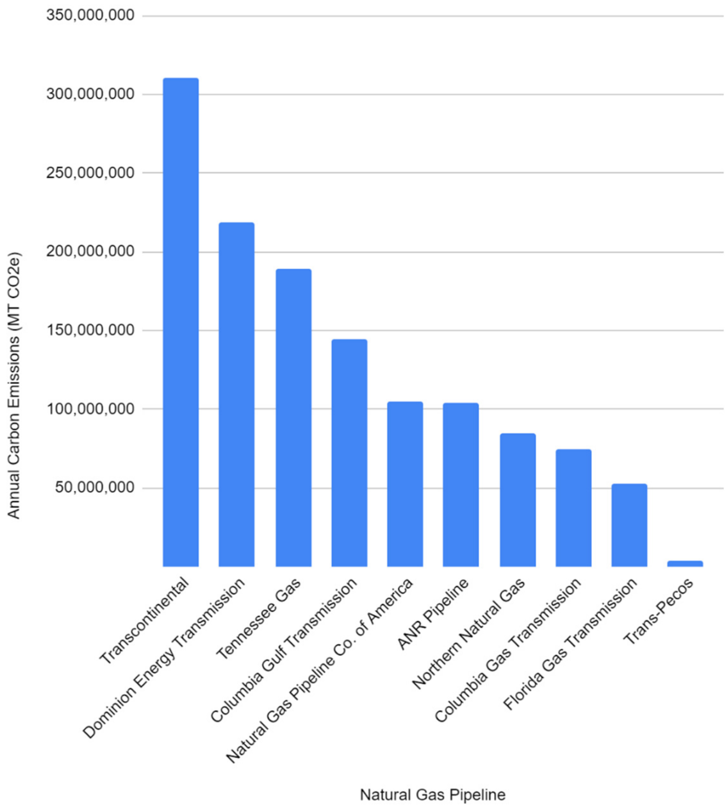

Figure 19. Top CO_2 Bottlenecks of the Natural Gas Industry for Transport.

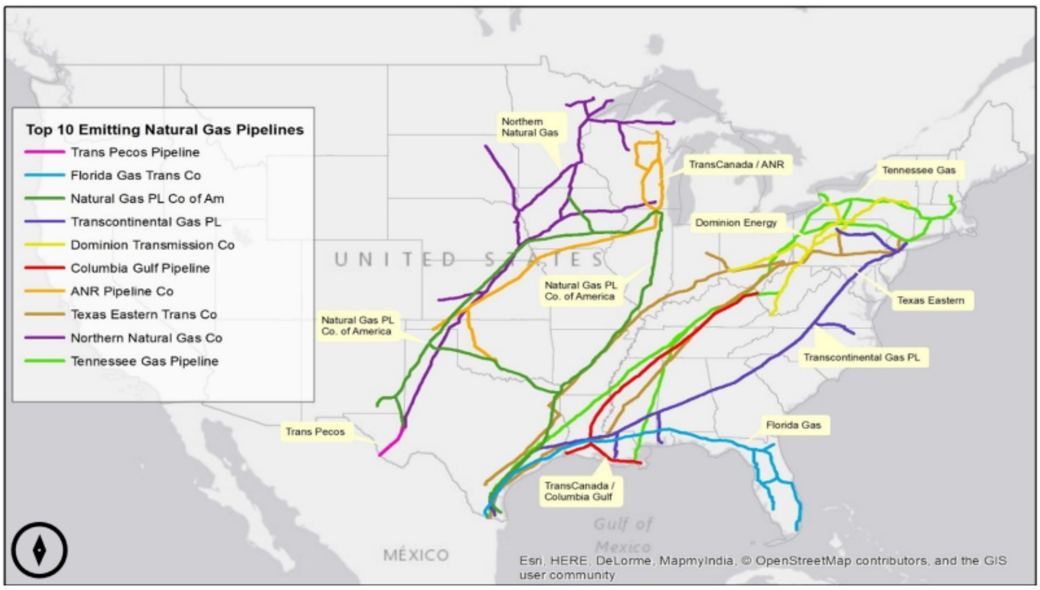

Figure 20. Map of Top 10 CO_2 Emission Bottlenecks- Natural Gas Pipelines in the United States (Generating using OpenStreetMap).

When comparing all three major processes within this sector, the transportation of oil incidentally enables the highest concentration of CO_2 emissions per year, followed by end-use & refining, and lastly oil extraction.

The overall results for the bottleneck calculations are shown in Figure 21 and mapped in Figure 22. Natural gas industry capacity data were retrieved from the EPA's FLIGHT Tool [46] & GHG Summary Reports [46]. The well extraction of both natural gas and oil often occur concurrently as a joint venture by one facility, obtaining a product that is known as *associated natural gas* which occurs within deposits of crude oil [54]. Thus, all top ten natural gas extraction facilities are simultaneously listed in the top ten oil extraction facilities because of their large dual-objective operations.

In comparison to both coal and oil industry activities, natural gas transmission ranks highest in terms of bottleneck capacity. When considering the entire natural gas industry, onshore transmission accounts for 91% of all CO_2 bottleneck emissions (Figures 17 and 19). Figure 20 illustrates the expanse of natural gas pipeline network, displaying the immensity of the interstate system that subsequently enables large quantities of fossil-fuels to disseminate across the American landscape, resulting in eventual CO_2 emissions. In fact, the leading natural gas bottleneck (Transcontinental Pipeline) delivers natural gas over a 10,000-mile transmission system, spanning from south Texas to New York City. According to Williams, the owner & operator of Transcontinental Pipeline, they handle 30% of the natural gas in the United States, 15% of which is transported through the Transcontinental system [61] representing a major CO_2 emission bottleneck.

Based on the methodology employed in this study, the results reveal that the top 10 CO_2 emission bottlenecks are predominantly constituted by oil and natural gas pipelines (Figure 21). Natural gas transmission accounts for 44% of the CO_2 emissions produced solely by these top ten entities, while oil pipelines enable 47%, and a single coal mine contributes 9%. This finding suggests that the extensive capacity of the American pipeline system is particularly responsible for allowing the wide distribution of fossil-fuels, which consequently results in mass quantities of harmful CO_2 emissions to be generated.

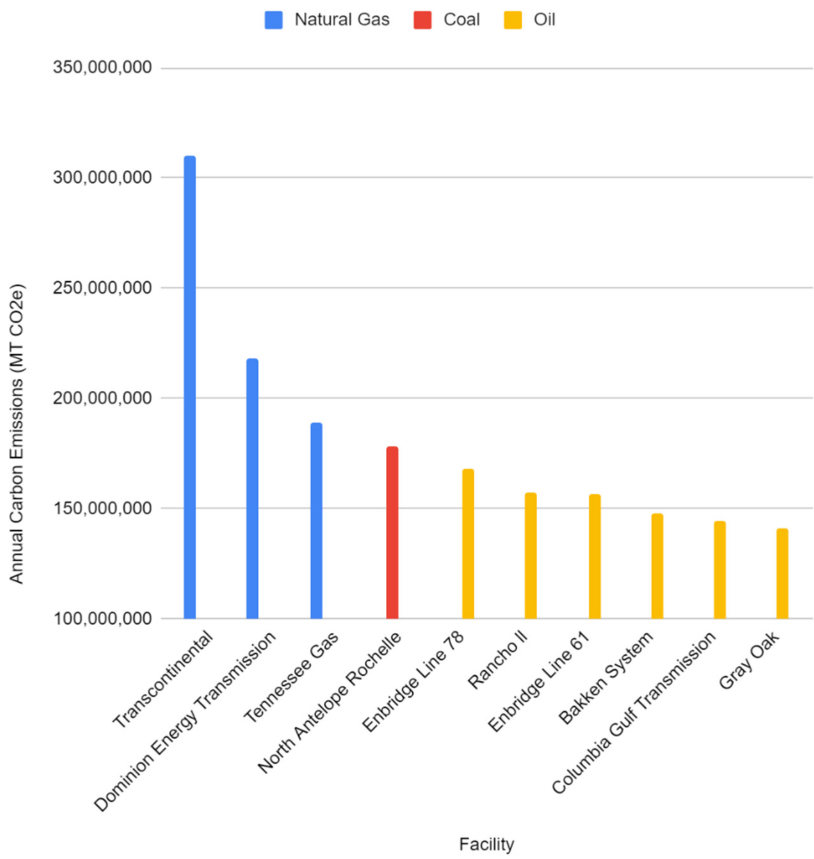

Figure 21. Overall Top 10 CO_2 Emission Bottlenecks Across All Fossil-Fuel Industries.

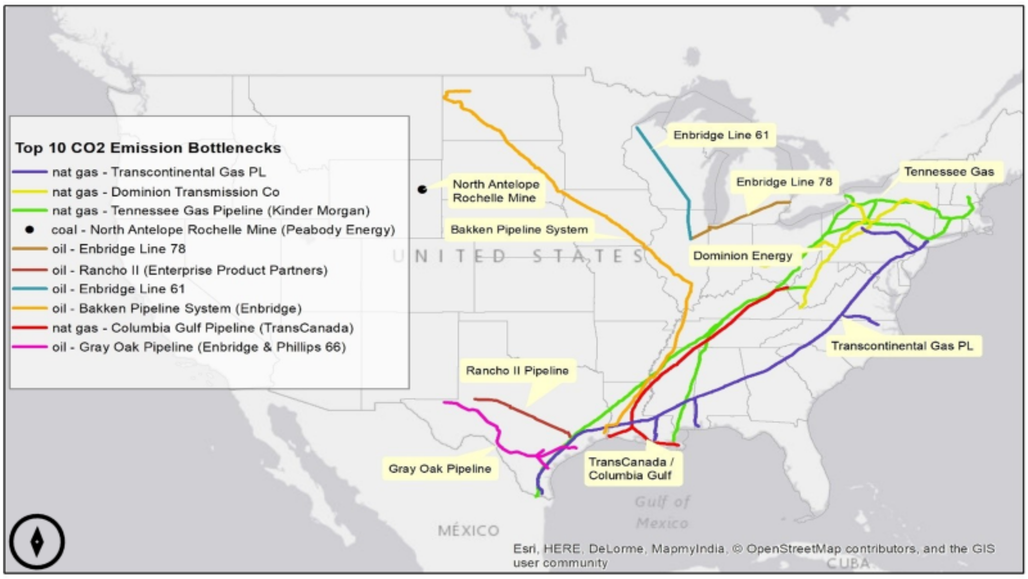

Figure 22. Map of Overall Top 10 CO_2 Emission Bottlenecks Across All Fossil-Fuel Industries in the United States (Generating using OpenStreetMap).

4. Discussion

A comparison of the results summarized in Figure 9 (conventional point) and Figure 21 (bottleneck) CO_2 sources shows that oil and natural gas pipelines are far more important that simple point-source emissions calculations would indicate. It also shifts the emissions liability from bottlenecks towards the east coast from the Midwest (from simplistic point-sources). The results showed that the prominent CO_2 emission bottlenecks are the transportation of both oil and natural gas, illuminating prime targets to focus environmental efforts against. While the extraction of oil is geographically concentrated in both North Dakota and Texas, the pipeline network is extensive and transcends both interstate and national boundaries, further complicating legal efforts. Seven out of eight of the oil pipelines responsible for facilitating the largest amount of CO_2 emissions are operated by Enbridge Inc., a multinational Canadian energy distribution company. Overall, Enbridge Inc. is accountable for contributing 74% of the entire oil industry's carbon emissions, making this company a likely prioritization for climate-related lawsuits. This may indicate that Enbridge is under particular risk for GHG emissions-related liability and thus warrant higher climate liability insurance premiums than other companies in the same sector. Considerable future work is necessary to calculate what these liabilities are to quantify the climate liability insurance premiums and the concomitant increase in the cost of natural gas and oil. As a whole, fossil-fuel related companies identified in Figures 9 and 21 have several areas of risk management which will be discussed below. They have increased risks due to legal liability and they also represent prime targets for eco-terrorism. These effects would tend to increase insurance costs. Finally, they are under risk of either regulatory or technical obsolescence.

4.1. Natural Gas & Oil Transportation as CO_2 Emission Bottlenecks-The Challenge of Liability

The companies and nations accountable for considerably contributing to the concentration of GHG's in the atmosphere are potentially increasingly liable for the resulting change in climate and harmful effects of pollution [4–28]. Polluting industries are thus financially vulnerable due to potential liability for increasing risks [62] and litigation [63], regulatory compliance costs [64], and the direct and physical effects of climate change on their operations [65]. Schwarze has argued to strategically address the dangers of climate change, the resulting economic damages must be redistributed using social and regulatory mechanisms, including corrective justice measures to transfer the costs of climate change onto companies responsible for contribution to its impacts [66]. To divert the externality costs of pollution from victims, a possible approach is to apply tort law, as its basic goal is to reduce the societal costs of human activities and to compensate those who are unduly harmed [67].

Climate liability is an effective way to increase industry knowledge about the size and probability of economic damages resulting from their conduct, and to establish institutions such as insurance to minimize potential costs associated with charges against major polluting entities [66]. In pursuit of ensuring that polluting industries rectify the harm they have caused to the environment, there are a handful of potential methods of assigning liability for climate change-related harms. The polluter-pays principle is an immediate way to account for damages [66] and has been shown to maximize liability as the polluters are held directly responsible for their emissions [40,68]. Claims based on negligent conduct associated with GHG emissions, failure to address the dangers of climate change through alteration of business practices, nuisance claims based on the hazardous impacts of emissions, and environmental liability statutes such as the Comprehensive Environmental Response, Compensation, and Liability Act [69] are all common approaches to holding polluting industries accountable for their contribution to atmospheric GHG concentration and the resulting climate impacts [66]. Ultimately, any attempt to address climate change related damages has inherent challenges and remains a convoluted endeavor in the United States and the broader global community. It is postulated that the option for victims to seek compensation for climate-related harm has the potential to discourage hazardous conduct of polluting industries, as pressures from victims for severe mitigation efforts is weakened in response to the availability of retroactive compensation [33]. Compensation, however, can serve numerous functions beyond payment for an injury, including the generation of a stimulus for change in business practices, and the assignment of responsibility for harm to specific polluting actors [33]. Consequently, major polluting companies face considerable exposure to compensation claims, litigation, and regulatory risk, as well as reputation damage if they fail to adopt proactive measures to reduce their GHG emissions [70].

4.2. Insurance as Risk-Management for Fossil-Fuel Pipelines

Establishing risk-management schemes for both fossil fuel companies and their insurers could preemptively mitigate their exposure to liability charges discussed above, with insurers supporting businesses' development of liability-risk strategies and encouraging behavior that accounts for the dangers of their conduct [65]. This proactive risk-management approach to insurance is the preferred scenario for all parties, as policyholders protect themselves against liability to an extent while inevitably becoming more cognizant of the magnitude of the risk associated with their operation. For pipelines transporting hazardous material, a risk management program is mandatory [71]. This preemptive condition to acquiring insurance coverage for pipeline operators reassures the insurance company that the operator has considered potential incidents and has developed a pre-planned response [71].

Of the varying classes of insurance that are relevant to pipelines, liability insurance is arguably the most critical [71]. Beyond insurance for property damage, business interruption, and construction, liability insurance can insure against damage caused by pipeline malfunction including leakage, explosion, fire, pollution, and casualties [71]. However, insurance does not safeguard against all causes of damage, but only accounts for specific perils [71], demonstrating that even a major natural gas or oil pipeline operator is vulnerable to liability charges beyond the scope of their insurance policy, namely the emission of GHGs. Further, the content of a pipeline considerably effects the level of risk to be insured, with hydrocarbon liquids and gases having the highest hazard and polluting potential [71]. Thus, it can be expected that pipeline operators identified in this study as having the highest emissions bottleneck potential such as Williams or Enbridge Inc. most critically need to consider liability insurance risks and the limitations of mere coverage, making stronger the demand for preemptive risk-management strategies and alteration of conduct. Major oil pipeline operators like Enbridge Inc. are at the mercy of environmental, commercial, and product liability charges [65], vulnerable to claims from victims who allege negligence, injury, or property damage as the fault of the insured polluter. Because estimating the impacts associated with pipeline incidents and GHG emissions from the oil industry is not an exact science, there is frequent underestimates of the consequences and inadequate coverage [65]. Insurers insure many of the primary carbon-intensive industries and it is anticipated that the brunt of the cost of climate change impacts will be incurred by these insured businesses [72]. Insuring against catastrophic events is challenging due to the high risk for underwriters, expenses of handling a large number of claims, and difficulty in assessing future harm [71], thus there are concerns that private company insurance may be insufficient to deal with large-scale GHG emission impacts such as climate change.

Ultimately, the insurance industry's response to climate change is of compelling importance as societies seek mitigative and adaptive solutions that include liabilities for insurers and their policyholders [66]. With regard to the mega-polluting actors of the fossil fuel industry, insurance coverage might prove vital to survive. Perhaps more than any other institution, the insurance industry has the capacity to make contributions to preemptive pollution mitigation through demanding risk-management strategies and tightening the terms and conditions of coverage [65], forcibly altering the conduct of major polluting actors. While *ex post* action directed at holding polluting industries accountable for GHG emissions is crucial, the value of the preemptive effect of *ex ante* action can effectively prevent and abate future CO_2 emissions.

4.3. Insurance and Investment Risks of the Major Pollution Bottlenecks: Oil and Gas Pipelines

The results of this study have shown oil pipelines may now present a substantial investment risk in part because of potentially increased insurance risks. These risks stem primarily from emission related liabilities. Compensation for non-market damages to natural resources explicitly exists in U.S. law (CERCLA), and these compensation schemes provide insight into potential pathways for future victims seeking compensation for GHG emissions-based damages. Specifically, there are different types of potential GHG lawsuits: (i) interstate claims, (ii) claims between private parties and the states, (iii) claims between private persons and industry, (iv) claims between states and industry, (v) claims between nations, and (vi) class action lawsuits [40]. In *Connecticut v. American Electric Power Co.* several states and environmental groups filed a significant climate change-related public nuisance lawsuit [73]. The plaintiff's alleged that coal-fired power plant's operation is a considerable public nuisance, and rather than seeking compensation in terms of monetary relief the states sought a mandated cut of emissions of a specified percentage for each following year [65,73]. Although the court dismissed this case as nonjusticiable under the political question doctrine [65], it illustrates the potential risks to not only lawsuits seeking compensation, but also those that could change a company's ability to function in a particular way.

There are several other specific risks involved with oil pipelines. First, there is a risk of sunk costs. There is a significant transition underway in the automobile market to electric vehicles—which makes oil pipelines particularly exposed as compared to the other technologies [74–77]. The Electric Vehicle Regional Market Penetration tool developed by Noori & Tatari [76] forecast that by 2030, electric vehicle market shares are predicted to account for 30% of new automobile sales. This electric vehicle market penetration is expected to impact both energy consumption and CO_2 emissions, and in the presence of continued technological innovation and supportive policies, has the potential to substitute nearly 1 million tons of gasoline with 3.2 billion kWh electricity and reduce 0.6 million tons of CO_2 emissions by 2030 [77]. In addition, with the reduction in cost of renewable energy sources (wind [78] and solar [79]) reducing the cost of electricity below those of fossil fuels [80], this indicates further economic pressure favoring electric cars. There are very few oil-burning power plants as they are uncompetitive with NG or renewables, which places the future demand of oil in question [81,82]. Finally, 4% of the world's fossil resources are used in plastic production [83], but this can also be reduced as recycling can be expanded when there is a financial incentive for consumers to recycle (without it the global plastic recycling rate is about 9% [84]). The new concept of distributed recycling with additive manufacturing (DRAM) has been shown to be economically advantageous for consumers to use their plastic waste to make high value products thus offsetting additional virgin plastic production [85–87]. Even if all of the current market drivers do not materialize to reduce oil use there has been substantial discussion about regulating carbon dioxide emissions, all of which would be expected to reduce oil demand and raise the costs of using it as a fuel [88,89].

Lastly, there are physical risks to pipelines themselves. The insurance risks related to natural disasters (historical leaks and the cost of environmental disasters) are already contained within insurance rates. Climate change, however, is increasing natural disasters [90,91] and would be expected to increase insurance rates for pipelines. Pipelines are well known targets both in times of war and from terrorists [92,93]. As negative consequences of climate change mount and pipelines are identified by ecoterrorists as being the primary target, there may be a wave of attacks strategically targeted against pipelines [94,95]. Future work is needed to quantify this risk as well as determine what increases in insurance rates would be expected. Oil pipelines are particularly vulnerable in this respect because of their physical exposure. For example, a drunk hunter accidently caused 150,000 gallons of oil to spill (one of the worst in the Trans-Alaska Pipeline) simply by shooting one bullet into the pipeline [96]. All of these factors must be carefully reviewed by long-term investors into oil and gas pipelines as the risks may far outweigh any potential returns.

4.4. Future Work

In addition to the applications outlined above there is future work to be completed on this approach by integrating a full life cycle analysis (LCA) [97], with updated values for current industry practices in each of the fossil fuel sectors. LCAs for renewable energy sources, are far more numerous in the literature because the emissions from fossil fuel plants are dominated by the combustion of the fuel itself. LCA are needed for targeting the full potential emissions over a given infrastructure's lifetime (e.g., would it be better from an emissions standpoint in the long term to target a new pipeline than a pipeline that may have higher capacity but was nearing its end of life?). In addition, future work could evaluate the different assessment methods encompassing direct emissions (on-site as is generally done using the point source method and compared here as for a single coal-fired power plant) [98], indirect (up-stream as in emissions from leaking natural gas pipelines and natural gas fields [99,100]) and induced (down-stream as in automobile emissions from processed oil [101]. These LCA-based results being incorporated into the methodology demonstrated here would expected to have some impact on the prioritization of lawsuits and other techniques meant to decarbonize the electric industry, however, as the emissions are dominated by the combustion the general trends found from this analysis provide a much more thorough strategic guidance than using point sources alone.

5. Conclusions

This paper has presented a comprehensive bottleneck calculation of CO_2 emissions in comparison to traditional point-source methods in order to effectively prioritize targets for climate liability. Results indicate that the top ten CO_2 emission bottlenecks in the U.S. are predominantly oil and natural gas pipelines, with oil pipelines accounting for 47% and natural gas transmission accounting for 44% of the CO_2 emissions produced solely by these top ten entities. Compared to traditional point-source emissions methodology, this study has demonstrated that a comprehensive bottleneck calculation is far more effective at accounting for the true liability of a polluting entity. By employing an all-inclusive approach to calculating a polluting entity's CO_2 emissions, legal actions may be more accurately focused on major polluters, and these companies may preemptively mitigate their pollution to curb vulnerability to litigation and risk. The bottleneck methodology presented here reveals the discrete link in the chain of the fossil-fuel lifecycle that is responsible for the largest amount of emissions, enabling informed climate change mitigation efforts and a considerable reduction in CO_2 emissions. This study has identified the largest sources of corporate carbon dioxide bottlenecks, but further research should establish an appropriate insurance rates for fossil fuel companies to mitigate the risks of climate-related liability.

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Appendix A

Appendix A.1. Methodology and Equations Employed to Calculate Total Annual CO_2 Emissions in Metric Tons of Carbon Dioxide Equivalent (MT CO_2 e)

The mass (m_{coal}) of coal produced per year from U.S. short tons (*US t*) is converted into pounds (*lb*) by:

$$m_{coal(lb)} = m_{coal\ (US\ t)} \times 2000 \frac{lbs}{US\ t} \tag{A1}$$

is converted into total annual CO_2 emissions in metric tons of carbon dioxide equivalent (MT CO_2 e) by [50–53]:

$$\frac{m_{CO_2(MT)}}{m_{coal(lb)}} = \frac{20.92 mmbtu}{m_{coal\ (MT_{coal})}} \times 26.08 \frac{(kgC)}{mmbtu} \times 44 \frac{kgCO_2}{12kgC} \times \frac{1\ MT_{coal}}{2204.6\ lb\ coal} \times \frac{1\ MT}{1000kg} = \frac{9.08 \times 10^{-4} MT\ CO_2}{lb\ coal} \tag{A2}$$

To convert oil pipeline capacity (O) in barrels per day (*bbl*) into total daily and annual CO_2 emissions (MT CO_2 e) [50,53]:

$$5.80 \frac{mmbtu}{bbl} \times 20.31 \frac{kgC}{mmbtu} \times 44 \frac{kgCO_2}{12kgC} \times \frac{1\ MT}{1000kg} = 0.43 \frac{MT_{CO_2}}{bbl} \times O_{bbl/day} = O_{MTCO_2/day} \tag{A3}$$

The $O_{MT\ CO_2/day}$ is multiplied by 365 days to obtain the MT CO_2 e per year:

$$O_{MTCO_2/year} = O_{MTCO_2/day} \times 365 \tag{A4}$$

To convert natural gas pipeline capacity (*N*) in thousand standard cubic feet (*Mcf*) to annual CO_2 emissions (MT CO_2 e) [51–53]:

$$N_{Mcf} \times \frac{0.0053\ MT\ CO_2}{therm} \times 10.37 \frac{therms}{Mcf} = 0.0549 \frac{MT\ CO_2}{Mcf} \times N_{Mcf} = N_{MT\ CO_2 e} \tag{A5}$$

Appendix A.2. Tables of Emission Results

Table A1. Top CO_2 Emission Point-Sources of the Coal Industry for Resource Extraction and End-use.

Type of Entity	Facility	Annual CO_2 Emissions (MT CO_2 e)
Resource Extraction	North Antelope Rochelle Mine (Peabody Energy)	178,541,482
	Black Thunder Mine (Arch Coal Inc.)	129,180,444
	Antelope Coal Mine (Cloud Peak Energy)	42,050,826
	Belle Ayr Mine (Blackjewel LLC)	33,536,807
	Eagle Butte Mine (Blackjewel LLC)	30,973,326
	Mc#1 Mine (Mach Mining LLC)	26,261,087
	Freedom Mine (Coteau Properties Co.)	25,756,896
	Spring Creek Coal Mine (Navajo Transitional Energy Co.)	25,002,788
	Buckskin Mine (Kiewit Corp.)	24,531,779
	Bailey Mine (CONSOL Energy Inc.)	23,127,468
	Total	538,962,903
End Use/Product Sale	James H. Miller Jr.	18,285,159
	Robert W. Scherer Power Plant	16,564,369
	Monroe Power Plant	16,269,093
	Gibson Generating Station	16,194,973
	Martin Lake Power Plant	14,757,909
	Labadie Power Station (Union Electric Co.)	14,730,396
	W. A. Parish Generating Station	14,491,668
	General James M. Gavin Power Plant	14,346,615
	Navajo Generating Station	13,846,974
	Plant Bowen (Georgia Power Co.)	13,312,712
	Total	152,799,868
	Industry Total	691,762,771

Table A2. Top CO_2 Emission Point-Sources of the Oil Industry for Resource Extraction, Transport, and End-use.

Type of Entity	Facility	Annual CO_2 Emissions (MT CO_2 e)
Resource Extraction	Marathon Oil Corporation (Williston Basin)	2,272,114
	Whiting Oil & Gas Corporation (Williston Basin)	2,202,496
	CRI Operating LLC (Williston Basin)	1,649,523
	Hess Corporation (Williston Basin)	1,477,609
	Oasis Petroleum North America LLC	1,313,727
	XTO Energy Inc. (Permian Basin) (ExxonMobil)	1,278,247
	COG Operating LLC	1,188,830
	WPX Energy Permian LLC	1,185,694
	Berry Petroleum Company	1,069,414
	EOG Resources Inc. (Permian Basin)	868,246
	Total	14,505,900
Transport	Enbridge Line 78	167,936,500
	Rancho II Pipeline (Enterprise Product Partners)	156,950,000
	Enbridge Line 61	156,322,200
	Bakken Pipeline System (Enbridge)	147,544,000
	Gray Oak Pipeline (Enbridge, Phillips 66)	141,255,000
	Alberta Clipper Line 67 (Enbridge)	125,560,000
	Enbridge Line 4	124,932,200
	Seaway to Beaumont/Port Arthur Pipeline (Enbridge, Enterprise Product Partners)	117,712,500
	Keystone Houston Lateral (TransCanada)	109,865,000
	Enbridge Line 6	104,685,650
	Total	1,242,898,050
End Use/Product Sale	Baytown Refinery (Exxonmobil)	10,666,655
	Galveston Bay Refinery (Marathon)	6,923,112
	Los Angeles Refinery (Marathon)	6,425,775
	Baton Rouge Refinery (Exxonmobil)	6,344,880
	Port Arthur Refinery (Motiva Enterprises LLC)	5,487,670
	Lake Charles Refinery (Phillips 66)	4,862,156
	Whiting Refinery (BP)	4,781,505
	Deer Park Refinery (Shell Oil Co. & Pemex)	4,154,899
	Garyville Refinery (Marathon)	4,074,113
	Norco Refinery (Shell Oil Co.)	3,821,971
	Total	57,542,736
	Industry Total	1,314,946,686

Table A3. Top CO_2 Emission Point-Sources of the Natural Gas Industry for Resource Extraction, Transport, and End-use.

Type of Entity	Facility	Annual CO_2 Emissions (MT CO_2 e)
Resource Extraction	Marathon Oil Corporation (Williston Basin)	2,272,114
	Whiting Oil & Gas Corporation (Williston Basin)	2,202,496
	CRI Operating LLC (Williston Basin)	1,649,523
	Hess Corporation (Williston Basin)	1,477,609
	Oasis Petroleum North America LLC	1,313,727
	XTO Energy Inc. (Permian Basin) (ExxonMobil)	1,278,247
	COG Operating LLC	1,188,830
	WPX Energy Permian LLC	1,185,694
	Berry Petroleum Company	1,069,414
	EOG Resources Inc. (Permian Basin)	868,246
	Total	14,505,900
Transport	Trans-Pecos Pipeline LLC	467,726
	Florida Gas Transmission Co. LLC (Kinder Morgan)	442,644
	Natural Gas Pipeline Co. of America LLC (Kinder Morgan)	202,912
	Transcontinental Gas Pipeline (Williams)	164,701
	Dominion Energy Transmission	152,154
	Columbia Gulf Transmission (TransCanada)	137,980
	ANR Pipeline (TransCanada)	137,831
	Northern Natural Gas (Berkshire Hathaway)	125,122
	Tennessee Gas Pipeline Co. LLC (Kinder Morgan)	88,832
	Columbia Gas Transmission (TransCanada)	66,692
	Total	1,986,594

Table A3. *Cont.*

Type of Entity	Facility	Annual CO_2 Emissions (MT CO_2 e)
End Use/Product Sale	W. A. Parish Generating Station	14,491,668
	West County Energy Center	7,167,296
	Plant McDonough-Atkinson	6,180,554
	Martin Power Plant	5,265,279
	Richmond County Combustion Turbine Plant	5,177,764
	Hines Energy Complex	5,026,094
	Plant H. Allen Franklin	4,553,304
	Ninemile Point Power Plant	4,118,889
	Forney Power Plant	4,098,711
	Sanford Power Plant	3,981,203
	Total	60,060,762
	Industry Total	76,553,256

Table A4. Overall Top 10 CO_2 Emission Point-Sources Across All Fossil-Fuel Industries in U.S.

Facility	Annual CO_2 Emissions (MT CO_2 e)
North Antelope Rochelle Coal Mine (Peabody Energy Corporation)	178,541,482
Enbridge Line 78	167,936,500
Rancho ll Pipeline (Enterprise Product Partners)	156,950,000
Enbridge Line 61	156,322,200
Bakken Pipeline System (Enbridge)	147,544,000
Gray Oak Pipeline (Enbridge, Phillips 66)	141,255,000
Black Thunder Coal Mine (Arch Coal Inc.)	129,180,444
Alberta Clipper Line 67 (Enbridge)	125,560,000
Enbridge Line 4	124,932,200
Seaway to Beaumont/Port Arthur Pipeline (Enbridge, Enterprise Products)	117,712,500
Total	1,445,934,326

Table A5. Top CO_2 Bottlenecks of the Coal Industry for Resource Extraction and End-use.

Type of Entity	Facility	Annual CO_2 Emissions (MT CO_2 e)
Resource Extraction	North Antelope Rochelle Mine (Peabody Energy)	178,541,482
	Black Thunder Mine (Arch Coal Inc.)	129,180,444
	Antelope Coal Mine (Cloud Peak Energy)	42,050,826
	Belle Ayr Mine (Blackjewel LLC)	33,536,807
	Eagle Butte Mine (Blackjewel LLC)	30,973,326
	Mc#1 Mine (Mach Mining LLC)	26,261,087
	Freedom Mine (Coteau Properties Co.)	25,756,896
	Spring Creek Coal Mine (Navajo Transitional Energy Co.)	25,002,788
	Buckskin Mine (Kiewit Corp.)	24,531,779
	Bailey Mine (CONSOL Energy Inc.)	23,127,468
	Total	538,962,903
End Use/Product Sale	James H. Miller Jr.	18,285,159
	Robert W. Scherer Power Plant	16,564,369
	Monroe Power Plant	16,269,093
	Gibson Generating Station	16,194,973
	Martin Lake Power Plant	14,757,909
	Labadie Power Station (Union Electric Co.)	14,730,396
	W. A. Parish Generating Station	14,491,668
	General James M. Gavin Power Plant	14,346,615
	Navajo Generating Station	13,846,974
	Plant Bowen (Georgia Power Co.)	13,312,712
	Total	152,799,868
	Industry Total	691,762,771

Table A6. Top CO_2 Bottlenecks of the Oil Industry for Resource Extraction, Transport, and End-use.

Type of Entity	Facility	Annual CO_2 Emissions (MT CO_2 e)
Resource Extraction	COG Operating LLC	44,467,031
	EOG Resources Inc. (Permian Basin)	27,756,075
	CRI Operating LLC	27,425,089
	XTO Energy Inc. (Permian Basin) (ExxonMobil)	24,262,919
	Whiting Oil & Gas Corporation (Williston Basin)	17,741,877
	Oasis Petroleum North America LLC	15,703,569
	Hess Corporation (Williston Basin)	15,642,390
	Marathon Oil Corporation (Williston Basin)	14,154,904
	WPX Energy Permian LLC	7,935,799
	Berry Petroleum Company	3,072,666
	Total	198,162,321
Transport	Enbridge Line 78	167,936,500
	Rancho II Pipeline (Enterprise Product Partners)	156,950,000
	Enbridge Line 61	156,322,200
	Bakken Pipeline System (Enbridge)	147,544,000
	Gray Oak Pipeline (Enbridge, Phillips 66)	141,255,000
	Alberta Clipper Line 67 (Enbridge)	125,560,000
	Enbridge Line 4	124,932,200
	Seaway to Beaumont/Port Arthur Pipeline (Enbridge, Enterprise Product Partners)	117,712,500
	Keystone Houston Lateral (TransCanada)	109,865,000
	Enbridge Line 6	104,685,650
	Total	1,242,898,050
End Use/Product Sale	Port Arthur Refinery (Motiva Enterprises LLC)	98,878,500
	Galveston Bay Refinery (Marathon)	91,815,750
	Baytown Refinery (ExxonMobil)	91,658,800
	Garyville Refinery (Marathon)	88,519,800
	Baton Rouge Refinery (ExxonMobil)	78,867,375
	Whiting Refinery (BP)	67,488,500
	Los Angeles Refinery (Marathon)	56,972,850
	Deer Park Refinery (Shell Oil Co. & Pemex)	53,363,000
	Lake Charles Refinery (Phillips 66)	45,515,500
	Norco Refinery (Shell Oil Co.)	39,237,500
	Total	712,317,575
	Industry Total	2,153,377,946

Table A7. Top CO_2 Bottlenecks of the Natural Gas Industry for Resource Extraction, Transport, and End-use.

Type of Entity	Facility	Annual CO_2 Emissions (MT CO_2 e)
Resource Extraction	COG Operating LLC	18,210,636
	EOG Resources Inc. (Permian Basin)	12,000,231
	XTO Energy Inc. (Permian Basin) (ExxonMobil)	11,219,906
	CRI Operating LLC (Williston Basin)	7,549,824
	Whiting Oil & Gas Corporation (Williston Basin)	5,596,600
	Oasis Petroleum North America LLC	4,811,806
	WPX Energy Permian LLC	4,517,306
	Hess Corporation (Williston Basin)	4,312,664
	Marathon Oil Corporation (Williston Basin)	2,308,790
	Berry Petroleum Company	79,204
	Total	70,606,969
Transport	Transcontinental Gas Pipeline (Williams)	310,261,456
	Dominion Energy Transmission	218,402,016
	Tennessee Gas Pipeline Co. LLC (Kinder Morgan)	189,107,413
	Columbia Gulf Transmission (TransCanada)	144,409,674
	Natural Gas Pipeline Co. of America LLC (Kinder Morgan)	104,712,239
	ANR Pipeline (TransCanada)	104,099,910
	Northern Natural Gas (Berkshire Hathaway)	84,778,381
	Columbia Gas Transmission (TransCanada)	74,956,511
	Florida Gas Transmission Co. LLC (Kinder Morgan)	52,743,007
	Trans-Pecos Pipeline LLC	4,035,443
	Total	1,287,506,052

Table A7. *Cont.*

Type of Entity	Facility	Annual CO_2 Emissions (MT CO_2 e)
End Use/Product Sale	W. A. Parish Generating Station	14,491,668
	West County Energy Center	7,167,296
	Plant McDonough-Atkinson	6,180,554
	Martin Power Plant	5,265,279
	Richmond County Combustion Turbine Plant	5,177,764
	Hines Energy Complex	5,026,094
	Plant H. Allen Franklin	4,553,304
	Ninemile Point Power Plant	4,118,889
	Forney Power Plant	4,098,711
	Sanford Power Plant	3,981,203
	Total	60,060,762
	Industry Total	1,418,173,782

Table A8. Overall Top 10 CO_2 Emission Bottlenecks Across All Fossil-Fuel Industries.

Facility	Annual CO_2 Emissions (MT CO_2 e)
Transcontinental Gas Pipeline (Williams)	310,261,456
Dominion Energy Transmission	218,402,016
Tennessee Gas Pipeline Co. LLC (Kinder Morgan)	189,107,413
North Antelope Rochelle Mine (Peabody Energy)	178,541,482
Enbridge Line 78	167,936,500
Rancho ll Pipeline (Enterprise Product Partners)	156,950,000
Enbridge Line 61	156,322,200
Bakken Pipeline System (Enbridge)	147,544,000
Columbia Gulf Transmission (TransCanada)	144,409,674
Gray Oak Pipeline (Enbridge & Phillips 66)	141,255,000
Total	1,967,679,741

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