

Lawrence Berkeley National Laboratory

LBL Publications

Title

Diesel Fuel Consumption in Prominent U.S. Open-Pit Mines: Site-Level Estimates

Permalink

<https://escholarship.org/uc/item/4gv081gr>

Authors

Szum, Carolyn

Breunig, Hanna

Publication Date

2026

DOI

10.2172/3017439

Copyright Information

This work is made available under the terms of a Creative Commons Attribution License, available at <https://creativecommons.org/licenses/by/4.0/>

Peer reviewed



Energy Analysis Division, Energy Technologies Area

Diesel Fuel Consumption in Prominent U.S. Open-Pit Mines: Site-Level Estimates

Carolyn Szum and Hanna Breunig

January 2026
LBNL-2001717



This work was supported by the U.S. Department of Energy's Office of Critical Minerals and Energy Innovation under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231.

Disclaimer

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or the Regents of the University of California.

Lawrence Berkeley National Laboratory is an equal opportunity employer.

Copyright Notice

This manuscript has been authored by an author at Lawrence Berkeley National Laboratory under Contract No. DE-AC02-05CH11231 with the U.S. Department of Energy. The U.S. Government retains, and the publisher, by accepting the article for publication, acknowledges, that the U.S. Government retains a non-exclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this manuscript, or allow others to do so, for U.S. Government purposes.

Acknowledgements

The work described in this study was conducted at Lawrence Berkeley National Laboratory and supported by the U.S. Department of Energy Office of Efficiency and Renewable Energy (EERE) in Fiscal Year 2025 and U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

The authors would like to thank Dr. Syed Saqline, Postdoctoral Fellow at Lawrence Berkeley National Laboratory, and Mr. Arun Sharma, Research Associate at Lawrence Berkeley National Laboratory, for their contributions to developing the geographic map of mine sites, which provided essential visualization support for this analysis. The authors also thank Dr. Sekhar Bhattacharyya, Assistant Teaching Professor in the John and Willie Leone Family Department of Energy and Mineral Engineering at The Pennsylvania State University, for his valuable clarification on the Pennsylvania State list of prominent U.S. open-pit mines, which helped guide the scope and accuracy of the dataset.

The authors thank the following experts for reviewing this report (affiliations do not imply that those organizations support or endorse this work):

Dr. Thomas Hendrickson

Lawrence Berkeley National Laboratory

Ms. Nica Campbell

Lawrence Berkeley National Laboratory

Table of Contents

Acknowledgements	iii
List of Figures	vi
List of Tables	vi
Acronyms and Abbreviations	vii
Abstract	ix
1. Introduction	1
1.1 Study Objective	2
2. Dataset Overview	4
2.1 Mine Site Selection	4
2.1.1 Dataset Adjustments	4
2.1.2 Dataset Variables	5
2.1.3 Mine Location Coordinates	5
2.1.4 Visualization Overview	8
2.1.5 Geographic Distribution of Diesel Consumption	8
3. Diesel Fuel Use Estimation by Methodology and Results	10
3.1 Reported Diesel Data	10
3.1.1 Data Sources	10
3.1.2 Unit Conversions	10
3.1.3 Calculation Methodology	11
3.1.4 Calculation Results	11
3.1.5 Data Verification and Treatment of Assumptions	12
3.1.6 Limitations	12
3.2 Renewable Diesel Carbon Dioxide (CO ₂)-Based Estimates	13
3.2.1 Data Sources	13
3.2.2 Unit Conversions	14
3.2.3 Calculation Methodology	14
3.2.4 Calculation Results	14
3.2.5 Data Verification and Treatment of Assumptions	15
3.2.6 Limitations	15
3.3 Diesel / Pellet Proxy Estimates	15
3.3.1 Data Sources	16
3.3.2 Unit Conversions	16
3.3.3 Calculation Methodology	17
3.3.4 Calculation Results	17
3.3.5 Data Verification and Treatment of Assumptions	18
3.3.6 Limitations	18
3.4 Scope 1 and 2 Carbon Dioxide Equivalent (CO ₂ e)-Based Estimates	19
3.4.1 Data Sources	19
3.4.2 Unit Conversions	20
3.4.3 Calculation Methodology	21
3.4.4 Justification for the 90% Diesel Share Assumption at Ray Mine	23
3.4.5 Calculation Results	24
3.4.6 Data Verification and Treatment of Assumptions	24
3.4.7 Limitations	24

3.5	Nitrogen Oxide (NO_x)-Based Estimates	25
3.5.1	Data Sources	25
3.5.2	Unit Conversions	26
3.5.3	Calculation Methodology	26
3.5.4	Calculation Results	28
3.5.5	Data Verification and Treatment of Assumptions	28
3.5.6	Limitations	28
4.	Confidence Framework and Data Reliability	30
4.1	Purpose and Structure	30
4.2	Evaluation Criteria	30
4.3	Confidence Scoring by Methodology	32
4.4	Dataset-Level Distribution	34
5.	Diesel Cost Estimates	36
5.1	Overview of Diesel Cost Estimates	36
5.2	Data Sources	36
5.3	Calculation Method	36
5.4	Calculation Results	36
6.	Conclusions	38
6.1	Overview and Study Framework	38
6.2	Dataset Findings and Methodological Insights	38
6.3	Data Gaps, Future Opportunities, and Strategic Implications	39
	References	41

List of Figures

Figure 2-1. Geographic Distribution of Prominent U.S. Open-pit Mine Sites with Diesel Estimates.	9
Figure 5-1. Diesel prices in the county where mines are located (representative of October 21, 2025).....	37

List of Tables

Table 2-1. Estimated Annual Diesel Consumption and Confidence Levels for U.S. Open-Pit Mines	6
Table 3-1. Estimated Annual Diesel Consumption for Mines with Directly Reported Values from Company Sustainability Disclosures.....	11
Table 3-2. Estimated Annual Diesel Consumption for Mines Derived from Avoided CO ₂ Emissions (Renewable Diesel Substitution)	15
Table 3-3. Annual and Three-Year Average Diesel Consumption for the Hibbing Taconite Mine	16
Table 3-4. Estimated Diesel Consumption for Minnesota and Michigan Iron Ore Mines (Pellet Proxy Method).....	18
Table 3-5. U.S. EPA Emission Factors for Diesel Combustion (Construction/Mining Equipment)	20
Table 3-6. Estimated Diesel Consumption for Ray and Nevada Gold Mines (Scope 1 and 2 CO ₂ e Back-Calculation).....	24
Table 3-7. Estimated Diesel Consumption for Mission Complex Copper Mine and CC&V Gold Mine (NOx Emissions Back-Calculation)	28
Table 4-1. Assumption Categories and Their Application Across Diesel Estimation Methods	30
Table 4-2. Confidence Scoring Framework for Diesel Estimation Methodologies	33

Acronyms and Abbreviations

AAA	American Automobile Association
AFDC	Alternative Fuels Data Center
ANL	Argonne National Laboratory
ASARCO	American Smelting and Refining Company L.L.C.
BSFC	Brake Specific Fuel Consumption
Btu	British Thermal Unit
CDC	Centers for Disease Control and Prevention
CC&V	Cripple Creek & Victor
CH ₄	Methane
CO ₂	Carbon Dioxide
CO ₂ e	Carbon Dioxide Equivalent
Cu	Copper
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
ESG	Environmental, Social, and Governance
GHG	Greenhouse Gas
GJ	Gigajoule
GWP	Global Warming Potential
HF Sinclair	HollyFrontier Sinclair Corporation (Renewable Diesel Producer)
Hibtac	Hibbing Taconite
Keetac	Keewatin Taconite
KMZ	Keyhole Markup Language Zipped (Google Earth File Format)
kWh	Kilowatt-Hour
L	Liter
LCA	Life-Cycle Assessment
LHV	Lower Heating Value
LT	Long Ton (Dry)
MJ	Megajoule
MDO	Mining Data Online
MSHA	Mine Safety and Health Administration
N ₂ O	Nitrous Oxide
NGM	Nevada Gold Mines
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NMHC	Non-Methane Hydrocarbon
NO _x	Nitrogen Oxides
OBD	On-board Diagnostics
PCDEQ	Pima County Department of Environmental Quality
PJ	Petajoule
SEC	U.S. Securities and Exchange Commission
SI	International System of Units (Système International d'Unités)

SSR	SSR Mining Inc.
t	Metric Tonne
tCO ₂ e	Metric Tonne of Carbon Dioxide Equivalent
U.S.	United States
USGS	U.S. Geological Survey
WGS84	World Geodetic System 1984
WLT	Wet Long Ton
WRI	World Resources Institute
WBCSD	World Business Council for Sustainable Development

Abstract

This report presents a comprehensive framework for estimating diesel fuel consumption and prices at open-pit mines in the United States. The framework includes transparent methods for calculating site-level diesel energy use when direct reporting is unavailable, and a structured confidence evaluation for each method. The framework is demonstrated to estimate current diesel consumption at 21 open-pit mines in the United States. Initial findings support ongoing efforts to strengthen the competitiveness and security of the U.S. industrial base by supporting data-driven supply chain analysis and decision-making, improved transparency in mining-sector energy use, and targeted deployment of energy innovation and cost-reduction strategies. Future updates to the dataset—coupled with expanded data transparency and method validation—will help ensure that the findings remain relevant as the sector continues to evolve.

1. Introduction

Mining is broadly defined as the extraction of minerals and ores from within the earth's crust (as cited in Worlanyo & Jiangfeng, 2021, p. 1). There are two primary categories of mining: underground and surface mining. Underground mining involves digging deep shafts or tunnels to reach mineral and ore deposits located far beneath the earth's surface. In contrast, surface mining removes the overlying soil and rock (overburden) to access resources near the earth's surface. Common surface mining techniques include strip mining, mountaintop removal, and open-pit mining (Worlanyo & Jiangfeng, 2021).

This report focuses on open-pit mining, a method in which minerals and ores are extracted from a large, terraced pit excavated in concentric layers that descend into the earth (Cummins, Inc., n.d.). Open-pit mining typically involves three main phases: exploration and extraction, material handling, and beneficiation and processing (Purhamadani et al., 2021). During the extraction phase, explosives are often used to fracture the rock, allowing mineral-bearing and waste material to be hauled out of the pit. This technique is commonly applied to deposits such as copper, gold, and iron ore that are near the surface but extend deeper or lack horizontal layering. Compared to strip mining, open-pit mines tend to have a smaller surface footprint (Cummins, Inc., n.d.).

Surface mining accounts for the vast majority of mining operations in the United States. There were 12,721 total mining operations in the United States in 2024 (Mine Health and Safety Administration, n.d.).¹ Historical U.S. Mine Safety and Health Administration (MSHA) data indicate that surface mines have consistently represented the dominant share of U.S. mining activity. In 2021, MSHA data compiled by the National Institute for Occupational Safety and Health (NIOSH) of the Center for Disease Control and Prevention (CDC) reported 12,567 total mines, of which 12,103 (96.3%) were surface mines (Centers for Disease Control and Prevention, 2025b, 2025a). Applying this proportion to 2024 mine counts suggests that approximately 11,975 of the mines active in 2024 are surface operations.

While MSHA does not publish a distinct figure for open-pit mines as a subset of surface mines, according to the U.S. Geological Survey (USGS), most key minerals mined in the United States are primarily extracted through open-pit methods, including: crushed stone, sand and gravel, metals (e.g., iron ore, copper, gold, zirconium, and rare earths, such as bastnaesite), and non-metals (e.g., boron, pumice, pumicite, and kyanite) (U.S. Geological Survey, 2025). Together, these represent 11,364 sites, or 93.8%, of all U.S. surface mines in 2021 (Centers for Disease Control and Prevention, 2025b, 2025a). Carrying this ratio forward to the 2024 data, it can be assumed that approximately 11,215 surface mines in the United States in 2024 use open-pit methods. This is roughly 90% of all U.S. mines in 2024, reflecting the dominance of surface mining and the prevalence of open-pit methods for key mineral commodities (Centers for Disease Control and Prevention, 2025b, 2025a; U.S. Geological Survey, 2025).

¹ MSHA's 2024 mine count data do not distinguish between surface and underground operations. Historical MSHA mine classifications are therefore used to estimate the 2024 surface mine count.

The mining sector also plays an important role in the U.S. economy, including domestic employment, and international trade. In 2024, U.S. mines (underground and surface) produced minerals worth approximately \$133.3 billion. The sector directly employed 315,340 mine workers, plus 86,030 in support activities and 82,216 in transportation, for a total of 487,586 direct jobs. When indirect and induced impacts are included, total employment reached 1,321,764 jobs nationwide. The most recent detailed economic impact data (2021) show the industry contributed \$194.4 billion to U.S. gross domestic product (GDP)—\$93.6 billion in direct effects and \$100.9 billion from indirect and induced activity—supported by \$81.57 billion in labor income and \$41 billion in tax payments (National Mining Association, 2025).

Diesel is the single largest energy source in U.S. mining, used primarily for mobile equipment and machinery, and accounts for roughly 34% of the industry's total annual energy consumption (about 447 PJ/year or 424 trillion Btu/year), followed by electricity (about 32%) and natural gas (about 22%), with the remaining 12% from other energy sources, such as coal, fuel oil, and gasoline (U.S. Department of Energy, 2007). The type and proportion of energy sources used at an individual mine site depends on the mine type (surface or underground) and on the processes employed. According to the U.S. DOE study, diesel consumption dominates the materials handling stage of mining (i.e., loading and haulage), accounting for 87% of total materials handling energy use. In general, diesel powers rubber-tired or tracked vehicles responsible for moving material and grading and, including service trucks, front-end loaders, bulldozers, pick-up trucks, bulk trucks, and rear-dump haul trucks (U.S. Department of Energy, 2007).

Given that approximately 90% of all U.S. mines are open-pit operations, diesel-intensive surface mining represents a critical nexus between energy supply, mineral production, and broader economic activity (U.S. Department of Energy, 2007; Centers for Disease Control and Prevention, 2025b, 2025a; U.S. Geological Survey, 2025; National Mining Association, 2025). Diesel is not only central to day-to-day mining operations, but also represents a potential point of vulnerability, as fluctuations in diesel availability or price can affect production costs, operational continuity, and the competitiveness of domestic mineral supply chains. Understanding where and how diesel is consumed across prominent open-pit mines is therefore essential for assessing energy risks, identifying efficiency opportunities, and informing strategies to strengthen the resilience of the U.S. mining sector.

Against this backdrop, this study develops a standardized framework for estimating diesel consumption at prominent U.S. open-pit mines, including cases where direct diesel reporting is unavailable. By combining multiple estimation approaches with a structured confidence framework and representative diesel cost data, the analysis supports improved transparency and comparability of diesel energy use across the U.S. mining sector.

1.1 Study Objective

Given diesel's dominant role in powering open-pit mining operations and its significant share of total U.S. mining energy use, there is a clear need to quantify diesel consumption more

precisely at individual mine sites. The objective of this study is to estimate diesel consumption at major open-pit mine sites using a consistent, multi-source, and quality-rated framework. This work also develops and applies methodologies to estimate diesel energy consumption when directly reported fuel data is unavailable, ensuring comparability and transparency across sites. Multiple calculation approaches—drawing on reported data, emissions records, production statistics, and engineering proxies—are evaluated and assigned confidence levels based on the number and type of assumptions required. In addition to quantifying diesel use, this study also evaluates county-level diesel price data to develop representative cost estimates for each mine location. These cost estimates provide important context for understanding the economic implications of diesel consumption, regional variability in fuel costs, and potential opportunities to enhance operational efficiency and competitiveness within the mining sector. More broadly, combining site-level diesel consumption estimates with cost data helps address a persistent data gap in facility-level energy intensity information, which is increasingly important for supply chain analysis, life-cycle assessment (LCA), and industrial decision-making. By establishing these standardized estimation methods and confidence criteria, the study creates a replicable process for quantifying diesel consumption at open-pit mines nationwide, enabling a more accurate, comprehensive understanding of diesel energy use across U.S. surface mining operations, even in cases where direct fuel reporting is absent.

2. Dataset Overview

This section describes the construction and structure of the dataset used in the analysis, including mine selection criteria, dataset adjustments, key variables, and geographic representation. The intent is to document how the set of prominent U.S. open-pit mines was defined and standardized prior to applying the diesel estimation methodologies. By establishing a consistent dataset foundation, this section supports transparency, reproducibility, and interpretation of the diesel consumption estimates that follow.

2.1 Mine Site Selection

This analysis of diesel consumption at U.S. open-pit mines began with the Pennsylvania State University (Penn State) *List of 20 Open-Pit Mines in the United States* as the reference set (Kohler, n.d.). These mines were selected by Penn State's College of Earth and Mineral Science due to one of the following factors: physical scale, production volume, or historical significance, rather than being selected based on a single metric. The mines are primarily metal operations concentrated in Nevada (gold) and Arizona (copper) (S. Bhattacharyya, personal communication, August 27, 2025). This initial reference list was subsequently refined through a defined selection and adjustment process, described in Section 2.1.1, to ensure consistency with the study scope and data availability.

2.1.1 Dataset Adjustments

To ensure that the study focused on active large-scale operations with measurable diesel use, several adjustments were made. A number of mines on the Penn State list were removed because they were either consolidated into larger complexes or no longer engaged in active mining, while additional mines were added where reliable data on diesel consumption was available.

Two Nevada mines—Cortez Complex Mine and Goldstrike Mine Complex—were removed because they are now encompassed within the larger Nevada Gold Mines (NGM) joint venture owned by Barrick Gold Corporation (61.5%) and Newmont Corporation (38.5%) (Barrick Gold Corporation, 2024). Including them separately would have led to double counting. Several other sites were excluded due to the fact they were not currently mining ore. The Ruby Hill Mine in Nevada owned by iGold Corporation, for example, is no longer operating as an active open-pit gold mine and is limited to residual heap leaching ((i-80 Gold Corp., 2024)). Similarly, the Miami Mine in Arizona, owned by Freeport-McMoRan Inc. continues to produce copper through leaching of stockpiles but does not operate a diesel-powered mining fleet (Mining Data Online Inc., 2025). The Mineral Park Mine in Arizona, an open-pit copper mine owned by Origin Mining Corporation, is undergoing redevelopment, with current activity limited to heap leaching, while the concentrator remains on care and maintenance until a planned restart in 2025 (Origin Mining Company, n.d.; Wheaton Precious Metals, n.d.-a, n.d.-b). The Hycroft Mine in Nevada, an open-pit gold mine owned by Hycroft Mining Holding Corporation, is also not in commercial production; activities there are restricted to exploration, technical studies, and site maintenance (Hycroft Mining Holding Corporation, 2024).

In contrast, two important sites absent from the Penn State list were added to this study. The first is the Pinto Valley Mine in Arizona. Owned by Capstone Copper Corporation, Pinto Valley is a large-scale open-pit copper operation with publicly available diesel consumption data, making it a valuable addition (Capstone Copper Corp., 2024). The other is the United Taconite Mine in Minnesota. Owned by Cleveland-Cliffs Corporation, it is one of the country's largest iron ore operations and has publicly available data on iron ore pellet production which can be used to approximate diesel fuel consumption (Minnesota Department of Revenue, 2024). These adjustments were made to improve the accuracy and representativeness of the dataset by ensuring that the mines included are both operationally significant and supported by reliable information on diesel use.

2.1.2 Dataset Variables

Table 2.1 summarizes the 21 mines retained in the study. The table presents mine name, location (county and state), latitude and longitude of the approximate mine centroid, mine owner, primary commodity of the mines, estimated annual diesel consumption (Gigajoules (GJ)/year), and the associated confidence level. Information on mine location (county and state) was obtained primarily from company sustainability reports and related corporate disclosures. These attributes were then cross-checked and verified using Google Earth or Google Maps to ensure accuracy of site identification. Mine ownership, and primary commodity were also obtained from company sustainability reports and related corporate disclosures. To ensure consistency across sites, annual diesel consumption is shown for calendar year 2023. The Kennecott Copper Mine is the sole exception, for which diesel consumption is shown for calendar year 2024. The confidence level, developed by the Berkeley Lab research team, is based on standardized methods that integrate reported data, emissions records, and production statistics, and is assigned according to the number and type of assumptions required; this methodology will be discussed in detail later in the report. Table 2.1 presents a consolidated set of site-level estimated values used throughout the report; the underlying estimation methodologies and corresponding results are presented in detail in Section 3.

2.1.3 Mine Location Coordinates

Latitude and longitude values for each mine site were determined using Google Earth Pro (World Geodetic System 1984 (WGS84) geographic coordinate system) (Wilkerson, 2024). Including location coordinates enables consistent site identification, supports geospatial visualization of diesel consumption patterns, and facilitates regional comparison and linkage to county-level attributes such as diesel prices. The coordinates represent the approximate centroid of the active open-pit area as visible in high-resolution satellite imagery. This method was chosen to provide a consistent geographic reference point across all mines in the dataset.

The use of Google Earth provides transparency and replicability, but values should be considered approximate given ongoing mine expansion and reclamation activities, which may alter pit boundaries over time. The coordinate data are sufficient for regional-scale mapping and comparative analysis of diesel consumption but are not intended for precise engineering or surveying applications (Szum, 2025).

Table 2-1. Estimated Annual Diesel Consumption and Confidence Levels for U.S. Open-Pit Mines

#	Mine Name	County	State	Latitude (°N)	Longitude (°W)	Owner	Primary Commodity	Estimated Annual Diesel Consumption (GJ / Year) ²	Confidence Level for Estimated Annual Diesel Consumption
1	Bagdad Mine	Yavapai County	AZ	34.352202	-113.122338	Freeport-McMoRan Corporation	Copper	2,187,700	High
2	Chino/Cobre Mine	Grant County	NM	32.473169	-108.042224	Freeport-McMoRan Corporation	Copper	1,042,900	High
3	Kennecott Copper Mine ³	Salt Lake County	UT	40.312529	-112.081635	Rio Tinto Group ⁴	Copper	6,568,199	Moderate
4	Mission Complex Mine	Pima County	AZ	31.989259	-111.057683	Grupo México ⁵	Copper	83,391	Low
5	Morenci Mine	Greenlee County	AZ	33.054702	-109.214295	Freeport-McMoRan Corporation (72%) and the Sumitomo Group (28%) ⁶	Copper	7,075,000	High
6	Pinto Valley Mine	Gila County	AZ	33.4145	-110.964000	Capstone Copper Corporation	Copper	1,413,002	High
7	Ray Mine	Pinal County	AZ	33.110863	-110.590214	Grupo México ⁷	Copper	1,849,059	Low
8	Safford/Lone Star Mine	Graham County	AZ	32.574462	-109.402360	Freeport-McMoRan Corporation	Copper	2,857,100	High
9	Sierrita Mine	Pima County	AZ	31.520663	-111.075082	Freeport-McMoRan Corporation	Copper	1,675,000	High
10	Tyrone Mine	Grant County	NM	32.382828	-108.223116	Freeport-McMoRan Corporation	Copper	584,000	High

² Diesel consumption values reflect calendar year 2023 for all sites, except Kennecott Copper Mine, which is reported for calendar year 2024.

³ Kennecott Copper Mine is also referred to as Bingham Canyon Mine.

⁴ Kennecott Copper Mine is owned by Rio Tinto Group through its subsidiary Kennecott Utah Copper L.L.C.

⁵ Mission Complex Mine is owned by Grupo Mexico through its subsidiary ASARCO L.L.C.

⁶ Morenci Mine is 28% owned by Sumitomo Group through its subsidiaries, Sumitomo Metal Mining (SMM) Arizona Inc. (15%) and SMM Morenci Inc. (13%).

⁷ Ray Mine is owned by Grupo Mexico through its subsidiary ASARCO L.L.C.

11	Bald Mountain Mine	White Pine County	NV	39.564289	-115.372149	Kinross Gold Corporation	Gold	1,380,770	High
12	Cripple Creek & Victor (CC&V) Gold Mine	Teller County	CO	38.440117	-105.085028	SSR Mining Corporation	Gold	858,716	Low
13	Fort Knox Mine	Fairbanks County	AK	65	-147.358000	Kinross Gold Corporation	Gold	2,614,975	High
14	Marigold Mine	Humboldt County	NV	40.433999	-117.100917	SSR Mining Corporation	Gold	1,805,498	High
15	Nevada Gold Mines (NGM) ⁸	Elko County	NV	40.495197	115.470335	Barrick Gold Corporation (61.5%), Newmont Corporation (38.5%)	Gold	9,759,485	Low
16	Round Mountain Mine ⁹	Nye County	NV	38.414701	-117.051623	Kinross Gold Corporation	Gold	1,654,246	High
17	Hibbing Taconite (Hibtac) Mine	St. Louis County	MN	47.46000	-92.95833	Cleveland-Cliffs Corporation (85.3%), U.S. Steel Corporation (14.7%)	Iron ore	856,268	Moderate
18	Keewatin Taconite (Keetac) Mine	Itasca County	MN	47.42003	-93.075038	U.S. Steel Corporation	Iron ore	638,769	Moderate
19	Minntac Mine	St. Louis County	MN	47.322673	-92.385324	U.S. Steel Corporation	Iron ore	1,704,729	Moderate
20	Tilden Mine	Marquette County	MI	46.447038	-87.636562	Cleveland-Cliffs Corporation	Iron ore	1,048,224	Moderate
21	United Taconite Mine	St. Louis County	MN	47.291010	-92.3252.09	Cleveland-Cliffs Corporation	Iron ore	652,270	Moderate

⁸ NGM, located in northeastern Nevada, comprises multiple open-pit and underground operations across several counties. NGM includes active, care and maintenance, and closed sites. The six active open-pit mines include: Cortez Complex, Gold Quarry Mine, Phoenix Mine, Twin Creeks Mine, Goldstrike Mine, and Carlin Complex Mine. The primary hub for NGM is its headquarters, located in Elko County, Nevada. Given the disparate locations for these mines, for this database, latitude and longitude coordinates were provided for the NGM headquarters in Elko County (Barrick Gold Corporation, 2024).

⁹ Round Mountain Mine is also referred to as the Smoky Valley Common Operations.

2.1.4 Visualization Overview

In addition to the tabular dataset, a geospatial visualization was developed to facilitate interpretation of mine-level diesel consumption in a regional context (Figure 2.1). Latitude and longitude values for each site were determined using Google Earth Pro, with coordinates representing the approximate centroid of the active open-pit area (see Section 2.1.3). These geographic reference points were combined with diesel consumption estimates derived from the standardized methodologies described later in this report to construct a map-based representation of the dataset. The visualization makes it possible to identify spatial clustering of operations as well as relative differences in diesel consumption intensity, highlighting, for example, concentrations of gold mining in Nevada and copper mining in Arizona, alongside major iron ore mines in Minnesota and Michigan and large gold operations in Alaska and Colorado.

2.1.5 Geographic Distribution of Diesel Consumption

Figure 2.1 presents estimated annual diesel energy consumption at prominent U.S. open-pit mines. Circle size is scaled to reflect consumption magnitude (GJ/year), while circle color conveys the primary commodity mined at the site. Light brown represents copper; yellow represents gold; and dark brown represents iron ore. The map integrates mine-level geographic centroids with calculated diesel consumption values, allowing readers to assess both the relative scale of diesel use across mining regions and the mineral consumed. By situating tabular data in a spatial framework, the visualization supports comparison across commodities and regions, and underscores the methodological link between coordinate-based site identification and diesel estimation procedures.

With the dataset defined and standardized, the following section applies a set of transparent, site-level methodologies to estimate diesel consumption across the selected open-pit mines.

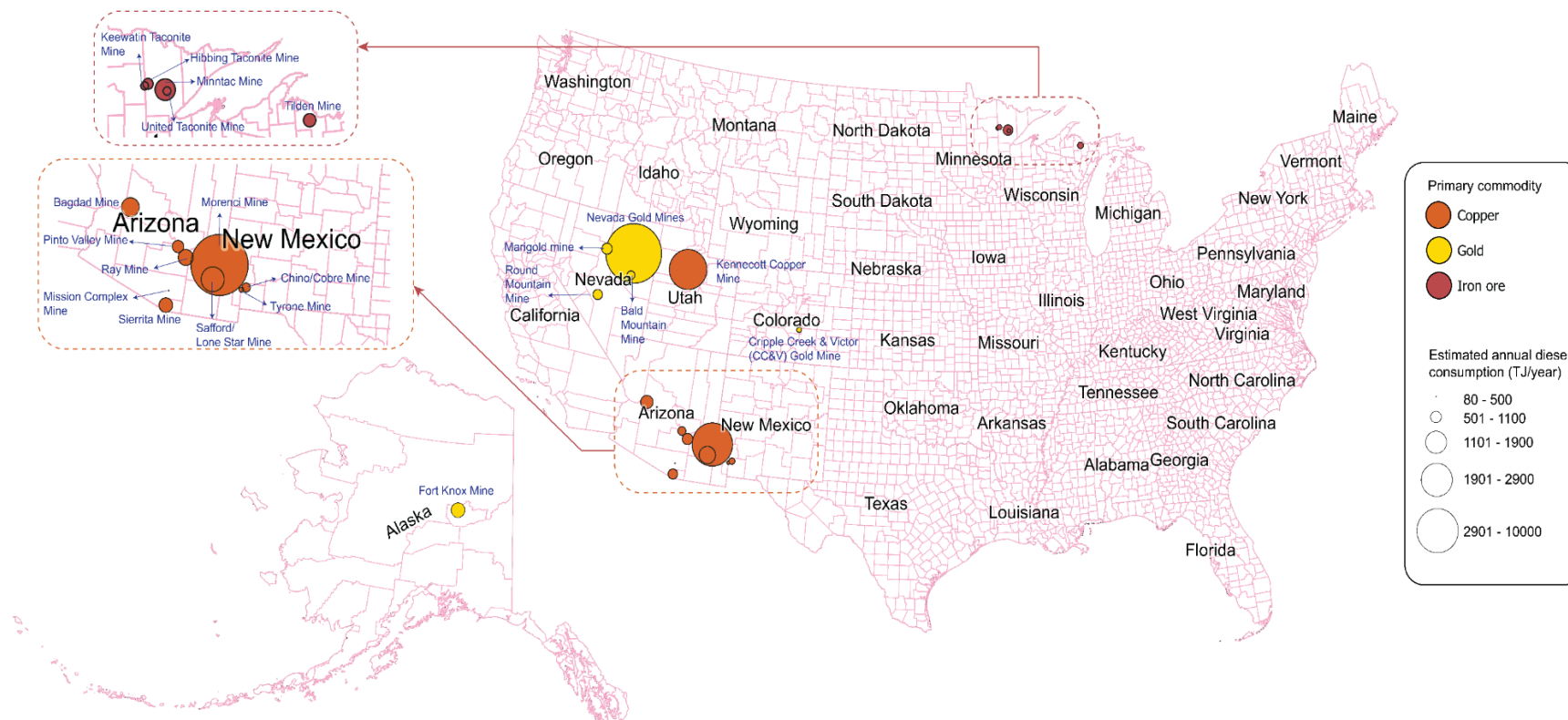


Figure 2-1. Geographic Distribution of Prominent U.S. Open-pit Mine Sites with Diesel Estimates.¹⁰

¹⁰ Refer to the main U.S. map for estimated annual diesel consumption by mine. Circle sizes in the inset maps are for visual reference only and are not scaled to diesel consumption.

3. Diesel Fuel Use Estimation by Methodology and Results

This analysis develops site-level estimates of annual diesel consumption for 21 prominent, active U.S. open-pit mines. Estimates were derived from multiple data sources and standardized calculation methods, with each approach assigned a confidence level based on the transparency and assumptions involved. To ensure comparability across sites, the methodology is organized into the following elements: (1) data sources used to compile reported or estimated diesel consumption values, (2) unit conversions applied to express results in common energy terms, (3) the calculation methodology (when diesel consumption is not directly reported), (4) results of the calculation methodology, (5) data verification procedures to confirm the integrity of reported or derived values, and (6) limitations reflecting variability in corporate reporting practices and estimation assumptions. The following subsections describe each estimation pathway in detail.

3.1 Reported Diesel Data

This method draws on directly reported diesel consumption from company sustainability disclosures, which provide verifiable records of mine-level fuel use. For 11 of the 21 open-pit mines analyzed (52%), companies disclosed diesel consumption in their publicly available sustainability reports. These data provide a direct record of on-site diesel use, and because they are drawn from corporate disclosures, represent the most transparent and verifiable information available for estimating diesel energy demand in the U.S. mining sector.

3.1.1 Data Sources

Reported values were compiled for Freeport-McMoRan operations (Bagdad, Chino/Cobre, Morenci,¹¹ Safford/Lone Star, Sierrita, and Tyrone); Capstone Copper's Pinto Valley Mine; Kinross Gold's Bald Mountain, Fort Knox, and Round Mountain Mines; and SSR Mining's Marigold Mine (Capstone Copper Corp., 2024; Freeport-McMoRan Inc., 2024; Kinross Gold Corporation, 2024; SSR Mining Inc., 2024). Together, these eleven sites comprise the subset of mines for which diesel consumption is directly reported, forming the high-confidence segment of the dataset.

3.1.2 Unit Conversions

Annual diesel consumption reported in liter (L) can be converted into GJ of energy using a representative Lower Heating Value (LHV) of diesel. The U.S. DOE *Alternative Fuels Data Center (AFDC) Fuel Properties Comparison* reports diesel LHV as 128,488 Btu per U.S. gal (U.S. Department of Energy, Alternative Fuels Data Center, 2024). Using International System of Units (SI) conversion factors, 1 Btu = 1,054.35 joules (J) and 1 U.S. gallon (gal) = 3.78541 L (UnitConverters.Net, 2025; U.S. Energy Information Administration, 2024), the reported diesel LHV was converted to energy per unit volume. This yields a value of 35.8 megajoules (MJ) per L, equivalent to 0.0358 GJ/L (UnitConverters.Net, 2025). The LHV basis was selected because it reflects the usable energy available during combustion—excluding the latent heat of vaporization of water in the exhaust—and is widely applied in transportation energy studies and models, including with Argonne National Laboratory (ANL) *Greenhouse Gases, Regulated*

¹¹ Morenci Mine is majority owned by Freeport-McMoRan Corporation (72%) and minority owned by Sumitomo Group subsidiaries (28%).

Emissions, and Energy Use in Transportation (GREET®) Model input fuel specifications (Argonne National Laboratory, 2025). We note this value can vary by region and by season.

3.1.3 Calculation Methodology

- **Step 1. Convert the LHV of diesel fuel from Btu to J.**

$$128,488 \text{ Btu/gal} \times 1,054.35 \text{ J/Btu} = 135,527,000 \text{ J/gal}$$

- **Step 2. Convert J per gal to MJ per L.**

$$135,527,000 \text{ J/gal} \div 3.78541 \text{ L/gal} = 35.8 \text{ MJ/L}$$

- **Step 3. Convert MJ per L to GJ per L.**

$$35.8 \text{ MJ/L} \div 1,000 = 0.0358 \text{ GJ/L}$$

This standard LHV conversion factor (0.0358 GJ/L) is applied uniformly across all subsequent estimation methods.

3.1.4 Calculation Results

Estimated annual diesel consumption for the eleven mines for which directly reported diesel consumption was available in company sustainability disclosures is shown in Table 3.1 below.

Table 3-1. Estimated Annual Diesel Consumption for Mines with Directly Reported Values from Company Sustainability Disclosures.

#	Mine Name	County	State	Latitude (°N)	Longitude (°W)	Owner	Primary Commodity	Estimated Annual Diesel Consumption (GJ / Year) ¹²	Confidence Level for Estimated Annual Diesel Consumption
1	Bagdad Mine	Yavapai County	AZ	34.352202	-113.122338	Freeport-McMoRan Corporation	Copper	2,187,700	High
2	Chino/Cobre Mine	Grant County	NM	32.473169	-108.042224	Freeport-McMoRan Corporation	Copper	1,042,900	High
5	Morenci Mine	Greenlee County	AZ	33.054702	-109.214295	Freeport-McMoRan Corporation (72%) and the Sumitomo Group (28%) ¹³	Copper	7,075,000	High

¹² Diesel consumption values reflect calendar year 2023 for all sites, except Kennecott Copper Mine, which is reported for calendar year 2024.

¹³ Morenci Mine is 28% owned by Sumitomo Group through its subsidiaries, Sumitomo Metal Mining (SMM) Arizona Inc. (15%) and SMM Morenci Inc. (13%).

6	Pinto Valley Mine	Gila County	AZ	33.4145	-110.964	Capstone Copper Corporation	Copper	1,413,002	High
8	Safford/Lone Star Mine	Graham County	AZ	32.574462	-109.40236	Freeport-McMoRan Corporation	Copper	2,857,100	High
9	Sierrita Mine	Pima County	AZ	31.520663	-111.075082	Freeport-McMoRan Corporation	Copper	1,675,000	High
10	Tyrone Mine	Grant County	NM	32.382828	-108.223116	Freeport-McMoRan Corporation	Copper	584,000	High
11	Bald Mountain Mine	White Pine County	NV	39.564289	-115.372149	Kinross Gold Corporation	Gold	1,380,770	High
13	Fort Knox Mine	Fairbanks County	AK	65	-147.358	Kinross Gold Corporation	Gold	2,614,975	High
14	Marigold Mine	Humboldt County	NV	40.433999	-117.100917	SSR Mining Corporation	Gold	1,805,498	High
16	Round Mountain Mine ¹⁴	Nye County	NV	38.414701	-117.051623	Kinross Gold Corporation	Gold	1,654,246	High

3.1.5 Data Verification and Treatment of Assumptions

For the eleven mines listed in Table 3.1, company-reported diesel consumption values were used. No proxy estimation was applied to these sites. In cases of joint ownership (e.g., Morenci Mine, with 72% majority ownership by Freeport-McMoRan and 28% minority ownership by Sumitomo Group subsidiaries), the full mine-level diesel consumption was retained rather than prorated by ownership share (Freeport-McMoRan Inc., 2024). This approach ensures that all values are reported on a consistent site-level basis, enabling comparability across the dataset.

3.1.6 Limitations

Although the reported values are drawn directly from company sustainability reports, variations in reporting methodologies and boundary definitions may affect comparability across mines. For example, some companies may include all diesel equipment (e.g., haul trucks, loaders, dozers, smelters, and other support equipment), while others report only haul-truck diesel use. Because diesel consumption in open-pit mining is concentrated in mobile materials-handling activities (Purhamadani et al., 2021; U.S. Department of Energy, 2007), sites reporting only a subset of fuel use—such as haul-truck diesel or stationary equipment fuel—may underrepresent total diesel consumption across the mine. These differences introduce potential uncertainty in cross-

¹⁴ Round Mountain Mine is also referred to as the Smoky Valley Common Operations.

site comparisons. Despite these limitations, direct reporting remains the most transparent and verifiable data source currently available.

3.2 Renewable Diesel Carbon Dioxide (CO₂)-Based Estimates

While direct reporting of diesel consumption (Table 3.1) provides the most reliable basis for quantifying mine-level fuel use, not all companies disclose diesel consumption in their sustainability reports. In some cases, companies instead report avoided or reduced greenhouse gas (GHG) emissions associated with operational changes, such as the substitution of fossil diesel with renewable diesel. These disclosures can be used to back-calculate estimates of underlying fossil diesel consumption, offering a complementary method when direct data are unavailable. Table 3.2 applies this approach to Rio Tinto's Kennecott Copper Mine, where reported avoided Scope 1 CO₂ emissions (i.e., direct emissions from on-site fuel combustion) from the transition to renewable diesel were converted into an estimate of total fossil diesel use.¹⁵ The renewable diesel product utilized at the Kennecott Copper Mine was developed by HollyFrontier (HF) Sinclair Corporation and consists of hydrotreated renewable diesel made from animal fats, distillers corn oil, and degummed soybean oil, processed at three U.S. facilities with a combined capacity of approximately 380 million gallons per year (HF Sinclair, 2025).

3.2.1 Data Sources

Estimated fossil diesel consumption for the Kennecott Copper Mine was derived from public disclosures by Rio Tinto announcing the mine's transition from fossil diesel to renewable diesel across its fleet of haul trucks, heavy equipment, concentrator, smelter, refinery, and tailings operations. These reports indicated an expected annual reduction of approximately 495,000 tonnes (t) of Scope 1 CO₂ emissions as a result of replacing fossil diesel with renewable diesel (ESG Today Writing Staff, 2024).¹⁶ Because Rio Tinto explicitly characterizes this reduction as a Scope 1 benefit, the reported avoided emissions are interpreted as reflecting direct combustion (tank-to-wheel) fossil carbon dioxide (CO₂) emissions rather than a full well-to-wheel LCA (Ranganathan et al., 2004). Accordingly, no life-cycle adjustment to the reported avoided emissions is applied in this calculation. To convert this avoided emissions figure into an estimate of total fossil diesel consumption, additional reference sources were used, including the U.S. Environmental Protection Agency (EPA) Emission Factors for GHG Inventories (U.S. Environmental Protection Agency, 2024).

¹⁵ According to the *GHG Protocol: A Corporate Accounting and Reporting Standard*, Scope 1 comprises direct emissions from sources owned or controlled by the company (e.g., combustion in owned or controlled boilers, furnaces, vehicles, or process equipment) (Ranganathan et al., 2004). This is discussed further in Section 3.4.

¹⁶ Because the reported reduction is framed as a Scope 1 benefit from fuel substitution, it reflects avoided fossil carbon at the point of combustion; the diesel back-calculation therefore uses a direct carbon dioxide (CO₂) combustion emission factor consistent with the Scope 1 boundary.

3.2.2 Unit Conversions

Calculations were standardized to L of diesel and GJ of energy. Fossil diesel was assumed to have an emission factor of 2.698 kilograms (kg) of CO₂ per L, derived from the U.S. EPA emission factor of 10.21 kg CO₂ per U.S. gallon (gal) (U.S. Environmental Protection Agency, 2024), converted using 1 U.S. gal = 3.78541 L (U.S. Energy Information Administration, 2024). Diesel energy content was converted using the LHV of 35.8 MJ per L (0.0358 GJ/L), consistent with the U.S. DOE AFDC and standard SI conversions (UnitConverters.Net, 2025; U.S. Department of Energy, Alternative Fuels Data Center, 2024). Conversion of MJ to GJ and t to kg followed SI relationships (UnitConverters.Net, 2025).

3.2.3 Calculation Methodology

The avoided CO₂ emissions reported by Rio Tinto were used to back-calculate the underlying volume of fossil diesel displaced.

- **Step 1. Obtain emissions factors.** The U.S. EPA specifies an emission factor of 10.21 kg CO₂ per U.S. gal of diesel (U.S. Environmental Protection Agency, 2024), which is equivalent to 2.698 kg CO₂ per L using the standard conversion of 1 U.S. gal = 3.78541 L (U.S. Energy Information Administration, 2024).

- **Step 2. Convert to kg.**

$$495,000 \text{ t} \times 1,000 = 495,000,000 \text{ kg CO}_2$$

- **Step 3. Convert to L of diesel.**

$$495,000,000 \text{ kg CO}_2 \div 2.698 \text{ kg CO}_2/\text{L} = 183,469,236.5 \text{ L diesel}$$

- **Step 4. Convert to energy units (LHV basis).** Diesel energy content is assumed to be 0.0358 GJ/L, based on the LHV (U.S. Department of Energy, Alternative Fuels Data Center, 2024). Multiplying by volume:

$$183,469,236.5 \text{ L} \times 0.0358 \text{ GJ/L} = 6,568,199 \text{ GJ}$$

3.2.4 Calculation Results

Following the estimation methodology above, the estimated total fossil diesel consumed by Kennecott's operations is 6,568,199 GJ. This value is shown in Table 3.2.

Table 3-2. Estimated Annual Diesel Consumption for Mines Derived from Avoided CO₂ Emissions (Renewable Diesel Substitution)

#	Mine Name	County	State	Latitude (°N)	Longitude (°W)	Owner	Primary Commodity	Estimated Annual Diesel Consumption (GJ / Year) ¹⁷	Confidence Level for Estimated Annual Diesel Consumption
3	Kennecott Copper Mine ¹⁸	Salt Lake County	UT	40.312529	-112.081635	Rio Tinto Group ¹⁹	Copper	6,568,199	Moderate

3.2.5 Data Verification and Treatment of Assumptions

This methodology relies on the reported avoided emissions figure as the anchor value. The U.S. EPA emission factor for diesel combustion (10.21 kg CO₂/gal) is a widely used and well-established reference (U.S. Environmental Protection Agency, 2024). No adjustments were made for ownership structure since the mine is wholly operated by Rio Tinto through Kennecott Utah Copper L.L.C. (Rio Tinto, 2025).

3.2.6 Limitations

The derived fossil diesel consumption estimate is an indirect calculation and therefore subject to several uncertainties. It relies on the accuracy and completeness of Rio Tinto's reported 495,000 t CO₂ reduction. If actual reductions are higher or lower, the reconstructed fossil baseline would shift accordingly. Despite these limitations, the estimate offers an important benchmark of the scale of fossil diesel use at a large, integrated U.S. open-pit copper mine and serves as a complement to the directly reported data presented in Table 3.1.

3.3 Diesel / Pellet Proxy Estimates

The third category estimates diesel use based on mine production statistics (e.g., ore moved, waste rock handled) combined with typical fuel intensity factors. These values require more assumptions and introduce greater uncertainty, but offer a systematic means of extending coverage across sites. For Minnesota and Michigan open-pit mines, iron ore pellet production provides a consistent proxy.²⁰ Table 3.3 applies this method to U.S. Steel Corporation's Keewatin Taconite and Minntac operations in Minnesota; Cleveland Cliff's United Taconite and Tilden operations in Minnesota and Michigan (respectively); and the Hibbing Taconite operation in Minnesota, jointly owned by Cleveland-Cliffs (85.3%) and U.S. Steel (14.7%) (Cleveland-Cliffs Inc., 2025; United States Steel Corporation, 2024).

¹⁷ Diesel consumption values reflect calendar year 2023 for all sites, except Kennecott Copper Mine, which is reported for calendar year 2024.

¹⁸ Kennecott Copper Mine is also referred to as Bingham Canyon Mine.

¹⁹ Kennecott Copper Mine is owned by Rio Tinto Group through its subsidiary Kennecott Utah Copper L.L.C.

²⁰ Pellets are small, round balls made from concentrated iron ore, which are heated and hardened into solid form.

3.3.1 Data Sources

Estimated diesel consumption for the five iron ore mines in Minnesota and Michigan was developed using a combination of production data and a standardized diesel intensity benchmark. Reported 2023 pellet production, expressed in long tons (LT), was obtained from the *Minnesota Department of Revenue Mining Tax Guide* for Minnesota open-pit mines (Hibbing Taconite, Keewatin Taconite, Minntac, and United Taconite) and from corporate disclosures for Michigan's Tilden Mine (Minnesota Department of Revenue, 2024; Cleveland-Cliffs Inc., 2025). To translate production into fuel use, a benchmark diesel intensity factor was derived from Cleveland-Cliffs' *Technical Report Summary for Hibbing Taconite* filed with the U.S. Securities and Exchange Commission (SEC). This report provided both diesel consumption and iron ore pellet production data for the Hibbing Taconite Mine for the years 2018 through 2020, enabling calculation of a three-year average diesel intensity factor (L of diesel per wet long ton (WLT) of pellet output) (SLR International Corporation, 2021). That benchmark, shown in Table 3.3 below, was then applied across comparable operations in the Lake Superior iron mining region to generate consistent, mine-level estimates of diesel consumption.

Table 3-3. Annual and Three-Year Average Diesel Consumption for the Hibbing Taconite Mine

	2018	2019	2020	Three-Year Average
Diesel Fuel Consumption (U.S. gal)	7,135,684	7,157,733	5,317,569	6,536,995
Diesel Fuel Consumption (L)	27,011,490	27,094,954	20,129,179	24,745,208
Total Iron Ore Pellets (Wet Long Ton (WLT))	7,799,330	7,473,344	5,454,679	6,909,118
Diesel Usage per Iron Ore Pellet (L/WLT)	3.46	3.63	3.69	3.59

(SLR International Corporation, 2021)

3.3.2 Unit Conversions

Several conversions were required to standardize reported diesel consumption and pellet production data into common energy terms for analysis. At Hibbing Taconite Mine, diesel consumption was originally reported in U.S. gal and converted to L using the standard factor of 1 U.S. gal = 3.78541 L (U.S. Energy Information Administration, 2024). Annual diesel consumption in L was then divided by annual pellet production in WLT to calculate a diesel usage intensity, expressed as L of diesel per WLT of pellet output. Based on Hibbing Taconite's 2018–2020 operating data, this ratio averaged 3.59 L/WLT (SLR International Corporation, 2021).

Because pellet production statistics for Minnesota and Michigan operations are reported in dry LT, the WLT-based benchmark was adjusted to an LT basis using an assumed pellet moisture content of 2%. This assumption is supported by the *Technical Report Summary on the Hibbing Taconite Property*, which states that shipped pellets contain approximately 2% moisture (SLR

International Corporation, 2021). Applying the moisture correction ensures the diesel intensity benchmark is properly aligned with the LT basis used in official production reporting, thereby avoiding overestimation of fuel use. The relationship between wet and dry tonnage is defined as $WLT = LT / (1 - \text{moisture fraction})$, or $WLT = LT / 0.98$. Accordingly, the diesel intensity factor was adjusted as $\text{Diesel per LT} = \text{Diesel per WLT} \times (WLT / LT) = 3.59 \times (1 / 0.98) = 3.66 \text{ L/LT}$.

Finally, L of diesel were converted into energy units using the LHV of 35.8 MJ per L (0.0358 GJ/L), consistent with the U.S. DOE AFDC and standard SI conversion factors (UnitConverters.Net, 2025; U.S. Department of Energy, Alternative Fuels Data Center, 2024). Conversion from MJ to GJ followed standard SI relationships (UnitConverters.Net, 2025). This chain of conversions produced a standardized diesel intensity benchmark of 3.66 L/LT, equivalent to 0.131 GJ/LT of iron ore pellet output.

3.3.3 Calculation Methodology

- **Step 1. Establish diesel-per-ton benchmark.** From Hibbing Taconite's 2018–2020 records, average diesel use was 3.59 L per WLT of pellets produced.
- **Step 2. Adjust for pellet moisture.** Pellet production data are reported as dry long tons (LT), requiring a conversion from WLT to LT. Assuming 2% pellet moisture (SLR International Corporation, 2021):

$$\text{Diesel per LT} = 3.59 \times (1 / (1 - 0.02)) = 3.66 \text{ L/LT}$$

- **Step 3. Apply benchmark to production.** The proxy factor of 3.66 L/LT was multiplied by 2023 pellet production at each mine.

$$\text{Diesel Consumption (L)} = \text{Pellet Production (LT)} \times 3.66 \text{ L/LT}$$

- **Step 4. Convert to energy terms.** L of diesel were converted into GJ using the factor of 0.0358 GJ/L.

3.3.4 Calculation Results

Utilizing this methodology, the resulting diesel consumption for each iron ore pellet mine is shown in Table 3.4 below.

Table 3-4. Estimated Diesel Consumption for Minnesota and Michigan Iron Ore Mines (Pellet Proxy Method)

#	Mine Name	County	State	Latitude (°N)	Longitude (°W)	Owner	Primary Commodity	Estimated Annual Diesel Consumption (GJ / Year) ²¹	Confidence Level for Estimated Annual Diesel Consumption
17	Hibbing Taconite (Hibtac) Mine	St. Louis County	MN	47.46000	-92.95833	Cleveland-Cliffs Corporation (85.3%), U.S. Steel Corporation (14.7%)	Iron ore	856,268	Moderate
18	Keewatin Taconite (Keetac) Mine	Itasca County	MN	47.42003	-93.075038	U.S. Steel Corporation	Iron ore	638,769	Moderate
19	Minntac Mine	St. Louis County	MN	47.322673	-92.385324	U.S. Steel Corporation	Iron ore	1,704,729	Moderate
20	Tilden Mine	Marquette County	MI	46.447038	-87.636562	Cleveland-Cliffs Corporation	Iron ore	1,048,224	Moderate
21	United Taconite Mine	St. Louis County	MN	47.291010	-92.3252.09	Cleveland-Cliffs Corporation	Iron ore	652,270	Moderate

3.3.5 Data Verification and Treatment of Assumptions

The Hibbing Taconite benchmark was checked against the original three-year reporting record to confirm that the 3.66 L/LT factor is representative. SI conversions (Btu to joules; U.S. gal to L) were verified against both U.S. DOE AFDC values and UnitConverters.net.

3.3.6 Limitations

The pellet proxy methodology introduces several sources of uncertainty. The diesel-per-ton factor is based on Hibbing Taconite's historical data and may not capture operational differences at other mines, such as haul distances, fleet efficiency, or mine depth. The 2% moisture assumption may vary by mine or year (SLR International Corporation, 2021), and deviations would affect the LT/WLT conversion. Production data reflect annual totals that may mask intra-annual variability. Because results are proxy-based rather than directly reported values, they should be treated as moderate confidence estimates. Nevertheless, this approach provides a transparent and standardized method for estimating diesel demand across U.S. iron ore pellet operations where direct reporting is unavailable.

When considering gold and copper mines, activity is not represented as pellet production, but rather metal in a concentrated or final refined form. For example, the *2018 USGS Minerals*

²¹ Diesel consumption values reflect calendar year 2023 for all sites, except Kennecott Copper Mine, which is reported for calendar year 2024.

Yearbook for Copper provides estimates of recoverable primary copper metal production capacity in metric tonnes (Flanagan, 2022). Data on mine productivity varies by mine and even by project within a single mine, with public data largely sourced from company reports, news reports, and limited data samples from market intelligence groups, such as MDO (Flanagan, 2022; Mining Data Online Inc., 2025). Across these sources, the method of measurement used to report copper production is inconsistent, making it challenging to conduct fair cross comparisons. For example, copper productivity is reported in terms of: “capacity”; “ore production”; “copper concentrate”, “metal in concentrate”, “cathode grade copper”, “payable metal”, with these variables reported at either annual or “life of mine” time-scales. Ore grade is necessary for converting capacity to ore, and the efficiency of beneficiation and post processing is needed to convert copper concentrate or ore grade to capacity or final product. Capacities may reflect the sizing of key equipment, such as storage facilities or electrowinning processes. In some cases annual production is based on a reported year, or a projection for the early-, final-, or average-years of the mine life (Flanagan, 2022). Converting these activity levels will require careful selection of diesel consumption conversion factors for the appropriate mining activities of a select site.

3.4 Scope 1 and 2 Carbon Dioxide Equivalent (CO₂e)-Based Estimates

According to the *GHG Protocol: A Corporate Accounting and Reporting Standard*, Scope 1 comprises direct GHG emissions from sources owned or controlled by the company (e.g., combustion in owned or controlled boilers, furnaces, vehicles, or process equipment). Scope 2 comprises indirect GHG emissions from the generation of purchased electricity, steam, heating, and cooling consumed by the company, with the associated emissions occurring at the generating facility. Electricity purchased for resale is reported under Scope 3 (Ranganathan et al., 2004).

In the context of large open-pit mining operations, diesel combustion for mobile equipment and stationary engines is typically a dominant contributor to Scope 1 emissions. For some mines, site-level Scope 1 or combined Scope 1 and 2 GHG emissions were reported in corporate sustainability disclosures, but direct diesel consumption data were not provided. In such cases, these CO₂e disclosures can be used to back-calculate diesel fuel use. These disclosures can be used to back-calculate diesel fuel use. This approach leverages company-reported CO₂e values, combined with diesel-specific emissions factors, to estimate the underlying L and GJ of diesel consumed. Table 3.6 summarizes the results for NGM (owned by Barrick Gold (61.5%) and Newmont Corporation (38.5%)), and Ray Mine (owned by American Smelting and Refining Company (ASARCO) L.L.C., a subsidiary of Grupo México).

3.4.1 Data Sources

Estimated diesel consumption for NGM and Ray Mine was derived from publicly reported Scope 1 and Scope 2 GHG emissions. For NGM, Barrick Gold’s 2023 *Sustainability Report* disclosed total Scope 1 and 2 emissions, along with the proportion attributable to diesel use in fleet and transport, which provided the basis for back-calculating diesel consumption at the site (Barrick Gold Corporation, 2024). For Ray Mine, Scope 1 emissions were estimated using

Grupo México's published emissions intensity factors (tCO₂e per t of copper (Cu) produced), adjusted for Ray's estimated share of ASARCO's 2022 Cu production, as reported by *Global Business Reports* (Global Business Reports, 2023; Grupo México, 2024). To isolate diesel-related Scope 1 emissions at Ray Mine, sector-specific evidence from industry reports and input from subject-matter experts were used as supporting justification for the assumption that approximately 90% of Scope 1 CO₂e emissions at Ray Mine can reasonably be attributed to diesel combustion in equipment (Global Business Reports, 2023; K. Murphy, personal communication, May 22, 2025; U.S. Department of Energy, 2007; Wang et al., 2024).

3.4.2 Unit Conversions

To convert reported Scope 1 and Scope 2 CO₂e values into L and GJ of diesel consumption, a sequence of unit conversions and emission factor adjustments was applied. Reported emissions in kilotonnes (kt) of CO₂e were first converted to kg using standard relationships: 1 t = 1,000 kg and 1 kt = 1,000,000 kg (UnitConverters.Net, 2025).

Because Scope 1 and Scope 2 disclosures are expressed as CO₂-equivalent (CO₂e)—which includes carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O)—the CO₂ fraction was isolated using U.S. EPA emission factors for diesel combustion. The U.S. EPA's GHG Emission Factors Hub (Table 2: Mobile Combustion) specifies that one U.S. gallon of diesel produces 10.21 kg CO₂. To account for non-CO₂ gases, values from Table 5 (Construction and Mining Equipment – Diesel Equipment) were incorporated: CH₄ at 1.01 g/gal (0.00101 kg/gal) and N₂O at 0.94 g/gal (0.00094 kg/gal) (U.S. Environmental Protection Agency, 2023). These factors were selected because they best represent mining fleets such as haul trucks, shovels, dozers, and support equipment, which define the operational boundary of open-pit mines.

Global warming potentials (GWP) from Table 11 of the U.S. EPA Hub were then applied (1 for CO₂, 28 for CH₄, and 265 for N₂O) (U.S. Environmental Protection Agency, 2025). This yields per-gallon emissions of 10.21 kg CO₂e from CO₂, 0.0283 kg CO₂e from CH₄, and 0.2491 kg CO₂e from N₂O, for a total of 10.487 kg CO₂e per gallon of diesel. Of this total, 10.21 kg is attributable to CO₂, meaning that 97.36% of diesel-related CO₂e arises directly from CO₂. This proportion was used to isolate CO₂ mass from reported CO₂e values before back-calculation. These emission factors and associated calculations are summarized in Table 3.5.

Table 3-5. U.S. EPA Emission Factors for Diesel Combustion (Construction/Mining Equipment)

Pollutant	Emission Factor per U.S. Gal of Diesel (g)	Emission Factor per U.S. Gal of Diesel (kg)	GWP (100-Year, AR5)	CO ₂ e per U.S. Gal (kg)	% of Total CO ₂ e (%)
CO ₂	10210	10.21	1	10.21	97.36%
CH ₄	1.01	0.00101	28	0.02828	0.27%
N ₂ O	0.94	0.00094	265	0.2491	2.67%
Total	—	—	—	10.48738	100%

(U.S. Environmental Protection Agency, 2023, 2025)

U.S. EPA factors are expressed per U.S. gal, so volumes were converted to L using 1 gal = 3.78541 L (U.S. Energy Information Administration, 2024). The factor of 10.21 kg CO₂/gal corresponds to 2.698 kg CO₂/L. This was applied to convert the isolated CO₂ mass into L of diesel consumed. Finally, diesel volumes were translated into energy units using the LHV of 35.8 MJ/L, or 0.0358 GJ/L (U.S. Department of Energy, Alternative Fuels Data Center, 2024).

3.4.3 Calculation Methodology

NGM

- **Step 1. Estimate Scope 1 and 2 CO₂e emissions for NGM.** Barrick Gold Corporation's *2023 Sustainability Report* shows total Scope 1 and 2 emissions were 6,359 kt CO₂e. The report also indicates that its NGM operation in the United States and its Pueblo Viejo operation in the Dominican Republic together accounted for almost 75% of these emissions. Barrick's emissions-by-country disclosure further indicates that 44% of Scope 1 and 2 emissions occur in the United States. Barrick's U.S. operations are reported collectively under the NGM complex, which comprises multiple individual mines and development projects in Nevada. In the absence of site-level emissions disclosures, the reported U.S. share is used as an emissions-based proxy for NGM's contribution to total Scope 1 and 2 emissions. (Barrick Gold Corporation, 2024).

$$\text{NGM Scope 1 and 2 emissions} = 6,359 \times 0.44 = 2,797.96 \text{ kt CO}_2\text{e}$$

- **Step 2. Attribute Scope 1 and 2 emissions to diesel.** Barrick reported that 27% of Scope 1 and 2 emissions were from diesel used in fleet and transport, and 3% from diesel used in power generation. Since NGM does not use diesel for power generation, only the 27% fleet and transport fraction applies (Barrick Gold Corporation, 2024; Barrick Mining Corporation, 2024).

$$\text{NGM diesel-attributed emissions} = 2,797.96 \times 0.27 = 755.4492 \text{ kt CO}_2\text{e}$$

- **Step 3. Isolate CO₂ from total CO₂e.** Based on U.S. EPA emission factors for mining equipment, CO₂ accounts for 97.36% of diesel-related CO₂e (with the remainder from CH₄ and N₂O) (U.S. Environmental Protection Agency, 2023).

$$\text{CO}_2 \text{ mass} = 755.4492 \times 0.9736 = 735.505341 \text{ kt CO}_2$$

- **Step 4. Convert to kg.**

$$735.505341 \times 1,000,000 = 735,505,341 \text{ kg CO}_2$$

- **Step 5. Determine the CO₂ emission factor for diesel.** The U.S. EPA's emission factor for fossil diesel is 10.21 kg CO₂ per U.S. gal. Converted to L (1 gal = 3.78541 L), this equals 2.698 kg CO₂ per L of diesel (U.S. Environmental Protection Agency, 2023).

$$\text{Diesel CO}_2 \text{ emissions factor} = 10.21 \text{ kg CO}_2/\text{gal} \div 3.78541 \text{ L/gal} = 2.698 \text{ kg CO}_2/\text{L}$$

- **Step 6. Convert CO₂ mass to diesel volume.**

$$\text{Diesel volume} = 735,505,341 \div 2.698 = 272,611,320 \text{ L}$$

- **Step 7. Convert diesel volume to energy terms.** Diesel volumes were converted to energy using a LHV of 35.8 MJ/L, or 0.0358 GJ/L (U.S. Department of Energy, Alternative Fuels Data Center, 2024).

$$\text{Diesel energy} = 272,611,320 \times 0.0358 = 9,759,485 \text{ GJ}$$

Ray Mine:

- **Step 1. Estimate Ray Mine's Scope 1 CO₂e.** Grupo México's *Emissions Intensity Targets for Grupo México's Operations* report shows 2022 Scope 1 emissions intensity as 2.18 tCO₂e per t Cu (Grupo México, 2024). Total 2022 Arizona Cu production for ASARCO's L.L.C.'s operations (includes Ray Mine, Mission Complex Mine, and Silver Bell Mine) as 112,232 t Cu.²² Although site-specific output isn't publicly broken out, Ray Mine likely accounted for ~65% of ASARCO's 2022 Cu output (as it was the largest operation of the three mines) (Global Business Reports, 2023). Given these assumptions:

$$\text{Estimated Ray Cu production: } 0.65 \times 112,232 = 72,950.8 \text{ t Cu}$$

$$\text{Ray Scope 1 CO}_2\text{e: } 2.18 \times 72,950.8 = 159,032.74 \text{ tCO}_2\text{e}$$

- **Step 2. Attribute Scope 1 CO₂e to diesel.** Assume 90% of Scope 1 at Ray is from diesel combustion in fleet/transport. Rationale/evidence is summarized in Section 3.4.4. of this report.

$$\text{Diesel-attributed CO}_2\text{e: } 159,032.74 \times 0.90 = 143,129.47 \text{ tCO}_2\text{e}$$

- **Step 3. Isolate CO₂ from CO₂e.** Assume the CO₂ share of diesel CO₂e = 97.36% (U.S. EPA, 2023).

$$\text{CO}_2: 143,129.47 \times 0.9736 = 139,350.85 \text{ t CO}_2$$

- **Step 4. Convert t CO₂ to kg CO₂.**

$$\text{CO}_2: 139,350.85 \times 1,000 = 139,350,852 \text{ kg CO}_2.$$

- **Step 5. Determine the CO₂ emission factor for diesel.** The U.S. EPA's emission factor for fossil diesel is 10.21 kg CO₂ per U.S. gal. Converted to L (1 gal = 3.78541 L), this equals 2.698 kg CO₂ per L of diesel (U.S. Environmental Protection Agency, 2023).

²² Ray Mine is owned by ASARCO L.L.C., a subsidiary of Grupo México.

Diesel CO₂ emissions factor = 10.21 kg CO₂/gal ÷ 3.78541 L/gal = 2.698 kg CO₂/L

- **Step 6. Convert CO₂ mass to diesel volume.**

Diesel volume = 139,350,852 kg CO₂ ÷ 2.698 = 51,649,685.7 L

- **Step 7. Convert diesel volume to energy terms.** Diesel volumes were converted to energy using an LHV of 35.8 MJ/L, or 0.0358 GJ/L (U.S. Department of Energy Alternative Fuels Data Center, 2024).

Diesel energy (GJ) = 51,649,686 × 0.0358 = 1,849,059 GJ

3.4.4 Justification for the 90% Diesel Share Assumption at Ray Mine

The assumption that approximately 90% of Ray Mine's Scope 1 emissions are attributable to diesel combustion in mobile equipment is supported by multiple lines of evidence. Global Business Reports (2023) notes that nearly all of Ray's direct emissions stem from diesel use in mining fleets. Major stationary processes (concentrator, solvent extraction and electrowinning) are electricity-intensive and therefore fall under Scope 2 (Global Business Reports, 2023). Independent expert analysis confirms this pattern: Kevin Murphy (S&P Global Market Intelligence) reports that diesel typically accounts for 90–99% of Scope 1 emissions at surface mines, where mobile equipment dominates fuel use (K. Murphy, personal communication, May 22, 2025). Peer-reviewed literature similarly identifies hauling and loading fleets as the primary source of direct GHG emissions (Wang et al., 2024), while U.S. DOE's *Mining Industry Energy Bandwidth Study* indicates diesel contributes up to 99.5% of mobile fleet energy consumption (U.S. Department of Energy, 2007). Together, this material supports the 90% estimate applied in this analysis.

3.4.5 Calculation Results

Table 3 6. Estimated Diesel Consumption for Ray and Nevada Gold Mines (Scope 1 and 2 CO₂e Back-Calculation)

#	Mine Name	County	State	Latitude (°N)	Longitude (°W)	Owner	Primary Commodity	Estimated Annual Diesel Consumption (GJ / Year) ²³	Confidence Level for Estimated Annual Diesel Consumption
7	Ray Mine	Pinal County	AZ	33.110863	-110.590214	Grupo México ²⁴	Copper	1,849,059	Low
15	Nevada Gold Mines (NGM) ²⁵	Elko County	NV	40.495197	115.470335	Barrick Gold Corporation (61.5%), Newmont Corporation (38.5%)	Gold	9,759,485	Low

3.4.6 Data Verification and Treatment of Assumptions

The U.S. EPA emission factor for diesel combustion is well-established (U.S. Environmental Protection Agency, 2023). For NGM, diesel shares of total GHG emissions were taken from corporate disclosures (Barrick Gold Corporation, 2024; Barrick Mining Corporation, 2024). For Ray Mine, the assumption that 90% of Scope 1 emissions are diesel-based was cross-checked against industry studies and expert reviews, which consistently place diesel combustion at 90% of Scope 1 emissions in open-pit operations (Global Business Reports, 2023; K. Murphy, personal communication, May 22, 2025; U.S. Department of Energy, 2007; Wang et al., 2024).

3.4.7 Limitations

This methodology is subject to several uncertainties. For NGM, reliance on corporate allocation of Barrick Good Corporation's portfolio-level emissions introduces potential reporting and boundary inconsistencies. For Ray, production shares were inferred from third-party reports rather than disclosed directly by the operator, and the 90% diesel attribution is based on industry norms rather than site-specific data. In both cases, isolating CO₂ from total CO₂e assumes a fixed 97.36% share, which may vary slightly in practice depending on fleet composition and emission controls. Despite these limitations, the approach provides a

²³ Diesel consumption values reflect calendar year 2023 for all sites, except Kennecott Copper Mine, which is reported for calendar year 2024.

²⁴ Ray Mine is owned by Grupo Mexico through its subsidiary ASARCO L.L.C.

²⁵ NGM, located in northeastern Nevada, comprises multiple open-pit and underground operations across several counties. NGM includes active, care and maintenance, and closed sites. The six active open-pit mines include: Cortez Complex, Gold Quarry Mine, Phoenix Mine, Twin Creeks Mine, Goldstrike Mine, and Carlin Complex Mine. The primary hub for NGM is its headquarters, located in Elko County, Nevada. Given the disparate locations for these mines, for this database, latitude and longitude coordinates were provided for the NGM headquarters in Elko County (Barrick Gold Corporation, 2024).

transparent and replicable method for estimating diesel consumption when only Scope 1 and 2 GHG emissions are reported.

3.5 Nitrogen Oxide (NO_x)-Based Estimates

This section applies a nitrogen oxide (NO_x)-based estimation pathway to address remaining data gaps at mine sites where direct diesel consumption, production data, and sufficiently detailed Scope 1 and/or 2 GHG emissions were not publicly reported to enable CO₂- or CO₂e-based back-calculation. NO_x are regulated air pollutants formed during high-temperature combustion of diesel fuel. In mining operations, most direct NO_x emissions originate from the exhaust of mobile diesel-powered equipment such as haul trucks, loaders, and dozers, with smaller contributions from stationary engines and generators. Because total site-level NO_x emissions are closely proportional to the amount of fuel combusted, reported or permitted NO_x values can be used as a proxy to estimate annual diesel consumption when direct fuel use data are unavailable.

Compared with CO₂-based approaches, NO_x-based estimation is inherently more uncertain because NO_x emissions are more sensitive to engine load, duty cycle, and operating conditions; however, experimental studies of heavy-duty diesel vehicles using on-board diagnostics (OBD) data demonstrate that fuel consumption, CO₂ emissions, and NO_x emissions are tightly coupled through engine work under controlled conditions (Hao et al., 2023).

Table 3.7 summarizes the results for the Cripple Creek & Victor (CC&V) Gold Mine (owned by SSR Mining Inc., previously Newmont Mining Corporation) and the Mission Complex Mine (owned by ASARCO L.L.C., a subsidiary of Grupo México), both of which had reported or permitted annual NO_x emissions that could be reliably attributed to diesel combustion.

3.5.1 Data Sources

For the CC&V Gold Mine, NO_x emissions data were obtained from *Newmont Corporation's 2023 Sustainability Report: Performance Data*, which documents site-level NO_x emissions for the operation prior to its divestiture to SSR Mining Inc. The dataset specifies both point-source and fugitive NO_x emissions, totaling 653.2 tonnes for 2023 (Newmont Corporation, 2024a, 2024b). The total value was used in this analysis because it represents the combined emissions from stationary and mobile combustion sources and provides the most complete indicator of overall site-level diesel combustion.

For the Mission Complex Mine (ASARCO L.L.C., a subsidiary of Grupo México), NO_x emissions were obtained from the *Technical Support Document for the ASARCO Mission Complex Title V Air Quality Permit #2026* issued by the Pima County Department of Environmental Quality (PCDEQ) (Pima County Department of Environmental Quality, 2024). This permit specifies allowable annual NO_x emissions from fugitive sources associated with mining operations. Because these fugitive emissions are generated almost exclusively by mobile diesel-powered equipment, they provide a reasonable basis for estimating total diesel combustion at the site.

3.5.2 Unit Conversions

To convert reported or permitted annual NO_x emissions into L and GJ of diesel consumption, a standardized sequence of unit conversions and engine performance relationships was applied. NO_x emissions were first converted to grams (g) where necessary using standard relationships: 1 short ton = 2,000 pounds (lb) and 1 lb = 453.59237 g (National Institute of Standards and Technology (NIST)), 2010)). Where emissions were reported in metric tonnes (t), 1 t = 1,000,000 g was used (UnitConverters.Net, 2025).

Because NO_x emissions are proportional to the mechanical work performed by diesel engines, total engine work output was inferred by dividing the reported NO_x mass by an appropriate emission factor (in g NO_x per kilowatt hour (kWh)). The U.S. EPA Tier 2 nonroad diesel engine standard specifies a combined non-methane hydrocarbon (NMHC) and NO_x limit of 6.4 g/kWh for engines rated above 560 kW (DieselNet, 2025)—the size class typical of haul trucks, loaders, and other equipment used in open-pit mining (Caterpillar, 2025; Caterpillar, 2025; Caterpillar, 2025). Tier 3 standards did not apply to this engine class, and Tier 4 standards have not been widely adopted in U.S. surface mining due to equipment age, cost, and limited retrofit requirements, making Tier 2 the most representative basis for estimating fleet-level emissions (Restrepo & Fulton, 2025; U.S. Environmental Protection Agency, 2016).

Once total engine work (kWh) was estimated, the mechanical work output was converted into the corresponding mass of diesel fuel combusted using a brake specific fuel consumption (BSFC) factor. BSFC represents the mass of fuel required to generate one kWh of mechanical work and is typically expressed in g/kWh. For large diesel engines operating at high load, BSFC values range from 200 to 250 g/kWh (Gonzalez, 2010; Dec & Lopez-Pintor, 2020). A baseline value of 200 g/kWh was selected for this analysis to represent efficient operation under heavy-duty conditions common in mine fleets.

The resulting fuel mass (g) was then converted to volume (L) using a standard diesel density of 851 g/L, derived from the diesel weight of 7.1 lb/gal (Bryson, 2025). This density reflects the physical properties of petroleum diesel under typical operating temperatures and altitudes for U.S. surface mines.

Finally, diesel volumes were translated into energy units (GJ) using the LHV of 35.8 MJ per L, or 0.0358 GJ/L, as established in Section 3.1 (U.S. Department of Energy, Alternative Fuels Data Center, 2024).

3.5.3 Calculation Methodology

CC&V Gold Mine

- **Step 1. Convert reported NO_x to grams (g).**
Total NO_x = 653.2 t × 1,000,000 g/t = 653,200,000 g.
- **Step 2. Estimate engine work from NO_x.**

Engine Work (kWh) = 653,200,000 g ÷ 6.4 g/kWh = 102,062,500 kWh.

- **Step 3. Convert engine work to diesel mass using the BSFC.**

Diesel Mass (g) = 102,062,500 kWh × 200 g/kWh = 20,412,500,000 g.

- **Step 4. Convert diesel mass to volume.**

Diesel Volume (L) = 20,412,500,000 g ÷ 851 g/L = 23,986,486 L.

- **Step 5. Convert L to energy (LHV basis).**

Diesel Energy (GJ) = 23,986,486 L × 0.0358 GJ/L = 858,716 GJ.

Mission Complex Mine

- **Step 1. Convert permitted NO_x (short tons/year) to g.**

69.9 short tons × 2,000 lb/ton × 453.59237 g/lb = 63,433,237 g.

- **Step 2. Infer engine work from NO_x.**

Engine Work (kWh) = 63,433,237 g ÷ 6.4 g/kWh = 9,911,444 kWh.

- **Step 3. Convert engine work to diesel mass using BSFC.**

Diesel Mass (g) = 9,911,444 kWh × 200 g/kWh = 1,982,288,800 g.

- **Step 4. Convert diesel mass to volume.**

Diesel Volume (L) = 1,982,288,800 g ÷ 851 g/L = 2,329,364 L.

- **Step 5. Convert L to energy (LHV basis).**

Diesel Energy (GJ) = 2,329,364 L × 0.0358 GJ/L = 83,391 GJ.

3.5.4 Calculation Results

Table 3-7. Estimated Diesel Consumption for Mission Complex Copper Mine and CC&V Gold Mine (NO_x Emissions Back-Calculation)

#	Mine Name	County	State	Latitude (°N)	Longitude (°W)	Owner	Primary Commodity	Estimated Annual Diesel Consumption (GJ / Year) ²⁶	Confidence Level for Estimated Annual Diesel Consumption
4	Mission Complex Mine	Pima County	AZ	31.989259	-111.057683	Grupo México ²⁷	Copper	83,391	Low
12	CC&V Gold Mine	Teller County	CO	38.440117	-105.085028	SSR Mining Corporation	Gold	858,716	Low

3.5.5 Data Verification and Treatment of Assumptions

The U.S. EPA Tier 2 nonroad diesel emission factor of 6.4 g NO_x/kWh for engines rated above 560 kW is a well-established regulatory benchmark (DieselNet, 2025). This size class was selected because engines in this range represent the dominant power category in open-pit mining, encompassing the haul trucks, loaders, dozers, and shovels that account for the majority of site-level diesel fuel consumption. Typical examples include the Cat 793 haul truck (1,976 kW), Cat 995 large wheel loader (1,739 kW), and Cat D11 dozer (634 kW)—all within or above the Tier 2 ≥ 560 kW classification (Caterpillar, 2025c, 2025b, 2025a). The assumed BSFC of 200 g/kWh is supported by industry research and U.S. Department of Energy analyses of heavy-duty diesel engine performance (Dec & Lopez-Pintor, 2020; Gonzalez, 2010).

3.5.6 Limitations

This methodology is subject to several uncertainties. For the CC&V Gold Mine, reliance on total reported NO_x emissions introduces potential ambiguity regarding the proportion of emissions originating from mobile versus stationary combustion sources. For the Mission Complex Mine, the fugitive NO_x values were drawn from permit-based estimates, which represent allowable rather than directly measured emissions and may not reflect year-to-year operational variability or partial adoption of higher-tier engines. Across both sites, the use of a Tier 2 emission factor (6.4 g NO_x/kWh) and a BSFC of 200 g/kWh assumes consistent engine performance under high-load conditions typical of open-pit operations; in practice, BSFC can vary with duty cycle, altitude, and maintenance condition (Dec & Lopez-Pintor, 2020; DieselNet, 2025; Gonzalez, 2010).

In addition, NO_x emissions are more sensitive than CO₂ emissions to engine load, duty cycle, and operating conditions, which introduces greater uncertainty when inferring fuel consumption from NO_x relative to CO₂-based approaches. Accordingly, NO_x-based back-calculation is

²⁶ Diesel consumption values reflect calendar year 2023 for all sites, except Kennecott Copper Mine, which is reported for calendar year 2024.

²⁷ Mission Complex Mine is owned by Grupo Mexico through its subsidiary ASARCO L.L.C.

applied only where direct fuel data or sufficiently detailed GHG emissions data were unavailable (Hao et al., 2023).

Lastly, haul trucks in surface mines may idle for extended durations—sometimes several hours per shift—particularly while queuing at loading or dumping points or during maintenance periods. Simulation-based analyses indicate average idling fuel consumption rates of approximately 0.12 L/min during shovel queuing and 0.02 L/min while waiting at crushers (Tokac et al., 2025). Adjustment for idling was not incorporated into the core NO_x-based calculation because idle operation produces minimal mechanical work and therefore cannot be represented by the same g NO_x/kWh relationship used for high-load combustion. Estimating the effect of idling would require information on the proportion of total engine time spent idling versus operating under load, as well as idling-specific NO_x emission factors. Collecting and validating such information was beyond the scope of this initial study.

Despite these limitations, the NO_x-based approach provides a transparent, data-driven, and replicable method for estimating diesel fuel use in open-pit mines where direct fuel consumption data are not publicly available.

4. Confidence Framework and Data Reliability

4.1 Purpose and Structure

Confidence levels were developed to convey the relative reliability of each mine-level diesel estimate and to ensure transparent interpretation of methodological uncertainty across the dataset. Each site's confidence rating—High, Moderate, or Low—reflects a structured evaluation of data provenance, methodological transparency, and the number and magnitude of assumptions required. The framework is applied consistently across all estimation pathways and confidence levels for each method are summarized in Table 4.2 and for each mine in Table 2.1.

4.2 Evaluation Criteria

Each methodology was evaluated using five standardized assumption categories that describe the main sources of uncertainty. These categories and their application across diesel estimation methods are summarized in Table 4.1 below.

Table 4-1. Assumption Categories and Their Application Across Diesel Estimation Methods

Assumption Category	Description of Sensitivity	Examples	Relevance to Methods
Emission Factor Applications	Uncertainty arising from use of standardized national or regulatory factors that may not reflect site-specific combustion or fleet conditions.	- At Kennecott Copper Mine, the application of the U.S. EPA emission factor (10.21 kilogram (kg) CO₂/gallon of diesel) to convert CO₂ emissions avoided to L of diesel consumed (U.S. Environmental Protection Agency, 2024). - At the CC&V Gold Mine, application of the U.S. EPA Tier 2 NO_x emission factor (6.4 g NO_x/kWh of engine work) to convert NO_x emissions to diesel engine work (DieselNet, 2025).	Emissions factors are used in the following methods: 3.2. Renewable Diesel CO₂-Based Estimates 3.4. Scope 1 and 2 CO₂e-Based Estimates 3.5. NO_x-Based Estimates

Proxy Benchmarks	Transfer of performance or intensity metrics from one representative mine or engine study to others with differing equipment, operational efficiency, ore grade, and haul distances across mines. High uncertainty in activity levels and methodologies for measuring activities related to ore and mined product.	Creating an estimate of diesel use per iron ore pellet from a single site (Hibbing Taconite Mine (Hibtac)) and applying it to other mines in the region (i.e., Keewatin Taconite (Keetac) Mine, Minntac Mine, Tilden Mine, and United Taconite Mine).	Proxy benchmarks are used in the following methods: 3.3 Diesel / Pellet Proxy Estimates
General Ratios / Shares	Allocation of emissions or production shares using literature or portfolio averages rather than direct mine disclosures (e.g., NGM 37.5 %, Ray 90 %).	- At NGM, the assumption that 27% of Scope 1 and 2 emissions are from diesel used in fleet and transport (Barrick Gold Corporation, 2024; Barrick Mining Corporation, 2024). - At Ray Mine, the assumption that 90% of Ray Mine's Scope 1 emissions are attributable to diesel combustion in mobile equipment (Global Business Reports, 2023; K. Murphy, personal communication, May 22, 2025; U.S. Department of Energy, 2007; Wang et al., 2024).	General ratios / shares are used in the following methods: 3.4. Scope 1 and 2 CO₂e-Based Estimates
Lengthy Conversion Sequences	Compounded uncertainty from multi-step chains where each conversion embeds separate assumptions.	At the CC&V Gold Mine, the NO_x-based estimate that chains together multiple assumptions: NO_x (t) → NO_x (g) → engine work (kWh) → fuel mass (g) → fuel volume (L) → energy (GJ). Each link introduces compounding uncertainty, typical of multi-step indirect estimation methods.	Lengthy conversion sequences are used in the following methods: 3.5. NO_x-Based Estimates

Temporal Assumptions	Use of historical or averaged data to represent 2023–2024 conditions; assumes limited change in production efficiency or fuel intensity over time.	The Hibbing Taconite Mine (Hibtac) uses historical data from 2018, 2019, and 2020 on diesel usage per WLT of iron ore pellets and applies this benchmark to 2023 pellet production at several different mines (i.e., Keewatin Taconite (Keetac) Mine, Minntac Mine, Tilden Mine, and United Taconite Mine).	Temporal assumptions are used in the following methods: 3.3 Diesel / Pellet Proxy Estimates
-----------------------------	--	---	---

4.3 Confidence Scoring by Methodology

Each diesel estimation pathway was assigned a confidence score based on the number of assumptions required to complete the calculation. See Table 4.2 below. This scoring system translates assumption counts into a three-tier confidence rating—High, Moderate, or Low—to ensure consistency and transparency across methodologies.

- High confidence applies where reported fuel use is taken directly from company disclosures with 0 assumptions (e.g., simple unit conversions only).
- Moderate confidence applies where 1–3 key assumptions are necessary—such as applying standard emission factors or proxy benchmarks derived from analogous sites.
- Low confidence reflects methods requiring 4 or more embedded assumptions, particularly where emissions, production, or equipment data must be inferred through multi-step conversion chains.

Using this framework, the Reported Diesel Data method ranks as high confidence because it draws on directly reported fuel consumption and requires no proxy assumptions. The Renewable-Diesel CO₂-based and Diesel/Pellet Proxy methods are moderate confidence, each involving one to three standardized assumptions. The Scope 1/2 CO₂e and NO_x-based approaches are classified as low confidence because they depend on four or more assumptions, including multiple emission-factor applications and multi-step conversions. Overall, this scoring scheme provides a consistent, replicable basis for assigning confidence levels across the dataset, linking the number and type of methodological assumptions directly to each mine’s reported or estimated diesel consumption.

Table 4-2. Confidence Scoring Framework for Diesel Estimation Methodologies

Diesel Estimation Method	Description	Number of Key Assumptions	Confidence Score*	Confidence Label	Primary Sources of Assumption Uncertainty
Reported Diesel Data	Reported annual diesel fuel consumption for selected U.S. open-pit mines based on company sustainability disclosures.	0	1	High	Minimal assumptions; uses directly reported data and simple unit conversions only.
Renewable Diesel CO₂-Based Estimates	Estimated diesel consumption from reported avoided CO ₂ emissions due to substitution of fossil diesel with renewable diesel, applying the U.S. EPA diesel CO ₂ emission factor (10.21 kg CO ₂ gal) (U.S. Environmental Protection Agency, 2023).	1	2	Moderate	Applies a standardized emission factor not verified at site level.
Diesel / Pellet Proxy Estimates	Diesel consumption at Minnesota and Michigan iron-ore mines estimated from a benchmark of 3.66 L diesel LT derived from Hibbing Taconite data, adjusted for 2 % pellet moisture, multiplied by 2023 pellet production (SLR International Corporation, 2021).	3	2	Moderate	Proxy benchmark assumes similar fleet efficiency and haul distances across mines; temporal assumption uses 2018–2020 data.

Scope 1 / 2 CO₂e Back-Calculation	Estimated diesel consumption from reported Scope 1 CO ₂ e emissions, assuming 90 % of Scope 1 from diesel and 97.36 % of CO ₂ e = CO ₂ , divided by U.S. EPA emission factor (10.21 kg CO ₂ gal) (U.S. Environmental Protection Agency, 2023).	4	3	Low	Multiple allocation and emission-factor assumptions; corporate-level data applied to site operations.
NO_x-Based Estimates	Derived from reported NO _x emissions converted to engine work using Tier 2 factor (6.4 g NO _x kWh), then to fuel via BSFC (200 g kWh), density (851 g L), and LHV (0.0358 GJ L) (Bryson, 2025; Dec & Lopez-Pintor, 2020; DieselNet, 2025; Gonzalez, 2010; U.S. Department of Energy, Alternative Fuels Data Center, 2024; U.S. Environmental Protection Agency, 2016).	4	3	Low	Chains multiple standardized factors (NO _x → kWh → fuel → energy); compounding uncertainty from fleet variability and engine efficiency.

4.4 Dataset-Level Distribution

The aggregate confidence distribution across the 21 open-pit mines is:

- High Confidence: 11 sites (52 %)
- Moderate Confidence: 6 sites (29 %)
- Low Confidence: 4 sites (19 %)

Over half of the dataset is grounded in directly reported, high-confidence fuel data. The remaining estimates extend coverage through standardized proxy and emissions-based approaches that, while more assumption-dependent, provide transparent and reproducible values for mines lacking direct disclosure.

This study did not include an assessment of whether multiple estimation methods could be applied to the same mine site. Although such an evaluation would be valuable for future work, it was beyond the scope and timeline of this initial analysis. Some overlap may exist where directly reported diesel consumption values could be compared with estimates derived from indirect approaches; however, this was not systematically examined in the present study. Future research should focus on improving data transparency and methodological comparability by:

1. Encouraging mine operators to report direct diesel consumption in sustainability disclosures;
2. Validating proxy and emissions-based methods through comparison with verified site-level fuel purchase or telemetry data; and
3. Quantifying uncertainty bounds (e.g., through Monte Carlo or scenario analysis) to characterize how methodological variability influences diesel use totals.

Collectively, these steps would strengthen the reliability and reproducibility of mine-level diesel energy estimates and enhance the credibility of subsequent decarbonization analyses.

5. Diesel Cost Estimates

5.1 Overview of Diesel Cost Estimates

Decisions in mining are driven by cost, and the use of diesel is a major cost point for mines, especially as open-pit mines age and require equipment to travel longer distances and process increasing quantities of low-grade ore. While mines may make contracts with fuel suppliers on price, the county-level diesel price is a valuable metric for the cost of delivery in the United States. Notably, none of the mines evaluated in this report are located in states with in-state diesel refining capacity. As such diesel is imported from refineries in the Gulf, from California, or from the Great Lakes region, depending on location.

Because Sections 3 and 4 quantify total diesel consumption in energy units (GJ per year), the price data in this section allow those values to be expressed in financial terms. This connection provides important context for assessing potential cost exposure and identifying where efficiency improvements could yield the greatest economic benefit.

5.2 Data Sources

On-road diesel prices reflect both federal and state motor fuel taxes. Federal and state tax rates were obtained from the U.S. Energy Information Administration's (EIA) *Federal and State Motor Fuels Taxes* table (U.S. Energy Information Administration, 2025). On-road gasoline prices were collected at the county level from GasBuddy on October 21, 2025, and from the American Automobile Association (AAA) Fuel Prices for Fairbanks, Alaska. These sources represent retail, on-road prices inclusive of applicable taxes; subsequent adjustments remove federal and state taxes to approximate off-road, untaxed diesel prices representative of bulk deliveries to industrial consumers.²⁸ Prices shift on a seasonal and even daily basis and may not be representative of long-term diesel contracts obtained by mines.

5.3 Calculation Method

- **Step 1. Adjust for taxes.**

Off-road Diesel Price (\$/gal) = On-road Diesel Price (\$/gal) - Federal tax (\$/gal) - State tax (\$/gal)

Example for Yavapai County:

\$3.521/gal - \$0.243/gal - \$0.180/gal = \$3.098/gal

5.4 Calculation Results

Off-road diesel price estimates range from 1.95 to 3.84 \$/gal (Figure 5.1), with an average of 3.12 \$/gal which is 14% lower than the national average on the same day recorded. At the

²⁸ Price data for 2023 and 2024 are more representative of periods when global diesel production was lower; however, gasoline prices in October 2024 differed only slightly from 2025 levels, averaging between -\$0.30 and +\$0.10 per gallon (American Automobile Association, 2025; GasBuddy, 2025).

county level, values changed from -15% (White Pine County NV) to 4% (Humboldt NV), with most counties only changing 2-3%.

Integrating these cost estimates with site-level diesel-use data provides a preliminary basis for estimating total annual fuel expenditures at each mine and highlights where fuel-efficiency improvements could have the largest financial impact. For large open-pit operations consuming hundreds of thousands to several million GJ of diesel per year, even modest improvements in fuel efficiency can have meaningful implications for annual fuel expenditures. By linking site-level diesel energy use (GJ/year) with localized fuel prices, this analysis supports the identification of mines that are most sensitive to diesel costs and where operational or technological interventions may offer the greatest potential benefit.

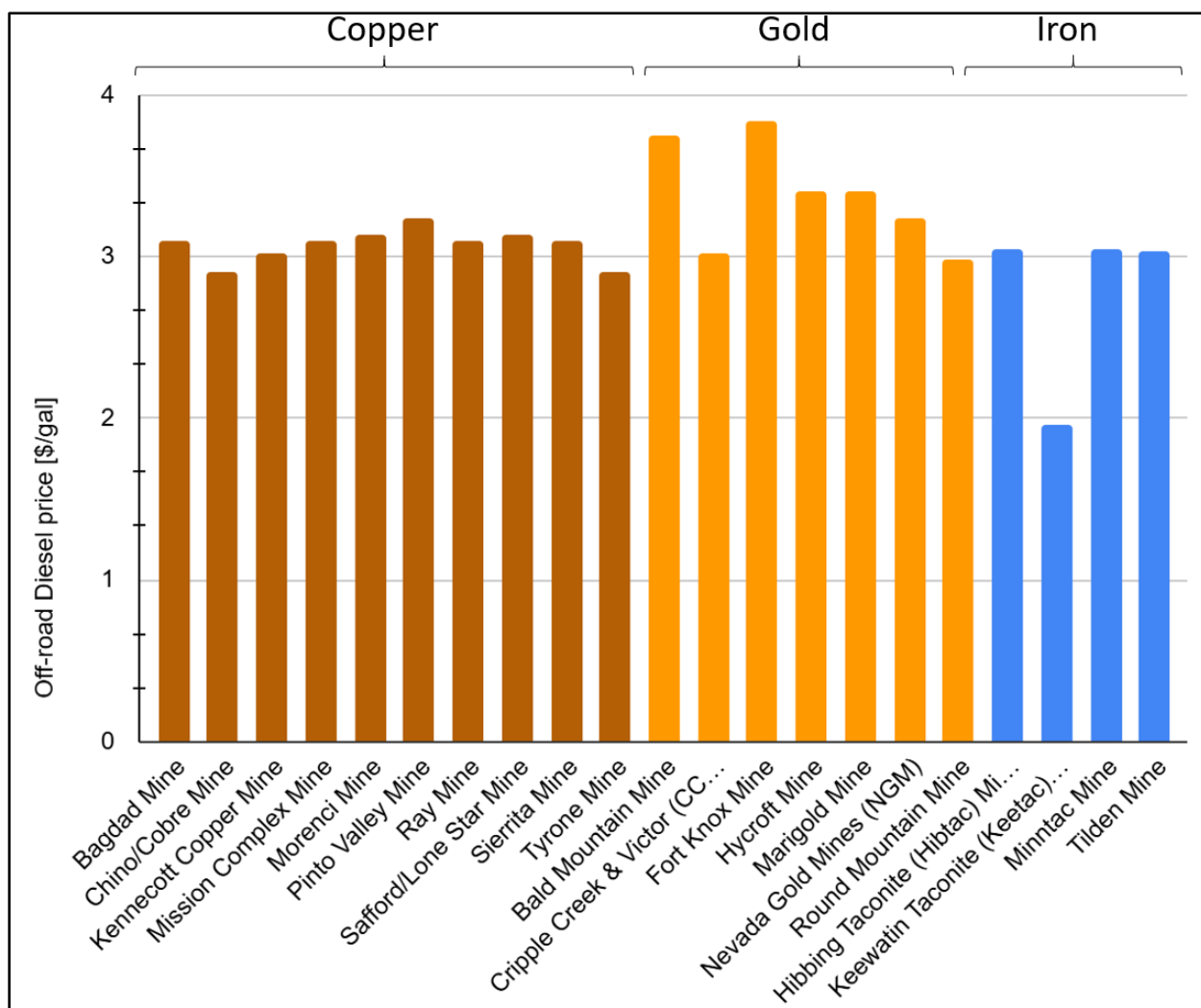


Figure 5-1. Diesel prices in the county where mines are located (representative of October 21, 2025)

6. Conclusions

6.1 Overview and Study Framework

The mining sector plays a central role in the U.S. economy, supporting domestic employment, industrial production, and international trade. In 2024, the industry directly employed nearly half a million workers and contributed more than \$190 billion to the nation's gross domestic product when indirect and induced effects are included (National Mining Association, 2025). Beyond its economic footprint, mining underpins critical supply chains for key commodities—such as copper, gold, and iron ore—that are essential to U.S. and global manufacturing, construction, and infrastructure (U.S. Geological Survey, 2025). Because the majority of these operations are open-pit mines, their energy use represents a significant portion of the total energy consumed in U.S. mining (Centers for Disease Control and Prevention, 2025b, 2025a; U.S. Department of Energy, Alternative Fuels Data Center, 2024). Diesel fuel, in particular, dominates this energy demand, accounting for roughly one-third of the sector's total consumption and powering the haul trucks, loaders, and dozers that are indispensable to materials handling and extraction (U.S. Department of Energy, 2007).

This study was undertaken to develop a standardized, transparent framework for estimating diesel fuel consumption at prominent open-pit mines across the United States. By integrating multiple data sources, such as company sustainability reports, air-quality permits, production statistics, etc., the analysis produces consistent, site-level estimates of annual diesel energy use, even in cases where direct reporting is unavailable. The study also applies a structured confidence framework that evaluates each estimation pathway according to data provenance, methodological transparency, and the number and type of assumptions required. Together, these components form a replicable, quality-rated methodology for assessing diesel use across the U.S. mining sector.

6.2 Dataset Findings and Methodological Insights

The dataset developed for this study covers 21 prominent open-pit mines. Results show wide variation in annual diesel energy consumption, reflecting differences in mine scale, commodity type, production capacity, and available reporting detail. Notably, no statistically significant trend line could be drawn between the mine surface area and diesel consumption, or between the metal production and the diesel consumption, for this sample size, although a positive trend was identified. Approximately half of the sites rely on directly reported fuel data, while others are estimated through standardized indirect methods—renewable-diesel CO₂ back-calculation, Scope 1 and 2 CO₂e estimation, pellet-production proxies, and NO_x-based back-calculations. While methods are presented at the annual scale, it is possible to apply the methods to datasets with higher temporal resolution. These methods extend coverage to mines without public diesel fuel-use disclosures, creating a view of diesel energy consumption in U.S. open-pit mining.

Each methodology carries specific limitations tied to data availability, the assumptions applied, and the precision of regulatory or engineering factors used. For instance, Scope 1 and 2 CO₂e estimates depend on corporate-level emission allocations, while NO_x-based estimates require

multi-step conversions and may omit fuel burned during idling. The associated uncertainties are reflected in the confidence framework presented in Section 4, which categorizes methods as high, moderate, or low confidence depending on the number of embedded assumptions. This framework allows users to interpret results transparently, recognizing both the strengths and inherent uncertainties of indirect estimation methods. Because mining operations and reporting practices evolve, new methods for estimating diesel are likely to be necessary that account for changing energy source use at mine sites, and confidence frameworks should be developed. Beyond quantifying diesel consumption, the study provides representative county-level cost estimates for off-road diesel fuel. These prices—expressed on a dollar-per-gallon basis and adjusted for federal and state taxes—illustrate regional variability in fuel costs across mine locations. Integrating these cost data with mine-level consumption estimates connects energy analysis to broader themes of operational efficiency and industrial competitiveness. By quantifying both the magnitude and cost of diesel use, the study highlights how fuel expenditures influence mining productivity and profitability, providing a foundation for identifying opportunities to improve efficiency and manage costs under real-world operating conditions.

6.3 Data Gaps, Future Opportunities, and Strategic Implications

The findings underscore several broader challenges and opportunities for the U.S. mining industry. Data on diesel fuel use are often aggregated behind paywalls, which is not a robust approach for stakeholders or the broader scientific community to characterize supply chains or to assess the implications of changes in the nature and intensity of mining activities—such as the closure, reactivation, or development of new open-pit mines. Like many energy consumption datasets, maintaining this dataset will still require tedious, labor intensive aggregation of data and routine updates to stay relevant. Methods that can improve the automation of energy demand estimates for current and future years would be a valuable contribution. There is also an important opportunity to evaluate the use of diesel at the equipment level to better understand the nature of work performed and the operational cycles that diesel-powered equipment faces. This evaluation is key to identifying opportunities for fuel cost reduction, ranging from data-driven operations research to the development of novel technologies that lower costs under real-world operating conditions. Finally, there is a need to evaluate the associated “hidden costs” of diesel at mine sites, which remain ongoing challenges for the industry. Relevant qualitative and quantitative measures include fuel handling and storage, variations in fuel quality, fluctuations in price, contracting and shipment reliability, maintenance of diesel equipment, and overall operator performance and satisfaction.

Taken together, the results of this study establish a foundation for improving the energy efficiency and energy security of U.S. mining operations. Looking ahead, improved transparency in site-level diesel fuel consumption will also be increasingly important for emerging supply-chain and trade-related reporting requirements, including Scope 3 emissions accounting and potential international carbon border adjustment mechanisms. By combining technical estimation methods with cost context, the analysis supports continued progress in energy management, industrial competitiveness, and innovation. Future updates to the dataset, coupled with expanded data transparency and method validation, will ensure that the findings remain relevant as the sector evolves. These efforts will strengthen the competitiveness and

security of the U.S. industrial base—helping to maintain global leadership while ensuring energy security and efficiency

References

American Automobile Association. (2025). *American Automobile Association Fuel Prices*.

American Automobile Association Fuel Prices. <https://gasprices.aaa.com/?state=AZ>

Argonne National Laboratory. (2025, May 23). *R&D GREET® Model*. Energy Systems and

Infrastructure Assessment. <https://greet.anl.gov/>

Barrick Gold Corporation. (2024). *Barrick Sustainability Report 2023*. Barrick Gold Corporation.

<https://www.barrick.com/English/sustainability/default.aspx>

Barrick Mining Corporation. (2024). *Sustainability Report 2024: Beyond the Horizon*. Barrick Mining Corporation.

https://s25.q4cdn.com/322814910/files/doc_downloads/sustainability/Barrick_Sustainability_Report_2024.pdf

Bhattacharyya, S. (2025, August 27). *Personal communication regarding open-pit mine diesel dataset* [Zoom].

Bryson, E. (2025, July 11). *How Much Does a Gallon of Diesel Weigh? (+ Cost Insights)*. OTR Solutions. <https://otrsolutions.com/how-much-does-a-gallon-of-diesel-weigh/>

Capstone Copper Corp. (2024). *2023 Sustainability Report: Building Capacity*. Capstone Copper Corp. <https://capstonecopper.com/sustainability>

Caterpillar. (2025a). *Large Dozers D11*. Large Dozers D11.

https://www.cat.com/en_US/products/new/equipment/dozers/large-dozers/15969853.html

Caterpillar. (2025b). *Large Wheel Loaders 995*. Large Wheel Loaders 995.

https://www.petersoncat.com/products/new/product-line/wheel-loaders/large-wheel-loaders?campaignid=22940770061&device=c&placement=&channel=Google+Ads&utm_source=Google+Ads&utm_medium=CPC+Campaign&utm_campaign=WebFX+Tech+Careers&utm_content=Earthmoving+and+Power&gad_source=1&gad_campaignid=22940781803&gbraid=0AAAAAC-

7ynipxKzu4ZB3Fr7TXEL1P4wIK&gclid=CjwKCAjwr8LHBhBKEiwAy47uUiDm-

TofqE55Ygx5PrhsD33XKC1ljaPgFMKfPOGp5lvBp1kDIQJliBoCNhQQAvD_BwE

Caterpillar. (2025c). *New Cat® 793 Features Best-in-class Payload, Increased Fuel Efficiency and Faster Cycle Times*. New Cat® 793 Features Best-in-Class Payload, Increased Fuel Efficiency and Faster Cycle Times. https://www.cat.com/en_US/news/machine-press-releases/new-cat-793-features-best-in-class-payload--increased-fuel-efficiency-and-faster-cycle-times.html

Centers for Disease Control and Prevention. (2025a). *Number of active mines by sector and year, 1983—2021*. Number of Active Mines by Sector and Year, 1983 - 2021.

[https://wwwn.cdc.gov/NIOSH-](https://wwwn.cdc.gov/NIOSH-Mining/MMWC/Mine?StartYear=1983&EndYear=2021&SelectedMineType=&SelectedCommodity=)

[Mining/MMWC/Mine?StartYear=1983&EndYear=2021&SelectedMineType=&SelectedCommodity=](https://wwwn.cdc.gov/NIOSH-Mining/MMWC/Mine?StartYear=1983&EndYear=2021&SelectedMineType=&SelectedCommodity=)

Centers for Disease Control and Prevention. (2025b). *Number of active underground mines by sector and year, 2013—2021*. Number of Active Underground Mines by Sector and

Year, 2013 - 2021. [https://wwwn.cdc.gov/NIOSH-](https://wwwn.cdc.gov/NIOSH-Mining/MMWC/Mine?StartYear=2013&EndYear=2021&SelectedMineType=1&SelectedCommodity=)

[Mining/MMWC/Mine?StartYear=2013&EndYear=2021&SelectedMineType=1&SelectedCommodity=](https://wwwn.cdc.gov/NIOSH-Mining/MMWC/Mine?StartYear=2013&EndYear=2021&SelectedMineType=1&SelectedCommodity=)

Cleveland-Cliffs Inc. (2025). *Sustainability Report 2024*. Cleveland-Cliffs Inc.

<https://www.clevelandcliffs.com/sustainability>

Cummins, Inc. (n.d.). *Types of Mining Methods*. Types of Mining Methods. Retrieved July 25, 2025, from <https://www.cummins.com/engines/mining/types-of-mining>

Dec, J. E., & Lopez-Pintor, D. (2020, June 4). *Low-Temperature Gasoline Combustion for High-Efficiency Medium- and Heavy-Duty Engines*. U.S. Department of Energy, Office of

Vehicle Technologies Annual Merit Review and Peer Evaluation, Washington, DC.

<https://www.energy.gov/eere/vehicles/articles/low-temperature-gasoline-combustion-high-efficiency-medium-and-heavy-duty>

DieselNet. (2025). *Emission Standards: USA: Nonroad Diesel Engines*. Emission Standards: USA: Nonroad Diesel Engines. <https://dieselnet.com/standards/us/nonroad.php#tier3>

ESG Today Writing Staff. (2024, October 30). *Rio Tinto Transitions U.S. Copper Mine Operations to Renewable Diesel*. ESG Today. <https://www.esgtoday.com/rio-tinto-transitions-u-s-copper-mine-operations-to-renewable-diesel/>

Flanagan, D. M. (2022). *2018 Minerals Yearbook, Volume I – Metals and Minerals: Copper [Advance Release]* (Minerals Yearbook). U.S. Geological Survey. <https://pubs.usgs.gov/myb/vol1/2018/myb1-2018-copper.pdf>

Freeport-McMoRan Inc. (2024). *2023 Annual Report on Sustainability*. Freeport-McMoRan Inc. <https://fcx.com/sites/fcx/files/documents/sustainability/2023-sustainability-report.pdf>

GasBuddy. (2025). *Search Gas Prices*. Search Gas Prices. <https://www.gasbuddy.com/home>

Global Business Reports. (2023). *Western USA Mining 2024: Pre-Release Edition*. Global Business Reports (GBR). https://www.gbreports.com/files/pdf/_2023/WestUSA-Mining-2023-Prerelease-v10.pdf

Gonzalez, M. (2010, September 29). *Late Intake Valve Closing and Exhaust Rebreathing in a V8 Diesel Engine for High Efficiency Clean Combustion*. DEER Conference 2010. https://www1.eere.energy.gov/vehiclesandfuels/pdfs/deer_2010/wednesday/presentations/deer10_gonzalez.pdf

Grupo México. (2024). *Emissions Intensity Targets for Grupo México's Operations*. Grupo México.

Hao, L., Ren, Y., Lu, W., Jiang, N., Ge, Y., & Wang, Y. (2023). Assessment of Heavy-Duty Diesel Vehicle NO_x and CO₂ Emissions Based on OBD Data. *Atmosphere*, 14(9), 1417. <https://doi.org/10.3390/atmos14091417>

HF Sinclair. (2025, March). *Investor Presentation*. https://s29.q4cdn.com/382181944/files/doc_presentations/2025/Mar/21/DINO-IR-Presentation_March-2025.pdf

Hycroft Mining Holding Corporation. (2024). *2023 Sustainability Report*. Hycroft Mining Holding Corporation. <https://hycroftmining.com>

i-80 Gold Corp. (2024). *2023 Sustainability Report: Transforming Tomorrow Together*. i-80 Gold Corp. https://www.i80gold.com/wp-content/uploads/2024/11/2023_I80-Sustainability-Report.pdf?utm_source=chatgpt.com

Kinross Gold Corporation. (2024). *2023 Sustainability Report*. Kinross Gold Corporation. https://s2.q4cdn.com/496390694/files/doc_downloads/sustainability/2024/Kinross-Gold-2023-Sustainability-Report-Final.pdf

Kohler, J. (n.d.). 9.2.4: *Mines in the U.S.* MNG 230: Introduction to Mining Engineering. Retrieved August 26, 2025, from <https://www.e-education.psu.edu/mng230/node/878>

Mine Health and Safety Administration. (n.d.). *Mine Safety and Health At a Glance: Fiscal Year*. Mine Safety and Health At a Glance: Fiscal Year. Retrieved July 25, 2025, from <http://www.msha.gov/mine-safety-and-health-glance-fiscal-year>

Mining Data Online Inc. (2025). *Mining Intelligence and News*. Mining Intelligence and News. <https://miningdataonline.com/>

Minnesota Department of Revenue. (2024). *2024 Mining Tax Guide* [2024 Mining Tax Guide]. Minnesota Department of Revenue. <https://www.revenue.state.mn.us>

Murphy, K. (2025, May 22). *S&P Global Market Intelligence Discussion* [Zoom].

National Mining Association. (2025). *Economic Contributions of Mining*. National Mining Association. https://nma.org/wp-content/uploads/2024/07/economic-contributions_2024_data_onepager.pdf#:~:text=Value%20of%20Production%20,Effects%20Indirect%20and%20Induced%20Total

Newmont Corporation. (2024a). *2023 Sustainability Report*. Newmont Corporation. https://s24.q4cdn.com/382246808/files/doc_downloads/2023/sustainability/newmont-2023-sustainability-report.pdf

- Newmont Corporation. (2024b). *Newmont 2023 Performance Data*. Newmont Corporation.
https://s24.q4cdn.com/382246808/files/doc_downloads/2023/sustainability/newmont-2023-Performance-Data.pdf
- Origin Mining Company. (n.d.). *Mineral Park Operation*. Mineral Park Operation. Retrieved August 18, 2025, from <https://originmine.com/mineral-park/>
- Pima County Department of Environmental Quality. (2024). *Technical Support Document for ASARCO Mission Complex Title V Air Quality Permit #2026*. Pima County Department of Environmental Quality.
https://webcms.pima.gov/UserFiles/Servers/Server_6/File/Government/Environmental%20Quality/Air/Mission%20Mine/2024%20Mission%20Mine%20TSD.pdf
- Purhamadani, E., Bagherpour, R., & Tudeszki, H. (2021). Energy consumption in open-pit mining operations relying on reduced energy consumption for haulage using in-pit crusher systems. *Journal of Cleaner Production*, 291, 125228.
<https://doi.org/10.1016/j.jclepro.2020.125228>
- Ranganathan, J., Corbier, L., Bhatia, P., Schmitz, S., Gage, P., Oren, K., Dawson, B., Spannagle, M., McMahon, M., Boileau, P., Frederick, R., Vanderborght, B., Thomson, F., Kitamura, K., Woo, C. M., Pankhida, N., Miner, R., Segalen, L., Koch, J., ... Cook, E. (2004). *The Greenhouse Gas Protocol A Corporate Accounting and Reporting Standard: Revised Edition*. World Resources Institute and the World Business Council for Sustainable Development. <https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf>
- Restrepo, L., & Fulton, L. M. (2025). Assessing hydrogen supply chains: An integrated review of leakage and energy efficiency studies. *International Journal of Hydrogen Energy*, 156, 150265. <https://doi.org/10.1016/j.ijhydene.2025.150265>
- Rio Tinto. (2023, December 5). *Rio Tinto Kennecott to fully transition to renewable diesel*. Rio Tinto Kennecott to Fully Transition to Renewable Diesel.

<https://www.riotinto.com/en/news/releases/2023/rio-tinto-kennecott-to-fully-transition-to-renewable-diesel>

Rio Tinto. (2025). *2024 Sustainability Fact Book* [Excel Workbook]. Rio Tinto Corporation.

SLR International Corporation. (2021, December 31). *Technical Report Summary on the Hibbing Taconite Property, Minnesota, USA S-K 1300 Report*. Technical Report Summary on the Hibbing Taconite Property, Minnesota, USA S-K 1300 Report.

<https://www.sec.gov/Archives/edgar/data/764065/000076406522000033/a20220211-8xkxex961.htm>

SSR Mining Inc. (2024). *ESG and Sustainability Data 2023*. SSR Mining Inc.

https://ssrmining.com/_resources/reports/SSR-Sustainability-Data-2023.pdf

Szum, C. (2025). *Google Earth Pro KMZ files for U.S. Open-pit Mine Coordinates* [Unpublished raw geospatial dataset; Keyhole Markup Language Zipped (KMZ) files]. Zotero.

Tokac, B., Zhang, Q., & Sari, Y. A. (2025). Environmental and economic comparison of diesel and electric trucks in open-pit mining operations. *Journal of Cleaner Production*, 507, 145540. <https://doi.org/10.1016/j.jclepro.2025.145540>

UnitConverters.Net. (2025). *Energy Converter*. Energy Converter.

<https://www.unitconverters.net/energy-converter.html>

United States Steel Corporation. (2024). *The Future of Steel: United States Steel Corporation 2023 Sustainability Report*. United States Steel Corporation.

<https://www.ussteel.com/sustainability>

U.S. Department of Energy. (2007). *U.S. Mining Industry Energy Bandwidth Study*. U.S. Department of Energy, Industrial Technologies Program.

https://www.energy.gov/sites/default/files/2013/11/f4/mining_bandwidth.pdf (example)

U.S. Department of Energy, Alternative Fuels Data Center. (2024). *Fuel Properties Comparison* (No. DOE/GO-102024-6212). U.S. Department of Energy.

file:///Users/ccszum/Desktop/fuel_comparison_chart.pdf

- U.S. Energy Information Administration. (2024, October). *Energy Conversion Calculators*.
Energy Conversion Calculators. <https://www.eia.gov/energyexplained/units-and-calculators/energy-conversion-calculators.php>
- U.S. Energy Information Administration. (2025). *Federal and State Motor Fuels Taxes* [Excel Workbook]. U.S. Energy Information Administration.
- U.S. Environmental Protection Agency. (2014). *Framework for Assessing Biogenic CO₂ Emissions from Stationary Sources*. U.S. Environmental Protection Agency.
[https://www3.epa.gov/climatechange/Downloads/Framework-for-Assessing-Biogenic-CO₂-Emissions.pdf](https://www3.epa.gov/climatechange/Downloads/Framework-for-Assessing-Biogenic-CO2-Emissions.pdf)
- U.S. Environmental Protection Agency. (2016, December 28). *Regulations for Emissions from Heavy Equipment with Compression-Ignition (Diesel) Engines* [Other Policies and Guidance]. Regulations for Emissions from Heavy Equipment with Compression-Ignition (Diesel) Engines. <https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-emissions-heavy-equipment-compression>
- U.S. Environmental Protection Agency. (2023). *2023 Emission Factors for Greenhouse Gas Inventories* [Technical Reference Table / Emission Factors Report]. U.S. Environmental Protection Agency. https://www.epa.gov/system/files/documents/2023-03/ghg_emission_factors_hub.pdf
- U.S. Environmental Protection Agency. (2024). *2024 Emission Factors for Greenhouse Gas Inventories* [Technical Reference Table / Emission Factors Report]. U.S. Environmental Protection Agency. https://www.epa.gov/system/files/documents/2024-02/ghg-emission-factors-hub-2024.pdf?utm_source=chatgpt.com
- U.S. Environmental Protection Agency. (2025). *2025 Emission Factors for Greenhouse Gas Inventories* [Technical Reference Table / Emission Factors Report]. U.S. Environmental Protection Agency. <https://www.epa.gov/system/files/documents/2025-01/ghg-emission-factors-hub-2025.pdf>

- U.S. Geological Survey. (2025). *Mineral Commodity Summaries 2025*. U.S. Department of the Interior. <https://doi.org/10.3133/mcs2025>
- Wang, Q., Gu, Q., Li, X., & Xiong, N. (2024). Comprehensive overview: Fleet management drives green and climate-smart open pit mine. *Renewable and Sustainable Energy Reviews*, 189, 113942. <https://doi.org/10.1016/j.rser.2023.113942>
- Wheaton Precious Metals. (n.d.-a). *Mineral Park*. Mineral Park. Retrieved August 18, 2025, from <https://www.wheatonpm.com/portfolio/development-projects/mineral-park/default.aspx>
- Wheaton Precious Metals. (n.d.-b). *Mineral Park*. Project Overview. Retrieved August 26, 2025, from <https://www.wheatonpm.com/portfolio/development-projects/mineral-park/default.aspx>
- Wilkerson, M. (2024, June 5). *WGS84: What is the World Geodetic System 1984*. Pointonnav.Com. <https://pointonnav.com/news/world-geodetic-system/>
- Worlanyo, A. S., & Jiangfeng, L. (2021). Evaluating the environmental and economic impact of mining for post-mined land restoration and land-use: A review. *Journal of Environmental Management*, 279, 111623. <https://doi.org/10.1016/j.jenvman.2020.111623>
- World Resources Institute & World Business Council for Sustainable Development. (2011). *Product Life Cycle Accounting and Reporting Standard* (Nos. 978-1-56973-773-6). World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD). file:///Users/ccszum/Downloads/Product-Life-Cycle-Accounting-Reporting-Standard_041613.pdf