Baseline Ecological Footprint of Sandia National Laboratories, New Mexico

Amy K. Coplen, Jack H. Mizner, Norion M. Ubechel

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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Abstract
The Ecological Footprint Model is a mechanism for measuring the environmental effects of operations at Sandia National Laboratories in Albuquerque, New Mexico (SNL/NM). This analysis quantifies environmental impact associated with energy use, transportation, waste, land use, and water consumption at SNL/NM for fiscal year 2005 (FY05). Since SNL/NM’s total ecological footprint (96,434 gha) is greater than the waste absorption capacity of its landholdings (338 gha), it created an ecological deficit of 96,096 gha. This deficit is equal to 886,470 lha, or about 3,423 square miles of Pinyon-Juniper woodlands and desert grassland. 89% of the ecological footprint can be attributed to energy use, indicating that in order to mitigate environmental impact, efforts should be focused on energy efficiency, energy reduction, and the incorporation of additional renewable energy alternatives at SNL/NM.
Acknowledgements

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### Abbreviations and Acronyms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-20</td>
<td>a fuel mixture of 20 percent biodiesel and 80 percent diesel</td>
</tr>
<tr>
<td>CFM</td>
<td>SNL/NM Carbon Footprint Model</td>
</tr>
<tr>
<td>CH4</td>
<td>methane</td>
</tr>
<tr>
<td>CNG</td>
<td>compressed natural gas</td>
</tr>
<tr>
<td>CO₂</td>
<td>carbon dioxide</td>
</tr>
<tr>
<td>CO₂E</td>
<td>CO₂ equivalent</td>
</tr>
<tr>
<td>COA</td>
<td>City of Albuquerque</td>
</tr>
<tr>
<td>CY</td>
<td>calendar year</td>
</tr>
<tr>
<td>DOE</td>
<td>U.S. Department of Energy</td>
</tr>
<tr>
<td>E-85</td>
<td>a fuel mixture of 75 percent ethanol and 15 percent gasoline</td>
</tr>
<tr>
<td>EFM</td>
<td>SNL/NM Ecological Footprint Model</td>
</tr>
<tr>
<td>EIA</td>
<td>Energy Information Administration</td>
</tr>
<tr>
<td>EMS</td>
<td>Environmental Management System</td>
</tr>
<tr>
<td>EPA</td>
<td>U.S. Environmental Protection Agency</td>
</tr>
<tr>
<td>FMOC</td>
<td>SNL/NM’s Facilities Management and Operations Center</td>
</tr>
<tr>
<td>FTE</td>
<td>Full Time Employee</td>
</tr>
<tr>
<td>FY</td>
<td>fiscal year</td>
</tr>
<tr>
<td>gal</td>
<td>gallon</td>
</tr>
<tr>
<td>GDP</td>
<td>gross domestic product</td>
</tr>
<tr>
<td>gha</td>
<td>global hectare</td>
</tr>
<tr>
<td>GHG</td>
<td>greenhouse gas</td>
</tr>
<tr>
<td>GWP</td>
<td>Global Warming Potential</td>
</tr>
<tr>
<td>ha</td>
<td>hectare</td>
</tr>
<tr>
<td>HD</td>
<td>heavy duty</td>
</tr>
<tr>
<td>HFC</td>
<td>hydrofluorocarbon</td>
</tr>
<tr>
<td>IPCC</td>
<td>International Panel on Climate Change</td>
</tr>
<tr>
<td>KAFB</td>
<td>Kirtland Air Force Base</td>
</tr>
<tr>
<td>kW</td>
<td>kilowatt</td>
</tr>
<tr>
<td>kWh</td>
<td>kilowatt hour</td>
</tr>
<tr>
<td>LD</td>
<td>light duty</td>
</tr>
<tr>
<td>lha</td>
<td>local hectare</td>
</tr>
<tr>
<td>MD</td>
<td>medium duty</td>
</tr>
<tr>
<td>mpg</td>
<td>miles per gallon (miles/gal)</td>
</tr>
<tr>
<td>MSW</td>
<td>mixed solid waste</td>
</tr>
<tr>
<td>MT</td>
<td>metric ton (tonne)</td>
</tr>
<tr>
<td>N₂O</td>
<td>nitrous oxide</td>
</tr>
<tr>
<td>P2</td>
<td>SNL/NM’s Pollution Prevention</td>
</tr>
<tr>
<td>PCB</td>
<td>polychlorinated biphenyl</td>
</tr>
<tr>
<td>PFC</td>
<td>perflourocarbons</td>
</tr>
<tr>
<td>PNM</td>
<td>Public Service Company of New Mexico</td>
</tr>
<tr>
<td>PV</td>
<td>photovoltaic</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>RECs</td>
<td>renewable energy certificates</td>
</tr>
<tr>
<td>Sandia</td>
<td>Sandia Corporation</td>
</tr>
<tr>
<td>SF₆</td>
<td>sulfur hexafluoride</td>
</tr>
<tr>
<td>SNL/NM</td>
<td>Sandia National Laboratories in Albuquerque, New Mexico</td>
</tr>
<tr>
<td>TA</td>
<td>Technical Area</td>
</tr>
<tr>
<td>t</td>
<td>short ton</td>
</tr>
<tr>
<td>tonne</td>
<td>metric ton</td>
</tr>
<tr>
<td>TTC</td>
<td>Thermal Test Complex</td>
</tr>
<tr>
<td>UNM</td>
<td>University of New Mexico</td>
</tr>
<tr>
<td>WAPA</td>
<td>Western Area Power Association</td>
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<tr>
<td>WARM</td>
<td>Waste Reduction Model</td>
</tr>
<tr>
<td>WWF</td>
<td>World Wide Fund for Nature (formerly World Wildlife Fund)</td>
</tr>
<tr>
<td>USAF</td>
<td>United States Air Force</td>
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</table>
1. Executive Summary

The Sandia National Labs / New Mexico (SNL/NM) Ecological Footprint Model (EFM) quantifies the environmental impacts associated with energy, transportation, waste, and land use at SNL/NM for Fiscal Year 2005 (FY05) by incorporating local emission factors, when applicable and available, and data derived from SNL/NM operations. The EFM will assist SNL/NM’s Environmental Management System (EMS) in identifying and evaluating environmental aspects and impacts and will aid in developing objectives and measurable targets to mitigate those impacts. The EFM is ultimately designed to gauge the environmental consequences associated with the numerous and diverse operations at SNL/NM.

The EFM is the summation of the carbon footprint and the land use footprint. The carbon footprint is calculated using the Carbon Footprint Model (CFM), a subset of the EFM, which takes carbon dioxide equivalent (CO₂E) emissions and translates these into a land area using land sequestration ratios. The greenhouse gas (GHG) emissions accounting under the CFM is consistent with the GHG reporting methods recommended in The GHG Protocol: A Corporate Accounting and Reporting Standard (The GHG Protocol), a reputable and widely used standard.¹ The land use footprint is determined by summing the total developed land area under SNL/NM control.

The EFM expresses the carbon footprint and ecological footprint of SNL/NM in global hectares (gha) of the world’s average biologically productive land, as well as local hectares (lha) of the regional landscape. The units of lha are unique to the Pinyon-Juniper woodland and desert grassland landscape where SNL/NM bases its operations. The EFM also accounts for the carbon dioxide (CO₂) sequestration capacity of this landscape, giving SNL/NM credit for keeping this landscape in tact. In addition, the EFM calculates a water footprint independent of the carbon and ecological footprints.

In FY05, SNL/NM emitted a net 429,111 metric tons (tonnes) of CO₂E GHGs, generating a carbon footprint of 96,395 gha, or 889,233 lha. The SNL/NM campus had 353 lha of developed land, considered to be the land use footprint, and 3,116 lha of undeveloped land, capable of sequestering 1,504 tonnes of CO₂. The EFM generates a total ecological footprint of 96,434 gha, or 889,586 lha. In addition, SNL/NM has a total water footprint of 207 gallons (gal) per full-time employee (FTE) per workday.

As illustrated in Figure 1, energy use has the largest impact on SNL/NM’s ecological footprint at 89 percent. Transportation makes up the next largest component at 10 percent. Waste is responsible for 2 percent, and land use has a negligible effect. This analysis indicates that energy use comprises the most significant contribution to SNL/NM’s overall ecological footprint. To mitigate further environmental impact, efforts should focus on energy efficiency, reduction, and the incorporation of renewable energy alternatives.

The baseline FY05 ecological footprint relies mainly on onsite data; commuting is the only category that accounts for offsite employee contributions. To make the model more inclusive, future analyses will incorporate more offsite data, such as electricity and water use. The FY05 baseline only accounts for CO₂, methane (CH₄), and nitrous oxide (N₂O) emissions. Eventually, the model will be designed to account for sulfur hexafluoride (SF₆), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), consistent with The GHG Protocol. These are more powerful GHGs than CO₂, and could contribute considerably to the carbon and ecological footprints.

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2 This pie chart does not include the CO₂ sequestration capacity of the SNL/NM campus (-0.35 percent).
2. Introduction

2.1 Problem Statement

Humanity is facing a global epidemic — the finite resources of the Earth’s biosphere cannot sustain the exponentially increasing material consumption and waste generation that the global economy demands. Economic activity in the United States (U.S.) and many other countries, as measured by Gross Domestic Product (GDP) standards, has been growing steadily. The expansion of the global economy, coupled with exponential world population growth (from three billion in 1959, to six billion in 1999) has resulted in a substantial increase in per-capita energy and material consumption in both developed and developing nations. This expedited resource consumption is severely degrading water, soil, forest, and air quality, as well as the general biodiversity of the Earth. The World Wide Fund for Nature’s (WWF’s) Living Planet Report 2006 estimates that human demand exceeded the long-term carrying capacity of the planet by about 25 percent in 2003. In ecology, this is referred to as an “overshoot” which takes place when the population of an organism uses resources beyond the capacity of the environment to replenish or sustain those resources. Global overshoot, measured as an ecological footprint, began in the 1980’s. The rapid consumption of natural resources is responsible for the unsustainable and increasing ecological deficit (Figure 2).

![Figure 2. Ecological Footprint and Biocapacity](image)

Humanity’s ecological footprint has increased over time and has exceeded the Earth’s biological capacity since the 1980s. (Source: Living Planet Report 2006 p. 20)

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In wake of these conditions, it is critical to assess human impact on the biosphere. Excessive human demand placed on the environment has affected the balance of ecological cycles by diminishing current natural resource reserves. Sustainability can only be reached by protecting natural capital from being systematically exploited. For these reasons, it is important to reliably and consistently monitor the consumption of natural resources, and to limit the effects that consumption has on the Earth’s ecological systems.

2.2  SNL and the EFM Geographic Boundary

SNL is managed and operated by the Sandia Corporation (Sandia), a subsidiary of the Lockheed Martin Corporation. SNL is a major research and development laboratory owned by the Department of Energy. SNL consists of locations in Albuquerque, New Mexico; Livermore, California; and Kauai, Hawaii.

The subject of the EFM analysis is the largest of the sites, the Sandia National Labs / New Mexico (SNL/NM) campus, which is located within the perimeter of the Kirtland Air Force Base (KAFB). SNL/NM consists of five secured technical areas (TAs), buildings in non-secured areas, and several remote testing areas. These test areas are collectively known as the Coyote Test Field and are located in the canyons on the west side of the Manzano Mountains. The Burn Site is located in the northeast region of KAFB and the Thermal Test Complex (TTC) is located within TA-III. The Solar Tower, southeast of TA-III, provides the campus with a portion of its electricity needs (Figure 3).

In 2005, SNL/NM conducted operations on 2,937 acres of U.S. Department of Energy (DOE) property, and 5,633 acres of U.S. Air Force (USAF) property, yielding a total of 8,570 acres of landholdings. The site housed 9,530 staff who operated in approximately 5.4 million gross square feet of on-site building space, and an additional 300,000 gross square feet of off-site building space leased by SNL/NM. Electricity and natural gas consumption, water use, and waste generation are not captured by SNL/NM at these off-site spaces, and therefore off-site space is not evaluated as a part of the land use footprint. However, travel associated with the employees that work at these off-site spaces is included in this analysis (i.e. commuting, airline and rental car travel, and fleet vehicle use).
Figure 3. SNL/NM Campus

SNL/NM campus lies within the boundary of KAFB, southeast of the Albuquerque metropolitan area and west of the Manzano Mountains.
The primary objective of SNL/NM is to develop, engineer, and test various non-nuclear components of nuclear weapons, as well as to implement the nation’s nuclear weapon policies through appropriate research and development. SNL/NM is also responsible for developing solutions to problems associated with hazardous waste created in nuclear weapons programs. SNL/NM conducts research and development in other fields, including environmental and alternative energy programs, computational biology, materials sciences, mathematics, and nonproliferation.

Sandia takes its responsibility for protecting the environment seriously and encourages employees, contractors, and visitors to be conscious of environmental issues by placing special emphasis on identifying and mitigating potential risks to the environment. To work towards being a leader in environmental stewardship, Sandia has implemented an Environmental Management System (EMS), for planning, reviewing, executing, and improving work processes and actions to reduce environmental impact.

The EMS is a progressive, proactive approach to protecting the environment, and ensuring the health and safety of Sandia’s employees and the community. The scope of Sandia’s EMS includes improving efficiency, conserving water and energy, reducing waste, recycling, green purchasing, and employing sustainable technologies in building projects. Furthermore, Sandia’s EMS is committed to implementing programs and improving performance for environmental protection, pollution prevention (P2), and environmental compliance.

### 2.3 Goals and Functions of the Baseline Ecological Footprint

The Ecological Footprint Model (EFM) will be used as a tool to assist in the evaluation of SNL/NM’s environmental aspects and impacts and in the development of objectives and measurable targets to mitigate those impacts. The primary goals of this analysis are to:

- Develop an EFM specific to SNL/NM,
- Generate a Fiscal Year 2005 (FY05) baseline ecological footprint to quantify the environmental impact and resource consumption of SNL/NM that can serve as an information body to support other projects and missions at SNL/NM,
- Introduce and integrate the EFM as a tool for assessing the environmental impact associated with numerous and diverse aspects of SNL/NM operations, and
- Develop a method applicable to other national laboratories, federal facilities, and other large institutions.

### 2.4 Ecological Footprint Method

The concept of the ecological footprint was developed by Mathis Wackernagel and William Rees. It is used as a tool to quantitatively measure environmental impact, and to identify major sources of biospheric degradation. The method measures direct and indirect demands placed on the environment by using biologically productive land area as a collective unit for providing resources and absorbing waste. It is an effective mechanism for quantifying global and local environmental impacts and can also assist in analyzing current degrees of industrial economic sustainability. Since natural capital is a limiting factor in
economic growth, ecological footprinting is not only a method for assessing environmental impact, but is also a tool comparable to economic state indicator models such as the GDP and the Retail Prices Index.\textsuperscript{6}

The relationship between human development and the natural cycles of the Earth can be measured by the ecological footprint. The ecological footprint determines the relative amount of land needed to sustain basic natural cycles and species diversity in response to human demand on the environment. The method considers the environmental impact of human activity from resource extraction to the influence of waste streams on the assimilation capacity of the Earth’s biosphere. An ecological footprint represents the relative area of biologically productive land that a given population or organization would require to regenerate the natural resources it consumes. It also includes the land required to assimilate the given population’s waste. An ecological footprint consists of two main components based on the population’s activities:

1. Land needed to counter balance carbon emissions, and
2. Land physically taken out of service by development.

This study considers these components of the carbon footprint and the land use footprint, respectively.

2.5 \textit{Carbon Footprint Method}

Increasing levels of greenhouse gas (GHG) emissions is a leading source of environmental impact today. Climatic changes occur as a net result of internal variability within the climate system and external factors, such as natural and anthropogenic forcing. Concentrations of atmospheric GHGs and their associated radiative forcing on the Earth’s climatic system have substantially increased as a result of human activity since the industrial revolution. According to the Intergovernmental Panel on Climate Change (IPCC), “there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.”\textsuperscript{7} This anthropogenic forcing must be consistently measured and limited; carbon footprinting can accomplish these tasks.

The carbon footprint method translates fossil-energy usage and environmental releases into GHG emissions and calculates the biologically productive land area needed to sequester these GHG emissions. Carbon footprinting uses known emission estimation methods and conversion factors to determine annual emission quantities based on the amount of fuel or energy consumed or miles traveled.

\textsuperscript{6} Lewan, L. and C. Simmons, “Annex 1: Ecological Footprint Analysis” \textit{The use of Ecological Footprint and Biocapacity Analyses as Sustainability Indicators for Sub-national Geographical Areas: A Recommended Way Forward}. (Ambiente Italia [ECIP], 27 August 2001). p. 1. Accessed at: \url{http://www.prosus.uio.no/english/sus_dev/tools/oslows/2.htm}; GreenFacts.org defines natural capital as “an extension of the economic notion of capital (manufactured means of production) to environmental ‘goods and services’. It refers to a stock (e.g., a forest) which produces a flow of goods (e.g., new trees) and services (e.g., carbon sequestration, erosion control, habitat).” GreenFacts Glossary. June 2008. October 2008. Accessed at: \url{http://www.greenfacts.org/glossary/mno/natural-capital-asset.htm}.

2.5.1 The GHG Protocol and Scopes Method

The Greenhouse Gas Protocol Initiative was launched in 1988, for the purpose of developing and encouraging the adoption of a consistent GHG inventory procedure for businesses. The GHG Protocol: A Corporate Accounting and Reporting Standard (The GHG Protocol) provides guidance on quantifying GHG emissions from the six GHGs covered by the Kyoto Protocol: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), sulfur hexafluoride (SF₆), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). Many organizations have adopted these standards, including the WWF, the U.S. Environmental Protection Agency (EPA) Climate Leaders, the U.S. Climate Registry, the California Climate Action Registry, and the Chicago Climate Exchange.

The GHG Protocol distinguishes between direct GHG emissions (from sources owned or controlled by the company), and indirect GHG emissions (from sources not owned or controlled by the company but still considered a consequence of the company’s operations). The protocol defines three “scopes” to distinguish between direct and indirect emissions: Scope 1 accounts for all direct emissions, which includes those from the combustion of fuel onsite, physical or chemical processing, the consumption of fuel in fleet vehicles, and fugitive emissions from releases such as equipment leaks and venting; Scope 2 includes only indirect emissions from electricity purchased from an outside provider; and Scope 3 is for all other indirect emissions, including those associated with the extraction, production, and transportation of purchased and sold materials and fuels, commuting, employee business travel, and waste disposal, among others (Figure 4).

For those entities that use the GHG Protocol for reporting their GHG emissions, Scope 1 and 2 are mandatory, while Scope 3 is optional.

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9 Ibid. p. 4.
10 Ibid. p. 25-27.
The scope methodology ensures that emissions will not be double-counted. The emissions associated with electricity generation, transmission and distribution, and end-use consumption is a good example of the accountability breakdown. Consider the following complex example provided by The GHG Protocol involving the generation of 100 MWh of electricity by Generator A, the purchase of this electricity by Trader B, the subsequent sale to Utility Company C, and the final consumption of electricity by End-user D (Figure 5). The theoretical total GHG emissions associated with this electricity is 20 t of emissions at 0.2 t/MWh, 1 t of which is considered line loss. Generator A reports 20 t of emissions in Scope 1, as these are direct emissions released at the generation plant. Trader B reports these emissions as optional information outside of Scope 1, 2, and 3. Utility company C reports 1 t under Scope 2, as these are indirect emissions associated with the consumption of the line loss resulting from transportation and delivery; utility company C also reports 19 t under Scope 3, as these are emissions associated with end-use consumption. End-user D reports 19 t under Scope 2, as these are indirect emissions associated with D’s consumption, and 1 t under Scope 3, as these are indirect emissions resulting from transportation and delivery upstream of the End-user.\(^{11}\)

\[\text{Figure 5. GHG Accounting from the Sale and Purchase of Electricity}\
\text{(Source: The GHG Protocol 2004 p. 29)}\]

**2.5.1.1 The SNL/NM EFM and The GHG Protocol**

The SNL/NM EFM reports CO\(_2\), CH\(_4\), and N\(_2\)O emissions, but at present does not include SF\(_6\), HFCs and PFCs. An FY07 baseline of SF\(_6\) has been conducted by the P2 program, and will be included in future analyses. HFCs and PFCs will be included as data from these emissions becomes available. The EFM reports under all three scopes (Table 1). In the future, the SNL/NM EFM will report fugitive emissions under Scope 1 and will also consider including transportation of purchased materials and goods, transportation of purchased fuels, electricity-related activities not included in Scope 2, and leased assets and outsourced activities as part of the SNL/NM GHG inventory under Scope 3.

Table 1. SNL/NM EFM GHG Emissions Reporting under GHG Protocol Scopes

<table>
<thead>
<tr>
<th>Scope 1</th>
<th>Scope 2</th>
<th>Scope 3</th>
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<tbody>
<tr>
<td>Natural gas consumption</td>
<td>Purchased Electricity</td>
<td>Employee commuting</td>
</tr>
<tr>
<td>Other stationary combustion</td>
<td></td>
<td>Employee Business Travel</td>
</tr>
<tr>
<td>Fleet fuel consumption</td>
<td></td>
<td>Waste Transportation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Waste Decomposition</td>
</tr>
</tbody>
</table>

2.6 SNL/NM Ecological and Carbon Footprint Model Parameters

The Carbon Footprint Model (CFM), a subset of the EFM, accounts for CO$_2$, CH$_4$, and N$_2$O emitted as a result of SNL/NM operations. Since CO$_2$ is the primary GHG emitted across all sectors of the industrial economy, this analysis converts CH$_4$ and N$_2$O emissions into CO$_2$ equivalent (CO$_2$E) emissions using corresponding global warming potentials (GWPs). CO$_2$ sequestered by the local landscape is subtracted from CO$_2$E emissions to yield overall net emissions. Figure 6 provides a schematic of SNL/NM’s emissions, sequestration, and resulting net emissions. These net emissions are then converted into an ecological footprint representing the land area required to sequester emissions. The baseline CFM can aid in the development of emission-reduction strategies.

Figure 6. Schematic of SNL/NM's Carbon Footprint Inputs
3. Methodology

This baseline ecological footprint analysis utilizes a compound based ecological footprint approach to compare the annual resource consumption of SNL/NM to the regenerative capacity of the Earth’s biosphere.\(^\text{12}\) This regenerative capacity is normalized into biologically productive hectares (ha) of land, which represent quantities of natural resources consumed. Since SNL/NM has a finite amount of biologically productive land constituted by its designated landholdings, this model determines whether SNL/NM is functioning within the means of its allocated resource base. If the collective demand (ecological footprint) of SNL/NM is larger than the resource supply capacity of its total landholdings, then SNL/NM is incurring an ecological deficit. Alternatively, if the footprint is smaller than the resource supply capacity, SNL/NM is generating an ecological surplus.

The EFM determines the biologically productive land area required to support SNL/NM. Four major categories of ecological impact are identified and studied in the EFM: Energy, Transportation, Land Use, and Waste (Figure 7). In addition to the ecological footprint, a water footprint is calculated.

Although the SNL/NM EFM utilizes Wackernagel’s and Rees’ methodology, there are some distinct differences to note. The SNL/NM model is specific to NM and uses emission factors specific to the State, when available, while the Wackernagel and Rees methodology uses emission factors based on national or global averages. In addition to calculating an ecological footprint in units of global hectares (gha), the SNL/NM EFM also determines an ecological footprint in terms of the local landscape in the unique units of local hectares (lha), which are defined in Appendix A of this report.

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\(^\text{12}\) For information on the compound based approach, see Wackernagel, Mathis, Chad Monfreda, Dan Moran, Paul Wermer, Steve Goldfinger, Diana Deumling, and Michael Murray. *National Footprint and Biocapacity Accounts 2005: The Underlying Calculation Method* (Global Footprint Network; Oakland, CA: 2005), p. 5-6.
Figure 7. Flow Diagram SNL/NM's Ecological Footprint Inputs and Outputs
The SNL/NM EFM is composed of two distinct parts: the land use footprint and the carbon footprint. The land use component is the area of developed land on the SNL/NM campus. The carbon footprint, as measured by the CFM, is composed of energy use, transportation, and waste. CO\(_2\), N\(_2\)O, and CH\(_4\) emissions from these three activities are summed using respective GWPs to yield CO\(_2\)E emissions.\(^{13}\) The emissions from these operations are then converted into a carbon footprint in \(\text{gha}\) by multiplying by a Land Sequestration Ratio. The methods used to calculate the components of the EFM are discussed below, including emission factors, sequestration ratios, and other constants. Sample calculations are included to provide the reader with sufficient detail to understand the methodology. Complete calculations of emissions, ecological footprints in \(\text{gha}\) and \(\text{lha}\), the water footprint, and the ecological deficit are provided in Appendices B through G of this report, a complete conversion table is provided in Appendix H.

### 3.1 Global Sequestration

The Land Sequestration Ratio (0.192 ha*yr/tonneCO\(_2\)) is the area of the Earth’s average forest land required to sequester CO\(_2\) emissions annually.\(^{14}\) Based on the fact that not all land types and bodies of water (i.e. forest, desert, ocean, lake) are equally biologically productive, the Land Equivalence Factor (1.17 \(\text{gha}/\text{ha}\)) compensates for the varying degree of biomass production over the Earth’s biosphere.\(^{15}\) This number is greater than 1 \(\text{gha}/\text{ha}\), because it takes more of the Earth’s average bioproductive land (given in units of \(\text{gha}\)) than the Earth’s average forest land (given in units of \(\text{ha}\)) to sequester the same amount of CO\(_2\). In general, this factor normalizes different types of land to the world’s average bioproductivity. To show the relationship of the land sequestration ratio and the land equivalence factor, a sample calculation of the carbon footprint is provided below.

**Sample Carbon Footprint Equation:**

a) Carbon Dioxide Equivalent Emissions: \(\text{tonneCO}_2E\)

b) Land Sequestration Ratio: 0.192 \(\text{ha}^*\text{yr}/\text{tonneCO}_2\)

c) Land Equivalence Factor: 1.17 \(\text{gha}/\text{ha}\)

\[
\left(0.192 \frac{\text{ha}^*\text{yr}}{\text{tonneCO}_2}\right) \left(1.17 \frac{\text{gha}}{\text{ha}}\right) = 0.225 \frac{\text{gha}^*\text{yr}}{\text{tonneCO}_2}
\]

\[
(\text{tonneCO}_2E) \left(0.225 \frac{\text{gha}^*\text{yr}}{\text{tonneCO}_2E}\right) = \text{gha}
\]

---


\(^{15}\) Ibid.
3.2 Local Sequestration

The Average Sequestration Capacity for the local landscape that SNL/NM operates on, in \( lha \cdot yr/tonneCO_2 \), is calculated using known and derived sequestration and primary production rates for Pinyon-Juniper woodlands and desert grassland vegetation (Appendix A provides details on this calculation). Due to the fact that SNL/NM operates in a desert environment, the average sequestration ratio of the local landscape (2.07 \( lha \cdot yr/tonneCO_2 \)) is much larger than that of the Earth’s average biologically productive land (0.225 \( gha \cdot yr/tonneCO_2 \)), indicating that a much larger area of the local landscape is required to sequester CO\(_2\) compared to that required by the Earth’s average biologically productive land. In fact, if we take the ratio of these two values, we see that it takes more than nine times as much local landscape to sequester the same amount of carbon as the Earth’s average forests (see sample calculation of sequestration ratio below).

Sample Sequestration Ratio Equation:

\[
\frac{2.07 \ lha \cdot yr}{tonneCO_2} = 9.22 \ \frac{gha}{gha} \times \frac{yr}{tonneCO_2}
\]

Note: Numbers may slightly differ due to rounding.

3.3 Energy Parameters

Energy contributions to SNL/NM’s ecological footprint consist of NM’s grid electricity mix, hydroelectricity, biomass electricity, solar electricity, natural gas, and diesel, gasoline, and jet fuel consumed for purposes other than transportation. The land use component for electricity generation and natural gas use (onsite electrical lines, pipelines, meters, etc.), are captured in the land use calculations of this study. The energy footprint accounts for emissions from the stationary combustion of diesel and gasoline fuel used in generators at the Burn Site and the TTC.\(^{16}\) See Appendix B for complete energy emissions and ecological footprint calculations.

3.3.1 Electricity Footprint Parameters

SNL/NM’s grid electricity is supplied by Public Service Company of New Mexico (PNM), through a contract with Western Area Power Association (WAPA). NM’s grid electricity is predominantly generated at coal-fired power plants. Hydroelectricity consumption is estimated as a percentage of the total hydroelectricity consumed by KAFB, and this value is subtracted from total electricity usage to yield grid electricity consumption. SNL/NM’s solar installations that were functioning in FY05, consist of two grid connected projects and one stand alone parking light system. This analysis accounts for the solar electricity by determining the emissions that are potentially offset by replacing NM’s grid electricity mix with solar-generated electricity. Therefore, an ecological footprint credit for solar electricity is calculated by subtracting

\(^{16}\) See section 2.2 and Figure 3 for more information on the burn site and the TTC.
the footprint associated with solar electricity production from that associated with NM’s grid electricity mix. SNL/NM also purchases biomass Renewable Energy Certificates (RECs) from WAPA. In FY05, Biomass RECs were purchased from WAPA’s Sierra Pacific Industries, California. Since this biomass energy is considered a credit and is not directly consumed by SNL/NM, this analysis accounts for the RECs by determining the emissions that are potentially offset by replacing NM’s grid electricity mix with biomass-generated electricity, in the same way that the solar electricity credit is calculated. The overall electricity footprint was calculated by summing these four footprint components (see sample electricity footprint equation below). Solar and Biomass components are negative because they are considered credits. All four components are discussed in more detail in sections 3.3.1.1 through 3.3.1.4. See Appendix B-I for complete electricity footprint calculations.

Sample Electricity Footprint Equation:

\[
\text{Grid} + \text{Hydro} - \text{Solar Credit} - \text{Biomass Credit} = \text{Total Electricity}
\]

3.3.1.1 Grid Electricity Footprint

The electricity footprint is calculated by determining the quantity of NM’s grid electricity SNL/NM consumed in FY05, as defined by the Facilities Management and Operations Center (FMOC). A CO\(_2\)E emission factor is calculated using the specific CO\(_2\), CH\(_4\), and N\(_2\)O emission factors for NM’s grid electricity mix for FY05 and corresponding GWPs.\(^{17}\) This CO\(_2\)E emission factor is used to determine total CO\(_2\)E emissions, which are then converted into an ecological footprint. The calculation of the grid electricity footprint in gha is provided below. See Appendix B-I-A for complete grid electricity calculations.

Sample Grid Emissions and Electricity Footprint Equations:

\[
\begin{align*}
\text{a) NM Grid CO}_2\text{E Emission Factor: } & 2.054 \frac{\text{lbs CO}_2}{\text{MWh}} \\
\text{b) NM Grid CH}_4\text{E Emission Factor: } & 0.013 \frac{\text{lbs CH}_4}{\text{MWh}} \\
\text{c) CH}_4\text{ GWP: } & 23 \frac{\text{lbsCO}_2E}{\text{lbsCH}_4} \\
\text{d) NM Grid N}_2\text{O Emission Factor: } & 4.4 \frac{\text{lbsN}_2\text{OE}}{\text{MWh}} \\
\text{e) N}_2\text{O GWP: } & 296 \frac{\text{lbsCO}_2E}{\text{lbsN}_2\text{O}}
\end{align*}
\]

\[
\left(2,054 \frac{lbsCO_2}{MWh} + 0.013 \frac{lbsCH_4}{MWh} (23) + 4.4 \frac{lbsN_2O}{MWh} (296)\right) / \left(2,205 \frac{lbs}{tonne}\right) = 1.52 \frac{tonneCO_2E}{MWh}
\]

f) FY05 Grid Electricity Consumption: 235,875 \(\frac{MWh}{yr}\)

g) NM Grid CO\(_2\)E Emission Factor: 1.52 \(\frac{tonneCO_2E}{MWh}\)

h) Land Sequestration Ratio: 0.192 \(\frac{ha \times yr}{tonneCO_2}\)

i) Land Equivalence Factor: 1.17 \(\frac{gha}{ha}\)

\[
\left(235,875 \frac{MWh}{yr}\right) \left(1.52 \frac{tonneCO_2E}{MWh}\right) = 359,138 \frac{tonneCO_2}{yr}
\]

\[
\left(359,138 \frac{tonneCO_2}{yr}\right) \left(0.192 \frac{ha \times yr}{tonneCO_2}\right) \left(1.17 \frac{gha}{ha}\right) = 80,677 gha
\]

Note: Numbers may slightly differ due to rounding.

### 3.3.1.2 Hydroelectricity Footprint

The hydroelectricity footprint is calculated using a generic ecological footprint in units of \(gha*yr/GWh\).\(^\text{18}\) Since the SNL/NM workforce is approximately 60 percent of the KAFB population, this analysis assumes responsibility for 60 percent of hydroelectricity consumption by KAFB.\(^\text{19}\) The calculation of the hydroelectricity footprint in \(gha\) is provided below. See Appendix B-I-B for complete hydroelectricity footprint calculations.

**Sample Hydroelectricity Footprint Equation:**

a) FY05 KAFB Hydroelectricity Consumption: 15,721 \(\frac{MWh}{yr}\)

b) SNL/NM’s % of KAFB population: 60%

c) Hydroelectricity Footprint Ratio: 75 \(\frac{gha \times yr}{GWh}\)

---

\(^{18}\) Chambers, et al. report a range from 10 to 75 \(ha*yr/GWh\) and note that “75 is based on a Californian mix of 96 per cent low altitude and 4 per cent high altitude installations.” p. 83. The hydroelectricity produced in New Mexico comes from the low altitude Elephant Butte Dam; the authors state that values are in \(ha*yr\) of world average productive space. This is equivalent to \(gha\). Chambers, Nicky, Craig Simmons, and Mathis Wackernagel. *Sharing Nature’s Interest.* (Earthscan, London: 2000) p. 83.

\(^{19}\) Correspondence with Lucille Roybal from Electricity and Fire Protection Engineering, February 2008.
3.3.1.3 Solar Electricity Footprint Credit

The electrical output associated with solar installations are calculated using their respective size, the hours of sunlight in a day, and capacity factors related to their specific technologies (e.g. photovoltaic [PV] and sterling engines). Like the hydroelectricity footprint, the solar electricity footprint is calculated using a generic ecological footprint in units of $gha \times yr/GWh$. Although the sterling engines are not considered PV installations, the generic PV footprint is the only generic solar footprint available at the time of publication.

In FY05, three solar installations were operating on the SNL/NM campus. Of these three installations, 40.25 kW are PV and 150kW are sterling engines, providing a total of 190.25 kW of solar electricity. The three solar installations of interest are:

- 0.25kW parking lot PV lighting installation,
- 40kW PV array installation, and
- 150kW sterling engines at the Solar Tower Facility.

The calculation of the solar electricity footprint credit in $gha$ is provided below. See Appendix B-I-C for complete solar electricity calculations.

**Sample Solar Electricity Footprint Credit Equation:**

a) Total Size of PV: 40.25$kW$
b) PV Capacity Factor: 0.256
c) Size of Sterling Engines: 150$kW$
d) Sterling Engine Capacity Factor: 0.191
e) Number of Hours in a Year: 8,760$h$

\[
\left(\frac{40.25kW \times 0.256 + (150kW \times 0.191)}{1,000,000 \times \frac{kWh}{GWh}}\right)(8760h) = 0.34GWh
\]

f) NM Grid $CO_2E$ Emission Factor: $\frac{1.52tonneCO_2E}{MWh}$

---

20 According to Greg Kolb in the Solar Systems Department at SNL/NM, capacity factor is the fraction of the year that the solar unit delivers its full rated capacity.

21 See section 2.2 and Figure 3 for information on the Solar Tower Facility.
g) Land Sequestration Ratio: 0.192 \( \frac{\text{ha} \cdot \text{yr}}{\text{tonneCO}_2} \)

h) Land Equivalence Factor: 1.17 \( \frac{\text{gha}}{\text{ha}} \)

\[
(0.34GWh \left( \frac{1,000 \text{MWh}}{GWh} \right) \left( \frac{1.52 \text{tonneCO}_2}{MWh} \right) \left( 0.192 \frac{\text{ha} \cdot \text{yr}}{\text{tonneCO}_2} \right) \left( 1.17 \frac{\text{gha}}{\text{ha}} \right) ) = 117 \text{gha(NMgrid)}
\]

i) PV Footprint Ratio: 24 \( \frac{\text{gha} \cdot \text{yr}}{\text{GWh}} \)

\[
(0.34GWh \left( \frac{24 \text{gha} \cdot \text{yr}}{\text{GWh}} \right) ) = 8 \text{gha(PV)}
\]

117gha – 8gha = 108gha

Note: Numbers may slightly differ due to rounding.

3.3.1.4 Biomass Footprint Credit
The biomass electricity footprint is determined using a generic biomass footprint. The calculation of the biomass footprint credit is provided below. See Appendix B-I-D for complete biomass footprint credit calculations.

Sample Biomass Footprint Credit Equation:

a) FY05 Biomass RECs: 6,700 \( \frac{\text{MWh}}{\text{yr}} \)

b) NM Grid CO2E Emission Factor: \( \frac{1.52 \text{tonneCO}_2}{\text{E MWh}} \)

c) Land Sequestration Ratio: 0.192 \( \frac{\text{ha} \cdot \text{yr}}{\text{tonneCO}_2} \)

d) Land Equivalence Factor: 1.17 \( \frac{\text{gha}}{\text{ha}} \)

\[
(6,700 \frac{\text{MWh}}{\text{yr}} \left( \frac{1.52 \text{tonneCO}_2}{\text{MWh}} \right) \left( 0.192 \frac{\text{ha} \cdot \text{yr}}{\text{tonneCO}_2} \right) \left( 1.17 \frac{\text{gha}}{\text{ha}} \right) ) = 2,292 \text{gha(NMgrid)}
\]

e) Biomass Footprint Ratio: 36.5 \( \frac{\text{gha} \cdot \text{yr}}{\text{GWh}} \)

\[
\left( \frac{6,700 \text{MWh}}{\text{yr}} \right) \left( \frac{36.5 \frac{\text{gha} \cdot \text{yr}}{\text{GWh}}}{1,000 \frac{\text{MWh}}{\text{GWh}}} \right) = 245 \text{gha(biomass)}
\]

---

22 Chambers, et al. report a range of 27 to 46 ha*yr/GWh based on the forest land required to grow the wood fuel. This analysis uses the median value of 36.5 gha. Chambers, Nicky, Craig Simmons, and Mathis Wackernagel. Sharing Nature's Interest. (Earthscan, London: 2000) p. 83.
2.292 \text{ gha}(NMgrid) - 245 \text{ gha}(biomass) = 2,047 \text{ gha}

Note: Numbers may slightly differ due to rounding.

### 3.3.2 Natural Gas Footprint Parameters

SNL/NM’s natural gas is supplied by PNM, through a contract with WAPA. The annual natural gas consumption for SNL/NM is recorded by FMOC. Since the energy content of natural gas decreases with increasing altitude (due to the expansion of gas) this analysis utilizes the CO$_2$ emission factor in kgCO$_2$/MMBtu for the lowest energy content provided by the Energy Information Administration (EIA).\(^{23}\) The EIA’s range of 975 to 1,000 Btu/scf reflects the lowest energy content and highest altitude; this study uses the upper end of this range (1,000 Btu/scf) for further calculations.\(^{24}\) The majority of natural gas consumed by SNL/NM is used for heating purposes, and is classified in the “commercial” category for CH$_4$ and N$_2$O emission factors (in g/MMBtu) provided by the EIA.\(^{25}\) These emission factors, in addition to the Land Sequestration Ratio and Land Equivalence Factor, are used to convert natural gas usage into annual CO$_2$ emissions. The calculation of the natural gas footprint in gha is provided below. See Appendix B-II for complete natural gas footprint calculations.

**Sample Natural Gas Footprint Equation:**

\[ \text{a) FY05 Natural Gas Consumption: } 530,239 \frac{\text{Mcf}}{\text{yr}} \]

\[ \text{b) Natural Gas CO}_2\text{ Emission Factor: } 54.01 \frac{\text{kgCO}_2}{\text{MMBtu}} \]

\[ \text{c) Natural Gas CH}_4\text{ Emission Factor: } 4.8 \frac{\text{gCH}_4}{\text{MMBtu}} \]

\[ \text{d) CH}_4\text{ GWP: } 23 \frac{\text{lbsCO}_2\text{E}}{\text{lbsCH}_4} \]

\[ \text{e) Natural Gas N}_2\text{O Emission Factor: } 0.1 \frac{\text{gN}_2\text{O}}{\text{MMBtu}} \]

\[ \text{f) N}_2\text{O GWP: } 296 \frac{\text{lbsCO}_2\text{E}}{\text{lbsN}_2\text{O}} \]

---


\(^{24}\) FMOC uses the energy content of 1,000 Btu/scf in its studies and calculations. Standard cubic foot (scf) is used interchangeably with cubic foot (cf) in this report.

\[
\left(\frac{530,239 \text{ Mcf}}{\text{yr}}\right) \left(\frac{1 \text{ Mcf}}{\text{MMBtu}}\right) \left(\frac{54.01 \frac{\text{kg CO}_2}{\text{MMBtu}}}{1000 \frac{\text{kg}}{\text{tonne}}}\right) + \left(\frac{4.8 \frac{\text{g CH}_4}{\text{MMBtu}}}{23} + 0.1 \frac{\text{g N}_2\text{O}}{\text{MMBtu}}\right) \left(\frac{1,000,000 \frac{\text{g}}{\text{tonne}}}{2961.0} + 238.4\right) = 28,712 \text{tonne CO}_2 \cdot E
\]

\( g \) Land Sequestration Ratio: \( 0.192 \frac{\text{ha}}{\text{tonne CO}_2} \)

\( h \) Land Equivalence Factor: \( 1.17 \frac{\text{gha}}{\text{ha}} \)

\[
(28,712 \text{tonne CO}_2 \left(0.192 \frac{\text{ha*yr}}{\text{tonne CO}_2}\right) \left(1.17 \frac{\text{gha}}{\text{ha}}\right) = 6,450 \text{gha}
\]

Note: \( \frac{\text{MMBtu}}{\text{Mcf}} \) is based on the energy content of \( 1,000 \frac{\text{Btu}}{\text{scf}} \) and the conversion of \( 1,000 \frac{\text{cf}}{\text{Mcf}} \).

Note: Numbers may slightly differ due to rounding.

### 3.3.3 Stationary Combustion Footprint

Diesel and gasoline are used to power generators onsite. Jet fuel is used at the Burn Site, located East of the Manzano Base, and the TTC, located within TA-III.\(^{26}\) The Air Quality Compliance Program provided fuel consumption data in gallons (gal). Gasoline and diesel usage for portable generators is reported by calendar year (CY), so a weighted average is used to estimate consumption for FY05. Stationary CO\(_2\) emission factors for gasoline and diesel fuel are provided by the EPA in units of lbsCO\(_2\)/MMBtu of fuel consumed, and that for jet fuel is provided by the EIA in units of kgCO\(_2\)/MMBtu.\(^{27}\) The gross heat of combustion of each fuel type is required to convert units of volume into energy.\(^{28}\) CH\(_4\) and N\(_2\)O emission factors for the stationary combustion of these fuels are not available at the time of publication and are not included in the calculation. A calculation of the gasoline stationary combustion footprint in gha is provided below. Complete gasoline, diesel, and jet fuel stationary combustion footprint calculations are contained in Appendix B-III.

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\(^{26}\) See section 2.2 and Figure 3 for more information on the Burn Site and the TTC.


Sample Gasoline Stationary Combustion Footprint Equation:

a) FY05 Gasoline Consumption: 7.5gal

b) Gasoline Stationary CO₂ Emission Factor: \(154 \frac{lbsCO_2}{MMBtu}\)

c) Motor Gasoline Gross Heat of Combustion: \(5.25 \frac{MMBtu}{barrel}\)

\[
(7.5gal) \left(154 \frac{lbsCO_2}{MMBtu}\right) \left(5.25 \frac{MMBtu}{barrel}\right) \left(\frac{42}{gal}\right) = 135 lbsCO_2
\]

d) Land Sequestration Ratio: \(0.192 \frac{ha \cdot yr}{tonneCO_2}\)

e) Land Equivalence Factor: \(1.17 \frac{gha}{ha}\)

\[
\frac{\left(135 lbsCO_2\right)}{\left(2.205 \frac{lbs}{tonne}\right)} \left(0.192 \frac{ha \cdot yr}{tonneCO_2}\right) \left(1.17 \frac{gha}{ha}\right) = 0.015 gha
\]

Note: Numbers may slightly differ due to rounding.

3.4 Transportation Parameters

The transportation contributions to the SNL/NM ecological footprint consist of fuel consumption from employee related travel, including commuting, business travel in rental cars, the use of Sandia owned fleet vehicles, and airline business travel. SNL/NM has a unique workforce consisting of full, part-time, and telecommuting Sandia employees, contractors, and student interns. In CY05, there were 9,530 MOWs at SNL/NM.

The total transportation footprint is calculated by determining the emissions from each category of transportation (commuting, rental cars, fleet, and airline travel) and summing these emissions. The details of the emissions calculations from each transportation category are discussed in the following sections. These total emissions are then converted into an ecological footprint using the Land Sequestration Ratio and Land Equivalence Factor discussed previously in detail in section 3.1.

3.4.1 Commuting Emissions

Employee data, which identifies full-time, part-time, and alternative work schedule employees, telecommuters, bicycle commuters, bus commuters, and car and vanpool riders is used to derive an approximate number of personal commuter vehicles. The average round trip commute is determined from data provided by a survey taken at a
SNL/NM 2008 Earth Day event. The number of workdays in a year is based on 260 eight hour days, less 31 holidays and vacation days in a year. Fuel efficiency data from 2002, is used as an estimate of the average commuter vehicle fuel efficiency. This data, along with vehicle specific data provided by a KAFB traffic survey, is used to determine an average fuel economy.

Emission factors are provided by the EIA; CO₂ emission factors are in units of lbs/gal, and CH₄ and N₂O emission factors are in g/mile. The CO₂ factor is dependent on the volume of fuel consumed, while CH₄ and N₂O factors are dependent on vehicle type; passenger cars, light duty (LD) trucks, and heavy duty (HD) vehicles have varying CH₄ and N₂O emissions factors. CH₄ and N₂O emissions factors are based on weighted averages of vehicle types taken from the KAFB traffic survey. Because this analysis assumes all commuter vehicles are gasoline fueled, CO₂ emissions are underestimated, while N₂O and CH₄ emissions are overestimated. A calculation of commuter emissions is provided below. See Appendix C-I for complete commuter emissions calculations, including the bicycle commuter offset and the bus commuter footprint.

**Sample Commuter Emissions Equation:**

a) # Personal Commuter Vehicles: \(7,777\) vehicles 

b) Average Round Trip Commute: \(26\) miles 

c) # Workdays in a year: \(229\) days 

d) Average Fuel Economy: \(18.5\) \(\frac{\text{miles}}{\text{gal}}\) 

e) Gasoline CO₂ Emission Factor: \(19.54\) \(\frac{\text{lbsCO₂}}{\text{gal}}\) 

f) Gasoline CH₄ Emission Factor: \(0.039\) \(\frac{gCH₄}{\text{mile}}\) 

g) CH₄ GWP: \(23\) \(\frac{lbsCO₂E}{lbsCH₄}\) 

h) Gasoline N₂O Emission Factor: \(0.040\) \(\frac{gN₂O}{\text{mile}}\) 

i) N₂O GWP: \(296\) \(\frac{lbsCO₂E}{lbsN₂O}\)

---

29 366 employees were surveyed at the Earth Day event, and their commute distances were averaged. 

30 [www.fueleconomy.gov](http://www.fueleconomy.gov) 


32 The EIA’s CO₂ emission factor for diesel is higher than that for gasoline, and N₂O and CH₄ factors for diesel are lower than that for gasoline, Ibid.
3.4.2 Rental Car Emissions

The Treasury and Travel department provide the number of miles driven in rental cars for business travel in CY06. According to the department, the number does not fluctuate significantly from year to year, and was used to estimate FY05 rental car miles.33 Treasury and Travel also report that the majority of cars rented by the SNL/NM workforce are midsize, therefore the average fuel economy for midsize cars is used to calculate CO₂ emissions.34 The EIA’s gasoline CO₂ emission factor is provided in units of lbsCO₂/gal. CH₄ and N₂O factors for the “Gasoline Passenger Cars” classification are in units of g/mile.35 A calculation of rental car emissions is provided below. See Appendix C-II for complete rental car emissions calculations.

Rental Car Emissions Equation:

\[
\text{a) \ # \ Miles \ Traveled \ in \ Rental \ Cars: \ 6,312,995 miles} \\
\text{b) \ Average \ Fuel \ Economy: \ 19.56 \frac{\text{miles}}{\text{gal}}} \\
\text{c) \ Gasoline \ CO₂ \ Emission \ Factor: \ 19.54 \frac{\text{lbsCO₂}}{\text{gal}}} \\
\text{d) \ Gasoline \ CH₄ \ Emission \ Factor: \ 0.011 \frac{\text{gCH₄}}{\text{mile}}} \\
\text{e) \ CH₄ \ GWP: \ 23 \frac{\text{lbsCO₂E}}{\text{lbsCH₄}}} \\
\]

33 Email communication with Anna Gibson, Travel Team Lead for Treasury and Travel Services March 10, 2008.
34 Based on an average of the city mpg of all 2002 mid-sized cars from www.fueleconomy.gov.
Gasoline N₂O Emission Factor: \(0.015 \frac{gN_2O}{\text{mile}}\)

g) N₂O GWP: \(296 \frac{\text{lbsCO}_2E}{\text{lbsN}_2O}\)

\[
(6,312,995 \text{ miles}) \left( \frac{19.54 \text{ lbsCO}_2}{\text{gal}} \right) \left( \frac{0.011 \frac{g\text{CH}_4}{\text{mile}}}{E} \right) + \left( \frac{2,205 \text{ lbs}}{\text{tonne}} \right) \left( \frac{0.015 \frac{gN_2O}{\text{mile}}}{1,000,000 \frac{\text{g}}{\text{tonne}}} \right)
\]

= 2,891 tonne\text{CO}_2E

Note: Numbers may slightly differ due to rounding.

### 3.4.3 Fleet Emissions

Data on SNL/NM fleet fuel consumption is provided by the Fleet Services Organization and accounts for the total internal fuel consumption of various fuels and miles traveled by various vehicle types. Fleet Services vehicles use diesel, gasoline, compressed natural gas (CNG), a 75 percent ethanol / 15 percent gasoline mix (E-85), and a 20 percent biodiesel / 80 percent diesel mix (B-20). Some Fleet Services vehicles run on electricity, and this electricity consumption is included in the energy footprint.

The EIA’s CO₂ emission factors are provided in units of lbs/gal, except for CNG, which is given in lbs/Mcf. CH₄ and N₂O factors for different vehicle types are given in units of g/mile. At the time of publication, the EIA does not have CH₄ and N₂O emission factors for E-85 fuel; CH₄ and N₂O emissions are based on a weighted average of 75 percent of ethanol emission factors and 15 percent of gasoline emission factors. For diesel fueled medium duty (MD) vehicles, an average between the CH₄ and N₂O emission factors for LD and HD vehicles is taken. This analysis does not account for CH₄ and N₂O emissions from biodiesel, as factors for this fuel are not available at the time of publication. A calculation of fleet emissions from E-85 fuel consumption is provided below. See Appendix C-III for complete fleet emissions calculations.

**Sample Fleet Emissions Equation E-85:**

a) Amount of E-85 Consumed: 39,306 gal

b) E-85 CO₂ Emission Factor: 2.93 \(\frac{\text{lbsCO}_2}{\text{gal}}\)

---

\[
\frac{2.93\text{lbsCO}_2}{\text{gal}} \times \frac{39,306\text{gal}}{2,205\text{tonne}} = 52\text{tonnesCO}_2
\]

c) Miles driven in E-85 Sedans / Station Wagons: 44,358 miles

d) Gas Passenger Cars CH\text{4} Emission Factor: 0.017 \frac{g\text{CH}_4}{\text{mile}}

e) LD Vehicles Ethanol CH\text{4} Emission Factor: 0.055 \frac{g\text{CH}_4}{\text{mile}}

f) CH\text{4} GWP: 23 \frac{\text{lbsCO}_2\text{E}}{\text{lbsCH}_4}

.g) Gas Passenger Cars N\text{2O} Emission Factor: 0.004 \frac{g\text{N}_2\text{O}}{\text{mile}}

h) LD Vehicles Ethanol N\text{2O} Emission Factor: 0.067 \frac{g\text{N}_2\text{O}}{\text{mile}}

i) N\text{2O} GWP: 296 \frac{\text{lbsCO}_2\text{E}}{\text{lbsN}_2\text{O}}

\[
(44,358\text{miles}) \left(15\% \left(0.017 \frac{g\text{CH}_4}{\text{mile}}\right) + 75\% \left(0.055 \frac{g\text{CH}_4}{\text{mile}}\right)\right) + 23 + \left(15\% \left(0.004 \frac{g\text{N}_2\text{O}}{\text{mile}}\right) + 75\% \left(0.067 \frac{g\text{N}_2\text{O}}{\text{mile}}\right)\right) = 1\text{tonneCO}_2\text{E}
\]

j) Miles driven in E-85 LD Trucks (4x4): 333,488 miles

k) Gas LD Trucks CH\text{4} Emission Factor: 0.016 \frac{g\text{CH}_4}{\text{mile}}

l) LD Vehicles Ethanol CH\text{4} Emission Factor: 0.055 \frac{g\text{CH}_4}{\text{mile}}

m) Gas LD Trucks N\text{2O} Emission Factor: 0.007 \frac{g\text{N}_2\text{O}}{\text{mile}}
n) LD Vehicles Ethanol N\(_2\)O Emission Factor: 0.067 \(\frac{gN\(_2\)O}{\text{mile}}\)

\[
\frac{333,488 \text{miles}}{\text{(333,488 miles)}} \left[ 15\% \left( 0.016 \frac{gCH\text{}_4}{\text{mile}} \right) + 85\% \left( 0.055 \frac{gCH\text{}_4}{\text{mile}} \right) \right] + 15\% \left( 0.007 \frac{gN\(_2\)O}{\text{mile}} \right) + 85\% \left( 0.067 \frac{gN\(_2\)O}{\text{mile}} \right) \right] \right) = 5\text{tonneCO}_2E
\]

\[
52\text{tonnesCO}_2 + 1\text{tonneCO}_2E + 7\text{tonneCO}_2E = 58\text{tonneCO}_2E
\]

Note: Numbers may slightly differ due to rounding.

### 3.4.4 Airline Emissions

The corporate airline travel footprint is determined by using the flight miles traveled by the SNL/NM workforce in CY05.\(^{37}\) The average miles per gallon (mpg)/passenger in CY05 is calculated using domestic flight passenger miles and jet fuel consumed for domestic flights from the Bureau of Transportation Statistics.\(^{38}\) Jet fuel emission factors are provided by the EIA; the CO\(_2\) emission factor for jet fuel is in units of lbs CO\(_2\)/gal, and the N\(_2\)O and CH\(_4\) emission factors are in units of g/gal.\(^{39}\) A calculation of airline emissions is provided below and in Appendix C-IV.

**Sample Airline Emissions Equation:**

a) SNL/NM Miles Flown in CY05: 58,455,515 miles

b) Domestic Flight Passenger Average mpg: 42.42 \(\frac{\text{miles}}{\text{gal}}\)

c) Jet fuel CO\(_2\) emission coefficient: 21.09 \(\frac{\text{lbsCO}_2}{\text{gal}}\)

d) Jet fuel CH\(_4\) Emission Coefficient: 0.27 \(\frac{gCH\text{}_4}{\text{gal}}\)

e) CH\(_4\) GWP: 23 \(\frac{\text{lbsCO}_2E}{\text{lbsCH}_4}\)

\(^{37}\) The authors assume this data is reported by CY, although this is not specified, and assume that CY data is adequate for this analysis.


f) Jet fuel N₂O Emission Coefficient: \(0.31 \frac{gN₂O}{gal}\)

g) N₂O GWP: \(296 \frac{lbsCO₂E}{lbsN₂O}\)

\[
\left(\frac{58,455,515\text{miles}}{42.42\frac{\text{miles}}{gal}}\right) \left(\frac{21.09\frac{lbsCO₂}{gal}}{2,205\frac{lbs}{tonne}}\right) \left(\frac{0.27 \frac{gCH₄}{gal}}{1,000,000 \frac{g}{tonne}}\right) \left(\frac{0.31 \frac{gN₂O}{gal}}{231.0}\right)
\]

\[= 13,316\text{tonneCO₂E}\]

Note: Numbers may slightly differ due to rounding.

### 3.4.5 Total Transportation Ecological Footprint

The transportation ecological footprint is determined by summing total transportation emissions and multiplying by the Land Sequestration Ratio and the Land Equivalence Factor. A calculation of the transportation footprint is provided below. For a complete calculation see Appendix C-V.

**Transportation Sample Equation:**

a) Total Transportation Emissions: \(41,419\text{tonneCO₂E}\)

b) Land Sequestration Ratio: \(0.192\frac{ha}{tonneCO₂}\)

c) Land Equivalence Factor: \(1.17\frac{gha}{ha}\)

\[
\left(41,419\text{tonneCO₂E}\right) \left(0.192\frac{ha}{tonneCO₂}\right) \left(1.17\frac{gha}{ha}\right) = 9,304\text{gha}
\]

Note: Numbers may slightly differ due to rounding.

### 3.5 Waste Footprint Parameters

The waste footprint is calculated using the EPA’s Waste Reduction Model (WARM), which accounts for the transportation of waste, the decomposition of waste, and recycling offsets. WARM uses a life-cycle assessment methodology to estimate emissions.\(^\text{40}\) The amount of recycled materials and municipal solid waste (MSW) are input into WARM in short tons (Tons) and emissions are output from the model in metric

tons (MT) (see Table 2 below).\textsuperscript{41} Numbers output by WARM in parentheses are negative values. A complete report from WARM is provided in Appendix D.

**Table 2. WARM Inputs and Emission Outputs**

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Tons* Recycled</th>
<th>Tons* Landfilled</th>
<th>Total MTCO2E **</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum Cans</td>
<td>2</td>
<td>-</td>
<td>(27)</td>
</tr>
<tr>
<td>Steel Cans</td>
<td>6</td>
<td>-</td>
<td>(10)</td>
</tr>
<tr>
<td>Corrugated Cardboard</td>
<td>290</td>
<td>-</td>
<td>(902)</td>
</tr>
<tr>
<td>Phonebooks</td>
<td>4</td>
<td>-</td>
<td>(12)</td>
</tr>
<tr>
<td>Dimensional Lumber</td>
<td>283</td>
<td>-</td>
<td>(696)</td>
</tr>
<tr>
<td>Mixed Paper, Office</td>
<td>168</td>
<td>-</td>
<td>(572)</td>
</tr>
<tr>
<td>Mixed Metals</td>
<td>1,268</td>
<td>-</td>
<td>(6,665)</td>
</tr>
<tr>
<td>Mixed Plastics</td>
<td>6</td>
<td>-</td>
<td>(8)</td>
</tr>
<tr>
<td>Mixed Recyclables</td>
<td>309</td>
<td>-</td>
<td>(899)</td>
</tr>
<tr>
<td>Mixed MSW</td>
<td>NA</td>
<td>11,040</td>
<td>17,552</td>
</tr>
<tr>
<td>Carpet</td>
<td>3</td>
<td>-</td>
<td>(24)</td>
</tr>
<tr>
<td>Personal Computers</td>
<td>29</td>
<td>-</td>
<td>(64)</td>
</tr>
<tr>
<td>Concrete</td>
<td>4,159</td>
<td>-</td>
<td>(32)</td>
</tr>
<tr>
<td>Tires</td>
<td>5</td>
<td>-</td>
<td>(9)</td>
</tr>
<tr>
<td>Total</td>
<td>17,570</td>
<td>11,040</td>
<td>7,632</td>
</tr>
</tbody>
</table>

Note: * Tons are short tons. ** MT are metric tons, or tonnes.

Recycling decreases the total ecological footprint, because the use of recycled materials conserves virgin materials in the production process and decreases the volume of material disposed of in landfills. Recycling results in an ecological gain (or credit) that offsets environmental costs contributing to the ecological footprint. CO\textsubscript{2}E recycling emission credits, output as negative values, are subtracted from CO\textsubscript{2}E emissions resulting from disposal of mixed MSW, output as a positive value, to yield net waste emissions.

\textsuperscript{41} This report uses “tonnes” to signify metric tons, while the WARM uses “MT.”
3.6 Land Use Parameters

SNL/NM operates on approximately 8,750 acres of land, not including remote sites that lie outside the boundaries of KAFB. Of this total area, 5,633 acres of this land are controlled by the USAF and 2,937 acres are owned by the DOE. The total developed land area (873 acres) includes all land that has been notably changed from its indigenous state and represents the total land use footprint. Total developed land area and gross building square footage (5,515,265 ft²), are used to calculate development density. These numbers are the best estimates available for FY05 and change from year to year.

The majority of land used by SNL/NM is comprised of arid short grass prairie, while a smaller portion consists of low density forest predominated by Pinyon-Pine and Juniper trees. These land types have relatively low carbon absorption capacities in relation to global averages. Developed land area is defined as land that has been altered from its indigenous state to support the operations of SNL/NM. The bulk of developed land used by SNL/NM includes five Technical Areas and several developments surrounding these areas, including permanent structures, sidewalks, parking lots, roads, other hardscapes, landscapes, and land used for sub-surface infrastructure. The developed land area is considered to be in lha units. The gha equivalent to this developed land area is found using the ratio of lha to gha detailed in Appendix A-III.

Development density is a measurement of land utilization effectiveness, and is a means of determining the potential for reducing site impact and urban sprawl on SNL/NM leased and owned properties. The development density is determined by dividing total building square footage by the land use footprint, or the total developed land area. A calculation of the development density is provided below.

Development Density Sample Equation:

\[
\text{a)} \quad \text{Total Building Square Footage: } 5,515,265 \text{ ft}^2 \\
\text{b)} \quad \text{Land Use Footprint (Total Developed Land Area): } 873 \text{ acres}
\]

\[
\left( \frac{5,515,265 \text{ ft}^2}{873 \text{ acres}} \right) = 14.5\%
\]

Note: Numbers may slightly differ due to rounding.

---

42 This is determined by taking the total impervious surface area from 2007 and subtracting the addition of new impervious surfaces in 2006 and 2007. This data was provided via email by Tom Romero in the Infrastructure Engineering Organization and Jim Alsup in the Planning and Project Development Organization.

43 Acreage by vegetation type was determined through correspondence with Jim Alsup March 2008.
3.7 Water Footprint Parameters

Annual water consumption data is provided by SNL/NM’s Infrastructure Engineering Organization. Data accounts for the number of gallons purchased from KAFB by SNL/NM in FY05, not including water loss between aquifer withdrawal and delivery. Water consumption is reported in total usage, gal/building ft\(^2\), gal/FTE, and gal/FTE/day. A calculation of the water footprint is provided, below.

**Water Footprint Sample Equation:**

a) Total Water Purchased in FY05: 406,254,588 gal

\[
\frac{406,254,588 \text{gal}}{5,515,265 \text{ft}^2} = 73.7 \frac{\text{gal}}{\text{ft}^2}
\]

b) Total Building Square Footage: 5,515,265 ft\(^2\)

c) Number of FTEs: 8,569 FTEs

\[
\frac{406,254,587 \text{gal}}{8,569 \text{FTEs}} = 47,408 \frac{\text{gal}}{\text{FTE}}
\]

d) # Workdays in a year: 229 days

\[
\left( \frac{47,408 \frac{\text{gal}}{\text{FTE}}}{229 \text{days}} \right) = 207 \frac{\text{gal}}{\text{FTE} \times \text{day}}
\]

Note: Numbers may slightly differ due to rounding.

---

\(^{44}\) Communication with Sharon Sanders from Infrastructure Engineering and Morgan Gerard from Energy Management May 2008.
4. Ecological Footprint Model Results

The SNL/NM EFM yields an FY05 baseline ecological footprint of 96,434 gha, or 889,586 lha (Table 3). As detailed in section 3.2 and Appendix A-III, the ecological footprint in lha is over nine times larger than that in gha, because the local landscape is less biologically productive than the Earth’s average bioproductivity. SNL/NM controls 3,116 lha of undeveloped land with a sequestration potential of 2.07 lha/tonneCO₂. Since SNL/NM’s total ecological footprint (96,434 gha) is greater than the waste absorption capacity of its landholdings (338 gha), it created an ecological land deficit of 96,096 gha. This deficit is equal to 886,470 lha, or about 3,423 square miles of Pinyon-Juniper woodlands and desert grassland. A calculation of the ecological deficit in lha is provided below.

Ecological Deficit Equation:

a) SNL/NM Ecological Footprint: 889,586 lha

b) SNL/NM controlled undeveloped land: 3,116 lha

889,586 lha – 3,116 lha = 886,470 lha

Note: Numbers may slightly differ due to rounding.

Table 3. SNL/NM Ecological Footprint by Component

<table>
<thead>
<tr>
<th>Component</th>
<th>Tonnes CO₂E</th>
<th>Footprint (gha)</th>
<th>Footprint (lha)</th>
<th>% of Carbon Footprint</th>
<th>% of Ecological Footprint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>352,691</td>
<td>79,229</td>
<td>730,872</td>
<td>82.19%</td>
<td>82.16%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>28,712</td>
<td>6,450</td>
<td>59,500</td>
<td>6.69%</td>
<td>6.69%</td>
</tr>
<tr>
<td>Commuting</td>
<td>22,961</td>
<td>5,158</td>
<td>47,581</td>
<td>5.35%</td>
<td>5.35%</td>
</tr>
<tr>
<td>Airline Travel</td>
<td>13,316</td>
<td>2,991</td>
<td>27,594</td>
<td>3.10%</td>
<td>3.10%</td>
</tr>
<tr>
<td>Waste Emissions</td>
<td>7,632</td>
<td>1,714</td>
<td>15,816</td>
<td>1.78%</td>
<td>1.78%</td>
</tr>
<tr>
<td>Rental Cars</td>
<td>2,891</td>
<td>649</td>
<td>5,990</td>
<td>0.67%</td>
<td>0.67%</td>
</tr>
<tr>
<td>Fleet</td>
<td>2,251</td>
<td>506</td>
<td>4,665</td>
<td>0.52%</td>
<td>0.52%</td>
</tr>
<tr>
<td>Land Use</td>
<td>N/A</td>
<td>38</td>
<td>353</td>
<td>N/A</td>
<td>0.04%</td>
</tr>
<tr>
<td>Stationary Combustion</td>
<td>160</td>
<td>36</td>
<td>331</td>
<td>0.04%</td>
<td>0.04%</td>
</tr>
<tr>
<td>Sequestration</td>
<td>-1,504</td>
<td>-338</td>
<td>-3,116</td>
<td>-0.35%</td>
<td>-0.35%</td>
</tr>
<tr>
<td>Carbon Footprint</td>
<td>429,110</td>
<td>96,395</td>
<td>889,233</td>
<td></td>
<td>99.96%</td>
</tr>
<tr>
<td>Ecological Footprint</td>
<td>96,434</td>
<td>889,586</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deficit</td>
<td>427,607</td>
<td>96,096</td>
<td>886,470</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.1 Energy Footprint Results

The SNL/NM EFM yields an energy footprint of 85,714 gha, or 790,703 lha, (Table 4). The energy footprint consists of electricity use, natural gas use, and stationary combustion. Electricity includes grid, hydropower, biomass, and solar contributions. Biomass and solar are considered credits to the ecological footprint (see negative values in Table 5).

SNL/NM’s consumption of NM’s predominantly coal-fired grid electricity is by far the largest sole contribution to the energy footprint, accounting for more than 92 percent (Table 4). This indicates that SNL/NM should focus efforts on energy efficiency, reduction strategies, and implementation of more alternative energy to lessen the ecological footprint. There are many exciting solar energy projects currently underway at SNL/NM, and with the rising cost of electricity (the price SNL/NM presently pays for electricity will double within the next year), it is important that these solar efforts are supported.

Table 4. Energy Footprint by Category

<table>
<thead>
<tr>
<th>Category</th>
<th>Tonnes CO₂E</th>
<th>Footprint (gha)</th>
<th>Footprint (lha)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>352,691</td>
<td>79,229</td>
<td>730,872</td>
<td>92.43%</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>28,712</td>
<td>64,50</td>
<td>59,500</td>
<td>7.52%</td>
</tr>
<tr>
<td>Stationary Combustion</td>
<td>160</td>
<td>36</td>
<td>331</td>
<td>0.04%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>381,564</strong></td>
<td><strong>85,714</strong></td>
<td><strong>790,703</strong></td>
<td><strong>100.00%</strong></td>
</tr>
</tbody>
</table>

Table 5. Electricity Footprint by Type

<table>
<thead>
<tr>
<th>Energy</th>
<th>Footprint (gha)</th>
<th>Footprint (lha)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid Electricity</td>
<td>80,677</td>
<td>744,230</td>
<td>101.83%*</td>
</tr>
<tr>
<td>Hydropower**</td>
<td>707</td>
<td>6,526</td>
<td>0.89%</td>
</tr>
<tr>
<td>Biomass Electricity**</td>
<td>-2,047</td>
<td>-18,884</td>
<td>-2.58%</td>
</tr>
<tr>
<td>Solar Electricity**</td>
<td>-108</td>
<td>-1,000</td>
<td>-0.14%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>79,229</strong></td>
<td><strong>730,872</strong></td>
<td><strong>100.00%</strong></td>
</tr>
</tbody>
</table>

Note:
* Totals more than 100%, due to negative contributions from biomass and solar electricity.

Natural gas use is the second largest contribution and accounts for eight percent of the energy footprint (Table 4). Since natural gas is mainly used for heating, ventilating, and air conditioning systems (commonly known as HVAC systems) year round, its use could be greatly reduced by implementing efficiency strategies, such as better building management.
Stationary combustion (gasoline and diesel to fuel generators and jet fuel used for experimentation) contributes the least to the energy footprint (0.04 percent). Given this low contribution and the fact that this fuel consumption is regulated by project managers, efforts should not be focused on reducing emissions from stationary combustion. Site-wide reductions should be considered priority, as these reductions have the potential to make extensive and permanent impacts.

4.2 Transportation Footprint Results

Although commuting, airline travel, rental cars, and fleet vehicle use did not contribute significantly to the ecological footprint individually (5, 3, 1, and 1 percent, respectively), their overall contribution totals ten percent, making transportation a significant contribution to the ecological footprint. Alleviating single passenger commuting has benefits beyond carbon reduction; specifically, it has the potential to lessen employee and corporate costs associated with fuel and vehicle maintenance, as well as traffic congestion and roads and parking infrastructure maintenance.

Currently, individual employees and small employee groups are engaging in dialog with public transportation authorities to make more commuting options available. EMS is currently working on a transportation study to research the possibility of providing incentives for alternative commuting and to make more alternative commuting options available. This project will include the development of an interactive website designed to gather data regarding commuting, to encourage and track alternative commuting over time, and to provide a forum for the workforce to discuss commuting related issues.

4.3 Waste Footprint Results

Emissions from landfilling MSW totaled 17,552 tonnes\(\text{CO}_2\text{E}\). 9,920 tonnes\(\text{CO}_2\text{E}\) are offset from recycling, resulting in a net emissions of 7,632 tonnes\(\text{CO}_2\text{E}\) from FY05 waste management practices (Table 6). These emissions generated a waste footprint of 1,714 gha, and 15,816 lha (Table 3). This waste footprint has a negligible effect on the overall ecological footprint of SNL/NM (less than two percent). Although the waste footprint proved to be a minimal contribution to the ecological footprint, recycling and waste reduction efforts decrease raw material consumption, as these recycled materials are manufactured into products that would normally require virgin resources. More accurate quantification of recycling offsets could show even greater offsets attributable to recycling efforts. In addition, Sandia profits financially from some recycling streams, and the authors expect recycling to become increasingly cost-effective in the future. Therefore, recycling efforts at SNL/NM should be intensified.
Table 6. FY05 WARM Output (Abbreviated)

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Total MTCO₂E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum Cans</td>
<td>(27)</td>
</tr>
<tr>
<td>Steel Cans</td>
<td>(10)</td>
</tr>
<tr>
<td>Corrugated Cardboard</td>
<td>(902)</td>
</tr>
<tr>
<td>Phonebooks</td>
<td>(12)</td>
</tr>
<tr>
<td>Dimensional Lumber</td>
<td>(696)</td>
</tr>
<tr>
<td>Mixed Paper, Office</td>
<td>(572)</td>
</tr>
<tr>
<td>Mixed Metals</td>
<td>(6,665)</td>
</tr>
<tr>
<td>Mixed Plastics</td>
<td>(8)</td>
</tr>
<tr>
<td>Mixed Recyclables</td>
<td>(899)</td>
</tr>
<tr>
<td>Mixed MSW</td>
<td>17,552</td>
</tr>
<tr>
<td>Carpet</td>
<td>(24)</td>
</tr>
<tr>
<td>Personal Computers</td>
<td>(64)</td>
</tr>
<tr>
<td>Concrete</td>
<td>(32)</td>
</tr>
<tr>
<td>Tires</td>
<td>(9)</td>
</tr>
<tr>
<td>Recycling Offset</td>
<td>(9,920)</td>
</tr>
<tr>
<td><strong>Net Emissions</strong></td>
<td><strong>7,632</strong></td>
</tr>
</tbody>
</table>

Note: See Appendix D for complete WARM output table.

4.4 Land Footprint Results

SNL/NM’s land use footprint is 353 ha, which is 0.04 percent of the overall ecological footprint (Table 3), and the development density is 14.5 percent (section 3.6). Development density is a measurement of land utilization effectiveness and is a means of determining the potential for reducing site impact and urban sprawl on SNL/NM leased and owned properties. Theoretically, a higher site density over time indicates that SNL/NM is growing responsibly, maintaining the natural landscape, and promoting in-fill development. This helps to offset SNL/NM’s CO₂ emissions, thereby decreasing the ecological footprint. Future land footprint analyses will indicate whether or not the site density is increasing or decreasing over time.

4.5 Water Footprint Results

Total water consumption at SNL/NM in FY05 is over 406 million gallons. Water consumption at SNL/NM is compared to consumption in the Albuquerque metropolitan area, at the University of New Mexico (UNM) main campus, and by the Intel Corporation to establish general water use characteristics in the area (Table 7). SNL/NM, UNM, and Intel Corporation water consumption is not included in the total water usage recorded by the city of Albuquerque (COA) water conservation office and is therefore significant to report. UNM main campus water consumption is similar to that of SNL/NM, in that most
water withdrawn is consumed.\textsuperscript{45} This comparison shows that SNL/NM is responsible for slightly over one percent of the total water use in the Albuquerque area.\textsuperscript{46}

\textbf{Table 7. Water Consumption Comparison - FY05}

<table>
<thead>
<tr>
<th>Water Use</th>
<th>SNL/NM</th>
<th>UNM</th>
<th>Intel</th>
<th>COA</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Use (million gal)</td>
<td>406</td>
<td>482</td>
<td>880</td>
<td>32,800</td>
<td>34,568</td>
</tr>
<tr>
<td>Percentage of Total Use</td>
<td>1.2%</td>
<td>1.4%</td>
<td>2.6%</td>
<td>94.9%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Water consumption at SNL/NM in FY05 is 73.7gal/ft\textsuperscript{2}, or 207gal/FTE/day. The closest comparison to this figure is CY03 data for the COA, which yields 193gal/person/day. FY05 water use by the COA should be less due to implementation of water conservation efforts since CY03.\textsuperscript{47}

KAFB wells draw from the Middle Rio Grande aquifer, the same aquifer that supplies the COA. Although the aquifer was once considered an unlimited water supply, geologists have recently discovered that it’s a fraction of the size it was originally thought to be (Figure 8). Albuquerque’s dry climate, which receives only 8.5 inches of precipitation annually, has a steadily growing population, which has been depleting the small supply offered by the aquifer. Ground water pumping is exceeding aquifer recharge, and water conservation is considered crucial to environmental stewardship at SNL/NM.\textsuperscript{48}

\textsuperscript{45} Water use data was provided by the COA water conservation officer Katherine Yuhas.
\textsuperscript{46} This analysis assumes total water use in the Albuquerque area to consist of water consumed by the four entities listed in Table 6. Private well withdraw as well as other usage not captured by the COA are not considered in this analysis.
Figure 8. True Capacity of the Middle Rio Grande Aquifer
(Source: SNL/NM Water Conservation Program, May 2008).
5. Conclusions

This analysis generates a baseline ecological footprint for SNL/NM. Findings show the major CO₂ emitting sources and their corresponding ecological footprints. As previously stated, the EFM consists of the land use footprint in addition to the carbon footprint. The land use footprint is a much smaller contribution to the ecological footprint, than is the carbon footprint, illustrated graphically in Figure 9, below. The use of a regionally specific sequestration capacity communicates findings in terms of the unique, local environment. This analysis can be refined in subsequent years and is ultimately a critical assessment of the environmental impacts of SNL/NM. In this sense, the study can be used to gauge the effectiveness of environmental impact mitigation strategies, including GHG reduction approaches.

![Figure 9. CO₂ Dominates SNL/NM Footprint.](image)

The majority of the SNL/NM ecological footprint can be attributed to the carbon footprint, while a smaller portion consists of the land use footprint.

5.1 Carbon Footprint by Scope

When the carbon footprint of SNL/NM is sorted by The GHG Protocol scopes, as indicated in Figure 4, it is apparent that Scope 2 is the largest contribution to the overall carbon footprint (Figure 10). Scope 2 makes up 82 percent of the carbon footprint and accounts solely for electricity purchased from an outside provider. Scope 3 makes up 11 percent of the carbon footprint and accounts for employee commuting, airline travel, waste emissions and rental car travel. Scope 1, SNL/NM’s direct emissions, makes up only seven percent of the carbon footprint and accounts for natural gas consumption, other stationary combustion, and fleet vehicle use. These results further emphasize the importance of focusing on energy reduction, particularly decreasing grid electricity consumption to reduce SNL/NM’s carbon and ecological footprints.
5.2 EFM Boundaries and Limits

It is important to note that there are limits associated with the EFM, some of which are inherent in the Wackernagel and Rees methodology and are discussed at length by Chambers et al. in *Sharing Nature’s Interest*. Other limits lie in the unique nature of the SNL/NM model. This baseline EFM will be improved upon in subsequent years to create a refined tool to mitigate SNL/NM’s ecological footprint.

Generally, the EFM only calculates the on-site ecological footprint. Data regarding off-site operations on leased properties is not readily available. In future analyses, the authors hope to incorporate offsite data to make the model more inclusive. In addition, the EFM only accounts for CO$_2$, CH$_4$, and N$_2$O emissions. In the future, the model will be designed to account for SF$_6$, HFCs, and PFCs, consistent with the *GHG Protocol* (Figure 4). SF$_6$ is used as a dielectric medium at SNL/NM, and large quantities are used in switch gears and Marx Generators. The P2 program at SNL/NM completed a

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baseline of SF₆ purchases for FY07 and FY08. This data will be used to quantify SF₆ emissions for the ecological footprint during those time periods.  

5.2.1 Energy Footprint Boundaries and Limits

This study does not account for the infrastructure or energy required for raw resource extraction, refinement, storage, transportation of coal or natural gas, or the construction of or land occupied by power plants, power lines, or pipelines existing off site. Further, the SNL/NM Model does not account for line loss. The authors consider the electricity generator and utility company to be responsible for these factors. If future analyses incorporate these components, they will be categorized under Scope 3, consistent with the scopes methodology of *The GHG Protocol*.  

When calculating the credits associated with hydroelectricity, biomass electricity, and solar electricity, the embodied energy of these three sources are considered. This is because generic global footprint factors are used to calculate the ecological footprint of alternative energy sources. Generic factors are used due to the lack of precise emission factors for biomass electricity, and the absence of consumer-end emissions altogether in the case of hydroelectricity and solar electricity. The embodied energy of NM’s grid energy is not factored into the energy footprint, as it is based on specific regional emission factors. The authors feel that this discrepancy in accounting methods between different sources of electricity is negligible for two reasons: 1) alternative energy sources play such a small role in the overall energy footprint, and 2) the methodology applied by the EFM acknowledges and accounts for the environmental impact of alternative energy sources. Finally, the footprint for stationary combustion does not include N₂O and CH₄ emissions, as little research has been done regarding these two GHGs emitted from gasoline, diesel, and jet fuel stationary combustion sources. Future analyses will account for these and other GHGs as their emission factors become available.

5.2.2 Transportation Footprint Boundaries and Limits

The ecological footprint parameters for transportation do not account for the impact for manufacturing or disposing of vehicles. Routine maintenance of fleet vehicles is accounted for, in the form of waste generated from this process (e.g., motor oil and tires are accounted for when they are disposed of, via the waste calculations). However, the impact of routine maintenance on commuter and rental vehicles are not accounted for, and is considered to be a part of commuter and rental company footprints, respectively.

The embodied energy for the construction and maintenance of vehicles, roads, and other transportation infrastructure belonging to SNL/NM is accounted for when disposed of as waste or recycled materials. Therefore, there may be a time lag (e.g., this FY05 baseline may be accounting for construction materials that were used 50 years prior). Since the disposal method (i.e. recycling versus landfilling) is ultimately what affects the model results, the author’s consider this to be an appropriate method. Finally,

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this analysis does not account for the embodied energy or maintenance of transportation infrastructure (e.g. airports, airplanes, municipal roads, etc.) outside the geographic boundaries of the SNL/NM site. These footprint components are considered to belong to other entities.

5.2.3 Waste Footprint Boundaries and Limits

The transportation emissions associated with Resources Conservation and Recovery Act wastes, which are hazardous wastes, Toxic Substance Control Act wastes, which are asbestos and polychlorinated biphenyl (commonly known as PCB) containing wastes, chemical wastes, and radioactive and mixed radioactive wastes are not accounted for, because SNL/NM does not track the entire journey of these wastes. In addition, the total environmental impact of hazardous and other special wastes, such as the exact environmental costs associated with the re-assimilation of these wastes types back into the biosphere or the damage resulting from improper disposal or accidental spillage, is not accounted for, as this type of analysis is beyond the Scope of this study.

The EPA’s WARM is used to determine the waste footprint in this analysis. WARM uses a life-cycle approach to calculate emissions. The EPA states that, “this life-cycle approach is not appropriate for use in inventories because of the diffuse nature of the emissions and emission reductions within a single emission factor.”

Although this analysis is partially based on an inventory approach, it also aims to be a comprehensive assessment. In this respect, life-cycle emissions of material goods benefit this analysis by providing a more complete and inclusive ecological footprint. Still, there are unknowns and ambiguities regarding the use of WARM. Future fiscal year analyses of this EFM will investigate the details regarding the WARM calculations, and will consider utilizing newer versions of WARM, alternatives to WARM, or possibly creating a unique model for capturing the waste footprint at SNL/NM.

5.2.4 Land Use Footprint Boundaries and Limits

Land Use is viewed in terms of developed land, which includes land area taken out of commission for buildings, parking lots, roads, and sidewalks onsite. This land would have otherwise been available for CO₂ sequestration. For this FY05 baseline, only land within the KAFB boundary was used. Sandia also has leased space outside of this boundary, and future analyses will account for this offsite developed land.

5.2.5 Water Footprint Boundaries and Limits

The water consumption portion of the analysis accounts for water purchased by SNL/NM from KAFB. It does not deduct the water returned to COA’s Southside Water Reclamation Plant or to the Rio Grande. It also does not account for water used in offsite leased buildings. Future analyses will account for offsite water use in leased buildings.

---

5.3 Next Steps

The methodology behind this baseline ecological footprint analysis will be improved with each subsequent analysis as described in section 5.2 and its subsections above. Future improvements to the methodology will be considered as more data becomes available. The study’s scope may be narrowed as specific components are evaluated and identified as negligible to the overall ecological footprint, or if it is determined that certain components are likely to remain relatively constant throughout time and cannot be realistically reduced. FY06, FY07, FY08, and subsequent year analyses will be completed and used to evaluate trends and to measure progress towards targeting effective environmental mitigation strategies. The results of this EFM are being used, along with other measures, to develop a sustainability scorecard for SNL/NM. This scorecard will evaluate trends such as water and energy use, waste generation, GHG emissions, and development density to measure performance.
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6. References


www.fueleconomy.gov
7. Glossary

**Average Sequestration Capacity** – The area of land required to sequester one tonne of CO₂.

**B-20** – A fuel mixture of 20 percent biodiesel and 80 percent diesel.

**Biologically Productive Land** – Land with adequate net primary production to support forests or agriculture.

**Biosphere** – the Earth’s surface, atmosphere, and sea that is inhabited by living things.

**Carbon Dioxide (CO₂)** – a GHG with GWP = 1.

**Carbon Footprint** – The relative area of biologically productive land needed to sequester the carbon emissions of a given population.

**Carbon Footprint Model (CFM)** – A subset of the EFM that accounts for CO₂E emissions from SNL/NM operations.

**Carrying Capacity** – The maximum population of a given species that can be supported by a given environment without diminishing the ability of the environment to support the same species population in the future.

**CO₂ Equivalent Emissions** – the sum of various GHGs that have been normalized to CO₂, using their GWPs.

**E-85** – A fuel mixture of 75 percent ethanol and 15 percent gasoline.

**Ecological Deficit** – The amount by which the ecological footprint of a given entity or population exceeds the biological capacity of space available to that population.

**Ecological Footprint** – The relative area of biologically productive land that a given population or organization would require to regenerate the natural resources it consumes and to assimilate it’s waste.

**Ecological Footprint Model (EFM)** – A model that accounts for the carbon footprint and the land use footprint of SNL/NM.

**Embodied Energy** – the energy used during the entire life cycle of a commodity for manufacturing, transportation, use, and disposal.

**Equivalence Factor** – a factor that translates a specific land use (such as world average forests) into a generic biologically productive area by adjusting for biomass productivity.

**Global Hectare (gha)** – One hectare of the Earth’s average biologically productive space.
GWP – Global Warming Potential; a measure of how much a specific GHG contributes to global warming in comparison to CO₂.

Hardscape – Landscape including sidewalks, paved surfaces, rock and xeriscaped areas.

Land Equivalence Factor – The ratio of the sequestration potential of Earth’s average bioproduc tive land to that of Earth’s average forest bioproduc tive land (1.17 gha/ha).

Land Sequestration Ratio – The area of average forest land required to sequester CO₂ emissions annually (0.192 ha/year/tonneCO₂).

Land Use Footprint – Land physically taken out of service by a given population.

Local Hectares (lha) – An area unit of measurement of the average biologically productive land on the SNL/NM campus.

Methane (CH₄) – a GHG with GWP = 23.

Natural Capital: A stock of natural assets that yield both goods and services on a continuous basis. The primary functions include resource production, waste assimilation, and life support services.

Nitrous Oxide (N₂O) – a GHG with GWP=296

Overshoot – When the population of an organism uses resources beyond the capacity of the environment to replenish or sustain those resources.

Scope 1 – All direct emissions including those from the combustion of fuel onsite, physical or chemical processing, the consumption of fuel in fleet vehicles, and fugitive emissions from releases such as equipment leaks, venting, etc. (GHG Protocol)

Scope 2 – Indirect emissions from electricity purchased from an outside provider. (GHG Protocol)

Scope 3 – Indirect emissions from optional reporting emission sources including those associated with the extraction, production, and transportation of purchased and sold materials and fuels, commuting, employee business travel, and waste disposal, among others. (GHG Protocol)
8. Appendices

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APPENDIX A: Local Sequestration Capacity Calculations

I. Pinyon-Juniper Sequestration Ratio: 53

a) NM Rangeland Grass/Legume Sequestration: 54 \(0.13 \frac{\text{tonneC}}{\text{ha} \times \text{yr}}\)

b) Desert Grassland Net Primary Production: \(0.95 \frac{\text{MgC}}{\text{ha} \times \text{yr}}\)

c) Pinyon-Juniper Net Primary Production: \(1.0 \frac{\text{MgC}}{\text{ha} \times \text{yr}}\)

\[
\left( \frac{0.13 \text{ tonneC}}{\text{ha} \times \text{yr}} \right) \times \left( \frac{x \text{ tonneC}}{\text{ha} \times \text{yr}} \right) = \left( \frac{0.95 \text{ MgC}}{\text{ha} \times \text{yr}} \right) \times \left( \frac{1.0 \text{ MgC}}{\text{ha} \times \text{yr}} \right) = x = 0.14 \text{ tonneC} \left( \frac{\text{ha}}{\text{yr}} \right)
\]

Note: Numbers may slightly differ due to rounding.

II. Local Sequestration Ratio:

a) Atomic Mass of C: 12.01g/mol
b) Atomic Mass of CO2: 44.01g/mol
c) Percentage of Grassland-Legume: 74%
d) Percentage of Pinyon-Juniper Woodlands: 26%

---

53 This calculation relies on the assumption that Aboveground Net Primary Production is proportional to the corresponding Land Sequestration Ratio. This assumption is based on evidence provided by Neary, et al. that an increase in carbon entering soil (carbon sequestration) is due to an increase in net primary productivity. Neary, D. G., Overby, S. T., & Hart, S. C. (2003). Chapter 18: Soilcarbon in Arid and Semiarid Forest Ecosystems. In J.M. Kimble, L. S. Heath, R. A. Birdsey, and R. Lal (Eds.), The Potential of U.S. Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect (pp. 306). Boca Raton, Florida: Lewis Publishers. CRC Press LLC.

54 Angerer, Jay, Joel Brown, Robert Blaisdell, and Jerry Stuth. “Carbon Sequestration Potential in New Mexico Rangelands.” Poster presented at the U.S. Climate Change Science Program Climate Science in Support of Decision Making (14-16 November 2005. Arlington, VA.) Accessed at: http://www.climatescience.gov/workshop2005/posters/P-CA1.8_Angerer.pdf. Note: this number is given in tons, and in the conversion to metric tons, the number remained the same with respect to significant figures. Also, this ratio is for a Grass/Legume mixture, and is the closest representation of desert grassland that is available at the time of publication.

\[
\left(0.13 \frac{\text{tonneC}}{\text{ha} \cdot \text{yr}} \times 74\% + 0.14 \frac{\text{tonneC}}{\text{ha} \cdot \text{yr}} \times 26\%\right) \left(\frac{44.01 \frac{\text{g}}{\text{mol} \ \text{CO}_2}}{12.01 \frac{\text{g}}{\text{mol} \ C}}\right) = 0.48 \frac{\text{tonneCO}_2}{\text{lha} \cdot \text{yr}}
\]

\[
= 2.07 \frac{\text{lha} \cdot \text{yr}}{\text{tonneCO}_2}
\]

**III. Ratio of Local Hectares to Global Hectares:**

a) Land Sequestration Ratio: \(0.192 \frac{\text{ha} \cdot \text{yr}}{\text{tonneCO}_2}\)

b) Land Equivalence Factor: \(1.17 \frac{\text{gha}}{\text{ha}}\)

c) Local Sequestration Ratio: \(2.07 \frac{\text{lha} \cdot \text{yr}}{\text{tonneCO}_2}\)

\[
\left(0.192 \frac{\text{ha} \cdot \text{yr}}{\text{tonneCO}_2}\right) \left(1.17 \frac{\text{gha}}{\text{ha}}\right) = 0.225 \frac{\text{gha} \cdot \text{yr}}{\text{tonneCO}_2}
\]

\[
\left(\frac{2.07 \frac{\text{lha} \cdot \text{yr}}{\text{tonneCO}_2}}{0.225 \frac{\text{gha} \cdot \text{yr}}{\text{tonneCO}_2}}\right) = 9.22 \frac{\text{ha}}{\text{gha}}
\]

Note: Numbers may slightly differ due to rounding.
APPENDIX B: Energy Calculations

I. Electricity Calculations

A. Grid Electricity Emissions and Footprint:

a) NM Grid CO\textsubscript{2} Emission Factor: \(2,054 \frac{\text{lbs CO}_2}{\text{MWh}}\)

b) NM Grid CH\textsubscript{4} Emission Factor: \(0.013 \frac{\text{lbsCH}_4}{\text{MWh}}\)

c) CH\textsubscript{4} GWP: \(23 \frac{\text{lbsCO}_2E}{\text{lbsCH}_4}\)

d) NM Grid N\textsubscript{2}O Emission Factor: \(4.4 \frac{\text{lbsN}_2O}{\text{MWh}}\)

e) N\textsubscript{2}O GWP: \(296 \frac{\text{lbsCO}_2E}{\text{lbsN}_2O}\)

\[
\left( 2,054 \frac{\text{lbs CO}_2}{\text{MWh}} + 0.013 \frac{\text{lbsCH}_4}{\text{MWh}} (23) + 4.4 \frac{\text{lbsN}_2O}{\text{MWh}} (296) \right) = 1.52 \frac{\text{tonneCO}_2E}{\text{MWh}}
\]

f) FY05 Grid Electricity Consumption: \(235,875 \frac{\text{MWh}}{\text{yr}}\)

g) NM Grid CO\textsubscript{2}E Emission Factor: \(1.52 \frac{\text{tonneCO}_2E}{\text{MWh}}\)

h) Land Sequestration Ratio: \(0.192 \frac{\text{ha* yr}}{\text{tonneCO}_2}\)

i) Land Equivalence Factor: \(1.17 \frac{\text{gha}}{\text{ha}}\)

\[
\left( 235,875 \frac{\text{MWh}}{\text{yr}} \right) \left( 1.52 \frac{\text{tonneCO}_2E}{\text{MWh}} \right) = 359,138 \frac{\text{tonneCO}_2}{\text{yr}}
\]

\[
\left( 359,138 \frac{\text{tonneCO}_2}{\text{yr}} \right) \left( 0.192 \frac{\text{ha* yr}}{\text{tonneCO}_2} \right) \left( 1.17 \frac{\text{gha}}{\text{ha}} \right) = 80,677 \text{ gha}
\]

j) Local Sequestration Ratio: \(2.07 \frac{\text{lh}a* \text{ yr}}{\text{tonneCO}_2}\)
Note: Numbers may slightly differ due to rounding.

**B. Hydroelectricity Footprint:**

a) FY05 KAFB Hydroelectricity Consumption: \(15,721 \frac{MWh}{yr}\)

b) SNL/NM’s % of KAFB population: 60%

c) Hydroelectricity Footprint Ratio: \(75 \frac{gha \times yr}{GWh}\)

\[
\left(\frac{15,721 \frac{MWh}{yr} \times 60\%}{1000 \frac{MWh}{GWh}}\right) \left(75 \frac{gha \times yr}{GWh}\right) = 707 \text{gha}
\]

d) Ratio of lha to gha: \(9.22 \frac{lha}{gha}\)

\[
(707 \text{gha}) \left(9.22 \frac{lha}{gha}\right) = 6,526 \text{lha}
\]

Note: Numbers may slightly differ due to rounding.

**C. Solar Electricity Footprint Credit:**

a) Total Size of PV: 40.25 kW

b) PV Capacity Factor: 0.256

c) Size of Sterling Engines: 150 kW

d) Sterling Engine Capacity Factor: 0.191

e) Number of Hours in a Year: 8,760 h

\[
\frac{[(40.25 kW)(0.256) + (150 kW)(0.191)](8760 h)}{1,000,000 \frac{kWh}{GWh}} = 0.34 \text{GWh}
\]

f) NM Grid CO₂E Emission Factor: \(\frac{1.52 \text{tonneCO}_2}{\text{E MWh}}\)
g) Land Sequestration Ratio: \(0.192 \frac{ha \cdot yr}{tonneCO_2}\)

h) Land Equivalence Factor: \(1.17 \frac{gha}{ha}\)

\[
(0.34GWh \left( \frac{1.000MWh}{GWh} \right) \left( \frac{1.52tonneCO_2}{MWh} \right) \left( \frac{0.192 \frac{ha \cdot yr}{tonneCO_2}}{} \right) \left( \frac{1.17 \frac{gha}{ha}}{} \right) = 117 gha(NMgrid)
\]

i) PV Footprint Ratio: \(24 \frac{gha \cdot yr}{GWh}\)

\[
(0.34GWh \left( \frac{24 \frac{gha \cdot yr}{GWh}}{} \right) = 8 gha(PV)
\]

\[117 gha - 8 gha = 108 gha\]

j) Ratio of lha to gha: \(9.22 \frac{lha}{gha}\)

\[
(108 gha \left( \frac{9.22 \frac{lha}{gha}}{} \right) = 1,000 lha
\]

Note: Numbers may slightly differ due to rounding.

**D. Biomass Footprint Credit:**

a) FY05 Biomass RECs: \(6,700 \frac{MWh}{yr}\)

b) NM Grid CO2E Emission Factor: \(1.52 \frac{tonneCO_2}{E MWh}\)

c) Land Sequestration Ratio: \(0.192 \frac{ha \cdot yr}{tonneCO_2}\)

d) Land Equivalence Factor: \(1.17 \frac{gha}{ha}\)

\[
(6,700MWh \left( \frac{1.52tonneCO_2}{MWh} \right) \left( \frac{0.192 \frac{ha \cdot yr}{tonneCO_2}}{} \right) \left( \frac{1.17 \frac{gha}{ha}}{} \right) = 2,292 gha(NMgrid)
\]
e) Biomass Footprint Ratio: $36.5 \frac{gha \cdot yr}{GWh}$

$$\left( \frac{6,700 \ MWh}{yr} \right) \left( \frac{36.5 \ \frac{gha \cdot yr}{GWh}}{1,000 \ \frac{MWh}{GWh}} \right) = 245 gha(biomass)$$

$2,292 gha(NMgrid) - 245 gha(biomass) = 2,047 gha$

f) Ratio of lha to gha: $9.22 \frac{lha}{gha}$

$\left( 2,047 \ gha \right) \left( 9.22 \frac{lha}{gha} \right) = 18,884 lha$

Note: Numbers may slightly differ due to rounding.

**E. Overall Electricity Footprint and Adjusted Total Emissions:**

a) Grid Electricity Footprint in gha: $80,677 \ gha$

b) Hydroelectricity Footprint in gha: $707 \ gha$

c) Solar Electricity Footprint Credit in gha: $108 \ gha$

d) Biomass Electricity Footprint Credit in gha: $2,047 \ gha$

e) Grid Electricity Footprint in lha: $744,230 \ lha$

f) Hydroelectricity Footprint in lha: $6,526 \ lha$

g) Solar Electricity Footprint Credit in lha: $1,000 \ lha$

h) Biomass Electricity Footprint Credit in lha: $18,884 \ lha$

$$Grid + Hydro - Solar - Biomass = Total.Electricity$$

$80,677 \ gha + 707 \ gha - 108 \ gha - 2,047 \ gha = 79,229 \ gha$

$744,230 \ lha + 6,526 \ lha - 1,000 \ lha - 18,884 \ lha = 730,872 \ lha$

i) Total Electricity Footprint: $79,229 \ gha$

j) Land Sequestration Ratio: $0.192 \ \frac{ha \cdot yr}{tonneCO_2}$
k) Land Equivalence Factor: 1.17 \frac{gha}{ha}

\[
\left( \frac{79,229 \text{ gha}}{1.17 \frac{\text{gha}}{\text{ha}}} \right) \div \left( 0.192 \frac{\text{ha} \times \text{yr}}{\text{tonneCO}_2} \right) = 352,691 \text{tonneCO}_2
\]

Note: Numbers may slightly differ due to rounding.

Note: Because hydroelectricity, biomass electricity, and solar electricity are calculated using generic footprint factors, their CO2E emissions are not calculated directly. Therefore, the electricity emissions are estimated by back calculating using the alternative energy footprints, the Land Sequestration Ratio, and the Land Equivalence Factor.

II. Natural Gas Footprint:

a) FY05 Natural Gas Consumption: 530,239 \frac{Mcf}{yr}

b) Natural Gas CO2 Emission Factor: 54.01 \frac{\text{kgCO}_2}{\text{MMBtu}}

c) Natural Gas CH4 Emission Factor: 4.8 \frac{\text{gCH}_4}{\text{MMBtu}}

d) CH4 GWP: 23 \frac{\text{lbsCO}_2E}{\text{lbsCH}_4}

e) Natural Gas N2O Emission Factor: 0.1 \frac{\text{gN}_2O}{\text{MMBtu}}

f) N2O GWP: 296 \frac{\text{lbsCO}_2E}{\text{lbsN}_2O}

\[
\left( 530,239 \frac{\text{Mcf}}{\text{yr}} \right) \left( 1 \frac{\text{MMBtu}}{\text{Mcf}} \right) \left( 54.01 \frac{\text{kgCO}_2}{\text{MMBtu}} \right) \left( 4.8 \frac{\text{gCH}_4}{\text{MMBtu}} \right) \left( 0.1 \frac{\text{gN}_2O}{\text{MMBtu}} \right) = 28,712 \text{tonneCO}_2E
\]
Note: 1 $\frac{MMBtu}{Mcf}$ is based on the energy content of $\frac{1,000 Btu}{scf}$ and the conversion of $\frac{1,000 cf}{Mcf}$.

g) Land Sequestration Ratio: 0.192 $\frac{ha}{tonneCO_2}$

h) Land Equivalence Factor: 1.17 $\frac{gha}{ha}$

\[
(28,712 \text{tonneCO}_2) \left( 0.192 \frac{ha \text{ yr}}{tonneCO_2} \right) \left( 1.17 \frac{gha}{ha} \right) = 6,450 gha
\]

i) Local Sequestration Ratio: 2.07 $\frac{lha \text{ yr}}{tonneCO_2}$

\[
(28,712 \text{tonneCO}_2) \left( 2.07 \frac{lha \text{ yr}}{tonneCO_2} \right) = 59,500 lha
\]

Note: Numbers may slightly differ due to rounding.

**III. Stationary Combustion Footprint:**

a) Motor Gasoline Gross Heat of FY05 Gasoline Consumption: 7.5 gal

b) Gasoline Stationary CO$_2$ Emission Factor: 154 $\frac{lbsCO_2}{MMBtu}$

c) Combustion: 5.25 $\frac{MMBtu}{barrel}$

\[
(7.5 \text{gal}) \left( 154 \frac{lbsCO_2}{MMBtu} \right) \left( 5.25 \frac{MMBtu}{barrel} \right) \left( 42 \frac{gal}{barrel} \right) = 144 lbsCO_2
\]

d) FY05 Diesel Consumption: 12,106 gal

e) Diesel Stationary CO$_2$ Emission Factor: 164 $\frac{lbsCO_2}{MMBtu}$

f) Diesel Gross Heat of Combustion: 5.83 $\frac{MMBtu}{barrel}$
\[
(12,106 \text{gal}) \left( \frac{164 \text{ lbsCO}_2}{\text{MMBtu}} \right) \left( \frac{5.83 \text{ MMBtu}}{\text{barrel}} \right) = 275,362 \text{lbsCO}_2
\]

\[
(3,637 \text{ gal}) \left( \frac{70.88 \text{ kgCO}_2}{\text{MMBtu}} \right) \left( \frac{2.205 \text{ lbs}}{\text{kg}} \right) \left( \frac{5.67 \text{ MMBtu}}{\text{barrel}} \right) = 76,727 \text{lbsCO}_2
\]

\[
\frac{144 \text{lbsCO}_2 + 275,362 \text{lbsCO}_2 + 76,727 \text{lbsCO}_2}{2,205 \text{ lbs \ tonne}} = 160 \text{tonneCO}_2
\]

\[
(160 \text{tonneCO}_2) \left( \frac{0.192 \text{ ha yr}}{\text{tonneCO}_2} \right) \left( \frac{1.17 \text{ gha}}{\text{ha}} \right) = 36 \text{gha}
\]

\[
(160 \text{tonneCO}_2) \left( \frac{2.07 \text{ lha yr}}{\text{tonneCO}_2} \right) = 331 \text{lha}
\]

Note: Numbers may slightly differ due to rounding.
APPENDIX C: Transportation Calculations

I. Commuter Emissions and Footprint

A. Personal Vehicle Commuter Emissions:

a) # Personal Commuter Vehicles: 7,777 vehicles

b) Average Round Trip Commute: 26 miles

c) # Workdays in a year: 229 days

d) Average Fuel Economy: 18.5 \frac{miles}{gal}

e) Gasoline CO₂ Emission Factor: 19.54 \frac{lbsCO₂}{gal}

f) Gasoline CH₄ Emission Factor: 0.039 \frac{gCH₄}{mile}

g) CH₄ GWP: 23 \frac{lbsCO₂E}{lbsCH₄}

h) Gasoline N₂O Emission Factor: 0.040 \frac{gN₂O}{mile}

i) N₂O GWP: 296 \frac{lbsCO₂E}{lbsN₂O}

\[
\left( 7,777 \frac{\text{vehicles}}{\text{day}} \right) \left( 26 \frac{\text{miles}}{\text{day}} \right) \left( 229 \frac{\text{days}}{\text{vehicle}} \right) \left( 19.54 \frac{\text{lbsCO₂}}{\text{gallon}} \right) \left( 0.039 \frac{\text{gCH₄}}{\text{mile}} \right) \left( 23 \right) + 1,000,000 \frac{\text{g}}{\text{tonne}}
\]

\[
= 22,806 \frac{\text{tonneCO₂E}}{\text{gallon}} \]

Note: Numbers may slightly differ due to rounding.

B. Bicycle Commuter Offset:

a) # Bicycle Commuter Miles in CY05:\textsuperscript{56} 206,391 miles

\textsuperscript{56} Although bicycle commuter statistics are given by CY, the authors assume that this is an adequate estimate of FY statistics.
b) Gasoline CO₂ Emission Factor: 19.54 $\frac{\text{lbsCO}_2}{\text{gal}}$

c) Average Fuel Economy: 18.5 $\frac{\text{miles}}{\text{gal}}$

d) Gasoline CH₄ Emission Factor: 0.039 $\frac{\text{gCH}_4}{\text{mile}}$

e) CH₄ GWP: $23 \frac{\text{lbsCO}_2E}{\text{lbsCH}_4}$

f) Gasoline N₂O Emission Factor: 0.040 $\frac{\text{gN}_2O}{\text{mile}}$

g) N₂O GWP: $296 \frac{\text{lbsCO}_2E}{\text{lbsN}_2O}$

\[
\begin{align*}
206,391\text{ miles} \left( \frac{19.54 \text{ lbsCO}_2}{\text{gal}} \right) &+ \left( \frac{0.039 \text{ gCH}_4}{\text{mile}} \right)(23) + \left( \frac{0.040 \text{ gN}_2O}{\text{mile}} \right)(296) \\
&= 102\text{ tonneCO}_2E
\end{align*}
\]

Note: Numbers may slightly differ due to rounding.

C. Bus Commuter Footprint and Adjusted Emissions:

a) # Bus Riders in CY05:⁵⁷ 200

b) Average Round Trip Commute: 26 $\frac{\text{miles}}{\text{day}}$

c) Work Days per Year: 229 $\frac{\text{days}}{\text{yr}}$

d) Bus Passenger Footprint:⁵⁸ $\frac{0.03\text{ gha}}{1000\text{ km}}$

⁵⁷ Although bus commuter statistics are given by CY, the authors assume that this is an adequate estimate of FY statistics.

e) Average Fuel Economy: 18.47 \( \frac{miles}{gal} \) 

f) Land Sequestration Ratio: 0.192 \( \frac{ha \text{ yr}}{tonneCO_2} \) 

g) Land Equivalence Factor: 1.17 \( \frac{gha}{ha} \) 

\[
(200 \left( \frac{26 \text{ miles}}{day} \right) \left( \frac{1.61 \text{ km}}{miles} \right) \left( \frac{229 \text{ days}}{200 \text{ day}} \right) \frac{0.03 \text{ gha}}{1000 \text{ km}} = 58 \text{ gha}
\]

\[
\left( \frac{58 \text{ gha}}{1.17 \text{ gha}} \right) \left( \frac{1 \text{ gha}}{ha} \right) = 256 \text{ tonneCO}_2
\]

Note: Numbers may slightly differ due to rounding.

**D. Overall Commuter Emissions and Footprint:**

a) Personal Vehicle Emissions: 22,806\( \text{ tonneCO}_2 E \)

b) Bicycle Emissions Offset: 102\( \text{ tonneCO}_2 E \)

c) Bus Passenger Emissions: 256\( \text{ tonneCO}_2 \)

d) Land Sequestration Ratio: 0.192 \( \frac{ha \text{ yr}}{tonneCO_2} \)

e) Land Equivalence Factor: 1.17 \( \frac{gha}{ha} \)

\[
22,806 \text{ tonneCO}_2 E - 102 \text{ tonneCO}_2 E + 256 \text{ tonneCO}_2 = 22,961 \text{ tonneCO}_2 E
\]

\[
(22,961 \text{ tonneCO}_2 E) \left( \frac{0.192 \text{ ha yr}}{\text{ tonneCO}_2} \right) \left( \frac{1.17 \text{ gha}}{ha} \right) = 5,158 \text{ gha}
\]
f) Local Sequestration Ratio: \(2.07 \frac{\text{lha} \cdot \text{yr}}{\text{tonneCO}_2}\)

\[
(22.961 \text{tonneCO}_2 E) \left(2.07 \frac{\text{gha} \cdot \text{yr}}{\text{tonneCO}_2}\right) = 47,581 \text{ lha}
\]

Note: Numbers may slightly differ due to rounding.

**II. Rental Car Emissions and Footprint:**

a) \# Miles Traveled in Rental Cars: 6,312,995 miles

b) Average Fuel Economy: 19.56 \(\frac{\text{miles}}{\text{gal}}\)

c) Gasoline CO\(_2\) Emission Factor: 19.54 \(\frac{\text{lbsCO}_2}{\text{gal}}\)

d) Gasoline CH\(_4\) Emission Factor: 0.011 \(\frac{\text{gCH}_4}{\text{mile}}\)

e) \(\text{CH}_4\) GWP: 23 \(\frac{\text{lbsCO}_2 E}{\text{lbsCH}_4}\)

f) Gasoline N\(_2\)O Emission Factor: 0.015 \(\frac{\text{gN}_2\text{O}}{\text{mile}}\)

g) \(\text{N}_2\text{O}\) GWP: 296 \(\frac{\text{lbsCO}_2 E}{\text{lbsN}_2\text{O}}\)

\[
\left(6,312,995 \text{ miles}\right) \frac{\left(19.54 \frac{\text{lbsCO}_2}{\text{gal}}\right)}{19.56 \frac{\text{miles}}{\text{gal}}} \left(2,204.62 \frac{\text{lbs}}{\text{tonne}}\right) + \frac{0.011 \frac{\text{gCH}_4}{\text{mile}}}{1,000,000} + \frac{0.015 \frac{\text{gN}_2\text{O}}{\text{mile}}}{1,000,000} = 2,891 \text{ tonneCO}_2 E
\]

h) Land Sequestration Ratio: 0.192 \(\frac{\text{ha} \cdot \text{yr}}{\text{tonneCO}_2}\)

i) Land Equivalence Factor: 1.17 \(\frac{\text{gha}}{\text{ha}}\)

\[
(2,891 \text{ tonneCO}_2 E) \left(0.192 \frac{\text{ha} \cdot \text{yr}}{\text{tonneCO}_2}\right) \left(1.17 \frac{\text{gha}}{\text{ha}}\right) = 649 \text{ gha}
\]
j) Local Sequestration Ratio: \(2.07 \frac{lha \cdot yr}{tonneCO_2}\)

\[
(2.891 \text{tonneCO}_2 E \left(2.07 \frac{lha \cdot yr}{tonneCO_2}\right)) = 5,990 lha
\]

Note: Numbers may slightly differ due to rounding.

**III. Fleet Emissions**

**A. E-85 Emissions:**

a) Amount of E-85 Consumed: 39,306 gal

b) E-85 CO₂ Emission Factor: \(2.93 \frac{lbsCO_2}{gal}\)

\[
(39,306 \text{gal}) \left(2.93 \frac{lbsCO_2}{gal}\right) = 52 \text{tonnesCO}_2
\]

c) Miles driven in E-85 Sedans / Station Wagons: 44,358 miles

d) Gas Passenger Cars CH₄ Emission Factor: 0.017 \(\frac{gCH_4}{mile}\)

e) LD Vehicles Ethanol CH₄ Emission Factor: 0.055 \(\frac{gCH_4}{mile}\)

f) CH₄ GWP: \(23 \frac{lbsCO_2E}{lbsCH_4}\)

g) Gas Passenger Cars N₂O Emission Factor: 0.004 \(\frac{gN_2O}{mile}\)

h) LD Vehicles Ethanol N₂O Emission Factor: 0.067 \(\frac{gN_2O}{mile}\)

i) N₂O GWP: \(296 \frac{lbsCO_2E}{lbsN_2O}\)
\[(44,358 \text{ miles}) \left( \frac{15\% \left( 0.017 \frac{\text{gCH}_4}{\text{mile}} \right) + 75\% \left( 0.055 \frac{\text{gCH}_4}{\text{mile}} \right)}{1,000,000 \frac{\text{g}}{\text{tonne}}} \right) \left( \frac{23 + 15\% \left( 0.004 \frac{\text{gN}_2\text{O}}{\text{mile}} \right) + 75\% \left( 0.067 \frac{\text{gN}_2\text{O}}{\text{mile}} \right)}{1,000,000 \frac{\text{g}}{\text{tonne}}} \right) \right) \]

\[= 1 \text{ tonneCO}_2E \]

j) Miles driven in E-85 LD Trucks (4x4): 333,488 miles

k) Gas LD Trucks CH\(_4\) Emission Factor: 0.016 \(\frac{\text{gCH}_4}{\text{mile}}\)

l) LD Vehicles Ethanol CH\(_4\) Emission Factor: 0.055 \(\frac{\text{gCH}_4}{\text{mile}}\)

m) Gas LD Trucks N\(_2\)O Emission Factor: 0.007 \(\frac{\text{gN}_2\text{O}}{\text{mile}}\)

n) LD Vehicles Ethanol N\(_2\)O Emission Factor: 0.067 \(\frac{\text{gN}_2\text{O}}{\text{mile}}\)

\[(333,488 \text{ miles}) \left( \frac{15\% \left( 0.016 \frac{\text{gCH}_4}{\text{mile}} \right) + 85\% \left( 0.055 \frac{\text{gCH}_4}{\text{mile}} \right)}{1,000,000 \frac{\text{g}}{\text{tonne}}} \right) \left( \frac{23 + 15\% \left( 0.007 \frac{\text{gN}_2\text{O}}{\text{mile}} \right) + 85\% \left( 0.067 \frac{\text{gN}_2\text{O}}{\text{mile}} \right)}{1,000,000 \frac{\text{g}}{\text{tonne}}} \right) \right) \]

\[= 5 \text{ tonneCO}_2E \]

52 tonneCO\(_2\) + 1 tonneCO\(_2\)E + 5 tonneCO\(_2\)E = 58 tonneCO\(_2\)E

Note: Numbers may slightly differ due to rounding.

**B. CNG Emissions:**

a) Amount of CNG Consumed: 707 gal

b) CNG CO\(_2\) Emission Factor: 120.36 \(\frac{\text{lbsCO}_2}{1,000 \text{cf}}\)

\[
\left( \frac{707 \text{ gal}}{1,000 \text{ cf} \text{gal}} \right) \left( \frac{120.36 \text{ lbsCO}_2}{1,000 \text{ cf} \text{gal}} \right) = 0.01 \text{ tonnesCO}_2
\]
c) Miles Driven in CNG LD Vehicles: \(148,110 \text{ miles}\)

d) Miles Driven in CNG MD Vehicles: \(240,587 \text{ miles}\)

e) LD Vehicles CNG CH\(_4\) Emission Factor: \(0.737 \frac{\text{gCH}_4}{\text{mile}}\)

f) MD Vehicles CNG CH\(_4\) Emission Factor: \(1.352 \frac{\text{gCH}_4}{\text{mile}}\)

g) \(\text{CH}_4\) GWP: \(23 \frac{\text{lb} \text{CO}_2 \text{E}}{\text{lb} \text{CH}_4}\)

h) LD Vehicles CNG N\(_2\)O Emission Factor: \(0.050 \frac{\text{gN}_2\text{O}}{\text{mile}}\)

i) MD Vehicles CNG N\(_2\)O Emission Factor: \(0.113 \frac{\text{gN}_2\text{O}}{\text{mile}}\)

j) \(\text{N}_2\text{O}\) GWP: \(296 \frac{\text{lb} \text{CO}_2 \text{E}}{\text{lb} \text{N}_2\text{O}}\)

\[
\frac{(148,110 \text{ miles})}{1,000,000} \left(0.737 \frac{\text{gCH}_4}{\text{mile}}\right) (23) + \frac{(240,587 \text{ miles})}{1,000,000} \left(1.352 \frac{\text{gCH}_4}{\text{mile}}\right) (23) + 0.050 \frac{\text{gN}_2\text{O}}{\text{mile}} \left(\frac{296}{1,000,000} \text{ tonne} \right) = 20.2 \text{ tonneCO}_2 \text{E}
\]

0.01 \text{ tonneCO}_2 + 20.2 \text{ tonneCO}_2 \text{E} = 20.2 \text{ tonneCO}_2 \text{E}

Note: Numbers may slightly differ due to rounding.

C. Gasoline Emissions:

a) Amount of Gas Consumed: 177,913 gal

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59 In this case, LD vehicles include Sedans / Station Wagons and LD 4X2 Trucks.

60 The MD vehicle CH\(_4\) emission factor is determined by averaging the LD factor (0.737 gCH\(_4\)/mile) and the HD factor (1.966 gCH\(_4\)/mile).

61 The MD vehicle N\(_2\)O emission factor is determined by averaging the LD factor (0.050 gN\(_2\)O/mile) and the HD factor (0.175 gN\(_2\)O/mile).
b) Gasoline CO$_2$ Emission Factor: $19.54 \frac{lbsCO_2}{gallon}$

\[
(177,913 \text{ gal}) \left( \frac{19.54 \text{ lbsCO}_2}{\text{gal}} \right) = 1,576.9 \text{ tonnesCO}_2
\]

c) Miles Driven in Gas Passenger Cars: 44,358 miles

d) Miles Driven in Gas LD Vehicles: 1,091,896 miles

e) Miles Driven in Gas MD Vehicles: 589,086 miles

f) Passenger Vehicles Gas CH$_4$ Emission Factor: $0.017 \frac{gCH_4}{mile}$

g) LD Vehicles Gas CH$_4$ Emission Factor: $0.016 \frac{gCH_4}{mile}$

h) MD Vehicles Gas CH$_4$ Emission Factor: $0.025 \frac{gCH_4}{mile}$

i) CH$_4$ GWP: $23 \frac{lbsCO_2E}{lbsCH_4}$

j) Passenger Vehicles Gas N$_2$O Emission Factor: $0.004 \frac{gN_2O}{mile}$

k) LD Vehicles Gas N$_2$O Emission Factor: $0.007 \frac{gN_2O}{mile}$

l) MD Vehicles Gas N$_2$O Emission Factor: $0.010 \frac{gN_2O}{mile}$

m) N$_2$O GWP: $296 \frac{lbsCO_2E}{lbsN_2O}$

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$^{62}$ The MD vehicle CH$_4$ emission factor is determined by averaging the LD factor (0.016gCH$_4$/mile) and the HD factor (0.033gCH$_4$/mile).

$^{63}$ The MD vehicle N$_2$O emission factor is determined by averaging the LD factor (0.007gN$_2$O/mile) and the HD factor (0.013N$_2$O/mile).
\begin{align*}
(44,358 \text{ miles}) & \left( 0.017 \frac{gCH_4}{\text{mile}} \right) (23) + \left( 0.004 \frac{gN_2O}{\text{mile}} \right) (296) + \left( \frac{1,000,000 \ g}{\text{tonne}} \right) \\
(1,091,896 \text{ miles}) & \left( 0.016 \frac{gCH_4}{\text{mile}} \right) (23) + \left( 0.007 \frac{gN_2O}{\text{mile}} \right) (296) + \left( \frac{1,000,000 \ g}{\text{tonne}} \right) \\
(589,086 \text{ miles}) & \left( 0.025 \frac{gCH_4}{\text{mile}} \right) (23) + \left( 0.010 \frac{gN_2O}{\text{mile}} \right) (296) + \left( \frac{1,000,000 \ g}{\text{tonne}} \right) = 4.7 \text{tonneCO}_2E \\
1,576.9 \text{tonnesCO}_2 + 4.7 \text{tonneCO}_2E = 1,582 \text{tonneCO}_2E
\end{align*}

Note: Numbers may slightly differ due to rounding.

**D. Diesel Emissions:**

a) Amount of Diesel Consumed: 53,008 gal

b) Diesel CO\textsubscript{2} Emission Factor: 22.37 $\frac{\text{lbsCO}\textsubscript{2}}{\text{gal}}$

\[
(53,008 \text{ gal}) \left( \frac{22.37 \text{lbsCO}_2}{\text{gal}} \right) = 537.9 \text{tonnesCO}_2
\]

c) Miles Driven in Diesel LD Vehicles: 225,484 miles

d) Miles Driven in Diesel MD Vehicles: 165,226 miles

e) Miles Driven in Diesel HD Vehicles: 78,124 miles

f) LD Vehicles Diesel CH\textsubscript{4} Emission Factor: 0.001 $\frac{gCH_4}{\text{mile}}$

g) MD Vehicles Diesel CH\textsubscript{4} Emission Factor: 0.003 $\frac{gCH_4}{\text{mile}}$
h) HD Vehicles Diesel CH$_4$ Emission Factor: $64 \ 0.051 \frac{gCH_4}{mile}$

i) CH$_4$ GWP: $23 \ \frac{lbgCO_2E}{lbgCH_4}$

j) LD Vehicles Diesel N$_2$O Emission Factor: $0.002 \ \frac{gN_2O}{mile}$

k) MD Vehicles Diesel N$_2$O Emission Factor: $0.025 \ \frac{gN_2O}{mile}$

l) HD Vehicles Diesel N$_2$O Emission Factor: $65 \ 0.048 \ \frac{gN_2O}{mile}$

m) N$_2$O GWP: $296 \ \frac{lbgCO_2E}{lbgN_2O}$

$\frac{(225,484 \ miles) \left( 0.001 \frac{gCH_4}{mile} \right) (23) + \left( 0.002 \frac{gN_2O}{mile} \right) (296) + \left( 0.003 \frac{gCH_4}{mile} \right) (23) + \left( 0.025 \frac{gN_2O}{mile} \right) (296) + \left( 0.051 \frac{gCH_4}{mile} \right) (23) + \left( 0.048 \frac{gN_2O}{mile} \right) (296)}{1,000,000 \ \frac{g}{tonne}}$ = 2.6 tonne CO$_2$E

$537.9 \ tonnesCO_2 + 2.5 \ tonnesCO_2E = 540 \ tonnesCO_2E$

Note: Numbers may slightly differ due to rounding.

\textbf{E. Biodiesel Emissions:}

\begin{itemize}
  \item a) Amount of Biodiesel Consumed: 6,261 gal
\end{itemize}

\textsuperscript{64} The MD vehicle CH$_4$ emission factor is determined by averaging the LD factor (0.016gCH$_4$/mile) and the HD factor (0.033gCH$_4$/mile).

\textsuperscript{65} The MD vehicle N$_2$O emission factor is determined by averaging the LD factor (0.007gN$_2$O/mile) and the HD factor (0.013N$_2$O/mile).
b) B-20 CO₂ Emission Factor: \(17.89 \frac{\text{lbsCO}_2}{\text{gal}}\)

\[
(\frac{17.89 \text{lbsCO}_2}{\text{gallon}}) \left(\frac{6,261 \text{gal}}{2,205 \text{tonne}}\right) = 51 \text{tonneCO}_2
\]

Note: Numbers may slightly differ due to rounding.

**E. Overall Fleet Emissions and Footprint:**

a) E-85 Emissions: \(58 \text{tonneCO}_2E\)

b) CNG Emissions: \(20 \text{tonneCO}_2E\)

c) Gasoline Emissions: \(1,582 \text{tonneCO}_2E\)

d) Diesel Emissions: \(540 \text{tonneCO}_2E\)

e) Biodiesel Emissions: \(51 \text{tonneCO}_2\)

\[58 \text{tonneCO}_2E + 20 \text{tonneCO}_2E + 1,582 \text{tonneCO}_2E + 540 \text{tonneCO}_2E + 51 \text{tonneCO}_2 = 2,251 \text{tonneCO}_2E\]

f) Land Sequestration Ratio: \(0.192 \frac{\text{ha} \times \text{yr}}{\text{tonneCO}_2}\)

g) Land Equivalence Factor: \(1.17 \frac{\text{g} \text{ha}}{\text{ha}}\)

h) Local Sequestration Ratio: \(2.07 \frac{\text{lha} \times \text{yr}}{\text{tonneCO}_2}\)

\[
(2,251 \text{tonneCO}_2E) \left(0.192 \frac{\text{ha} \times \text{yr}}{\text{tonneCO}_2}\right) \left(1.17 \frac{\text{g} \text{ha}}{\text{ha}}\right) = 506 \text{g} \text{ha}
\]

\[
(2,251 \text{tonneCO}_2E) \left(2.07 \frac{\text{lha} \times \text{yr}}{\text{tonneCO}_2}\right) = 4,665 \text{lha}
\]

Note: Numbers may slightly differ due to rounding.

**IV. Airline Emissions:**

a) SNL/NM Miles Flown in CY05: \(58,455,515 \text{ miles}\)

b) Domestic Flight Passenger Average mpg: \(42.42 \frac{\text{miles}}{\text{gal}}\)
c) Jet fuel CO₂ emission coefficient: \(21.09 \frac{\text{lbsCO}_2}{\text{gal}}\)

d) Jet fuel CH₄ Emission Coefficient: \(0.27 \frac{\text{gCH}_4}{\text{gal}}\)

e) CH₄ GWP: \(23 \frac{\text{lbsCO}_2 E}{\text{lbsCH}_4}\)

f) Jet fuel N₂O Emission Coefficient: \(0.31 \frac{\text{gN}_2O}{\text{gal}}\)

g) N₂O GWP: \(296 \frac{\text{lbsCO}_2 E}{\text{lbsN}_2O}\)

\[
\left(\frac{58,455,515 \text{ miles}}{42.42 \frac{\text{miles}}{\text{gal}}} \right) \left(21.09 \frac{\text{lbsCO}_2}{\text{gal}}\right) + \left(0.27 \frac{\text{gCH}_4}{\text{gal}}\right)(23) + \left(0.31 \frac{\text{gN}_2O}{\text{gal}}\right)(296)
\]

= 13,316 tonneCO₂E

Note: Numbers may slightly differ due to rounding.

V. Overall Transportation Emissions and Footprint:

a) Commuter Emissions: 22,961 tonneCO₂E

b) Rental Car Emissions: 2,891 tonneCO₂E

c) Fleet Emissions: 2,251 tonneCO₂E

d) Airline Emissions: 13,316 tonneCO₂E

\[22,961 \text{ tonneCO}_2 E + 2,891 \text{ tonneCO}_2 E + 2,251 \text{ tonneCO}_2 E + 13,316 \text{ tonneCO}_2 E = 41,419 \text{ tonneCO}_2 E\]

e) Land Sequestration Ratio: \(0.192 \frac{\text{ha}}{\text{tonneCO}_2}\)

f) Land Equivalence Factor: \(1.17 \frac{\text{gha}}{\text{ha}}\)

g) Local Sequestration Ratio: \(2.07 \frac{\text{lha} \cdot \text{yr}}{\text{tonneCO}_2}\)
(41,419\text{tonneCO}_2E) \left( 0.192 \frac{\text{ha}}{\text{tonneCO}_2} \right) \left( 1.17 \frac{\text{gha}}{\text{ha}} \right) = 9,304 \text{gha}

(41,419\text{tonneCO}_2E) \left( 2.07 \frac{\text{lha}\,*\,\text{yr}}{\text{tonneCO}_2} \right) = 85,832 \text{lha}

Note: Numbers may slightly differ due to rounding.
APPENDIX D: Waste Calculations

Table D-1. WARM Outputs - GHG Emissions from Projected Alternative Management of Municipal Solid Wastes

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<td><strong>Total</strong></td>
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<td>0</td>
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**Waste Footprint:**

a) Net Waste Emissions: \(7,632\text{tonneCO}_2E\)

b) Land Sequestration Ratio: \(0.192 \left(\frac{\text{ha}}{\text{tonneCO}_2}\right)\)

c) Land Equivalence Factor: \(1.17 \left(\frac{\text{gha}}{\text{ha}}\right)\)

\[
\left(7,632\text{tonneCO}_2E\right) \left(0.192 \left(\frac{\text{ha}}{\text{tonneCO}_2}\right)\right) \left(1.17 \left(\frac{\text{gha}}{\text{ha}}\right)\right) = 1,714\text{gha}
\]

d) Local Sequestration Ratio: \(2.07 \left(\frac{\text{lha} \cdot \text{yr}}{\text{tonneCO}_2}\right)\)

\[
\left(7,632\text{tonneCO}_2E\right) \left(2.07 \left(\frac{\text{lha} \cdot \text{yr}}{\text{tonneCO}_2}\right)\right) = 15,816\text{lha}
\]
APPENDIX E: Land Use Calculations

Development Density:

a) Total Building Square Footage: \( 5,515,265 \text{ ft}^2 \)

b) Land Use Footprint (Total Developed Land Area): \( 873 \text{ acres} \)

\[
\frac{5,515,265 \text{ ft}^2}{873 \text{ acres}} = 14.5\%
\]

\[
\frac{43,579 \text{ ft}^2}{\text{acre}}
\]

Note: Numbers may slightly differ due to rounding.
APPENDIX F: Water Footprint Calculation

Water Footprint:

a) Total Water Purchased in FY05: 406,254,588 gal

\[
\frac{406,254,588 \text{ gal}}{5,515,265 \text{ ft}^2} = 73.7 \frac{\text{gal}}{\text{ft}^2}
\]

c) Number of FTEs: 8,569 FTE

\[
\frac{406,254,587 \text{ gal}}{8,569} = 47,408 \frac{\text{gal}}{\text{FTE}}
\]

e) # Workdays in a year: 229 days

\[
\left( \frac{47,408 \frac{\text{gal}}{\text{FTE}}}{229 \text{ days}} \right) = 207 \frac{\text{gal}}{\text{FTE} \times \text{day}}
\]

Note: Numbers may slightly differ due to rounding.
APPENDIX G: Ecological Deficit

Ecological Deficit:

a) SNL/NM Ecological Footprint: 889,586 lha

b) SNL/NM controlled undeveloped land: 3,116 lha

889,586 lha − 3,116 lha = 886,470 lha
APPENDIX H: Conversions and Unit Abbreviations

**Prefixes**

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<thead>
<tr>
<th>Prefix</th>
<th>Value</th>
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<tr>
<td>mega (M)</td>
<td>1,000,000</td>
</tr>
<tr>
<td>giga (G)</td>
<td>1,000,000,000</td>
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<tr>
<td>kilo (k)</td>
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**Weight**

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<tr>
<td>tonne</td>
<td>1,000 kilogrammes (kg)</td>
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<tr>
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<td>= 2,205 pounds (lbs)</td>
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<tr>
<td>short ton (ton)</td>
<td>2,000 pounds (lbs)</td>
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<td>= 0.907 metric tons (tonne)</td>
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**Distance**

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<tbody>
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<td>1 mile</td>
<td>1.61 kilometer (km)</td>
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**Area**

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<tr>
<td>acre</td>
<td>43,578.54 square feet (ft²)</td>
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<tr>
<td>hectare (ha)</td>
<td>2.47 acres</td>
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**Volume**

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<tr>
<td>barrel</td>
<td>42 gal</td>
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<tr>
<td>1,000 cubic feet (cf)</td>
<td>7,480.52 gal</td>
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<tr>
<td>Mcf</td>
<td>1,000 cubic feet (cf)</td>
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**Energy**

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<td>cf</td>
<td>1,000 British thermal units (Btu)</td>
</tr>
<tr>
<td>MMBtu</td>
<td>1,000,000 British thermal units (Btu)</td>
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<tr>
<td>Wh</td>
<td>watt * hr</td>
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**Global Warming Potentials (GWPs)**

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<td>Methane (CH₄)</td>
<td>23 + \frac{lbsCO_2E}{lbsCH_4}</td>
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<td>Nitrous oxide (N₂O)</td>
<td>296 + \frac{lbsCO_2E}{lbsN_2O}</td>
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**Constants**

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<th>Formula</th>
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<tr>
<td>Land Equivalence Factor</td>
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<td>Local Sequestration Ratio</td>
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MS0735, Howard Passell, 6313
MS0950, Darcy M. Mauro, 102651
MS1037, Bob Brandhuber, 4130
MS1042, Joanna Eckstein, 4133
MS1042, Ralph Wrons, 4133
MS1042, Stephanie Salinas, 4133
MS1042, Su Hwang, 4131
MS1042, Terry Cooper, 4133
MS1093, Amy Coplen, 4131
MS1094, Jack Mizner, 4131
MS1112, David Castillo, 4139
MS1117, Robert Rivera, 4139
MS1305, Judi Lavin, 1132
MS1464, Jim Alsup, 4853
MS1464, Ralph J. Cipriani, 4853
MS1477, Chris Evans, 4825
MS1477, Darell Rogers, 4846
MS1477, Israel Martinez, 4846

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Jeff Eagan (3), Department of Energy Office of Environmental Policy and Assistance
Paul Hesse, Energy Information Administration
Carolyn Holloway, DOE National Nuclear Services Administration Sandia Site Office
Perry Lindstrom, Energy Information Administration
Bruce Milne, UNM
B.J. Morris, DOE National Nuclear Services Administration
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Norion Ubechel (5), University of New Mexico
Nathan McDowell, Los Alamos National Laboratories
Mike Ebinger, Los Alamos National Laboratories
Katherine Yuhas, City of Albuquerque