SANDIA REPORT

SAND2008-7838
Unlimited Release
Printed January 2009

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

Sandia is a multiprogram laboratory operated by Sandia Corporation,
a Lockheed Martin Company, for the United States Department of Energy's
National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Approved for public release; further dissemination unlimited.

Sandia National Laboratories

Printed on 100% post-consumer fiber recycled paper

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represent that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof, or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof, or any of their contractors.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865) 576-8401
Facsimile: (865) 576-5728
E-Mail: reports@adonis.osti.gov
Online ordering: http://www.osti.gov/bridge

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd.
Springfield, VA 22161

Telephone: (800) 553-6847
Facsimile: (703) 605-6900
E-Mail: orders@ntis.fedworld.gov
Online order: http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online

Sandia National Laboratories SAND REPORT 2008-7838
January 2009

SAND2008-7838

Unlimited Release
Printed January 2009

Baseline Ecological Footprint of Sandia National Laboratories, New Mexico

Amy K Coplen, Jack Mizner, Norion M. Ubechel
Environmental Management Department
Sandia National Laboratories/New Mexico
P.O. Box 5800
Albuquerque, NM 87185

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

The authors thank the Facilities Management Operations Center, the Environmental Safety and Health Center, the Emergency Management Department, as well as the other Sandia organizations that helped with this study. SNL/NM employees and contractors who contributed to this study include Jim Alsup, Jennifer Payne, Eleni Otto, Joanna Eckstein, Margie Marley, Ed Pioquinto, Donald Helfrich, Phillip Pohl, Sharon Moyer, Deborah Lynn Moore, Willie J. Johns, Darcy M. Mauro, Ralph J. Cipriani, Brenda Bailey-White, Mary Bultmann, David Castillo, Randy Castillo, Leroy Duran, Chris Evans, Morgan Gerard, Anna Gibson, Kristin Klossner, Tom Romero, Sam McCord, Robert Rivera, Darell Rogers, Lucille Roybal, Stephanie Salinas, Sharon Sanders, Consuelo Silva, Lorenzo Spangler, Michael Spoerner, Doug Vetter, Ralph Wrons, Judi Lavin, Erin Murphy, and Pascale Waffelaert. The authors would also like to thank Nathan McDowell and Mike Ebinger from Los Alamos National Laboratories, Brian McPherson from New Mexico State University, Katherine Yuhas from the City of Albuquerque, John Dickenson from the Office of the State Engineer, Michael Campana from the University of New Mexico, employees from PNM, Michael Goodrich from Shaw Environmental, Waste Management, Inc., and the many others who contributed to this analysis.

Table of Contents

Abbreviations and Acronyms 7
1. Executive Summary 9
2. Introduction 11
2.1 Problem Statement 11
2.2 SNL and the EFM Geographic Boundary 12
2.3 Goals and Functions of the Baseline Ecological Footprint 14
2.4 Ecological Footprint Method 14
2.5 Carbon Footprint Method 15
2.5.1 The GHG Protocol and Scopes Method 16
2.5.1.1 The SNL/NM EFM and The GHG Protocol 17
2.6 SNL/NM Ecological and Carbon Footprint Model Parameters 18
3. Methodology 19
3.1 Global Sequestration 21
3.2 Local Sequestration 22
3.3 Energy Parameters 22
3.3.1 Electricity Footprint Parameters 22
3.3.1.1 Grid Electricity Footprint 23
3.3.1.2 Hydroelectricity Footprint 24
3.3.1.3 Solar Electricity Footprint Credit 25
3.3.1.4 Biomass Footprint Credit 26
3.3.2 Natural Gas Footprint Parameters 27
3.3.3 Stationary Combustion Footprint 28
3.4 Transportation Parameters 29
3.4.1 Commuting Emissions 29
3.4.2 Rental Car Emissions 31
3.4.3 Fleet Emissions 32
3.4.4 Airline Emissions 34
3.4.5 Total Transportation Ecological Footprint 35
3.5 Waste Footprint Parameters 35
3.6 Land Use Parameters 37
3.7 Water Footprint Parameters 38
4. Ecological Footprint Model Results 39
4.1 Energy Footprint Results 40
4.2 Transportation Footprint Results 41
4.3 Waste Footprint Results 41
4.4 Land Footprint Results 42
4.5 Water Footprint Results 42
5. Conclusions 45
5.1 Carbon Footprint by Scope 45
5.2 EFM Boundaries and Limits 46
5.2.1 Energy Footprint Boundaries and Limits 47
5.2.2 Transportation Footprint Boundaries and Limits 47
5.2.3 Waste Footprint Boundaries and Limits 48
5.2.4 Land Use Footprint Boundaries and Limits 48
5.2.5 Water Footprint Boundaries and Limits 48

5.3 Next Steps 49
6. References 51
7. Glossary 53
8. Appendices 55
Distribution 84

List of Figures

Figure 1. The Baseline Ecological Footprint of SNL/NM by Category - FY05 10
Figure 2. Ecological Footprint and Biocapacity 11
Figure 3. SNL/NM Campus 13
Figure 4. Overview of Scopes and Emissions Across a Value Chain 16
Figure 5. GHG Accounting from the Sale and Purchase of Electricity 17
Figure 6. Schematic of SNL/NM's Carbon Footprint Inputs 18
Figure 7. Flow Diagram SNL/NM's Ecological Footprint Inputs and Outputs 20
Figure 8. True Capacity of the Middle Rio Grande Aquifer 44
Figure 9. CO_2 Dominates SNL/NM Footprint. 45
Figure 10. SNL/NM Carbon Footprint by The GHG Protocol Scopes 46

List of Tables

Table 1. SNL/NM EFM GHG Emissions Reporting under GHG Protocol Scopes 18
Table 2. WARM Inputs and Emission Outputs 36
Table 3. SNL/NM Ecological Footprint by Component 39
Table 4. Energy Footprint by Category 40
Table 5. Electricity Footprint by Type 40
Table 6. FY05 WARM Output (Abbreviated) 42
Table 7. Water Consumption Comparison - FY05 43
Table D-1. WARM Outputs - GHG Emissions from Projected Alternative Management of Municipal Solid Wastes 78

List of Appendices

APPENDIX A: Local Sequestration Capacity Calculations 56
APPENDIX B: Energy Calculations 58
APPENDIX C: Transportation Calculations 65
APPENDIX E: Land Use Calculations 80
APPENDIX F: Water Footprint Calculation 81
APPENDIX G: Ecological Deficit 82
APPENDIX H: Conversions and Unit Abbreviations 83

Abbreviations and Acronyms

B-20	a fuel mixture of 20 percent biodiesel and 80 percent diesel
CFM	SNL/NM Carbon Footprint Model
CH4	methane
CNG	compressed natural gas
CO_2	carbon dioxide
CO_2E	CO_2 equivalent
COA	City of Albuquerque
CY	calendar year
DOE	U.S. Department of Energy
E-85	a fuel mixture of 75 percent ethanol and 15 percent gasoline
EFM	SNL/NM Ecological Footprint Model
EIA	Energy Information Administration
EMS	Environmental Management System
EPA	U.S. Environmental Protection Agency
FMOC	SNL/NM's Facilities Management and Operations Center
FTE	Full Time Employee
FY	fiscal year
gal	gallon
GDP	gross domestic product
gha	global hectare
GHG	greenhouse gas
GWP	Global Warming Potential
ha	hectare
HD	heavy duty
HFC	hydrofluorocarbon
IPCC	International Panel on Climate Change
KAFB	Kirtland Air Force Base
kW	kilowatt
kWh	kilowatt hour
LD	light duty
lha	local hectare
MD	medium duty
mpg	miles per gallon (miles/gal)
MSW	mixed solid waste
MT	metric ton (tonne)
N_2O	nitrous oxide
P2	SNL/NM's Pollution Prevention
PCB	polychlorinated biphenyl
PFC	perflourocarbons
PNM	Public Service Company of New Mexico
PV	photovoltaic

RECs	renewable energy certificates
Sandia	Sandia Corporation
SF_6	sulfur hexafluoride
SNL/NM	Sandia National Laboratories in Albuquerque, New Mexico
TA	Technical Area
t	short ton
tonne	metric ton
TTC	Thermal Test Complex
UNM	University of New Mexico
WAPA	Western Area Power Association
WARM	Waste Reduction Model
WWF	World Wide Fund for Nature (formerly World Wildlife Fund)
USAF	United States Air Force

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 (CO_2E) 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 (CO_2) 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 CO_2E 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 CO_2. 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.

[1] World Resources Institute and World Business Council for Sustainable Development, *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard*. (Washington, D.C., March 2004).

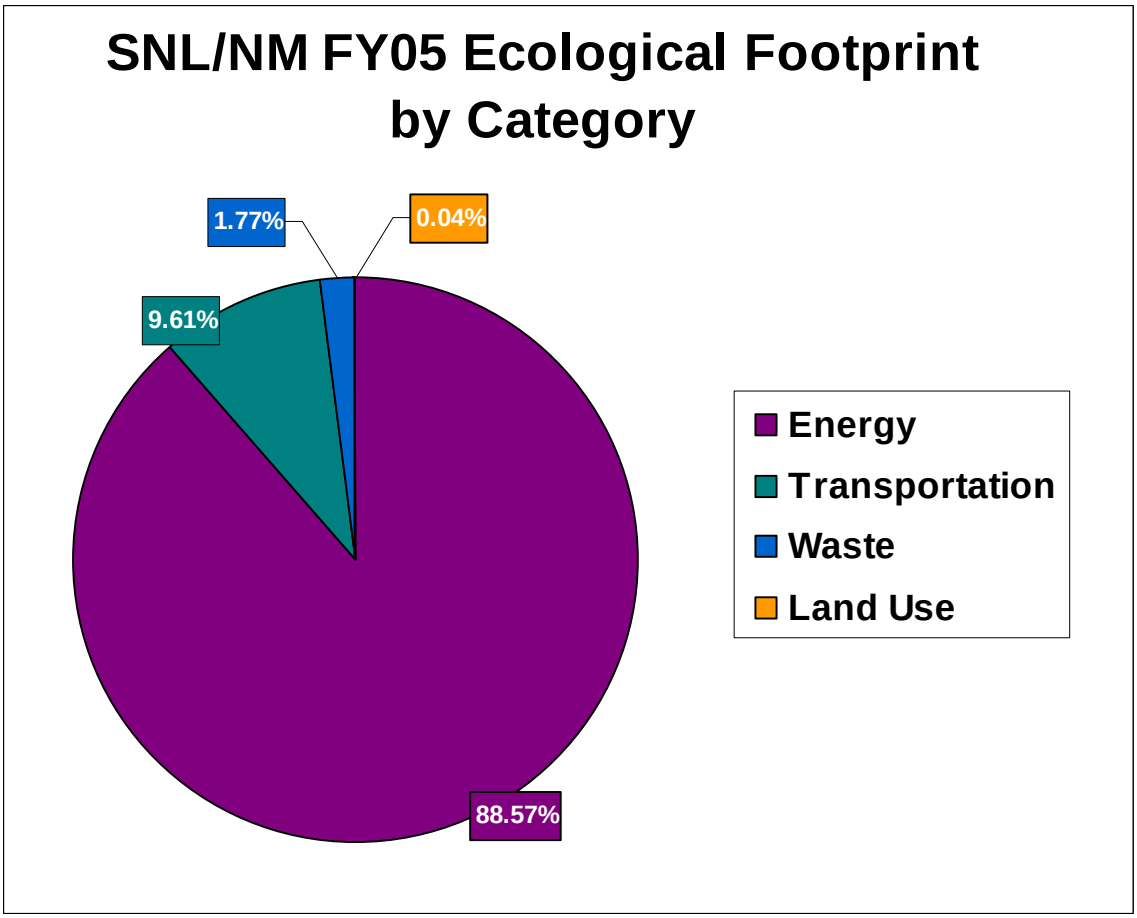

Figure 1. The Baseline Ecological Footprint of SNL/NM by Category - FY05[2]

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 CO_2, methane (CH_4), and nitrous oxide (N_2O) emissions. Eventually, the model will be designed to account for sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), consistent with *The GHG Protocol*. These are more powerful GHGs than CO_2, and could contribute considerably to the carbon and ecological footprints.

[2] This pie chart does not include the CO_2 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.[3] 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.[4] 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.[5] The rapid consumption of natural resources is responsible for the unsustainable and increasing ecological deficit (Figure 2).

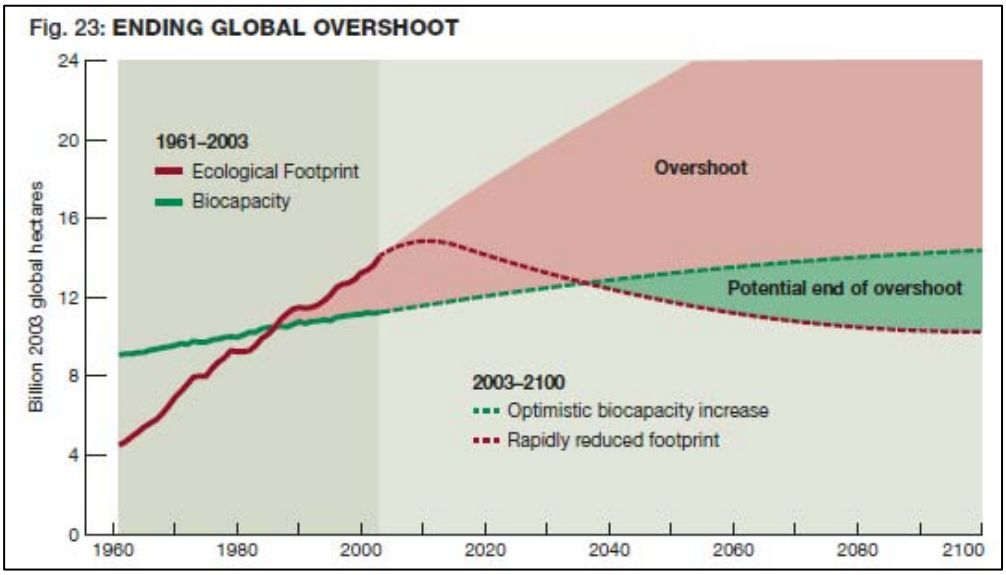

Figure 2. Ecological Footprint and Biocapacity

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)

[3] U.S. Census Bureau, Population Division. "World Population Trends." June 2008. October 2008. Accessed at: http://www.census.gov/ipc/www/idb/worldpopinfo.html.

[4] WWF *Living Planet Report 2006*, Ed. Hails, Chris, Jonathan Loh, and Steven Goldfinger (Gland, Switzerland: WWF, October 2006) p. 1.

[5] Wackernagel, Mathis, Steven Goldfinger, Justin Kitzes, Audrey Peller, Jonathan Loh, Paul Werner, Gary Gibson, Josh Kearns, Robert Williams, Susan Burns, and Brooking Gatewood., "Ecological Footprint," *Living Planet Report 2006*, Ed. Loh and Goldfinger (Gland, Switzerland: WWF, 2006) p. 14.

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).

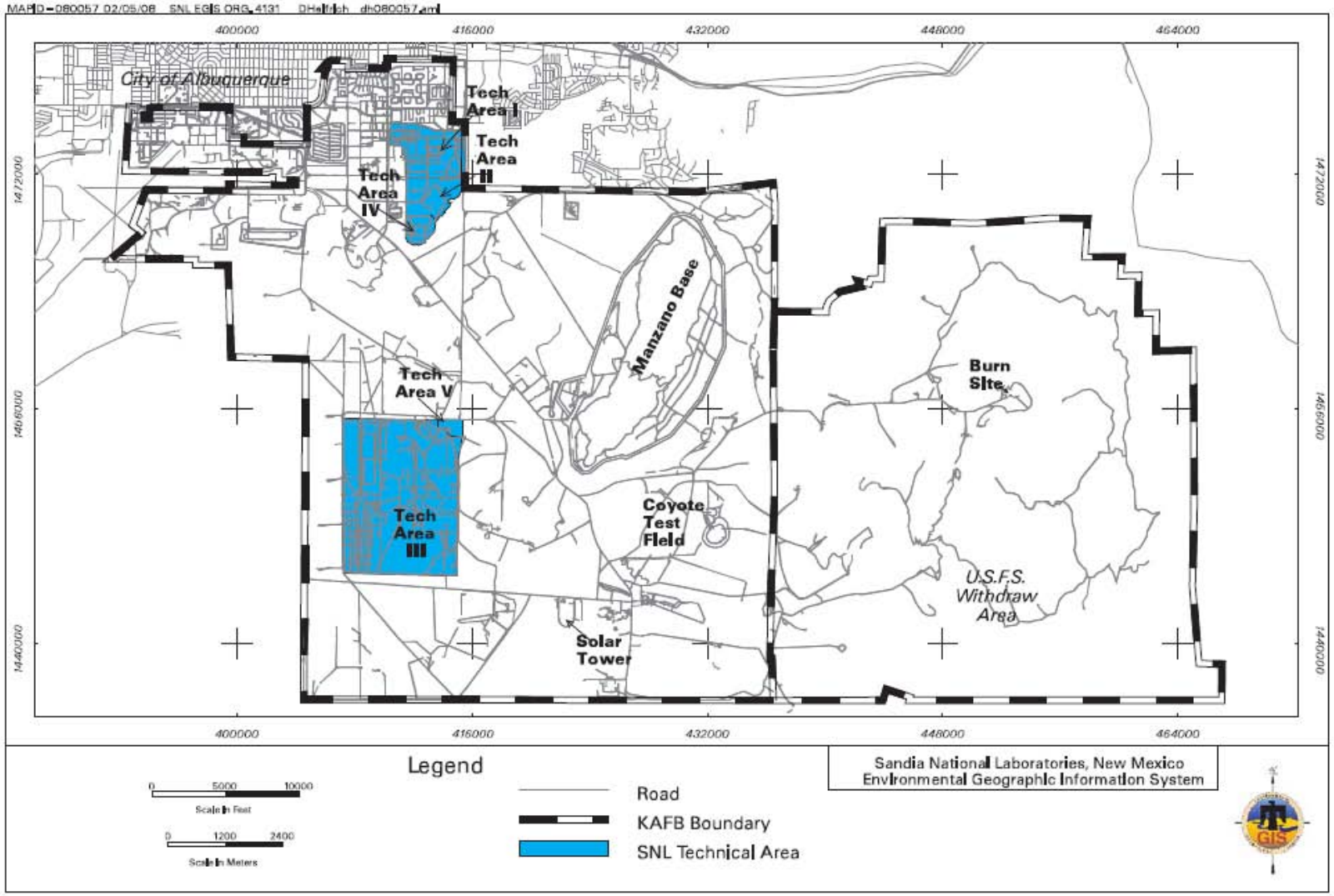

Figure 3. SNL/NM Campus

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.[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 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."[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.

---

[6] Lewan, L. and C. Simmons, "Annex 1: Ecological Footprint Analysis" *The use of Ecological Footprint and Biocapacity Analyses as Sustainability Indicators for Sub-national Geographical Areas: A Recommended Way Forwar*d. (Ambiente Italia [ECIP], 27 August 2001). p. 1. Accessed at: 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: http://www.greenfacts.org/glossary/mno/natural-capital-asset.htm.

[7] IPCC "Climate Change 2001: Synthesis Report; Summary for Policymakers." *IPCC Third Assessment Report.* (Wembley, United Kingdom, 24-29 September 2001.) p. 5.

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 (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).[8] 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.[9]

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).[10]

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

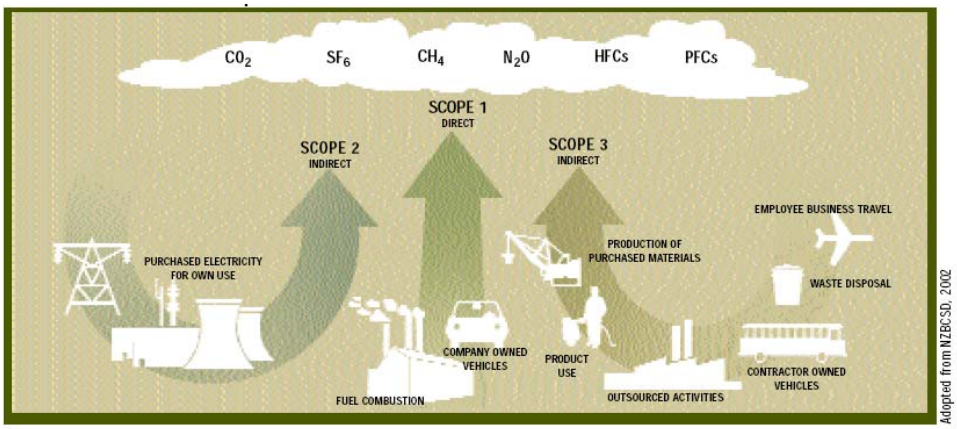

Figure 4. Overview of Scopes and Emissions Across a Value Chain

(Source: The GHG Protocol 2004, p. 26.)

[8] World Resources Institute and World Business Council for Sustainable Development, *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard*. (Washington, D.C., March 2004) p. 2.
[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]

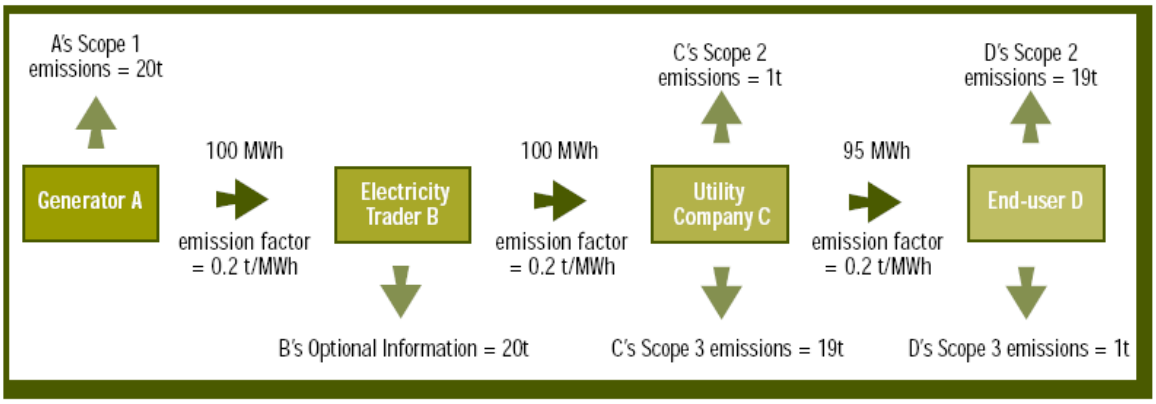

Figure 5. GHG Accounting from the Sale and Purchase of Electricity

(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_2O 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.

[11] World Resources Institute and World Business Council for Sustainable Development, *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard.* (Washington, D.C., March 2004) p. 28.

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

Scope 1	Scope 2	Scope 3
Natural gas consumption Other stationary combustion Fleet fuel consumption	Purchased Electricity	Employee commuting Employee Business Travel Waste Transportation Waste Decomposition

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_2O 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_2O emissions into CO_2 equivalent (CO_2E) emissions using corresponding global warming potentials (GWPs). CO_2 sequestered by the local landscape is subtracted from CO_2E 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.

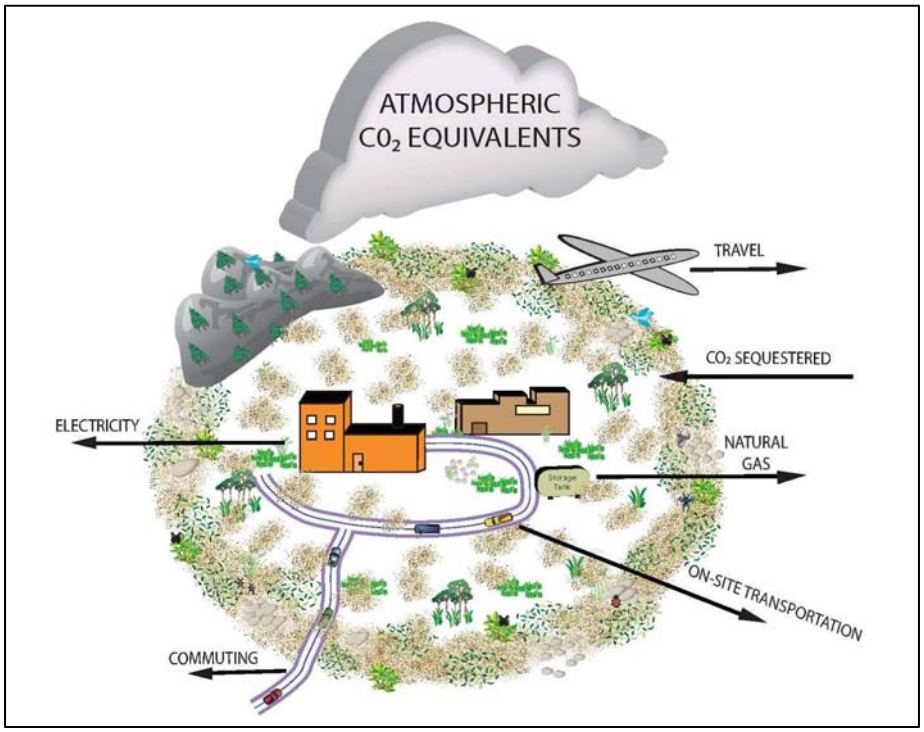

Figure 6. Schematic of SNL/NM's Carbon Footprint Inputs

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.[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.

[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.

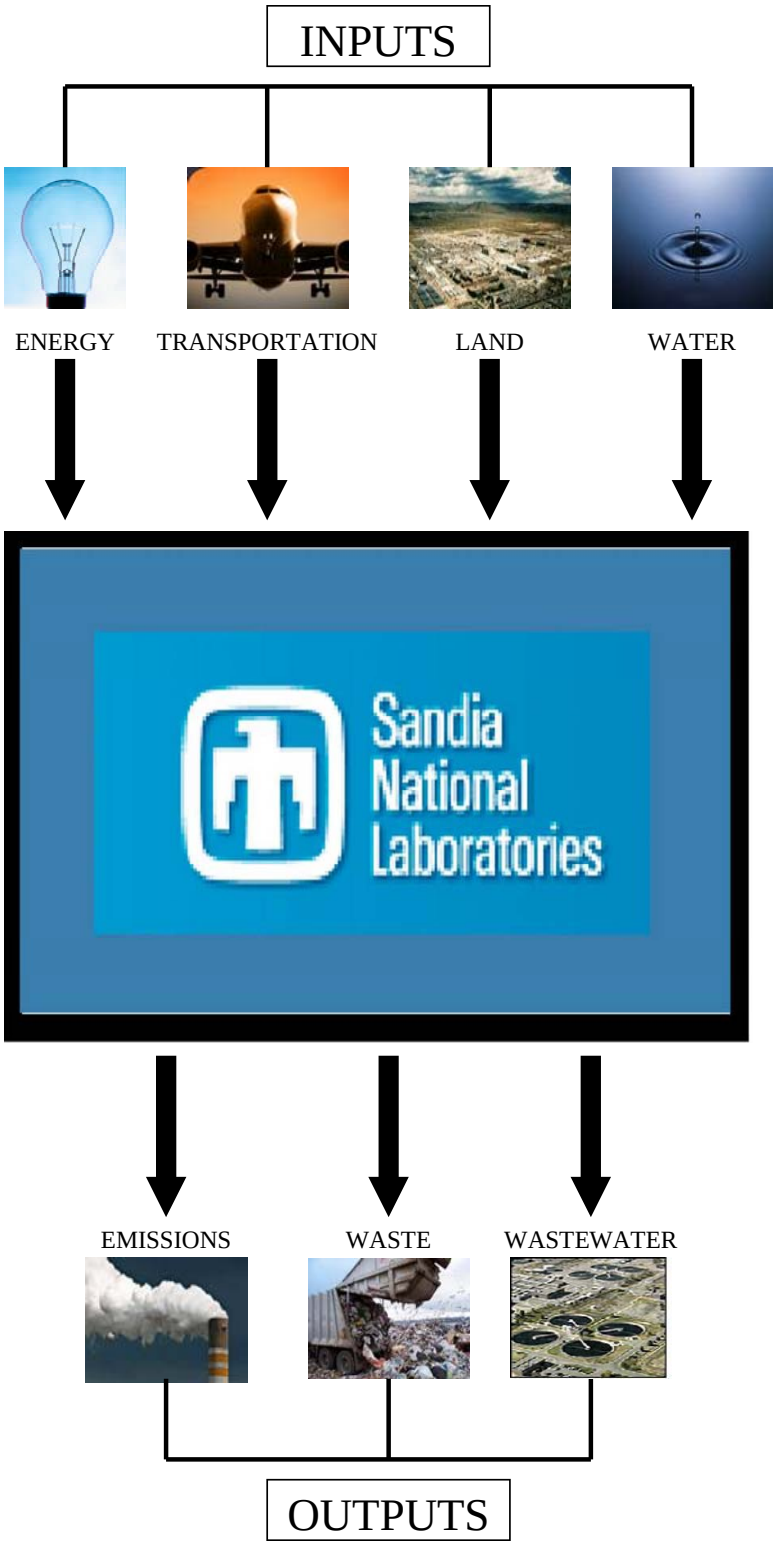

Figure 7. Flow Diagram SNL/NM's Ecological Footprint Inputs and Outputs

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_2O, and CH_4 emissions from these three activities are summed using respective GWPs to yield CO_2E emissions.[13] The emissions from these operations are then converted into a carbon footprint in *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 *gha* and *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 *gha*/ha) compensates for the varying degree of biomass production over the Earth's biosphere.[15] This number is greater than 1 *gha*/ha, because it takes more of the Earth's average bioproductive land (given in units of *gha*) than the Earth's average forest land (given in units of 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: $tonneCO_2E$

b) Land Sequestration Ratio: $0.192\dfrac{ha*yr}{tonneCO_2}$

c) Land Equivalence Factor: $1.17\dfrac{gha}{ha}$

$$\left(0.192\frac{ha*yr}{tonneCO_2}\right)\left(1.17\frac{gha}{ha}\right)=0.225\frac{gha*yr}{tonneCO_2}$$

$$\left(tonneCO_2E\right)\left(0.225\frac{gha*yr}{tonneCO_2E}\right)=gha$$

[13] IPCC. "Climate Change 2001: Working Group I: The Scientific Basis: Chapter 6. Radiative Forcing of Climate Change; 6.12.2 Direct GWPs." *IPCC Third Assessment Report.* (Wembley, United Kingdom, 24-29 September 2001.) Accessed at: http://www.grida.no/publications/other/ipcc%5Ftar/?src=/climate/ipcc_tar.

[14] Chambers, Nicky, Craig Simmons, and Mathis Wackernagel. *Sharing Nature's Interest*. (Earthscan, London: 2000) p. 85.

[15] Ibid.

3.2 Local Sequestration

The Average Sequestration Capacity for the local landscape that SNL/NM operates on, in *lha**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**yr/tonneCO_2) is much larger than that of the Earth's average biologically productive land (0.225 *gha**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:

$$\frac{2.07\,\dfrac{lha * yr}{tonneCO_2}}{0.225\,\dfrac{gha * yr}{tonneCO_2}} = 9.22\,\frac{lha}{gha}$$

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:

$$Grid + Hydro - SolarCredit - BiomassCredit = Total.Electricity$$

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_2E emission factor is calculated using the specific CO_2, CH_4, and N_2O emission factors for NM's grid electricity mix for FY05 and corresponding GWPs.[17] This CO_2E emission factor is used to determine total CO_2E 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:

a) NM Grid CO_2 Emission Factor: $2{,}054\frac{lbs\,CO_2}{MWh}$

b) NM Grid CH_4 Emission Factor: $0.013\frac{lbsCH_4}{MWh}$

c) CH_4 GWP: $23\frac{lbsCO_2E}{lbsCH_4}$

d) NM Grid N_2O Emission Factor: $4.4\frac{lbsN_2O}{MWh}$

e) N_2O GWP: $296\frac{lbsCO_2E}{lbsN_2O}$

[17] EIA. Office of Coal, Nuclear, Electric and Alternate Fuels. *State Electricity Profiles 2005*. (Washington, DC: 2007). Pg. 156 (CO_2 and N_2O); EIA. Updated State-level GHG Emission coefficients for Electricity Generation 1998-2000. (April 2002). Pg. 4. (CH_4).

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

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

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

h) Land Sequestration Ratio: $0.192\,\frac{ha*yr}{tonneCO_2}$

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

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

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

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.[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.[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: $75\,\frac{gha*yr}{GWh}$

[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.

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

Note: Numbers may slightly differ due to rounding.

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).[20] Like the hydroelectricity footprint, the solar electricity footprint is calculated using a generic ecological footprint in units of *gha**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.[21]

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

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

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: $0.192\frac{ha*yr}{tonneCO_2}$

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

$$(0.34GWh)\left(\frac{1{,}000MWh}{GWh}\right)\left(\frac{1.52tonneCO_2}{MWh}\right)\left(0.192\frac{ha*yr}{tonneCO_2}\right)\left(1.17\frac{gha}{ha}\right)=117gha(NMgrid)$$

i) PV Footprint Ratio: $24\frac{gha*yr}{GWh}$

$$(0.34GWh)\left(24\frac{gha*yr}{GWh}\right)=8gha(PV)$$

$$117gha-8gha=108gha$$

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.[22] 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: $6{,}700\frac{MWh}{yr}$

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

c) Land Sequestration Ratio: $0.192\frac{ha*yr}{tonneCO_2}$

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

$$(6{,}700MWh)\left(\frac{1.52tonneCO_2}{MWh}\right)\left(0.192\frac{ha*yr}{tonneCO_2}\right)\left(1.17\frac{gha}{ha}\right)=2{,}292gha(NMgrid)$$

e) Biomass Footprint Ratio: $36.5\frac{gha*yr}{GWh}$

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

[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.

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

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_2O 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_2E 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:

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

b) Natural Gas CO_2 Emission Factor: $54.01\frac{kgCO_2}{MMBtu}$

c) Natural Gas CH_4 Emission Factor: $4.8\frac{gCH_4}{MMBtu}$

d) CH_4 GWP: $23\frac{lbsCO_2E}{lbsCH_4}$

e) Natural Gas N_2O Emission Factor: $0.1\frac{gN_2O}{MMBtu}$

f) N_2O GWP: $296\frac{lbsCO_2E}{lbsN_2O}$

---

[23] According to the City of Albuquerque website, Albuquerque lies at about 5,000 feet. City of Albuquerque. "Albuquerque's Environmental Story." May 2008. Accessed at: http://www.cabq.gov/aes/s1clim.html; Emission factors were taken from: EIA. Fuel Emission Factors (From Appendix H of the instructions for Form EIA-1605). May 2008. Accessed at: http://www.eia.doe.gov/oiaf/1605/techassist.html.

[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.

[25] EIA. Fuel Emission Factors (From Appendix H of the instructions for Form EIA-1605). May 2008. Accessed at: http://www.eia.doe.gov/oiaf/1605/techassist.html.

$$\left(530{,}239\frac{Mcf}{yr}\right)\left(1\frac{MMBtu}{Mcf}\right)\left(\frac{\left(54.01\frac{kgCO_2}{MMBtu}\right)}{\left(1000\frac{kg}{tonne}\right)}+\frac{\left(4.8\frac{gCH_4}{MMBtu}(23)+0.1\frac{gN_2O}{MMBtu}(296)\right)}{\left(1{,}000{,}000\frac{g}{tonne}\right)}\right)$$

$$=28{,}712 tonneCO_2E$$

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

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

$$\left(28{,}712 tonneCO_2\right)\left(0.192\frac{ha*yr}{tonneCO_2}\right)\left(1.17\frac{gha}{ha}\right)=6{,}450 gha$$

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

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_2O 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.

---

[26] See section 2.2 and Figure 3 for more information on the Burn Site and the TTC.

[27] EPA, 2003. "Chapter 3: Stationary Internal Combustion Sources; 3.3 Gasoline and Diesel Industrial Engines; Table 3.3-1. Emission Factors for Uncontrolled Gasoline and Diesel Industrial Engines," *Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition, Volume I: Stationary Point and Area Sources.* May 2008. Accessed at: http://www.epa.gov/ttn/chief/ap42/ch03/final/c03s03.pdf; EIA. Fuel Emission Factors (From Appendix H of the instructions for Form EIA-1605). May 2008. Accessed at: http://www.eia.doe.gov/oiaf/1605/techassist.html.

[28] EIA. Office of Integrated Analysis and Forecasting. "Chapter 6. Table 6-5. Carbon Coefficients and Underlying Data for Petroleum Products." *Documentation for Emissions of GHGs in the U.S. 2005*. October 2007. U.S. DOE Wash, D.C. May 2008. Accessed at: http://www.eia.doe.gov/oiaf/1605/ggrpt/documentation/pdf/0638(2005).pdf. p. 186.

Sample Gasoline Stationary Combustion Footprint Equation:

a) FY05 Gasoline Consumption: $7.5 gal$

b) Gasoline Stationary CO_2 Emission Factor: $154 \frac{lbsCO_2}{MMBtu}$

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

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

d) Land Sequestration Ratio: $0.192 \frac{ha * yr}{tonneCO_2}$

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

$$\frac{(135 lbsCO_2)}{\left(2{,}205\frac{lbs}{tonne}\right)}\left(0.192\frac{ha * yr}{tonneCO_2}\right)\left(1.17\frac{gha}{ha}\right) = 0.015 gha$$

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.[29] 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.[30] 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; CO_2 emission factors are in units of lbs/gal, and CH_4 and N_2O emission factors are in g/mile.[31] The CO_2 factor is dependent on the volume of fuel consumed, while CH_4 and N_2O factors are dependent on vehicle type; passenger cars, light duty (LD) trucks, and heavy duty (HD) vehicles have varying CH_4 and N_2O emissions factors. CH_4 and N_2O 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, CO_2 emissions are underestimated, while N_2O and CH_4 emissions are overestimated.[32] 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: $7{,}777 \mathit{vehicles}$

b) Average Round Trip Commute: $26 \mathit{miles}$

c) # Workdays in a year: $229 \mathit{days}$

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

e) Gasoline CO_2 Emission Factor: $19.54 \frac{lbsCO_2}{gal}$

f) Gasoline CH_4 Emission Factor: $0.039 \frac{gCH_4}{mile}$

g) CH_4 GWP: $23 \frac{lbsCO_2E}{lbsCH_4}$

h) Gasoline N_2O Emission Factor: $0.040 \frac{gN_2O}{mile}$

i) N_2O GWP: $296 \frac{lbsCO_2E}{lbsN_2O}$

[29] 366 employees were surveyed at the Earth Day event, and their commute distances were averaged.
[30] www.fueleconomy.gov
[31] EIA. Fuel Emission Factors (From Appendix H of the instructions for Form EIA-1605). May 2008. Accessed at: http://www.eia.doe.gov/oiaf/1605/techassist.html.
[32] The EIA's CO_2 emission factor for diesel is higher than that for gasoline, and N_2O and CH_4 factors for diesel are lower than that for gasoline, Ibid.

$$\left(7{,}777\frac{vehicles}{day}\right)(26miles)\left(229\frac{days}{vehicle}\right)$$

$$\left(\frac{\left(19.54\frac{lbsCO_2}{gallon}\right)}{\left(18.5\frac{miles}{gal}\right)\left(2{,}205\frac{lbs}{tonne}\right)}+\frac{\left(0.039\frac{gCH_4}{mile}\right)(23)+\left(0.040\frac{gN_2O}{mile}\right)(296)}{\left(1{,}000{,}000\frac{g}{tonne}\right)}\right)$$

$$=22{,}806tonneCO_2E$$

Note: Numbers may slightly differ due to rounding.

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 CO_2 emissions.[34] The EIA's gasoline CO_2 emission factor is provided in units of $lbsCO_2$/gal. CH_4 and N_2O 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:

a) # Miles Traveled in Rental Cars: $6{,}312{,}995miles$

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

c) Gasoline CO_2 Emission Factor: $19.54\frac{lbsCO_2}{gal}$

d) Gasoline CH_4 Emission Factor: $0.011\frac{gCH_4}{mile}$

e) CH_4 GWP: $23\frac{lbsCO_2E}{lbsCH_4}$

[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.
[35] EIA. Fuel Emission Factors (From Appendix H of the instructions for Form EIA-1605). May 2008. Accessed at: http://www.eia.doe.gov/oiaf/1605/techassist.html.

f) Gasoline N_2O Emission Factor: $0.015\frac{gN_2O}{mile}$

g) N_2O GWP: $296\frac{lbsCO_2E}{lbsN_2O}$

$$(6{,}312{,}995 miles)\left(\frac{\left(\frac{19.54 lbsCO_2}{gal}\right)}{\left(19.56\frac{miles}{gal}\right)\left(2{,}205\frac{lbs}{tonne}\right)}+\frac{\left(0.011\frac{gCH_4}{mile}\right)(23)+\left(0.015\frac{gN_2O}{mile}\right)(296)}{1{,}000{,}000\frac{g}{tonne}}\right)$$
$$=2{,}891 tonneCO_2E$$

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 CO_2 emission factors are provided in units of lbs/gal, except for CNG, which is given in lbs/Mcf. CH_4 and N_2O factors for different vehicle types are given in units of g/mile.[36] At the time of publication, the EIA does not have CH_4 and N_2O emission factors for E-85 fuel; CH_4 and N_2O 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 CH_4 and N_2O emission factors for LD and HD vehicles is taken. This analysis does not account for CH_4 and N_2O 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 CO_2 Emission Factor: $2.93\frac{lbsCO_2}{gal}$

[36] EIA. Fuel Emission Factors (From Appendix H of the instructions for Form EIA-1605). May 2008. Accessed at: http://www.eia.doe.gov/oiaf/1605/techassist.html.

$$(39{,}306\,gal)\frac{\left(\frac{2.93\,lbsCO_2}{gal}\right)}{\left(2{,}205\,\frac{lbs}{tonne}\right)} = 52\,tonnesCO_2$$

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

d) Gas Passenger Cars CH_4 Emission Factor: $0.017\,\frac{gCH_4}{mile}$

e) LD Vehicles Ethanol CH_4 Emission Factor: $0.055\,\frac{gCH_4}{mile}$

f) CH_4 GWP: $23\,\frac{lbsCO_2E}{lbsCH_4}$

g) Gas Passenger Cars N_2O Emission Factor: $0.004\,\frac{gN_2O}{mile}$

h) LD Vehicles Ethanol N_2O Emission Factor: $0.067\,\frac{gN_2O}{mile}$

i) N_2O GWP: $296\,\frac{lbsCO_2E}{lbsN_2O}$

$$(44{,}358\,miles)\frac{\left(\left(15\%\left(0.017\,\frac{gCH_4}{mile}\right)+75\%\left(0.055\,\frac{gCH_4}{mile}\right)\right)23+\left(15\%\left(0.004\,\frac{gN_2O}{mile}\right)+75\%\left(0.067\,\frac{gN_2O}{mile}\right)\right)(296)\right)}{\left(1{,}000{,}000\,\frac{g}{tonne}\right)}$$

$$= 1\,tonneCO_2E$$

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

k) Gas LD Trucks CH_4 Emission Factor: $0.016\,\frac{gCH_4}{mile}$

l) LD Vehicles Ethanol CH_4 Emission Factor: $0.055\,\frac{gCH_4}{mile}$

m) Gas LD Trucks N_2O Emission Factor: $0.007\,\frac{gN_2O}{mile}$

n) LD Vehicles Ethanol N_2O Emission Factor: $0.067\frac{gN_2O}{mile}$

$$(333{,}488miles)\frac{\left(\left(15\%\left(0.016\frac{gCH_4}{mile}\right)+85\%\left(0.055\frac{gCH_4}{mile}\right)\right)23+\left(15\%\left(0.007\frac{gN_2O}{mile}\right)+85\%\left(0.067\frac{gN_2O}{mile}\right)\right)(296)\right)}{\left(1{,}000{,}000\frac{g}{tonne}\right)}$$

$$=5tonneCO_2E$$

$$52tonnesCO_2+1tonneCO_2E+7tonneCO_2E=58tonneCO_2E$$

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_2O 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: $58{,}455{,}515miles$

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

c) Jet fuel CO_2 emission coefficient: $21.09\frac{lbsCO_2}{gal}$

d) Jet fuel CH_4 Emission Coefficient: $0.27\frac{gCH_4}{gal}$

e) CH_4 GWP: $23\frac{lbsCO_2E}{lbsCH_4}$

[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.

[38] Bureau of Transportation Statistics. Table 4-21: Energy Intensity of Certificated Air Carriers, All Services. May 2008. Accessed at: http://www.bts.gov/publications/national_transportation_statistics/html/table_04_21.html.

[39] EIA. Fuel Emission Factors (From Appendix H of the instructions for Form EIA-1605). May 2008. Accessed at: http://www.eia.doe.gov/oiaf/1605/techassist.html.

f) Jet fuel N_2O Emission Coefficient: $0.31\frac{gN_2O}{gal}$

g) N_2O GWP: $296\frac{lbsCO_2E}{lbsN_2O}$

$$\frac{(58{,}455{,}515miles)}{\left(42.42\frac{miles}{gal}\right)}\left(\frac{\left(21.09\frac{lbsCO_2}{gal}\right)}{\left(2{,}205\frac{lbs}{tonne}\right)}+\frac{\left(0.27\frac{gCH_4}{gal}\right)(23)+\left(0.31\frac{gN_2O}{gal}\right)(296)}{\left(1{,}000{,}000\frac{g}{tonne}\right)}\right)$$

$$=13{,}316tonneCO_2E$$

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: $41{,}419tonneCO_2E$

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

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

$$(41{,}419tonneCO_2E)\left(0.192\frac{ha}{tonneCO_2}\right)\left(1.17\frac{gha}{ha}\right)=9{,}304gha$$

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.[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

[40] For more information on the methodology behind WARM see EPA. *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks* (EPA 530-R-02-006) May 2008. Accessed at: http://epa.gov/climatechange/wycd/waste/SWMGHGreport.html.

tons (MT) (see Table 2 below).[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

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

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_2E recycling emission credits, output as negative values, are subtracted from CO_2E emissions resulting from disposal of mixed MSW, output as a positive value, to yield net waste emissions.

[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 ft^2), are used to calculate development density.[42] 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.[43] 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:

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

b) Land Use Footprint (Total Developed Land Area): $873\,acres$

$$\frac{\left(\dfrac{5{,}515{,}265\,ft^2}{873\,acres}\right)}{\left(43{,}579\,\dfrac{ft^2}{acre}\right)} = 14.5\%$$

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. [44] 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: $406{,}254{,}588 gal$

b) Total Building Square Footage: $5{,}515{,}265\, ft^2$

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

c) Number of FTEs: $8{,}569$ FTEs

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

d) # Workdays in a year: $229 days$

$$\frac{\left(47{,}408 \frac{gal}{FTE}\right)}{(229 days)} = 207 \frac{gal}{FTE * day}$$

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*/tonneCO_2. 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

Component	Tonnes CO_2E	Footprint (*gha*)	Footprint (*lha*)	% of Carbon Footprint	% of Ecological Footprint
Electricity	352,691	79,229	730,872	82.19%	82.16%
Natural gas	28,712	6,450	59,500	6.69%	6.69%
Commuting	22,961	5,158	47,581	5.35%	5.35%
Airline Travel	13,316	2,991	27,594	3.10%	3.10%
Waste Emissions	7,632	1,714	15,816	1.78%	1.78%
Rental Cars	2,891	649	5,990	0.67%	0.67%
Fleet	2,251	506	4,665	0.52%	0.52%
Land Use	N/A	38	353	N/A	0.04%
Stationary Combustion	160	36	331	0.04%	0.04%
Sequestration	-1,504	-338	-3,116	-0.35%	-0.35%
Carbon Footprint	429,110	96,395	889,233		99.96%
Ecological Footprint		96,434	889,586		
Deficit	427,607	96,096	886,470		

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

Category	Tonnes CO_2E	*Footprint (gha)*	*Footprint (lha)*	Percentage
Electricity	352,691	79,229	730,872	92.43%
Natural Gas	28,712	64,50	59,500	7.52%
Stationary Combustion	160	36	331	0.04%
Total	**381,564**	**85,714**	**790,703**	

Table 5. Electricity Footprint by Type

Energy	Footprint (*gha*)	Footprint (*lha*)	Percentage
Grid Electricity	80,677	744,230	101.83%*
Hydropower**	707	6,526	0.89%
Biomass Electricity**	-2,047	-18,884	-2.58%
Solar Electricity**	-108	-1,000	-0.14%
Total	**79,229**	**730,872**	

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 tonnesCO_2E. 9,920 tonnesCO_2E are offset from recycling, resulting in a net emissions of 7,632 tonnesCO_2E 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)

Commodity	Total $MTCO_2E$
Aluminum Cans	(27)
Steel Cans	(10)
Corrugated Cardboard	(902)
Phonebooks	(12)
Dimensional Lumber	(696)
Mixed Paper, Office	(572)
Mixed Metals	(6,665)
Mixed Plastics	(8)
Mixed Recyclables	(899)
Mixed MSW	17,552
Carpet	(24)
Personal Computers	(64)
Concrete	(32)
Tires	(9)
Recycling Offset	**(9,920)**
Net Emissions	**7,632**

Note: See Appendix D for complete WARM output table.

4.4 Land Footprint Results

SNL/NM's land use footprint is 353 *lha*, 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 CO_2 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.[45] This comparison shows that SNL/NM is responsible for slightly over one percent of the total water use in the Albuquerque area.[46]

Table 7. Water Consumption Comparison - FY05

Water Use	SNL/NM	UNM	Intel	COA	Total
Water Use (million gal)	406	482	880	32,800	34,568
Percentage of Total Use	1.2%	1.4%	2.6%	94.9%	100%

Water consumption at SNL/NM in FY05 is 73.7gal/ft^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.[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.[48]

[45] Water use data was provided by the COA water conservation officer Katherine Yuhas.
[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.
[47] COA. *Progress Report for 2002-2006.* Goal 5: Environmental Protection and Enhancement. "Desired Community Condition: Water resources are sustainably managed, conserved and protected to provide a long term supply and drought reserve." Accessed at: http://www.cabq.gov/progress/pdf/per-capita-water.pdf.
[48] SNL/NM Water Conservation Program website. May 2008. Accessed at: http://www.sandia.gov/aqua/default.htm.

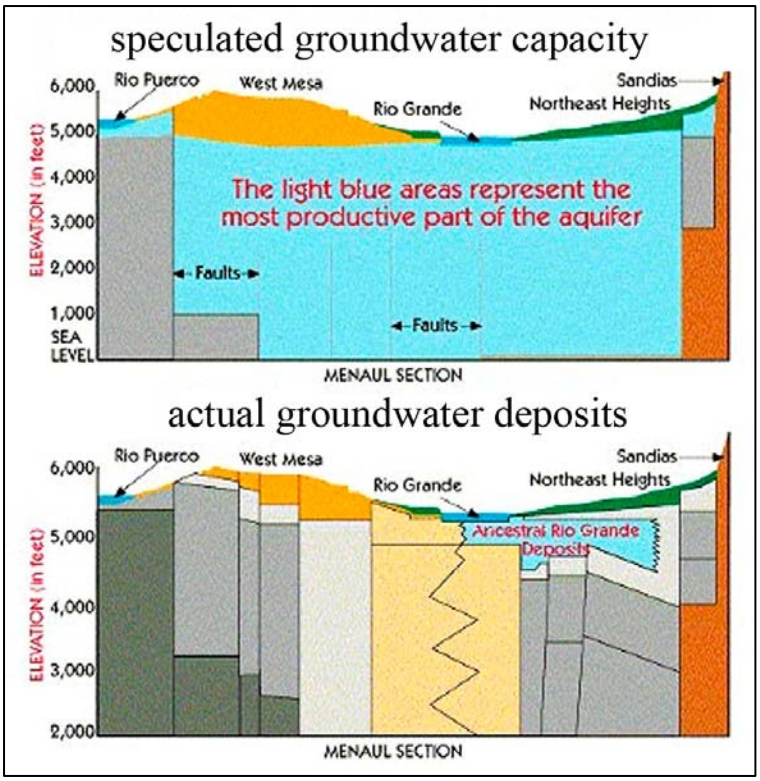

Figure 8. True Capacity of the Middle Rio Grande Aquifer

(Source: SNL/NM Water Conservation Program, May 2008).

5. Conclusions

This analysis generates a baseline ecological footprint for SNL/NM. Findings show the major CO_2E 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. CO_2 Dominates SNL/NM Footprint.
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.

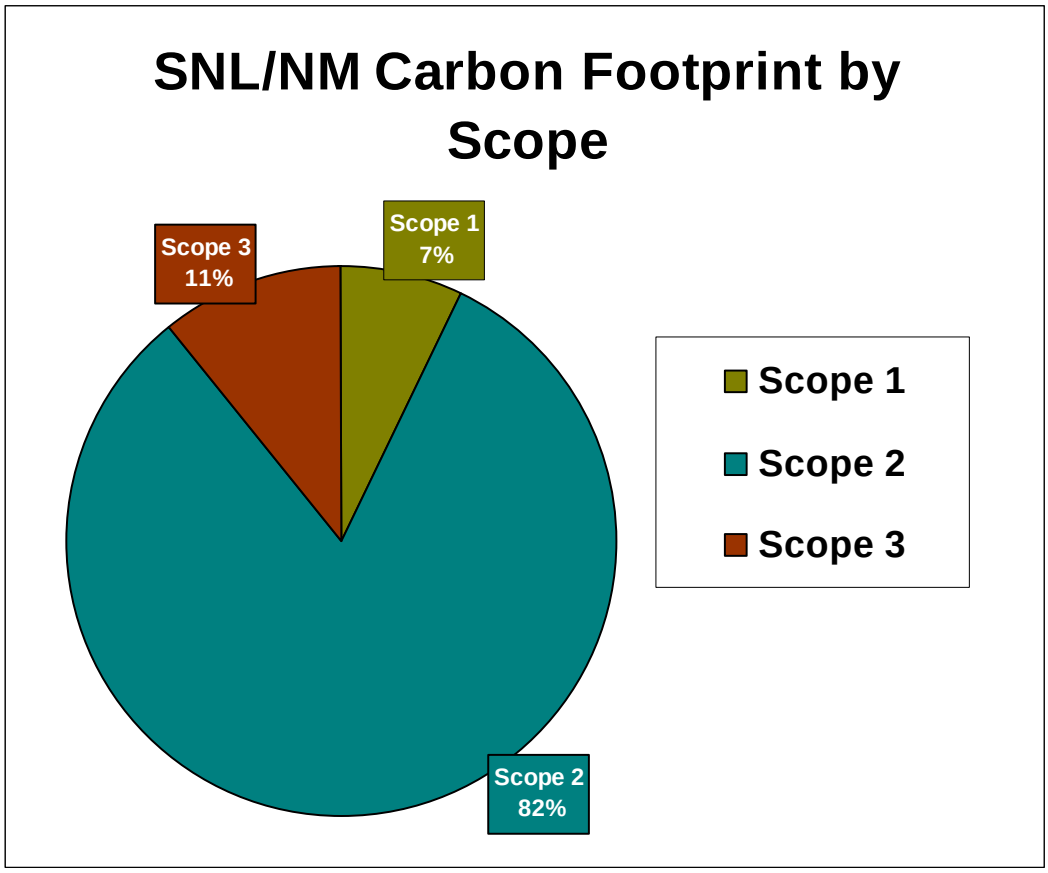

Figure 10. SNL/NM Carbon Footprint by The GHG Protocol Scopes

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*.[49] 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_2O 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

[49] Chambers, Nicky, Craig Simmons, and Mathis Wackernagel. *Sharing Nature's Interest*. (Earthscan, London: 2000) p. 69-76.

baseline of SF_6 purchases for FY07 and FY08. This data will be used to quantify SF_6 emissions for the ecological footprint during those time periods.[50]

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*.[51]

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 N_2O and CH_4 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,

[50] Gerard, Morgan. "Sulfur Hexafluoride Baseline." Pollution Prevention Program, SNL/NM. September 30, 2008. p. 1.

[51] World Resources Institute and World Business Council for Sustainable Development, *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard.* (Washington, D.C., March 2004) p. 29.

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."[52] 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 CO_2 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.

[52] EPA. WARM website. May 2008. Accessed at: http://www.epa.gov/climatechange/wycd/waste/calculators/Warm_home.html.

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.

This page intentionally blank.

6. References

Bureau of Transportation Statistics. Table 4-21: Energy Intensity of Certificated Air Carriers, All Services. May 2008. Accessed at: http://www.bts.gov/publications/national_transportation_statistics/html/table_04_21.html

Chambers, Nicky, Craig Simmons, and Mathis Wackernagel. *Sharing Nature's Interest*. (Earthscan, London: 2000).

City of Albuquerque. "Albuquerque's Environmental Story." May 2008. Accessed at: http://www.cabq.gov/aes/s1clim.html.

City of Albuquerque. *Progress Report for 2002-2006.* Goal 5: Environmental Protection and Enhancement. "Desired Community Condition: Water resources are sustainably managed, conserved and protected to provide a long term supply and drought reserve." Accessed at: http://www.cabq.gov/progress/pdf/per-capita-water.pdf.

EIA. Fuel Emission Factors (From Appendix H of the instructions to Form EIA-1605). May 2008. Accessed at: http://www.eia.doe.gov/oiaf/1605/techassist.html.

EIA. Office of Coal, Nuclear, Electric and Alternate Fuels. *State Electricity Profiles 2005*. (Washington, DC: 2007).

EIA. Office of Integrated Analysis and Forecasting. "Chapter 6. Table 6-5. Carbon Coefficients and Underlying Data for Petroleum Products." *Documentation for Emissions of GHGs in the U.S. 2005*. October 2007. U.S. DOE Wash, D.C. May 2008. Accessed at: http://www.eia.doe.gov/oiaf/1605/ggrpt/documentation/pdf/0638(2005).pdf.

EIA. Updated State-level GHG Emission coefficients for Electricity Generation 1998-2000. (April 2002).

EPA, 2003. "Chapter 3: Stationary Internal Combustion Sources; 3.3 Gasoline and Diesel Industrial Engines; Table 3.3-1. Emission Factors for Uncontrolled Gasoline and Diesel Industrial Engines," *Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition, Volume I: Stationary Point and Area Sources.* May 2008. Accessed at: http://www.epa.gov/ttn/chief/ap42/ch03/final/c03s03.pdf.

EIA. Fuel Emission Factors (From Appendix H of the instructions to Form EIA-1605). May 2008. Accessed at: http://www.eia.doe.gov/oiaf/1605/techassist.html.

EPA. *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks* (EPA 530-R-02-006) May 2008. Accessed at: http://epa.gov/climatechange/wycd/waste/SWMGHGreport.html.

EPA. WARM website. May 2008. Accessed at: http://www.epa.gov/climatechange/wycd/waste/calculators/Warm_home.html.
.

Gerard, Morgan. "Sulfur Hexafluoride Baseline." Pollution Prevention Program, SNL/NM. September 30, 2008. p. 1.

GreenFacts Glossary. June 2008. October 2008. Accessed at: http://www.greenfacts.org/glossary/mno/natural-capital-asset.htm.

IPCC "Climate Change 2001: Synthesis Report; Summary for Policymakers." *IPCC Third Assessment Report.* (Wembley, United Kingdom, 24-29 September 2001.)

IPCC. "Climate Change 2001: Working Group I: The Scientific Basis: Chapter 6. Radiative Forcing of Climate Change; 6.12.2 Direct GWPs." *IPCC Third Assessment Report.* (Wembley, United Kingdom, 24-29 September 2001.) Accessed at: http://www.grida.no/publications/other/ipcc%5Ftar/?src=/climate/ipcc_tar.

Lewan, L. and C. Simmons, "Annex 1: Ecological Footprint Analysis" *The use of Ecological Footprint and Biocapacity Analyses as Sustainability Indicators for Sub-national Geographical Areas: A Recommended Way Forwar*d. (Ambiente Italia [ECIP], 27 August 2001).Accessed at: http://www.prosus.uio.no/english/sus_dev/tools/oslows/2.htm

SNL/NM Water Conservation Program website. May 2008. Accessed at: http://www.sandia.gov/aqua/default.htm.

U.S. Census Bureau, Population Division. "World Population Trends." June 2008. October 2008. Accessed at: http://www.census.gov/ipc/www/idb/worldpopinfo.html.

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).

World Resources Institute and World Business Council for Sustainable Development, *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard*. (Washington, D.C., March 2004).

WWF *Living Planet Report 2006*, Ed. Hails, Chris, Jonathan Loh, and Steven Goldfinger (Gland, Switzerland: WWF, October 2006).

www.fueleconomy.gov

7. Glossary

Average Sequestration Capacity – The area of land required to sequester one tonne of CO_2.

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 (CO_2) – 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 CO_2E 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.

CO_2 Equivalent Emissions – the sum of various GHGs that have been normalized to CO_2, 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 CO_2.

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

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

Land Sequestration Ratio – The area of average forest land required to sequester CO_2 emissions annually (0.192ha*year/tonneCO_2).

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 (CH_4) – 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 (N_2O) – 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

APPENDIX A: Local Sequestration Capacity Calculations.....56
APPENDIX B: Energy Calculations 58
APPENDIX C: Transportation Calculations 65
APPENDIX D: Waste Calculations.....78
APPENDIX E: Land Use Calculations.....80
APPENDIX F: Water Footprint Calculation 81
APPENDIX G: Ecological Deficit.....82
APPENDIX H: Conversions and Unit Abbreviations 83

APPENDIX A: Local Sequestration Capacity Calculations

I. Pinyon-Juniper Sequestration Ratio: [53]

a) NM Rangeland Grass/Legume Sequestration:[54] $0.13\frac{tonneC}{ha*yr}$

b) Desert Grassland Net Primary Production:[55] $0.95\frac{MgC}{ha*yr}$

c) Pinyon-Juniper Net Primary Production: $1.0\frac{MgC}{ha*yr}$

$$\left(\frac{0.13\frac{tonneC}{ha*yr}}{0.95\frac{Mg.C}{ha.yr}}\right)=\left(\frac{x\frac{tonneC}{ha*yr}}{1.0\frac{Mg.C}{ha.yr}}\right)\quad x=0.14\frac{tonneC}{ha*yr}$$

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.

[55] Neary, D. G., S. T. Overby, & S. C. Hart (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. 297). Boca Raton, Florida: Lewis Publishers. CRC Press LLC.

$$\left(0.13\frac{tonneC}{ha*yr}\times 74\% + 0.14\frac{tonneC}{ha*yr}\times 26\%\right)\left(\frac{44.01\frac{g}{mol}CO_2}{12.01\frac{g}{mol}C}\right) = 0.48\frac{tonneCO_2}{lha*yr}$$

$$= 2.07\frac{lha*yr}{tonneCO_2}$$

III. Ratio of Local Hectares to Global Hectares:

a) Land Sequestration Ratio: $0.192\frac{ha*yr}{tonneCO_2}$

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

c) Local Sequestration Ratio: $2.07\frac{lha*yr}{tonneCO_2}$

$$\left(0.192\frac{ha*yr}{tonneCO_2}\right)\left(1.17\frac{gha}{ha}\right) = 0.225\frac{gha*yr}{tonneCO_2}$$

$$\frac{\left(2.07\frac{lha*yr}{tonneCO_2}\right)}{\left(0.225\frac{gha*yr}{tonneCO_2}\right)} = 9.22\frac{lha}{gha}$$

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_2 Emission Factor: $2{,}054\frac{lbs\,CO_2}{MWh}$

b) NM Grid CH_4 Emission Factor: $0.013\frac{lbsCH_4}{MWh}$

c) CH_4 GWP: $23\frac{lbsCO_2E}{lbsCH_4}$

d) NM Grid N_2O Emission Factor: $4.4\frac{lbsN_2O}{MWh}$

e) N_2O GWP: $296\frac{lbsCO_2E}{lbsN_2O}$

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

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

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

h) Land Sequestration Ratio: $0.192\frac{ha*yr}{tonneCO_2}$

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

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

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

j) Local Sequestration Ratio: $2.07\frac{lha*yr}{tonneCO_2}$

$$(359{,}138 tonneCO_2)\left(2.07\frac{lha * yr}{tonneCO_2}\right) = 744{,}230 lha$$

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: $75\frac{gha * yr}{GWh}$

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

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

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

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: $8{,}760 h$

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

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

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

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

$$(0.34GWh)\left(\frac{1{,}000MWh}{GWh}\right)\left(\frac{1.52tonneCO_2}{MWh}\right)\left(0.192\frac{ha*yr}{tonneCO_2}\right)\left(1.17\frac{gha}{ha}\right)=117gha(NMgrid)$$

i) PV Footprint Ratio: $24\frac{gha*yr}{GWh}$

$$(0.34GWh)\left(24\frac{gha*yr}{GWh}\right)=8gha(PV)$$

$$117gha-8gha=108gha$$

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

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

Note: Numbers may slightly differ due to rounding.

D. Biomass Footprint Credit:

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

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

c) Land Sequestration Ratio: $0.192\frac{ha*yr}{tonneCO_2}$

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

$$(6{,}700MWh)\left(\frac{1.52tonneCO_2}{MWh}\right)\left(0.192\frac{ha*yr}{tonneCO_2}\right)\left(1.17\frac{gha}{ha}\right)=2{,}292gha(NMgrid)$$

e) Biomass Footprint Ratio: $36.5\frac{gha*yr}{GWh}$

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

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

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

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

Note: Numbers may slightly differ due to rounding.

E. Overall Electricity Footprint and Adjusted Total Emissions:

a) Grid Electricity Footprint in *gha*: $80{,}677gha$

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

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

d) Biomass Electricity Footprint Credit in *gha*: $2{,}047gha$

e) Grid Electricity Footprint in *lha*: $744{,}230lha$

f) Hydroelectricity Footprint in *lha*: $6{,}526lha$

g) Solar Electricity Footprint Credit in *lha*: $1{,}000lha$

h) Biomass Electricity Footprint Credit in *lha*: $18{,}884lha$

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

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

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

i) Total Electricity Footprint: $79{,}229gha$

j) Land Sequestration Ratio: $0.192\frac{ha*yr}{tonneCO_2}$

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

$$\frac{\left(\frac{79{,}229\,gha}{1.17\frac{gha}{ha}}\right)}{\left(0.192\frac{ha*yr}{tonneCO_2}\right)} = 352{,}691\,tonneCO_2$$

Note: Numbers may slightly differ due to rounding.

Note: Because hydroelectricity, biomass electricity, and solar electricity are calculated using generic footprint factors, their CO_2E 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 CO_2 Emission Factor: $54.01\frac{kgCO_2}{MMBtu}$

c) Natural Gas CH_4 Emission Factor: $4.8\frac{gCH_4}{MMBtu}$

d) CH_4 GWP: $23\frac{lbsCO_2E}{lbsCH_4}$

e) Natural Gas N_2O Emission Factor: $0.1\frac{gN_2O}{MMBtu}$

f) N_2O GWP: $296\frac{lbsCO_2E}{lbsN_2O}$

$$\left(530{,}239\frac{Mcf}{yr}\right)\left(1\frac{MMBtu}{Mcf}\right)\left(\frac{\left(54.01\frac{kgCO_2}{MMBtu}\right)}{\left(1000\frac{kg}{tonne}\right)}+\frac{\left(4.8\frac{gCH_4}{MMBtu}(23)+0.1\frac{gN_2O}{MMBtu}(296)\right)}{\left(1{,}000{,}000\frac{g}{tonne}\right)}\right)$$

$$= 28{,}712\,tonneCO_2E$$

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

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

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

$$\left(28{,}712 tonneCO_2\right)\left(0.192\frac{ha * yr}{tonneCO_2}\right)\left(1.17\frac{gha}{ha}\right) = 6{,}450 gha$$

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

$$\left(28{,}712 tonneCO_2\right)\left(2.07\frac{lha * yr}{tonneCO_2}\right) = 59{,}500 lha$$

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: $5.25\frac{MMBtu}{barrel}$

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

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: $5.83\frac{MMBtu}{barrel}$

$$(12{,}106\,gal)\left(164\frac{lbsCO_2}{MMBtu}\right)\frac{\left(5.83\frac{MMBtu}{barrel}\right)}{\left(42\frac{gal}{barrel}\right)} = 275{,}362\,lbsCO_2$$

g) FY05 Jet Fuel Consumption: $3{,}637\,gal$

h) Jet Fuel Stationary CO_2 Emission Factor: $70.88\frac{kgCO_2}{MMBtu}$

i) Jet Fuel Gross Heat of Combustion: $5.67\frac{MMBtu}{barrel}$

$$(3{,}637\,gal)\left(70.88\frac{kgCO_2}{MMBtu}\right)\left(2.205\frac{lbs}{kg}\right)\frac{\left(5.67\frac{MMBtu}{barrel}\right)}{\left(42\frac{gal}{barrel}\right)} = 76{,}727\,lbsCO_2$$

j) Land Sequestration Ratio: $0.192\frac{ha*yr}{tonneCO_2}$

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

$$\frac{144\,lbsCO_2 + 275{,}362\,lbsCO_2 + 76{,}727\,lbsCO_2}{\left(2{,}205\frac{lbs}{tonne}\right)} = 160\,tonneCO_2$$

$$(160\,tonneCO_2)\left(0.192\frac{ha*yr}{tonneCO_2}\right)\left(1.17\frac{gha}{ha}\right) = 36\,gha$$

l) Local Sequestration Ratio: $2.07\frac{lha*yr}{tonneCO_2}$

$$(160\,tonneCO_2)\left(2.07\frac{lha*yr}{tonneCO_2}\right) = 331\,lha$$

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 CO_2 Emission Factor: $19.54 \frac{lbsCO_2}{gal}$

f) Gasoline CH_4 Emission Factor: $0.039 \frac{gCH_4}{mile}$

g) CH_4 GWP: $23 \frac{lbsCO_2E}{lbsCH_4}$

h) Gasoline N_2O Emission Factor: $0.040 \frac{gN_2O}{mile}$

i) N_2O GWP: $296 \frac{lbsCO_2E}{lbsN_2O}$

$$\left(7{,}777 \frac{vehicles}{day}\right)(26 miles)\left(229 \frac{days}{vehicle}\right)$$
$$\left(\frac{\left(19.54 \frac{lbsCO_2}{gallon}\right)}{\left(18.5 \frac{miles}{gal}\right)\left(2{,}205 \frac{lbs}{tonne}\right)} + \frac{\left(0.039 \frac{gCH_4}{mile}\right)(23) + \left(0.040 \frac{gN_2O}{mile}\right)(296)}{\left(1{,}000{,}000 \frac{g}{tonne}\right)}\right)$$
$$= 22{,}806 tonneCO_2E$$

Note: Numbers may slightly differ due to rounding.

B. Bicycle Commuter Offset:

a) # Bicycle Commuter Miles in CY05:[56] $206{,}391 miles$

[56] Although bicycle commuter statistics are given by CY, the authors assume that this is an adequate estimate of FY statistics.

b) Gasoline CO_2 Emission Factor: $19.54\frac{lbsCO_2}{gal}$

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

d) Gasoline CH_4 Emission Factor: $0.039\frac{gCH_4}{mile}$

e) CH_4 GWP: $23\frac{lbsCO_2E}{lbsCH_4}$

f) Gasoline N_2O Emission Factor: $0.040\frac{gN_2O}{mile}$

g) N_2O GWP: $296\frac{lbsCO_2E}{lbsN_2O}$

$$206{,}391miles\left(\frac{\left(19.54\frac{lbsCO_2}{gal}\right)}{\left(18.5\frac{miles}{gal}\right)\left(2{,}204.6\frac{lbs}{tonne}\right)}+\frac{\left(0.039\frac{gCH_4}{mile}\right)(23)+\left(0.040\frac{gN_2O}{mile}\right)(296)}{\left(1{,}000{,}000\frac{g}{tonne}\right)}\right)$$

$$=102tonneCO_2E$$

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: $26\frac{miles}{day}$

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

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

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

[58] Chambers, Nicky, Craig Simmons, and Mathis Wackernagel. *Sharing Nature's Interest*. (Earthscan, London: 2000) p. 86.

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

f) Land Sequestration Ratio: $0.192\frac{ha*yr}{tonneCO_2}$

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

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

$$\frac{\left(\frac{58gha}{1.17\frac{gha}{ha}}\right)}{\left(0.192\frac{hayear}{tonneCO_2}\right)}=256tonneCO_2$$

Note: Numbers may slightly differ due to rounding.

D. Overall Commuter Emissions and Footprint:

a) Personal Vehicle Emissions: $22{,}806tonneCO_2E$

b) Bicycle Emissions Offset: $102tonneCO_2E$

c) Bus Passenger Emissions: $256tonneCO_2$

d) Land Sequestration Ratio: $0.192\frac{ha*yr}{tonneCO_2}$

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

$$22{,}806tonneCO_2E-102tonneCO_2E+256tonneCO_2=22{,}961tonneCO_2E$$

$$(22{,}961tonneCO_2E)\left(0.192\frac{ha*yr}{tonneCO_2}\right)\left(1.17\frac{gha}{ha}\right)=5{,}158gha$$

f) Local Sequestration Ratio: $2.07\frac{lha*yr}{tonneCO_2}$

$$(22{,}961 tonneCO_2E)\left(2.07\frac{gha*yr}{tonneCO_2}\right)=47{,}581 lha$$

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: $19.56\frac{miles}{gal}$

c) Gasoline CO_2 Emission Factor: $19.54\frac{lbsCO_2}{gal}$

d) Gasoline CH_4 Emission Factor: $0.011\frac{gCH_4}{mile}$

e) CH_4 GWP: $23\frac{lbsCO_2E}{lbsCH_4}$

f) Gasoline N_2O Emission Factor: $0.015\frac{gN_2O}{mile}$

g) N_2O GWP: $296\frac{lbsCO_2E}{lbsN_2O}$

$$(6{,}312{,}995 miles)\left(\frac{\left(\frac{19.54 lbsCO_2}{gal}\right)}{\left(19.56\frac{miles}{gal}\right)\left(2{,}204.62\frac{lbs}{tonne}\right)}+\frac{\left(0.011\frac{gCH_4}{mile}\right)(23)+\left(0.015\frac{gN_2O}{mile}\right)(296)}{1{,}000{,}000\frac{g}{tonne}}\right)$$

$$=2{,}891 tonneCO_2E$$

h) Land Sequestration Ratio: $0.192\frac{ha*yr}{tonneCO_2}$

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

$$(2{,}891 tonneCO_2E)\left(0.192\frac{ha*yr}{tonneCO_2}\right)\left(1.17\frac{gha}{ha}\right)=649 gha$$

j) Local Sequestration Ratio: $2.07\frac{lha*yr}{tonneCO_2}$

$$\left(2{,}891 tonneCO_2E\right)\left(2.07\frac{lha*yr}{tonneCO_2}\right)=5{,}990 lha$$

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 CO_2 Emission Factor: $2.93\frac{lbsCO_2}{gal}$

$$\left(39{,}306 gal\right)\frac{\left(\frac{2.93 lbsCO_2}{gal}\right)}{\left(2{,}205\frac{lbs}{tonne}\right)}=52 tonnesCO_2$$

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

d) Gas Passenger Cars CH_4 Emission Factor: $0.017\frac{gCH_4}{mile}$

e) LD Vehicles Ethanol CH_4 Emission Factor: $0.055\frac{gCH_4}{mile}$

f) CH_4 GWP: $23\frac{lbsCO_2E}{lbsCH_4}$

g) Gas Passenger Cars N_2O Emission Factor: $0.004\frac{gN_2O}{mile}$

h) LD Vehicles Ethanol N_2O Emission Factor: $0.067\frac{gN_2O}{mile}$

i) N_2O GWP: $296\frac{lbsCO_2E}{lbsN_2O}$

$$(44{,}358 miles)\frac{\left(\left(15\%\left(0.017\frac{gCH_4}{mile}\right)+75\%\left(0.055\frac{gCH_4}{mile}\right)\right)23+\left(15\%\left(0.004\frac{gN_2O}{mile}\right)+75\%\left(0.067\frac{gN_2O}{mile}\right)\right)(296)\right)}{\left(1{,}000{,}000\frac{g}{tonne}\right)}$$

$$=1 tonneCO_2E$$

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

k) Gas LD Trucks CH_4 Emission Factor: $0.016\frac{gCH_4}{mile}$

l) LD Vehicles Ethanol CH_4 Emission Factor: $0.055\frac{gCH_4}{mile}$

m) Gas LD Trucks N_2O Emission Factor: $0.007\frac{gN_2O}{mile}$

n) LD Vehicles Ethanol N_2O Emission Factor: $0.067\frac{gN_2O}{mile}$

$$(333{,}488 miles)\frac{\left(\left(15\%\left(0.016\frac{gCH_4}{mile}\right)+85\%\left(0.055\frac{gCH_4}{mile}\right)\right)23+\left(15\%\left(0.007\frac{gN_2O}{mile}\right)+85\%\left(0.067\frac{gN_2O}{mile}\right)\right)(296)\right)}{\left(1{,}000{,}000\frac{g}{tonne}\right)}$$

$$=5 tonneCO_2E$$

$$52 tonnesCO_2+1 tonneCO_2E+5 tonneCO_2E=58 tonneCO_2E$$

Note: Numbers may slightly differ due to rounding.

B. CNG Emissions:

a) Amount of CNG Consumed: $707 gal$

b) CNG CO_2 Emission Factor: $120.36\frac{lbsCO_2}{1{,}000cf}$

$$\frac{(707 gal)}{\left(7{,}480.5\frac{gal}{1{,}000cf}\right)}\frac{\left(\frac{120.36 lbsCO_2}{1{,}000cf}\right)}{\left(2{,}205\frac{lbs}{tonne}\right)}=0.01 tonnesCO_2$$

c) Miles Driven in CNG LD Vehicles:[59] $148{,}110 miles$

d) Miles Driven in CNG MD Vehicles: $240{,}587 miles$

e) LD Vehicles CNG CH_4 Emission Factor: $0.737 \frac{gCH_4}{mile}$

f) MD Vehicles CNG CH_4 Emission Factor:[60] $1.352 \frac{gCH_4}{mile}$

g) CH_4 GWP: $23 \frac{lbsCO_2E}{lbsCH_4}$

h) LD Vehicles CNG N_2O Emission Factor: $0.050 \frac{gN_2O}{mile}$

i) MD Vehicles CNG N_2O Emission Factor:[61] $0.113 \frac{gN_2O}{mile}$

j) N_2O GWP: $296 \frac{lbsCO_2E}{lbsN_2O}$

$$(148{,}110 miles)\frac{\left(\left(0.737 \frac{gCH_4}{mile}\right)(23)+\left(0.050 \frac{gN_2O}{mile}\right)(296)\right)}{\left(1{,}000{,}000 \frac{g}{tonne}\right)}$$

$$+(240{,}587 miles)\frac{\left(\left(1.352 \frac{gCH_4}{mile}\right)(23)+\left(0.113 \frac{gN_2O}{mile}\right)(296)\right)}{\left(1{,}000{,}000 \frac{g}{tonne}\right)} = 20.2 tonneCO_2E$$

$$0.01 tonneCO_2 + 20.2 tonneCO_2E = 20 tonneCO_2E$$

Note: Numbers may slightly differ due to rounding.

C. Gasoline Emissions:

a) Amount of Gas Consumed: $177{,}913 gal$

[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_2O emission factor is determined by averaging the LD factor ($0.050 gN_2O$/mile) and the HD factor ($0.175 N_2O$/mile).

b) Gasoline CO_2 Emission Factor: $19.54\frac{lbsCO_2}{gallon}$

$$(177{,}913gal)\frac{\left(\frac{19.54lbsCO_2}{gal}\right)}{\left(2{,}205\frac{lbs}{tonne}\right)}=1{,}576.9tonnesCO_2$$

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

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

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

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:[62] $0.025\frac{gCH_4}{mile}$

i) CH_4 GWP: $23\frac{lbsCO_2E}{lbsCH_4}$

j) Passenger Vehicles Gas N_2O Emission Factor: $0.004\frac{gN_2O}{mile}$

k) LD Vehicles Gas N_2O Emission Factor: $0.007\frac{gN_2O}{mile}$

l) MD Vehicles Gas N_2O Emission Factor:[63] $0.010\frac{gN_2O}{mile}$

m) N_2O GWP: $296\frac{lbsCO_2E}{lbsN_2O}$

[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_2O emission factor is determined by averaging the LD factor (0.007gN_2O/mile) and the HD factor (0.013N_2O/mile).

$$(44{,}358 miles)\frac{\left(\left(0.017\frac{gCH_4}{mile}\right)(23)+\left(0.004\frac{gN_2O}{mile}\right)(296)\right)}{\left(1{,}000{,}000\frac{g}{tonne}\right)}+$$

$$(1{,}091{,}896 miles)\frac{\left(\left(0.016\frac{gCH_4}{mile}\right)(23)+\left(0.007\frac{gN_2O}{mile}\right)(296)\right)}{\left(1{,}000{,}000\frac{g}{tonne}\right)}+$$

$$(589{,}086 miles)\frac{\left(\left(0.025\frac{gCH_4}{mile}\right)(23)+\left(0.010\frac{gN_2O}{mile}\right)(296)\right)}{\left(1{,}000{,}000\frac{g}{tonne}\right)}=4.7 tonneCO_2E$$

$$1{,}576.9 tonnesCO_2+4.7 tonneCO_2E=1{,}582 tonneCO_2E$$

Note: Numbers may slightly differ due to rounding.

D. Diesel Emissions:

a) Amount of Diesel Consumed: $53{,}008 gal$

b) Diesel CO_2 Emission Factor: $22.37\frac{lbsCO_2}{gal}$

$$(53{,}008 gal)\frac{\left(\frac{22.37 lbsCO_2}{gal}\right)}{\left(2{,}205\frac{lbs}{tonne}\right)}=537.9 tonnesCO_2$$

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_4 Emission Factor: $0.001\frac{gCH_4}{mile}$

g) MD Vehicles Diesel CH_4 Emission Factor: $0.003\frac{gCH_4}{mile}$

h) HD Vehicles Diesel CH_4 Emission Factor:[64] $0.051\frac{gCH_4}{mile}$

i) CH_4 GWP: $23\frac{lbsCO_2E}{lbsCH_4}$

j) LD Vehicles Diesel N_2O Emission Factor: $0.002\frac{gN_2O}{mile}$

k) MD Vehicles Diesel N_2O Emission Factor: $0.025\frac{gN_2O}{mile}$

l) HD Vehicles Diesel N_2O Emission Factor:[65] $0.048\frac{gN_2O}{mile}$

m) N_2O GWP: $296\frac{lbsCO_2E}{lbsN_2O}$

$$(225{,}484miles)\frac{\left(\left(0.001\frac{gCH_4}{mile}\right)(23)+\left(0.002\frac{gN_2O}{mile}\right)(296)\right)}{\left(1{,}000{,}000\frac{g}{tonne}\right)}+$$

$$(165{,}226miles)\frac{\left(\left(0.003\frac{gCH_4}{mile}\right)(23)+\left(0.025\frac{gN_2O}{mile}\right)(296)\right)}{\left(1{,}000{,}000\frac{g}{tonne}\right)}+$$

$$(78{,}124miles)\frac{\left(\left(0.051\frac{gCH_4}{mile}\right)(23)+\left(0.048\frac{gN_2O}{mile}\right)(296)\right)}{\left(1{,}000{,}000\frac{g}{tonne}\right)}=2.6tonneCO_2E$$

$$537.9tonnesCO_2+2.5tonneCO_2E=540tonneCO_2E$$

Note: Numbers may slightly differ due to rounding.

E. Biodiesel Emissions:

a) Amount of Biodiesel Consumed: $6{,}261gal$

[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).

[65] The MD vehicle N_2O emission factor is determined by averaging the LD factor (0.007gN_2O/mile) and the HD factor (0.013N_2O/mile).

b) B-20 CO_2 Emission Factor: $17.89\frac{lbsCO_2}{gal}$

$$(6{,}261gal)\frac{\left(\frac{17.89lbsCO_2}{gallon}\right)}{\left(2{,}205\frac{lbs}{tonne}\right)} = 51tonneCO_2$$

Note: Numbers may slightly differ due to rounding.

E. Overall Fleet Emissions and Footprint:

a) E-85 Emissions: $58tonneCO_2E$

b) CNG Emissions: $20tonneCO_2E$

c) Gasoline Emissions: $1{,}582tonneCO_2E$

d) Diesel Emissions: $540tonneCO_2E$

e) Biodiesel Emissions: $51tonneCO_2$

$$58tonneCO_2E + 20tonneCO_2E + 1{,}582tonneCO_2E + 540tonneCO_2E + 51tonneCO_2 = 2{,}251tonneCO_2E$$

f) Land Sequestration Ratio: $0.192\frac{ha*yr}{tonneCO_2}$

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

h) Local Sequestration Ratio: $2.07\frac{lha*yr}{tonneCO_2}$

$$(2{,}251tonneCO_2E)\left(0.192\frac{ha*yr}{tonneCO_2}\right)\left(1.17\frac{gha}{ha}\right) = 506gha$$

$$(2{,}251tonneCO_2E)\left(2.07\frac{lha*yr}{tonneCO_2}\right) = 4{,}665lha$$

Note: Numbers may slightly differ due to rounding.

IV. Airline Emissions:

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

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

c) Jet fuel CO_2 emission coefficient: $21.09\frac{lbsCO_2}{gal}$

d) Jet fuel CH_4 Emission Coefficient: $0.27\frac{gCH_4}{gal}$

e) CH_4 GWP: $23\frac{lbsCO_2E}{lbsCH_4}$

f) Jet fuel N_2O Emission Coefficient: $0.31\frac{gN_2O}{gal}$

g) N_2O GWP: $296\frac{lbsCO_2E}{lbsN_2O}$

$$\frac{(58{,}455{,}515miles)}{\left(42.42\frac{miles}{gal}\right)}\left(\frac{\left(21.09\frac{lbsCO_2}{gal}\right)}{\left(2{,}205\frac{lbs}{tonne}\right)}+\frac{\left(0.27\frac{gCH_4}{gal}\right)(23)+\left(0.31\frac{gN_2O}{gal}\right)(296)}{\left(1{,}000{,}000\frac{g}{tonne}\right)}\right)$$

$$=13{,}316tonneCO_2E$$

Note: Numbers may slightly differ due to rounding.

V. Overall Transportation Emissions and Footprint:

a) Commuter Emissions: $22{,}961tonneCO_2E$

b) Rental Car Emissions: $2{,}891tonneCO_2E$

c) Fleet Emissions: $2{,}251tonneCO_2E$

d) Airline Emissions: $13{,}316tonneCO_2E$

$$22{,}961tonneCO_2E+2{,}891tonneCO_2E+2{,}251tonneCO_2E+13{,}316tonneCO_2E=41{,}419tonneCO_2E$$

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

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

g) Local Sequestration Ratio: $2.07\frac{lha*yr}{tonneCO_2}$

$$\left(41{,}419 tonneCO_2E\right)\left(0.192\frac{ha}{tonneCO_2}\right)\left(1.17\frac{gha}{ha}\right)=9{,}304gha$$

$$\left(41{,}419 tonneCO_2E\right)\left(2.07\frac{lha*yr}{tonneCO_2}\right)=85{,}832lha$$

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

Material	Baseline Generation of Material (Tons)	Projected Source Reduction (Tons)	Annual GHG Emissions from Source Reduction (MTCO2E)	Projected Recycling (Tons)	Annual GHG Emissions from Recycling (MTCO2E)	Projected Landfilling (Tons)	Annual GHG Emissions from Landfilling (MTCO2E)	Projected Combustion (Tons)	Annual GHG Emissions from Combustion (MTCO2E)	Projected Composting (Tons)	Annual GHG Emissions from Composting (MTCO2E)	Total Annual GHG Emissions (MTCO2E)
Aluminum Cans	2	0	0	2	(27)	0	0	0	0	NA	NA	(27)
Steel Cans	6	0	0	6	(10)	0	0	0	0	NA	NA	(10)
Copper Wire	0	0	0	0	0	0	0	0	0	NA	NA	0
Glass	0	0	0	0	0	0	0	0	0	NA	NA	0
HDPE	0	0	0	0	0	0	0	0	0	NA	NA	0
LDPE	0	0	0	0	0	0	0	0	0	NA	NA	0
PET	0	0	0	0	0	0	0	0	0	NA	NA	0
Corrugated Cardboard	290	0	0	290	(902)	0	0	0	0	NA	NA	(902)
Magazines/third-class mail	0	0	0	0	0	0	0	0	0	NA	NA	0
Newspaper	0	0	0	0	0	0	0	0	0	NA	NA	0
Office Paper	0	0	0	0	0	0	0	0	0	NA	NA	0
Phonebooks	4	0	0	4	(12)	0	0	0	0	NA	NA	(12)
Textbooks	0	0	0	0	0	0	0	0	0	NA	NA	0
Dimensional Lumber	283	0	0	283	(696)	0	0	0	0	NA	NA	(696)
Medium Density Fiberboard	0	0	0	0	0	0	0	0	0	NA	NA	0
Food Scraps	0	NA	NA	NA	NA	0	0	0	0	0	0	0
Yard Trimmings	0	NA	NA	NA	NA	0	0	0	0	0	0	0
Grass	0	NA	NA	NA	NA	0	0	0	0	0	0	0
Leaves	0	NA	NA	NA	NA	0	0	0	0	0	0	0
Branches	0	NA	NA	NA	NA	0	0	0	0	0	0	0
Mixed Paper, Broad	0	NA	NA	0	0	0	0	0	0	NA	NA	0
Mixed Paper, Resid.	0	NA	NA	0	0	0	0	0	0	NA	NA	0
Mixed Paper, Office	168	NA	NA	168	(572)	0	0	0	0	NA	NA	(572)
Mixed Metals	1,268	NA	NA	1,268	(6,665)	0	0	0	0	NA	NA	(6,665)
Mixed Plastics	6	NA	NA	6	(8)	0	0	0	0	NA	NA	(8)
Mixed Recyclables	309	NA	NA	309	(899)	0	0	0	0	NA	NA	(899)
Mixed Organics	0	NA	NA	NA	NA	0	0	0	0	0	0	0
Mixed MSW	11,040	NA	NA	NA	NA	11,040	17,552	0	0	NA	NA	17,552
Carpet	3	0	0	3	(24)	0	0	0	0	NA	NA	(24)
Personal Computers	29	0	0	29	(64)	0	0	0	0	NA	NA	(64)
Clay Bricks	0	0	0	0	NA	0	0	NA	NA	NA	NA	0
Concrete	4,159	NA	NA	4,159	(32)	0	0	NA	NA	NA	NA	(32)
Fly Ash	0	NA	NA	0	0	0	0	NA	NA	NA	NA	0
Tires	5	0	0	5	(9)	0	0	0	0	NA	NA	(9)
Total	17,570	0	0	6,530	(9,920)	11,040	17,552	0	0	0	0	7,632

Waste Footprint:

a) Net Waste Emissions: $7{,}632 tonneCO_2E$

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

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

$$\left(7{,}632 tonneCO_2E\right)\left(0.192 \frac{ha}{tonneCO_2}\right)\left(1.17 \frac{gha}{ha}\right) = 1{,}714 gha$$

d) Local Sequestration Ratio: $2.07 \frac{lha * yr}{tonneCO_2}$

$$\left(7{,}632 tonneCO_2E\right)\left(2.07 \frac{lha * yr}{tonneCO_2}\right) = 15{,}816 lha$$

APPENDIX E: Land Use Calculations

Development Density:

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

b) Land Use Footprint (Total Developed Land Area): $873 acres$

$$\frac{\left(\dfrac{5{,}515{,}265\,ft^2}{873 acres}\right)}{\left(43{,}579\,\dfrac{ft^2}{acre}\right)} = 14.5\%$$

Note: Numbers may slightly differ due to rounding.

APPENDIX F: Water Footprint Calculation

Water Footprint:

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

b) Total Building Square Footage: $5{,}515{,}265\, ft^2$

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

c) Number of FTEs: $8{,}569$ FTE

$$\frac{406{,}254{,}587 gal}{8{,}569} = 47{,}408 \frac{gal}{FTE}$$

e) # Workdays in a year: $229 days$

$$\frac{\left(47{,}408 \frac{gal}{FTE}\right)}{(229 days)} = 207 \frac{gal}{FTE * day}$$

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

mega (M)	= 1,000,000
giga (G)	= 1,000,000,000
kilo (k)	= 1,000

Weight

tonne	= 1,000 kilogrammes (kg)
	= 2,205 pounds (lbs)
short ton (ton)	= 2,000 pounds (lbs)
	= 0.907 metric tons (tonne)

Distance

1 mile	= 1.61 kilometer (km)

Area

acre	= 43,578.54 square feet (ft^2)
hectare (ha)	= 2.47 acres

Volume

barrel	= 42 gal
1,000 cubic feet (cf)	= 7,480.52 gal
Mcf	= 1,000 cubic feet (cf)

Energy

cf	= 1,000 British thermal units (Btu)
MMBtu	= 1,000,000 British thermal units (Btu)
Wh	= watt * hr

Global Warming Potentials (GWPs)

Carbon dioxide (CO_2) = 1

Methane (CH_4) $= 23 \frac{lbsCO_2E}{lbsCH_4}$

Nitrous oxide (N_2O) $= 296 \frac{lbsCO_2E}{lbsN_2O}$

Constants

Land Sequestration Ratio $= 0.192 \frac{ha}{tonneCO_2}$

Land Equivalence Factor $= 1.17 \frac{gha}{ha}$

Local Sequestration Ratio $= 2.07 \frac{lha * yr}{tonneCO_2}$

This page intentionally blank.

Distribution

MS0112, Kristin Klossner, 10601
MS0719, Phillip Pohl, 6761
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

Jay P. Angerer, Blackland Research and Extension Center
Steve Black, DOE National Nuclear Services Administration Service Center
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
John O'Connell (3), City of Albuquerque
Dick Richards, Energy Information Administration
Josh Silverman, DOE, Office of Environmental Policy and Assistance
Norion Ubechel (5), University of New Mexico
Nathan McDowell, Los Alamos National Laboratories
Mike Ebinger, Los Alamos National Laboratories
Katherine Yuhas, City of Albuquerque

Sandia National Laboratories