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# Sustainable NREL: Laboratory Life Cycle Assessment of Environmental Footprint

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# Sustainable NREL: Laboratory Life Cycle Assessment of Environmental Footprint

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## EXECUTIVE SUMMARY

The National Renewable Energy Laboratory (NREL) has used life cycle assessment to create a carbon dioxide ($CO_2$) environmental footprint. Transportation, water, natural gas and electricity, and solid waste disposal are the major $CO_2$ emission contributors at the Laboratory. In FY 2003 (October 2002-September 2003), these categories yielded a total of 29 million kg $CO_2$ - equivalent. The major components were electricity, 22.3 million kg $CO_2$-equivalent.; and natural gas, 3.275 million kg $CO_2$ (these yield 77% and 11%, respectively, to the $CO_2$ footprint). Other contributors were domestic air travel and commuter travel, both of which came in at 5%, and international air travel at 2%. Solid waste disposal, water, and fleet vehicle emissions were negligible in relation to the other components. NREL is enacting several measures to reduce emissions at the front end of the material life cycle. Green purchasing, reducing water use, reducing the need for travel, and purchasing alternative fuel fleet vehicles are all ways to reduce energy consumption and $CO_2$ emissions. In addition, recycling helps reduce $CO_2$ emissions in the final stage of the waste disposal life cycle. The large area of interest is obviously the electricity and natural gas consumed at the Laboratory. The Laboratory has implemented almost all life cycle cost effective energy efficiency measures and all new construction is state of the practice. The Laboratory continues to examine ways of simultaneously reducing energy use and maintaining the integrity of its research and development activities.

## INTRODUCTION

As part of its sustainability program, Sustainable NREL, the National Renewable Energy Laboratory (NREL) has recently undertaken the development of a life cycle assessment (LCA)-based carbon dioxide ($CO_2$) "environmental footprint". This assessment is the baseline against which the Laboratory measures its progress to achieve a sustainability goal of working toward "environmental neutrality" in all its operations. This goal identifies the environmental consequences of the choices the Laboratory makes and measures the cumulative effect of those choices in terms of a functional $CO_2$ common denominator. The use of such a universal metric allows the Laboratory to better understand the relative impacts of its decisions, measure progress toward environmental neutrality, benchmark performance against goals and other similar institutions, and in general take responsibility for its actions.

## APPROACH

The approach to developing this environmental assessment is based on quantifying the environmental impacts of the energy consuming activities of the Laboratory in terms of $CO_2$ production. This LCA comprehensively includes all energy consuming activities. In developing the assessment, it is practical to break down Laboratory activities into major categories: transportation, building energy use, waste disposal, and water. Each category is in turn disaggregated into subcategories to effectively facilitate the LCA. Laboratory sustainability activities to reduce $CO_2$ production in these categories are also included and discussed in the respective categories.

Transportation has subsets of fleet data, air travel miles, and commuting. Likewise, building and process energy consumption is divided into natural gas and electricity use. Waste disposal has two areas of concentration, solid waste dispensed to the landfill and the positive effects of recycling materials. Water has two elements of analysis: the amount of $CO_2$ emitted in raw water treatment, and the $CO_2$ emitted by distributing and pumping water to the Laboratory site.

This baseline information provides a common denominator for assessing the environmental impacts of Laboratory activities and thus forms a basis for including and considering the environmental impacts of management decisions around Laboratory activities.

## ASSESSMENT

### Transportation

Transportation at the Laboratory falls into three main categories, fleet vehicles, air travel, and employee commuting. A category to include deliveries to and from the Laboratory will be added later. Figure 1 illustrates a breakdown of these categories based on mileage.

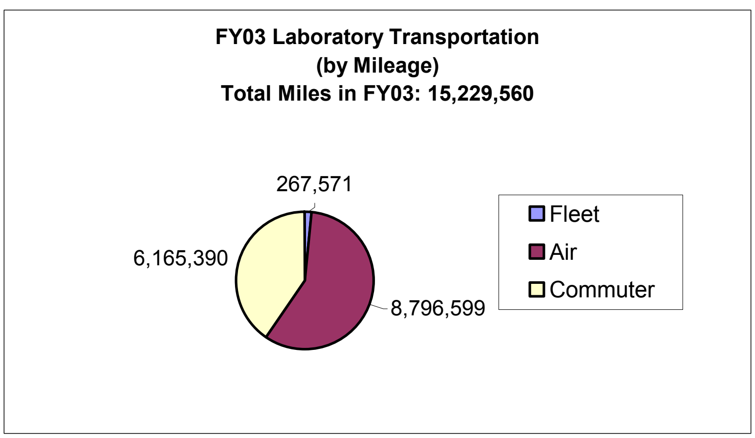


**Figure 1: Laboratory Transportation Breakdown**

The Laboratory fleet consists of 48 leased vehicles; 31 are alternate fuel vehicles (AFVs). The Laboratory is converting its fleet to 100% AFVs as soon as possible given their availability for leasing through the General Services Administration. Laboratory fleet transportation vehicle types include 18 ethanol (E85), 7 compressed natural gas bi-fuel (CNG/bi), 4 CNG, two electric, 17 petroleum-fueled (13 regular unleaded and 4 diesel [1 leased]) vehicles (1).

For assessment purposes, each type of fuel was converted to a gasoline equivalent. Totals for the fleet account for 2% or 267,571 miles traveled in FY 2003 (1). According to the Energy Information Administration (EIA), one gallon of gas converts to 0.124 MMBtu. This number is converted into $CO_2$ production with the EPA Climate Leaders Partnership sourced $CO_2$ measurement conversion factor of a gallon of gasoline releases 6.5 kg of $CO_2$ (2). The Laboratory fleet used 11,267 gallons gasoline equivalent and emitted 73,235 kg of $CO_2$ (see Equation 1).

$$11{,}267 \text{ gallons X } 6.5 \text{ kg } CO_2\text{/gallon} = 73{,}235 \text{ kg } CO_2 \quad \text{Equation (1)}$$

In FY 2003 the Laboratory spent more than $1 million in air travel. NREL employees flew 6,689,199 miles domestically and 2,107,400 internationally (3). This information was obtained from the Laboratory's travel agency. It is important to separate domestic from international travel as the Bureau of Transportation Statistics cites different conversion factors for each. Domestic flights convert to 3,890 Btu/ passenger mile and international flights convert to 3,964 Btu/ passenger mile (4). Applying Climate Leader's conversion factor of 1Btu= $52.79 \times 10^{-6}$ kg $CO_2$, the $CO_2$ equivalent for total Laboratory air travel is 1,814,642 kg of $CO_2$ (see Equations 2 and 3).

$$6{,}689{,}199 \text{ miles x } 3{,}890\text{Btu/mile x } 52.79 \times 10^{-6} \text{ kg } CO_2\text{/Btu}$$
$$=1{,}373{,}648 \text{ kg } CO_2 \quad \text{Equation (2) (Domestic flights)}$$

$$2{,}107{,}400 \text{ miles x } 3{,}964 \text{ Btu/mile x } 52.79 \times 10^{-6} \text{ Kg } CO_2\text{/Btu}$$
$$= 440{,}994 \text{ kg } CO_2 \quad \text{Equation (3) (International flights)}$$

The Laboratory has teleconferencing equipment in place. This equipment displaces some of the need for air travel. Meetings, interviews, and seminars that would have warranted either a trip to Washington, D.C. or to the Laboratory in Colorado were completed via teleconference. In FY 2003, 31 trips did not require Laboratory employees to travel, which saved approximately 44,950 miles or 9,230 kg of $CO_2$ (see Equation 4).

$$31 \text{ trips from D.C. to Colorado saved x } 1{,}450 \text{ air miles/trip x } 3{,}890 \text{ Btu/mile}$$
$$\text{x } 52.79 \times 10^{-6} \text{ kg } CO_2\text{/Btu}= 9{,}230 \text{ Kg } CO_2 \quad \text{Equation (4)}$$

Some 40% of the Laboratory's total transportation mileage in FY 2003 was attributable to employees commuting to and from work. To estimate commuting mileage, an average employee commute estimate was developed. This estimate was based on an assessment of all employees' addresses (locations) with respect to the Laboratory location. The average commuter estimate of 28.09 miles roundtrip multiplied by the number of employees (950) resulted in a total of 26,685 miles per day. When this number is multiplied by the national average working days per year

(234), the total was an estimate of 6,244,290 miles. Using the conservative Corporate Average Fuel Economy fleet average mileage of 27.5 mpg, results in a Laboratory gasoline usage for commuting of 227,069 gallons or 1,457,950 kg $CO_2$ (see Equation 5).

28.09 miles/commuter day x 950 commuters x 234 working days/year x 6.5 kg $CO_2$/gallon gasoline x gallon gasoline/27.5 miles= 1,475,950 kg $CO_2$ Equation (5)

The Laboratory promotes alternative modes of commuting by offering free bus passes, carpooling and vanpooling coordination, bike lockers, and information on hybrid vehicles currently on the market. A recent Laboratory commuter poll found that 132 employees (some 15% of all employees) participate in some form of alternative commuting. The $CO_2$ savings attributable to this alternative commuting are currently being evaluated.

### Building Energy Use

This is the energy being consumed by Laboratory buildings and some process loads. Building energy use is for heating, cooling, lighting, plug loads, etc. The sources of this energy are natural gas and electricity. The Laboratory has installed a site metering system that measures building-by-building electrical use. Natural gas use is similarly measured. The site metering system data are in turn aggregated in a central database that provides building energy use for the Laboratory as a whole.

For FY 2003, 21,777,183 kWh of electricity were consumed (6). To include life cycle impacts, a $CO_2$ conversion factor was used that captures considerations around the production of the electricity used. In this case, the source electricity was produced from an electrical system that is primarily supplied by coal-fired power plants. The conversion factor used, 1 kWh = 1.024 kg $CO_2$, was developed by the U.S. Environmental Protection Agency for the geographic region in which the Laboratory is located (2). The electrical consumption resulted in the production of 22,299,835 kg of $CO_2$ (see Equation 6).

21,777,183 kWh x 1.024 kg $CO_2$/kWh = 22,299,835 kg $CO_2$ Equation (6)

For FY 2003, 62,046 MMBtu of natural gas were used. Since the natural gas is used (combusted) at the Laboratory site, there is not comparable source adjustment as was the case with electricity use. The conversion factor used is, 1 MMBtu = 52.79 kg $CO_2$ (2) The natural gas consumption resulted in the production of 3,275,408 kg of $CO_2$ (see Equation 7).

62,046 MMBtu x 52.79 kg $C0_2$/MMBtu = 3,275,408 kg $CO_2$ Equation (7)

The Laboratory has installed multiple on-site renewable energy resources that produce electric energy. The technologies include wind and photovoltaics. These sources produced some 121 MWh in FY 2003. The Laboratory also purchases 10% of its annual electrical energy use in the form of wind power. This purchase amounts to some 2 million kWh with an associated $CO_2$ credit of 2,048,000 kg $CO_2$ (see Equation 8).

2,000,000 kWh x 1.024kg $CO_2$/ kWh = 2,048,000 kg $CO_2$ Equation (8)

## Waste Disposal

Carbon dioxide is generated from solid waste that the Laboratory sends to the landfill. Methane is the major greenhouse gas emitted from landfills. A calculation tool developed by Climate Neutral was used to convert the amount of methane generated by the Laboratory solid waste to a $CO_2$ equivalent (7). For the 213 tons of solid waste sent to the landfill in FY 2003, roughly 59,000 kg $CO_2$ was produced (8).

This number would have been much larger if the Laboratory did not actively promote recycling. In FY 2003 alone, 117 tons of material, including paper, glass, plastic, aluminum, and cardboard, were recycled. A breakdown of recycled materials is shown in Figure 2 (9). Again, using the Climate Neutral tool, this equates to approximately 32,000 kg of $CO_2$ not produced. However, even the process of recycling contributes to $CO_2$ emissions. This impact will be analyzed in the future and accounted for in the overall ecological footprint.

Of note, office paper in landfills contributes significantly to methane production. The office paper Average Measured Methane Yield is 217.3 ml/dry gram (7). Accordingly, the Laboratory has targeted both the purchasing and the recycling of office paper. The office paper purchased at the laboratory is 30% Recycled by Fiber Weight. In FY 2003, 12,389 reams of paper (approximately 74,334 lb) were purchased and 186,182 lb were recycled (10). There is an obvious discrepancy between the amount of paper purchased and the amount recycled. The Laboratory's goal is to reduce external sources of paper (Figure 3). In addition, the Laboratory is implementing an electronic processing initiative to further reduce office paper use.

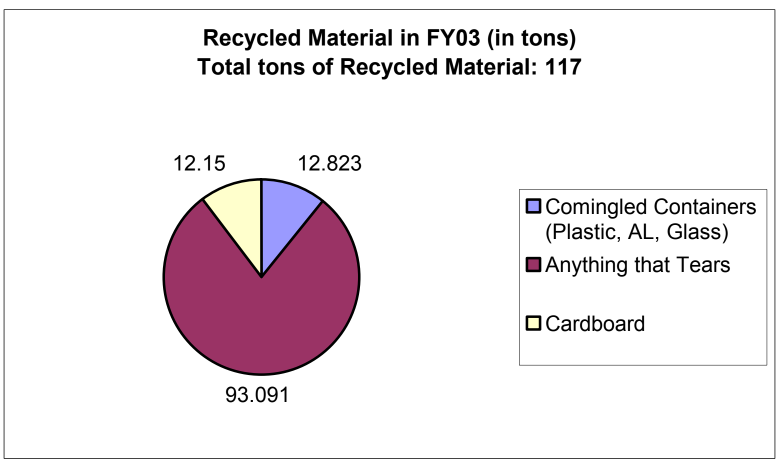


**Figure 2: Breakdown of recycled materials at NREL**

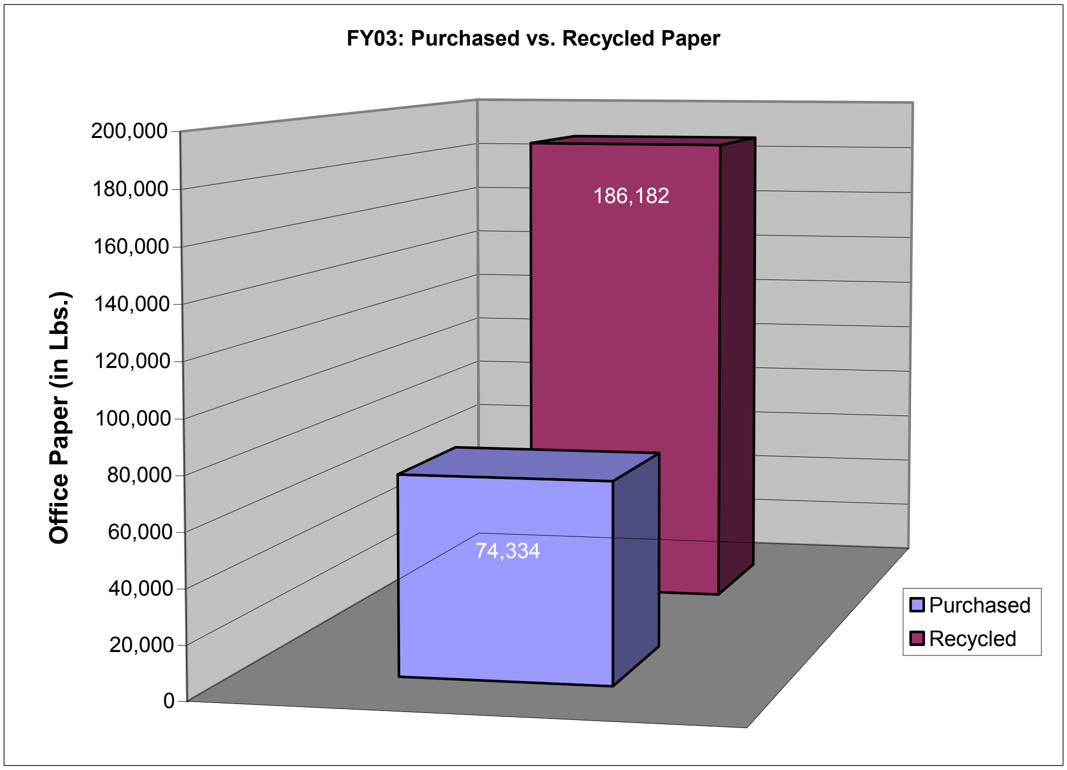


**Figure 3: Purchased versus recycled paper**

## Water

When tracing the life cycle of water consumption, the pumping and distribution to the point of use is only one aspect. For the purposes of this LCA, the boundary is set at the treatment of raw water and ends at the distribution and pumping of water to the Laboratory. The wastewater generated by the Laboratory in terms of sewage is complex but important, as the methane count in this water is high. The Laboratory will investigate this element in the future. In FY 2003, the Laboratory used 9,575,000 gallons of water at its Golden campus buildings (6). In FY 2003, Consolidated Mutual Water District pumped, distributed, and treated 909,560,100 gallons of water for the system in which the Laboratory is included (see Figure 4). According to Consolidated Mutual's records, 1,290,816 kWh of electricity was used for pumping and distribution and 19,086 MMBtu of natural gas was used in raw water treatment (11). When the total gallons of water are divided by the electricity and natural gas used, conversion factors of 705 gallons/kWh and 47,656 gallons/MMBtu are derived respectively. These conversion factors were then applied to the 9,575,000 gallons used, yielding 13,581 kWh of electricity and 201 MMBtu of natural gas to pump, distribute, and treat water for the Laboratory. This energy use equals a total of 24,525 kg $CO_2$ (see Equations 9 and 10).

201 MMBtu x 52.79 kg $CO_2$/MMBtu=10,610 kg $CO_2$ Equation (9)

13,581 kWh x 1.024 kg $CO_2$/ kWh= 13,907 kg $CO_2$ Equation (10)

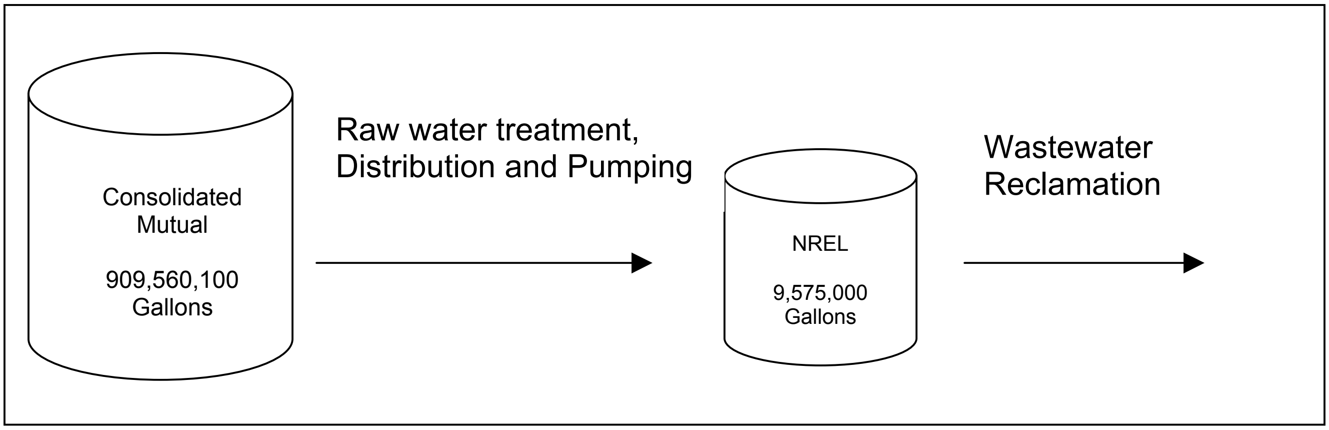


**Figure 4: Distribution of Consolidated Mutual Water to NREL**

## RESULTS

When examining the $CO_2$ emitted from Laboratory-wide operations, it is important to disaggregate the main contributors to $CO_2$ production. The major contributors to $CO_2$ emissions are electricity and natural gas (77% and 11%, respectively). The remaining 12% of the footprint embodies travel; domestic air travel and commuter travel each contribute 5%. International travel contributes 2% to the total $CO_2$ emissions footprint. NREL fleet vehicles, solid waste disposal, and water have contributed negligible amounts of $CO_2$ in relation to the entire footprint. Figure 5 illustrates which categories consume the most energy and consequently emit the most $CO_2$. The Laboratory does have greenhouse gas emissions that result from its R&D activities. These emissions are tracked and are relatively insignificant and are not included in the assessment.

| SOURCE | Total for FY 2003 | kg CO2 Eq. | % of Total $CO_2$ Emitted |
|---|---|---|---|
| Natural Gas | 62,046 MMBtu | 3,275,408 | 11% |
| Electricity | 21,777,183 kWh | 22,299,835 | 77% |
| Water (electricity consumed) | 9575000 gallons: 13,581 kWh | 13,907 | Negligible |
| Water (natural gas consumed) | 9575000 gallons: 201 MMBtu | 10,611 | Negligible |
| Commuter Vehicle Emissions | 227,069 gallons gas | 1,475,949 | 5% |
| International Air Travel Emissions | 2,107,400 miles | 440,994 | 2% |
| Domestic Air Travel Emissions | 6,689,199 miles | 1,373,648 | 5% |
| Fleet Vehicle Emissions | 11,267 gallons gas & eq. | 73,236 | Negligible |
| Solid Waste Disposal | 213 tons sent to landfill | 58,957 | Negligible |

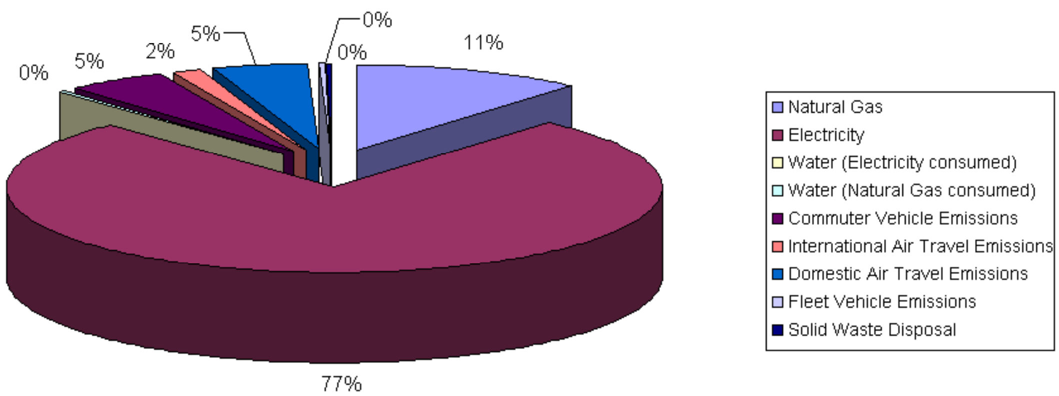


**Figure 5: NREL $CO_2$ footprint breakdown by category**

## CONCLUSIONS

The use of LCA is fundamental to understanding and managing $CO_2$ emissions. The first step in reducing $CO_2$ emissions is to determine their sources. Viewing the Laboratory operations in the context of LCA allows the Laboratory to make improvements from "cradle to grave" in each category described.

Life cycle assessment of $CO_2$ emissions is an emerging practice. This assessment required considerable research and a "bringing together" of disparate information and analysis tools. Accordingly, the assessment described in this paper has contributed to the development of the practice of LCA of $CO_2$ emissions.

The FY 2003 $CO_2$ footprint will serve as a baseline for Laboratory $CO_2$ production. The Laboratory will complete LCA-based $CO_2$ footprints for each succeeding fiscal year. Refinements and enhancements to the process will be implemented. Importantly, the wastewater assessment element will be addressed. In addition, measurement of the impact of reduction strategies in each category will be included. This paper also intends to encourage feedback that will result in improvements to the assessment process.

The Laboratory's sustainability program focuses on the importance of reducing the amount of material entering the Laboratory. Green purchasing, employing hybrid vehicles in the fleet, teleconferencing to reduce air travel, recycling, and water saving measures such as xeriscaping are all viable ways to reduce $CO_2$ emissions.

Consistent with the R&D function of the Laboratory, a significant fraction of the Laboratory energy consumption is for building energy use. The philosophy behind the Laboratory's sustainability activities is that its mission and sustainability are compatible. This means that the Laboratory will work to find ways to reduce its overall energy consumption without compromising its scientific endeavors.

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