

MEASURING CARBON FOOTPRINT IN AN OPERATIONAL UNDERGROUND RAIL ENVIRONMENT

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Abstract—As part of a commitment to meet local and national CO₂ emission targets, Tube Lines calculated the carbon emissions that arise from the life cycle of all of its operations and projects. The 2006 data (2006 baseline) represents the carbon footprint used to make business and investment decisions and drive change to ensure that carbon management is central to the way Tube Lines undertakes its work.

In 2008, the baseline was updated to account for changes in Tube Lines projects and operations. Tube Lines had reduced its carbon footprint by 5,277 metric tons (5,817 tons) by the end of 2008 based on its 2006 baseline. In 2009, a further 1,000 metric ton (1,102 ton) reduction target has been set based on the 2008 baseline and will be met.

Keywords—carbon, carbon footprint, emissions, fuel

INTRODUCTION

Tube Lines Overview

Tube Lines¹ has a 30-year public private partnership (PPP) contract with London Underground (LU) to maintain and upgrade all infrastructure on the Jubilee, Northern, and Piccadilly underground metro lines. This work encompasses upgrading the signalling on all three lines to increase capacity and reliability and reduce journey times; upgrading 100 stations with an emphasis on improving security, information flow, and the general environment for passengers; introducing a new fleet of trains on the Piccadilly line in 2014 and refurbishing the fleets on the other two lines; and replacing and refurbishing hundreds of kilometres of track and numerous lifts and escalators and improving the general travelling environment for passengers.

CO₂ Emission Reduction Targets

In the UK, the following CO₂ emission reduction targets have been set:

- UK government national target of 1.2% per year until 2050
- London target of 1.7% per year until 2025

To meet these targets, Tube Lines calculated its carbon footprint (impact of human activities

on the environment based on the amount of greenhouse gasses produced, measured in units of CO₂) and instituted measures that achieved the targeted reductions.

Working with the Carbon Trust (an organisation created by the UK government to help businesses accelerate the move to a low carbon economy) and AEA Energy and Environment (AEA), which maintains the UK National Atmosphere Emissions Inventory (NAEI) (the official air emissions inventory for the UK), Tube Lines calculated its carbon footprint, separating it into the following two components:



Corporate (direct) footprint - energy and utilities consumption

Process (indirect) footprint - embedded/indirect CO₂ emissions resulting from materials use, waste generation, and transport

Tube Lines' Carbon Footprint

The corporate and process components of Tube Lines' carbon footprint (see **Figure 1**) consist of the following emissions:

- **Corporate footprint**—emissions resulting from Tube Lines' direct operation of its premises, its paper consumption, and its employees' commutes. To calculate its corporate footprint, Tube Lines measured

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¹ Tube Lines is indirectly owned by Bechtel Enterprises (one-third) and Ferrovial (two-thirds).

ABBREVIATIONS, ACRONYMS, AND TERMS

AEA	AEA Energy and Environment
DSM	distribution services management
ERU	emergency response unit
GPS	global positioning system
GSM	global system for mobile communication
L&E	lifts and elevators
LED	light-emitting diode
LU	London Underground
NAEI	National Atmosphere Emissions Inventory
PPP	public private partnership
P-Way	permanent way
ZWTL	zero waste to landfill

A process champion was identified and a workshop was held to identify the carbon footprint for 34 typical work processes, e.g., escalator refurbishment.

during the course of Tube Lines' work, e.g., track replacement, station modernisation, and fleet maintenance. To calculate the process carbon footprint, Tube Lines used a complex set of calculations and AEA's carbon impact tool to perform a life-cycle assessment of each process, e.g., escalator refurbishment (see **Figure 2**). This assessment evaluated environmental impacts and identified inputs and outputs in terms of resources, waste, materials, and fuel.

The impacts in terms of CO₂ emissions were also determined, with the amount of CO₂ tied to the control mechanism required to achieve best practicable means. For each process, a process champion was identified and a workshop was held to identify and quantify material types and volumes, waste types and volumes, and transportation. Data was obtained from bottom-up forecasts, method statements, and bills of quantities.

The following formula was developed:

(Materials used + waste generated + materials transport + staff transport) x AEA conversion factors =



Metric tons of CO₂

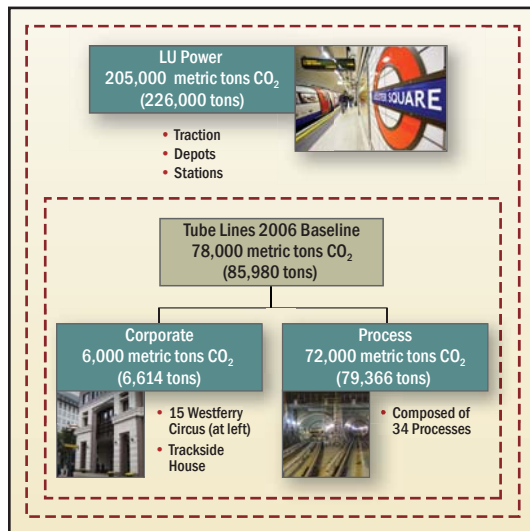


Figure 1. Elements Constituting Tube Lines' Carbon Footprint

full-year 2006 energy and utilities (gas and water) consumption from utility bills, paper consumption from ordering records, and employee commute emission levels from a study conducted in 2006, then converted the values into equivalent metric tons of CO₂.

- **Process footprint**—emissions resulting from 34 processes that Tube Lines chose to measure. These processes involve materials use and waste generation and the transportation of materials and people

This data was then processed and converted into equivalent metric tons of CO₂ emissions for an average process, e.g., carbon footprint for an average station modernisation. The process carbon footprint was then factored up by multiplying the individual carbon footprints by the number of times the process was carried out, e.g.: (carbon footprint for an average station modernisation x number of station modernisations completed) + (carbon footprint for an average metre of track replacement x number of metres of track replacement completed), etc.

In identifying the CO₂ impact of an activity, Tube Lines has also been able to identify and target efficiency improvements to reduce the CO₂ impact of that activity. However, standardising the process footprints has posed a challenge. Whilst track replacement can be standardised for a metre of track, the amount of standardisation that can be achieved in station modernisation is less obvious and involved considerable thought and analysis by Tube Lines and AEA.

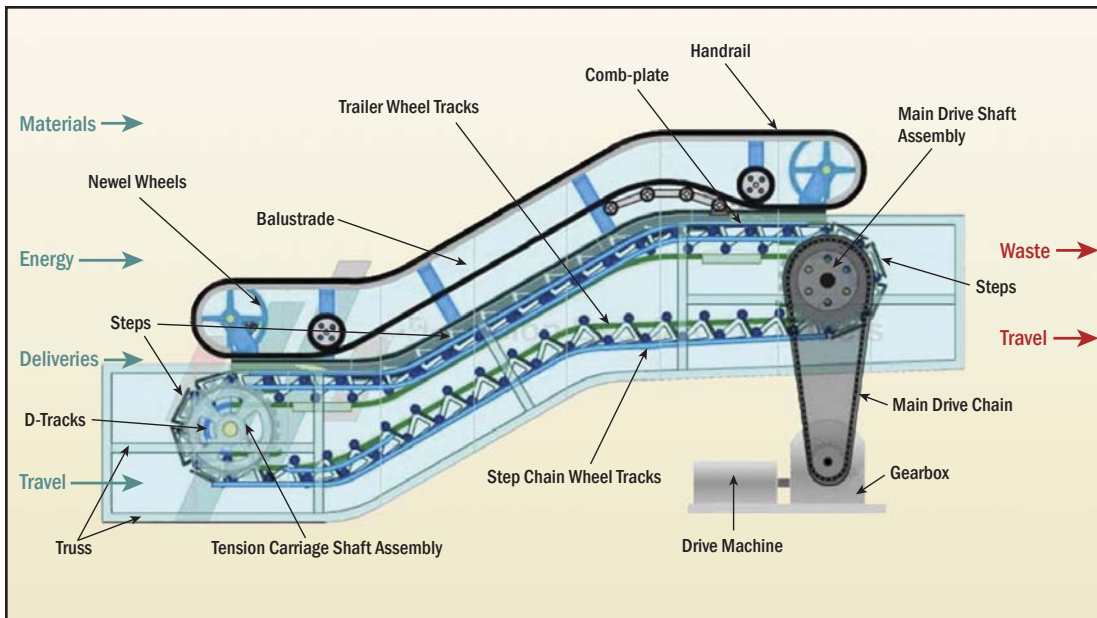


Figure 2. Escalator Cross-Section

Energy consumption was reduced by 20% in 2007 and 5% in 2008 against 2% annual targets.

ENVIRONMENTAL BUSINESS OBJECTIVES



“Go Green” is the name of Tube Lines’ environmental management system. Environmental business objectives are set by Tube Lines’ Executive Committee and are tied into the employee bonus scheme.

2006–2008 Objectives

Over the past few years, the following objectives were set:

- 2006 Energy Consumption (kWh) – 5% reduction at Head Office by the end of 2006
A 3.5% reduction was achieved!
- 2007 Energy Consumption (kWh) – 2% reduction at Head Office, Trakside House, Stratford Training Centre, and Piccadilly line depots by the end of 2007

This target was set based on the technical potential for reducing energy consumption, achievements in reducing energy consumption during the preceding year, expectations of potential reductions in energy consumption at each location, and forecasted weather. During 2007, air-conditioning thresholds were adjusted at office locations, lighting banks and controls were re-set, movement detectors were fitted, lift use was restricted during off hours, and employee awareness was raised. Tube

Lines also converted to a green energy tariff so that all Tube Lines-sourced electricity (Head Office, Trakside House, and Stratford Training Centre) comes from renewable energy.

A 20% reduction was achieved!

- 2008 Energy Consumption (kWh) – 2% reduction at Head Office, Trakside House, Stratford Training Centre, and Piccadilly line depots by the end of 2008

During 2008, new personal computer equipment was provided to all Tube Lines sites. This new equipment automatically goes into a “sleep” state when left unattended, which saves energy. Blade-type computer servers were also employed. Tube Lines increased its energy savings by giving up occupancy of two floors at its Westferry Circus offices and sharing other areas with other tenants (79/21 split based on floor space occupied).

A 5% reduction was achieved!

- 2007 Paper Consumption – 15% reduction in white A4 paper usage
A 44% reduction was achieved!
- 2008 Paper Consumption – 5% reduction in white A4 paper usage

This target was established after measuring the number of A4 and A3 reams of paper purchased in 2007. The data was collected for 15 Westferry Circus, Stratford Training Centre, and other smaller sites. The target

Table 1. Tube Lines CO₂ Reductions

Activity That Reduces CO ₂	CO ₂ Reduction, metric tons (tons)
Reduction in electricity consumption	1,189.3 (1,311.0)
Reduction in paper consumption	23.0 (25.4)
More fuel-efficient DSM road fleet	41.6 (45.6)
Dedicated paper recycling by DSM	2,804.9 (3,091.9)
ERU fleet	2.0 (2.2)
P-Way sleeper popping	24.0 (26.5)
ZWTL – Kingsbury Embankment	47.0 (51.8)
GSM	9.7 (10.7)
Installation of GPS on ERU fleet	2.4 (2.6)
Reduced waste seat covers	0.8 (0.9)
In situ wheel turning	32.5 (35.8)
Hose nozzle to reduce water	0.5 (0.6)
Platform resurfacing – infrared method, 2007	77.8 (85.7)
DSM fleet improvements	21.7 (23.9)
Using Acton for storage	46.0 (50.7)
ZWTL – P-Way civils embankment works	121.2 (133.6)
Platform resurfacing – infrared method, 2008	29.2 (32.2)
Information technology computer refresh	1.6 (1.8)
Procurement of fire doors	137.0 (151.0)
Gas consumption at Westferry Circus and Trackside House	72.8 (80.2)
Water consumption at Westferry Circus and Trackside House	8.3 (9.1)
Overtiling on stations	4.0 (4.4)
L&E metal savings	169.0 (186.3)
ZWTL – P-Way civils embankment works	95.9 (105.7)
Borough lifts	23.7 (26.1)
Truss escalator replacement at Heathrow Airport	19.7 (21.7)
TOTAL	5,006 (5,518)
DSM distribution services management ERU emergency response unit GPS global positioning system GSM global system for mobile communication L&E lifts and elevators P-Way permanent way ZWTL zero waste to landfill	

LU has provided funding to review low-carbon technologies for use in an underground energy-efficient “model” station.

for 2008 was to reduce paper consumption by 5% across the business based on the total amount ordered in 2007.

A 22% reduction was achieved!

- **2007 Fuel Efficiency—5% improvement in fuel efficiency of commercial road fleet over 7.5 metric tons (8.3 tons)**

A 14% reduction was achieved!

- **2008 Fuel Efficiency—Maintain achievement of 2007 target for commercial road fleet over 7.5 metric tons (8.3 tons)**

This level was maintained!

(To be third-party verified in 2009.)

Current or Recently Completed Objectives

The following activities have also been completed or are under way:

- **Corporate**
 - Inclusion of an energy assessment in the investment application form
 - Updates to the environmental training courses to include energy management
 - Quantification of the financial implications of climate change on Tube Lines
- **Stations**
 - Installation of long-life lamps and light-emitting diodes (LEDs) during station modernisations
 - Trial use of 360-degree cameras
 - Installation of waterless urinals
 - Identification of 22 energy-saving initiatives, with estimated savings of 2,199,000 kWh electricity and 908 metric tons (1,001 tons) of CO₂. LU has provided funding to review all available low-carbon technologies for use in stations. The purpose of this report is to prioritise those technologies for use in practical trials in the underground energy-efficient “model” station proposed to LU.
- **P-Way**
 - Extension of zero-waste-to-landfill (ZWTL) pilot to the entire permanent way (P-Way)
- **Jubilee and Northern Lines Upgrade Project**
 - Investigation of power supply upgrades
 - Investigation of reconfiguring distribution network

- Installation of 20 kilometres (12.4 miles) of composite conductor rail
- Reorganisation of track power segments
- Discussions with LU regarding coasting
- Modelling of temperature and humidity on Jubilee and Northern lines
- Sustainable design of supporting infrastructure
 - Northern line control centre—green roof/intelligent lighting
 - Stratford train crew accommodation—zero-maintenance cladding/optimal use of natural light/intelligent lighting/green roof/flexible floor design
- **Piccadilly Line Upgrade Project**
 - Consideration of environmental innovation, energy efficiency, and CO₂ impacts embedded in prequalification process for new rolling stock
 - Investigation of energy storage
 - Investigation of composite materials

CARBON CONSUMPTION

By the end of December 2007, the CO₂ impact of all processes was determined and the 2007 reduction was estimated to be 1,085 metric tons (1,196 tons) against the 2006 baseline data.

The 2008 reduction target of 5,000 metric tons (5,512 tons) was then agreed to and planned to be achieved through potential reductions in electricity, gas, water, paper, and fuel consumption and waste production, as well as increases in recycling and transportation efficiencies, as depicted in **Table 1**. This 2008 target was equivalent to a 6% reduction of Tube Lines' 2006 (baseline) footprint.

The target was agreed to by the Executive Committee. **Figure 3** and Table 1 show that by the end of Period 13 2008, the target had been met: a reduction of 5,006 metric tons (5,518 tons) of CO₂ was achieved. This was subsequently increased to 5,277 metric tons (5,817 tons) during the verification process.

Tube Lines is not able to provide monthly figures for plant and equipment fuel usage since the use of diesel/petrol plant and equipment is discouraged and restrictions exist for its use in Section 12 stations (fire regulated). However, fuel usage has formed part of the CO₂ management process assessments.

The original 2008 achieved reduction of 5,006 metric tons was subsequently increased to 5,277 metric tons during the verification process.

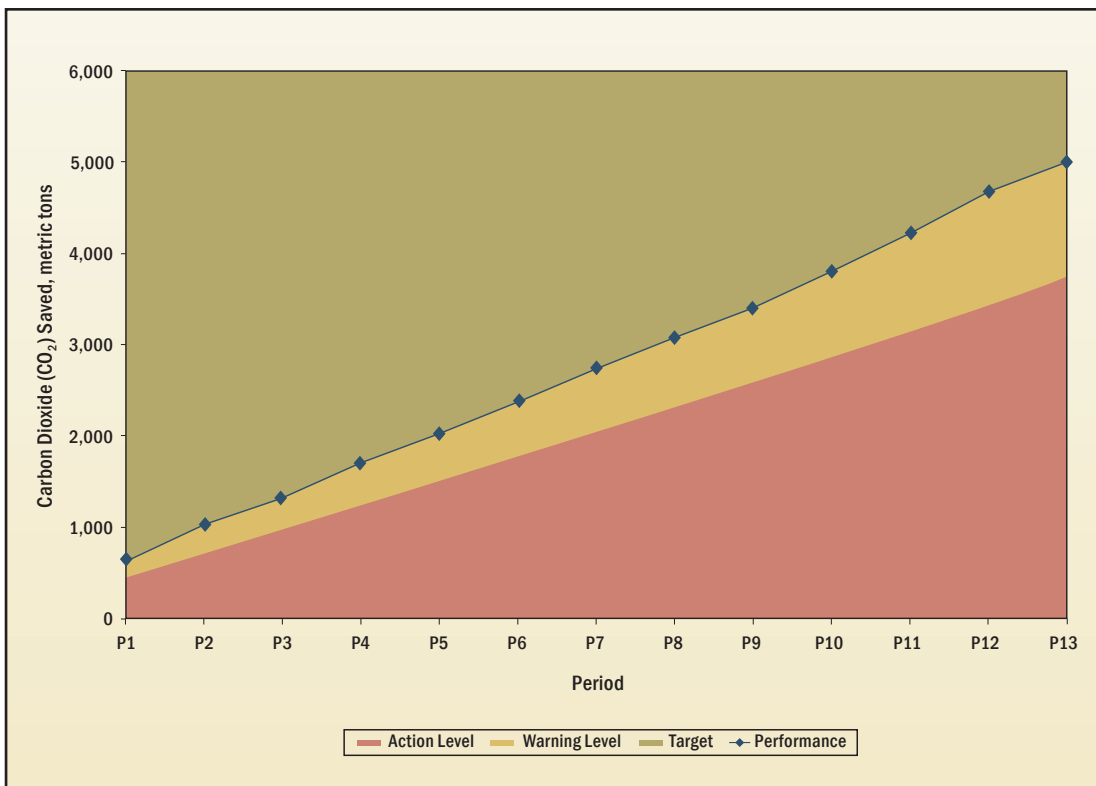


Figure 3. 2008 CO₂ Reductions by Period

In 2008, a 22% reduction in paper consumption led to cost savings in paper purchased.

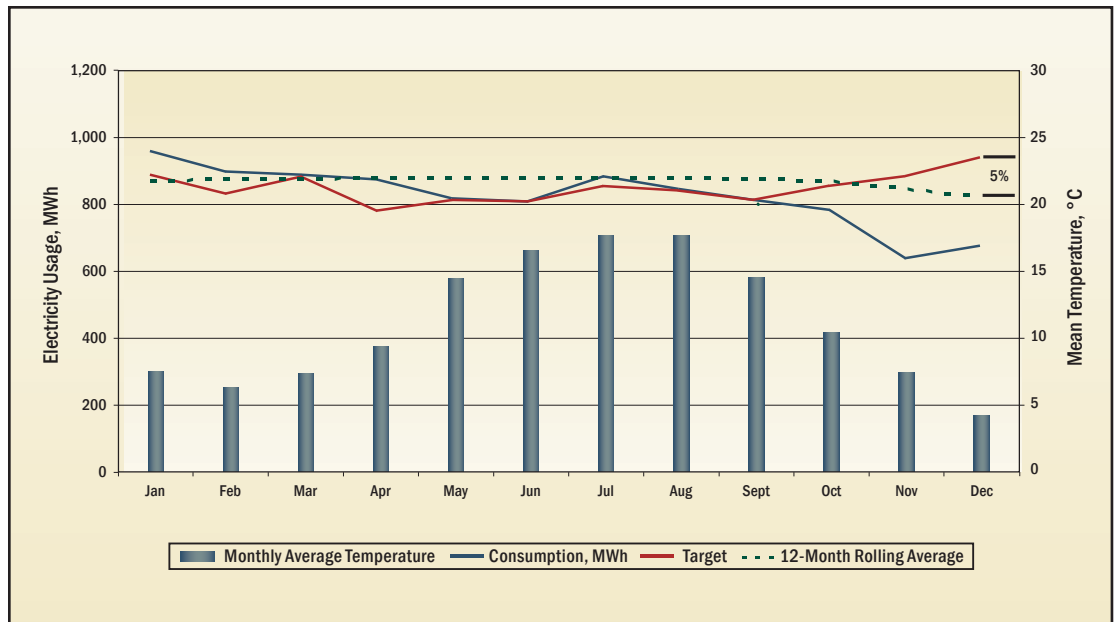


Figure 4. 2008 Target and Average Energy Usage

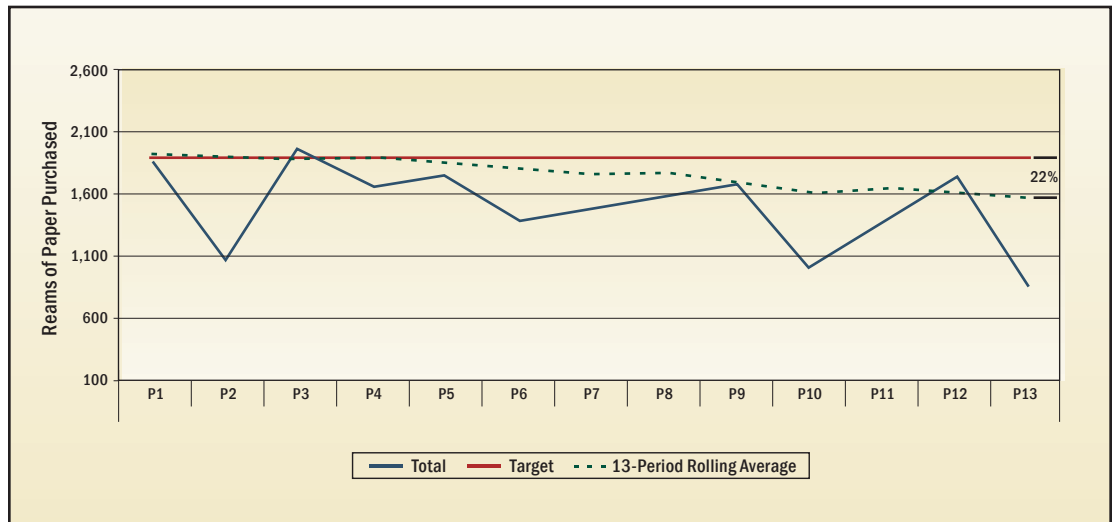


Figure 5. 2008 Paper Usage

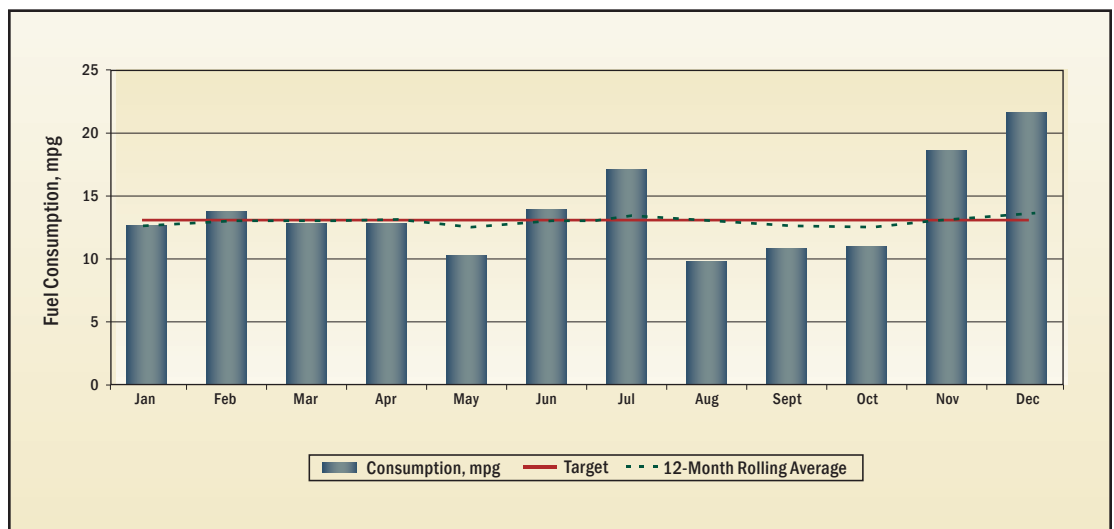


Figure 6. 2008 Fleet Fuel Consumption

As shown in **Figure 4**, energy consumption at the end of 2008 was 5% below 2007 performance levels and surpassed the 2% reduction target.

By the end of 2008, the yearly paper consumption was 22% below 2007 levels and surpassed the 5% reduction target (see **Figure 5**).

As shown in **Figure 6**, by the end of 2008, fleet fuel consumption was on target to maintain or slightly improve upon its 2007 performance—achieving 13 miles (21 km) per UK gallon (11 miles [18 km] per US gallon).

Through the Tube Lines business objective targets, corporate and process footprint activities and improvements that target a reduction against the LU power footprint can also be tracked (see **Table 2**).

Table 2. LU CO₂ Reductions

Activity That Reduces LU CO ₂ Level	CO ₂ Reduction, metric tons (tons)
<ul style="list-style-type: none"> • Installation of green roofs 	1,050 (1,157)
<ul style="list-style-type: none"> • Creation of “model” station (proposal submitted to LU): <ul style="list-style-type: none"> – Automatic/controlled lighting – Use of waste heat in tunnels for heating – Reduced use of escalators during off hours – Installation of wind turbines for auxiliary supply 	6 (6.6)
	188 (207)
	52 (57)
	19 (21)

CONCLUSIONS

Tube Lines has developed a mechanism for evaluating the carbon footprint of its day-to-day operations and created a baseline against which it can make focussed operational and investment decisions to reduce CO₂. The aim of this programme is to introduce CO₂ management into the business case process. ■

ACKNOWLEDGMENTS

The author would like to thank Charlotte Simmonds and the rest of the Tube Lines “Go Green” Environment team for their valuable contributions to this paper. Since Charlotte has now left Tube Lines, all enquiries on this topic and associated environmental management issues should be forwarded to Steven Judd at steven.judd@tubelines.com.

BIOGRAPHY



Elisabeth Culbard, PhD, is a technical expert in the field of sustainability, environmental and social impact assessment, and construction management. She has more than 25 years of experience on transport and infrastructure projects in London, the UK, and internationally, providing problem-solving technical solutions, hands-on construction management expertise, and strategic environmental and sustainability policy advice. Elisabeth’s responsibilities include developing sustainability and responsible procurement programs across a range of Bechtel Civil’s business portfolio of projects; in particular, Crossrail, Tube Lines, and Autostrada Transylvania. She is also experienced in finding workaround solutions to problems that can cause project delays or budget overruns.

Elisabeth was team leader on Bechtel’s Strategy Working Group on Climate Change and a Steering Group Member on the UK Construction Industry Research Information Association project on “How to Deliver Socially Responsible Construction Projects.” She is also an Expert Member on a Joint Institute of Civil Engineering/Engineers Against Poverty Panel on “Promoting Social Development in International Procurement.”

Elisabeth was involved in route optioneering, contaminated land remediation, and construction supervision and sustainability planning for the High Speed 1 Temple Mills Depot. She also worked on the Channel Tunnel as environment manager, leading the project through the Hybrid Bill; project stakeholder engagement; and 4 years of environmental planning, design integration, and construction execution.

Before joining Bechtel, Elisabeth was responsible for the day-to-day environmental and social performance of the International Finance Corporation’s global portfolio of infrastructure construction projects. This work won her the prestigious James Wolfensohn Excellence Award for due diligence on global railway projects.

Elisabeth received her DIC (Diplomate of Imperial College of Science and Technology) from the University of London; her PhD in Environmental Engineering from the Royal School of Mines, Imperial College of Science and Technology, University of London; and her BSc with Combined Honours in Geology and Environmental Science from the University of Aston in Birmingham; all in the UK.

The aim of this programme is to introduce CO₂ management into the business case process.

