Global Warming Reduction Benefits of Manufactured Biowax-Fiber Fireplace Logs

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Table of Contents

List of Tables

Executive Summary

Climate change and the emissions of green house gases have become some of today's most pressing societal issues. The purpose of this study was to evaluate and compare the green house gas emissions (GHG) from commonly used fireplace fuels. The focus of the analysis was the State of California, as California has taken a leading role in the measurement and regulation of green house gas emissions from anthropogenic sources. While the data utilized to support the final calculations of fireplace GHG emission are based on California fireplace usage, the conclusions noted herein are applicable to other states with large metropolitan areas where fireplace usage is common.

In 2004, anthropogenic activities in California were responsible for 492 million metric tons of carbon dioxide (CO_2) equivalent greenhouse gas emissions. California is the second largest emitter among U.S. states after Texas and only nine nations in the world have greater total GHG emissions. The combustion of biomass fuels in lieu of fossil fuels is generally recognized to reduce global warming impacts.

Residential fireplaces are in wide use in California and because of California's large population there are more fireplaces in California than in any other state. Fireplaces can be fueled by four sources of energy: natural gas, liquefied petroleum gas (LPG), cordwood, and wax-fiber firelogs. Historically, wax-fiber firelogs have been composed of both biomass fiber and petroleum wax, i.e., a mixture of biomass and fossil fuels. A new generation of wax-fiber firelogs now available replaces the petroleum waxes with natural waxes, making an entirely biomass-derived product.

Wax-fiber firelogs have become popular for use in solid fuel fireplaces. Fifty-seven percent of solid fuel fireplace users reported using wax-fiber firelogs in 2006, with 22% using them as their normal fuel. Over 100 million firelogs are sold annually.

Through its manufacture of firelogs, Duraflame estimates that it annually recycles approximately 50,000 tons of byproduct fiber comprised of wood chips, sawdust, and agricultural biomass generated by agriculture and other industries. Additionally, Duraflame estimates that in 2007, it will displace another 50,000 tons of petroleum-based fuel with byproduct biomass-derived wax blends.

There are six fireplace hardware/fuel options available for California residents. These are: (1) vented natural gas fireplaces, (2) vented LPG fireplaces, (3) vented natural gas log sets, (4) vented LPG log sets, (5) cordwood burned in solid fuel fireplaces, and (6) wax-fiber firelogs burned in solid fuel fireplaces. Unvented gas-fueled fireplaces, unvented gas-fueled log sets, and fireplace inserts are not part of California's fireplace inventory because unvented gas-fueled fireplaces and unvented gas-fueled log sets are not legal in California and because once fireplaces have been converted to heaters by the installation of gas, pellet or cordwood inserts, they no longer fill the role of a traditional fireplace. (Electric fireplaces also have not been included as GHG issues associated with electric power are outside the scope of this evaluation.)

There are fewer gas fireplaces fueled by LPG than by natural gas and the LPG units are often in more rural areas where natural gas service is not available. About 73% of solid fuel fireplaces and 80% of gas-fueled fireplaces are used in a given year. Most fireplaces, that are used, are used for aesthetics or for occasional secondary heat, very few are used for primary heat, principally due to their low heating efficiencies. On the average a fireplace in California, if it is used, is used 38 times per year with a fire

duration between 2.5 hrs to 3.5 hrs. (It should be noted that, not surprisingly, the frequency of fireplace usages is different in the different climate zones in California. The quoted usage frequency is based on data primarily derived from the California Central Valley and the San Francisco Bay Area. Fireplace usage will be greater in colder settings such as the Sierras and north coast and less in the south coast and Imperial Valley areas.)

Because of the different operational characteristics among the six fireplace hardware/fuel options, each fireplace option consumes a different amount of energy for a typical residential fireplace fire. Further, unlike utilitarian heaters, fireplaces are used more for aesthetics and for the comfort that radiant heat provides in the proximity of the fire. In many cases, the net overall home heating effectiveness is negative due to drawing large volumes of unheated outside air into the home. For these reasons, appliance efficiencies are not applicable for comparisons between the fireplace/fuel options. To provide a basis for comparison, the concept of a Fireplace Fire Event (FFE) was developed. Simply put, the FFE is the single typical fireplace fire that ranges between 2.5 hrs and 3.5 hrs in duration and that provides the consumer with the fireplace experience. The amount of energy it consumes to provide that experience varies with the fireplace/fuel option (Table ES-1).

Table ES-1
Energy per Fireplace Fire Event (FFE)

Fireplace/Fuel Type	Btu/FFE	Fuel Unit/FFE
Vented NG Fireplace	76,800	74.8 ft^3
Vented LPG Fireplace	76,800	0.84 gal.
Vented NG Log Set	155,950	151.8 ft^3
Vented LPG Log Set	155,950	1.70 gal.
Wax-Fiber Firelog in Solid Fuel Fireplace	79,760	6 lbs.
Cordwood in Solid Fuel Fireplace	219,390	26.9 dry lbs

NG = Natural Gas

Gas fireplaces are generally installed at the time of home construction or during home remodeling. There is little difference in the typical purchase and installation cost between a comparable gas fireplace ($1580) and solid fuel fireplace ($1640). If a gas fireplace is installed in a home at the time of construction or remodeling, the use of solid fuel is no longer an option. If, on the other hand, a solid fuel fireplace is installed at the time of construction or remodeling, future cordwood, wax-fiber firelog, and gas options remain. Gas log sets are designed for retrofit installation into existing solid-fueled fireplaces and preserve the “fireplace feel.” The installation of a gas log set to an existing solid fuel fireplace is a common scenario due primarily to the convenience that natural gas provides. Industry records confirm the fact that a large number of homes continue to have gas log sets installed into their existing solid fuel fireplaces.

Nationally, between 0.80 million and 0.97 million gas log sets were shipped annually to retailers in the 2001 and 2005 time period. As with gas fireplaces, once a gas log set is installed solid fuel can no longer be burned in the fireplace unless the gas log set is removed. The typical cost (including modifying the associated gas piping) of installing a gas log set into an existing solid fuel fireplace in a home already with natural gas or propane service is $1209. The typical cost of removing a gas log set and returning the fireplace to solid fuel use is $92.

After installation of a fireplace at the time of construction or at the time a major home remodeling it is unreasonable to assume that many home owners would voluntarily replace one with the another in response to environmental concerns due to the high costs and household disruption it would involve. However, there are an estimated 2.7 million solid fuel fireplaces in use in California that can be converted with gas log sets to gas use and 1.1 million solid fuel fireplaces with a gas log set already installed that could be removed returning the fireplace to solid fuel use. As noted, the cost of having a gas log set removed is minimal ($92). The cost of adding a gas log set is more substantial ($1209). An evaluation of real cost per fire which included both direct fuel costs and the amortized cost of installing a log set over its expected lifetime (12.7 yrs) showed that the real cost per fireplace fire was substantially higher with the use of gas log sets as compared to wax-fiber firelogs (Table ES-2).

Table ES-2
Vented Gas Log Set and Wax-Fiber Firelog Costs

Fireplace/Fuel Type	Cost of Fuel per Fire[1]	Amortized Cost of Gas Log Set Addition per Fire[2]	Total Cost per Fire
Vented Natural Gas Log Set	$1.81	$2.50	$4.31
Vented LPG Log Set	$3.36	$2.50	$5.86
Wax-fiber Firelog	$2.99	-	$2.99

[1]Fuel costs used in calculations = 197.2 cents/gallon LPG, $11.92/1000 cubic feet natural gas, $2.99/6 lb firelog.
[2]Average lifetime of gas log set has been estimated as 12.7 years. On the average, fireplaces are used for 38 fires per year in California.

There are four major components to greenhouse gas emissions from fireplaces. (1) Carbon dioxide directly emitted from fuel combustion in the fireplace. (2) Secondary CO_2 emitted from energy used in the extraction, harvesting, manufacturing, handling, processing, transporting, etc. of the fuel prior to it being burned in the fireplace. (3) Methane directly emitted as a product of incomplete combustion when the fuel is burned in the fireplace. (4) Fugitive CH_4 emissions from the natural gas system prior to the natural gas reaching the fireplace. A key factor in the evaluation GHG emissions from fireplaces is that while the secondary CO_2 associated with preparing biomass fuels and the CH_4 directly emitted from biomass fuel upon combustion in the fireplace are considered to be contributors to GHG inventories and have been accounted for in the analysis, CO_2 directly emitted upon combustion of biomass is not included in greenhouse gas inventories. The contribution of each of the four components and the biomass credit are well understood, can be documented and are upon review of the supporting data intuitively reasonable.

The significant finding is that the Biowax-fiber firelogs burned in a solid fuel fireplace has the lowest GHG emission levels among all the options. Starting with the option producing the highest amount of greenhouse gas emissions in descending order are: (1) vented LPG log set, (2) vented natural gas log set, (3) traditional petroleum wax-fiber firelogs burned in a solid fuel fireplace, (4) vented LPG fireplace, (5) vented natural gas fireplace, (6) cordwood burned in a solid fuel fireplace, and (7) Biowax-fiber firelogs burned in a solid fuel fireplace (Table ES-3).

Table ES-3
Fireplaces in California and Their Greenhouse Gas Emissions

Fireplace/Fuel Type	Number of Fireplaces in Use in California[1]	GHG Emission per Fireplace per Fire (lbs. CO_2-Eq./FFE[2])
Vented Gas Fireplaces		
Natural Gas	1.7 million	11.7
LPG	0.2 million	12.6
Vented Gas Log Sets		
Natural Gas	1.0 million	24.0
LPG	0.06 million	25.7
Solid Fuel Fireplaces	2.7 million[3]	
Cordwood		5.5
Traditional Petroleum Wax-Fiber Firelogs		17.5
Biowax-Fiber Firelogs		4.3

[1]73% of solid fuel fireplaces and 80% of gas-fueled fireplace are used, only the number used are shown in the table.
[2]FFE = Fireplace Fire Event
[3]22% of solid fuel fireplaces users normally use wax-fiber firelogs, more use them less frequently.

1. Introduction

In 2004, anthropogenic activities in California were responsible for 492 million metric tons of carbon dioxide (CO_2) equivalent greenhouse gas (GHG) emissions[1]. This contributes 6% to the total United States GHG. California is the second largest emitter among U.S. states after Texas and only nine nations in the world have greater total GHG emissions[2]. Many initiatives have been put forward in California for GHG mitigation. Related to GHG reductions and of particular note here is Executive Order S-06-06, which orders the increased use of bioenergy in California. The combustion of biomass fuels in lieu of fossil fuels reduces global warming impacts.

While the focus of this analysis is based on fireplace usage in California, because fireplaces are similarly and commonly used for aesthetic and minor heating purposes in many areas in the United States, the conclusions of the analysis presented here would be applicable to other States particularly with large metropolitan areas where fireplace use is greatest.

Residential fireplaces are in wide use in California and because of California's large population there are more fireplaces in California than in any other state. Fireplaces can be fueled by four sources of energy: natural gas, liquefied petroleum gas (LPG), cordwood, and wax-fiber firelogs. Natural gas and LPG are, of course, fossil fuels and cordwood is biomass, i.e., bioenergy. Wax-fiber firelogs have been popular in solid fuel fireplaces due to their convenience to consumers and nationally over 100 million firelogs are sold annually[3]. Reduced emissions of federal criteria and hazardous air pollutants as compared to cordwood through their use have been well documented.

Traditional wax-fiber firelogs have been composed of both biomass fiber and petroleum wax, i.e., a mixture of biomass and fossil fuels. A new generation of wax-fiber firelogs has replaced the petroleum waxes with natural waxes. Not only do these new "bioenergy" firelogs offer the same consumer convenience and lower emissions of federal criteria and hazardous air pollutants as compared to cordwood but also produce low GHG emissions as well.

A brief discussion of (1) greenhouse gases as they relate to fireplace emissions, (2) manufactured firelogs, and (3) fireplace characteristics and their use in California is provided here to document the global warming benefits of the use Biowax-fiber firelogs in California. A comparison of consumer costs associated with fireplace fuel options is also provided to permit economic evaluation.

2. Greenhouse Gases

Naturally occurring greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Several classes of halogenated substances that contain fluorine, chlorine, or bromine are also greenhouse gases, but they are, for the most part, solely a product of industrial activities. Although the direct greenhouse gases CO_2, CH_4, and N_2O occur naturally in the atmosphere, human activities have changed their atmospheric concentrations. From the pre-industrial era (i.e., ending about 1750) to 2004, concentrations of these greenhouse gases have increased globally by 35, 143, and 18 percent, respectively[4,5].

There are also several gases that do not have a direct global warming effect but indirectly affect terrestrial and/or solar radiation absorption by influencing the formation or destruction of greenhouse gases, including tropospheric and stratospheric ozone. These gases include carbon monoxide (CO), oxides of nitrogen (NO_x), and non-methane volatile organic compounds (NMVOCs). Aerosols, which are extremely small particles or liquid droplets, such as those produced by sulfur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia (NH_3) gases or from combustion processes (namely composed of organic compounds or elemental carbon) can also affect the absorptive characteristics of the atmosphere.

Greenhouse gases emitted from fireplaces include carbon dioxide, methane, nitrogen oxides, carbon monoxide, and a variety of non-methane volatile organic compounds. Fine particles, with an elemental carbon content in the tens of a percent level, are also emitted from fireplaces. Ironically, fine particles, particularly those with a measurable elemental carbon, have a global cooling effect in contrast to a warming effect.

As with the complete combustion of any organic material, carbon dioxide and water are the end products of complete combustion in fireplaces. The combustion efficiency of fireplaces, regardless of the fuel type, is generally over 90%; consequently the carbon dioxide emission levels can be estimated from the carbon content of the fuel and the fuel burn rate. The fraction of carbon that is not completely combusted is primarily in the form of creosote and soot accumulated on chimney surfaces or as char in combustion residue (bottom ash) with a smaller fraction lost as products of incomplete combustion (PIC) in air emissions.

According to the U.S. Environmental Protection Agency's inventory of greenhouse gas emission for 2004, about 85% of the greenhouse gas emissions (in units of CO_2 equivalents) are due to carbon dioxide and the overwhelming majority of its emissions are from combustion[6]. Methane is the second most important greenhouse gas accounting for about 8% of the total greenhouse gas emissions (again in units of CO_2 equivalents). The largest anthropogenic source of methane emissions in the U.S. is landfills with emissions from natural gas systems importantly a close second. As fireplaces are combustion sources and natural gas is one of the key fuel options, the primary focus of this evaluation is carbon dioxide and methane emissions.

While sulfur dioxide, nitrogen oxides, carbon monoxide, NMVOC, and particles are measurable in fireplace emissions, they are of significantly less importance in terms of global warming than carbon dioxide and methane from emissions directly or indirectly from the use of fireplaces. They are emitted only at low levels, they have short lifetimes in the atmosphere and have low global warming potentials[7,8]. Because carbon monoxide (1) is emitted at very low levels as compared to carbon dioxide, (2) has only a small indirect global warming impact, and (3) oxidizes to carbon dioxide with a residence time of a few months in the atmosphere, its global warming impact as compared to carbon dioxide and methane from fireplaces is negligible and it has simply been "counted" as carbon dioxide. Similarly, since (1) sulfur dioxide, nitrogen oxides, and particulate emissions are low as compared to carbon dioxide and methane, (2) they have smaller inherent global warming (or cooling) properties, and (3) the overwhelming majority of nitrogen oxide emissions from fireplaces are in the form of NO and NO_2 not in the form of the important greenhouse gas N_2O, their contribution to global warming impact from fireplaces can be considered negligible as compared to carbon dioxide and methane.

3. Manufactured Fireplace Firelogs

The Duraflame brand firelog was the first widely available commercial firelog. It was created as a result of research in the late 1960's aimed at adding value to sawdust byproduct generated from the milling of pencil slats by California Cedar Products Company (CCPC) at its factory in Stockton, California. CCPC engineers determined that softwood cedar fiber had a very good absorbency and bonded well with petroleum wax. These same engineers discovered they could extrude (rather than using the far less efficient older press or mold technology) the mixture of sawdust and wax, descriptively named "pasta" by an Italian engineer, into a log-shaped form. The extruded logs were designed for burning in residential fireplaces as an alternative to natural firewood. In 1972, this new extruded wax-sawdust fireplace log was introduced to the marketplace with the brand name of Duraflame. While the initial distribution of the firelog product was through supermarkets, during the 1980's it was expanded to mass merchandisers, hardware/ home center outlets and warehouse clubs. In 2006, over 100 million firelogs were burned in homes across North America. More than 30% of firelogs are sold in California[3].

Duraflame continues to be the leading brand in the market with a large share of what is now a $250 million firelog market. Beginning in 2006, Duraflame embarked on a strategy to convert the petroleum wax component of its firelogs to non-petroleum, "Biowaxes" which allowed both for a product with global warming reduction benefits and for the conservation of petroleum resources. The product composed of Biowaxes has been tested and found to perform comparably with the traditional petroleum wax-based firelogs and to have comparable emissions of criteria pollutants and air toxics[9]. Of significance is the fact that emissions of criteria pollutants and air toxics from wax-fiber firelogs are less than from natural cordwood.

Firelogs have traditionally been manufactured in three size categories: small (3 to 3.5 lbs), medium (5 lbs), and large (6 lbs). The average size of small logs is 3.2 lbs. Small, medium and large firelogs comprise approximately 20%, 30%, 50% of the retail market and their average retail price is $1.69, $2.49, and $2.99, respectively. The 5 lb and 6 lb firelogs are designed for a typical fireplace 3 to 4 hour burn event; the small firelogs have a burning duration about half of that.

Wax-fiber firelogs are comprised of 50% to 60% wax or wax-like materials with the remaining fraction fiber. The wax or wax-like materials act as a binder holding the fiber together in the log form and increase the fuel energy content. The energy content of a typical wax-fiber formulation is approximately 14,000 Btu per dry pound as compared to about 8500 Btu per dry pound for natural cordwood[9-11]. Further, as dried fiber is necessary due to the hydrophobic nature of waxes, the average moisture content of wax-fiber firelogs is much less than normal cordwood used in fireplaces. A survey of studies showed that the average moisture content of firelogs was 2.2% on a dry basis as compared to 24.1% for cordwood. (See Table 2.) Because of an inherent higher energy content and lower water content, firelogs have a higher energy density than normal cordwood. Accordingly, less mass of fuel is required for a comparable fire and consequently for emissions comparisons with cordwood to be meaningful they need to be made on a per fireplace fire-event rather than on a unit mass basis. This has historically caused considerable confusion, as the natural tendency is to compare solid fuels on a unit mass basis.

Air emissions from fireplaces burning cordwood have been of concern to regulators and air quality scientists. Besides carbon dioxide and water produced by combustion, cordwood produces various products of incomplete combustion (PIC) including particles (primarily submicron in size), carbon monoxide, and organic compounds which are emitted both as particles and as gases (NMVOC). Some of the organic compounds are hazardous air pollutants (HAP); notable among them are formaldehyde, benzene, and polycyclic organic matter (POM). The air emissions of PIC are considerably less from wax-fiber firelogs than from cordwood and the environmental advantage of burning wax-fiber firelogs in lieu of cordwood is well documented[9-29]. Wax-fiber firelogs have been shown to offer a cost-effective alternative to cordwood for the reduction of air pollutants from fireplaces[30].

Through its manufacture of firelogs, Duraflame estimates that it annually recycles approximately 50,000 tons of byproduct fiber comprised of wood chips, sawdust, and agricultural biomass generated by agriculture and other industries. Additionally, Duraflame estimates that in 2007, it will displace over 100 million pounds (50,000 tons) of petroleum-based fuel with natural wax blends. These natural wax blends are derived from organic, renewable materials of plant and animal origin, generally classified as fatty and stearic acids. They are produced in the process of making other higher value materials for the food, pharmaceutical, health and beauty, and paper making industries. Generally, these byproducts are either marketed for use as industrial boiler fuel, or for use in lower value products such as animal feed. Many are considered as future feedstock for the production of ethanol or bio-diesel.

4. Fireplaces and Their Usage

Fireplaces represent a real and increasing source of greenhouse gases. In 2005, there were an estimated 38 million occupied (occupied year around) households with usable fireplaces in the United States[31]. Survey data have shown that about 17% of the homes with fireplaces have more than one fireplace[32-35]. Because some households own more than one fireplace, the average number of fireplaces owned in households with fireplaces is 1.3[34]. When the multiple fireplace factor is taken into consideration it can be calculated that there are a total of 49 million fireplaces nationwide in year-around occupied households. When vacant and seasonal housing units are also considered this rises to a total of 57 million fireplaces in the United States as of the end of 2005. In 2005, 55% of new single-family houses completed had one or more fireplaces. During the time period between 2000 and 2005, the number of new single-family houses with one fireplace averaged 726,000 annually, the number of new single-family houses with two or more fireplaces averaged 70,000 annually, and the number of new multifamily units with one or more fireplaces averaged 33,000 annually[36]. There is no indication that this growth in the number of fireplaces will substantially change.

5. Gas-Fueled Fireplaces

Fireplaces can use gas or solid fuel. In 2001, approximately 26% of fireplaces used natural gas or liquefied petroleum gas (LPG) as a fuel[37]. (Frequently, LPG is referred to as simply propane or “bottled gas” and natural gas is referred to as “piped gas.”) The percentage of gas-fueled fireplaces has increased since 2001 because a higher fraction of gas-fueled fireplaces made up new fireplace sales since 2001 and between 0.80 and 0.97 million new gas firelog sets were reported to have been shipped to retailers annually between 2001 and 2005[38]. A recent survey found that by 2006 the number of fireplaces nationally that were gas-fueled had risen to 39%[34].

The number of households that use natural gas is far greater than use LPG. Nationally, the ratio of the number of households reporting using natural gas to the number of households reporting using LPG as a household fuel is greater than seven to one (2005 data)[31]. In California, proportionately even a larger fraction of households use natural gas as compared to LPG. The ratio of homes using natural gas to LPG in California is near 19 to one (2000 data)[39]. Similarly, the ratio of the total amount of natural gas to LPG energy consumed was 24.5 to one in California in 2001[40].

Included in the approximate 39% of fireplaces estimated to be gas-fueled are: (1) fireplace inserts, (2) true gas fireplaces, and (3) gas logs sets. Fireplace inserts are gas heaters designed for the installation into an existing solid-fuel fireplace cavity and after installation the unit is no-longer what would be considered a true fireplace with the typical fireplace dual aesthetic and secondary heating role, but rather more of a utilitarian space heater. True gas fireplaces are generally installed at the time of construction or during home remodeling. Gas-log sets are designed for retrofit installation into existing solid-fueled fireplaces and preserve the "fireplace feel." There are both vented and vent-free gas fireplaces and gas log sets. Further there are two types of vented gas fireplaces, direct vent and B-vent.

- **Direct Vent Gas Fireplaces**

Direct vent gas fireplaces are sealed units that draw their combustion air from, and vent their exhaust to, the outside air. Venting can be extended vertically or horizontally out of the home. A common type of venting is coaxial, which has the exhaust pipe contained within the air inlet pipe, so the temperature of the combustion air is raised, and the temperature of the exhaust is lowered, creating more efficient combustion.

- **B-Vent Gas Fireplaces**

B-vent gas fireplaces draw their combustion air from the room, and exhaust is vented outdoors. These units use a draft hood for the proper venting of exhaust. B-vent gas fireplaces have lower efficiency than direct vent because already heated room air is used as combustion air, which is then exhausted to the outdoors, taking heat away from the room. They are generally less costly than direct vent gas fireplaces and therefore are frequently installed in tract housing.

- **Vent-Free Gas Fireplaces**

Vent-free gas fireplaces receive their combustion air from the room in which the unit is placed, and all of the products of combustion are exhausted into the room as well. Vent free gas fireplaces have a maximum heat input limit in order to avoid emitting excess CO, CO_2, or NO_x into the room, and the units also have an O_2 depletion sensor or other device to shut the unit down if oxygen levels become too low. There is considerable concern regarding indoor air quality and damage to homes by moisture created from their use, as combustion gases are not vented. Vent-free gas fireplaces are currently not legal in California.

- **Vented Gas Log Sets**

Vented gas log sets are used in existing fireplaces with the damper open. They are primarily used for aesthetics because all products of combustion (including the vast majority of the heat produced) are vented up and out of the chimney.

- **Vent-Free Gas Log Sets**

Vent-free gas log sets can be used in a fireplace with the damper closed, or can be in their own enclosure placed in a fireplace. As with vent free gas fireplaces, all of the products of combustion are exhausted into the room. Also, the same concerns about indoor air quality and home damage as vent-free fireplaces apply. Vent-free gas log sets are not legal in California.

Vented (both direct vent and B-vent) fireplaces and vented gas log sets are widely used in California and are the focus of gas-fueled fireplaces in this evaluation. Vent-free units have not been not considered as their use is prohibited in California.

In order to assess fuel consumption rates and associated greenhouse gas emissions, a review was conducted of all advertised brands of vented gas fireplaces and vented gas log sets produced by the two industries' major manufacturers. (See Appendices A and B.) The results are summarized in Table 1. It should be noted that vented gas log sets average about twice the heat input as vented gas fireplaces due to mandated industry safety restrictions associated with the operation of vented gas fireplaces at higher energy input.

Table 1
Typical Energy Input for Gas-Fueled Fireplaces

Parameter	All Vented Gas Fireplaces, Btu/hr (x1000)	Direct Vent Gas Fireplace, Btu/hr (x1000)	B-Vent Gas Fireplace, Btu/hr (x1000)	Vented Gas Log Sets, Btu/hr (x1000)
Mean	30.72	30.51	31.56	62.38
Standard Deviation	9.58	9.65	9.31	10.84
Median	30	30	30	70
n	237	189	48	88

When the energy input for a given model was reported as a range, the mid-point of the range was used to calculate the mean.

6. Solid Fuel Fireplaces

Of the approximately 61% of fireplaces that are solid fuel burning fireplaces (35 million), about 28% have inserts, leaving 27 million true solid fuel burning fireplaces nationally. As with gas-fueled fireplace inserts, solid fuel fireplace inserts burning cordwood or pellets are essentially heaters and are not part of this evaluation. There are two fundamental types of solid fuel fireplaces, site-built masonry fireplaces and factory-built fireplaces.

- **Masonry Solid Fuel Fireplaces**

Masonry fireplaces are generally constructed of mortar, brick, cement blocks, cinder blocks and/or stone. The firebox is frequently constructed with firebrick or sometimes with metal. Their chimneys are often lined with chimney tiles. The chimneys are usually rectangular or square with dimensions ranging from as small as 6 inches by 6 inches to as large as 2 feet by 2 feet. Masonry fireplaces are usually an integral part of the structure.

- **Factory-Built Solid Fuel Fireplaces**

There are two types of factory-built fireplaces. One type is the freestanding fireplace, which usually consists of an inverted sheet metal funnel and stovepipe directly above the fire bed. Only a few percent of the factory-built fireplaces are freestanding. The other type (by far the most common) is the “zero-clearance” fireplace. The zero-clearance fireplace is constructed with an iron or heavy-gauge steel firebox lined with firebrick and surrounded by multiple steel walls with spaces for air circulation. The zero-clearance models are installed on site directly into a wall. There are three common sizes of zero-clearance fireplaces. These are 36-inch, 42-inch and 48-inch, which refer to the front width of the firebox opening. However, these are nominal size designations, in that, the height, depth, and back widths are variable with models. Typical factory-built fireplace chimneys are made of round metal pipe and range in size from 6 inches in diameter to 12 inches in diameter.

Among true solid fuel burning fireplaces (i.e., those without inserts), cordwood and wax-fiber firelogs are the most common fuel types. Cordwood use is the most common. However wax-fiber firelog use is substantial. During the 1994/1995 heating season, thirty percent of fireplace users reported burning manufactured wax/fiber firelogs occasionally and 12% reported using manufactured wax/fiber firelogs exclusively[41]. A 2006 survey reported that 57% of cordwood fireplace users had used a wax-fiber firelog during the past year and 22% of fireplace users normally used firelogs as their primary fuel[42]. Other types of manufactured logs made of compressed biomass and recycled materials are sometimes used in fireplaces, but their usage is very small as compared to natural cordwood and wax-fiber firelogs[42].

Fuel moisture is important when considering greenhouse gas emissions for solid fuel burning appliances, as considerable energy is required for the state change of liquid water-to-water vapor. This energy requirement impacts combustion efficiency, emissions, and the amount of fuel required to achieve a given heating or aesthetic effect. Fuel moisture ranges widely depending on cordwood seasoning practices. The average moisture content of cordwood was found from numerous in-home measurements to be 24.1% with a standard deviation of 12.9% (Table 2). It is the general “rule of thumb” that properly seasoned wood has a moisture content of less than about 25% on a dry basis. Consequently, a significant amount of cordwood that is used has a moisture content outside the range producing optimal efficiency and making cordwood emissions and the amount of wood used in many homes considerably higher than is calculated for the “average” cordwood case.

Table 2
Solid-Fuel Moisture

Parameter	Cordwood Percent Moisture (DB)[1,2]	Firelog Percent Moisture (DB)[1,3]
Mean	24.1	2.2
Standard Deviation	12.9	0.4
Median	21.4	2.2
Mode	17.0	2.2
n	820	30

1. DB = dry basis, i.e., the mass of water divided by the mass of dry wood.
2. Data from references 43-65.
3. Data from references 10-17, 19-21, 24.

The moisture content of wax-fiber firelogs is about one-tenth that of typical cordwood (Table 2) and their heat content per unit mass is substantially higher than for cordwood (14,000 Btu/dry lb for wax-fiber firelogs as compared to 8500 Btu/dry lb for typical cordwood). Consequently, the manufacturers' instructions are for one-at-a-time use and the consumers' expectation/satisfaction in terms of fireplace aesthetics and radiant heat is also consistent with a one-at-a-time burning scenario. Firelog burn rates are much smaller than cordwood burn rates due to their higher heat content, lower water content, and the one-at-a-time usage instructions (Table 3). Firelog burn rates average 0.74 dry kg/hr. The mean burn rate for cordwood in fireplaces in the U.S. was determined to be 5.13 dry kg/hr. The median and mode burn rate values were considerably less at 4.20 dry kg/hr and 3.50 dry kg/hr, respectively than the mean value due to the preponderance of smaller zero-clearance fireplaces in use. For this reason the mode is considered a better representation of the central tendency for cordwood in fireplaces. These cordwood burn rates are consistent with the facts that the typical cordwood fireplace fire consists of 4 to 7 pieces of cordwood[32,66] averaging between 7 and 8 lbs in weight[67] and the typical fireplace fire duration is 3.5 hours. (See Table 6.)

Table 3
Cordwood and Wax-Fiber Firelog Burn Rates in Fireplaces

Parameter	Cordwood Burn Rate[1] (dry kg/hr)	Firelog Burn Rate[2] (dry kg/hr)
Mean	5.13	0.74
Standard Deviation	3.03	0.28
Median	4.20	0.70
Mode	3.50	0.58
n	557	28

1. Data from references 18,22,49,55, 64-84.
2. Data from references 10-17, 19-21, 24.

7. Fireplaces in California

In order to gauge the magnitude of the effect of using Biowax-fiber firelogs in lieu of gas, cordwood or traditional petroleum wax-fiber firelogs on greenhouse gas emissions in California, it is necessary to estimate both the number of fireplaces and their usage.

Because of their low heating efficiency (typically reported as between 5% and 30%)[85,86], fireplaces are not generally used as a primary heating source. Nationally, in 2005, only 59,000 households reported using their fireplace (fireplace without insert) as their primary heating source out of 38 million occupied households with usable fireplaces[31]. Most fireplaces without inserts are used for secondary heating, aesthetics or simply not used at all in a given year. Data suggest that in California, about 73% of solid fuel fireplaces and 80% gas-fueled fireplaces are used (Table 4). It is speculated that the slightly higher usage rate associated with the gas-fueled fireplaces is due to the fact that gas-fueled fireplaces are more convenient to use than solid fuel fireplaces. On the average, if a fireplace is used, it is used 38 times per year in California (Table 5) with a fire duration of about 3.5 hours for solid fuel fireplaces and 2.5 hours for gas-fueled fireplaces (Table 6).

Not surprisingly, the frequency of fireplace usage is different in the different climate zones in California. The 38 times per year value was based on data primarily derived from the central valley and bay area. Fireplace usage will be greater in colder settings such as in the Sierras and north coast and less in the south coast and Imperial Valley areas.

The shorter typical fire duration of the solid fuel fireplace as compared to gas-fueled fireplaces is believed to be an artifact of reporting. With a cordwood or a wax-fiber firelog fire, the fire slowly dies and transitions into a glowing coal bed making it difficult to define when the fire is over. Whereas with the gas-fueled fireplace, the fire is instantly out when the gas is turned off.

The average amount of cordwood burned per fireplace that is used in California is 0.60 cords per year as estimated by a statewide survey[92]. Other regional surveys of cordwood usage in fireplaces report similar values, however it is believed by some that the values reported for cordwood usage in fireplaces are higher than the true amount due to the difficulty for the home occupant to estimate, in the units of cords, the relatively small amount of fuel typically consumed in a fireplace.

The weight of a cord of wood varies with the tree species making-up the fuel. An estimate of the weight of a cord of wood based on the species make-up characteristic of the cordwood fuel available to the South Coast Air Basin of California is 3081 lbs on a dry basis[93].

Table 4
Frequency of Residential Fireplace Usage

Area, Year, Reference,	Usage Category	Fraction by Category	Fraction Not Used
San Joaquin Valley, 2002, reference 87	Almost Every Day	0.16	
	Several Times a Week	0.20	
	Several Times a Month	0.14	
	Rarely	0.28	
	Never	0.22	0.22
San Joaquin Valley, 1999, reference 88	Daily	0.12	
	4-6 Times a Week	0.10	
	1-3 Times a Week	0.24	
	Less than Once a Week	0.22	
	Never	0.32	0.32
California, 2002, reference 32	Used Last Year? Yes	0.77	
	Used Last Year? No	0.23	0.23
U.S., 2002, reference 89	Almost Every Day	0.15	
	1 or 2 Times a Week	0.23	
	1 or 2 Times a Month	0.24	
	1 or 2 Times a Season	0.17	
	Almost Never/Never	0.19	0.19
U.S., 1994-1995, reference 41	5-7 Times per Week	0.11	
	3-4 Times per Week	0.10	
	1.2 Times per Week	0.18	
	1-2 Times per Month	0.13	
	1-2 Times per Season	0.17	
	Don't Use	0.31	0.31
West/Mountain, 2004, reference 33	1-2 Times or More per Month	0.51[1] (0.65)[2]	
	1-2 Times per Season	0.15[1] (0.15)[2]	
	Almost Never/Never	0.34[1] (0.20)[2]	0.34
Mean of "Not Used" Category			0.27

[1]Solid Fuel Fireplaces
[2]Gas-Fueled Fireplaces

Table 5
Typical Number of Residential Fireplace Fires per Year

Location, Reference	Average Number of Fires per Year
San Joaquin Valley, reference 87	39
San Joaquin Valley, reference 88	48
Fresno, reference 90	46
San Francisco, reference 32	26
San Joaquin Valley, reference 32	47
Sacramento Area, reference 32	31
U.S., reference 34	32
Average	38

Table 6
Typical Length of Fires

Location(s), Reference	Length of Fire (hours)	
	Cordwood-Fueled Fireplace	Gas-Fueled Fireplace
Composite of homes in San Francisco, Sacramento, Seattle, and Dallas, reference 91	3.3	
Composite of homes in San Francisco, San Joaquin Valley, and Sacramento area, reference 32	4.6	
Fresno, reference 90	2.6	
U.S., reference 33	4.1	2.7
West/Mountain region, reference 33	2.7	2.1
U.S., reference 34	3.6	2.6
Mean	3.5	2.5
Firelog-Fueled Fireplace Description, Reference	Length of Fire (hours)[2]	
5 lb, petroleum wax, coffee fiber, mean of 2 tests, reference 10	3.2	
3 lb, traditional petroleum-wax-fiber, mean of 2 tests, reference 10	2.5	
6 lb, traditional petroleum wax-fiber, mean of 2 tests, reference 10	3.8	
5 lb, traditional petroleum wax-fiber, mean of 2 tests, reference 10	3.3	
6 lb, traditional petroleum wax-fiber, mean of 2 tests, reference 10	3.8	
6 lb, traditional petroleum wax-fiber, mean of 3 tests[1], reference 11	3.8	
6 lb, Biowax-fiber, 1 test[1], reference 9	3.6	
5 lb, Biowax-fiber, 1 test[1], reference 9	3.4	
Composite of homes in San Francisco, San Joaquin Valley, and Sacramento area, survey of 66 firelog users, reference 32	3.3 (survey average)	

[1]The test entailed burning two firelogs sequentially with the second firelog added when the last visible flame from the first firelog went out. The duration of the test was divided by two to obtain the duration corresponding to one firelog.
[2]For all tests, the time to when the last visible flame went out was used to determine the length of the fire.

The U.S. Census Bureau, U.S. Department of Housing and Urban Development, U.S. Department of Commerce, U.S. Department of Energy, the Hearth, Patio and Barbecue Association, and national marketing surveys along with various regional surveys commissioned by both public and private sector interests provide a considerable database and have been applied, both nationally and regionally, to the estimation of the number of various types of residential heating equipment[30,93,94]. Using data from these sources the number of (1) solid fuel fireplaces (2) vented gas fireplaces (both natural gas and LPG), and (3) vented gas log sets installed in fireplaces (both natural gas and LPG) currently used in California was estimated. The input data sources and calculations are shown in Tables 7, 8 and 9. One non-intuitive note

– because the availability of natural gas is considerable higher in California than it is nationally and the availability of natural gas will influence the selection of natural gas as compared to solid fuel fireplaces, an “adjustment factor” was developed for California (Table 8). Similarly, the data show less LPG is used in California than nationally and an adjustment factor for the fact that LPG use in California is less than the national average has been made (Table 8).

The results of the calculation of the number of fireplaces in use in California are shown in Table 9. It is estimated that 1.7 million vented “true” natural gas fireplaces, 1.0 million vented natural gas log sets, 0.2 million vented “true” LPG fireplaces, 0.06 million vented LPG log sets, and 2.7 million solid fuel fireplaces are currently in use in California.

Table 7
Households and Usable Fireplaces in California

Location, Year, Reference	Total Housing Units (X 1000)	Total Year-Around Occupied Housing Units (X 1000)	Occupied Housing Units with Usable Fireplace (X 1000)	Percent of Year-Around Occupied Housing Units with an Usable Fireplace
U.S., 2005, ref. 31	124,377	108,871	37,804	34.7
West Census Region, 2005, ref 31.	-	23,858	10,702	44.8
San Francisco, 1998, ref. 95	700.2	663.2	319.1	48.1
San Jose, 1998, ref. 96	591.0	565.9	326.9	57.8
Oakland, 1998, ref. 97	895.0	855.7	475.3	55.5
San Diego, 2002, ref. 98	1072.0	999.1	475.5	47.6
Riverside-San Bernardino-Ontario, 2002, ref. 99	1229.5	1083.9	572.8	52.8
Anaheim-Santa Ana, 2002, ref. 100	995.6	937.5	531.6	56.7
Los Angeles-Long Beach, 2003, ref. 101	3318.5	3131.0	1121.5	35.8
Sacramento, 2004, ref. 102	727.5	669.4	385.9	57.6
California Average				51.5

Table 8
Factors for Adjusting the Proportions of Fireplaces in California that are Natural Gas- and LPG-Fueled

Parameter,	Year	Fuel[1]	California (%)	National (%)	Ratio	References
Occupied Units Using Fuel as Main Heating Fuel	2000	NG	66.4	46.7	1.42	39,103
		LPG	3.56	5.94	0.599	
Occupied Units Using Fuel for Any Purpose	2001	NG	85.4	62.6	1.36	37
		LPG	5.6	8.8	0.636	
Households with NG Available in Neighborhood	2001	NG	89.2	72.6	1.23	37
Portion of Total Household Energy Consumed	2001	NG	34.1	22.2	1.53	40
		LPG	12.8	17.0	0.753	
Average (Used as Adjustment Factor)		NG			1.38	
		LPG			0.663	

[1]NG = Natural Gas

Table 9
The Number of Fireplaces in Use in California

Calculation Element	Source of Data
51.7% of occupied households in CA have usable fireplace	Table 7
12,097,894 occupied housing units in CA in 2005	Ref. 104
12.3 million occupied housing units in CA as of end of 2006, estimated from 2005 building permits and 2005 occupied housing units value	Ref. 105
Among fireplace owners average number owned is 1.3	Ref. 34
0.517 X 12.3 million X 1.3 fireplaces per fireplace household = 8.3 million usable fireplaces in CA	
10% of fireplaces have an insert installed	Ref. 34
8.3 million X 0.90 = 7.5 million fireplaces without inserts	
Nationally 61% are solid fuel fireplaces and 39% are gas-fueled	Ref. 34
Nationally 85% of the gas-fueled fireplaces are natural gas fueled and 15% are LPG-fueled	Ref. 34
39% X 0.85 = 33% natural gas, 39% X 0.15 = 6% LPG	
In summary, nationally 61% are solid fuel, 33% natural gas, 6% LPG	
CA natural gas adjustment factor 1.38 and LPG adjustment factor 0.663	Table 8
Natural gas fireplaces in CA, 33% X 1.38 = 46%	
LPG fireplaces in CA, 6% X 0.663 = 4%	
Solid fuel fireplaces in CA, 100% -46% -4% = 50%	
64% of gas-fueled fireplaces are true gas fireplaces, 36% are gas log sets installed in fireplaces originally designed for solid fuel.	Ref. 34
46% X 0.64 = 29% vented natural gas fireplaces 46% X 0.36 = 17% vented natural gas log sets 4% X 0.64 = 3% vented LPG gas fireplaces 4% X 0.36 = 1% vented LPG gas log sets	
73% of solid fuel fireplaces are used, 80% of gas-fueled fireplaces are used	Table 4
0.29 X 0.80 X 7.5 million = **1.7 million vented natural gas fireplaces in use** 0.17 X 0.80 X 7.5 million = **1.0 million vented natural gas log sets in use** 0.03 X 0.80 X 7.5 million = **0.2 million vented LPG fireplaces in use** 0.01 X 0.80 X 7.5 million = **0.06 million vented LPG gas log sets in use** 0.50 X 0.73 X 7.5 million = **2.7 million solid fuel fireplaces in use**	

8. Cost of Fuel Options

Economic implications are components of any GHG mitigation strategy. Each of the six fireplace/fuel options, (1) vented natural gas fireplaces, (2) vented LPG fireplaces, (3) vented natural gas log sets, (4) vented LPG log sets, (5) cordwood in solid fuel fireplaces, and (6) wax-fiber firelogs in solid fuel fireplaces, have different fuel and hardware costs associated with them. Tables 10 through 13 illustrate the key costs. These costs were obtained from various surveys of retailers.

An existing solid fuel fireplace can be used with cordwood or wax-fiber firelogs or it can be converted to gas (natural gas or LPG) with a log set. Usually the conversion to gas also requires that the gas piping system inside the home be modified or extended. These costs are included in the tabulations. Once a fireplace has had a gas log set added, it can no longer burn solid fuel, and hence the cordwood and wax-fiber firelog options are no longer available. However, the gas log set can be permanently removed, returning the fireplace to its solid fuel burning capabilities. The cost for removal of a gas log set is included along with the cost of installation in Table 10. As can be seen, it is considerably more costly to install a gas log set ($1209) than it is to remove one ($92).

Table 10
Costs for Installing or Removing a Vented Gas Log Set to/from an Existing Fireplace

Activity	Purchase Price	Cost of Purchasing and Installing	Typical Cost of Modifying/Extending Existing Gas Piping[1]	Total Cost	Ref.
Install Vented Gas Log Set to Solid Fuel Fireplace				$900, $1250 (two estimates, avg. = $1075)	108
	$590				109
		$680			34
		$385-$1000 (range of cost estimates, mid-pt. = $693)	$300-$1000 (range of cost estimates, mid-pt = $650)	$1343 (sum of mid-points)	App. C
Average	$590	$686	$650	**$1209**	
Remove Gas Log Set and Return to Solid Fuel Use	$80-$105, range of cost estimates, mid-point is **$92** It was noted by some fireplace retail personnel that many residents could remove the log set and close off the gas piping themselves at no cost.				App. C

[1]Assumes home already has natural gas or LPG service for centralized furnace, cooking range, or water heater.

In contrast to gas log sets, the installation of both solid fuel fireplaces and gas fireplaces generally occurs at the time of home construction, at the time of home purchase, or as part of a major remodel. As can be seen from the data in Table 11, it is slightly more expensive to install a solid fuel fireplace than a gas-fired one. The slightly greater cost associated with a solid fuel fireplace is due to the smaller and simpler chimney system that a gas-fueled fireplace requires. This small one time difference in the two fireplace types' costs is not significant when amortized over the lifetime of the fireplaces.

Table 11
Costs for the Installation of a Vented Gas Fireplace as Compared to a Solid Fuel Fireplace

Fireplace Type	Cost of Purchasing and Installing Fireplace at Time of Home Construction	Cost of Purchasing and Installing Fireplace at Time of Home Purchase
Vented Gas Fireplace[1]	$1580	$1380
Solid Fuel Fireplace[1]	$1640	$1720
Vented Gas Fireplace (purchase)[2]	$1950	

[1]Data from reference 34
[2]Data from reference 109

The difference in fuel costs to provide a typical fireplace fire, i.e., a fireplace fire event (FFE) varies with fuel type due to characteristically different amounts of energy required for the different fireplace/fuel scenarios and the different unit prices for the different fuels. The cost for a typical fire for each of the fireplace/fuel scenarios is shown in Table 12.

Table 12
Fuel Cost Comparison

Fireplace/Fuel Type	Btu/FFE[1]	Fuel Unit/FFE[1]	Cost of Fuel per Fire[2]	Cost of Fuel per Year[3]
Vented NG Fireplace	76,800	74.8 ft^3	$ 0.89	$34
Vented LPG Fireplace	76,800	0.84 gal.	$1.66	$63
Vented NG Log Set	155,950	151.8 ft^3	$1.81	$69
Vented LPG Log Set	155,950	1.70 gal.	$3.36	$128
Wax-Fiber Firelog in Solid Fuel Fireplace	79,760	6 lbs.	$2.99	$114
Cordwood in Solid Fuel Fireplace	219,390	26.9 dry lbs (bulk)	$2.47[4]	$60
		0.75 ft^3 (bundle)	$3.99[5]	$152

NG = Natural Gas
[1]FFE = Fireplace Fire Event
[2]LPG fuel cost (197.2 cents per gallon) used in estimate is for the West census region, 2006, ref 110
Natural gas fuel cost ($11.92/$10^3$ $ft^{3)}$ used in estimate is for California, 2006, ref. 111, neither costs include taxes
[3]The average number of FFE's per season is 38, see Table 5
[4]Bulk cordwood data used in calculation are $283/cord (See Appendix D) and 3081 lbs/cord.
[5]A bundle of cordwood as purchased at a retail store is usually 0.75 cubic feet, costs $3.99 and is designed to fulfill the fuel requirements of a single FFE.

A common scenario is the installation of a gas log set to an existing solid fuel fireplace. Industry records confirm the fact that a large number of homes continue to have gas log sets installed into their existing solid fuel fireplaces. Nationally, between 0.80 million and 0.97 million gas log sets were shipped annually to retailers in the 2001 and 2005 time period[38]. This growth is due in part to the fact that gas fuel for fireplaces did not become popular until the late 1980's and many older homes still have existing solid fuel fireplaces (both factory-built metal units and site-built masonry units). As the majority of fireplaces are in a suburban setting, the convenience and availability of inexpensive natural gas make gas log sets attractive to the suburban consumer. In addition, gas-fueled appliances are viewed as clean burning. Similarly, the same suburban premium on convenience and clean burning properties has also made wax-fiber firelogs popular. The data in Table 13 compares the cost per fire for these two popular scenarios, i.e., the cost per fire of a solid fuel fireplace after it has been converted to gas with a log set to the cost per fire of burning wax-fiber firelogs. The cost of gas log conversion is amortized per fire over the normal lifetime (12.7 years)[112] of a gas log set. As can be seen the wax-fiber firelog offers a lower cost per fire than either natural gas or LPG. (A fewer but still significant number of fireplaces per capita and proportionally more LPG units are used in rural settings where natural gas service is not available.)

Table 13
Cost Comparison of Burning Wax-Fiber Firelogs to Using a Solid Fuel Fireplace Converted to Gas (Using a Log Set)

Fireplace/Fuel Type	Cost of Fuel per Fire[1]	Amortized Cost of Log Set Installation per Fire	Total Cost (per fire) of Operation of Fireplaces over the Lifetime of the Log Set[2]	Total Cost (per year) of Operation of Fireplaces over the Lifetime of the Log Set[2]
Vented NG Log Set	$1.81	$2.50	$4.31	$164
Vented LPG Log Set	$3.36	$2.50	$5.86	$223
Wax-fiber Firelog	$2.99	-	$2.99	$114

NG = Natural Gas
[1]See Table 12.
[2]It is estimated that the average lifetime of a log set is 12.7 yrs (See ref. 112), that the typical cost of the complete installation of a log set into an existing solid fuel fireplace is $1209, and that there are on the average 38 fires per season in a California fireplace. (See Table 5.)

9. Global Warming Reduction Benefits of Manufactured Biowax-Fiber Firelogs

There are four major components to greenhouse gas emissions from fireplaces. (1) Carbon dioxide directly emitted from fuel combustion in the fireplace. (2) Secondary CO_2 emitted from energy used in the extraction, harvesting, manufacturing, handling, processing, transporting, etc. of the fuel prior to it being burned in the fireplace. (3) Methane directly emitted as a product of incomplete combustion when the fuel is burned in the fireplace. (4) Fugitive CH_4 emissions from the natural gas system prior to the natural gas reaching the fireplace. A key factor in the evaluation is that while the secondary CO_2 associated with preparing biomass fuels and the CH_4 directly emitted from biomass fuel upon combustion in the fireplace are considered to be contributors to GHG inventories (and are accounted for here), CO_2 directly emitted upon combustion of biomass is not included in greenhouse gas inventories[6].

Calculations for each of the four components contributing to GHG emissions have been provided in Appendix E for each of the six fireplace/fuel scenarios and the results are summarized in Table 14. The contribution of each of the four components and the biomass credit are well understood, can be documented and are upon review of the supporting data intuitively reasonable. The significant finding is that the Biowax-fiber firelogs burned in a solid fuel fireplace have the lowest GHG emission levels among all the options.

Table 14
Greenhouse Gas Emissions from Fireplaces[1]

Gas Emissions[2]	Vented NG Fireplaces	Vented LPG Fireplaces	Vented NG Log Sets	Vented LPG Log Sets	Cordwood	Traditional Wax-Fiber Firelogs	Petroleum-Free Biomass Firelogs
CO_2 Directly Emitted (lbs. CO_2/FFE)	9.3	10.6	18.9	21.6	49.7	13.3	13.2
GHG CO_2 Directly Emitted (lbs. CO_2-Eq./FFE)	9.3	10.6	18.9	21.6	0 (biomass fuel)	8.9[3]	0 (biomass fuel)
GHG CO_2 Emitted from Energy Investment (lbs. CO_2-Eq./FFE)	1.4	2.0	3.0	4.1	1.6	3.7	3.6
Total GHG CO_2 (lbs. CO_2-Eq./FFE)	10.7	12.6	21.9	25.7	1.6	12.6	3.6
CH_4 Directly Emitted (lbs. CO_2-Eq./FFE)	0.004	0.004	0.008	0.007	4.1	4.9	0.7
CH_4 Fugitive System Emissions (lbs. CO_2-Eq./FFE)	1.0	negligible	2.1	Negligible	negligible	negligible	negligible
Total Greenhouse Gas Emissions (lbs. CO_2-Eq./FFE)	**11.7**	**12.6**	**24.0**	**25.7**	**5.5**	**17.5**	**4.3**

NG = Natural Gas
[1]Calculations and assumptions for data shown in Table are in Appendix E
[2]FFE = Fireplace Fire Event
[3]Of the total 13.3 lbs CO_2/FFE emitted, 8.9 lbs is from fossil carbon and 4.4 lbs is from modern carbon

- **CO_2 Directly Emitted from the Combustion of Fuel in the Fireplace**

The complete combustion of fossil and biomass fuels produces CO_2 and H_2O. The primary reason for the different levels of CO_2, as shown in Table 14, for the different fireplace/fuel options is that each fireplace/fuel option consumes different amounts of energy for its characteristic fireplace fire event (FFE). Cordwood burned in a solid fuel fireplace consumes the largest mass of fuel and the corresponding largest emissions of CO_2. Both the natural gas and LPG vented log sets have higher energy inputs than their respective "true" fireplaces and their CO_2 emissions are commensurately higher. A secondary factor that influences CO_2 emissions is that each fuel has characteristically different amounts of carbon per unit of energy. This factor is well documented and has been taken into consideration in the calculations provided in Appendix E.

- **Biomass Fuel**

There has been considerable confusion and misunderstanding regarding the role of biomass fuels and global warming. Simply and succinctly put, the impact of CO_2 directly emitted from the combustion of biomass fuels does not add to the GHG burden in the atmosphere. This is recognized by the Intergovernmental Panel on Climate Change (IPCC) Guidelines for Greenhouse Gas Inventories, and with some caveats, these standardized guidelines specifically preclude CO_2 directly emitted from biomass from being included in GHG inventories[113]. The caveats relate to the biomass fuel associated with permanent deforestation or agricultural materials not being renewed. (Neither is the case for typical cordwood or Biowax-fiber firelogs.) The United States Environmental Protection Agency in its 1990 to 2004 Inventory of Greenhouse Gas Emission and Sinks clearly explains the appropriate GHG treatment of CO_2 directly emitted from the combustion of biomass[6]. "The combustion of biomass fuels such as wood, charcoal, wood waste, and biomass-based fuels such as ethanol from corn and woody crops generates CO_2. However, in the long run the CO_2 emitted from biomass consumption does not increase atmospheric CO_2 concentrations, assuming the biogenic carbon emitted is offset by the uptake of CO_2 resulting from the growth of new biomass. As a result, CO_2 emissions from biomass combustion have been estimated separately from fossil fuel-based emissions and are not included in the U.S. totals." To be consistent with this approach, the direct emissions of CO_2 from the combustion of the biomass fuels evaluated here (cordwood, the Biowax-fiber firelogs, and the fiber portion of the traditional petroleum wax firelogs) have been calculated and are included in Appendix E and Table 14 but have not been counted as greenhouse CO_2. Due to the recognized lack of global warming impacts from CO_2 directly emitted from the combustion of biomass it has been common to refer to the combustion of bio-fuels as being a "carbon neutral" event.

While the emission of carbon dioxide from combustion of biomass fuels is not considered in calculating green house gas emissions, there are additional factors related to the use of biomass fuels that can contribute to global warming. The two key factors are: (1) Carbon dioxide emitted from energy consumption in the preparation and transport of the fuels is a GHG as this energy is primarily derived from fossil fuels. (2) Methane emitted from the direct combustion of biomass fuels is a potent GHG. Methane is not directly involved in the photosynthetic/respiration/sequestration/atmospheric cycle and needs to be included in the GHG inventory. While the emission factor for CH_4 is considerably lower than for CO_2 from the direct combustion of biomass fuels, it is 21 times more potent in its global warming impact than CO_2 (GWP = 21) making its contribution to GHG inventories high enough to be considered. Both CO_2

indirectly produced from fuel preparation and transport, and CH_4 from direct biomass combustion have been calculated for the two biomass fuels evaluated here and are included in Appendix E and Table 14.

Two additional factors that have caused confusion associated with the burning of biomass fuels and global warming are: (1) different GHG uptake and release rates and (2) land use changes.

GHG Uptake and Release Rates – On the one hand, it has been documented that juvenile trees photosynthesize and remove CO_2 from the atmosphere at a faster rate than mature trees, suggesting that the renewable harvesting of mature trees such as for cordwood provides a global warming benefit[114-116]. On the other hand, it has been suggested that burning wood rather than using the same wood for structural materials (e.g., for furniture or home construction) or allowing it to go to a landfill accentuates global warming impacts due to immediate release of GHG upon combustion as compared to a slow release of GHG due to decay of structural or land filled materials. Further complicating the issue is the suggestion that since CH_4 with its higher GWP is the dominant gas released (albeit slowly released) from anaerobic decay in landfills that burning of biomass fuels is actually preferable to land filling in terms of global warming. It needs to be remembered that the effect of these uptake and release rate issues for biomass fuels is small as contrasted to the magnitude of the difference for global warming between recycling biomass carbon over a few years (or perhaps over a few decades at most) compared to bringing additional fossil carbon into the modern carbon cycle. Further, the differences in release or uptake rates in GHG appears to be less of an issue for the combustion of biomass fuels derived from agricultural materials as compared to wood. Agricultural biomass, in addition to wood fiber, has been used as a fiber source in firelogs and vegetable oils and waxes are used in the petroleum-free Biowax-fiber firelogs. Conceptually, the burning of agricultural biomass fuels in a residential fireplace is no different than burning them in-place in the field in terms of CO_2 emissions impacts on global warming. According to the U.S. Environmental Protection Agency's Inventory of Greenhouse Gases and Sinks[6], "Field burning of crop residues is not considered a net source of CO_2, because the carbon released to the atmosphere as CO_2 during burning is assumed to be reabsorbed during the next growing season."

Land Use Changes – If the biomass used for fuel is associated with land use changes, there are possible global warming implications. Namely, if wood fuel is associated with permanent deforestation or if agricultural fuel is from a source that is taken out of agricultural service, e.g, due to urbanization, the GHG emitted upon its combustion is not subsequently removed from the atmosphere and there is a net global warming impact. Neither of these scenarios is generally applicable to petroleum-free biomass firelogs as the wood fiber is from managed forests, the agricultural fiber is from commercial farms, and the vegetable oils and waxes are typically from large agricultural operations or plantations. Additionally, since the raw materials used for the manufacture of the petroleum-free biomass firelogs are already byproducts, their use in firelogs makes no change in land usage.

- **CO_2 Emitted from Energy Investment**

Each fireplace fuel has energy invested into it prior to reaching a residential fireplace. The term that is used to describe this energy investment is Energy Return On Energy Investment (EROEI).

The majority of energy invested into the extraction, harvesting, manufacturing, handling, processing, transporting, etc. of the fireplace fuels examined here is in the form of petroleum gasoline, diesel or heating oil. The average carbon release rate per unit energy for these fuels when coupled with the EROEI and the amount of energy characteristically consumed in each fireplace/fuel option for a FFE allows for an estimate of the amount of CO_2 that is emitted from these secondary sources for each FFE. The EROEI values and calculation of the amount of CO_2 emitted are shown in Appendix E. The weight of CO_2 emitted from the energy investment per FFE for each fireplace/fuel option is tabulated in Table 14. As noted for land use changes, since the raw materials used for the manufacture of the petroleum-free biomass firelogs are already byproducts, their use in firelogs does not change the energy consumed in the steps prior to the actual manufacture (with associated transport) of the firelog proper, consequently the estimates shown here represent a conservatively high value for CO_2 emitted for them from energy investment.

- **CH_4 Directly Emitted from the Combustion of Fuel in the Fireplace**

Methane is a product of incomplete combustion (PIC) and there are tabulations of emission factors that can be used to directly calculate its emissions from fireplaces for each fuel option. The CH_4 emission factors for natural gas and LPG are very low as compared to solid fuels such as cordwood and firelogs. The calculations of CH_4 emitted from the direct combustion of the various fireplace/fuel options are shown in Appendix E and tabulated in Table 14. Because CH_4 has a GWP of 21, the standard reporting convention was followed and the weight of CH_4 emitted was converted to units of carbon dioxide equivalents (CO_2-Eq.) by multiplication by 21. It should be noted that the CH_4 emission factor measured for the Biowax-fiber firelog was considerably lower than those measured for traditional wax-fiber firelogs that contained petroleum wax. It is believe that the higher fraction of alkanes (hydrocarbons) associated with petroleum (perhaps containing some short-chained compounds) was responsible for the higher values seen with the firelogs containing petroleum waxes.

- **CH_4 Fugitive Emissions from the Natural Gas System**

Twenty one percent of the total 2004 national anthropogenic emissions of CH_4 were from fugitive sources from the natural gas system[6]. Consistent with this are the facts that approximately 90% of natural gas (by volume) is CH_4 and that there are numerous fugitive emission points in the natural gas system. (See Tables E1 and E2 in Appendix E.) From the total annual natural gas production levels and the total mass estimated to have been lost, the fraction of the total amount of natural gas that is delivered to a fireplace that is lost prior to reaching the fireplace can be calculated. This fraction is 0.0175. Applying this fraction to the amount of natural gas burned in both vented natural gas fireplaces and vented natural gas log sets per FFE allowed the amount of natural gas lost prior to reaching the fireplace for each FFE to be calculated. The complete calculations are provided in Appendix E and the results are shown in Table 14. The standard reporting convention was followed and the weight of CH_4 emitted was converted to units of carbon dioxide equivalents (CO_2-Eq.) by multiplication by 21. An investigation into the manufacture and delivery of LPG revealed that its fugitive CH_4 emissions were negligible.

Each of the four components that contributed to greenhouse gas emissions from fireplaces have been summed to provide a total greenhouse gas emission value per fireplace fire for each of the fireplace/fuel options (Table 14). Intermediate values and the overall totals are reported in units of weight carbon dioxide equivalents per fireplace fire event (CO_2-Eq./FFE). Starting with the option producing the highest amount of greenhouse gas emissions in descending order are: (1) vented LPG log set, (2) vented natural gas log set, (3) traditional petroleum wax-fiber firelogs burned in a solid fuel fireplace, (4) vented LPG fireplace, (5) vented natural gas fireplace, (6) cordwood burned in a solid fuel fireplace, and (7) Biowax-fiber firelogs burned in a solid fuel fireplace. Simply stated – the use of Biowax biomass fiber firelogs in a solid fuel fireplace in place of any other reasonable fireplace fuel option provides the greatest greenhouse gas emissions reduction.

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Appendices

A Survey of Gas Firelog Sets

B Survey of Vented Gas Fireplace Models

C Cost Estimates for the Removal or Installation of a Gas Firelog Set in an Existing Fireplace at Various California Locations

D California Firewood Prices

E Calculations

Appendix A
Survey of Gas Firelog Sets

RH PETERSON, 14724 EAST PROCTOR, CITY OF INDUSTRY, CA 91745

MODEL	LOG LENGTHS 12-16	18-22	24-28	30-36	42-96	VENTED (Y OR N)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
CHARRED MOUNTAIN OAK		X	X	X		Y	N/P	50 - 90
CHARRED AMERICAN OAK		X	X	X		Y	N/P	50 - 90
CHARRED RUGGED SPLIT		X	X	X		Y	N/P	50 - 90
CHARRED CEDAR		X	X	X		Y	N/P	50 - 90
CHARRED AGED CEDAR		X	X	X		Y	N/P	50 - 90
CHARRED OAK		X	X	X		Y	N/P	50 - 90
CHARRED ROYAL ENGLISH OAK		X	X	X		Y	N/P	50 - 90
CHARRED NORTHERN OAK		X	X	X		Y	N/P	50 - 90
CHARRED SPLIT OAK		X	X	X		Y	N/P	50 - 90
CHARRED FOREST OAK		X	X	X		Y	N/P	50 - 90
NOBLE OAK		X	X	X		Y	N/P	50 - 90
BURNT RUSTIC OAK	X	X	X	X		Y	N/P	50 - 90
BURNT SPLIT OAK		X	X	X		Y	N/P	50 - 90
AMERICAN OAK		X	X	X		Y	N/P	50 - 90
WOOD STACK		X	X	X		Y	N/P	50 - 90
RED OAK		X	X	X		Y	N/P	50 - 90
AGED CEDAR		X	X	X		Y	N/P	50 - 90
SPLIT OAK DESIGNER PLUS		X	X	X		Y	N/P	50 - 90
WOODLAND OAK		X	X	X		Y	N/P	50 - 90
HERITAGE DESIGNER		X	X	X		Y	N/P	75 - 90
WHITE BIRCH		X	X	X		Y	N/P	50 - 90
ROYAL ENGLISH DESIGNER OAK		X	X	X		Y	N/P	75 - 90
SPLIT OAK		X	X	X		Y	N/P	50 - 90
GOLDEN OAK DESIGNER PLUS		X	X	X	X	Y	N/P	50 - 90
FOREST OAK		X	X	X		Y	N/P	50 - 90
SPLIT FOREST OAK		X	X	X		Y	N/P	50 - 90
WESTERN CAMPFYRE		X	X	X		Y	N/P	50 - 90
CEDAR		X	X	X		Y	N/P	50 - 90
CHARRED RED OAK		X	X	X		Y	N/P	50 - 90
BURNT HERITAGE OAK		X	X	X		Y	N/P	50 - 90
CHARRED ROYAL OAK		X	X	X	X	Y	N/P	50 - 90
RUSTIC OAK DESIGNER		X	X	X	X	Y	N/P	50 - 90
RIPPED SPLIT OAK		X	X	X		Y	N/P	40 - 120
RIPPED SPLIT OAK DESIGNER PLUS		X	X	X		Y	N/P	40 - 120
GOLDEN OAK	X	X	X	X	X	Y	N/P	25 - 90
RUSTIC OAK	X	X	X	X	X	Y	N/P	25 - 90
POST OAK		X	X	X		Y	N/P	50 - 90
COASTAL DRIFTWOOD		X	X	X		Y	N/P	50 - 90
ROYAL ENGLISH OAK		X	X	X	X	Y	N/P	50 - 90
HERITAGE OAK		X	X	X		Y	N/P	50 - 90

RH PETERSON, 14724 EAST PROCTOR, CITY OF INDUSTRY, CA 91745 - CONTINUED

MODEL	LOG LENGTHS 12-16	18-22	24-28	30-36	42-96	VENTED (Y OR N)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
CHARRED TRAIL OAK	X	X	X	X		N	N.A.	N.A.
CHARRED FRONTIER OAK	X	X	X	X		N	N.A.	N.A.
GOLDEN OAK DESIGNER		X	X	X		N	N.A.	N.A.
SPLIT OAK		X	X	X		N	N.A.	N.A.
FOREST OAK		X	X	X		N	N.A.	N.A.
VALLEY OAK	X	X	X			N	N.A.	N.A.
GOLDEN OAK DESIGNER	X	X				Y	N/P	39
CHARRED OAK	X	X				Y	N/P	39
EVENING FYRE	X	X	X	X		N	N.A.	N.A.
CHARRED AGED SPLIT	X	X	X	X		N	N.A.	N.A.

HARGROVE MFG., 207 WELLSTON PARK RD, SAND SPRINGS, OK 74063

MODEL	LOG LENGTHS 12-16	18-22	24-28	30-36	42-96	VENTED (Y OR N)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
CLASSIC OAK	X	X	X	X		Y	N/P	N.A.
FULL PAN OAK	X	X	X	X		Y	N/P	N.A.
FULL PAN WESTERN PINE	X	X	X	X		Y	N/P	N.A.
GRAND OAK	X	X	X	X	X	Y	N/P	N.A.
HARGROVE SELECT		X	X	X	X	Y	N/P	N.A.
MOUNTAIN ASPEN		X	X	X		Y	N/P	N.A.
MOUNTAIN TIMBER		X	X	X		Y	N	N.A.
MOUNTAIN TIMBER				X	X	Y	N	N.A.
SUMMIT OAK				X	X	Y	N/P	N.A.
WESTERN PINE	X	X	X	X	X	Y	N/P	N.A.
CUMBERLAND CHAR		X	X	X		N	N/P	27 - 35
HIGHLAND GLOW		X	X			N	N/P	22 - 40
TIMBERLAND GLOW		X	X			N	N/P	22 - 40
CANYON WILDFIRE		X	X	X		Y	N/P	N.A.
INFERNO		X	X	X		Y	N/P	N.A.
MAGNIFICENT INFERNO		X	X	X		Y	N/P	N.A.
SUPREME PONDEROSA			X	X	X	Y	N/P	N.A.
TWILIGHT INFERNO		X	X	X		Y	N/P	N.A.

DESA INTERNATIONAL, 2701 INDUSTRIAL DRIVE, BOWLING GREEN, KY 42102

MODEL	LOG LENGTHS 12-16	18-22	24-28	30-36	42-96	VENTED (Y OR N)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
BILTMORE SPLIT OAK		X	X			N	N/P	30 - 39
CUMBERLAND OAK			X			N	N/P	39
RIVER CANYON OAK		X	X	X		N	N/P	25 - 36
SEASONAL OAK		X	X			N	N/P	27.5 - 31.5
WHITE MOUNTAIN OAK			X	X		N	N/P	10 - 39
AMHERST OAK		X	X			Y	N/P	40 - 60
BERKSHIRE SPLIT OAK		X	X	X		Y	N/P	45 - 70
MENDOCINO OAK		X	X			Y	N/P	55 - 70
OXFORD OAK		X	X			Y	N/P	40 - 60

MONESSEN HEARTH SYSTEMS, 149 CLEVELAND DRIVE, PARIS, KY 40361

MODEL	LOG LENGTHS 12-16	18-22	24-28	30-36	42-96	VENTED (Y OR N)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
VDY DUZY 2			X	X		Y	N/P	50 - 65
VDY DUZY 3			X	X		Y	N/P	50 - 65
VDY DUZY 4			X	X		Y	N/P	50 - 65
VDY DUZY 5			X	X		Y	N/P	50 - 65
VWF AMERICAN OAK		X	X	X	X	Y	N/P	60 - 80
VWF MASSIVE OAK		X	X	X	X	Y	N/P	60 - 80
VWF SPLIT PINE		X	X	X	X	Y	N/P	60 - 80
VWF SPLIT RIVER OAK		X	X	X	X	Y	N/P	60 - 80
VWF WEATHERED PINE		X	X	X	X	Y	N/P	60 - 80
VWF WHITE BIRCH		X	X	X	X	Y	N/P	60 - 80
VWF 36		X	X	X	X	Y	N/P	60 - 80
VWF SEE-THRU		X	X	X	X	Y	N/P	60 - 80
CHARRED TIMBER		X	X	X		Y	N/P	19 - 38
DEB EMBERBLAZE AGED HICKORY		X	X	X		N	N/P	18 - 38
DLX AGED SPLIT		X	X			N	N/P	14 - 33
CTCL CHARRED TIMBER		X	X	X		N	N/P	19 - 38
SMRL EMBERED SPLIT MAPLE		X	X	X		N	N/P	18 - 36
DYD CHARRED HICKORY			X			N	N/P	23 - 36
KSCL EMBERED KENTUCKY STACK		X	X	X		N	N/P	18 - 36
DTS DESIGNER LOG				X		N	N/P	24 - 38

HEATMASTER, PO BOX 1717, ANGIER, NC 27501

MODEL	LOG LENGTHS 12-16	18-22	24-28	30-36	42-96	VENTED (Y OR N)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
CHAMPION		X	X			Y	N/P	N.A.
RUSTIC MOUNTAIN OAK		X	X			Y	N/P	N.A.
RADIANCE		X	X			Y	N/P	N.A.
PREMIER SPLIT OAK		X	X	X		Y	N/P	N.A.
DELUXE BLACKJACK OAK		X	X	X		Y	N/P	N.A.
CLASSIC BLACKJACK OAK		X	X	X		Y	N/P	N.A.
CHOICE HIGHLAND OAK		X	X	X		Y	N/P	N.A.
CHARRED BLACKJACK OAK		X	X	X		Y	N/P	N.A.
OLD ENGLISH OAK		X	X	X		N	N/P	N.A.
HERITAGE SPLIT OAK		X	X	X		N	N/P	N.A.
FREEDOM GLO		X	X	X		N	N/P	N.A.
EMBER GLO		X	X	X		N	N/P	N.A.

AMERICAN HEARTH SYSTEMS, 918 FREEBURG AVE, BELLEVILLE, IL 62222

MODEL	LOG LENGTHS 12-16	18-22	24-28	30-36	42-96	VENTED (Y OR N)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
ULTRA SMART BURNER	X	X	X	X		N	N/P	N.A.

RASMUSSEN GAS LOGS & GRILLS, 12028 E PHILADELPHIA ST, WHITTIER, CA 90601

MODEL	LOG LENGTHS 12-16	18-22	24-28	30-36	42-96	VENTED (Y OR N)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
EVENING CROSS FIRE		X	X	X		Y	N.A.	N.A.
EVENING LONE STAR		X	X	X		Y	N.A.	N.A.
PRESTIGE OAK		X	X	X	X	Y	N.A.	N.A.
EVENING PRESTIGE		X	X	X		Y	N.A.	N.A.
WHITE BIRCH		X	X	X		Y	N.A.	N.A.
MANZANITA	X	X	X	X		Y	N.A.	N.A.
EVENING CAMPFIRE		X	X	X		Y	N/P	N.A.
CROSS-FIRE		X	X	X		Y	N/P	N.A.
BONFIRE		X	X	X	X	Y	N/P	N.A.
LONE STAR	X	X	X	X		Y	N/P	N.A.
FROSTED OAK		X	X	X		Y	N/P	N.A.
TIMBERFIRE				X	X	Y	N/P	N.A.
CHILLBUSTER I		X	X	X		N	N/P	N.A.

GOLDEN BLOUNT, INC., 4301 WESTGROVE DR, ADDISON, TX 75001

MODEL	LOG LENGTHS 12-16	18-22	24-28	30-36	42-96	VENTED (Y OR N)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
TEXAS BONFIRE		X	X	X		Y	N/P	N.A.
BIG KAHUNA				X	X	Y	N/P	N.A.
BIG KAHUNA SEE-THRU				X	X	Y	N/P	N.A.
TEXAS HICKORY		X	X	X		Y	N/P	N.A.
SPLIT BONFIRE			X			Y	N/P	N.A.
SPLIT SERIES	X	X	X	X		Y	N/P	N.A.
TEXAS STACK				X		Y	N/P	N.A.
PAUL BUNYAN		X	X	X		Y	N/P	N.A.
SUPER SIX		X	X	X		Y	N/P	N.A.
TEXAS HICKORY FIRE SEE-THRU		X	X	X		Y	N/P	N.A.
TEXAS FLAME		X	X	X		N	N/P	19 - 38
EMBERBARK		X	X	X		N	N/P	19 - 35

LENNOX HEARTH PRODUCTS, 1110 WEST TAFT AVE, ORANGE, CA 92865

MODEL	LOG LENGTHS 12-16	18-22	24-28	30-36	42-96	VENTED (Y OR N)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
SHGL-18-R		X				Y	N/P	36
SHGL-18-R		X				N	N/P	36
SHGL-24-R			X			Y	N/P	39
SHGL-24-R			X			N	N/P	39
VFGL-18-4		X				N	N/P	14 - 25
VFGL-24-4			X			N	N/P	32
VFGL-28-4			X			N	N/P	32
VFST-27-2			X			N	N/P	34

EMPIRE COMFORT SYSTEMS, INC., 918 FREEBURG AVE, BELLEVILLE, IL 62222

MODEL	LOG LENGTHS 12-16	18-22	24-28	30-36	42-96	VENTED (Y OR N)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
CHARRED OAK	X	X	X	X		Y	N/P	40 - 75
CHARRED OAK	X	X	X	X		N	N/P	32 - 38
SUPER CHARRED OAK		X	X	X		Y	N/P	40 - 75
SUPER CHARRED OAK		X	X	X		N	N/P	32 - 38
BIRCH		X	X	X		Y	N/P	40 - 75
BIRCH		X	X	X		N	N/P	32 - 38
HICKORY		X	X	X		Y	N/P	40 - 75
HICKORY		X	X	X		N	N/P	32 - 38
PONDEROSA		X	X	X		Y	N/P	40 - 75
PONDEROSA		X	X	X		N	N/P	32 - 38
SASSAFRAS		X	X	X		Y	N/P	40 - 75
SASSAFRAS		X	X	X		N	N/P	32 - 38
SUPER SASSAFRAS		X	X	X		Y	N/P	40 - 75
SUPER SASSAFRAS		X	X	X		N	N/P	32 - 38
AGED OAK		X	X	X		Y	N/P	40 - 75
AGED OAK		X	X	X		N	N/P	32 - 38
FLINT HILL		X	X	X		N	N/P	28 - 40

NAPOLEON FIREPLACES, 24 NAPOLEON RD, BARRIE, ON L4M 4Y8, CANADA

MODEL	LOG LENGTHS 12-16	18-22	24-28	30-36	42-96	VENTED (Y OR N)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
PHAZER		X	X	X		Y	N/P	55 - 65
FIBERGLOW		X	X	X		N	N/P	40

PORTLAND WILLAMETTE, 6800 NE 59TH PLACE, PORTLAND, OR 97218

MODEL	LOG LENGTHS 12-16	18-22	24-28	30-36	42-96	VENTED (Y OR N)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
SUPREME OAK	X	X	X	X		Y	N/P	N.A.
MAGIC OAK	X	X	X	X		Y	N/P	N.A.
DELUXE OAK	X	X	X	X		Y	N/P	N.A.
SPLIT OAK	X	X	X	X		Y	N/P	N.A.
NEW ENGLAND BIRCH	X	X	X	X		Y	N/P	N.A.
MANZANITA DRIFTWOOD BURL		X	X			Y	N/P	N.A.
MANZANITA DRIFTWOOD		X	X	X		Y	N/P	N.A.
BLAZING OAK	X	X				Y	N/P	N.A.
CRAGGY PINE	X	X	X	X		Y	N/P	N.A.
GEORGIAN OAK			X	X		Y	N/P	N.A.
SPLIT WOOD		X	X	X		Y	N/P	N.A.
BURNT OAK		X	X	X		Y	N/P	32 - 84

SURE HEAT MF, 3130 MOON STATION RD, KENNESAW, GA 30144

MODEL	LOG LENGTHS 12-16	18-22	24-28	30-36	42-96	VENTED (Y OR N)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
COUNTRY OAK		X	X	X		N	N/P	22 - 40
OAKWOOD		X	X			N	N/P	22 - 40
VALLEY OAK		X	X	X		N	N/P	22 - 40
MOUNTAIN ASH		X	X	X		Y	N	45 - 60
BURNT RIVER OAK		X	X	X		Y	N	45 - 60
COUNTRY OAK		X	X	X		Y	N	45 - 60
COLONIAL BARK		X	X	X		Y	N	45 - 60
CAMPFIRE		X	X	X		Y	N	45 - 60
CROSS CUT		X	X			Y	N	45 - 60

DESIGN DYNAMICS, 2701 SOUTH HARBOR BLVD, SANTA ANA, CA 92704

MODEL	LOG LENGTHS 12-16	18-22	24-28	30-36	42-96	VENTED (Y OR N)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
ARCADIA		X	X			Y	N/P	37 - 58
AVALON		X	X			Y	N/P	38 - 68
CALIFORNIA MAPLE		X	X			Y	N/P	30 - 67
CASCADE		X	X	X		Y	N/P	59 - 74
HARDWOOD		X	X			Y	N/P	30 - 67
KENTUCKY ELM		X	X			Y	N/P	30 - 67
VALHALLA		X	X			Y	N/P	37 - 58
CALICO		X	X	X		N	N/P	21 - 39
MONTEBELLO		X	X			N	N/P	24 - 39
SHERIDAN		X	X			N	N/P	24 - 39
YUKON		X	X			N	N/P	24 - 39

FMI, 2701 SOUTH HARBOR BLVD, SANTA ANA, CA 92704

MODEL	LOG LENGTHS 12-16	18-22	24-28	30-36	42-96	VENTED (Y OR N)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
ARLINGTON OAK		X	X			Y	N/P	40 - 60
STANDARD MANCHESTER OAK		X	X	X		Y	N/P	45 - 70
NEWCASTLE OAK		X	X	X		Y	N/P	50 - 75
MANCHESTER MULTI-SIDED		X	X			Y	N/P	55 - 75
HEAT MAJIC		X	X	X		N	N/P	N.A.
EMBER MASTER		X	X	X		N	N/P	N.A.

Appendix B
Survey of Vented Gas Fireplace Models

CFM MAJESTIC, 410 ADMIRAL BLVD, MISSISSAUGA, ON L5T 2N6, CANADA

MODEL	VENT (DV OR B)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
CHATEAU DVT38	DV	N/P	46
CHATEAU DVT38S2	DV	N/P	56
CHATEAU DVT44	DV	N/P	60
BROOKHAVEN 20DVT	DV	N/P	8.7 - 13
EXTREME VIEW 33XDV	DV	N/P	22
EXTREME VIEW 36XDV	DV	N/P	27.5
EXTREME VIEW 39XDV	DV	N/P	31
GRAND STYLE DV360	DV	N/P	30
GRAND STYLE DV580	DV	N/P	38
HI STYLE DVBR36	DV	N/P	24
HI STYLE DVBR42	DV	N/P	27
PERFECT VIEW 33LDVR	DV	N/P	16
PERFECT VIEW 33LDVT	DV	N/P	16
PERFECT VIEW 36LDVR	DV	N/P	19.5
PERFECT VIEW 36LDVT	DV	N/P	19.5
PERFECT VIEW 39LDVR	DV	N/P	23
PERFECT VIEW 39LDVT	DV	N/P	23
PERFECT VIEW 43LDVR	DV	N/P	27
PERFECT VIEW 43LDVT	DV	N/P	27
THE REGAL COVE 360DVS3	DV	N/P	38
BAY DVRTSB	DV	N/P	30
THE REGAL DUAL VIEW 360DVS2	DV	N/P	38
THE REGAL CROSSING 360DVSL	DV	N/P	38
THE REGAL CROSSING 360DVSR	DV	N/P	38
COMFORT PRO DVHVAC36	DV	N/P	40
TRIBUTE 36CDVR	DV	N/P	21

FPI, 6988 VENTURE ST, DELTA, BC V4G 1H4, CANADA

MODEL	VENT (DV OR B)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
LIBERTY L676	DV	N/P	40 - 42
LIBERTY L900	DV	N/P	46.5 - 48
PANORAMA P33	DV	N/P	21.5 - 22.5
PANORAMA P36	DV	N/P	30
PANORAMA P36D	DV	N/P	30
PANORAMA P40	DV	N/P	43 - 45
PANORAMA P42	DV	N/P	35
PANORAMA P48	DV	N/P	48 - 51
PANORAMA P121	DV	N/P	39 - 40
PANORAMA P131	DV	N/P	39 - 40

HEAT-N-GLO, 20802 KENSINGTON BLVD, LAKEVILLE, MN 55044

MODEL	VENT (DV OR B)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
6000G	DV	N	30
6000GL	DV	N	30
6000GLX	DV	N	40
6000GCF	DV	N	30
8000CF	DV	N/P	36.5 - 37.5
8000TV	DV	N/P	37.5
8000TR	DV	N/P	37.5
BRAVO	DV	N	23
6000GBV	B	N	27
CERONA 36	DV	N	37.5
CERONA 42	DV	N	48
CRESENT	DV	N	29.5
CRESENT II	DV	N	11.5
ESCAPE - 36DV	DV	N	40
ESCAPE - 42DV	DV	N	52
EVEREST	DV	N	33
INIFINITY	DV	N	35
SL-350TRS-C	DV	N	24
SL-550TR	DV	N	21
SL-550TRS	DV	N	27
SL-550TV	DV	N	21
SL-750TR	DV	N	30
SL-750TRS	DV	N	23
SL-750TV	DV	N	23
SL-950TR	DV	N	30
SL-950TV	DV	N	30
SOHO	DV	N	12
SOULSTICE	DV	N/P	17.5
GATEWAY	B	N/P	35
L/R-CORNER-HV-IPI	DV	N	38.5
PASSAGE	DV	N	31
PIER	DV	N	37.5
SEE-THROUGH	DV	N	38.5
ST-42TVFL-IPI	B	N/P	38.5
TWILIGHT II	DV	N/P	37 - 38
CYCLONE	DV	N	15
CYCLONE-CUST	DV	N	15

HEATILATOR, 1915 WEST SAUNDERS ST, MT PLEASANT, IA 52641

MODEL	VENT (DV OR B)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
ICON 100	DV	N/P	40 - 59
ICON 60	DV	N/P	33.5 - 48
CNXT 4236	DV	N/P	40
RBV 4236	B	N/P	40
RBV 4842	B	N/P	43
CNXT 4842	DV	N/P	45
ND3630	DV	N/P	20
ND3933	DV	N/P	22
ND4236	DV	N/P	25
ND4842	DV	N/P	30
NB3630	B	N/P	20
NB3933	B	N/P	22
NB4236	B	N/P	25
NB4842	B	N/P	30
AZTEC	DV	N/P	23
CD4236	DV	N/P	30
CD4842	DV	N/P	33
CB4236	B	N/P	30
CB4842	B	N/P	33
GDST5244I	DV	N/P	43 - 48
GDCH60	DV	N/P	26 - 34
GDCL/CR60	DV	N/P	26 - 34
GDFL60	DV	N/P	26 - 34
GDST60	DV	N/P	26 - 34
GBCL/CR36	B	N/P	34
GBFL36	B	N/P	34
GBST36	B	N/P	34

SUPERIOR, 1110 TAFT AVE, ORANGE, CA 92865

MODEL	VENT (DV OR B)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
SDDV-40	DV	N/P	30
SDDV-35	DV	N/P	27
SSDVST	DV	N/P	37.5
SSDVPF	DV	N/P	37.5
SSDV-4035	DV	N/P	29
SSDV-3530	DV	N/P	23
SSBV-3530	B	N/P	23
SSBV-4035	B	N/P	29
B-40	B	N/P	15
BBV-36	B	N/P	24
BBV-42	B	N/P	30

NAPOLEON FIREPLACES, 24 NAPOLEON RD, BARRIE, ON L4M 4Y8, CANADA

MODEL	VENT (DV OR B)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
BGD33NR	DV	N/P	16.4
GD33NR	DV	N/P	22
BGD34NT	DV	N/P	16.4
GD34NT	DV	N/P	24.5
GD36NTR	DV	N/P	26
BGD36NTR	DV	N/P	17
B36DF	DV	N/P	23
BGD42N-D	DV	N/P	30
BGD48N	DV	N/P	36
BGD40N	DV	N/P	30
GD70NT-S	DV	N/P	35
GD80NT-M	DV	N/P	43
GD82NT	DV	N/P	26
BGD36CF	DV	N/P	17
BGD42CF	DV	N/P	24
BGNV36	B	N/P	17
BGNV40	B	N/P	30
BGNV42	B	N/P	28.5

VANGUARD HEATING PRODUCTS, 2701 INDUSTRIAL DR, BOWLING GREEN, KY 42102

MODEL	VENT (DV OR B)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
VALUE LINE 32	DV	N/P	18
VALUE LINE 36	DV	N/P	26
PERFORMANCE LINE 36	DV	N/P	32
PERFORMANCE LINE 42	DV	N/P	35
PREMIUM LINE 36	DV	N/P	27
PREMIUM LINE 42	DV	N/P	40
SEE-THRU	DV	N/P	31.5 - 35
PENINSULA	DV	N/P	31.5 - 35
CORNER	DV	N/P	31.5 - 35
VALUE LINE	B	N	15
PERFORMANCE LINE	B	N	25
PREMIUM LINE 36	B	N	40
PREMIUM LINE 42	B	N	45
PENINSULA	B	N/P	42
SEE-THRU	B	N/P	42

TRAVIS INDUSTRIES, 4800 HARBOUR POINTE BLVD., MUKILTEO, WA 98275

MODEL	VENT (DV OR B)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
BUNGALOW DVL	DV	N/P	40
CAMBRIDGE DVL	DV	N/P	40
CAMBRIDGE DVS	DV	N/P	31
CRAFTSMAN DVL	DV	NP	40
CRAFTSMAN DVS	DV	N/P	31
BUNGALOW	DV	N/P	16.5
TREE OF LIFE	DV	N/P	16.5
VICTORIAN LACE	DV	N/P	16.5
ROSARIO DVL	DV	N/P	40
ROSARIO DVS	DV	N/P	31
VICTORIAN LACE DVL	DV	N/P	40
VICTORIAN LACE DVS	DV	N/P	31
WINTHROP	DV	N/P	5.2 - 6.7
LOPI DVS	DV	N/P	31
LOPI HEARTHVIEW (864)	DV	N/P	31
LOPI DVL	DV	N/P	40
LOPI HEARTHVIEW (864HH)	DV	N/P	39 - 40
LOPI 21	DV	N/P	16.5
32DVS	DV	N/P	31
864TRV	DV	N/P	31
34 DVL	DV	N	40
BED & BREAKFAST 21	DV	N/P	16.5
REVOLUTION 36CF	DV	N/P	49 - 50
36 DV-XL	DV	N/P	43
44 DV XXL	DV	N/P	58

FMI, 2701 SOUTH HARBOR BLVD, SANTA ANA, CA 92704

MODEL	VENT (DV OR B)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
TUDOR T5000	DV	N/P	17 - 24
TUDOR T6000	DV	N/P	16 - 26
VICTORIAN 36	DV	N/P	22 - 32
VICTORIAN 42	DV	N/P	22 -35
CHATEAU 36	DV	N/P	18 - 27
CHATEAU 42	DV	N/P	24 - 40
SANTA FE	DV	N/P	N.A.
BALBOA	DV	N/P	N.A.
PUEBLO P324	B	N/P	15 - 25
PUEBLO P325	B	N/P	15 - 25
MISSION 36	B	N/P	40
MISSION 42	B	N/P	45
ASPEN	B	N/P	42
MARBLEHEAD	B	N/P	42

LENNOX HEARTH PRODUCTS, 1110 WEST TAFT AVE, ORANGE, CA 92865

MODEL	VENT (DV OR B)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
LSM45-2	DV	N/P	47 - 60
LSM40-2	DV	N/P	40 - 50
LSS-35	DV	N/P	31 - 33
LSS-40	DV	N/P	39 - 41.5
ELDV-45	DV	N/P	25 - 30
ELDV-40	DV	N/P	25 - 30
ELDV-35	DV	N/P	25 - 30
EDV-4540	DV	N/P	35
EDV-4035	DV	N/P	30
EDV-3530	DV	N/P	27
EDVST	DV	N/P	39
EDVPF	DV	N/P	39
EDVCR/CL	DV	N/P	39
EBVST	B	N/P	37.5
EBVPF	B	N/P	37.5
EBVCR/CL	B	N/P	34
LBV-38/43	B	N/P	50
MPB4540	B	N/P	29
MPB4035	B	N/P	29
MPB3530	B	N/P	20
MPB3328	B	N/P	17.5
MPD4540	DV	N/P	29
MPD4035	DV	N/P	29
MPD3530	DV	N/P	20
MPD3328	DV	N/P	17.5
MPD35ST	DV	N/P	22 - 30
MPB35ST	B	N/P	22 - 30
LMDV4035	DV	N/P	27
LMDV3530	DV	N/P	20
LMDV3328	DV	N/P	17.5

PACIFIC ENERGY FIREPLACE PRODUCTS LTD, 2975 ALLENBY RD, DUNCAN, BC V9L 6V8, CANADA

MODEL	VENT (DV OR B)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
THE ESTATE	DV	N/P	30
THE ESTEEM	DV	N/P	21

MONESSEN HEARTH SYSTEMS, 149 CLEVELAND DRIVE, PARIS, KY 40361

MODEL	VENT (DV OR B)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
7000 SERIES	B	N/P	50
BBV400A	B	N/P	22
SBV400A	B	N/P	29
SBV500A	B	N/P	31.5
624BV	B	N/P	42
3000 SERIES	DV	N/P	30
BDV300	DV	N/P	15 - 21
BDV400	DV	N/P	17 - 24
BDV500	DV	N/P	20 - 26
BDV600	DV	N/P	20 - 26
SDV500C	DV	N/P	22 - 30
SDV600C	DV	N/P	25 - 32

KOZY HEAT FIREPLACES, 204 INDUSTRIAL PARK DR, LAKEFIELD, MN 56150

MODEL	VENT (DV OR B)	NATURAL GAS (N) / PROPANE (P)	BTU/HR (IN 1000'S)
932	DV	N/P	26
936	DV	N/P	35 - 36
942	DV	N/P	40 - 42
944	DV	N/P	36 - 40
961	DV	N/P	38
SP-36	DV	N/P	30 - 32
ST PAUL	DV	N/P	39
WINDOM	DV	N/P	18 - 21
PRINCTON	DV	N/P	34.8 - 35
THIEF RIVER FALLS	DV	N/P	28
MINNETONKA	DV	N/P	40
TWO HARBORS	DV	N/P	14.6 - 14.7

Appendix C

Cost Estimates for the Removal or Installation of a Gas Firelog Set in an Existing Fireplace at Various California Locations

Anaheim Patio & Fireside, Inc.
425 N Berry St.
Brea, CA 92821
(714) 617-9445

Abercrombie & Co. Stoves & Stuff
17593 Penn Valley Drive
Penn Valley, CA 95946
(530) 432-2499

Custom Fireside Shops, Inc.
5545 Auburn Blvd
Sacramento, CA 95841
(916) 331-2423

Central Coast Fireplaces
5715 Ground Squirrel Hollow
Paso Robles, CA 93446
(805) 226-8306

Blaze Fireplaces
101 Cargo Way
San Francisco, CA 94124
(415) 495-2002

The Warm Heart
440 Enterprise St.
San Marcos, CA 92078
(760) 744-8680

Valley Stove & Spa
7431 Rosedale Highway
Bakersfield, CA 93308
(661) 587-0242

1-800 Plumbing
Riverside, CA 92501
(951) 485-0236

Seven fireplace shops and one plumber were contacted in California. Assuming a 36 inch manufactured fireplace, the quoted generic price for the purchase and installation of a gas log set ranged from $385 to $1000. Assuming a 15-foot gas line was needed with access through a crawl space, the cost of installation of the gas piping ranged from $300 to $1000. The quoted generic cost for removing a gas log set and capping the gas line ranged from $85 to $105.

Appendix D
California Firewood Prices
(All prices are for one cord of firewood delivered to residence.)

Holiday Firewood
Pasadena
(626) 285-0860
$250 – mixed

Sepulveda
Palm Desert
(800) 349-4726
$367.98 to $403.94 – mixed

Custom Country
San Clemente
(949) 768-8635
$305 – mixed

Homestead Firewood
Yucaipa
(909) 797-2398
$260 – mixed

Mapes Enterprises
South Lake Tahoe
(530) 544-5034
$200 – mixed

NPC Firewood
Gold River
(916) 853-9543
$440.70 – hardwood

Rosenbaum Ranch
San Juan Capistrano
(949) 364-6468
$255 – Eucalyptus/Pine

Whitts Woodyard
Los Angeles
(310) 478-2630
$374.55 – mixed

A-1 Firewood
Elk Grove
(916) 686-9595

$324 – Walnut
$360 – Almond
$410 – Oak
A-Corp Firewood
Bakersfield
(661) 589-4224
$249 – mixed

Aptos Firewood
Felton (near Santa Cruz)
(831) 479-4400
$315 – mixed

Mt Shasta News
Classified Ads
$170 – Lodgepole
$250 – Oak
$225 – Locust

Bay Area Craigslist
Los Gatos
$200 – Oak & Madrone

Sacramento Craigslist
$150 – mixed
$300 – Oak
$240 – Eucalyptus

Appendix E
Calculations

Contents of Appendix E

1. Abbreviations Used in Calculations

AW	Atomic Weight
C	Carbon
CO_2-Eq.	Carbon Dioxide Equivalent
EROEI	Energy Return on Energy Investment
FFE	Fireplace Fire Event
GHG	Greenhouse Gas
GWP	Global Warming Potential
LPG	Liquefied Petroleum Gas
MW	Molecular Weight
NG	Natural Gas

2. Calculations and Assumptions – Direct Emissions of CO_2 from Combustion

Vented Natural Gas Fireplace	
30.72 X 10^3 Btu/hr	Table 1 in text
2.5 hrs/FFE	Table 6 in text
33 lbs C/10^6 Btu	Ref. E1
Ratio MW CO_2/AW Carbon = 44/12 = 3.67	
(30.72 X 10^3 Btu/hr) X (2.5 hrs/FFE) X (33 lbs C/10^6 Btu) X (3.67) = 9.30 lbs CO_2/FFE	
Vented LPG Fireplace	
30.72 X 10^3 Btu/hr	Table 1 in text
2.5 hrs/FFE	Table 6 in text
37.7 lbs C/10^6 Btu	Ref. E1
Ratio MW CO_2/AW Carbon = 3.67	
(30.72 X 10^3 Btu/hr) X (2.5 hrs/FFE) X (37.7 lbs C/10^6 Btu) X (3.67) = 10.6 lbs CO_2/FFE	
Vented Natural Gas Log Set	
62.38 X 10^3 Btu/hr	Table 1 in text
2.5 hrs/FFE	Table 6 in text
33 lbs C/10^6 Btu	Ref. E1
Ratio MW CO_2/AW Carbon = 3.67	
(62.38 X 10^3 Btu/hr) X (2.5 hrs/FFE) X (33 lbs C/10^6 Btu) X (3.67) = 18.9 lbs CO_2/FFE	
Vented LPG Log Set	
62.38 X 10^3 Btu/hr	Table 1 in text
2.5 hrs/FFE	Table 6 in text
37.7 lbs C/10^6 Btu	Ref. E1
Ratio MW CO_2/AW Carbon = 3.67	
(62.38 X 10^3 Btu/hr) X (2.5 hrs/FFE) X (37.7 lbs C/10^6 Btu) X (3.67) = 21.6 lbs CO_2/FFE	

Cordwood — Solid Fuel Fireplace	
3.50 dry Kg/hr (mode of burn rate distribution, see discussion in text)	Table 3 in text
3.5 hrs/FFE	Table 6 in text
2.2 lbs/Kg	
0.501 carbon fraction of dry wood fuel, mean of 29 tree species	Ref. E2
Ratio MW CO_2/AW Carbon = 3.67	
(3.50 dry Kg/hr) X (3.5 hrs/FFE) X (2.2 lbs/Kg) X (0.501 carbon fraction) X (3.67)= 49.7 lbs CO_2/FFE	
Traditional Petroleum Wax-Fiber Firelog — Solid Fuel Fireplace	
0.74 dry Kg/hr (mean burn rate)	Table 1 in text
3.3 hrs	Table 6 in text
2.2 lbs/Kg	
0.676 carbon fraction in dry firelog	Refs. E18 & E19
Assume 55% wax and 45% fiber	
Carbon fraction in wood fiber 0.501 (mean of 29 tree species)	Ref. E2
Carbon fraction in wax = (0.55) X (X) + (0.45) X (0.501) = (1) X (0.676), therefore, X = 0.82	
Ratio MW CO_2/AW carbon = 3.67	
Total CO_2/FFE = (0.74 dry Kg/hr) X (3.3 hrs) X (2.2 lbs/Kg) X (0.676 fraction total carbon) X (3.67) = 13.3 lbs CO_2/FFE	
Modern carbon fraction (0.45) X (0.501) = 0.225	
Fossil carbon fraction (0.55) X (0.82) = 0.451	
Modern carbon CO_2/FFE = (0.74 dry Kg/hr) X (3.3 hrs) X (2.2 lbs/Kg) X (0.225 fraction modern carbon) X (3.67) = 4.43 lbs CO_2/FFE	
Fossil carbon CO_2/FFE = (0.74 dry Kg/hr) X (3.3 hrs) X (2.2 lbs/Kg) X (0.0.451 fraction fossil carbon) X (3.67) = 8.90 lbs CO_2/FFE	
Biowax-Fiber Firelog — Solid Fuel Fireplace	
0.74 dry Kg/hr (mean burn rate)	Table 1 in text
3.3 hrs/FFE	Table 6 in text
2.2 lbs/Kg	
0.670 carbon fraction in dry firelog	Ref. E3
Ratio MW CO_2/AW Carbon = 3.67	
(0.74 dry Kg/hr) X (3.3 hrs/FFE) X (2.2 lbs/Kg) X (0.670 fraction carbon) X (3.67) = 13.2 lbs CO_2/FFE	
GHG CO_2 in lbs CO_2-Eq. from Direct Emissions (GWP CO_2 = 1)	
Vented Natural Gas Fireplace = 9.30 lbs CO_2-EQ./FFE	
Vented LPG Fireplace = 10.6 lbs CO_2-EQ./FFE	
Vented Natural Gas Firelog Set = 18.9 lbs CO_2-EQ./FFE	
Vented LPG Firelog Set = 21.6 lbs CO_2-EQ./FFE	
Cordwood — Solid Fuel Fireplace = 0 lbs CO_2-EQ./FFE	

Traditional Petroleum Wax-Fiber Firelog — Solid Fuel Fireplace = 8.9 lbs CO_2-EQ./FFE	
Biowax-fiber Firelog— Solid Fuel Fireplace= 0 lbs CO_2-EQ./FFE	

3. Calculations and Assumptions – Indirect CO_2 Emissions Due to Energy Trajectory (Energy Investment)

Vented Natural Gas Fireplace	
EROEI for natural gas (onshore) = 10.3	Ref. E4
Assume energy investment primarily in the form of petroleum gas, diesel, and heating oil with an avg. GHG of 84 g CO_2-Eq./MJ	Ref. E5
Direct Energy Used per FFE = (30.72 X 10^3 Btu/hr) X (2.5 hrs/FFE) = 76,800 Btu/FFE	Data from tables 1 and 6 in text
Energy Investment = (1/10.3) X (76,800 Btu/FFE) = 7456 indirect Btu/FFE	
Indirect CO_2 GHG emissions = (7465 Btu/FFE) X (1055 J/Btu) X (84 g/CO_2-Eq./MJ) X (1 MJ/10^6J) X (1 lb/454 g) = 1.4 lb CO_2-Eq./FFE	
Vented LPG Fireplace	
69% of LPG is from natural gas plants, 31% is from refineries	Ref. E6
Assume EROEI for LPG from natural gas plants equals EROEI for natural gas (10.3)	Ref. E4
Assume EROEI for LPG from refineries equals EROEI for petroleum gas (0.85)	Ref. E5
Weighted EROEI = (0.69) X (10.3) + (0.31) X (0.85) = 7.38	
Assume energy investment primarily in the form of petroleum gas, diesel, and heating oil with an avg. GHG of 84 g CO_2-Eq./MJ	Ref. E5
Direct energy used per FFE 76,800 Btu/FFE	See previous calc.
Energy investment (1/7.38) X (76,800 Btu/FFE) = 10,406 Btu/FFE	
Indirect CO_2 GHG emissions (10,406 Btu/FFE) X (1055 J/Btu) X (84 g CO_2-Eq/MJ) X (MJ/10^6J) X (1 lb/454 g) = 2.0 lb CO_2-Eq./FFE	
Vented Natural Gas Log Set	
EROEI = 10.3	Ref. E4
Assume energy investment primarily in the form of petroleum gas, diesel, and heating oil with an avg. GHG of 84 g CO_2-Eq./MJ	Ref. E5
Direct energy used per FFE (62.38 X 10^3 Btu/hr) X 2.5 hr/FFE) = 155,950 Btu/FFE	Data from tables 1 and 6 in text
Energy investment (1/10.3) X (155,950 Btu/FFE) = 15,141 Btu/FFE	
Indirect CO_2 GHG emissions (15,141Btu/FFE) X (1055 J/Btu) X (84 g CO_2-Eq./MJ) X (MJ/ 10^6J) X (1 lb/454 g) = 3.0 lb CO_2-Eq./FFE	
Vented LPG Log Set	

EROEI = 7.38	See previous calc
Assume energy investment primarily in the form of petroleum gas, diesel, and heating oil with an avg. GHG of 84 g CO_2-Eq./MJ	Ref E5
Direct energy used per FFE (62.38 X 10^3 Btu/hr) X (2.5 hr/FFE) = 155,950 Btu/FFE	Data from tables 1 and 6 in text
Energy investment (1/7.38) X (155,950 Btu/FFE) = 21,131 Btu/FFE	
Indirect CO_2 GHG emissions (21,131 Btu/FFE) X (1055 J/Btu) X (84 g CO_2-Eq./MJ) X (MJ/ 10^6J) X (1 lb/454 g) = 4.1 lb CO_2-Eq./FFE	
Cordwood — Solid Fuel Fireplace	
3.50 dry Kg/hr (mode of burn rate distribution, see discussion in text)	Table 3 in text
3.5 hrs/FFE	Table 6 in text
8634 Btu/dry lb (mean of 29 tree species)	Ref. E3
Direct energy used per FFE (3.50 dry Kg/hr) X (3.5 hrs/FFE) X (2.2 lbs/Kg) X (8634 Btu/lb) = 232,686 Btu/FFE	
Energy investment (1/27.6) X (232,686 Btu/FFE) = 8431 Btu/FEE	
Indirect CO_2 GHG emissions (8431 Btu/FFE) X (1055 J/Btu) X (84 g CO_2-Eq./MJ) X (MJ/ 10^6 J) X (1 lb/454 g) = 1.6 lb CO_2-Eq./FFE	
Traditional Petroleum Wax-Fiber Firelog — Solid Fuel Fireplace	
Appx. composition: 55% petroleum waxes, 45% wood and agricultural fibers (pressed form)	
EROEI grass pellets = 13.8, petroleum gasoline = 0.85	Refs. E5 & E8
Total energy = 13,969 Btu/lb	Data from Refs. E18 and E19
Energy in fiber portion = 8634 Btu/lb (mean of 29 tree species)	Ref E2
Energy in petroleum waxes (0.55) X (X) + (0.45) X (8634 Btu/lb) = (1) X (13,969 Btu/lb), therefore X = 18,334 Btu/lb	
Total energy in fiber = (8634 Btu/lb) X (0.45) X (6 lbs/FFE) = 23,312 Btu/FFE	
Total energy in petroleum waxes = (18,334 Btu/lb) X (0.60) X (6 lbs/FFE) = 60,502 Btu/FFE	
Total energy in firelog = (18,334 Btu/lb) X (6 lb/FFE) = 60,502 Btu/FFE	
Weighed EROEI = (60,5020 Btu/FFE) / (83,814 Btu/FFE) X (0.85) + (23,312 Btu/lb) / (83,814 Btu/lb) X (13.8) = 4.44	
Assume energy investment primarily in the form of petroleum gas, diesel, and heating oil with an avg. GHG of 84 g CO_2-Eq./MJ	Ref E5
Direct energy used per FFE (13,969 Btu/lb) X (6 lbs) = 83,814 Btu/FFE	Data from Ref. E3
Energy investment (1/4.44) X (83,814 Btu/FFE) = 18,877 Btu/FEE	
Indirect CO_2 GHG emissions (18,8771 Btu/FFE) X (1055 J/Btu) X (84 g CO_2-Eq./MJ) X (MJ/ 10^6 J) X (1 lb/454 g) = 3.7 lbs CO_2-Eq./FFE	

Biowax-Fiber Firelog — Solid Fuel Fireplace	
Appx. composition: 60% natural oils and waxes, 40% wood and agricultural fibers (pressed form)	
EROEI grass pellets = 13.8, palm oil = 1.06	Refs. E5 & E8
Total energy = 13,293 Btu/lb	Data from Ref. E3
Energy in fiber portion = 8634 Btu/lb (mean of 29 tree species)	Ref E2
Energy in natural oils and waxes (0.60) X (X) + (0. 40) X (8634 Btu/lb) = (1) X (13,293 Btu/lb), therefore X = 16,398 Btu/lb	
Total energy in fiber = (8634 Btu/lb) X (0.40) X (6 lbs/FFE) = 20,722 Btu/FFE	
Total energy in natural oils and waxes = (16,398 Btu/lb) X (0.60) X (6 lbs/FFE) = 59,033 Btu/FFE	
Total energy in firelog = (13,293 Btu/lb) X (6 lb/FFE) = 79,758 Btu/FFE	
Weighed EROEI = (59,033 Btu/FFE) / (79,758 Btu/FFE) X (1.06) + (20,722 Btu/lb) / (79,758 Btu/lb) X (13.8) = 4.37	
Assume energy investment primarily in the form of petroleum gas, diesel, and heating oil with an avg. GHG of 84 g CO_2-Eq./MJ	Ref E5
Direct energy used per FFE (13,293 Btu/lb) X (6 lbs) = 79,758 Btu/FFE	Data from Ref. E3
Energy investment (1/4.37) X (79,758 Btu/FFE) = 18,251 Btu/FEE	
Indirect CO_2 GHG emissions (18,251 Btu/FFE) X (1055 J/Btu) X (84 g CO_2-Eq./MJ) X (MJ/ 10^6 J) X (1 lb/454 g) = 3.6 lbs CO_2-Eq./FFE	
GHG CO_2 in lbs CO_2-Eq. from Indirect Emissions Due to Energy Trajectory (Energy Investment) (GWP CO_2 = 1)	
Vented Natural Gas Fireplace = 1.4 lbs CO_2-EQ./FFE	
Vented LPG Fireplace = 2.0 lbs CO_2-EQ./FFE	
Vented Natural Gas Firelog Set = 3.0 lbs CO_2-EQ./FFE	
Vented LPG Firelog Set = 4.1 lbs CO_2-EQ./FFE	
Cordwood — Solid Fuel Fireplace = 1.6 lbs CO_2-EQ./FFE	
Traditional Petroleum Wax-Fiber Firelog — Solid Fuel Fireplace= 3.7 lbs CO_2-EQ./FFE	
Biowax-Fiber Firelog— Solid Fuel Fireplace= 3.6 lbs CO_2-EQ./FFE	

4. Calculations and Assumptions – Direct Emissions of CH_4 from Combustion

Vented Natural Gas Fireplace	
76,800 Btu/FFE	See previous calc.
EPA emission factor 2.31 lbs $CH_4/10^6$ std ft^3 (2.31 lbs $CH_4/10^6$ std ft^3) X (1 std ft^3/1027 Btu NG) = 2.24 X 10^{-9} lbs CH_4/Btu	Ref E9

GRI emission factor for vented room heaters with yellow-tipping flames 3.21 lbs $CH_4/10^9$ Btu = 3.21X 10^{-9} lbs CH_4/Btu	Ref E10
Avg. of EPA and GRI emission factors 2.72 X 10^{-9} lbs CH_4/Btu	
Direct CH_4 emissions (76,800 Btu/FFE) X (2.72 X 10^{-9} lbs CH_4/Btu) = 2.09 X 10^{-4} lbs CH_4/FFE	
Vented LPG Fireplace	
76,800 Btu/FFE	See previous calc.
EPA emission factor 0.2 lbs $CH_4/10^3$ gal. 0.2 lbs $CH_4/10^3$ gal. = 2 X 10^{-4} lbs CH_4/gal. (2 X 10^{-4} lbs CH_4/gal.) / (9.15 X 10^4 Btu/gal. LPG) = 2.18 X 10^{-9} lbs CH_4/Btu	Ref E11
Direct CH_4 emissions (76,800 Btu/FFE) X (2.18 X 10^{-9} lbs CH_4/Btu) = 1.67 X 10^{-4} lbs CH_4/FFE	
Vented Natural Gas Log Set	
155,950 Btu/FFE	See previous calc.
Emission factor 2.72 X 10^{-9} lbs CH_4/Btu	2.72 X 10^{-9} lbs CH_4/Btu
Direct CH_4 emissions (155,950 Btu/FFE) X (2.72 X 10^{-9} lbs CH_4/Btu) = 4.24 X 10^{-4} lbs CH_4/FFE	
Vented LPG Log Set	
155,950 Btu/FFE	See previous calc.
EPA emission factor 2.18 X 10^{-9} lbs CH_4/Btu	Ref. E11 and previous calc.
Direct CH_4 emissions (155,950 Btu/FFE) X (2.18 X 10^{-9} lbs CH_4/Btu) = 3.40 X 10^{-4} lbs CH_4/FFE	
Cordwood — Solid Fuel Fireplace	
Weight of dry fuel/FFE = (3.50 dry Kg/hr) X (3.5 hrs/FFE) X (2.2 lbs/Kg) = 26.9 lbs/FFE	Tables 1 and 6 in text
CH_4 emission factor (from literature review) = 7.21 g CH_4/Kg dry fuel	Ref. E12
Direct CH_4 emissions (26.9 lbs/FFE) X (7.21 g CH_4/Kg) X (1 Kg/2.2 lbs) X (1 lb/454 g) = 1.94 X 10^{-1} lbs CH_4/FFE	
Traditional Petroleum Wax-Fiber Firelog — Solid Fuel Fireplace	
6 lb firelog/FFE = 2.73 Kg/FFE	
Emission factor = 38.75 CH_4/Kg fuel	Ref. E12
Direct CH_4 emissions (2.73 Kg/FFE) X (38.75 g CH_4/Kg) (1 lb/454 g) = 2.33 X 10^{-1} lbs CH_4/FFE	
Biowax-Fiber Firelog — Solid Fuel Fireplace	

6 lb firelog/FFE = 2.73 Kg/FFE	
Emission factor = 5.9 g CH_4/Kg fuel	Ref. E3
Direct CH_4 emissions (2.73 Kg/FFE) X (5.9 g CH_4/Kg) (1 lb/454 g) = 3.55 X 10^{-2} lbs CH_4/FFE	
GHG CH_4 in lbs CO_2-Eq. from Direct Emissions (GWP CO_2 = 21)	
Vented Natural Gas Fireplace = 4.39 X 10^{-3} lbs CO_2-EQ./FFE	
Vented LPG Fireplace = 3.51 X 10^{-3} lbs CO_2-EQ./FFE	
Vented Natural Gas Firelog Set= 8.90 X 10^{-3} lbs CO_2-EQ./FFE	
Vented LPG Firelog Set = 7.14 X 10^{-3} lbs CO_2-EQ./FFE	
Cordwood — Solid Fuel Fireplace = 4.07lbs CO_2-EQ./FFE	
Traditional Petroleum Wax-Fiber Firelog— Solid Fuel Fireplace = 4.89 lbs CO_2-EQ./FFE	
Biowax-Fiber Firelog— Solid Fuel Fireplace = 7.46 X 10^{-1} lbs CO_2-EQ./FFE	

5. Calculations and Assumptions – Fugitive CH_4 Emissions

Fugitive Loss of CH_4 in Natural Gas System	
2004 national production of natural gas 18.8 X 10^{12} std.ft^3	Ref. E13
Natural gas averages 89.9% CH_4	Table E1
2004 national production of CH_4 = (1.88 X 10^{13} std. ft^3 NG) X (0.899) = 1.69 X 10^{13} std. ft^3 CH_4	
Volume of 1 lb-mole (16 lbs) of methane is 378.7 std ft^3	Ref. E14
Weight of 2004 national production of CH_4 (1.69 X 10^{13} std ft^3) / (378.7 std ft^3/16 lb) = 7.14 X 10^{11} lbs CH_4	
In 2004, 5,658Gg CH_4 lost in natural gas system (5.658 g X 10^{12} g CH_4) (5.658 X 10^{12} g CH_4) X (1 lb/454 g) = 1.25 X 10^{10} lbs CH_4 lost (See Table E2 for list of fugitive sources)	Ref. E13
Fraction of delivered CH_4 lost (1.25 X 10^{10} lbs) / (7.14 X 10^{11} lbs) = 0.0175	
Vented Natural Gas Fireplace	
76,800 Btu/FFE	See previous calc.
Weight CH_4 delivered per FFE (76,800 Btu/FFE) X (1 std ft^3/1027 Btu) X (0.899 fraction CH_4) x 16 lbs CH_4/ 378.7 std ft3) = 2.84 lbs CH_4	
Weight of CH_4 lost per FFE (2.84 lbs CH_4) X (0.0175) = 4.97 X 10^{-2} lbs CH_4	
Vented Natural Gas Log Set	
155,950 Btu/FFE	See previous calc.
Weight CH_4 delivered per FFE (155,950 Btu/FFE) X (1 std ft^3/1027 Btu) X (0.899 fraction CH_4) x (16 lbs CH_4/ 378.7 std ft^3) = 5.78 lbs CH_4	

Weight of CH_4 lost per FFE (5.78 lbs CH_4) X (0.0175) = 1.01X 10^{-1} lbs CH_4	
Vented LPG Fireplaces and Vented LPG Log Sets	
The fugitive emissions of CH_4 associated with LPG are small. Studies have shown that less than 1% of hydrocarbon emissions from refineries are methane and methane is only at the fraction of a percent level in LPG as compare to being the major constituent in natural gas.	Table E3 and Refs. E13 and E15
Cordwood — Solid Fuel Fireplace, Traditional Petroleum Wax-Fiber Firelog — Solid Fuel Fireplace, and Biowax-Fiber Firelog — Solid Fuel Fireplace	
Fugitive CH_4 emissions related to cordwood and firelogs are negligible.	
GHG CH_4 in lbs CO_2-Eq. from Fugitive Emissions (GWP CO_2 = 21)	
Vented Natural Gas Fireplace = 1.0 lbs CO_2-EQ./FFE	
Vented LPG Fireplace = 0 lbs CO_2-EQ./FFE	
Vented Natural Gas Firelog Set= 2.1 lbs CO_2-EQ./FFE	
Vented LPG Firelog Set = 0 lbs CO_2-EQ./FFE	
Cordwood — Solid Fuel Fireplace = 0 lbs CO_2-EQ./FFE	
Traditional Petroleum Wax-Fiber Firelog — Solid Fuel Fireplace= 0 lbs CO_2-EQ./FFE	
Biowax-Fiber Firelog— Solid Fuel Fireplace= 0 lbs CO_2-EQ./FFE	

6. Tables

Table E1
Average Composition of Natural Gas

City	Components of Gas, % by Volume								Heating Value (Btu/ft^3)
	Methane	Ethane	Propane	Butanes	Pentanes	Hexanes plus	CO_2	N_2	
Baltimore, MD	94.40	3.40	0.60	0.50	0.00	0.00	0.60	0.50	1051
Birmingham, AL	93.14	2.50	0.67	0.32	0.12	0.05	1.06	2.14	1024
Boston, MA	93.51	3.82	0.93	0.28	0.07	0.06	0.94	0.39	1057
Columbus, OH	93.54	3.58	0.66	0.22	0.06	0.03	0.85	1.11	1028
Dallas, TX	86.30	7.25	2.78	0.48	0.07	0.02	0.63	2.47	1093
Houston, TX	92.50	4.80	2.00	0.30	…	…	0.27	0.13	1031
Kansas City, MO	72.79	6.42	2.91	0.50	0.06	trace	0.22	17.10	945
Los Angeles, CA	86.50	8.00	1.90	0.30	0.10	0.10	0.50	2.60	1084
Milwaukee, WI	89.01	5.19	1.89	0.66	0.44	0.02	0.00	2.73	1051
New York, NY	94.52	3.29	0.73	0.26	0.10	0.09	0.70	0.31	1049
Phoenix, AZ	87.37	8.11	2.26	0.13	0.00	0.00	0.61	1.37	1071
Salt Lake City, UT	91.17	5.29	1.69	0.55	0.16	0.03	0.29	0.82	1082
San Francisco, CA	88.69	7.01	1.93	0.28	0.03	0.00	0.62	1.43	1086
Washington, D.C.	95.15	2.84	0.63	0.24	0.05	0.05	0.62	0.42	1042
Average	89.90	5.11	1.54	0.36	0.10	0.04	0.57	2.39	1050
Standard Deviation	5.82	1.95	0.82	0.15	0.11	0.03	0.29	4.33	38

Data from reference E14

Table E2
Methane Emission Sources within the Natural Gas Industry

Segment	Emission Source Types (Facilities / Equipment)	Equipment Components and Practices (that cause emissions)
Production	Wells, Surface Equipment, Gathering Facilities	Valve Stems, Flanges, Compressor Seals, Pneumatic Devices, Glycol Dehydrator Vents, Chemical Injection Pumps, Maintenance Blowdowns, Flaring, Compressor Exhaust, Line Leaks, Pressure Relief Valve (PRV) Lifts, Etc.
Processing	Gas Plants	Valve Stems, Flanges, Compressor Seals, Glycol Dehydrator Vents, Maintenance Blowdowns, Flaring, Compressor Exhaust, Line Leaks, PRV Lifts, Etc.
Transmission	Transmission Pipelines, Meter and Pressure Regulating Stations, and Compressor Stations	Valve Stems, Flanges, Compressor Seals, Pneumatic Devices, Maintenance and Emergency Blowdowns, Flaring, Compressor Exhaust, Line Leaks, Etc.
Storage	Underground Injection / Withdrawal Facilities, Liquefied Natural Gas (LNG) Facilities	Valve Stems, Flanges, Compressor Seals, Pneumatic Devices, Glycol Dehydrator Vents, Chemical Injection Pumps, Maintenance Blowdowns, Flaring, Compressor Exhaust, Line Leaks, PRV Lifts, Etc.
Distribution	Mains (pipelines), Services (pipelines), Meter and Pressure Regulating Stations	Valve Stems, Flanges, Pneumatic Devices, Maintenance Blowdowns, Line Leaks, Etc.

Reference E16

Table E3
Average Composition of LPG[1]

Component	Percent by Volume
Propane	94%
Ethane	2%
Propylene	3%
Butanes	1%

[1]Data from reference D17

7. References for Appendix E

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