CLEAN HEAT

Putting Home Heating Fuels into Environmental Perspective

When thinking of energy consumption on a national scale, the large iron and steel mills of Gary, Indiana or the congested freeways of Los Angeles come to mind. Home space heating intuitively does not seem significant. However, there were an estimated 99 million households in the U.S. in 1997, most of which required some form of space heating. Approximately six quadrillion Btus (quads) of energy were consumed for space heating in those households, representing about $45 billion in expenditures. Significantly, energy used directly for space heating represents about 8% of the total energy consumed nationally for all purposes, including transportation. In addition, considerable ancillary energy beyond the 8% is also needed for the ultimate production of space heat. This includes energy for such activities as extracting, transporting, processing and distributing fossil fuels. About 86% of the space heating energy is derived from fossil fuels.

The major energy sources for residential space heating, in descending order of use, are natural gas, fuel oil, wood, electricity, liquefied petroleum gas (LPG), coal and kerosene. All forms of energy consumption have associated environmental and human health impacts. These include impacts to ambient air, water, and land. Concepts such as "total environmental costs" (TECs), "environmental externalities," and "energy return on investment" (EROI) have been introduced to aid in the assessment of the real environmental and societal costs of energy. Even with these concepts, environmental concerns and associated regulations are frequently myopic and national or global issues take the back seat to local air quality problems. To see the "bigger picture" when comparing national or global scale air quality impacts for the various home heating energy options, the emissions from off-site production, processing, and transportation of the energy must be taken into consideration along with the pollu-

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tants emitted locally from individual residences.

Regional visibility loss due to fine particles, global warming caused by greenhouse gases and the damage to lakes and rivers from acid precipitation are among the most topical large scale air quality issues of the day. Home space heating contributes to each of them.

ENERGY TRAJECTORY

The sequence of linked activities which connect the supply of an energy resource with a specific end use has been referred to as the energy trajectory. For example, for coal, the energy trajectory to the residential space heating end use consists of:
1. Extraction (surface or underground mining),
2. Transportation from the mine to the processing plant (trucking, conveyor or mine rail),
3. Processing (cleaning, sulfur removal, crushing, sizing and drying), 4. Storage (above- and underground piles, silos or bins),
5. Distribution to a coal-fired power plant or to a residential heating unit (unit train, mixed train, river barge, pipeline slurry, trucking and/or conveyors), and,
6. Combustion for the production of energy. If the coal is delivered to a coal-fired power plant for power generation two additional components of the energy trajectory are the transmission of the power produced to the home and its final use for electric heating in the home. Air pollutant emission factors need to be determined for each step of the trajectory and finally summed to obtain an overall emission value. In addition, the efficiency of each step must also be taken into consideration because successive efficiency losses with each step have the effect of causing more energy or energy equivalents to pass through the initial stages of the trajectory with a commensurate increase in the total air emissions.

Natural gas and petroleum have similar energy trajectories as coal (i.e., extraction, transportation to processing facilities, processing, storage, transportation to a power plant or residential heating unit, combustion, and the case of electricity, transmission of electric power to the home and its use there to produce heat). The trajectory of petroleum products is more complex than for either coal or natural gas because production and processing of LPG, kerosene, distillate oil and residual oil are interrelated.

Energy Consumed by Source for Residential Space Heating in the United States

	electricity	natural gas	fuel oil	kerosene	LPG	wood	coal
households (x 10^6)	37.1	52.6	10.7	3.6	5.6	20.4	0.2
total energy consumed	119 billion KWH	3570 billion cubic ft.	6.51 billion gallons	0.34 billion gallons	3.25 billion gallons	27.4 million cords	3 million short
total energy consumed in quads	0.41 (1.22)[1]	3.67	0.90	0.05	0.30	0.55	0.06
percent of total	6.9	61.8	15.1	0.8	5.1	9.2	1.0

1. The 1.22 quad value in parenthesis is the energy consumed by power plants to produce the 0.41 quads of electricity consumed in residences for space heating.

The energy trajectory for wood to residential home heating is quite different and simpler than for fossil fuels. Air emissions from the actual home heating combustion step dominate the overall emissions for its energy trajectory. The energy return on investment (EROI) for wood harvesting is very high, i.e., the ratio of energy obtained from the wood to the energy consumed in fossil fuel to harvest it is large.

GREENHOUSE GASES

Carbon dioxide, methane and nitrous oxide are the principal greenhouse gases from energy sources. Methane and nitrous oxide are more potent greenhouse gases than carbon dioxide. The capacity of methane and nitrous oxide to trap heat and their longer lifetime in the atmosphere produce a global warming potential (GWP) of 21 and 310, respectively, as com-

"In terms of global atmospheric impacts, natural gas and wood are the two winners."

pared to carbon dioxide which has a GWP of 1. The standard convention for reporting total greenhouse gas effects is to multiply the emissions of methane and nitrous oxide by 21 and 310, respectively, then add these values to the carbon dioxide value. It is also the standard convention to express greenhouse gas emissions as "carbon equivalents" which simply means that the greenhouse gas emissions are expressed as the mass of carbon that would be in the greenhouse gases if they were all carbon dioxide.

In reviewing the relative contributions of carbon dioxide, methane and nitrous oxide to the greenhouse effect, it was discovered that carbon dioxide from combustion dominates the impact for all energy sources used for home heating. Except for natural gas, carbon dioxide is responsible for more than 95% of the greenhouse gas impact from the energy sources. (Less than 4% is from methane and less than 1% is from nitrous oxide.) For natural gas, methane contributes about 11% to its total greenhouse effect. This is reasonable when the facts that natural gas is composed primarily of methane and that considerable natural gas losses occur in the extraction, transport and processing of natural gas are taken into consideration.

The effective carbon dioxide emissions from residential wood combustion (RWC) is about 40% lower than its actual carbon dioxide emissions because the harvesting of mature trees for cordwood permits rapid carbon fixation in younger replacement trees. While carefully managed wood fuel plantations could achieve a nearly "greenhouse gas neutral" condition, a reasonable estimate of the steady state condition produced by standard wood harvesting practices is that on the average about 40% of the carbon emitted by RWC is fixed (removed from the atmosphere) by the forest biomass.

Residential wood combustion has the lowest effective greenhouse impact per unit of energy delivered followed by natural gas. Electricity has the highest greenhouse impact, with the direct use of coal and petroleum being intermediate in impacts. It is reasonable that electricity has a higher impact than either coal or petroleum burned directly in home heating appliances since 1.22 quads of energy were consumed by electric power generating units in 1993 to produce only 0.41 quads delivered to residences for home heating and since coal and petroleum together account for 64% of the electrical energy generated.

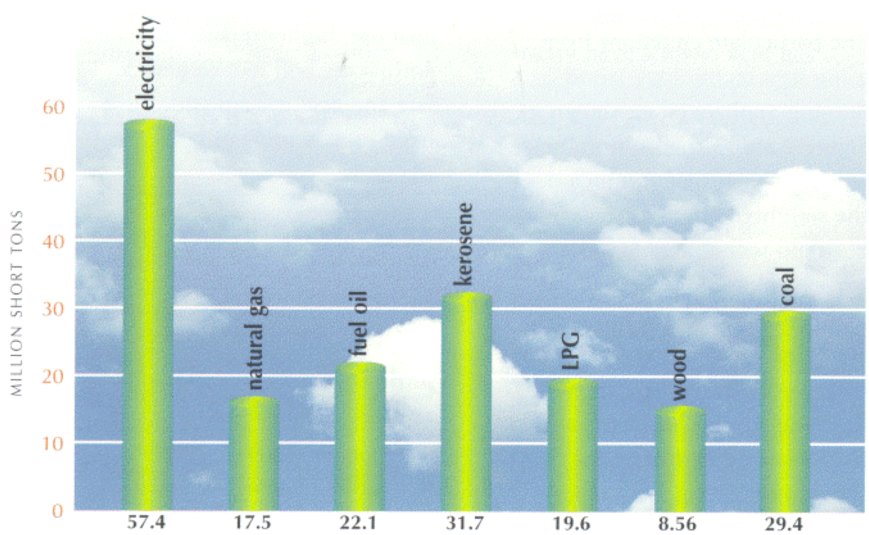

Figure 1. Carbon equivalents of greenhouse gases per quad of heat delivered

FINE PARTICLES

Atmospheric fine particles originate from two processes, i.e., from the direct emissions of particles (primary particles) and from the transformation of emitted gases to particles once they are in the atmosphere (secondary particles). The principal sources of secondary particles are the formation of ammonium sulfate particles from sulfur dioxide gas and the formation of ammonium nitrate particles from nitrogen oxide gases. Consequently, the emissions of primary particles as well as sulfur dioxide and nitrogen oxides need to be evaluated to estimate the effective fine particulate impacts of the various home heating options.

Sulfur dioxide gas is produced by combustion and is directly related to the sulfur content of the fuel. Sulfur diox-

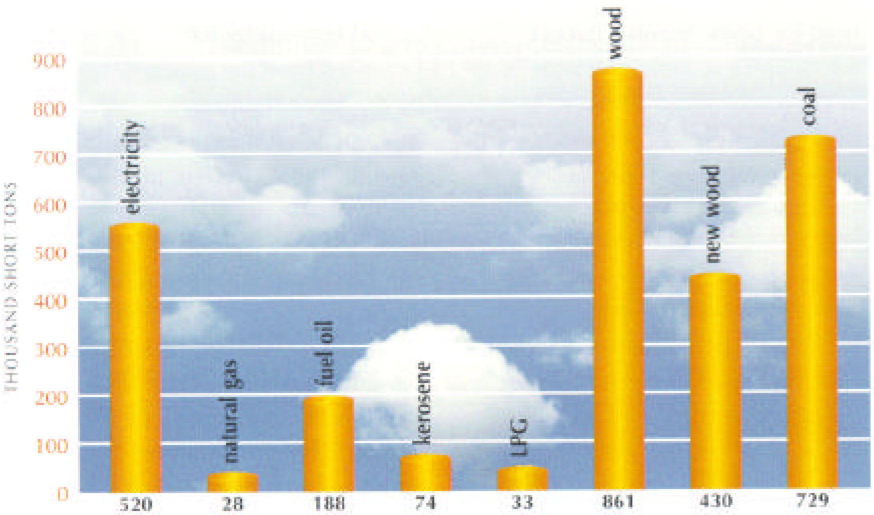

Figure 2. Effective fine particulate emissions per quad of heat delivered

ide is also released in the energy trajectory of fossil fuels during desulfurization steps. Nitrogen oxide gases are produced by combustion, both from nitrogen contained in the fuels and from the oxidation of atmospheric nitrogen at high temperatures. It is estimated that about 30% of sulfur dioxide gas and about 7% of nitrogen oxide gases are converted to secondary particles.

For all sources, except RWC, secondary particles make up the majority of the total effective fine particulate values. Primary particles formed by combustion make up 98% of the effective particulate value for RWC. Secondary ammonium sulfate particles account for between 65% to 90% of the total effective fine particulate impacts for coal, petroleum products and electricity. In the case of natural gas, secondary ammonium nitrate accounts for 72% of the effective fine particulate value and secondary ammonium sulfate accounts for 22%.

Natural gas has the lowest effective fine particulate emissions per unit of heat delivered for residential heating, followed by LPG. Residential wood combustion has the highest value. The direct use of coal and electricity also show high values with fuel oil and kerosene intermediate. It should be noted that the emission factors for RWC used in this analysis primarily reflected old technology wood burning units and that a 50% reduction in the value shown in Figure 2 is reasonably achievable with new technology devices. It should also be noted that a reduction in particulate emissions by 50% or more makes RWC comparable to electricity in terms of effective fine particulate emissions. The projected fine particulate emissions from using new technology wood burning appliances are shown in Figure 2 above the caption "new wood." This projection includes the weighted effect of replacing both old technology wood stoves and using advanced fireplaces designs and/or using manufactured fuels in fireplaces. As with wood stoves, new technology coal stoves should reduce particulate emissions below that shown in Figure 2 since many coal appliances in use are older units. However, there are no

"Residential wood combustion is often perceived as environmentally dirty due to elevated emissions of fine particles from older wood burning devices. What's often overlooked is that its contribution to global problems such as global warming and acid precipitation is smaller than any other home heating energy option and that new technology appliances produce far less particles than older appliances."

data to estimate the magnitude of this expected reduction in emissions for coal-fired heaters. Also, in regards to residential coal use, higher quality fuel, i.e., anthracite, will reduce particulate and acid gas emissions if utilized more widely in home heating units.

ACID PRECIPITATION

Emissions of nitrogen oxides and sulfur dioxide gases forming nitric acid (HNO_3) and sulfuric acid (H_2SO_4) are the primary causes of acid precipitation. Both HNO_3 and H_2SO_4 are strong mineral acids with H_2SO_4 producing two equiva-

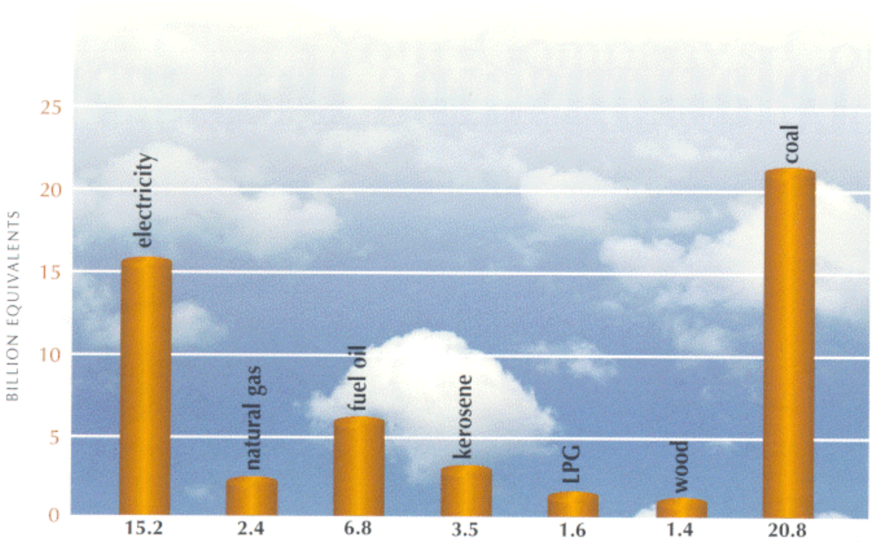

Figure 3. Carbon equivalents of greenhouse gases per quad of heat delivered

lents of acid per mole (two H+ ions per molecule). Weak organic acids (carboxylic acids) are also emitted into the atmosphere particularly from combustion sources such as RWC, but their impact on acid precipitation is very small. Interestingly, organic acids in the presence of strong mineral acids tends to raise the pH (lessen the acidity) due to their buffering capacity.

Acid equivalents emitted per unit of energy delivered for residential heating were calculated to compare acid impacts among the energy sources. While emissions of both nitrogen oxides and sulfur dioxide contribute to acid impacts, it is interesting to note that the contribution from nitrogen oxides was about an order of magnitude higher than sulfur dioxide for natural gas and the reverse was true for coal directly burned in coal heaters. For all other energy sources the contributions of nitrogen oxides and sulfur dioxide to acid impacts were within a factor of ten of each other. While all steps in the energy trajectory contributed to acidic impacts, the combustion step (as compared to extraction, processing and transportation steps) dominated the impact for the electricity, wood and coal sources. For petroleum and natural gas sources the combustion step contributions were within the same order of magnitude as the combined preparatory steps.

Wood combustion has the lowest acid impact per unit of energy, followed by natural gas and LPG. The direct use of coal has the highest value and electricity the second highest. (One factor that tends to make electricity have a lower acid gas impact than the direct use of coal, even though coal combustion accounts for about 56% of the energy consumed in electric power generation, is that most power plants have acid gas control systems.) The acidic impacts per unit of heat delivered from fuel oil and kerosene are intermediate with kerosene being lower than fuel oil primarily due the fact that there is less sulfur in kerosene than in number 2 distillate fuel oil.

Summary of Space Heating Options and Global Atmospheric Impacts

- When the contributions of all the components of energy production for residential space heating and the atmospheric fate of pollutants are taken into consideration, wood combustion has the lowest greenhouse gas and acid precipitation impacts per unit of heat delivered among the energy options. Although its fine particulate impact, based on existing wood burning appliances, was the highest among the options, average reductions in fine particulate values greater than 50% can be achieved with new wood burning appliances

- The direct in-home use of natural gas has the lowest fine particulate impact per unit of heat delivered. While not as low as RWC, natural gas also has low greenhouse gas and acid precipitation impacts. LPG has similar emissions characteristics as natural gas.

- In regards to national or global scale air quality impacts, residential wood heating with new technology appliances and the direct use of natural gas (and LPG) are the most sound environmental options.

Dr. James E. Houck is vice president of Omni Environmental Services, Inc. He has over 26 years of air quality experience, has published and presented more than 100 papers on air quality topics, and has provided air quality support for industrial, utility and public sector clients.