Energy Vol. 7, No. 4, pp. 359–365, 1982
Printed in Great Britain.

0360-5442/82/040359–07$03.00/0

A COMPARATIVE RISK ANALYSIS OF FUELWOOD USE IN THE PACIFIC NORTHWEST

P. N. PETTY and W. J. HOPP
Pacific Northwest Laboratory, Richland, WA 99352, U.S.A.

(*Received* 31 *July* 1981)

Abstract—A risk impact analysis is performed for residential space heating derived from fuelwood in the Pacific Northwest. Direct risks associated with the collection and use of fuelwood in homes are characterized and computed per 10^{12} Btu of fuelwood harvested. The hazards identified are then compared to similar risks associated with the generation of electricity using four different fuels: coal, oil, natural gas, and uranium. The resulting comparison indicates that the acquisition and use of fuelwood in residences is several times more costly in terms of loss of life and injury incurred, than electricity derived from the conventional fuels compared.

1. INTRODUCTION

A recent survey on residential energy consumption by the Bonneville Power Administration[1] clearly shows the use of fuelwood for residential space heating to be on the rise. It is estimated that 9% of regional residential space heating requirements in the Pacific Northwest are met by burning wood.[2] Since approximately 50% of all wood burned in the Pacific Northwest is harvested by non-professionals, there exists a large and increasing segment of the population engaging in a relatively hazardous means of obtaining the energy needed for space heating. The magnitude of the risks involved in harvesting wood are not generally recognized. Our preliminary analysis indicates that the collection of fuelwood is significantly more risky than the extraction of conventional fuels, including underground coal mining.

In addition to the risks associated with the collection of fuelwood, residential space heating with wood poses significant fire risks. The fire problem related to the use of solid fuel burning appliances has already become a nationally recognized problem. In this paper, we present a refinement of previous findings concerning the fire safety issue and combine the estimated risks from residential fires with harvesting hazards to allow comparison with operational risks associated with electrical energy generation using four different fuels.

Identifying benefits and risks of alternative energy systems is an important part of any rational attempt to develop a coherent set of energy policies. Much work has already been done in the attempt to quantitatively assess the relative risks associated with alternative energy systems. Identifying risks and benefits is only the first step in the process, the next step requires attaching value to both benefits and risks and comparing them. Valuing an energy system's benefits and risks is necessarily a subjective process that has recently been the subject of considerable controversy.

Although risks from energy systems can be calculated, they are not always easy to compare. The risks identified are not uniform in time, space, or severity. For example, comparing premature deaths per quantity of energy for different energy systems is complicated by the fact that these deaths do not occur at the same point in time or to the same set of individuals. Comparing catastrophic events in which hundreds of lives are lost (but have a small probability of occurance) with more routine events where fewer lives are lost (but are more likely to occur) is a very difficult matter.[3] Another complexity is comparing premature deaths due to chronic exposure to toxic substances, occurring far into the future, with immediate deaths caused by industrial accidents.

Briefly, several conceptual problems exist with comparative risk assessments of alternative energy systems: (a) valuation of risk in a common denomination is impossible without subjective value judgements, (b) selecting an appropriate discount rate to apply to these risks to obtain a present value is a subjective process as well, (c) the problems imposed by externalities complicates the task of identifying and quantifying risk values. Despite problems with the theory and application of risk assessment, this type of analysis can play a valuable role in the larger problem of determining and implementing acceptable public policy. Acceptable policy must balance the widely divergent perceptions of the relative risks associated with competing energy systems.[4] Public perception of risks and benefits of different energy systems must be supplemented by the best available information on those risks. So, even though the methods and techniques of risk assessment are not fully developed, exploring the risk differentials that exist between alternative energy systems is an important part of developing rational and consistent energy policy. The objective of this article is to provide insight into an increasingly important source of risk, the acquisition and use of fuelwood in homes.

1.1 *Purpose*

The purpose of this paper is to present findings of a study of the risks associated with the acquisition and use of fuelwood in the Pacific Northwest Region (including Washington, Oregon, and Idaho). We have focused exclusively on direct risks associated with harvesting and burning firewood in residences. This was done to highlight the relative importance of harvesting and combustion risks, which have received little attention in recent studies. Additionally, these impacts are direct and of immediate effect, as opposed to the long-term nature of indirect impacts, such as the health effects from chronic exposure to emissions from woodburning.

We feel that this study characterizes the most important internalized risks associated with use of fuelwood for space heating in the Pacific Northwest. Assessing the relative value of risks and benefits from fuelwood is beyond the scope of this study. However, to put the risks of fuelwood use in perspective, similar operational risk estimates of electricity generation from coal, oil, natural gas, and uranium are compared to fuelwood risks. The results show clearly that fuelwood use has significantly higher risk than direct operational risks of electricity generation.

1.2 *Methodology*

Our analysis of the risks associated with residential combustion of wood focuses on harvesting and use hazards. We have excluded from consideration the health effects associated with the degradation of air quality. The statistics used as the basis for the estimate of risks from harvesting are derived from two years of data from the state of Washington commercial logging industry. Isolating statistics for those functions most like the activities private woodcutters perform to harvest fuelwood permits direct estimate of the risks associated with private woodcutting. To evaluate fire risks, we have utilized available statistics describing the risks of injury and premature fatality from residential fires resulting directly from the use of wood for space heating. The statistics from the state of Oregon are used as a basis for the estimate of fire related injuries and deaths per GWe/plant/yr.

A GWe/plant/yr, used in this analysis, represents delivered heat value of 22.5×10^{12} Btu. The amount of fuelwood required to deliver that amount of heat energy to residences will be calculated assuming the current use mix between fireplaces (assumed to be 10% efficient on average) and woodstoves (assumed to be 50% efficient).[5] The regional capital stock, at the current use mix is approx. 26% efficient at converting the potential energy contained in the wood burned annually into heat in homes. This implies that approx. 86×10^{12} Btu of fuelwood would be needed as input, to deliver 22.5×10^{12} Btu. This is equivalent to about 3.8 million cords of wood.

The sum of the harvesting and fire hazards will be compared to statistics on the generation of electrical energy taken from the final report of the Committee on Nuclear and Alternative Energy Systems, National Academy of Sciences.[6] These comparisons are presented in Tables 2 and 3.

1.3 *Content and organization*

The paper is organized as follows: first, harvesting risks are estimated on a per 10^{12} Btu basis. These estimates are then converted to ratios per GWe/plant/yr to facilitate the final comparison with conventional energy sources. Second, the incidence of fire related injuries and deaths is estimated per 10^{12} Btu. These estimates are also converted to the GWe/plant/yr basis. Finally, these estimates are summed and compared to similar estimates made for electric energy generation. Conclusions are made and suggestions for further work are presented.

2. FUELWOOD RISK ASSESSMENT

2.1 *Harvesting injuries and deaths*

In the Pacific Northwest the amount of fuelwood that is harvested annually equals approximately three million cords.[7] Fifty per cent of this cordwood is harvested by nonprofessionals for their own use. Since the harvesting activity is highly decentralized, as is the use of fuelwood in homes, no adequate direct measurement of the resulting number of annual injuries and deaths has been made.

We examined statistics describing occupational hazard for workers in the logging industry in Washington state as a surrogate for injury information on the private collection of fuelwood in the region. It is reported that the occupational hazard statistics for the logging industry in the state of Washington are of high quality.[8] We selected Washington's statistics because they were detailed enough to allow separating risk according to job classification. By estimating the energy content of the total Washington timber harvest[9] these hazards were converted to ratios per 10^{12} Btu of wood harvested. Table 1 shows the injury statistics per 10^{12} Btu on average for the industry.

We then selected those activities that most accurately represent what we considered a reasonable approximation of what the nonprofessional must do to harvest fuelwood. Our reasoning is that similar activities impose similar levels of risk. Isolating those activities most similar to both commercial and private woodcutting is essential to make the inference that a similar probability of injury exists for both groups.

We identified the occupational group "fallers and buckers" as the group which more nearly equates with what the nonprofessional woodcutters must do. Commercial fallers and buckers must cut wood and move it to a cable yarding system, a residential woodcutter generally cuts and moves wood to a truck. In either case the tasks involved are similar.

The statistics for the state of Washington show that "fallers and buckers" are 80% more likely to experience an injury or fatality than the industry average. This being the case, it is necessary to adjust the average by multiplying by 1.8 to adequately represent the level of risk incurred by "fallers and buckers" on the job. Adjusting the ratio results in an estimate of 26.4 injuries, 190 lost work days, and 0.162 deaths per 10^{12} Btu of wood harvested. For the amount of fuelwood necessary to deliver 22.5×10^{12} Btu as heat in homes (86×10^{12} Btu fuelwood harvested) these ratios translate to an expected 2280 injuries, 16,460 lost work days, and 13.9 deaths resulting from harvesting.

The method used to generate these estimates assumes direct comparability between risk of injury and death for commercial loggers and the nonprofessional woodcutter per amount of wood energy harvested. There are several reasons to believe that the private nonprofessional experiences proportional risk or greater when harvesting wood: (a) private woodcutters are not likely to be as familiar with the equipment and techniques used for harvesting wood. They may be compared to inexperienced workers in all industries, which have been found to be 10 times

Table 1. Washington commercial logging injuries per 10^{12} Btu harvested; average values are given for the years 1976 and 1978.

Deaths	Injuries	Lost work days
0.09	14.7	126.0

Total wood harvested in the State of Washington averaged about 11 billion board feet for the years 1976 and 1978 (using the Scribner log rule for expressing volume harvested in board feet). To convert from board feet to energy content of the wood harvested, the following assumptions were made:

$$1 \text{ boardfoot} = \frac{1 \text{ ft}^3}{12 \text{ bf}} \times \frac{1.137 \text{ tons}}{80.6 \text{ ft}^3} \times \frac{2000 \text{ lbs}}{1 \text{ ton}} \times \frac{8500 \text{ Btu}}{1 \text{ lb}} = 20{,}000 \text{Btu};$$

$80.6 \text{ ft}^3 = 1.37$ tons (dry weight), 12 boardfeet = 1 ft^3, 1 ton=2000 lbs, 1 lb = 8500 Btu.

Table 2. Deaths during routine operations by energy source per GWe/plant/yr: electricity generation and fuelwood combustion.

Energy Source	Extraction[a]	Processing	Transport[b]	Conversion[c]	Total[d]
Coal (3×10^6 tons) deep	1.7	0.02	2.3[e]	0.01	4.0
surface	0.3				2.6
Oil onshore & offshore (12×10^6 bbl)	0.2[f]	0.08	0.05	0.01	0.4
Natural gas (67×10^9 ft^3)	0.16	0.01	0.02	0.01	0.2
Uranium (150 tons from 75,000 tons/ore)	0.2	0.001	0.01	0.01	0.2
Fuelwood in the Pacific Northwest (3.8×10^6 cords)	13.9			10.0	23.9

[a] Fuelwood estimate includes only risk of falling and bucking the fuelwood required to provide equivalent delivered heat energy of 22.5×10^{12} Btu, assuming current use mix between woodstoves and fireplaces in the Pacific Northwest Region.

[b] Transportation risks excluded from fuelwood totals.

[c] Conversion at power station for coal, oil, natural gas and uranium. Combustion risk for fuelwood is calculated using fire incidence statistics per amount of fuelwood consumed in Oregon State during 1980.

[d] Totals may not add due to rounding.

[e] Estimates are not based on coal trains per se, but on the overall rate of train accidents. This estimate is likely high for coal transportation and the issue needs further detailed analysis.

[f] With reprocessing, the uranium oxide requirement could be reduced to 1.4 tons. Presumably, the mean extraction risk would be reduced proportionately, and the processing risk increased. The net result could be lower total risk.

more likely on average to experience work related injury associated with mechanical equipment.[10] Bureau of Labor Statistics studies show there is a strong negative association between injury rates and length of service for all classes of workers in all industries. (b) Commercial loggers are more efficient. Their injury and death statistics, measured per amount of wood collected, would be lower than similar statistics for the less efficient nonprofessionals because they collect more wood per unit of time working. (c) Consumer Product Safety Commission estimates of injuries and deaths associated with the use of wood harvesting equipment for the calendar year 1980 tend to substantiate our concern over the risks from wood harvesting to the general public. The Safety Commission estimates that over 23,000 injuries occur annually throughout the nation. CPSC estimates that there are 50 or more deaths occurring annually which are related to the use of chainsaws alone.[11]

On the other hand, there are factors which tend to support an assumption of something less than direct comparability between commercial logging and nonprofessional woodcutting: (a) The scale of operations is widely different between the two activities; commercial loggers using heavy equipment not available to the nonprofessional. The machinery may be a source of a large portion of the risk for commercial loggers. (b) Commercial loggers work 40 hours per week and therefore they may be subject to greater fatigue than the weekend woodcutter. Fatigue is associated with increased risk of injury. (c) Commercial logging operations log terrain of all slopes including very steep areas which may be highly dangerous, while the convenience weekend woodcutter generally cuts wood which is readily accessible.

Table 3. Accidential injuries and lost workdays during routine operations, by energy source per GWe/plant/yr: electricity generation and fuelwood combustion.[6]

Energy source	Accidents[a]	Lost workdays[b]
Coal mining[c] (3 x 10^6 tons) underground	112	15,000
surface	41	3,000
Oil (12 x 10^6 bbl)	32	3,600
Natural gas (67 x 10^9 ft^3)	18	2,000
Nuclear (150 tons of uranium)	15	1,500
Fuelwood (3.8 x 10^6 cords)	2,384	17,420[d]

[a]Accidents calculated for fuelwood harvesting and residential combustion. Residential fires related to the use of electrical appliances are excluded.

[b]A permanently disabling accident was crediting with 6,000 lost workdays, and a temporary disability with 100 lost workdays. These figures for Coal through Nuclear energy are based on 1977 statistics. The estimate for fuelwood use is based on 1980 data. The quantities of the various inputs and assumed efficiencies are similar to the assumptions made for Table 2.

[c]Synthetic liquid fuel from coal might be estimated to have a rate equal to that for coal plus an allowance for the conversion process.

[d]Lost workdays from fire related injuries are calculated at 4 days per injury.

Exactly how these factors balance out is difficult to tell. Lacking more detailed information, we have concluded that, on balance, commercial logging and nonprofessional woodcutting are activities which are similar enough to warrant direct comparison in terms of occupational risk. For the purposes of this study, we apply the ratios of injuries and deaths per quantity of wood harvested directly from commercial fallers and buckers to private woodcutting.

2.2 *Combustion injuries and deaths*

An emerging national trend has been identified by national fire protection professionals: "In 1977, heating shot out front as the leading cause of fire incidents. It appears that there has been an increase in the use of supplemental heating devices, such as fireplaces, woodburning stoves... which are causing a serious fire problem"[12] The use of solid fuel burning devices in residences throughout the nation is directly linked to an increase in residential fires. In 1978 residential fires were responsible for more loss of life, more injuries, and greater dollar loss than any other type of fire despite the fact that residential fires account for only 26% of all fires occurring that year.

Fire related injuries and deaths associated with residential combustion of wood have been tracked statistically in the State of Oregon. In 1980, fires related to the use of solid fuel burning appliances were the cause of 3 deaths, 68 serious injuries, and $6 million in property damage.[13] During 1980, fuelwood consumed in the state of Oregon equalled approx. 24×10^{12} Btu. This is equivalent to 2.81 injuries and 0.1243 deaths per 10^{12} Btu of fuelwood consumed.

We assume that the fire experience related to the use of fuelwood in the state of Oregon is representative of the fire experience per amount of fuelwood burned throughout the region. Applying the above ratios of injuries and deaths per 10^{12} Btu to 86.2×10^{12} Btu fuelwood harvested, results in 242 injuries, and 10 deaths. These estimates are added to the harvesting estimates and compared in Tables 2 and 3.

3. COMPARISON OF RISKS ASSOCIATED WITH FUELWOOD USE IN THE PACIFIC NORTHWEST WITH RISKS ASSOCIATED WITH ELECTRICITY GENERATION

The risk estimates for the direct use and acquisition of fuelwood in the Pacific Northwest include injuries and deaths from fuelwood harvesting and residential fires. Tables 2 and 3 also show estimates of direct operational risks identified for electrical energy generation using four fuels: coal, oil, natural gas, and uranium. The rational for making this comparison is that these different sources of energy are directly substitutable for residential space heating. As direct substitutes, these different energy sources can be analyzed to identify which has the comparative advantage in terms of overall risk.

Comparative risk analysis is complicated by the fact the each of the risks associated with these energy alternatives differs in timing, dispersion, and severity. The risks quantified here are only those risks directly impacting the processes of extracting natural resources, processing them, transporting them, and converting these resources into electric energy or space heat. Externalities such as air quality degradation are excluded from the present analysis.

The estimates presented in Tables 2 and 3 are based on operating an electric generation station of 1 GWe (gigawatt equals 10^9 W) capacity, at 33% efficiency and at 75% of capacity. Such a GWe/plant/yr corresponds to a fuel input of about 67.3×10^{12} Btu and an electrical output of 22.5×10^{12} Btu. Fuelwood combustion in residences in the Pacific Northwest at present is about 26% efficient at delivering potential energy in fuelwood burned into heat in homes. At that level of efficiency the amount of fuelwood necessary to deliver heat equal to a GWe/plant/yr is about 3.8 million cords of wood. The risks identified in Tables 2 and 3 indicate that risks associated with the use of fuelwood for space heating are several times higher than the next most risky alternative, coal-fired electricity. In terms of deaths attributable to the collection and use of fuelwood alone, wood energy is seen to be nearly six times more hazardous than the death rate for coal-fired electricity.

4. CONCLUSIONS

The risks associated with obtaining residential space heat from fuelwood or electricity as estimated in Tables 2 and 3 are not perfectly comparable. We have not estimated risks associated with transporting fuelwood, while the estimates used for risk from electrical energy generation did not include risk associated with converting electricity to space heat in homes. Although some injuries and deaths may occur due to transporting fuelwood and electric heating related fires, we believe that these factors are smaller in magnitude than those included in this analysis. If anything, the wood transportation hazards are probably higher than the risks of fire from electrical space heating in residences. Thus, we feel that our conclusion that fuelwood is a more hazardous source of energy than electricity is justified.

The risk estimates presented here are based on the probability of injuries and deaths occurring during routine operations of electrical energy generation, and the collection and combustion of fuelwood in homes. The generation of electricity is a highly centralized energy system, while the use of fire wood in homes for space heating is a highly decentralized energy system. This essential difference has important implications about how the problem of mitigating the risks identified with fuelwood use may successfully be approached. This difference also must be considered when assessing the relative importance of these alternatives to the national energy supply system.

We have concluded that:

(1) There exists a significant risk differential between electricity generation using the four fuels compared, and residential combustion of wood. These risks are measured in terms of loss of life and injuries incurred during routine process of extracting natural resources, processing these resources, transporting them, and converting them into usable energy. The collection and use of wood for space heating is seen as nearly six times more costly in terms of loss of life than the most hazardous alternative, coal-fired electricity.

(2) While several forms of risks to health, environmental quality, or social and political risks are excluded from this comparison; the risks identified and compared here should serve as a "red flag" to those who formulate energy policies. Significant progress at mitigating the risks associated with harvesting and burning fuelwood in homes could be achieved through public information programs, seminars on safe acquisition and use of fuelwood, and a tightening of the

building code process to insure a greater degree of compliance to existing codes dealing with woodstove installation.

(3) The trend toward increasing use of fuelwood for residential space heating is a result of a number of factors, which appear likely to continue to shift energy demand from traditional sources of energy to fuelwood. This shift toward using fuelwood for space heating requirements has been made without a general knowledge of the inherent risks associated with this source of energy, and without sufficient information to allow an informed judgement on its relative risks and benefits compared to the alternatives.

(4) The risks identified and others associated with the use of fuelwood in homes are of sufficient magnitude, and effect a sufficient proportion of the population, to deserve continued research. Additional research is needed to advance the status of risk-benefit analysis in general, to estimate the magnitude of the indirect impacts associated with fuelwood and other energy sources, and to investigate the degree to which commercial logging statistics can validly be used to approximate risks from residential woodcutting.

REFERENCES

1. DOE, *The Pacific Northwest Residential Energy Survey.* Bonneville Power Administration and PNUCC, Portland, OR (1980).
2. P. Petty, W. Hopp, and A. Chockie, "Biomass Energy Utilization in the Pacific Northwest: Impacts Associated With Residential Use of Solid Fuels", in *Proc. Int. Convention on Residential Solid Fuel,* Oregon Graduate Center. Northwest Environmental Research Center, Portland, OR 97208 (1981).
3. S. H. Schneider, *Energy* **4**, 919 (1979).
4. M. B. Spangler, *Energy J.* **2**(1), 37 (1981).
5. DOE, *Major Accomplishments, Sept. 1977–Oct. 1980, Improving Efficiency, Safety, and Utility of Wood Burning Units.* Washington, DC 20036 (1980).
6. NAS, *Energy in Transition*: 1985–2010. National Research Council, Washington, D.C. (1979).
7. T. G. Esvelt and M. L. Roberts, "The Use of Wood for Residential Space Heating in the Pacific Northwest", in *Proc. Solwest* 80 *Conf.* BPA, Portland, OR 97208 (1980).
8. M. N. Goldberg, *Worker Safety in Logging Practices.* Washington, D.C. (1974).
9. J. A. Bergvall *et al. Washington Mill Survey.* Reports No. 5 & 6, State of Washington, DNR, Olympia, WA 98504 (1976–78).
10. N. Root and M. Hofer, *Mon. Labor Rev.* **12**, 76 (1979).
11. CPSC, *CY* 1980 *Product Summary,* National Injury Information Clearing House, Washington, DC 20207 (1981).
12. U.S. Fire Administration, *Highlights of Fire in the United States*: 1978. FEMS, Washington, DC (1981).
13. State of Oregon, Department of Commerce, *Annual Statistical Report for CY,* 1979. Office of the State Fire Marshall, Salem, OR 97310 (1980).
14. S. Leavette, Personal communication regarding data on file at State of Washington Management Information Section, Industrial Safety and Health, Department of Labor and Industries, Olympia, WA 98504 (1980).
15. BLS, *Occupational Injuries and Illnesses in the United States by Industry,* 1978. U.S. Department of Labor, Washington, DC 20402 (1980).