# ENVIRONMENTAL TRADEOFFS: LIFE CYCLE APPROACH TO EVALUATE THE BURDENS AND BENEFITS OF EMISSION CONTROL SYSTEMS IN THE WOOD PANEL INDUSTRY

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## ABSTRACT

This life cycle inventory was conducted for the American Forest & Paper Association in order to develop a more complete picture of the burdens associated with various emission control technologies currently used in the wood products industry. Control technologies evaluated included biofilters, regenerative thermal oxidation units (RTOs), and regenerative catalytic oxidation units. The control technologies are used to reduce emissions of volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) from press and dryer exhaust streams at plants producing a variety of wood products. If the evaluation of emissions control systems is limited to an evaluation of their efficiency in controlling on-site emissions, significant on- and off-site environmental burdens associated with the operation of control systems can be overlooked. The study found that employing a systems approach to evaluate the emission control technologies clearly identifies the trade-offs involved in controlling VOC and HAP emissions from panel plant press and dryer vents. The control technologies under consideration reduce life cycle HAP and particulate emissions and, in most cases, VOC emissions. These on-site reductions come at the expense of higher energy consumption and associated increases in life cycle emissions of nitrogen oxides, sulfur oxides, greenhouse gases, and solid waste, as well as a variety of fossil fuel combustion-related HAPs including hydrochloric acid, hydrofluoric acid, and mercury. Projections of the effects on energy, greenhouse gases, and VOC and HAP emissions are made based on the use of RTO technology to control panel plant emissions industry-wide.

Various emission control technologies are used in the wood panel industry to reduce emissions of volatile organic compounds (VOCs) and and hazardous air pollutants (HAPs) from panel plant press and dryer vents. Commonly used control technologies include biofilters (BFs), regenerative thermal oxidation units (RTOs), and regenerative catalytic oxidation units (RCOs). While the use of these technologies controls on-site VOC and HAP emissions, additional off-site and on-site burdens are incurred for the production, transport, and disposal of materials used by the control systems, as well as for the production, transport, and combustion of fuels that are directly used in control equipment (e.g., natural gas burned in RTOs and RCOs) or used to produce electricity used by the control systems. A life cycle inventory (LCI) such as this study uses a systems approach to identify and quantify the trade-offs involved in controlling VOC and HAP emissions from press and dryer vents at wood panel plants.

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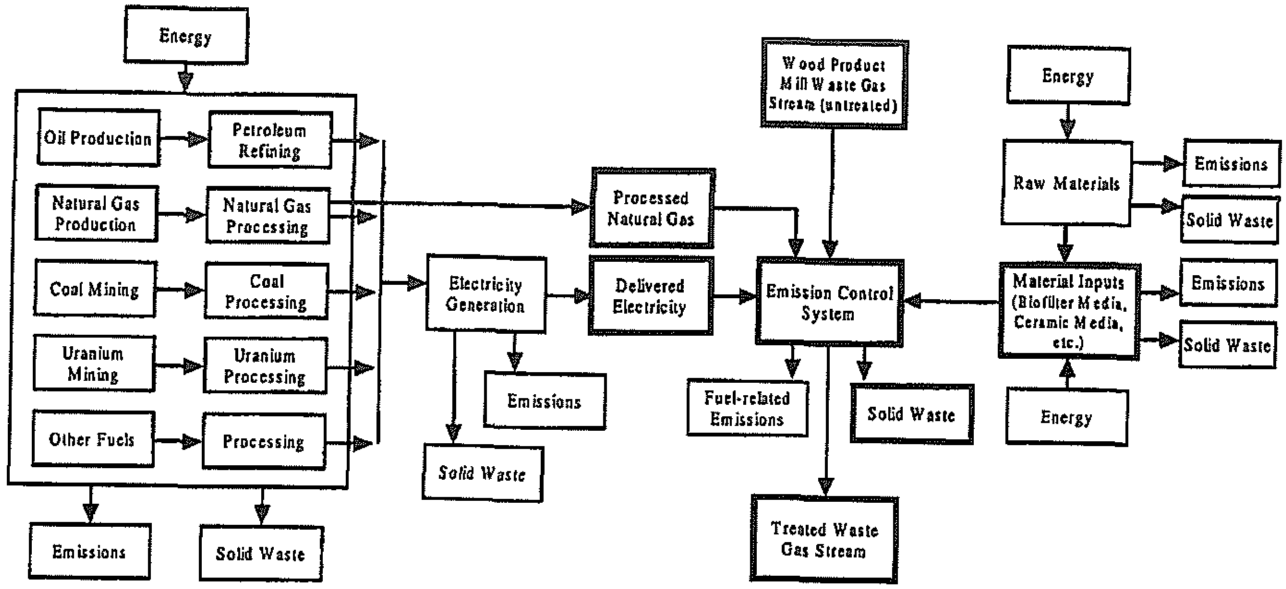

Figure 1.— Systems approach flow diagram for emission control system operation. Bold outlined boxes indicate inputs and outputs typically considered in an analysis of emission control system operation.

## BACKGROUND

An LCI uses a systems approach to quantify the energy consumption and environmental emissions (i.e., atmospheric emissions, waterborne wastes, and solid wastes) for a given system based upon the study boundaries established. Rather than focusing on a single manufacturing step or environmental emission, this type of analysis evaluates the entire life cycle of a system, from raw material acquisition to final disposition. An LCI is not an impact assessment, that is, it does not attempt to determine the fate of emissions, or the relative risk to humans or to the environment due to emissions from the systems.

If the evaluation of emissions control systems is limited to an evaluation of their efficiency in controlling on-site emissions, significant environmental burdens associated with the operation of control systems can be overlooked. These burdens may be incurred upstream or downstream of the facility where the control equipment is used. For example, RTOs and RCOs reduce VOC and HAP emissions by burning the exhaust gases using natural gas. Control systems also require electricity for the fans used to route press and dryer exhaust streams through the control system, as well as material resources for the production of biofilter media and ceramic media. The use of these energy and material resources incurs environmental burdens that are identified only by using a systems approach. Thus, the systems viewpoint of an LCI identifies the upstream energy and emissions associated with on-site energy and material use for managing emissions in the exhaust gas streams at the plant site.

Using site-specific survey data and national average fuels data for the generation of purchased power, the technologies were compared with each other and with a no-control baseline scenario.

## PURPOSE OF THE STUDY

The purpose of this LCI was to assess the overall environmental implications of using end-of-line emission control devices to reduce VOC and volatile HAP emissions from wood products plants. Using a systems approach to quantify the environmental burdens associated with materials and energy use for each control technology provides a more comprehensive picture of the environmental profile and allows these burdens to be put in perspective with the environmental benefit of using the emission control technology to manage on-site VOC/HAP emissions at wood products plants.

The bold outlined boxes in **Figure 1** illustrate the elements that would typically be included in an on-site analysis of emission control system operation. In contrast, a systems analysis (such as this LCI) includes all the steps shown in the flow diagram. As the figure illustrates, an on-site analysis excludes many areas where significant environmental burdens may be incurred, while an LCI provides a much more complete picture of the environmental burdens and benefits associated with control system operation.

## SCOPE AND BOUNDARIES

This LCI analysis examines the use of various types of VOC/HAP control equipment. The analysis includes cradle-to-grave data for the materials and fuels used in the operation of the control equipment as reported in a survey of 11 wood products plants. The analysis does not include production, installation, or disposal of the control equipment itself (e.g., biofilter or thermal oxidation vessels or chambers, burners, fans, etc.). The analysis includes operation of only the VOC/HAP emission control equipment specified and does not include other plant operations associated with the production of wood products, including but not limited to wood processing operations, operation of presses and dryers, and operation of any other emission control equipment. Most plants reported the use of additional emission control technologies such as scrubbers, cyclones, and wet electrostatic precipitators (WESPs); however, analysis of the operation and effectiveness of these

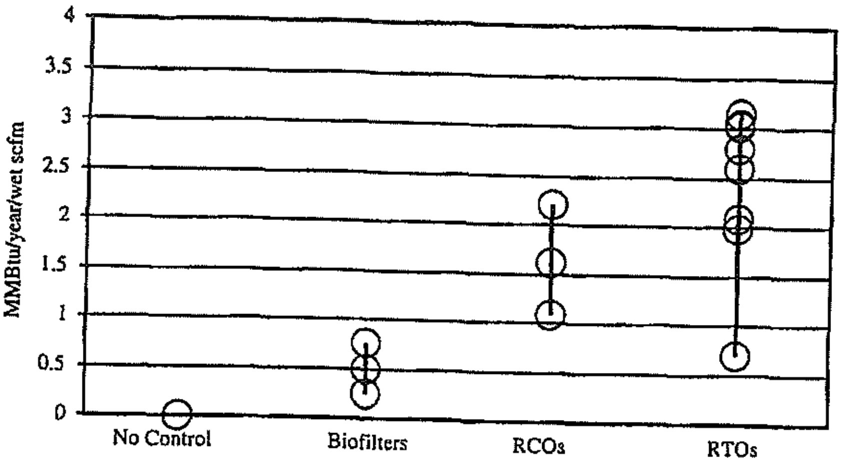

Figure 2. — Life cycle energy consumption for emission control system operation.

technologies either alone or in combination with BFs, RTOs, and RCOs was not in the scope of this analysis.

The scope of an LCI does not include assessment of potential impacts on human health and the environment associated with the environmental burdens identified, nor does it address operating costs.

Inlet and outlet waste gas stream composition data were available for many but not all plants in the survey. For those plants where usable emissions test data were available, this analysis reports both controlled and uncontrolled emissions of VOCs and HAPs. It was not possible to evaluate the effectiveness of the control system or the no-control scenario for plants where usable emissions test data were not available.

The study does not address wastewaters that may be generated at some facilities by the VOC/HAP control equipment because the data were inadequate to characterize the quantity and composition of wastewater generated and how it will be managed. Where wastewaters are generated, their treatment and management will impose additional treatment costs and environmental burdens.

## BASIS FOR COMPARISON

Control systems were compared on the basis of equivalent volume of waste gas (e.g., press and/or dryer exhaust) treated by the control system. Data on material and fuel use reported by each plant were converted to the equivalent volume basis, expressed in wet standard cubic feet per minute (scfm), using annual operating data provided by each plant.

## METHODOLOGY

Data on material and energy use were developed from a detailed survey of 11 plants producing various wood products and using different types of control technologies to control emissions from sources such as dryers and presses. The facilities were selected to include a range of geographic locations and wood furnishes. Wood products produced by the plants surveyed included oriented strandboard, particleboard, medium density fiberboard, plywood, veneer, and hardboard.

After the data were converted to a common basis of wet scfm of waste gas treated, an LCI analysis was conducted for each plant/source/control scenario. The LCI methodology used is consistent with the LCI methodology described in ISO's international environmental management standards 14040 and 14041 on Life Cycle Assessment (ISO 1997, 1998).

## ASSUMPTIONS AND LIMITATIONS

Detailed survey forms were sent to the participating plants; however, in many cases there were significant gaps in the data provided. In these cases, technical experts at the National Council for Air and Stream Improvement (NCASI) provided additional data from separate studies to fill gaps in the data provided by the plants. In cases where no actual data were available from the plant surveys or other sources, NCASI experts also provided guidance in estimating data. For example, missing data on ceramic media use were estimated based on the average use (in material use per scfm of exhaust gas treated) reported by other plants using the same control technology.

## LIFE CYCLE MODEL INPUTS

Material and energy inputs and disposed solid wastes for each plant/source/control scenario included in the survey were normalized on the basis of annual operation and scfm of waste gas treated. In the 11 plants surveyed, there were 15 different combinations of plant/source/control. Scenarios are identified by letters to protect confidentiality.

The normalized data show considerable variation within each control technology. This may be expected because of the limited size of the data set. Differences in factors such as the following are also expected to contribute to the data scatter:

- Type of wood product produced at the plant (variations in materials and processes used)
- Source of the waste gas stream (e.g., press or dryer)
- Waste gas stream flow rate, temperature, and composition
- Type and quality of biofilter or ceramic media used
- Proper installation, operation, and maintenance of the system
- Effect of other emission control systems (e.g., scrubbers, cyclones, and WESPs) used in addition to studied system.

Because of the site-to-site variability as well as the regional variability in the fuel mix used to produce purchased power, the general comparative findings in this study for the control technologies may not be applicable to control systems operating at other plants at different sites. However, the results and conclusions reported here are valid for the systems studied.

## RESULTS

Results are presented in graphic form showing the range of results for each control technology. Median values are reported in the text.

### ENERGY

Energy results include not only the energy directly consumed at the plant, but also the energy to extract, produce, and deliver each type of fuel. For example, energy use reported for electricity consumption includes not only the energy value of the electricity used at the

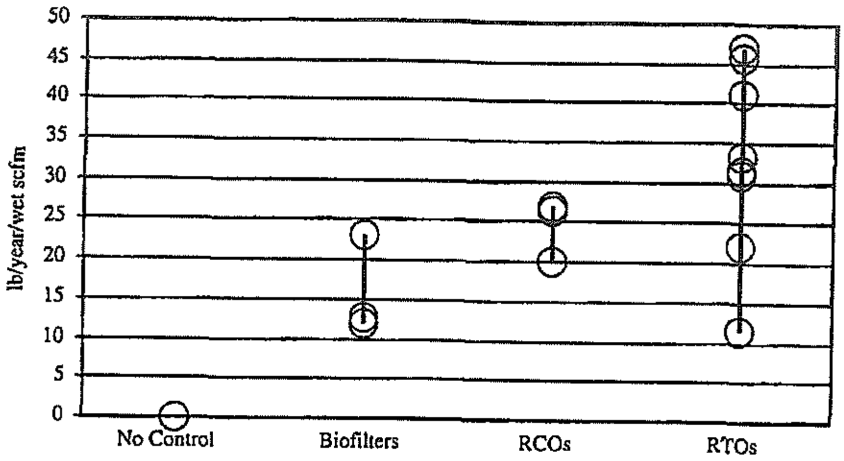

Figure 3. — Life cycle solid waste for emission control system operation.

plant, but also the energy associated with mining, processing, and delivery of coal and other fuels to power plants to generate electricity. To provide a consistent basis for comparing facilities in different geographic locations, energy and emissions for power generation are based on the average composite U.S. electrical grid (Franklin Associates 2001).

**Figure 2** illustrates the energy results for each control scenario compared to a baseline value of zero for no HAP/VOC control technology used. Median energy consumption for the technologies are (in million BTUs/yr./scfm): 0.5 for BFs, 1.6 for RCOs, and 2.7 for RTOs. These energy requirements can be compared to a baseline no-control option requiring no additional energy.

For the BF systems, energy requirements are dominated by electricity used to power fans and pumps, with purchased electrical energy accounting for 87 to 99 percent of the total life cycle energy consumed. Natural gas and electricity dominate energy requirements for RCOs and RTOs, although the relative percentages vary from plant to plant.

The survey data revealed a large range in natural gas requirements among the eight RTO systems, a factor of 7 from lowest to highest natural gas use. Analysis of plant data revealed that the two RTO units with the lowest natural gas consumption were the only two in the survey that used structured media. In addition, one of these two systems had an inlet gas stream that was higher in temperature and VOC content than other RTO inlet streams, making the waste gas stream more combustible. It is not possible to be certain whether these observations explain any or all of the variability because of the limited amount of operating data available from each facility.

### SOLID WASTE

Solid waste results include wastes associated with materials production, natural gas, electricity, and media disposal. Solid waste includes process wastes, fuel-related wastes, and solid wastes discarded by the plant. Process wastes are the solid wastes generated by the various processes throughout the life cycle of a material. Fuel-related wastes are the wastes from the production and combustion of fuels used for process energy and transportation. Solid wastes discarded by the plant include spent biofilter media and ceramic media disposed at the end of their useful life by incineration, landfill, or a combination of the two, as reported by the plants. Discard rates for spent media were based on media quantities and replacement intervals reported by the plants. All solid wastes are assumed to be non-hazardous under the Resource Conservation and Recovery Act, an assumption supported by the observation that the vast majority of the solid waste is associated with off-site power and natural gas production.

Solid waste results for the various control scenarios are shown in **Figure 3**. Solid waste comparisons among the control systems are generally similar to energy comparisons, reflecting the major influence of energy-related solid wastes in the life cycles. These results can be compared to a baseline no-control option involving the generation of no additional solid waste.

Materials production accounts for 6 percent or less of the total solid waste for each system, while media disposal accounts for 2 to 31 percent of total solid waste for BF systems and 2 to 7 percent for thermal oxidation systems. Most of the solid waste for each system is associated with the production of electricity and natural gas and therefore is produced and disposed off-site by the energy producers or suppliers.

### ATMOSPHERIC EMISSIONS

Atmospheric emissions for each system include emissions from material processes (such as the production of biofilter or ceramic media) and those associated with the extraction, processing, and combustion of fuels. These emissions are released at the various locations where material and fuel extraction, processing, and consumption occur.

In addition, for those plants where inlet and outlet gas stream test data were available, the analysis includes controlled emissions of VOCs/HAPs, particulates, nitrogen oxides, and carbon monoxide from the plant waste gas streams, as well as uncontrolled releases that would occur if no control technology were used.

In the discussion of results, atmospheric emissions generated off-site for the production and transport of materials and fuels, combustion of fuels (excluding natural gas combustion in RTOs and RCOs), and disposal processes for the operation of the control equipment are referred to as *non-source emissions*. Non-source emissions are reported only for scenarios using emission control equipment. *Source emissions* include VOCs/HAPs, particulates, nitrogen oxides, and carbon monoxide in the controlled or uncontrolled waste gas stream, as well as emissions associated with the combustion of natural gas for control scenarios using RCOs and RTOs. Thus, total life cycle emissions for controlled scenarios are the sum of non-source emissions and controlled source emissions, while emissions for the corresponding uncontrolled scenarios consist entirely of uncontrolled source emissions.

On-site emissions (source emissions) data from the plants and NCASI sources are characterized for far fewer parameters than off-site emissions (non-source emissions) from the LCI database for

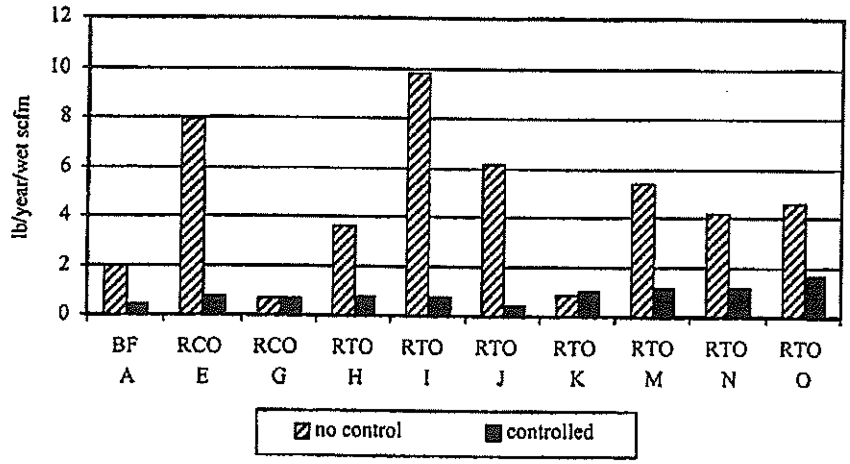

Figure 4. — VOC emissions: comparison of uncontrolled (source) and controlled (source + non-source). Note: Controlled value shown for RTO I may be understated because no data on controlled source emissions were provided by plant. All other controlled values include non-source emissions and controlled source emissions.

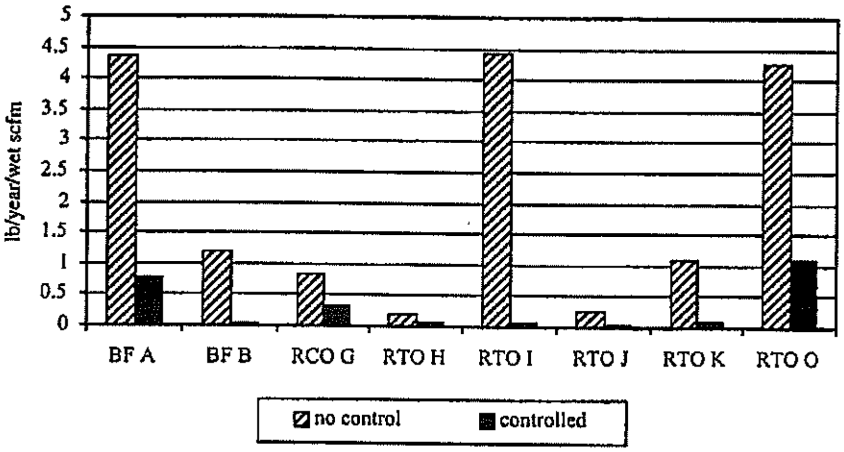

Figure 5. — HAP emissions: comparison of uncontrolled (source) and controlled (source + non-source).

fuels and materials (Franklin Associates 2001). As a consequence, emissions comparisons can be constructed for only a limited number of parameters. A bar graph format was used to present results for emissions where data were available for a comparison of inlet and outlet waste gas streams (i.e., VOCs, HAPs, particulates, nitrogen oxides, carbon monoxide). A different format, displaying the range of values for each technology on a common axis, was used to present results where the baseline for the uncontrolled scenario is zero (i.e., energy, solid waste, sulfur oxides, greenhouse gases).

It is important to note that an earlier extensive study of emissions from panel plants, conducted by NCASI separately from this study (NCASI 1999a-f) has confirmed that except for a limited number of HAPs (namely methanol, acetaldehyde, and formaldehyde) and total VOCs, most atmospheric emissions are absent or at very low levels in panel plant press and dryer vents. In addition to VOC and HAP emissions data, for some control scenarios NCASI was able to provide actual or estimated values for inlet and outlet emissions of particulates, nitrogen oxides, and carbon monoxide.

*VOCs.* — The control technologies included in this study are intended to remove a number of VOC compounds, so it is to be expected that baseline no-control VOC emissions would be higher than those where treatment technologies are employed. However, VOC inlet and outlet data were not available for all of the facilities.

Life cycle controlled and uncontrolled emissions for each scenario are shown in **Figure 4**. In all cases, the control equipment reduced source emissions of VOCs by at least 60 percent. However, when the non-source emissions for materials and fuels for operation of the control equipment are included, there are two cases (RCO G and RTO K) where total life cycle controlled VOC emissions are equivalent to or higher than uncontrolled source emissions. In both cases, the uncontrolled source emissions of VOCs were very low to begin with (**Fig. 4**). Compared to a no-control baseline, the average reduction in life cycle VOC emissions for the six RTO scenarios with data was 61.7 percent.

*HAPs.* — The U.S. Environmental Protection Agency has proposed Maximum Achievable Control Technology (MACT) standards (U.S. EPA 2001c) for the wood panel industry to control HAPs emissions. It would be useful, therefore, to characterize the total HAP emissions for the various control technologies and the no-control baseline. Unfortunately, this is not a straightforward exercise. First of all, the Clean Air Act (U.S. EPA 2001a) lists numerous HAPs, most of which are not routinely measured in emission tests. More importantly, however, no standard way to compare the potential environmental or human health significance of different HAPs is agreed upon. As a result, comparisons of HAP emissions from dissimilar sources are often of limited value. Nonetheless, an attempt has been made to examine the HAP profiles of the various control options and the baseline no-control case.

NCASI has conducted an extensive sampling program to identify the HAPs in panel plant vents (NCASI 1999a-f). The NCASI studies found that methanol and formaldehyde are the primary HAPs present in these emissions, with acetaldehyde also commonly found, but usually at lower levels. Other HAPs are not present in significant amounts (NCASI 1999a-f). HAP source emissions data were available for 8 of the 15 control scenarios in this study. Controlled HAP emissions are the total weight of actual HAP compounds in the vent gases after treatment.

To analyze total life cycle HAPs for the control scenario, it is necessary to add the quantity of controlled source HAPs to the quantity of non-source HAPs for the materials and fuels used to operate the control systems. The data suggest that the only significant non-source HAP emissions in terms of mass are hydrochloric acid and hydrofluoric acid. Non-source HAP emissions included in the life cycle controlled emissions in **Figure 5** were estimated as being equal to the total of hydrochloric acid, hydrofluoric acid, formaldehyde, and other aldehydes. (Although the weights of formaldehyde and other aldehydes are very small in comparison to HCl and HF, they are included in the total HAP emissions for consistency, since source emissions of HAPs include aldehydes.)

Using this approach, it was possible to examine the HAP profiles for two biofilters, one RCO, and five RTOs. **Figure 5** graphically illustrates life cycle controlled and uncontrolled emissions for each scenario.

Looking at individual controlled/uncontrolled comparisons, there were no cases where life cycle controlled HAP emissions were higher than uncontrolled HAP emissions, although in two of the eight comparisons (RCO G and RTO H), the percent reduction in source and total HAPs was less than 70 percent. On average, the installation of control technologies resulted in an 83 percent reduction in total HAP emissions with the average for RTOs being 84.3 percent.

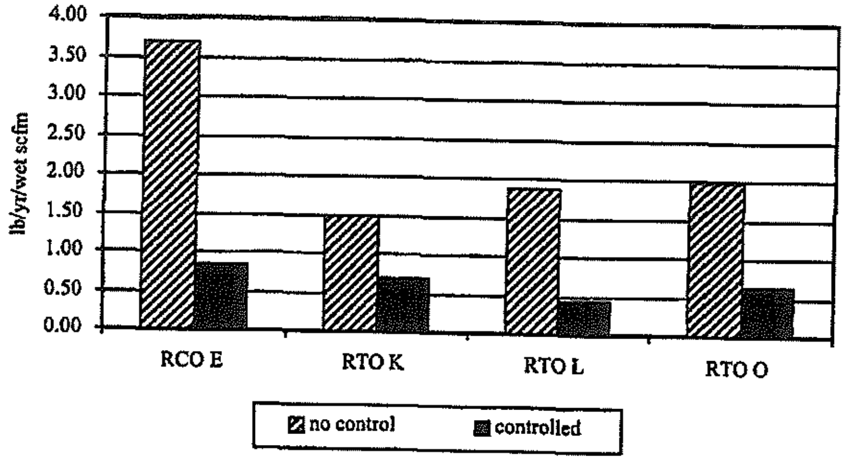

Figure 6. — Particulates emissions: comparison of uncontrolled (source) and controlled (source + non-source).

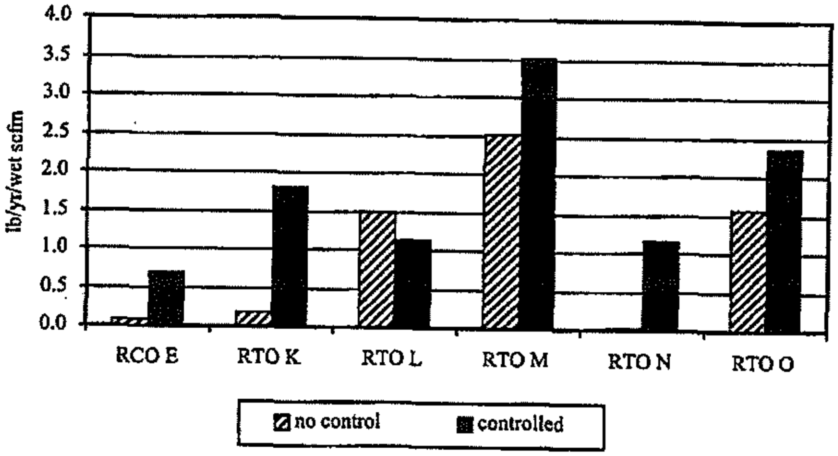

Figure 7. — Nitrogen oxides emissions: comparison of uncontrolled (source) and controlled (source + non-source).

Again, it is important to emphasize that this life cycle analysis of HAPs compares uncontrolled panel plant source emissions of methanol, formaldehyde, and acetaldehyde to controlled emissions consisting of reduced source emissions of these three HAPs plus non-source emissions of hydrochloric acid, hydrofluoric acid, formaldehyde, and other aldehydes. No attempt has been made to apply weightings to the individual HAPs according to their environmental or human health significance. Other important HAPs (e.g., mercury and a number of other heavy metals) are emitted in the various "controlled" scenarios but the amounts are too small to impact the estimates of the total mass of HAP emissions. This does not mean, however, that they are unimportant.

*Particulates.* — On-site particulates are present in both the inlet and outlet waste gas streams, although there were many gaps in the control inlet and outlet data available for plants studied in this analysis. Non-source particulate emissions that were calculated for each controlled system largely reflect the influence of purchased power.

**Figure 6** shows the particulate emissions for the four scenarios for which both controlled and uncontrolled source particulate emissions data were available in addition to non-source particulate emissions. For the three plants using RTOs, the average reduction in particulate emissions across the RTO (i.e., reduction in source emissions) was 76 percent (median 81%, range 64% to 84%), while the average reduction in life cycle particulate emissions (source + non-source) was 66 percent (median 68%, range 54% to 76%). It should be noted that these calculations are based on a sample of only three plants for which inlet and outlet data were available.

*Nitrogen oxides ($NO_x$).* — $NO_x$ are present in both the inlet and outlet waste gas streams, including emissions from the combustion of natural gas in RTOs

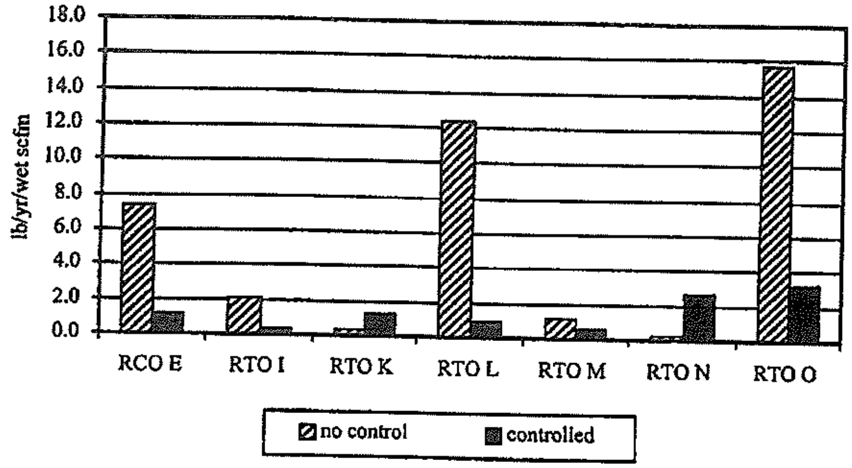

Figure 8.— Carbon monoxide emissions: comparison of uncontrolled (source) and controlled (source + non-source).

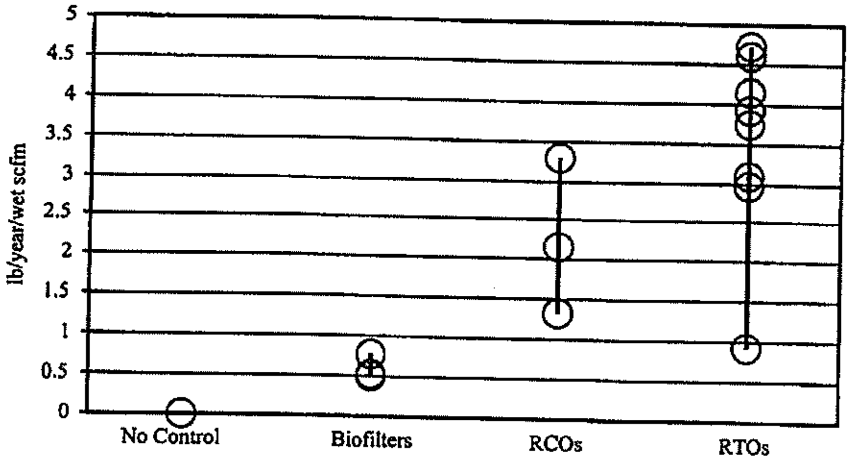

Figure 9.— Life cycle sulfur oxides emissions for emission control system operation.

and RCOs. There were several gaps in the control inlet and outlet data for the plant scenarios analyzed in this study. Non-source $NO_X$ emissions for the controlled systems, like particulate emissions, largely reflect the influence of purchased power.

**Figure 7** shows the $NO_X$ emissions for the six scenarios for which both controlled and uncontrolled source $NO_X$ emissions data were available in addition to non-source $NO_X$ emissions. Five of these six plants used RTOs. For the RTO systems, changes in $NO_X$ across the RTO (i.e., changes in source emissions) ranged from a decrease of 0.95 lb./yr./scfm to an increase of 1.01 lb./yr./scfm (average 0.10 increase, median 0.28 increase). Life cycle changes in $NO_X$ ranged from a decrease of 0.34 lb./yr./scfm to an increase of 1.63 lb./yr/scfm (average 0.84 increase, median 1.0 increase). Two RTO scenarios, L and O, showed a decrease in $NO_X$ across the RTO (although for RTO O there was still a net increase in $No_X$ emissions when life cycle $NO_X$ for control system operation were added) It is interesting to note that for the two scenarios L and O where $NO_X$ across the RTO appeared to decrease, the inlet $NO_X$ was based on emission factors, while the RTO systems for which measured data on inlet $NO_X$ were available (K, M, and N) all showed an increase in $NO_X$ across the RTO.

*Carbon monoxide (CO).* CO emissions are highly variable from wood products sources. Direct wood fired rotary dryers, direct wood or natural gas fired tube dryers, and natural gas fired veneer dryers create varying amounts of CO during combustion. The amount of CO generated depends on a multitude of factors, including the amount of excess air available, temperature of combustion, residence time, and burner efficiency.

CO source emissions from plants included in this study reflect the variability expected in the industry. Uncontrolled source emissions of CO from direct fired sources, measured at the inlets to RCOs and RTOs in this study, ranged from 0.22 to 15.7 pounds per wet scfm of emissions. **Figure 8** shows the life cycle CO emissions for the seven scenarios for which both controlled and uncontrolled source CO emissions data were available in addition to non-source CO emissions. Six of these seven plants used RTOs. For the RTO systems, controlled source CO emissions ranged from 0.05 to 2.83 lb./yr./scfm, while total life cycle controlled emissions (controlled source plus non-source) ranged from 0.38 to 3.21 lb./yr./scfm.

*Sulfur oxides ($SO_X$).* — Life cycle $SO_X$ emissions for the control scenarios are shown in **Figure 9**. Emissions of $SO_X$ from the baseline no-control option are zero because there is no reason to expect $SO_X$ levels in vent gases (which would normally be very low in any event) to be impacted by the control device. Thus, **Figure 9** shows only the increase in $SO_X$ associated with control system operation.

For the on-site boiler and BF control systems, total controlled emissions of $SO_X$ are the same as non-source emissions, since no combustion of natural gas is reported for those facilities. The RCO and RTO control systems have additional $SO_X$ releases from the combustion of natural gas in the control equipment. $SO_X$ emission factors relevant to each plant scenario were not available, so $SO_X$ emissions from natural gas combustion in RCO and RTO systems were calculated using generic emissions data for the combustion of natural gas in industrial equipment (Franklin Associates 2001). Median values for total controlled $SO_X$ emissions (in lb./yr./scfm) were 0.53 for BFs, 2.17 for RCOs, and 3.83 for RTOs.

*Greenhouse gases (GHG).* — GHG emissions for each control scenario are shown in **Figure 10**. Total GHG emissions, expressed in pounds of carbon dioxide equivalents, are calculated from fossil $CO_2$, methane ($CH_4$), and nitrous oxide ($N_2O$) emissions and global warming potentials for these substances published by the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2000).

In addition to non-source emissions of $CO_2$, carbon dioxide emissions also result from the destruction of VOCs and HAPs by the control equipment; however, since the majority of the VOCs and HAPs destroyed is from the wood itself, the carbon dioxide emissions from their destruction can be considered part of the natural carbon cycle and thus "neutral" from a GHG accounting perspective. This convention for dealing with emissions of biomass carbon is consistent with widely accepted protocols for performing GHG emission inventories, including the protocols used by the EPA and the IPCC (U.S. EPA 2000).

GHG emissions, like other atmospheric emissions, show the impact of electrical power and natural gas use. Draft sections of AP-42 (U.S. EPA 2001b) contained $CO_2$ emission factors relevant to some scenarios studied but did not distinguish between source emissions of $CO_2$ (e.g., from the wood products or from operation of direct fired dryers) and emissions resulting from the combustion of natural gas in RCOs and RTOs. Thus, GHG emissions for the combustion of natural gas are based on "generic" emissions for the combustion of natural gas in industrial equipment (Franklin Associates 2001).

Draft AP-42 factors for various control scenarios reported some $CO_2$ in uncontrolled waste gas streams. The source of the $CO_2$ was not explained; however, some if not most of this $CO_2$ was likely from the operation of the direct fired dryers. Because control inlet and outlet $CO_2$ draft emission factors lacked emission source detail and were not available for all scenarios studied, they were not used in this study. Baseline no-control emissions of GHGs were assumed to be zero in order to ensure that the life cycle GHG increases reported here reflect only those associated with use of the control system.

GHG emissions in pounds of carbon dioxide equivalents are shown in **Figure 10** for the control scenarios and a baseline of zero for no-control. Median values for total controlled greenhouse gas emissions (in lb./yr./scfm) were 71 for BFs, 213 for RCOs, and 353 for RTOs.

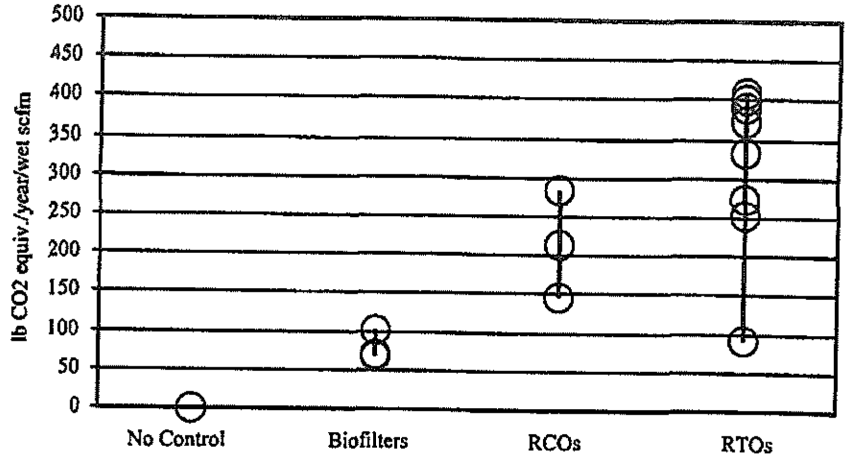

Figure 10. — Life cycle greenhouse gas emissions for emission control system operation.

### WATERBORNE EMISSIONS

Waterborne emissions for each system include emissions from material processes (such as the production of biofilter or ceramic media) and those associated with the extraction, processing, and combustion of fuels. These emissions are released at the various locations where material and fuel extraction, processing, and consumption occur.

The plants surveyed did not provide sufficient information on the frequency of washouts, quantity of water used, and composition of wastewater that would allow for an analysis of on-site wastewater impacts related to use of the control devices. All of the wastewater impacts evaluated in the LCI were thus indirect, i.e., from the production and consumption of fuels and materials, predominantly fuel related. As a consequence, the results of the control technology comparisons for any one parameter are very similar to those for the other parameters.

## NATIONAL IMPACTS

In order to better understand the national implications of the LCI profiles developed in this study, the profile data for RTOs have been used to develop estimates of total U.S. burdens under a no-control scenario and an RTO-control scenario. RTOs have been selected because this is the technology best represented in the survey data and most widely used in the industry for control of panel plant VOC emissions.

NCASI data from industry surveys were used to estimate the total amount of press and dryer vent gas generated by U.S. panel plants that, under MACT standards, would likely be subject to control by RTOs. Annual increases from industry-wide use of RTOs are calculated for selected results and compared to a baseline no-control scenario. Results for selected categories are shown in **Table 1**.

### ENERGY

The Department of Energy has estimated that, in 1994, "softwood veneer, plywood, and reconstituted wood product" facilities required $172 \times 10^6$ million BTUs/yr. This included, among other primary energy sources, 20 billion ft.$^3$ of natural gas and 6,970 million kWh of purchased power (U.S. DOE 1997).

Using median values for natural gas and power consumption for RTOs multiplied by the total estimated volume of gas that would be treated, it is estimated that industry-wide use of RTOs would increase on-site energy requirements by 31 billion ft.$^3$ of natural gas per year and 2,070 million kWh of purchased power per year. These represent increases in on-site natural gas and power consumption of 156 and 30 percent, respectively. Converting the natural gas and power consumption figures to combustion energy (using conversion factors of 1,013 BTUs/ft.$^3$ of natural gas and 3,413 BTUs/kWh) yields a total on-site energy impact of $38.7 \times 10^6$ million BTUs, an in-

*TABLE 1. — Median life cycle results for RTO operation for entire wood panel industry.*

| Parameter | Median value | Median value, annual basis[a] | Annual increase in energy and emissions for the wood panel industry[b] |
|---|---|---|---|
| | (per wet scfm)[c] | (per scf)[c] | |
| Energy | 2.69 MM BTU/yr. | 5.61 BTU | 6.97.E + 07 MM BTU |
| Greenhouse gas (as $CO_2$ equiv.) | 353 lb./yr. | 7.4E-04 lb. | 4,572 1,000 tons |
| VOCs | *(3.02) lb./yr.* | *-6.3E-06 lb.* | *(39.1) 1,000 tons* |
| HAPs | (0.97) lb./yr. | -2.0E-06 lb. | (12.6) 1,000 tons |
| Solid waste | 32.3 lb./yr. | 6.7E-05 lb. | 418 1,000 tons |
| Particulates | (1.35) lb./yr. | -2.8E-06 lb. | (17.5) 1,000 tons |
| Sulfur oxides | 3.83 lb./yr. | 8.0E-06 lb. | 49.7 1,000 tons |
| Nitrogen oxides | 1.00 lb./yr. | 2.1E-06 lb. | 12.9 1,000 tons |
| Carbon monoxide | (1.07) lb./yr. | -2.2E-06 lb. | (13.9) 1,000 tons |
| Mercury | 3.2E-06 lb./yr. | 6.7E-12 lb. | 84 lb. |

[a] Based on average mill operating hours from mill survey.

[b] Based on $12.4 \times 10^{12}$ scf waste gas for the wood panel industry annually. Results shown in the table are life cycle results (that is, they include on-site, upstream, and downstream burdens, e.g., for production and combustion of fuels, production and disposal of materials used by the control systems, etc.); therefore, energy and greenhouse gas results shown in the table are higher than results reported in the text for the increases associated with on-site energy consumption. (Source: Franklin Associates life cycle model, 2001.)

[c] scfm = standard $ft.^3$ per minute; scf = standard $ft.^3$.

crease of 22 percent in total on-site energy requirements, compared to DOE's baseline statistics.

### GREENHOUSE GASES

Carbon dioxide emissions for the wood panel industry were estimated using DOE 1994 data on direct consumption of electricity (6,970 million kWh) and natural gas (20 billion $ft.^3$) in the wood panel industry. Multiplying these energy consumption figures by life cycle carbon dioxide emissions of 1,535 lb. $CO_2$/1,000 kWh and 134 lb. $CO_2$/1,000 $ft.^3$ of natural gas (Franklin Associates 2001), it is estimated that in 1994 the total quantity of carbon dioxide releases from the wood panel industry associated with on-site use of natural gas and electricity was 6.7 million short tons. Using the median electricity and natural gas consumption data for RTOs, the increase in carbon dioxide for operation of RTOs is 3.7 million short tons, a 55 percent increase in carbon dioxide emissions. ($CO_2$ equivalents from methane and other GHGs were not included in this estimate.)

### VOCs AND HAPs

Based on median RTO values for VOC and HAP removal per wet scfm/yr. and releases of $12.4 \times 10^{12}$ wet standard cubic feet of gas per year by the wood panel industry, RTOs provide reductions in life cycle emissions of VOCs and total mass of HAPs equaling 39,000 and 12,600 tons per year, respectively, compared to the no-control baseline. This represents a life cycle reduction of 61.7 percent in VOC emissions and 84.3 percent in HAP emissions. Again, it is important to note that the HAPs in the no-control scenario consist of panel plant source emissions of methanol, formaldehyde, and acetaldehyde, while those in the RTO control scenario consist of reduced source emissions of these three compounds but additional amounts of a variety of fuel-related HAPs including acid gases, as well as much smaller quantities of mercury and other heavy metals.

## CONCLUSIONS

The results of the LCI of emission control systems indicate that additional VOC and HAP loads associated with operation of control equipment were found in nearly every case to be outweighed by the reduction in source emissions of VOCs and HAPs. Although VOC/HAP emissions and particulate emissions were reduced, the use of control systems resulted in greater life cycle burdens for energy, solid waste, $NO_X$, $SO_X$, GHG, and other emissions not discussed individually.

In addition:

- In terms of specific HAP compounds, the no-control scenarios involve the release of greater amounts of uncontrolled panel plant source emissions of methanol, formaldehyde, and acetaldehyde, while the control scenarios reduce these source emissions of HAPs but generate greater amounts of combustion-related HAPs including hydrochloric acid, hydrofluoric acid, mercury, and heavy metals.
- Among the different control technologies, the relative life cycle burdens are usually closely tied to power and natural gas consumption.
- VOC and total HAP burdens vary considerably from site to site depending on both the destruction efficiency of the control device and the amounts of power and natural gas required by the control equipment. In addition, the variation in the amounts of VOCs and HAPs in the untreated waste gas streams for the different plant sources and control scenarios makes it difficult to make general conclusions about which control systems are most effective in reducing source VOC and HAP emissions while minimizing VOC and HAP emissions from a life cycle standpoint.
- Using the median results for RTOs, the control technology for which the most data were available, it is estimated that the use of this control device on all panel plant press and dryer vents in the United States would increase on-site natural gas consumption by over 150 percent, on-site purchased power requirements by 30 percent, and total on-site energy consumption by 22 percent. Greenhouse gas emissions of fossil $CO_2$ from the panel plants and from the electrical power producers would increase by 55 percent. Life cycle emission reductions in VOCs and total HAPs of 61.7 and 84.3 percent would be accomplished by the use of RTOs.

Although it is possible, using plant survey data and data on the fuels used for national power generation, to make general comparative statements about the control technologies, there is considerable variation within each control technology in results for plant/source combinations. Because of this site-to-site variability and the regional variability in the fuel mix used to produce purchased power, the overall rankings found in this study for the control technologies may not be appropriate for other sites. Regardless of site-specific variations in operation of control technologies, however, it is clear that the application of the control technologies examined in this report can be expected to result in increased life cycle burdens for energy, solid waste, and essentially every fossil fuel combustion-related parameter except VOCs, the total mass of HAPs, and particulates.

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