APPENDIX B

ESTIMATION OF FORMALDEHYDE EMISSIONS

FROM COMPOSITE WOOD PRODUCTS

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Estimation of Formaldehyde Emissions from Composite Wood Products

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1. INTRODUCTION

Composite wood products (CWP) is a general term used to refer to wood panel products including particleboard (PB), medium density fiberboard (MDF), and hardwood plywood board (HWPW). These products are used in the construction and remodeling industry and are made from wood plies, particles, or fibers that are bound with adhesives or resin binding materials. Emissions originate from the binding materials which typically contain formaldehyde. Over time, the formaldehyde from these products is emitted, or off-gassed.

This appendix describes a methodology to estimate formaldehyde emissions from CWP products (PB, MDF, and HWPW) after they are manufactured and uses the best information available. Key variables for estimating emissions are the amount of CWP "consumed" [1] in various years in California and the corresponding formaldehyde emission rate over time. The methodology estimates formaldehyde emissions from CWP for California, as well as for individual counties, air basins, and air districts.

The year 2002 was chosen as the inventory year because industry survey data were available. Emission estimates reflect those emissions from CWP consumed in the year 2002 as well as emissions from CWP consumed prior to 2002 since CWP products continue to emit formaldehyde over time. In the following sections, the methodology and the underlying assumptions are described.

2. MATERIALS AND METHODS

2.1. Emission Characteristics

Formaldehyde emissions from CWP exhibit a declining emission rate after they are manufactured. The emission rate declines quickly during the first 25 days, then gradually declines over a longer period of time. Because this process can last years (Zinn, et al, 1990), CWP consumed in previous years will have residual

[1] The term "consumed" as used in this methodology refers to CWP manufactured in California, CWP imported into California, and excludes CWP exported from California to other regions.

emissions that will impact the estimate in current and future years. In addition, CWP is often laminated or coated on the surface, which can also change the emission characteristics.

To estimate total emissions, the emissions from PB, MDF, and HWPW in 2002 as well as the declining emissions over time need to be characterized and quantified.

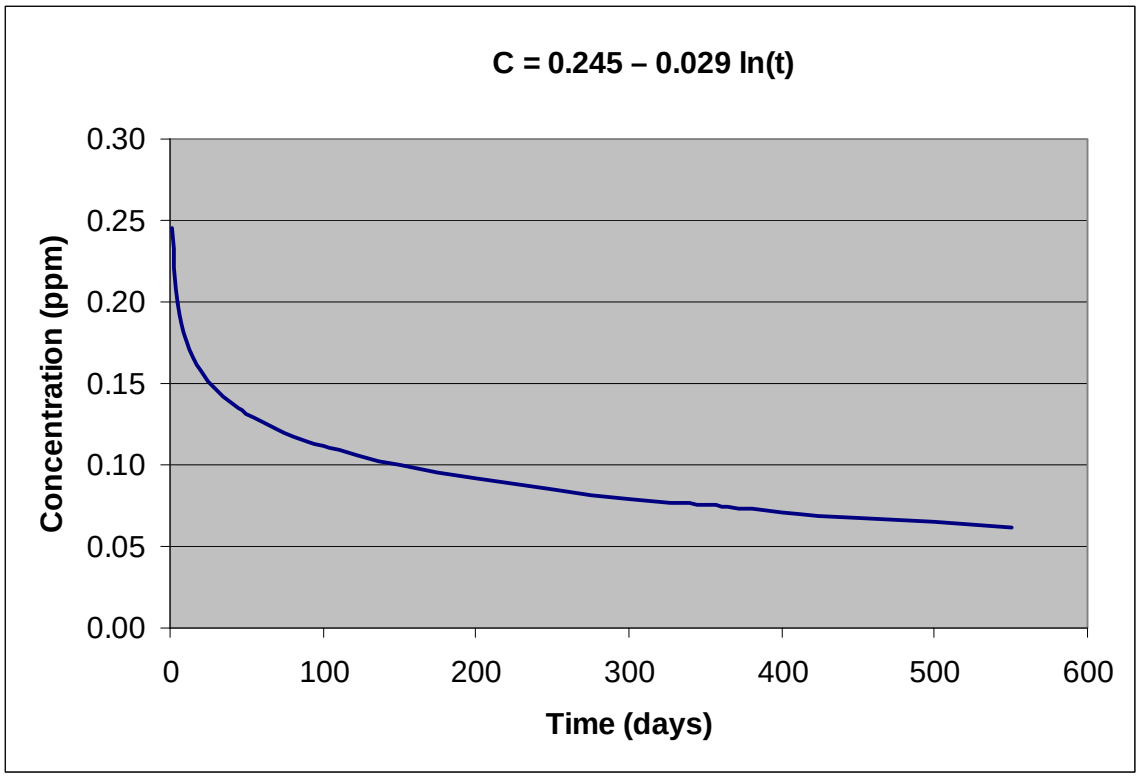
2.1.1 Raw Particleboards (PB)

The emission decay curve for raw particleboards has been described in a study conducted by the National Particleboard Association (NPA) (now the Composite Panel Association, CPA) and several particleboard manufacturers (Zinn, et al, 1990). Sixteen samples of particleboards were tested at certain time intervals in FTM-2 large chambers. A regression model from pooled data depicts how the formaldehyde concentration declines with time:

$$C = 0.245 - 0.029 \ln(t) \qquad (1)$$

In this equation, *C* is the air concentration (ppm), and t is the time after manufacturing (in days). Assuming that the average initial concentration is 0.18 ppm (from Zinn, et al, 1990), then the calculated half-life is about 200 days.

Figure 1. Decline of formaldehyde air concentration with time (Zinn, et al, 1990)



The Zinn study provided emissions estimates in parts per million (ppm). However, to estimate total emissions, emission flux density (formaldehyde emissions per unit area per unit time) is needed. ARB staff first converted formaldehyde air concentration from ppm to µg/m^3 (1 ppm = 1230 µg/m^3 at 25^{o}C). Then, using the air exchange rate (0.5/hr) and the loading rate (0.13 ft^2/ft^3) from Zinn[2], converted formaldehyde concentration from µg/m^3 to emission flux density using the following equation (Myers and Nagaoka, 1981; Myers,1984):

$$F = CN / L \qquad (2)$$

where *F* is flux density, µg/m^2/hr;
C is air concentration, µg/m^3;
N is air exchange rate of chamber, 1/hr;
L is loading rate of particleboard in chamber, m^2/m^3;

From Equation (2) and experimental parameters used for the test, a coefficient of 1443 is obtained to convert air concentration (ppm) to emission rate (µg/m^2/hr). ARB staff derived an emission rate decline model from equations (1) and (2):

$$F = 353.54 - 41.85\ln(t) \qquad (3)$$

where *F* is the flux density in µg/m^2/hr, and t is time (day). The initial flux density is 353.54 µg/m^2/hr, and the flux density decreases to 106.64 µg/m^2/hr at the end of the first year (Table 1). Assuming equation (3) is applicable to the decline trend through the whole lifespan of particleboards, the decay curve of the flux density is plotted for the first 11 years after manufacturing (Figure 2). The flux density at the end of each year is calculated (Table 1).

Table 1. Concentration and flux density at the end of each year as calculated from equation (1)-(3): Particleboard

t (year)	C (ppm)	C (µg/m^3)	C/C$_0$[a] (%)	F (µg/ m^2/ hr)
0	0.245	301.35	100.00	353.54
1	0.074	90.90	30.16	106.64
2	0.054	66.18	21.96	77.64
3	0.042	51.71	17.16	60.67
4	0.034	41.45	13.76	48.63
5	0.027	33.49	11.11	39.29
6	0.022	26.99	8.96	31.66
7	0.017	21.49	7.13	25.21
8	0.014	16.73	5.55	19.62
9	0.010	12.53	4.16	14.69
10	0.007	8.77	2.91	10.29
11	0.004	5.50	1.83	6.45

[a] C_0 represents the initial air concentration

[2] Personal communication, Zinn to Li 2006

From equation (3), the cumulative emissions for any period of time can be calculated numerically using the following equation:

$$E(t_1, t_2) = \int_{t_1}^{t_2} F(t)dt = \sum_{t_1}^{t_2} F(t_i)\Delta t_i \qquad (4)$$

Where $E(t_1,t_2)$ is the cumulative emission from time t_1 to time t_2, $F(t_i)$ is the flux density at time t_i, and Δt_i is the time interval (hr). Using equation (4), annual emissions from CWP of various ages can be calculated (Figure 3). It is estimated that about 27 percent of emissions occur in the first year, and 17 percent in the 2nd year (Table 2). The calculation also shows that about 76 percent of the emissions occurred in the first five years, and 99 percent of the emissions have occurred by the end of the 11th year (Table 2). For this reason, to provide a comprehensive emissions estimate, it is necessary to determine board consumption not only for the emission inventory year (2002), but also for the previous ten years and to account for the emissions that would occur in the inventory year from board consumption in previous years.

Figure 2. Decline of formaldehyde flux density with time

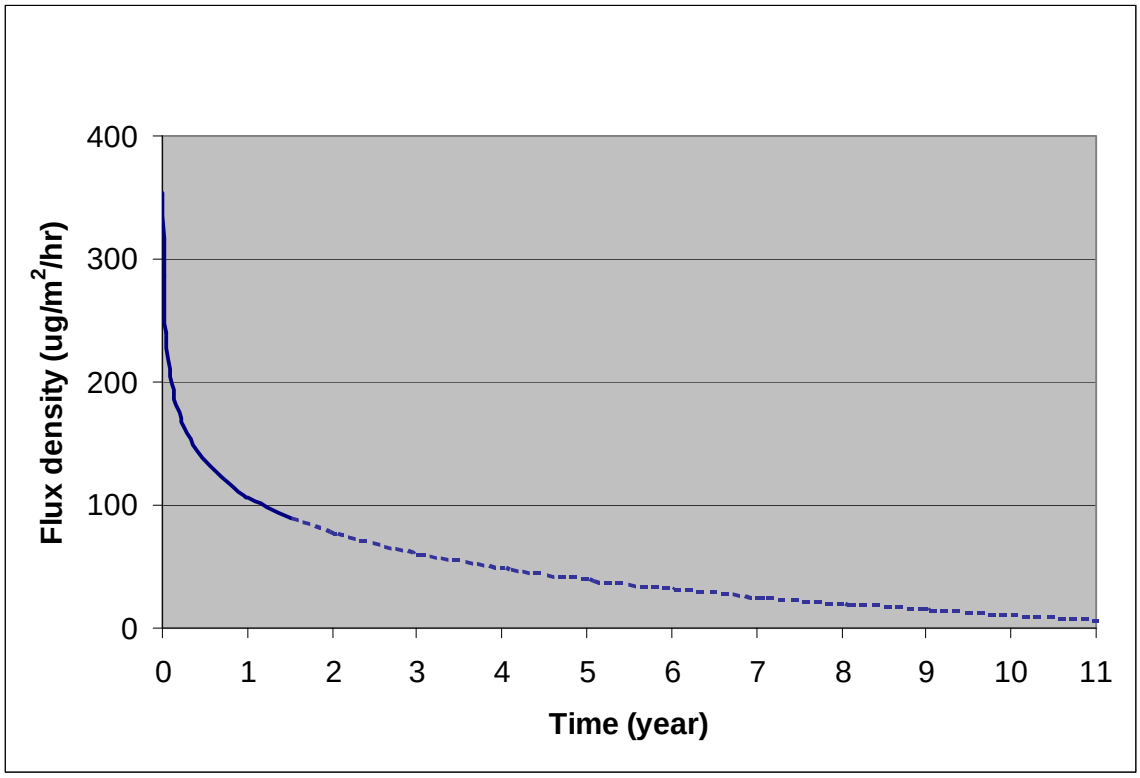
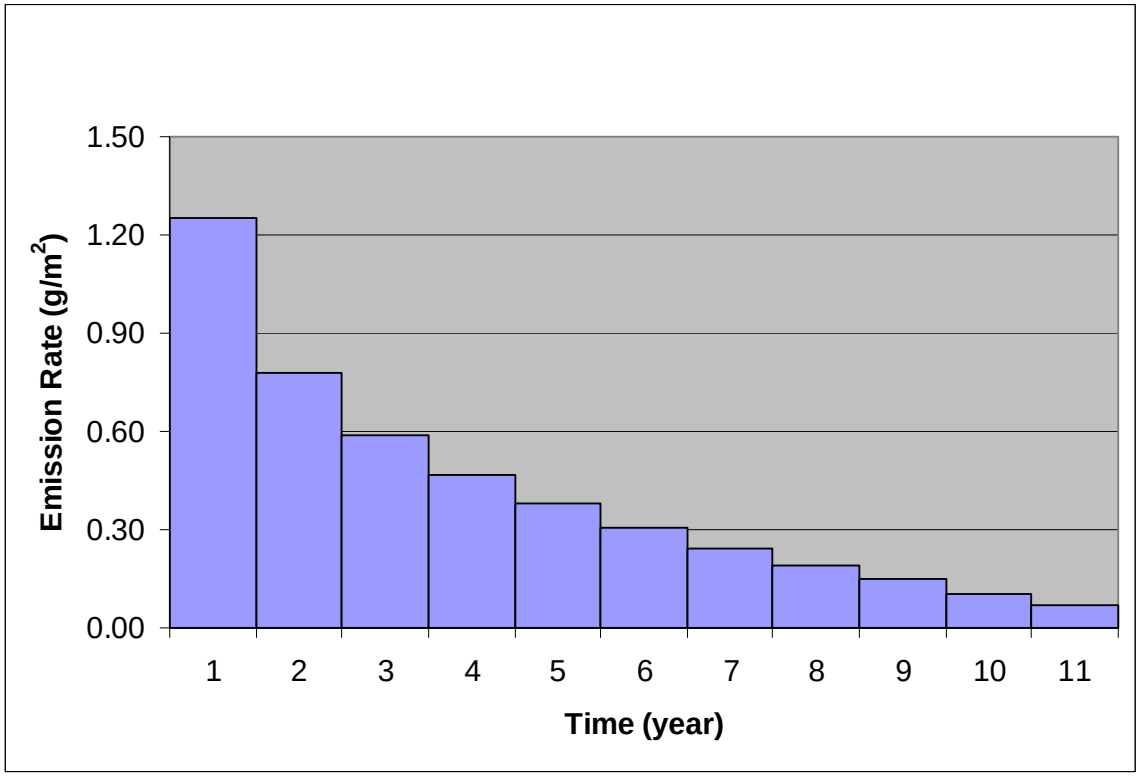


Table 2. Annual emissions and its percentage of total emission after manufacturing as calculated from equation (3)-(4): Particleboard

t (year)	Annual Emission (g/m^2)	Annual Emission (%)	Cumulative Annual Emission (g/m^2)	Cumulative Annual Emission (%)
1	1.26	27.47	1.26	27.47
2	0.78	16.93	2.04	44.41
3	0.59	12.89	2.63	57.30
4	0.47	10.23	3.10	67.53
5	0.38	8.25	3.48	75.79
6	0.31	6.66	3.78	82.45
7	0.24	5.34	4.03	87.78
8	0.19	4.20	4.22	91.98
9	0.15	3.21	4.36	95.19
10	0.11	2.32	4.47	97.52
11	0.07	1.48	4.54	98.99

Figure 3. Formaldehyde annual emissions at different ages after manufacturing



2.1.2 Laminated Particleboard

A large proportion of particleboard is coated or laminated on one side or both sides with various materials such as paper and vinyl. Surface coating or laminating creates a physical barrier so that the emission rate is lower and the emissions are released over a longer period of time. There is an array of coating and laminating methods in use, and there is limited data regarding the market shares of each laminated product. In addition, there is limited information about the effects of coating and laminating on the emission process; ARB staff was not able to find any long-term studies on emissions from laminated boards. As described below, in this methodology, the flux rate from particleboards laminated on one side was estimated differently from that of two-side laminated boards. ARB staff made certain assumptions based on their knowledge of the industry to allow for quantification.

2.1.2.1 One-side Lamination

Because emission rate test data was not available for one-side laminated particleboards, ARB staff assumed that the initial flux would be approximately the half that of raw particleboards, and it would take approximately 20 years for formaldehyde to off-gas. For boards laminated on one side, the emission decline curve for the raw boards is modified to represent the flux rate from one-side laminated boards using the following assumptions:

- To account for the effects of lamination, it takes approximately 20 years for particleboards to off-gas the formaldehyde;
- At the end of 20 years, the emission flux density of single side laminated boards is about the same as that from raw boards at the end of 11 years, and is small thereafter;
- The total emissions from laminated boards in 20 years are approximately the same as the total emissions from raw boards over an 11 year period.

Consistent with these assumptions, the following equation is used to describe how the flux density declines with time from one-side laminated boards:

$$F = 191.92 - 20.93\ln(t) \qquad (5)$$

Equation (5) is derived from equation (3) to fulfill the above assumptions, and represents the average flux density from both laminated and unlaminated surfaces. The initial flux is 191.92 µg/m^2/hr, which is about 54 percent of the raw particleboards. The decline parameter is 20.93, which is half of the raw particleboards. This equation characterizes a lower and more gradual emission declining curve (Table 3). The estimated total emissions in 20 years with equation (5) are about the same with that estimated using equation (3) for 11 years (Tables 2 and 4).

Table 3. Concentration and flux density at the end of each year as calculated from equation (5): One-side laminated particleboards

Age (year)	C (ppm)	C ($\mu g/m^3$)	C/C_0 [a] (%)	F ($\mu g/ m^2/ hr$)
0	0.133	163.59	100.00	191.92
1	0.047	58.37	35.68	68.47
2	0.037	46.00	28.12	53.97
3	0.032	38.77	23.70	45.49
4	0.027	33.64	20.56	39.47
5	0.024	29.66	18.13	34.80
6	0.021	26.41	16.14	30.98
7	0.019	23.66	14.46	27.76
8	0.017	21.28	13.01	24.96
9	0.016	19.18	11.72	22.50
10	0.014	17.30	10.57	20.29
11	0.013	15.60	9.54	18.30
12	0.011	14.05	8.59	16.48
13	0.010	12.62	7.71	14.80
14	0.009	11.30	6.91	13.25
15	0.008	10.07	6.15	11.81
16	0.007	8.92	5.45	10.46
17	0.006	7.83	4.79	9.19
18	0.006	6.82	4.17	8.00
19	0.005	5.85	3.58	6.86
20	0.004	4.94	3.02	5.79

[a] C_0 represents the initial air concentration

Table 4. Annual emissions and its percentage of total emissions after manufacturing as calculated from equation (5): One-side laminated particleboards

Age (year)	Annual Emission (g/m^2)	Annual Emission (%)	Cumulative Annual Emission (g/m^2)	Cumulative Annual Emission (%)
1	0.77	16.70	0.77	16.70
2	0.52	11.34	1.29	28.03
3	0.43	9.32	1.72	37.35
4	0.37	7.99	2.08	45.34
5	0.32	7.00	2.41	52.35
6	0.29	6.21	2.69	58.56
7	0.26	5.55	2.95	64.11
8	0.23	4.98	3.18	69.09
9	0.21	4.49	3.38	73.58
10	0.19	4.05	3.57	77.63
11	0.17	3.65	3.74	81.28
12	0.14	3.15	3.88	84.42
13	0.12	2.70	4.00	87.12
14	0.11	2.30	4.11	89.43
15	0.11	2.30	4.22	91.73

Age (year)	Annual Emission (g/m^2)	Annual Emission (%)	Cumulative Annual Emission (g/m^2)	Cumulative Annual Emission (%)
16	0.09	1.95	4.31	93.68
17	0.08	1.64	4.38	95.32
18	0.07	1.60	4.45	96.92
19	0.06	1.32	4.51	98.23
20	0.05	1.07	4.56	99.30

2.1.2.2 Two-side Lamination

Lamination on both sides of particleboards generally reduces emissions by a factor of 10 compared to emissions from raw boards (Kelly et al., 1999). Under the typical test condition (70^oF, 50% RH, and 1.0 air change per hour), the emission rate ranges from >2.5 to 55 $\mu g/m^2/hr$ for a dozen laminated industrial particleboards, which occupy about 80 percent market share of particleboards (Kelly et al., 1999). The average emission rate is about 20 $\mu g/m^2/hr$. The emission rate is low for laminated boards, but presumably lasts much longer based on the mass balance principle. To estimate emissions from particleboards laminated on both sides, the following assumptions were made:

- A flat emission rate, 20 $\mu g/ m^2/ hr$, instead of a decline curve, best represents emissions from particleboards laminated on both sides;
- Emissions last more than 20 years. However, emissions after 20 years are estimated to be very small, and are not included. We assume that the emissions are released over a 20 year period.

2.1.3 Medium Density Fiberboards (MDF) and Hardwood Plywood Boards (HWPW)

The decay curve (1) or (3) was obtained from chamber experiments on raw particleboards. In the methodology, it is assumed that the emissions from raw medium density fiberboards (MDF), and raw hardwood plywood boards (HWPW) follow the same decay pattern of particleboards, but with different initial emission levels. Based on the emissions and production survey data in 2002 collected by the Stationary Source Division of ARB, the arithmetic average and production weighted average of emission rates were calculated. The measured initial emission rates for raw PB, MDF, and HWPW are 239.9, 309.3 and 115.2 $\mu g/m^2/hr$, respectively. Therefore, the emission decline curve for MDF is adjusted as:

$$F = \frac{309.3}{239.9} \times (353.54 - 41.85\ln(t)) \qquad (6)$$

For HWPW, the decline curve is adjusted as:

$$F = \frac{115.2}{239.9} \times (353.54 - 41.85\ln(t)) \quad (7)$$

A large percentage of MDF boards are used as laminated boards, while most HWPW boards are used as raw boards. For MDF boards that are laminated on one side, the flux decline curve is modified from equation (5), and is presented as

$$F = \frac{309.3}{239.9} \times (191.92 - 20.93\ln(t)) \quad (8)$$

For MDF boards that are laminated on both sides, the flat emission rate is estimated as 20 x 309.3/239.9, which is approximately 26 μg/m^2/hr. It is assumed that emissions last over a 20-year time span at this flat emission rate.

The flux rates of formaldehyde from particleboards, MDF and HWPW boards, with and without lamination, are summarized in Table 5.

Table 5. Formaldehyde flux density (μg/m^2/hr) from laminated and unlaminated surfaces of particleboards, MDF, and HWPW boards

Board Type	**PB**	**MDF**	**HWPW**
Raw board	$F = 353.54 - 41.85\ln(t)$	$F = \frac{309.3}{239.9} \times (353.54 - 41.85\ln(t))$	$F = \frac{115.2}{239.9} \times (353.54 - 41.85\ln(t))$
One-side laminated	$F = 191.92 - 20.93\ln(t)$	$F = \frac{309.3}{239.9} \times (191.92 - 20.93\ln(t))$	n/a
Two-side laminated	20	26	n/a

2.2 Estimation of 2002 Emission Inventory at Various Spatial Scales

Currently, we do not have California specific or county specific consumption data. However, national statistics on CWP production and consumption are available. A top-down method is employed for allocating the consumption of CWP and formaldehyde emissions from the national level to the state, county, air basin and air district levels.

We used national consumption data along with population data to obtain state-level CWP consumption. Residential housing construction data were then used to apportion statewide formaldehyde emissions at various spatial scales (i.e., county, air basin, air district). Annual profiles for board consumption and emission rate are applied in the emission estimation. In the following sections,

the 2002 California CWP formaldehyde emission inventory is spatially allocated and reported by county, air basin, and air district.

2.2.1 Estimation of 2002 Emissions for the State

The US production, import and export data of PB, MDF and HWPW products are collected for the period of 1983-2002 (USDA, Forest Service). The US annual consumption of these products from 1983 to 2002 was calculated by ARB staff (see notes on Table 6). It is assumed that California consumption of CWP is proportional to the National consumption by its population size. The California annual consumption data were obtained by scaling down the US annual consumption by the proportion of California population on a yearly basis.

The 2002 annual emissions consist of emissions from raw boards and laminated boards used between 1983 and 2002:

$$ES_{2002} = \sum_{i=1}^{3} \sum_{j=1}^{3} \sum_{k=1983}^{2002} (cE_{i,j,k} A_{i,j,k}) \qquad (9)$$

where ES_{2002} is the 2002 emissions of the State (tons);

c is a coefficient of unit conversion from gram to short ton;

i represents the composite wood category, and *i* = 1, 2, 3, corresponding to PB, MDF and HWPW, respectively;

j represent the surface type of board, and *j* = 1,2,3, corresponding to raw board, 1-side lamination, and 2-side lamination, respectively;

k represents the year when the board is put into use, and *k* = 1983 – 2002;

$E_{i,j,k}$ is the annual emission rate of the boards (g/m^2);

$A_{i,j,k}$ is the annual consumption of boards (m^2).

The annual CWP consumption from 1983 to 2002 is presented in Table 6. To estimate the emissions, ARB staff had to develop assumptions on what percentage of each category were laminated based on professional judgment and an understanding of the CWP industry. The assumptions are as follows: 25 percent particleboards are used as raw boards, and 75 percent are used as laminated boards, of which 75 percent are laminated on both sides, and 25 percent on one side. For MDF, it is assumed that 10 percent are used as raw boards, and 90 percent are used as used as laminated boards, of which 85 percent are laminated on both sides, and 15 percent on one side. All HWPW boards are assumed to be used as raw boards. The assumptions for market share distribution are summarized in Table 7.

Table 6. US and California populations and consumptions of CWP (1983-2002)

Year	Population		Consumption (m^3)						CA Consumption (m^2)		
			PB		MDF		HWPW		PB [a]	MDF [a]	HWPW [b]
	US	CA	US	CA	US	CA	US	CA			
1983	233,792,000	25,337,000	6,159,000	667,000	1,912,166	207,229	3,688,741	399,764	35,038,309	10,878,180	20,984,988
1984	235,825,000	25,816,000	6,781,000	742,000	2,258,060	247,192	3,493,921	382,483	38,968,978	12,975,962	20,077,850
1985	237,924,000	26,403,000	7,019,000	779,000	2,347,976	260,561	3,854,862	427,783	40,887,154	13,677,718	22,455,818
1986	240,133,000	27,052,000	7,527,000	848,000	2,549,968	287,265	3,982,265	448,619	44,509,611	15,079,513	23,549,555
1987	242,289,000	27,717,000	7,819,000	895,000	2,874,976	328,887	4,661,957	533,311	46,955,773	17,264,409	27,995,344
1988	244,499,000	28,393,000	8,062,000	936,000	2,981,176	346,196	4,168,798	484,111	49,144,415	18,173,006	25,412,657
1989	246,819,000	29,142,000	6,875,000	812,000	1,833,685	216,504	2,970,486	350,726	42,608,918	11,365,026	18,410,827
1990	249,623,000	29,828,000	6,688,000	799,000	1,712,263	204,602	2,684,071	320,726	41,951,843	10,740,263	16,835,986
1991	252,981,000	30,458,000	6,570,000	791,000	1,667,588	200,772	2,385,013	287,147	41,522,486	10,539,189	15,073,331
1992	256,514,000	30,987,000	7,012,000	847,000	1,938,398	234,159	2,508,425	303,019	44,467,823	12,291,826	15,906,499
1993	259,919,000	31,314,000	7,698,000	927,000	2,313,532	278,725	2,645,037	318,663	48,681,082	14,631,235	16,727,741
1994	263,126,000	31,523,000	8,431,000	1,010,000	2,668,841	319,732	2,834,655	339,597	53,019,919	16,783,849	17,826,620
1995	266,278,000	31,711,000	7,861,000	936,000	2,454,353	292,288	3,082,744	367,123	49,143,820	15,343,225	19,271,572
1996	269,394,000	31,962,000	8,460,000	1,004,000	2,805,875	332,900	2,856,780	338,940	52,690,268	17,475,087	17,792,126
1997	272,647,000	32,452,000	8,686,000	1,034,000	3,157,322	375,802	3,208,007	381,835	54,269,203	19,727,163	20,043,847
1998	275,854,000	32,862,000	9,104,000	1,085,000	3,483,163	414,943	3,545,842	422,410	56,933,565	21,781,788	22,173,748
1999	279,040,000	33,417,000	9,196,000	1,101,000	3,530,555	422,809	3,803,121	455,450	57,809,217	22,194,686	23,908,160
2000	282,193,477	34,098,740	9,453,000	1,142,000	3,692,000	446,121	4,095,000	494,818	59,960,609	23,418,446	25,974,685
2001	285,107,923	34,784,382	8,703,000	1,062,000	3,654,000	445,804	4,437,000	541,333	55,737,696	23,401,763	28,416,426
2002	287,984,799	35,392,962	8,968,000	1,102,000	3,995,000	490,980	4,301,000	528,587	57,855,941	25,773,248	27,747,369

[a] Assuming 3/4 inch average thickness of PB and MDF boards
[b] Assuming 3/8 inch average thickness of HWPW boards

Data Sources:

- ✓ 1983-99 U.S. Dept. of Agriculture, U.S. Forest Products Annual Market Review and Prospects, 1965-1999. April 2001.
- ✓ 2000 U.S. Dept. of Agriculture, U.S. Forest Products Annual Market Review and Prospects, 1999-2002. December 2001.
- ✓ 2001 U.S. Dept. of Agriculture, U.S. Forest Products Annual Market Review and Prospects, 2000-2003. December 2002.
- ✓ 2002 U.S. Dept. of Agriculture, U.S. Forest Products Annual Market Review and Prospects, 2001-2004. April 2004.

Notes:

1. Consumption = Production + Imports – Exports
2. The Import and Export values for 1980-99 for PB and MDF are combined in the cited reference. Based on 2002 values assume the split for Imports to be 50% PB and 50% MDF. Assume the split for Exports to be 56% PB and 44% MDF.
3. The values for 1980-99 in the cited reference were in units of million sq. feet. To convert million sq ft to 1,000 cu meters, the conversion factors listed on page ii of the report were used:
   For PB & MDF (3/4-in. basis) multiply by 1.77
   For HWPW (3/8-in. basis) multiply by 0.885
4. The 2000 and 2001 Imports for PB, MDF, and HWPW are interpolated from the 1999 and 2002 values. The actual values were not listed in the cited references.
5. The 2000 and 2001 Exports for PB and MDF are interpolated from the 1999 and 2002 values. The actual values were not listed in the cited references.
6. The values for 2005 and 2006 are cited as estimates in the referenced report

Table 7: The share of raw boards and laminated boards for PB, MDF, and HWPW

Board Type	PB	MDF	HWPW
Raw	0.25	0.10	1.00
One-side lamination	0.19	0.14	0.00
Two-side lamination	0.56	0.76	0.00

2.2.2 Estimation of 2002 Emissions by County

The statewide consumption of CWP varies from year to year, and the emission rate declines with time. Therefore, the statewide emissions in 2002 were calculated from a time series that represent the emissions in 2002 from boards consumed in 2002 as well as in previous years. The method to calculate emissions at the county level follows the same concept. The statewide emissions are apportioned spatially into 58 counties of California by the number of residential house construction units. Once the time series of county level emissions were established, total emissions at the county level were then obtained by accumulating emissions from products used in 2002 and prior years.

CWP are primarily used for residential housing construction, nonresidential building construction, and furniture materials. It is assumed that annual consumption of CWP at the county level is proportional to its residential housing construction units in that year. Nonresidential buildings also use particle wood products as building materials and as raw boards for furniture. However, nonresidential construction is usually reported as dollar value in economic statistics, and is not comparable to the number of units for residential housing construction. To apportion to the county level, we assumed that nonresidential construction and furniture materials are proportional to residential housing construction, and used only residential housing construction units to allocate statewide emissions to emissions at the county level:

$$EC_{2002,l} = \sum_{i=1}^{3}\sum_{j=1}^{3}\sum_{k=1983}^{2002}(cE_{i,j,k}A_{i,j,k}\frac{RHU_{k,l}}{RHU_k}) \qquad (10)$$

where $EC_{2002,\,l}$ is the 2002 emissions in county l (tons), (l = 1 – 58);

$RHU_{k,l}$ is the residential housing units constructed in year k *and in county* l, (k = 1983-2002, and l = 1 - 58),

RHU_k is the total residential housing units constructed in year k in all California counties (k = 1983-2002), and

$$RHU_k = \sum_{k=1}^{58} RHU_{k,l} \qquad (11)$$

All other symbols were defined in equation (9).

Residential housing construction data at the county level were obtained from RAND California, which is an online source for California and U.S. Statistics.

However, the time series of the residential construction units started from 1988, and the data from 1983 to 1987 were not available. To extend the residential housing construction time series to 1983, the average family size was calculated by dividing the population increment with the new housing construction units per year from 1988 to 1992 in each county. The county specific family size was then used to back-calculate housing construction units in the county based on the annual population increment from 1983 to 1987.

2.2.3 Estimation of 2002 Emissions by Air Basin and Air District

Constructing emission inventories is often done by allocating emission estimates by air basin and/or air district. Air basins or air districts contain one or more counties. Air basins or air districts may contain a whole county, or only part of a county's territory; therefore, some counties are split between two or more air basins or air districts. Partitioning of county level emissions to air basins and air districts is based on the population distribution of the county in the target air basins or air districts. For example, 17 percent of the population of Kern County resides in the Mojave Desert (MD) air basin, and the rest of the population resides in the San Joaquin Valley (SJV) air basin. Therefore, 17 percent of the county's emissions are attributed to the MD air basin, and 83 percent goes to the SJV air basin. The same method also applies to apportioning the county level emissions to the air districts.

3. RESULTS

3.1 Statewide Emissions

In 2002, formaldehyde emissions from laminated and unlaminated particleboards were estimated at 452 tons, of which 71 tons were from those particleboards consumed in 2002, with the remaining emissions from particleboards consumed prior to 2002 (Table 8). Emissions from unlaminated particleboard alone were estimated at 141 tons. Particleboards laminated on one side generated 100 tons emissions, while particleboards laminated on two sides generated 211 tons emissions.

In 2002, formaldehyde emissions from medium-density fiberboards (MDF) were estimated at 190 tons (Table 9), much lower than the emissions from particleboards. MDF boards used in 2002 emitted 27 tons, which is less than 14 percent of total MDF emissions. The remaining emissions were contributed by MDF boards consumed between 1983 and 2001. Although the emission rate from laminated MDF boards was low, emissions from laminated boards contributed the majority of emissions because it was assumed a large percentage of MDF boards in use were laminated. Emissions from raw MDF boards were estimated at 29 tons, and one-sided and two-sided laminated MDF boards generated 34 tons and 127 tons, respectively.

In 2002, formaldehyde emissions from hardwood plywood boards (HWPW) were estimated at 236 tons, of which 73 tons were from the HWPW boards used in 2002, and 163 tons were from HWPW boards used from 1992 to 2001 (Table 10). All emissions were from uncovered HWPW boards.

In summary, 2002 formaldehyde emissions were estimated at 878 tons from all three categories of CWP consumed from 1983 to 2002. Emissions from the CWP consumed in 2002 were 170 tons and the rest of the emissions were from boards used prior to 2002 (Table 11). As shown in Table 12, emissions in 2002 from particleboards, MDF boards, and HWPW boards were estimated at 452 tons, 190 tons, and 236 tons, respectively. Emissions from particleboards were larger than the sum of emissions from MDF boards and HWPW boards. Emissions from raw particleboards were estimated at 406 tons, and boards with one-side and two-side laminations generated 134 tons and 338 tons emissions, respectively.

Table 8. The 2002 emissions (tons) from particleboards consumed from 1983 to 2002

Year of board consumption	Lamination Type (ton/year)			Contribution to 2002 Emissions (ton/year)	Cumulative Contribution to 2002 Emissions (ton/year)	Contribution to 2002 Emissions (%)	Cumulative Contribution to 2002 Emissions (%)
	No	1-side	2-side				
1983	0.0	0.7	7.6	8.3	8.3	1.8	1.8
1984	0.0	1.0	8.5	9.4	17.8	2.1	3.9
1985	0.0	1.2	8.9	10.1	27.9	2.2	6.2
1986	0.0	1.4	9.7	11.1	39.0	2.4	8.6
1987	0.0	1.7	10.2	11.9	50.9	2.6	11.3
1988	0.0	2.1	10.7	12.8	63.7	2.8	14.1
1989	0.0	1.9	9.3	11.1	74.8	2.5	16.6
1990	0.0	2.2	9.1	11.3	86.1	2.5	19.1
1991	0.0	2.5	9.0	11.5	97.6	2.5	21.6
1992	1.7	3.1	9.7	14.5	112.1	3.2	24.8
1993	3.0	3.7	10.6	17.3	129.4	3.8	28.6
1994	4.4	4.5	11.5	20.4	149.8	4.5	33.2
1995	5.1	4.7	10.7	20.5	170.3	4.5	37.7
1996	7.0	5.6	11.4	24.0	194.2	5.3	43.0
1997	9.3	6.4	11.8	27.5	221.7	6.1	49.1
1998	11.9	7.6	12.4	31.9	253.6	7.1	56.1
1999	15.0	8.8	12.6	36.3	289.9	8.0	64.2
2000	19.5	10.6	13.0	43.1	333.1	9.6	73.7
2001	24.0	12.0	12.1	48.1	381.1	10.6	84.4
2002	39.9	18.1	12.6	70.6	451.7	15.6	100.0
Total	140.7	99.8	211.3	451.7		100.0	

Table 9. The 2002 Emissions (tons) from MDF boards consumed from 1983 to 2002

Year of board consumption	Lamination Type (ton/year)			Contribution to 2002 Emissions (ton/year)	Cumulative Contribution to 2002 Emissions (ton/year)	Contribution to 2002 Emissions (%)	Cumulative Contribution to 2002 Emissions (%)
	No	1-side	2-side				
1983	0.0	0.2	4.1	4.3	4.3	2.3	2.3
1984	0.0	0.3	4.9	5.2	9.6	2.8	5.0
1985	0.0	0.4	5.2	5.6	15.2	2.9	8.0
1986	0.0	0.4	5.7	6.2	21.4	3.2	11.2
1987	0.0	0.6	6.6	7.2	28.5	3.8	15.0
1988	0.0	0.7	6.9	7.7	36.2	4.0	19.0
1989	0.0	0.5	4.3	4.8	41.0	2.5	21.5
1990	0.0	0.5	4.1	4.6	45.6	2.4	24.0
1991	0.0	0.6	4.0	4.6	50.2	2.4	26.4
1992	0.2	0.8	4.7	5.7	55.9	3.0	29.4
1993	0.5	1.0	5.6	7.1	63.0	3.7	33.1
1994	0.7	1.3	6.4	8.4	71.4	4.4	37.5
1995	0.8	1.3	5.8	8.0	79.5	4.2	41.8
1996	1.2	1.7	6.7	9.6	89.0	5.0	46.8
1997	1.7	2.2	7.5	11.4	100.4	6.0	52.8
1998	2.4	2.7	8.3	13.3	113.8	7.0	59.8
1999	3.0	3.1	8.5	14.6	128.3	7.6	67.4
2000	3.9	3.8	8.9	16.7	145.0	8.8	76.2
2001	5.2	4.7	8.9	18.8	163.8	9.9	86.1
2002	9.2	7.5	9.8	26.5	190.3	13.9	100.0
Total	28.8	34.4	127.1	190.3		100.0	

Table 10. The 2002 emissions (tons) from HWPW boards consumed from 1983 to 2002

Year of board consumption	Lamination Type (ton/year)			Contribution to 2002 Emissions (ton/year)	Cumulative Contribution to 2002 Emissions (ton/year)	Contribution to 2002 Emissions (%)	Cumulative Contribution to 2002 Emissions (%)
	No	1-side	2-side				
1983	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1984	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1985	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1986	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1987	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1988	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1989	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1990	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1991	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1992	2.4	0.0	0.0	2.4	2.4	1.0	1.0
1993	3.9	0.0	0.0	3.9	6.3	1.6	2.6

1994	5.7	0.0	0.0	5.7	11.9	2.4	5.0
1995	7.8	0.0	0.0	7.8	19.7	3.3	8.3
1996	9.0	0.0	0.0	9.0	28.7	3.8	12.1
1997	13.2	0.0	0.0	13.2	41.9	5.6	17.7
1998	17.8	0.0	0.0	17.8	59.7	7.5	25.3
1999	23.8	0.0	0.0	23.8	83.5	10.1	35.3
2000	32.5	0.0	0.0	32.5	116.0	13.7	49.1
2001	46.9	0.0	0.0	46.9	162.9	19.9	68.9
2002	73.5	0.0	0.0	73.5	236.4	31.1	100.0
Total	236.4	0.0	0.0	236.4		100.0	

Table 11. The 2002 emissions (tons) from PB, MDF, and HWPW boards consumed from 1983 to 2002

Year of board consumption	Lamination Type (ton/year)			Contribution to 2002 Emissions (ton/year)	Cumulative Contribution to 2002 Emissions (ton/year)	Contribution to 2002 Emissions (%)	Cumulative Contribution to 2002 Emissions (%)
	No	1-side	2-side				
1983	0.0	0.9	11.8	12.7	12.7	1.4	1.4
1984	0.0	1.3	13.4	14.7	27.4	1.7	3.1
1985	0.0	1.6	14.1	15.7	43.1	1.8	4.9
1986	0.0	1.8	15.4	17.2	60.3	2.0	6.9
1987	0.0	2.3	16.8	19.1	79.4	2.2	9.0
1988	0.0	2.9	17.6	20.5	99.9	2.3	11.4
1989	0.0	2.3	13.6	15.9	115.8	1.8	13.2
1990	0.0	2.7	13.2	15.9	131.7	1.8	15.0
1991	0.0	3.1	13.0	16.1	147.8	1.8	16.8
1992	4.3	3.9	14.3	22.5	170.4	2.6	19.4
1993	7.3	4.8	16.2	28.2	198.6	3.2	22.6
1994	10.8	5.9	17.9	34.5	233.1	3.9	26.5
1995	13.7	6.0	16.5	36.3	269.4	4.1	30.7
1996	17.2	7.3	18.1	42.6	312.0	4.8	35.5
1997	24.2	8.6	19.3	52.0	364.0	5.9	41.4
1998	32.1	10.3	20.7	63.1	427.1	7.2	48.6
1999	41.7	11.9	21.0	74.7	501.8	8.5	57.1
2000	55.9	14.5	22.0	92.3	594.1	10.5	67.6
2001	76.1	16.7	21.0	113.8	707.9	13.0	80.6
2002	122.5	25.6	22.4	170.5	878.3	19.4	100.0
Total	405.8	134.2	338.3	878.3		100.0	

Table 12. Summary of 2002 statewide emissions (tons) from CWP

Category	Raw Boards	Laminated on 1-side	Laminated on 2-side	Total
PB	141	100	211	452
MDF	29	34	127	190
HWPW	236	0	0	236
Total	**406**	**134**	**338**	**878**

3.2 Emissions by County

The number of residential house units constructed between 1983 and 2002 for all 58 counties in California are shown in Tables 13a and 13b.

For any county, formaldehyde emissions in 2002 consisted of emissions from PB, MDF, and HWPW boards consumed between 1983 and 2002 in that county. Emissions at the county level from CWP consumed in individual years were calculated from 1983 to 2002. In 2002, Los Angeles County has the largest emissions (104 tons), followed by Riverside County (94 tons) (Table 14).

Table 13a. Residential housing construction (units) by county: 1983 – 1992

County	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Alameda	4,042	4,224	3,429	4,860	3,111	6,552	6,028	2,998	2630	3,078
Alpine	4	0	8	17	0	15	9	14	10	16
Amador	94	121	201	174	228	278	401	318	370	302
Butte	1,219	1,101	1,219	1,297	1,258	1,360	1,949	1,911	1498	894
Calaveras	425	291	358	403	559	613	766	645	532	418
Colusa	93	21	52	83	21	47	71	99	117	116
Contra Costa	3,182	2,736	2,931	3,880	4,159	8,104	7,670	4,281	3952	3,899
Del Norte	0	7	13	47	61	145	129	206	110	103
El Dorado	647	476	1,021	1,259	1,463	2,350	2,176	1,952	1716	1,070
Fresno	3,634	4,014	3,688	2,983	3,525	4,134	7,104	5,352	4364	4,993
Glenn	76	44	22	44	11	57	40	93	151	113
Humboldt	0	88	265	309	442	657	748	875	687	624
Imperial	225	131	206	281	244	622	771	1,087	789	1,001
Inyo	81	0	0	0	0	31	91	69	50	44
Kern	3,834	3,535	3,562	3,834	3,345	3,158	4,303	4,889	3398	4,366
Kings	339	254	311	127	57	319	532	627	594	619
Lake	394	467	480	308	221	338	495	532	483	399
Lassen	72	24	30	66	125	136	108	176	138	91
Los Angeles	22,470	19,765	19,465	23,630	23,773	50,498	48,341	25,045	16195	11,907
Madera	445	423	423	378	400	820	1,177	1,558	1130	1,043
Marin	0	0	0	85	256	1,386	1,414	807	433	302
Mariposa	58	58	101	72	72	171	177	173	140	126
Mendocino	444	404	565	525	404	427	618	562	486	372
Merced	1,262	1,515	1,420	1,136	915	1,341	1,692	1,178	986	1,460
Modoc	28	19	0	0	0	9	15	8	17	16

County	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Mono	51	0	0	0	9	207	275	247	78	82
Monterey	1,560	1,481	1,106	1,303	1,027	1,482	2,231	1,383	931	736
Napa	265	133	232	365	332	974	966	707	756	417
Nevada	1,102	851	1,102	1,202	1,302	1,424	1,142	1,145	963	824
Orange	9,396	9,964	12,264	12,437	12,066	23,455	16,637	11,979	6569	5,943
Placer	1,565	1,657	2,072	2,302	2,716	3,922	4,704	2,888	2276	1,614
Plumas	45	0	113	136	68	256	216	297	243	301
Riverside	7,729	8,981	10,820	12,686	15,164	35,496	25,702	15,631	9356	8,206
Sacramento	7,272	6,002	6,097	7,685	9,495	11,397	13,121	10,422	4862	5,781
San Benito	4	17	26	26	38	508	530	282	167	365
San Bernardino	5,908	5,867	7,405	10,096	12,341	18,933	19,951	13,209	6835	7,238
San Diego	9,461	11,764	10,647	15,640	17,030	28,552	18,710	15,796	7908	6,059
San Francisco	1,711	1,770	2,327	2,487	756	1,931	1,508	1,077	987	629
San Joaquin	3,885	4,012	4,833	5,307	5,117	3,792	4,179	3,188	2149	2,749
San Luis Obispo	1,593	1,927	2,371	2,927	2,260	2,564	2,553	1,471	1017	666
San Mateo	984	1,219	955	617	588	2,410	2,420	827	834	938
Santa Barbara	1,713	1,735	1,629	1,692	1,354	1,470	1,541	1,269	1037	719
Santa Clara	5,086	5,174	4,648	3,289	2,565	6,465	4,859	5,321	3765	2,836
Santa Cruz	702	683	839	917	917	1,128	968	552	411	636
Shasta	592	846	1,269	1,142	1,058	1,315	1,616	2,368	1223	1,091
Sierra	25	0	0	0	0	22	17	11	20	25
Siskiyou	82	0	66	0	0	183	233	175	133	187
Solano	2,258	1,534	1,621	2,634	3,763	5,288	6,233	2,314	1442	1,803
Sonoma	2,057	1,731	2,155	2,971	3,167	4,675	4,518	3,644	2208	1,976
Stanislaus	1,688	1,639	1,639	2,210	2,880	5,007	6,318	3,951	1643	2,179
Sutter	404	216	108	243	270	331	699	1,070	567	739
Tehama	269	229	269	216	216	151	235	319	331	306
Trinity	19	58	77	19	0	112	84	65	66	64
Tulare	1,857	1,884	1,748	1,748	1,638	1,521	2,009	2,133	1990	1,966
Tuolumne	362	252	362	676	409	586	741	848	561	363
Ventura	3,667	3,375	3,189	3,614	3,853	5,154	5,026	2,612	2194	1,720
Yolo	596	439	816	628	690	1,072	820	1,284	1115	606
Yuba	80	112	96	144	175	208	160	373	306	271
Total	117,059	115,266	122,668	143,153	147,914	255,559	237,747	164,313	105,919	97,407

Table 13b. Residential housing construction (units) by county: 1993 – 2002

County	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Total
Alameda	2,567	3,128	2,950	3,898	6,500	5,897	4,511	4,208	3,236	3,572	81,419
Alpine	21	20	41	16	10	65	50	30	54	62	462
Amador	224	163	186	140	118	157	256	274	239	315	4,558
Butte	707	855	656	592	591	910	960	1,078	1,044	1,185	22,283
Calaveras	372	359	288	226	260	298	302	426	570	520	8,631
Colusa	122	77	62	35	52	51	48	46	34	41	1,288
Contra Costa	3,433	3,869	3,354	3,552	3,514	4,249	4,589	5,639	5,136	5,805	87,934
Del Norte	112	149	97	51	45	50	35	44	56	79	1,539
El Dorado	808	1,024	880	1,486	1,079	1,172	1,435	1,562	2,174	1,947	27,697
Fresno	4,147	4,638	4,091	3,461	2,756	3,034	3,032	3,196	3,963	3,839	79,948

County	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Total
Glenn	92	80	42	78	100	50	54	42	68	72	1,329
Humboldt	683	524	506	396	462	373	404	373	545	538	9,500
Imperial	626	854	497	331	327	394	333	677	756	1,062	11,215
Inyo	46	45	16	23	18	19	18	18	20	17	606
Kern	3,396	3,145	3,304	2,812	2,637	3,453	3,157	3,060	3,637	4,881	71,706
Kings	543	672	667	654	783	757	493	443	668	699	10,158
Lake	270	194	172	103	168	84	165	187	118	313	5,891
Lassen	46	83	159	121	84	83	116	107	95	125	1,984
Los Angeles	7,259	7,621	8,405	8,607	10,424	11,692	14,383	17,071	18,253	19,364	384,168
Madera	799	687	855	619	505	633	619	648	793	982	14,936
Marin	301	351	578	742	598	713	736	633	375	440	10,151
Mariposa	111	84	110	127	58	71	74	85	95	88	2,050
Mendocino	339	286	277	238	259	266	270	275	353	458	7,829
Merced	1,107	1,052	867	871	1,010	1,032	1,003	1,553	1,131	1,726	24,257
Modoc	11	10	10	9	7	10	14	20	10	27	240
Mono	74	98	64	82	96	115	213	244	310	92	2,337
Monterey	869	1,466	1,323	1,496	1,713	1,178	2,081	1,702	1,064	1,223	27,354
Napa	415	394	316	232	350	483	720	535	907	1,194	10,693
Nevada	660	737	730	599	645	668	815	847	680	912	18,349
Orange	6,410	12,644	8,300	10,207	12,251	10,101	12,348	12,367	8,646	12,020	226,004
Placer	2,102	2,861	2,574	2,847	3,837	5,206	4,896	6,379	5,974	7,188	69,581
Plumas	122	197	96	120	120	123	101	188	191	260	3,194
Riverside	7,299	8,286	6,946	7,499	9,784	12,493	14,579	15,410	19,014	22,664	273,745
Sacramento	5,065	5,129	3,863	3,870	4,339	6,842	7,743	7,750	9,434	12,854	149,023
San Benito	404	491	422	443	630	745	581	541	340	148	6,708
San Bernardino	5,852	4,730	3,953	5,014	5,593	6,113	7,072	6,580	8,527	10,616	171,833
San Diego	5,602	6,935	6,608	6,868	11,402	12,173	16,427	15,927	15,638	15,738	254,885
San Francisco	1,001	948	515	1,478	1,721	2,336	3,811	3,365	1,819	1,330	33,507
San Joaquin	2,628	2,276	2,321	2,409	2,475	3,229	4,046	5,323	4,399	6,280	74,596
San Luis Obispo	855	1,047	985	1,176	1,329	1,730	1,664	1,650	2,025	1,972	33,781
San Mateo	510	900	1,424	1,105	1,519	2,175	901	2,317	1,441	1,423	25,507
Santa Barbara	549	700	792	775	903	1,026	915	924	1,113	1,732	23,588
Santa Clara	3,439	3,954	3,484	7,501	8,810	7,526	7,010	7,054	5,960	4,513	103,259
Santa Cruz	345	509	503	536	751	639	506	587	602	922	13,652
Shasta	1,243	973	772	716	676	694	809	972	1,021	1,349	21,745
Sierra	15	20	17	16	9	10	14	19	18	17	275
Siskiyou	164	144	176	153	138	125	154	147	216	194	2,670
Solano	1,469	1,501	1,115	1,737	1,542	2,204	1,953	2,346	2,560	2,461	47,777
Sonoma	1,939	2,451	1,927	1,464	2,121	2,964	3,052	2,555	2,579	1,835	51,989
Stanislaus	1,983	1,483	1,347	1,428	1,472	2,090	2,310	3,413	3,195	3,109	50,983
Sutter	616	463	474	287	246	208	183	249	447	658	8,477
Tehama	269	251	233	154	95	154	155	221	186	298	4,557
Trinity	46	54	36	32	31	50	46	33	47	42	981
Tulare	1,761	1,903	1,727	1,428	1,338	1,455	1,653	1,651	1,773	1,988	35,171
Tuolumne	251	230	185	154	246	413	194	278	252	300	7,663
Ventura	1,372	2,464	2,166	2,353	2,316	3,182	4,442	3,971	3,446	2,507	62,622
Yolo	871	683	709	798	714	1,591	1,465	1,216	1,300	1,389	18,802
Yuba	314	155	120	118	139	153	221	84	210	376	3,814
Total	84,656	97,047	85,293	94,283	111,716	125,707	140,137	148,540	148,757	167,761	2,710,902

Table 14. 2002 Formaldehyde emissions (tons) by county from CWP used between 1983 and 2002

County	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Total
Alameda	0.4	0.5	0.4	0.6	0.4	0.5	0.4	0.3	0.4	0.7	0.9	1.1	1.3	1.8	3.0	3.0	2.4	2.6	2.5	3.6	26.8
Alpine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2
Amador	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	1.5
Butte	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.5	0.5	0.7	0.8	1.2	6.6
Calaveras	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.4	0.5	2.7
Colusa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Contra Costa	0.3	0.3	0.4	0.5	0.5	0.6	0.5	0.4	0.6	0.9	1.1	1.4	1.4	1.6	1.6	2.1	2.4	3.5	3.9	5.9	30.3
Del Norte	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5
El Dorado	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.2	0.3	0.2	0.3	0.4	0.4	0.7	0.5	0.6	0.8	1.0	1.7	2.0	9.8
Fresno	0.4	0.5	0.5	0.4	0.5	0.3	0.5	0.5	0.7	1.2	1.4	1.7	1.7	1.6	1.3	1.5	1.6	2.0	3.0	3.9	25.0
Glenn	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.5
Humboldt	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.5	3.2
Imperial	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.2	0.1	0.2	0.2	0.2	0.4	0.6	1.1	4.2
Inyo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Kern	0.4	0.5	0.5	0.5	0.4	0.3	0.3	0.5	0.5	1.0	1.1	1.1	1.4	1.3	1.2	1.7	1.7	1.9	2.8	5.0	24.0
Kings	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.3	0.3	0.5	0.7	4.0
Lake	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.3	1.5
Lassen	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.7
Los Angeles	2.4	2.5	2.5	2.8	3.1	4.0	3.2	2.4	2.5	2.8	2.4	2.7	3.6	3.9	4.9	5.9	7.7	10.6	14.0	19.7	103.5
Madera	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.2	0.4	0.3	0.2	0.3	0.3	0.4	0.6	1.0	5.0
Marin	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.3	0.4	0.4	0.4	0.3	0.4	3.4
Mariposa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.6
Mendocino	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.5	2.3
Merced	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.5	1.0	0.9	1.8	8.2
Modoc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Mono	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.1	0.9
Monterey	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.5	0.6	0.7	0.8	0.6	1.1	1.1	0.8	1.2	9.2
Napa	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.4	0.3	0.7	1.2	4.1
Nevada	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.4	0.5	0.5	0.9	5.4
Orange	1.0	1.3	1.6	1.5	1.6	1.9	1.1	1.2	1.0	1.4	2.1	4.5	3.5	4.6	5.7	5.1	6.6	7.7	6.6	12.2	72.1

Placer	0.2	0.2	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.4	0.7	1.0	1.1	1.3	1.8	2.6	2.6	4.0	4.6	7.3	29.8
Plumas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.3	1.1
Riverside	0.8	1.1	1.4	1.5	2.0	2.8	1.7	1.5	1.4	1.9	2.4	2.9	3.0	3.4	4.6	6.3	7.8	9.6	14.5	23.0	93.7
Sacramento	0.8	0.8	0.8	0.9	1.2	0.9	0.9	1.0	0.7	1.3	1.7	1.8	1.6	1.7	2.0	3.4	4.1	4.8	7.2	13.1	50.9
San Benito	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.3	0.3	0.3	0.2	2.6
San Bernardino	0.6	0.7	0.9	1.2	1.6	1.5	1.3	1.3	1.0	1.7	2.0	1.7	1.7	2.3	2.6	3.1	3.8	4.1	6.5	10.8	50.4
San Diego	1.0	1.5	1.4	1.9	2.2	2.3	1.3	1.5	1.2	1.4	1.9	2.5	2.8	3.1	5.3	6.1	8.8	9.9	12.0	16.0	83.9
San Francisco	0.2	0.2	0.3	0.3	0.1	0.2	0.1	0.1	0.2	0.1	0.3	0.3	0.2	0.7	0.8	1.2	2.0	2.1	1.4	1.4	12.2
San Joaquin	0.4	0.5	0.6	0.6	0.7	0.3	0.3	0.3	0.3	0.6	0.9	0.8	1.0	1.1	1.2	1.6	2.2	3.3	3.4	6.4	26.5
San Luis Obispo	0.2	0.2	0.3	0.4	0.3	0.2	0.2	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.9	0.9	1.0	1.5	2.0	10.8
San Mateo	0.1	0.2	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.2	0.2	0.3	0.6	0.5	0.7	1.1	0.5	1.4	1.1	1.4	9.2
Santa Barbara	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.4	0.4	0.5	0.5	0.6	0.9	1.8	7.4
Santa Clara	0.6	0.7	0.6	0.4	0.3	0.5	0.3	0.5	0.6	0.7	1.1	1.4	1.5	3.4	4.1	3.8	3.7	4.4	4.6	4.6	37.7
Santa Cruz	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.5	0.9	4.4
Shasta	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.4	0.6	0.8	1.4	6.8
Sierra	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Siskiyou	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	1.0
Solano	0.2	0.2	0.2	0.3	0.5	0.4	0.4	0.2	0.2	0.4	0.5	0.5	0.5	0.8	0.7	1.1	1.0	1.5	2.0	2.5	14.2
Sonoma	0.2	0.2	0.3	0.4	0.4	0.4	0.3	0.4	0.3	0.5	0.6	0.9	0.8	0.7	1.0	1.5	1.6	1.6	2.0	1.9	15.8
Stanislaus	0.2	0.2	0.2	0.3	0.4	0.4	0.4	0.4	0.2	0.5	0.7	0.5	0.6	0.6	0.7	1.0	1.2	2.1	2.4	3.2	16.3
Sutter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.7	2.8
Tehama	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.3	1.5
Trinity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Tulare	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.3	0.5	0.6	0.7	0.7	0.6	0.6	0.7	0.9	1.0	1.4	2.0	11.6
Tuolumne	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.2	0.3	2.0
Ventura	0.4	0.4	0.4	0.4	0.5	0.4	0.3	0.3	0.3	0.4	0.5	0.9	0.9	1.1	1.1	1.6	2.4	2.5	2.6	2.5	19.9
Yolo	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.3	0.2	0.3	0.4	0.3	0.8	0.8	0.8	1.0	1.4	7.2
Yuba	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.4	1.4
Total	**12.7**	**14.7**	**15.7**	**17.2**	**19.1**	**20.5**	**15.9**	**15.9**	**16.1**	**22.5**	**28.2**	**34.5**	**36.3**	**42.6**	**52.0**	**63.1**	**74.7**	**92.3**	**113.8**	**170.5**	**878.3**

3.3 Emissions by Air Basin and Air District

Many counties are split into more than one air basin or air district. Emissions in such a county need to be apportioned to the relevant air districts or air basins based on population distribution (Table 15).

The South Coast (SC) air basin contains Los Angeles, Orange, Riverside, and San Bernardino counties, all generating large emissions. The South Coast total emissions are 284 tons, larger than emissions from any other California air basin (Table 16). San Francisco (SF), San Joaquin Valley (SJV) and Sacramento Valley (SV) are the second, the third, and the fourth largest air basins for formaldehyde emissions from CWP.

Table 15. Apportioning 2002 formaldehyde emissions from county to air basin (AB) and air district (DIS)

CO	AB	DIS	County	CO Population in AB|DIS	CO Total Population	AB/CO Ratio	CO Emission (tons)	AB Partial Emission (tons)
1	SF	BA	Alameda	1,488,560	1,488,560	1.000	26.8	26.8
2	GBV	GBU	Alpine	1,258	1,258	1.000	0.2	0.2
3	MC	AMA	Amador	36,704	36,704	1.000	1.5	1.5
4	SV	BUT	Butte	208,791	208,791	1.000	6.6	6.6
5	MC	CAL	Calaveras	42,440	42,440	1.000	2.7	2.7
6	SV	COL	Colusa	19,656	19,656	1.000	0.4	0.4
7	SF	BA	Contra Costa	989,422	989,422	1.000	30.3	30.3
8	NC	NCU	Del Norte	27,931	27,931	1.000	0.5	0.5
9	LT	ED	El Dorado (partial)	36,091	165,708	0.218	9.8	2.1
9	MC	ED	El Dorado (partial)	129,617	165,708	0.782	9.8	7.7
10	SJV	SJU	Fresno	837,459	837,459	1.000	25.0	25.0
11	SV	GLE	Glenn	27,185	27,185	1.000	0.5	0.5
12	NC	NCU	Humboldt	128,648	128,648	1.000	3.2	3.2
13	SS	IMP	Imperial	149,948	149,948	1.000	4.2	4.2
14	GBV	GBU	Inyo	18,506	18,506	1.000	0.2	0.2
15	MD	KER	Kern (partial)	118,536	699,330	0.169	24.0	4.1
15	SJV	SJU	Kern (partial)	580,794	699,330	0.831	24.0	19.9
16	SJV	SJU	Kings	135,218	135,218	1.000	4.0	4.0
17	LC	LAK	Lake	61,269	61,269	1.000	1.5	1.5
18	NEP	LAS	Lassen	33,986	33,986	1.000	0.7	0.7
19	MD	AV	Los Angeles (partial)	311,190	9,910,524	0.031	103.5	3.3
19	SC	SC	Los Angeles (partial)	9,599,334	9,910,524	0.969	103.5	100.3
20	SJV	SJU	Madera	129,728	129,728	1.000	5.0	5.0
21	SF	BA	Marin	250,451	250,451	1.000	3.4	3.4
22	MC	MPA	Mariposa	17,416	17,416	1.000	0.6	0.6
23	NC	MEN	Mendocino	88,258	88,258	1.000	2.3	2.3
24	SJV	SJU	Merced	224,488	224,488	1.000	8.2	8.2
25	NEP	MOD	Modoc	9,478	9,478	1.000	0.1	0.1
26	GBV	GBU	Mono	13,330	13,330	1.000	0.9	0.9
27	NCC	MBU	Monterey	415,712	415,712	1.000	9.2	9.2

CO	AB	DIS	County	CO Population in AB|DIS	CO Total Population	AB/CO Ratio	CO Emission (tons)	AB Partial Emission (tons)
28	SF	BA	Napa	129,357	129,357	1.000	4.1	4.1
29	MC	NSI	Nevada	95,623	95,623	1.000	5.4	5.4
30	SC	SC	Orange	2,962,903	2,962,903	1.000	72.1	72.1
31	LT	PLA	Placer (partial)	13,558	277,256	0.049	29.8	1.5
31	MC	PLA	Placer (partial)	24,648	277,256	0.089	29.8	2.7
31	SV	PLA	Placer (partial)	239,050	277,256	0.862	29.8	25.7
32	MC	NSI	Plumas	20,890	20,890	1.000	1.1	1.1
33	MD	MOJ	Riverside (partial)	17,878	1,686,571	0.011	93.7	1.0
33	MD	SC	Riverside (partial)	10,119	1,686,571	0.006	93.7	0.6
33	SC	SC	Riverside (partial)	1,305,575	1,686,571	0.774	93.7	72.6
33	SS	SC	Riverside (partial)	352,999	1,686,571	0.209	93.7	19.6
34	SV	SAC	Sacramento	1,303,052	1,303,052	1.000	50.9	50.9
35	NCC	MBU	San Benito	56,208	56,208	1.000	2.6	2.6
36	MD	MOJ	San Bernardino (partial)	403,725	1,816,127	0.222	50.4	11.2
36	SC	SC	San Bernardino (partial)	1,412,402	1,816,127	0.778	50.4	39.2
37	SD	SD	San Diego	2,948,968	2,948,968	1.000	83.9	83.9
38	SF	BA	San Francisco	790,830	790,830	1.000	12.2	12.2
39	SJV	SJU	San Joaquin	608,594	608,594	1.000	26.5	26.5
40	SCC	SLO	San Luis Obispo	254,525	254,525	1.000	10.8	10.8
41	SF	BA	San Mateo	715,656	715,656	1.000	9.2	9.2
42	SCC	SB	Santa Barbara	409,212	409,212	1.000	7.4	7.4
43	SF	BA	Santa Clara	1,720,757	1,720,757	1.000	37.7	37.7
44	NCC	MBU	Santa Cruz	258,211	258,211	1.000	4.4	4.4
45	SV	SHA	Shasta	171,774	171,774	1.000	6.8	6.8
46	MC	NSI	Sierra	3,602	3,602	1.000	0.1	0.1
47	NEP	SIS	Siskiyou	44,821	44,821	1.000	1.0	1.0
48	SF	BA	Solano (partial)	285,466	411,868	0.693	14.2	9.9
48	SV	YS	Solano (partial)	126,402	411,868	0.307	14.2	4.4
49	NC	NS	Sonoma (partial)	58,146	470,055	0.124	15.8	2.0
49	SF	BA	Sonoma (partial)	411,909	470,055	0.876	15.8	13.9
50	SJV	SJU	Stanislaus	479,203	479,203	1.000	16.3	16.3
51	SV	FR	Sutter	82,942	82,942	1.000	2.8	2.8
52	SV	TEH	Tehama	57,552	57,552	1.000	1.5	1.5
53	NC	NCU	Trinity	13,240	13,240	1.000	0.3	0.3
54	SJV	SJU	Tulare	384,650	384,650	1.000	11.6	11.6
55	MC	TUO	Tuolumne	56,281	56,281	1.000	2.0	2.0
56	SCC	VEN	Ventura	787,965	787,965	1.000	19.9	19.9
57	SV	YS	Yolo	179,780	179,780	1.000	7.2	7.2
58	SV	FR	Yuba	63,085	63,085	1.000	1.4	1.4
Total				**35,392,962**				**878.3**

Table 16. 2002 formaldehyde emissions (tons) from CWP by air basin (AB), air district (DIS) and county

AB	DIS	County	Total
GBV	GBU	Alpine	0.2
		Inyo	0.2
		Mono	0.9
	GBU Total		1.3
GBV Total			1.3
LC	LAK	Lake	1.5
	LAK Total		1.5
LC Total			1.5
LT	ED	El Dorado (partial)	2.1
	ED Total		2.1
	PLA	Placer (partial)	1.5
	PLA Total		1.5
LT Total			3.6
MC	AMA	Amador	1.5
	AMA Total		1.5
	CAL	Calaveras	2.7
	CAL Total		2.7
	ED	El Dorado (partial)	7.7
	ED Total		7.7
	MPA	Mariposa	0.6
	MPA Total		0.6
	NSI	Nevada	5.4
		Plumas	1.1
		Sierra	0.1
	NSI Total		6.6
	PLA	Placer (partial)	2.7
	PLA Total		2.7
	TUO	Tuolumne	2.0
	TUO Total		2.0
MC Total			23.8
MD	AV	Los Angeles (partial)	3.3
	AV Total		3.3
	KER	Kern (partial)	4.1
	KER Total		4.1
	MOJ	Riverside (partial)	1.0
		San Bernardino (partial)	11.2
	MOJ Total		12.2
	SC	Riverside (partial)	0.6
	SC Total		0.6
MD Total			20.1
NC	MEN	Mendocino	2.3
	MEN Total		2.3
	NCU	Del Norte	0.5
		Humboldt	3.2
		Trinity	0.3

AB	DIS	County	Total
	NCU Total		4.0
	NS	Sonoma (partial)	2.0
	NS Total		2.0
NC Total			8.2
NCC	MBU	Monterey	9.2
		San Benito	2.6
		Santa Cruz	4.4
	MBU Total		16.2
NCC Total			16.2
NEP	LAS	Lassen	0.7
	LAS Total		0.7
	MOD	Modoc	0.1
	MOD Total		0.1
	SIS	Siskiyou	1.0
	SIS Total		1.0
NEP Total			1.8
SC	SC	Los Angeles (partial)	100.3
		Orange	72.1
		Riverside (partial)	72.6
		San Bernardino (partial)	39.2
	SC Total		284.1
SC Total			284.1
SCC	SB	Santa Barbara	7.4
	SB Total		7.4
	SLO	San Luis Obispo	10.8
	SLO Total		10.8
	VEN	Ventura	19.9
	VEN Total		19.9
SCC Total			38.1
SD	SD	San Diego	83.9
	SD Total		83.9
SD Total			83.9
SF	BA	Alameda	26.8
		Contra Costa	30.3
		Marin	3.4
		Napa	4.1
		San Francisco	12.2
		San Mateo	9.2
		Santa Clara	37.7
		Solano (partial)	9.9
		Sonoma (partial)	13.9
	BA Total		147.4
SF Total			147.4
SJV	SJU	Fresno	25.0
		Kern (partial)	19.9
		Kings	4.0
		Madera	5.0
		Merced	8.2

AB	DIS	County	Total
		San Joaquin	26.5
		Stanislaus	16.3
		Tulare	11.6
	SJU Total		116.5
SJV Total			116.5
SS	IMP	Imperial	4.2
	IMP Total		4.2
	SC	Riverside (partial)	19.6
	SC Total		19.6
SS Total			23.8
SV	BUT	Butte	6.6
	BUT Total		6.6
	COL	Colusa	0.4
	COL Total		0.4
	FR	Sutter	2.8
		Yuba	1.4
	FR Total		4.1
	GLE	Glenn	0.5
	GLE Total		0.5
	PLA	Placer (partial)	25.7
	PLA Total		25.7
	SAC	Sacramento	50.9
	SAC Total		50.9
	SHA	Shasta	6.8
	SHA Total		6.8
	TEH	Tehama	1.5
	TEH Total		1.5
	YS	Solano (partial)	4.4
		Yolo	7.2
	YS Total		11.6
SV Total			108.1
Grand Total			**878.3**

4. DISCUSSION

Creating an inventory for formaldehyde emissions from CWP is a challenging endeavor given the complexity and limited test data and consumption data. This methodology systematically accounts for formaldehyde emissions from CWP at state and regional levels and uses the best available information. However, room exists to improve the emission estimates in this study. Developing a comprehensive formaldehyde emission inventory is ultimately dictated by the availability of data required for emission calculations. A list of assumptions has been made to bridge the gap between reality and data availability. The flux density and board consumption data are the two critical elements of this methodology. Studies revealed that the emission rate of formaldehyde varies

with the ambient temperature, humidity, and ventilation rate (Myers and Nagaoka, 1981; Myers 1984 and 1985). The effects of environmental factors on emission rate were not considered in the methodology. Emission estimation may be improved once more and better data become available. Examples of information that could support improvements include:

- Long term studies of flux density decline characteristics of all three types of boards (PB, MDF, and HWPW), from unlaminated and laminated surfaces with various materials;
- California specific production, import, export, and consumption data of various CWP, including those laminated and unlaminated, and used as raw boards, semi-products, and furniture, and
- Investigation into effects of environmental factors, such as temperature, humidity and ventilation rate, on flux density.

5. SUMMARY

A methodology has been developed to estimate formaldehyde emissions from composite wood products (CWP) at various spatial scales. The methodology accounts for emissions from CWP manufactured in the inventory year and consumed prior to the inventory year. The statewide annual emissions of formaldehyde in 2002 are estimated as 878 tons, which represents the emissions from CWP consumed in 2002 and in the previous 19 years. The statewide annual emissions of 2002 were also apportioned to counties, air basins, and air districts based on population and/or residential construction units.

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Reference and Data Sources

James L. Howard. USDA, Forest Service. *US forest products annual market review and prospects, 1999-2000*. Research Note FPL-RN-0278.

James L. Howard. USDA, Forest Service. *US forest products annual market review and prospects*, 1999-2002. Research Note FPL-RN-0282.

James L. Howard. USDA, Forest Service. *US forest products annual market review and prospects*, 2000-2003. Research Note FPL-RN-0287.

James L. Howard. USDA, Forest Service. *US forest products annual market review and prospects*, 2001-2004. Research Note FPL-RN-0292.

James L. Howard. USDA, Forest Service. *US forest products annual market review and prospects*, 2001-2005. Research Note FPL-RN-0299.

James L. Howard. USDA, Forest Service. *US forest products annual market review and prospects*, 2002-2006. Research Note FPL-RN-0302.

Kelly, T. J, D. L. Smith, and J. Satola, 1999. Emission rates of formaldehyde from materials and consumer products found in California homes. Environ. Sci. Technol. 33:81-88.

Myers, G.E. 1985. The effects of temperature and humidity on formaldehyde emission from UF-bonded boards: a literature critique. *Forest Prod J*. 35(9):20-31.

Myers, G.E., 1984. Effects of ventilation rate and board loading on formaldehyde concentration: a critical review of the literature. *Forest Prod J*. 34(10):59-68.

Myers, G.E., M. Nagaoka. 1981. Emission of formaldehyde by particleboard: Effect of ventilation rate and loading on air-concentration levels. *Forest Prod J*. 31(7):39-44.

RAND California: An online source for California and U.S. Statistics. Website: http://ca.rand.org/cgi-bin/homepage.cgi.

Zinn, T. W., D. Cline, and W.F. Lehmann. 1990. Long-term study of formaldehyde emission decay from particleboard. *Forest Prod J*. 40(6):15-18.