

Appendix H

Comparison of the Proposed Phase 1 and Phase 2 Standards to Selected International Standards

A. Overview

In contrast to “building material” standards in Europe and Japan, the proposed Phase 1 and Phase 2 standards for hardwood plywood (HWPW), particleboard (PB), and medium density fiberboard (MDF), with effective dates in the 2009 to 2012 timeframe, are product-specific. Based on the use of published equations correlating the results of a selected formaldehyde (HCHO) emission/content tests (Risholm-Sundman et al., 2006) and results from a study to compare the metrics used in the U.S. and Europe (Groah et al., 1991), the relative stringency of the proposed standards has been estimated. It is postulated that the equivalent U.S. large chamber test value (i.e., ASTM E1333) for the European E1, Japanese F☆☆☆ and F☆☆☆☆ standards applicable to composite wood products subject to the proposed Airborne Toxic Control Measure (ATCM) are:

Standard	Product(s)	Test Method	Numerical Value	≈ E1333 (ppm)
CARB-P1	HWPW	E1333	0.08 ppm	0.08
“	PB	“	0.18 ppm	0.18
“	MDF	“	0.21 ppm	0.21
CARB-P2	HWPW	E1333	0.05 ppm	0.05
“	PB	“	0.09 ppm	0.09
“	MDF	“	0.11 ppm	0.11
E1	HWPW	EN 717-1	0.12 mg m ⁻³	0.14
“	PB	“	“	0.14
“	PB, MDF	EN 120	8 mg 100 g ⁻¹	0.10
F☆☆☆	All	JIS A1460	0.5 mg L ⁻¹	0.07
F☆☆☆☆	All	JIS A1460	0.3 mg L ⁻¹	0.04

⁽¹⁾ See Appendix A for “Product(s)” abbreviations. The F-star standards apply to all wood products specified in the CARB standards. The “≈ E1333” values were calculated using data in ASTM (1996), Battelle (1996), and Risholm-Sundman et al. (2006) (see Appendix B).

Although there remains a measure of uncertainty as to the exact “E1333-equivalent” concentrations represented by the E1 and F-star standards, the

following semi-quantitative assignments can be made relative to the proposed Phase 1 and Phase 2 standards:

Relative Stringency of the Proposed Phase 1 (P1) and Phase 2 (P2) Standards to the E1 and F-star Standards ¹			
P1 (ppm)	E1	F☆☆	F☆☆☆
HWPW (0.08)	More	Comparable	Less
PB (0.18)	Less	Less	Less
MDF (0.21)	Less	Less	Less
P2 (ppm)	E1	F☆☆	F☆☆☆
HWPW (0.05)	More	More	Comparable
PB (0.09)	More	Comparable	Less
MDF (0.11)	Comparable	Less	Less
⁽¹⁾ Values in parentheses are the proposed Phase 1 or Phase 2 standards in ppm. “More” means the proposed standard is “more stringent” than applicable E1, F☆☆, or F☆☆☆ standards.			

Overall, except for HWPW, the proposed Phase 1 standards are generally less stringent than existing standards in Europe and Japan. However, adoption of the proposed Phase 2 standards, would establish standards of equivalent or greater stringency than the European E1, and of comparable stringency to the Japanese F☆☆ standards, except for MDF.

B. Purpose

This analysis attempts to reconcile the positions held by industry, environmental health advocates, and air quality analysts, and to determine the relative stringency of the proposed Phase 1 and Phase 2 standards for HWPW, PB, and MDF.

C. U.S. National vs. Proposed CARB Standards

In the U.S., the large chamber test procedure (ASTM E1333) is the standard test method used to measure the HCHO level in HWPW, PB, and as appropriate, MDF. In consideration of the numerical value of the voluntary HUD standard and product loading rate (Table H-1), raw panels meeting the voluntary standards would have the following HCHO emission factors ($\text{mg m}^{-2} \text{hr}^{-1}$):

Table H-1. Estimated HCHO Emission Factors for HWPW, PB, and MDF Compliant with the 1985 HUD Standard ⁽¹⁾			
Wood Product	HUD Standard (ppm)	Loading Rate (m ² m ⁻³)	Emission Rate (mg m ⁻² hr ⁻¹)
HWPW	0.2	0.425	0.21
PB	0.3	0.425	0.43
MDF	0.3	0.26	0.71
⁽¹⁾ Sources: ASTM (1996), NPA (1994). "HUD Standard" for MDF is a voluntary standard selected for use by the NPA.			

The following equation was used to calculate the emission rates in Table 1:

$$ER = 1.23 C_s \times (N \div L)$$

Where:

- ER = HCHO emission rate (mg m⁻² hr⁻¹)
- 1.23 = constant for converting HCHO concentration (mg m⁻³ ppm⁻¹)
- C_s = ASTM E1333 steady-state HCHO concentration (ppm)
- N = chamber ventilation rate in air changes per hour (hr⁻¹)
- L = product loading rate (m² m⁻³)

The emission rates (mg m⁻² hr⁻¹) for HWPW, PB, and MDF meeting their respective HUD standards were calculated as follows:

- $ER_{HWPW} = 1.23 \text{ mg m}^{-3} \text{ ppm}^{-1} (0.2 \text{ ppm}) \times (0.5 \text{ hr}^{-1} \div 0.425 \text{ m}^2 \text{ m}^{-3}) = 0.21$
- $ER_{PB} = 1.23 \text{ mg m}^{-3} \text{ ppm}^{-1} (0.3 \text{ ppm}) \times (0.5 \text{ hr}^{-1} \div 0.425 \text{ m}^2 \text{ m}^{-3}) = 0.43$
- $ER_{MDF} = 1.23 \text{ mg m}^{-3} \text{ ppm}^{-1} (0.3 \text{ ppm}) \times (0.5 \text{ hr}^{-1} \div 0.26 \text{ m}^2 \text{ m}^{-3}) = 0.71$

The estimates for HWPW and PB approximate values for uncoated HWPW and PB of 0.007 to 0.170 and 0.104 to 0.508 mg HCHO m⁻² hr⁻¹, respectively (Battelle, 1996), manufactured to meet applicable HUD standards. For MDF, the reported range of values for uncoated MDF was 0.210 to 0.385 mg HCHO m⁻² hr⁻¹, which may in part be due to the lower loading rate specified by ASTM in the E1333 test protocol (0.26 m² m⁻³) vs. the loading rate used in the Battelle study (0.46 m² m⁻³).

In Table H-2, the estimated emission rates for the composite wood products subject to the proposed ATCM are listed along with the % reduction in emission rate relative to products manufactured to meet the HUD standard.

Table H-2. Comparison of Estimated Emission Rates and % Reduction in Emission Rate Relative to the 1985 HUD Standard: HWPW, PB, and MDF			
Standard or Mean	----- Emission Rate (mg HCHO m ⁻² hr ⁻¹) -----		
	HWPW	PB	MDF
HUD	0.210	0.434	0.710
2002 Mean	0.131	0.264	0.367
Phase 1	0.099	0.224	0.262
Phase 2	0.062	0.112	0.137
	----- % Reduction from 1985 HUD Standard -----		
2002 Mean	-38	-39	-48
Phase 1	-53	-48	-63
Phase 2	-71	-74	-81

D. European E1 Standard: Comparison between the EN 717-1 and E1333 Tests

In Europe, the principal tool for measuring surface emissions of HCHO from composite wood products is the WKI (Wilhelm Klauditz Institute) chamber, specified in the EN 717-1 test method. A comparison of the test conditions and HCHO standards for PB in Europe vs. those in the U.S. is shown in Table H-3:

Table H-3. Test Specifications in the European EN 717-1 and U.S. E1333 Chamber-based Tests for Measuring HCHO Emissions from Particleboard ¹		
Test Parameter	EN 717-1	E1333
Loading Rate (m ² m ⁻³)	1.00	0.43
Min. Chamber Size (m ³)	10	22.7
Temperature (C)	23 ± 1	25 ± 1
Relative Humidity (%)	45 ± 5	50 ± 4
Air Exchange Rate (hr ⁻¹)	1 ± 0.1	0.5 ± 0.05
Edge Sealing	Partial	None
Conditioning	None	7-days ± 3 hr
Test Duration	4-days	16-20 hr
HCHO Emission Limit (mg m ⁻³)	0.12 (E1)	0.37 (HUD)
⁽¹⁾ Sources: Analyscentrum (2006); Groah et al. (1991); Risholm-Sundman et al. (2006)		

Although both the EN 717-1 and the E1333 tests measure steady-state HCHO levels resulting primarily from surface emissions off-gassing from PB in the test chamber, the numerical values from the two tests are not directly

comparable due to differences in test temperature, relative humidity, and edge sealing.

To convert an EN 717-1 test result to a comparable E1333 value, temperature and relative humidity correction factors of 1.24 and 1.10 (ASTM, 1996), respectively, need to be applied to raise the effective emissions in an EN 717-1 test due to the lower test temperature (23 vs. 25 C) and relative humidity (45 vs. 50%) that is used. With respect to the effects of edge sealing, Groah et al. (1991) reported that panels tested by the EN 717-1 protocol exhibited 20% lower HCHO concentration values than when measured by the North American large-chamber protocol (E1333). As the edges of the test material are partially sealed in the EN 717-1 test and unsealed in the E1333 test, this difference may be an important factor contributing to the consistently lower HCHO values in the EN 717-1 test. In consideration of this finding, it is proposed that another adjustment factor be applied to correct the test results measured using the EN 717-1 when comparing them to results obtained using the E1333 test. For example, in applying this correction factor to the E1 standard concentration of 0.12 mg m^{-3} , the concentration used for calculating an emission rate would be raised to 0.144 mg m^{-3} (a 20% increase), and so forth for other EN 717-1 results.

Using a modification of the emission rate equation specified on page 3, differences in test temperature, relative humidity, and edge sealing between the two methods are accounted for and PB meeting the E1 standard is estimated to emit HCHO at the following rate:

$$\begin{aligned} ER_{E1PB} &= C_s \times (N + L) \times T_c \times H_c \times E_c \\ &= (0.12) \times (1) \times (1.24) \times (1.10) \times (1.2) \\ &= \underline{0.196} \text{ mg m}^{-2} \text{ hr}^{-1} \end{aligned}$$

Where:

ER_{E1PB} = HCHO emission rate ($\text{mg m}^{-2} \text{ hr}^{-1}$) from E1-compliant PB

C_s = EN 717-1 steady-state HCHO concentration (mg m^{-3})

N = chamber ventilation rate in air changes per hour (1.0 hr^{-1})

L = product loading rate ($1.0 \text{ m}^2 \text{ m}^{-3}$)

T_c = temperature correction for 23 C to 25 C (ASTM, 1996)

H_c = relative humidity correction for 45% to 50% (ASTM, 1996)

E_c = edge sealing correction for EN 717-1 to E1333 (Groah et al., 1991)

By comparison, PB meeting the HUD standard was estimated to have an emission rate of $0.43 \text{ mg m}^{-2} \text{ hr}^{-1}$, roughly 2¼-times greater than that of E1-PB (Table H-2). A comparison of the emission rates is shown in Table H-4:

Table H-4. Emission Rates and % Differences Between Existing and Proposed HCHO Emission Standards in the U.S. and Europe: HWPW and MDF

Standard or Mean	----- mg HCHO m ⁻² hr ⁻¹ -----		
	HWPW	PB	MDF
1985 HUD	0.210	0.434	0.710
2002 Survey Mean	0.131	0.264	0.367
2009 CARB Phase 1	0.099	0.224	0.262
2011-12 CARB Phase 2	0.062	0.112	0.137
European E1 Standard	0.196	0.196	0.196
Comparison	----- % Difference -----		
Phase 1 vs. European E1	-50	+14	+34
Phase 2 vs. European E1	-68	-42	-30

E. European E1 Standard: Comparison between the EN 120 and E1333 Tests

By the EN 120 test, the E1 limit is 8 mg HCHO per 100 g of dry board. In this regard, Risholm-Sundman et al. (2006) reported that 12-mm E1-compliant PB with an EN 120 value of 4.6 mg 100g⁻¹ had an EN 717-1 value of 0.07 mg m⁻³. In attempting to reconcile the relationship between measures of composite panel HCHO content between Europe and Japan, they developed linear equations correlating the values of EN 717-1 and EN 120 tests to the Japanese JIS A1460 test. The equations developed by Risholm-Sundman et al. (2006) are listed in Table H-5, and were used to develop the relationships between the EN 717-1 and EN 120 tests, for subsequent comparison with the U.S. E1333 test. Using a derived version of their published equations, the above mentioned E1-compliant PB would be estimated to exhibit an EN 717-1 value of 0.06 mg HCHO m⁻³.

Table H-5. Equations for Comparing the HCHO Test Values Measured by European, Japanese, and U.S. Protocols¹

For converting:	Equation	R ²
EN 717-1 → JIS A1460	6.8561[EN 717-1] + 0.0463 = JIS A1460	0.73
EN 120 → JIS A1460	0.0825[EN 120] + 0.0816 = JIS A1460	0.76
EN 120 → EN 717-1	0.012[EN 120] + 0.005 = EN 717-1	NA
EN 717-1 → E1333	[EN 717-1] x 0.98 = E1333	NA

⁽¹⁾ Sources: Risholm-Sundman et al. (2006); Groah et al. (1991). Units: EN 717-1 (mg m⁻³); JIS A1460 (mg L⁻¹); EN 120 (mg 100 g⁻¹), E1333 (ppm). NA = not applicable; an R² was not expressly calculated for either equation, but are expected to be of similar magnitude.

As the EN 120 test is not used on HWPW, the E1 standard by this protocol applies, for purposes of this analysis, only to PB and MDF. The estimates in Table H-6 were calculated as a basis for gauging the relative stringency of the proposed Phase 1 and Phase 2 standards for PB and MDF.

Table H-6. Relationship Between the EN 120 Values and the Proposed CARB Phase 1 and Phase 2 Standards for PB and MDF ¹		
EN 120 (mg 100 g ⁻¹)	EN 717-1 (mg m ⁻³)	≈ E1333 (ppm)
6	0.07	0.07
8	0.10	0.10
10	0.12	0.12
12	0.15	0.15
14	0.17	0.17
⁽¹⁾ The EN 120 value for complying with the E1 standard is 8 mg 100 g ⁻¹ .		

F. Japan's "F-star" Standards: Comparison between the JIS A1460 and E1333

In Japan, the HCHO content of building materials, including composite wood products, is regulated through building code requirements. Using a tiered system of HCHO emission limits, the "Japanese F-star" standards allow primarily for the use of F☆☆ and F☆☆☆ composite wood products in home construction, which are among the most stringent HCHO standards in the world today. In panel-manufacturing plants, the Japanese 24-hr desiccator test is used to ensure the quality of panels produced, and will hereafter be referred to as the JIS A1460 test (Building Center of Japan, 2004). In comparison to the E1333 test, the edges of the test materials in the JIS A1460 are also not sealed, but environmental conditions are cooler (20 vs. 25 C) and more humid (70-80% vs. 50%). To comply with the F☆☆ and F☆☆☆ standards, the allowable HCHO concentrations using the JIS A1460 test are 0.5 and 0.3 mg HCHO L⁻¹, respectively (Risholm-Sundman et al., 2006).

Using the equations by Risholm-Sundman et al. (2006) that correlate the values of EN 717-1 and EN 120 tests with the JIS A1460 test, the following E1333-equivalent concentrations were calculated (see Part I):

Table H-7. Relationship Between the JIS A1460 F☆☆☆ and F☆☆☆☆ Standards to Estimated EN 717-1, EN 120, and E1333 Test Values¹

JIS A1460 (mg L ⁻¹)	EN 717-1 (mg m ⁻³)	EN 120 (mg 100 g ⁻¹)	≈ E1333 (ppm)
0.5 (F☆☆☆)	0.07	5.1	0.07
0.3 (F☆☆☆☆)	0.04	2.7	0.04

⁽¹⁾ EN 717-1 and EN 120 values estimated using the equations in Risholm-Sundman et al. (2006); E1333 values were estimated using the equation on page 5 for converting EN 717-1 results.

H. References

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Building Center of Japan. 2004. Performance Testing and Evaluation Manual for Emission Rate of Formaldehyde from Building Materials. Publication No. BR-BO-11-02. From: http://www.bcj.or.jp/en/03/src/SickhouseManual_0404.pdf Downloaded: 8 November 2006.

Groah WJ, J Bradfield, G Gramp, R Rudzinski, and G Heroux. 1991. Comparative response of reconstituted wood products to European and North American test methods for determining formaldehyde emissions. Environmental Science & Technology, 25(1): 117-122.

National Particleboard Association (NPA). 1994. Medium Density Fiberboard. ANSI A208.2-1994. 10 pp.

Risholm-Sundman M, A Larsen, E Vestin, and A Weibull. 2006. Formaldehyde emission – comparison to different standard methods. Submitted to Atmospheric Environment, March 2006. 12 pp.

I. Calculation Details for E1333-equivalency

CARB-P1: No adjustment needed -- E1333 test is the basis for the standard.

CARB-P2: No adjustment needed -- E1333 test is the basis for the standard.

E1/EN717-1: (1) Calculate an emission rate (ER in mg HCHO m⁻² hr⁻¹) for an E1-compliant panel; (2) The calculated ER applies to all composite wood products (i.e., HWPW, PB, and MDF) -- use the calculated ER and back-calculate the E1333 concentration that would result if HWPW, PB, and MDF were tested in an E1333 chamber at the ASTM specified loading rates.

(1) Calculate an emission rate for an E1-compliant panel

$$\begin{aligned}ER_{E1} &= C_s \times (N \div L) \times T_c \times H_c \times E_c \\&= (0.12) \times (1) \times (1.24) \times (1.10) \times (1.2) \\&= \underline{0.196} \text{ mg m}^{-2} \text{ hr}^{-1}\end{aligned}$$

(2) Back-calculate an E1333 test concentration for HWPW, PB, and MDF

$$\begin{aligned}ER_{HWPW} &= 1.23 \times C_s \times (N \div L) \\[ER \div (N \div L)] &= 1.23 \times C_s \\[ER \div (N \div L)] \div 1.23 &= C_s \text{ -- E1333/HWPW} \\[0.196 \div (0.5 \div 0.425)] \div 1.23 &= C_s \\[0.196 \div 1.176] \div 1.23 &= C_s \\0.14 \text{ ppm} &= C_s\end{aligned}$$

$$\begin{aligned}ER_{PB} &= 1.23 \times C_s \times (N \div L) \\[ER \div (N \div L)] \div 1.23 &= C_s \text{ -- E1333/PB} \\[0.196 \div (0.5 \div 0.425)] \div 1.23 &= C_s \\[0.196 \div 1.176] \div 1.23 &= C_s \\0.14 \text{ ppm} &= C_s\end{aligned}$$

EN 120: (1) Apply the equation for converting EN 120 test values (mg HCHO 100 g⁻¹) to EN 717-1 values (mg HCHO m⁻³) developed by Risholm-Sundman et al. (2006); (2) Convert the EN 717-1 test values to E1333 values (ppm) using the adjustment explained in Groah et al. (1991).

(1) Convert the EN 120 value for an E1 panel to an EN 717-1-equivalent value

$$\begin{aligned}[0.012 \times (\text{EN120})] + 0.005 &= \text{EN 717-1} \\(0.012 \times 8) + 0.005 &= \text{EN 717-1} \\(0.096 + 0.005) &= 0.101\end{aligned}$$

(2) Convert the EN 717-1-equivalent value to an E1333 value (ppm)

$$\begin{aligned} [\text{EN 717-1}] \times 0.98 &= \text{E1333} \\ (0.101 \times 0.98) &= 0.10 \text{ ppm} \end{aligned}$$

Note: The EN 717-1 standard is in mg m^{-3} . While a 20% adjustment, as proposed by Groah et al. (1991) could account for differences in edge sealing, etc., the units must then be converted to “ppm” by dividing the EN 717-1 concentration by $1.23 \text{ mg m}^{-3} \text{ ppm}^{-1}$. Thus, the adjustment factor used above is 0.98 ($= 1.2 \div 1.23$).

F☆☆ and F☆☆☆/JIS A1460: (1) Apply the equation by Risholm-Sundman et al. (2006) to convert JIS A1460 test values to EN 717-1 values; (2) Convert the EN 717-1 test values to E1333 values (ppm) using the adjustment explained in Groah et al. (1991).

(1) Convert JIS A1460 test values into EN 717-1-equivalent concentrations

$$\begin{aligned} 6.8561 \times [\text{EN 717-1}] + 0.0463 &= \text{JIS A1460} \\ 6.8561 \times [\text{EN 717-1}] &= (\text{JIS A1460}) - 0.0463 \\ \text{EN 717-1}_{\text{F☆☆}} &= [(\text{JIS A1460}) - 0.0463] \div 6.8561 \\ &= [0.5 - 0.0463] \div 6.8561 \\ &= 0.066 \approx 0.07 \\ \\ \text{EN 717-1}_{\text{F☆☆☆}} &= [0.3 - 0.0463] \div 6.8561 \\ &= 0.037 \approx 0.04 \end{aligned}$$

(2) Convert the EN 717-1-equivalent value to an E1333 value (ppm)

$$\begin{aligned} [\text{EN 717-1}] \times 0.98 &= \text{E1333} \\ (0.07 \times 0.98) &= 0.07 \text{ ppm (F☆☆)} \\ (0.04 \times 0.98) &= 0.04 \text{ ppm (F☆☆☆)} \end{aligned}$$