8.0. VISIBILITY AND COST IMPACT ANALYSIS OF PROPOSED REGIONAL HAZE ALTERNATIVES

8.1 RESULTS IN BRIEF

The proposed regional haze (RH) program is designed to ensure reasonable progress toward the national visibility goal. It allows broad discretion on the part of the States in determining control measures to be imposed based on statutory criteria. Under the structure of the proposed RH rule, the States are able to consider the cost of emission reduction strategies in light of the degree of visibility improvement to be achieved. For this Regulatory Impact Analysis (RIA) the individual decisions on effectiveness of each of the control strategies applied in each region is modeled in a very limited way. Therefore the cost estimates presented in this report for meeting the presumptive visibility target are likely high estimates of actual implementation costs. The actual control cost of the proposed RH rule is likely to lie somewhere between zero and the estimates for the presumptive targets presented in this report.

Based on projected emissions levels for the year 2010 and progress toward attainment of the current ozone standard and the new $PM_{2.5}$ NAAQS (as estimated in Chapter 6), this analysis estimates that 76 mandated Class I areas need additional reductions to meet a presumptive target of improving the most impaired days (average of the 20 percent highest days) 1.0 deciview from 2000 to 2010. This analysis also estimates that 58 Class I areas need additional reductions to meet an alternative target of improving the most impaired days 1.0 deciview from 2000 to 2015 (i.e., an average of a 0.67 deciview improvement from 2000 to 2010). The additional cost of any implementation of the proposed RH rules will vary depending on the visibility targets submitted and approved as part of State plans. If targets are adjusted through that process to parallel the implementation programs for the new ozone and PM standards, the costs for meeting the adjusted targets in those areas will be borne by the ozone and PM programs. In this analysis costs are estimated assuming no changes in the presumptive target of 1.0 deciview improvement over 10 years for every mandatory Class I Federal area, or an alternative target of 1.0 deciview improvement over 15 years (i.e., an average 0.67 deciview improvement over 10 years). The additional control cost associated with meeting the presumptive 1.0 deciview target in 48 of these areas, and partial achievement in 28 areas is estimated to be $2.7 billion (1990 dollars). The additional control cost associated with meeting the alternative presumptive 0.67 deciview target in 41 of these areas, and partial achievement in 17 areas is estimated to be $2.1 billion (1990 dollars). In summary, the expected control cost associated with the proposed RH rule ranges from $0 to a maximum of $2.7 billion.

The estimate of the incremental cost of alternative presumptive visibility targets are also affected by: 1) an analysis baseline that understates the visibility progress achieved by CAA mandated controls and implementation of a new ozone standard over the period 2000 to 2010; 2) the inability to model full attainment of the selected $PM_{2.5}$ 15/65 standard; and 3) how close some of the residual Class I area counties are to natural background conditions. These factors suggest that the actual cost of achieving visibility improvements incremental to the selected ozone and $PM_{2.5}$ standards should be lower.

8.2 INTRODUCTION

This chapter presents the visibility improvements and cost impacts of proposed alternative RH targets. This analysis estimates the projected costs (in 1990 dollars) of installing, operating, and maintaining those additional controls needed by the year 2010 to meet the presumptive visibility targets in our nation's Class I designated areas. The following sections in this chapter cover:

- Cost analysis methodology;
- Visibility improvements and cost results for alternative RH targets; and
- Analytical uncertainties, limitations, and potential biases.

8.3 COST ANALYSIS METHODOLOGY

This analysis estimates the emission reductions and control costs for achieving the alternative presumptive visibility improvement targets described in Chapter 3. Since Class I areas rarely contain emissions sources, and because pollutants that degrade visibility can be transported over long distances by prevailing winds, controls must be imposed on sources located outside of Class I areas that contribute to visibility degradation in Class I areas.

The analysis is confined to the 141 Class I areas located in 121 counties in the 48 contiguous States. Further, the set of Class I areas is subdivided into the same six regions defined for the particulate matter (PM) analysis. The boundaries of these six control regions are depicted in Chapter 6 in Figure 6.2. The boundaries of these regions are delineated to reflect both the meteorological conditions that influence the long-range transport of visibility precursors and the locations of their major sources (e.g., electric utilities). Control measure selection is limited to emission sources in each control region. In addition, selection of some control measures that primarily affect coarse particles (i.e., particles greater than 2.5 microns) is limited to the county containing the Class I area. This limitation prevents control measures that have a minor affect on visibility (e.g., fugitive dust control for unpaved roads) from being selected in counties that are relatively distant from Class I areas.

The baseline for the RH analysis is the projected emissions inventory from the analysis of the selected $PM_{2.5}$ 15/65 standard and the remaining set of control measures that are not already selected in that analysis. Chapter 6 presents the analysis of the $PM_{2.5}$ 15/65 standard.

If the RH rule is finalized on schedule, the first period for which visibility improvements are to be evaluated is estimated to be the years 2000 through 2010. In order to evaluate visibility improvements, visibility monitors must be established in the Class I areas of concern, and it is likely to take a few years to establish these monitors. Ideally, this Regulatory Impact Analysis (RIA) would evaluate the potential improvements in visibility over the ten year period from 2000 to 2010, and would account for emission reductions achieved from current CAA mandated controls (e.g., Title IV sulfur dioxide (SO_2) cap on utility sources) and due to promulgated $PM_{2.5}$ and ozone NAAQS. However, this requires developing a year 2000 emissions inventory and a set of control measure impacts incremental to the year 2000. Instead, the RH analysis takes advantage of the 2010 emissions inventory and incremental control measure database established for the $PM_{2.5}$ and ozone analyses discussed in Chapters 6 and 7.

Control costs for attaining the alternative presumptive visibility improvement targets are evaluated incremental to attainment of the promulgated $PM_{2.5}$ standard. If a Class I area is projected to meet the presumptive visibility improvement target in the year 2010 as a result of $PM_{2.5}$-related control measures, no additional control is needed. However, if the goal is not met, additional control measures are modeled. This baseline provides conservative estimates (i.e., potentially overstates) of the cost of achieving alternative visibility goals for two reasons. First, the progress achieved by measures related only to $PM_{2.5}$ control through the year 2010 does not include progress achieved due to measures already mandated under the 1990 CAA, or progress achieved due to controls needed to meet the new ozone standard. These control measures, which are not in the baseline of the RH analysis, may contribute to further visibility improvement from 2000 to 2010. Second, applying the set of control measures included in the $PM_{2.5}$ analysis results in residual nonattainment for some areas. To the extent that these areas are actually able to achieve additional reductions to attain the $PM_{2.5}$ standard, further visibility improvements may also be realized.

The costs in this analysis reflect *real, before-tax, 1990 dollars* and a *7 percent real interest (discount) rate.* "Real" dollars are those uninfluenced by inflation; in other words, a "1990 dollar" is assumed to be worth the same today as it was in 1990. "Before-tax" means that the cost analysis does not consider the effects of income taxes (State or federal). Because income taxes are merely transfer payments from one sector of society to another, their inclusion in the cost analysis would not affect total cost estimates. The year 1990 was selected as the cost reference date to be consistent with the analysis base year. Finally, to be consistent with the real-dollar analytical basis, a 7 percent real interest rate was used, in accordance with Office of Management and Budget guidance.

8.3.1 Estimating Visibility

Decreases in visibility are often directly proportional to decreases in light transmittance in the atmosphere (Trijonis et al., 1990). Light transmittance is attenuated by scattering and absorption by both gases and particles. The light-extinction coefficient is a measure of the total fraction of light that is attenuated per unit distance (Sisler, 1996):

$$b_{ext} = b_{Ray} + b_{sp} + b_{ag} + b_{abs}$$

where:

b_{ext}	=	total light extinction coefficient (1/Mm),
b_{Ray}	=	light extinction coefficient due to natural Rayleigh scatter (1/Mm),
b_{sp}	=	light extinction coefficient due to scattering by particles (1/Mm),
b_{ag}	=	light extinction coefficient due to absorption by gases (1/Mm), and
b_{abs}	=	light extinction coefficient due to absorption by particles (1/Mm).

The light extinction coefficient is calculated by multiplying the concentration of an aerosol species by its light-extinction efficiency, and summing over all species.

The term b_{Ray} refers to the natural Rayleigh scatter from air molecules, mainly nitrogen and oxygen. Depending on altitude, this term has a value of 9 to 12 Mm^{-1} (inverse megameters) (Sisler and Malm, 1994).

The term b_{sp} can be broken into the various species of fine and coarse particles that scatter light. Because fine particles are much more efficient at light scattering than coarse particles, several fine particle species are specified, whereas coarse particles are kept as one category. Fine particles with significant light-extinction efficiencies include sulfates, nitrates, organic carbon, elemental carbon (soot), and soil (Sisler, 1996).

A complicating factor for sulfates, nitrates, and some organic compounds is that these aerosols are hygroscopic, i.e., they absorb water, which greatly enhances their light-scattering abilities. The amount of water absorbed is a function of the relative humidity. A relationship between the relative humidity and scattering efficiency for ammonium sulfate aerosols has been developed, and is also applied to ammonium nitrate aerosols (Sisler, 1996). Recent research indicates that organics are not hygroscopic to weakly hygroscopic (Sisler, 1996) and thus in this analysis, the light scattering efficiency for organics is not assumed to be a function of the relative humidity.

A detailed expression for b_{sp} can thus be written (Sisler, 1996):

$$b_{sp} = 3f(RH) \cdot [SULFATE] + 3f(RH) \cdot [NITRATE] + 4[OMC] + 1[SOIL] + 0.6[CM]$$

where:

3	=	dry scattering efficiency of sulfate and nitrates (m^2/g),
f(RH)	=	function describing scattering characteristics of sulfates and nitrates, based on the relative humidity (unitless),
[*SULFATE*]	=	concentration of ammonium sulfate aerosols ($\mu g/m^3$),
[*NITRATE*]	=	concentration of ammonium nitrate aerosols ($\mu g/m^3$),
4	=	dry scattering efficiency of organic mass from carbon (m^2/g),
[*OMC*]	=	concentration of organic aerosols ($\mu g/m^3$),
1	=	dry scattering efficiency of soil (m^2/g),
[*SOIL*]	=	concentration of fine soil ($\mu g/m^3$),
0.6	=	dry scattering efficiency of coarse particles (m^2/g), and
[*CM*]	=	concentration of coarse particles ($\mu g/m^3$).

The function *f(RH)* is calculated as follows:

$$f(RH) = t_0 + t_2(1/(1-RH))^2 + t_3(1/(1-RH))^3 + t_4(1/(1-RH))^4$$

where:

RH	=	relative humidity, and
t_x	=	parameters presented in Table 8.1 below.

Table 8.1 Parameter Determining the Effect of Relative Humidity on Visibility

Season	t_0	t_2	t_3	t_4
Spring	0.7554	0.3091	-0.0045	-0.0035
Summer	0.5108	0.4657	-0.0811	0.0043
Autumn	-0.0269	0.8284	-0.1955	0.0141
Winter	1.1886	0.2869	-0.0332	0.0011
Annual	0.5176	0.5259	-0.0947	0.0056

Source: Table 5.1, Sisler, 1996.

The term b_{ag} represents absorption due to gases; NO_2 is the only major light-absorbing gas in the lower atmosphere. This component is assumed to be negligible since concentrations of NO_2 are expected to be negligible in rural areas (Sisler and Malm, 1994) which is generally applicable for Class I areas. However, this may be a poor assumption for locations close to significant NO_x emission sources, such as power plants or urban areas (Sisler, 1996).

The final term of the light-extinction coefficient equation, b_{abs}, represents absorption of light by elemental carbon. This term represents approximately 30 percent of the non-Rayleigh extinction budget (Sisler, 1996). Recent research has indicated that direct measurements of absorption by the laser integrated plate method (LIPM) are much more accurate than using absorption estimates based on mass concentrations of light-absorbing carbon. For that reason, this analysis bases b_{abs} on empirical data from monitored sites in the IMPROVE network.

Once the light-extinction coefficient is determined, the visibility index called deciview (*dv*) can be calculated (Sisler, 1996):

$$dv = 10 \cdot \ln(b_{ext} \cdot 10^{-3} / 0.01\, km^{-1})$$

where:

10^{-3} = constant to convert Mm^{-1} to km^{-1}.

A change of one *dv* represents a change of approximately ten percent in b_{ext}, “which is a small but perceptible scenic change under many circumstances” (Sisler, 1996, p.1-7).

8.3.2 Estimating the Effect of Control Measures on Visibility

Given the available data available from the IMPROVE monitoring network and the changes in sulfate, nitrate, and primary PM emissions modeled using the source-receptor (S-R) matrix described in Chapter 6, light extinction (b_{ext}) is calculated using the following equation:

$$b_{ext} = b_{Ray} + 3f(RH) \cdot [SULFATE] + 3f(RH) \cdot [NITRATE] + 4[OMC] + 1[SOIL] + 0.6[CM] + b_{abs}$$

The S-R matrix provides concentration estimates of ammonium sulfate (SULFATE), ammonium nitrate (NITRATE), and coarse mass (CM= PM_{10} - $PM_{2.5}$). A common assumption for light scattering by background gases (b_{Ray}) is 10 Mm^{-1}. Appendix E provides estimates for f(RH), OMC, SOIL, and b_{abs} based on summary data from 43 relevant IMPROVE monitoring sites between 1992-1995. For Class I areas without monitoring data, values are assigned based on either the closest monitored site or an average of up to three proximate monitored sites. The values are assumed constant in this analysis, even though it is known that certain types of control measures may affect the baseline levels of OMC and b_{abs}. The exact relationship between these factors and specific control measures has not been established, and therefore these values are held constant.

8.3.3 Selecting Control Measures with the Regional Haze Optimization Model

The RH optimization model works in a manner similar to the PM optimization model discussed in Chapter 6. However, in this case, the receptor county of interest contains a Class I area, and reductions in $PM_{2.5}$ precursors at the receptor are translated into improvements in visibility (i.e., reductions in light extinction). Control measures that are not already selected in the PM analyses are available for the RH analysis.

The optimization routine developed for this analysis employs the following steps:

Step 1. The remaining control measures in the incremental control measure data file are sorted by source number, precursor pollutant controlled, and cost per ton of pollutant reduced.

Step 2. The *incremental* improvement in visibility is calculated *for each Class I area county* for the least costly (on a cost per ton basis) control measure for each individual source/pollutant combination.

Step 3. The measure with the *lowest average cost per increment of visibility improvement* is selected and the deciview levels at each receptor are adjusted to reflect implementation of the selected measure.

Step 4. Steps 2 through 3 are repeated until all input receptors meet the target level *or* all remaining measures are exhausted. The same $1 billion per microgram per cubic meter control measure selection threshold that is used in the PM optimization model is also used in the RH optimization model.

Step 5. Adjust final post-control visibility predictions in all Class I areas nationwide to account for the trans-boundary effect of control measures selected outside each control region.

8.3.4 Scaling Annual Average Deciview Values Relative to Average Peak Values

As proposed, the RH rule suggests a 1.0 deciview change in the average deciview value of the 20 percent worst days over a ten year period. However, the S-R matrix used to estimate pollution concentrations that contribute to RH formation, outputs annual average values for the pollutants of concern (ammonium sulfate, ammonium nitrate, and primary PM_{10} and $PM_{2.5}$). This analysis uses the most recent monitoring data from Class I areas to translate a 1.0 deciview change in the 20 percent worst days to an equivalent change for an annual average day. Appendix E contains the data used to make this calculation.

The average of the 20 percent worst days each year is also be referred to as the 90th percentile value, and can be compared to the annual average or mean value. The ratio of the 90th percentile deciview value to the mean deciview value varies by Class I area. Based on the most recent IMPROVE data, the average ratio of the 90th percentile deciview value to the mean deciview value for all Class I areas is 1.4. Therefore, a 1.0 deciview change in the average of the 20 percent worst days correlates to a 0.7 deciview change in the annual average day (1.0 divided by 1.4). Similarly, a 0.67 deciview change in the 20 percent worst days correlates to a 0.5 deciview change in the annual average day (0.67 divided by 1.4). These annual average equivalent targets are used in this analysis.

8.3.5 Baseline Visibility

The visibility baseline in this analysis is represented by the estimated visibility improvement between the 2010 CAA baseline case and the post-$PM_{2.5}$ 15/65 case. Table 8.2 summarizes the visibility measurements in terms of deciviews for the two cases. As the table shows, the average visibility improvement in the annual average deciview value for counties containing Class I areas in the Midwest/Northeast and the Southeast regions is more than the target of 0.7 deciviews.

Table 8.2 Projected Annual Average Deciview Values by Control Region

Region	No. of Counties Containing Class I Areas	2010 CAA Baseline	2010 Post-$PM_{2.5}$ 15/65	Average Annual Deciview Improvement
Midwest/Northeast	16	23.1	21.2	1.9
Southeast	13	22.5	21.1	1.4
South Central	14	16.8	16.4	0.4
Rocky Mountain	30	17.6	17.1	0.5
Northwest	18	19.3	19.0	0.3
West	30	17.8	17.3	0.5
Nation	121	19.1	18.3	0.8

Table 8.3 indicates the number of Class I area counties for which additional control measures may be needed incremental to the baseline (i.e., incremental to partial attainment of the $PM_{2.5}$ 15/65 standard). Nearly all Class I area counties in the Midwest/Northeast and Southeast regions are projected to meet the alternative presumptive visibility improvement targets without any additional controls beyond partial attainment of the selected $PM_{2.5}$ 15/65 standard. However, a majority of the Class I area counties located in the South Central, Northwest and West regions are projected to need additional reductions to meet the alternative goals. For the more stringent 1.0 deciview target, a majority of the Class I areas in the Rocky Mountain region are also

Table 8.3 Number of Class I Area Counties Not Achieving Alternative Visibility Goals in the Baseline

Control Region	Number of Class I Area Counties	Number of Class I Area Counties After $PM_{2.5}$ 15/65 Control	
		1.0 Deciview Goal Over 15 Years (0.67 Deciview Target)	1.0 Deciview Goal Over 10 Years (1.0 Deciview Target)
Midwest/Northeast	16	0	0
Southeast	13	0	1
South Central	14	11	11
Rocky Mountain	30	14	27
Northwest	18	17	18
West	30	16	19
Nation	121	58	76

projected to need additional reductions. These areas also have the highest proportion of predicted biogenic aerosol emissions, which places them closer to natural conditions than other regions. This would tend to support establishing alternative targets for these areas.

8.5 VISIBILITY IMPROVEMENT RESULTS

This section presents the incremental visibility improvements achieved for each alternative presumptive visibility improvement target in Class I area counties that did not achieve the goal in the baseline. Included are estimates of the additional number of Class I area counties that achieve the alternative presumptive visibility improvement targets, as well as the average improvement realized. As discussed in section 8.3.4, a 1.0 deciview improvement goal for the average 20 percent worst days is roughly equivalent to a 0.7 deciview improvement goal for the annual average day. Similarly, a 0.67 deciview improvement in the average 20 percent worst days is roughly equivalent to a 0.5 deciview improvement in the annual average day.

Table 8.4 presents the number of Class I area counties that initially do not achieve each alternative presumptive visibility improvement target and the estimated number of Class I area counties that are not able to achieve the goals after additional control measures are modeled.

Table 8.4 Estimated Number of Class I Area Counties That Do NOT Achieve Alternative Presumptive Visibility Improvement Targets and the Average Deciview Shortfall

Region	1.0 Deciview Goal Over 15 Years (0.67 Deciview Target)			1.0 Deciview Goal Over 10 Years (1.0 Deciview Target)		
	Baseline[a]	Post-Control[b]	Average Deciview Shortfall	Baseline[a]	Post-Control[b]	Average Deciview Shortfall
Midwest/Northeast	0	0	--	0	0	--
Southeast	0	0	--	1	0	--
South Central	11	3	0.16	11	9	0.18
Rocky Mountain	14	3	0.06	27	4	0.22
Northwest	17	1	0.12	18	2	0.20
West	16	10	0.16	19	13	0.29
Nation	58	17	0.14	76	28	0.23

a Baseline represents counties that do not achieve sufficient progress toward the visibility goal after considering partial attainment of the selected $PM_{2.5}$ 15/65 standard.

b Post-control represents counties that do not achieve sufficient additional progress toward the visibility goal after considering additional controls not already selected in the $PM_{2.5}$ 15/65 analysis.

Also shown is the average deciview shortfall for the counties that do not reach the goal. This table indicates that 28 of the 76 initially noncompliant Class I area counties are not able to achieve the 1.0 deciview goal, and 17 of the 58 initially noncompliant counties are not able to achieve the 0.67 deciview goal. The areas not able to achieve the goal are concentrated in the West and South Central control regions. The majority of the West region areas are in central and southern California and Arizona. Several of these counties are also residually nonattainment in the $PM_{2.5}$ 15/65 analysis based on the results presented in Chapter 6.

For the 28 areas not achieving the 1.0 deciview goal after controls are applied, the region wide annual average deciview shortfall ranges from 0.18 to 0.29, meaning that on average these areas achieved from 0.41 to 0.52 (i.e., 59 to 72 percent) of the 0.7 deciview improvement needed to reach the goal. For the 17 areas not achieving the 0.67 deciview goal, the region wide annual average deciview shortfall ranges from 0.03 to 0.25, meaning that on average these areas achieved from 0.25 to 0.47 (i.e., 50 to 94 percent) of the 0.5 deciview improvement needed to reach the goal.

8.6 COST ANALYSIS RESULTS

This section presents the cost of achieving alternative regional haze goals incremental to control achieved in the $PM_{2.5}$ 15/65 analysis. Under the structure of the proposed RH rule, the States are able to take into account costs for emissions reductions strategies in light of the degree of visibility improvement to be achieved. Therefore, high cost control measures that have only minor effects on visibility can be avoided. For some Class I areas, there may not exist any cost effective control measures that can be applied in the time period covered by this analysis. In these areas the incremental control costs of the proposed RH rule will be zero. The actual control cost of the proposed RH rule is likely to lie somewhere between the zero and the estimates for the presumptive targets presented in this report. Based on the control strategies selected by the Grand Canyon Visibility Transport Commission, the majority of which are currently part of implementation plans for other criteria polutants, the costs will be on the lower end of this range.

The incremental cost of the RH rule presented in this RIA is compromised by the residual nonattainment projected to exist for the analysis of the selected $PM_{2.5}$ 15/65 standard. An analysis that models full attainment of the $PM_{2.5}$ standard should reduce the incremental cost of a RH rule in areas where there is significant overlap.

Table 8.5 shows the total annual control cost of alternative presumptive RH targets incremental to the selected $PM_{2.5}$ 15/65 standard. For both target levels the largest fraction of the control cost is realized in the Rocky Mountain and Northwest regions. This seems logical since there are relatively few counties projected to be nonattainment for the selected $PM_{2.5}$ 15/65 standard in these regions. Therefore, less control and accompanying visibility improvement is achieved in these regions in the baseline analysis.

Table 8.5 Regional Haze National Control Cost Summary--Total Annual Cost[a] (million 1990 dollars)

Control Region	1.0 Deciview Goal Over 15 Years (0.67 Deciview Target)	1.0 Deciview Goal Over 10 Years (1.0 Deciview Target)
Midwest/Northeast	--	--
Southeast	0 - 70	0 - 150
South Central	0 - 440	0 - 490
Rocky Mountain	0 - 580	0 - 670
Northwest	0 - 710	0 - 1,000
West	0 - 320	0 - 420
Nation	0 - 2,100	0 - 2,700

a Costs are incremental to partial attainment of the selected $PM_{2.5}$ 15/65 standard. Totals may not agree due to rounding.

8.7 ANALYTICAL UNCERTAINTIES, LIMITATIONS, AND POTENTIAL BIASES

Because a quantitative uncertainty cannot be assigned to every input, the total uncertainty in the emission reduction, air quality, and cost outputs cannot be estimated. Nonetheless, the individual uncertainties can be characterized qualitatively.

Air quality projections to 2010 embody several component uncertainties, such as uncertainties in emission data, emission growth rates, baseline air quality data, and air quality modeling. These uncertainties are addressed in Chapter 4.

As noted in Section 6.7 the optimization model annual cost inputs are in the form of average incremental cost per ton reduced. Even if these cost per ton estimates are adjusted to account for source size differences (as is done for some point source controls), these adjustments do not account for other important cost-determining variables, such as source status (new versus retrofit), annual operating hours, equipment, materials of construction, and unit prices for utilities, materials, and labor.

The least-cost optimization model also introduces a measure of uncertainty. For instance, when calculating the cost per average microgram per cubic meter reduced, the model does not count any emission reductions that are in excess of those needed to meet a specified visibility goal. This assumption could cause the cost per average microgram per cubic meter—and, in turn, the final control costs—to be overstated or understated depending upon whether control of the precursor was beneficial.

8.8 REFERENCES

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