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Appraisal of Alternative Building Materials for Reduction of CO_2 Emissions by Case Modeling

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ABSTRACT: Global Warming is one of the major concerns in environmental issues. Its effects are being exposed faster than anticipated recently. It causes adverse ecological and socioeconomical effects. The 4th Assessment Report issued by the U. N.'s Intergovernmental Panel on Climate Change (IPCC) states that it is appropriate to define Global Warming was caused by greenhouse gases due to human activities which plays a significant role by over loading the atmosphere with carbon dioxide (CO_2) emissions since 1750. One of the most effective ways to prevent global warming is to replace materials which emit high level of CO_2 with those of low level CO_2 emission materials. Usually, CO_2 emission can be presented as embodied CO_2 (ECO_2) and operational CO_2 emissions. In this paper, appraisal of the embodied CO_2 emission level of using traditional building materials (i.e. cement, steel, glass and timber) and alternative building materials (i.e. slag cement, recycle steel, cullet glass and plywood formwork) have been made by case modelling. The results show that the amount of CO_2 emission is reduced after using alternative building materials by more than one-third (34.8%).

Key words: Environmental, Embodied CO_2, Global, Warming , Atmosphere

INTRODUCTION

Global warming, the phenomenon of unusual increase in global surface temperature, has been put into one of the major concerns in environmental management and protection starting from the late twentieth century (Zhiqui, 1997; Park, *et al.*, 2003). Series of natural disasters have occurred in unusual ways such as the unexpected increase in numbers of droughts, wildfires, floods, crops failures and heat waves etc and the rate of disasters were increased over 80% within 40 years since 1960 (IPCC, 2007) . The increase in disasters also leads to the increase in hazardous losses (NRC, 1999; Tobin and Montz, 2009).

In responses, the United Nations Framework Convention on Climate Change (UNFCCC) helps to initiate the Kyoto Protocol in Japan in December 1997 and was entered into force in February 2005. The major feature of it is that it outlined the binding targets for industrialized countries on reduction of greenhouse gas. It is well known that CO_2 emitted from combustion of fossil fuels is the major contributing compound among the several greenhouse gases (Hanaki and Ichinose, 1995). After the announcement of the 4th Assessment Report from February 2007 to May 2007, it states that global warming is appropriate to be defined as the consequent of greenhouse gases emissions made by human activities (IPCC, 2007). As the result, scientists around the world are attempting to reduce CO_2 emissions on developing energy utilizing measures to increase energy efficiency (Reay, 2008; Wu and Zhang, 2008; Harris, 1999); enhancement on production process and further development on various assessment and analysis methods on measuring and recording CO_2 intensity (Owens, 1998; Harris, 1999).

Cement industry is responsible for 20% of the overall man-made carbon dioxide emission. This is also contributes to about 10% of the made-made global warming potential (Anand, Vrat, and Dahiya, 2006). Cement industry is closely related to construction industry and therefore to the overall economic activity. Hong Kong is a rapid developed city with the highest

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population density in east Asia. During the 80s and 90s, substantial numbers of high-rise residential buildings were built without considering the environmentally friendly aspect (Chen *et al.*, 2001). Besides, it is shown that more than half of the total primary energy requirement in Hong Kong is from commercial and residential buildings (Lam and Ng, 1994).

Therefore, the objective of this study is trying to appraise the results on CO_2 emission reduction by reducing the use of traditional materials by substituting with alternative building materials (i.e. slag cement, recycled steel, cullet glass and plywood formwork). Besides, the performance of reducing total CO_2 emission by substituting alternative building materials will be verified by a case study on a typical high rise building in Hong Kong.

MATERIALS & METHODS

This study aims to presents a model by estimating the amount of CO_2 emission reduction on constructing a typical high rise building before and after substituting traditional building materials with the proposed environmentally friendly building materials. Four major building materials namely cement, steel, glass and timber will be substituted with alternative building materials slag cement, recycled steel, cullet glass and plywood respectively. The amount of CO_2 emission is estimated by referring to the total weight of different building materials used multiplied by the CO_2 emission intensity of those materials obtained from previous researchers (Table 2). The study based on some assumptions that the strengths of the traditional and alternative materials are the same.
The formula for calculation is expressed as follows:

$$V \times D \times C = \text{Amount of } CO_2 \text{ emission (kg)} \qquad \textbf{(Equation 1)}$$

Where as: V = volume of building material used (m^3)
D =Density of the building material (kg/m^3)
C = Embodied carbon dioxide emission ($kg\ CO_2$/ ton)

The total amount of CO2 emitted by the traditional building materials will hence be calculated and compared with those emitted by the suggested building materials. Therefore, the total percentage reduction on CO2 emission by using the alternative building materials can be concluded. The conceptual model of this study is shown in Fig. 1.

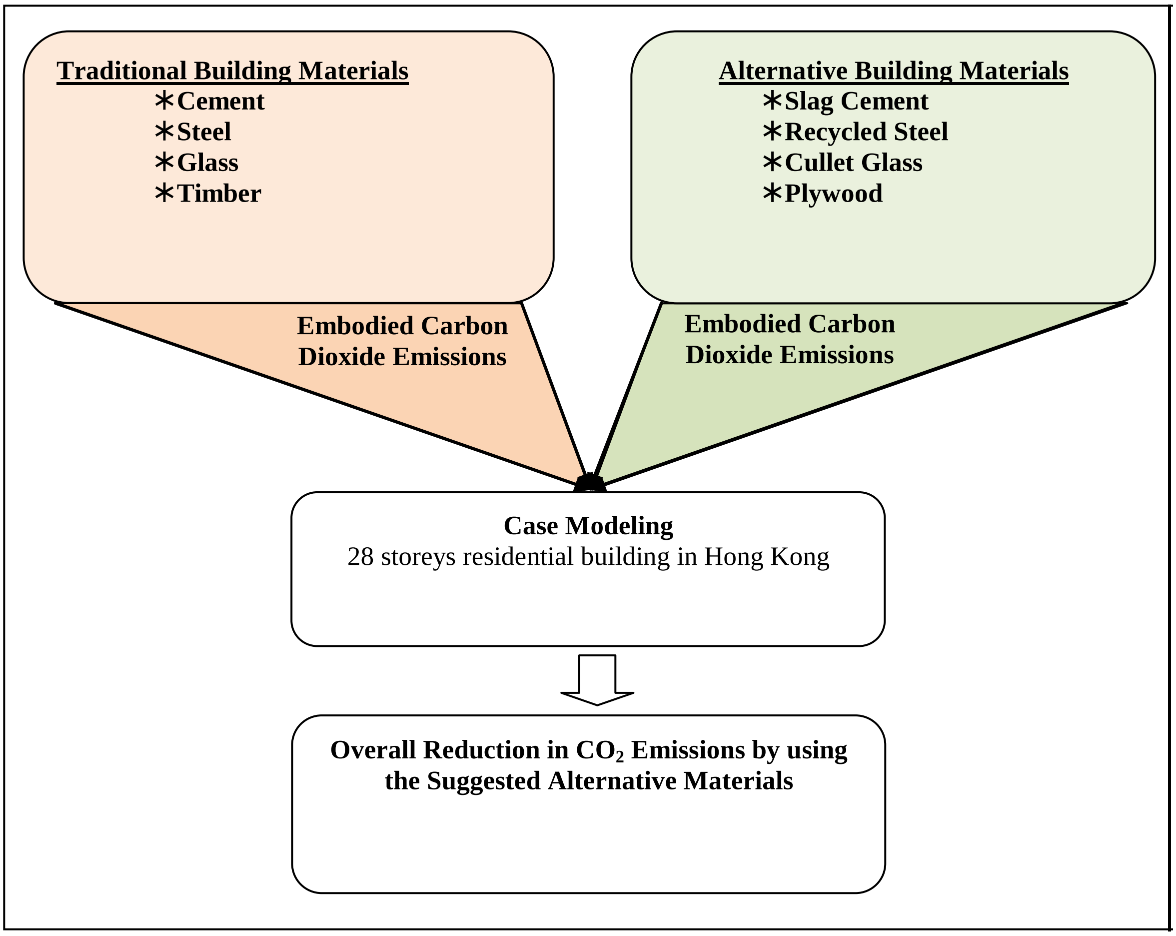

Fig. 1. Methodology of case modeling in this study

The effects of using alternative materials are examined with a 28-stories high rise building with typical floor plan shown in Fig. 2.Total volumes of the materials used are calculated by referring to floor plans of the building and the results are shown in the following Table 1. The total weights of the materials used are calculated by referring to Equation 1, given that the densities of the four assessed building materials are known.

Life cycle analysis is used in many studies on estimating the total CO_2 emission of a residential building (Adalberth, 1997; Arena and de Rosa, 2003). Generally, it consists of four steps: goal definition and scope, inventory analysis, impact analysis and improvement assessment (Curren, 1996). However, the methodology of these two analysis still requires further development (Owens, 1998), therefore, this study may only focuses on inventory analysis. Carbon dioxide emissions are quantified based on their embodied carbon dioxide intensity which is released by the energy consumed to create the building.

According to Dimoudi and Tompa (2008), Construction industry is one of the biggest consumers of resources and raw materials. The embodied ECO_2 intensity is usually presented as mass of embodied carbon dioxide per unit mass of material which is expressed as kilograms of CO_2 per ton of material ($kgCO_2/t$) (ISE, 1999). In this study, the embodied carbon dioxide emissions of the four traditional building materials, cement, steel, glass and timber, are compared to those of the alternative building materials. Basically, carbon dioxides are emitted mainly during the manufacturing process. Therefore, the amounts of carbon dioxide emissions of the four building materials studied by former researchers are summarized in the following Table 2.

Fig. 2. Floor plan of the target building for case modeling

Table 1. Total volume and weight of the target building

	Total Volume (m^3)	Density (kg/m^3)	Total Weight (kg)
Concrete -	5792.5		
Cement	695.1	3150	2189565
Steel-			
Reinforced Steel	154.1	7850	1209685
Steel H-pile	2131.1 (total length)	223 (unit weight, kg/m)	475235
Glass windows	18.7	3500	65450
Timber formwork	154.6	550	85030

Table 2. Summaries of previous researchers on embodied carbon dioxide emissions of different building materials

CO_2 emissions during manufacturing process				
	Ref. (ISE, 1999) *[kg CO_2/t]*	Ref. (Hammond and Jones, 2006) *[kg CO_2/t]*	Ref (Seo and Hwang, 2001); *[kg CO_2/t]*	Remarks
Cement		820	815	In General
		755		Portland Slag Cement (8 % slag)
		279		Portland Slag Cement (64-73% slag)
Concrete	119			In-situ subStrut
	163			In-situ superStruct
		163		Mix (1:1.5:3)
		211		Mix (1:1:2)
			46[kg CO_2/t]	Ready mix
Steel	2030			Structural
	2698			Sheet
	1656			Stainless
		1790	1992.6[kg CO_2/t]	Section
		1640		Sheet
Glass	1130	770		General
		1126		Toughened
			840.7[kg CO_2/t]	Sheet glass
Timber	1465	750	740.7[kg CO2/t]	

According to Table 2. we concluded that data sourced from Hammond and Jones (2006), it gives a more comprehensive data on carbon dioxide emissons by different building materials. The total amount of CO_2 emission can be calculated by Equation 1 and the results are shown in Table 3.

As shown in Table 3. reinforced steel is having the highest ECO_2 intensity (1790kg CO_2/t) followed by steel H-pile (1640kg CO_2/t). It means that steel emits the largest amount of CO_2 when it is used to produce a component. This gives us a signal that usage of steel must be reduced in order to obtain a significant reduction in the overall emissions of carbon dioxide. Besides, steel is also the major part of a building and it possesses the highest percentage (60%) of the total carbon dioxide emission when comparing to the other building materials. The percentage distribution of the total CO_2 emissions of the four selected building materials is shown in Fig. 3.

This study mainly focused on the four major building materials used in the construction industry: cement, steel, glass and timber. Each of them emits different amount of CO_2 during construction and it is well-known that CO_2 emissions induced from combustion during production is the major contributing compound (Hanaki and Ichinose, 1995). Different measures or action plans have been carried out globally in order to reduce CO_2 emissions (Reay, 2008; Wu and Zhang, 2008). Many environmentally friendly materials are developed which can be used to replace the traditional materials and they are introduced in the following paragraphs.

Table 3. Material Inventory and ECO_2 Emissions

Materials	Total Weight (kg)	ECO_2 Intensity (kg CO_2/t)	Total ECO_2 Emissions ($x10^6$)
Cement	2189565	820	1795
Reinforcement	1209685	1790	2165
Steel H-pile	475235	1640	779
Glass windows	65450	770	50
Timber	85030	1350	115

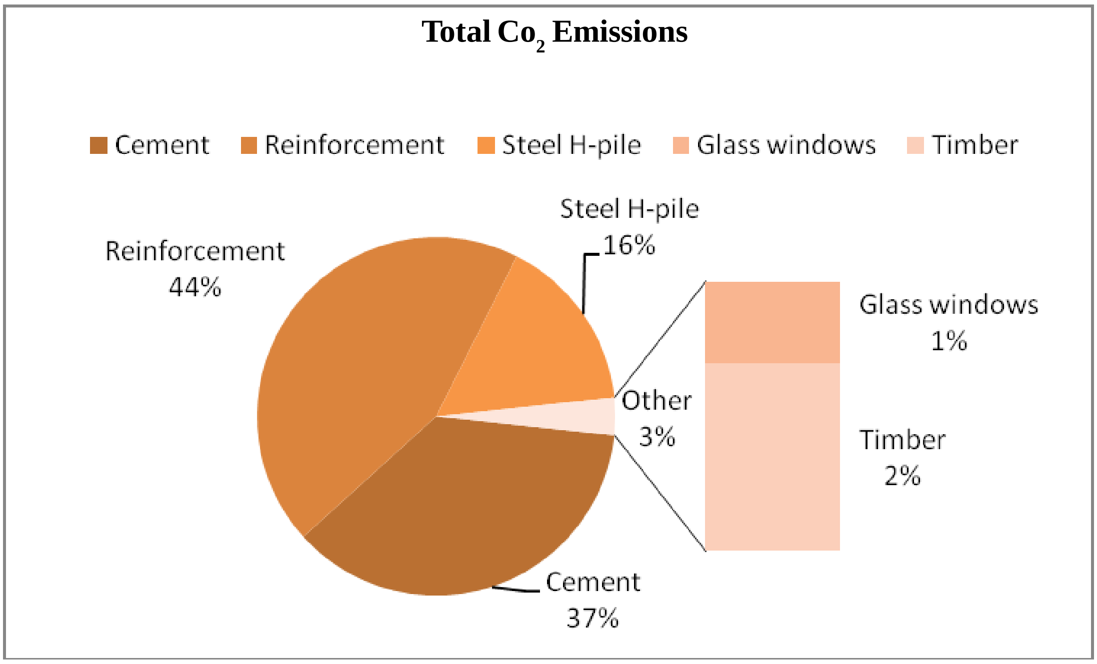

Fig. 3. Breakdown of percentage of the total ECO_2 emissions produced by cement, timber, glass and steels

Cement is the major component in making concrete which is the most general building materials used in construction works (Seo and Hwang, 2001). As mentioned before, cement production contributes 5% of the global carbon dioxide emissions and it is mainly come from combustion of fossil fuels and from calcinations process. Besides, it contributes about 36.4%, which is the second high; of the carbon dioxide emissions in construction (refer to Fig. 3). The cement industry has reduced the amount of CO_2 emission significantly since the early 1980's and many researches are still focusing on studies on further reduction of the release of carbon dioxide. There are many proposed methods such as: improve energy efficiency by using high-efficiency classifiers, motor systems and process control systems (Feng, Ross, and Wang, 1995). One of the approaches is to add alternative materials, e.g. slag cement to partially substitute ordinary cement in concrete mixtures. Higher reduction of CO_2 emissions can be achieved by adding higher proportion of slag cement in the concrete mixtures. Moderate strength can still be obtained by having 50%-60% slag proportion (Fu, *et al.*, 2000) Therefore, the slag cement proportion is set at 60% in the case modelling. In Table 2, it shows that around 34% of CO_2 emissions can be reduced by substituting 64-73% ordinary cement with slag cement in concrete mixtures (Hammond and Jones, 2006) and the percentage reduction is shown in Table 4.

Steel is used in reinforced concrete and structural steel design structures. It has very high embodied carbon dioxide intensity (ISE, 1999), i.e. more carbon dioxide will be emitted in making steel and uses it in construction. Besides, carbon dioxide emitted from steel production is about 5%-15% of the total carbon dioxide emissions in some key developing countries and it even contributes about 60% of the overall carbon dioxide emissions in construction (refer to Fig. 3). Therefore, it is urged to replace steel with a more environmentally friendly material for construction and recycled steel is suggested in this study. Recycled steel is manufactured entirely by recycled scrap iron. It is salvaged from automobiles, appliances and steel- reinforced structures e.g. demolished reinforced concrete buildings. According to Das and Kandpal (1997), by using recycled steel, CO_2 emissions can be reduced by about 35% when compared to virgin steel It is due to less energy and combustion are required to extract impurities in recycled steel.

Glass is in increasing consumption on many high rise commercial buildings for construction of curtain wall recently. Therefore, finding ways to reduce the carbon dioxide emission from glass becomes necessary with the increasing proportion of glass being used in buildings. Fortunately, glass can be recycled very easily. Cullet glass is the recycled crushed glass which can be added during glass manufacturing process (Cook, 1978). It is more energy efficient than making glass from basic raw materials and it can be accounted up to 90% of the raw materials for making glass. Basically, there are two ways of CO_2 reduction by adding cullet: 1) reduction in fuel consumption; and 2) reduction in usage of soda ash, limestone and dolomite. They are all carbonates which give off carbon dioxide when melted. The research from Larsen et al. (2009), it is estimated that carbon dioxide emissions can be reduced by 500kg CO_2 per tonne of cullet glass for remelting. When compare to ISE (1999), the embodied carbon of producing glass, i.e. 770kg CO_2 per ton of glass, about 65% of the CO_2 emission can be reduced per ton.

Timber is also being widely used as formwork or finishes in the building houses in many countries. When comparing to other building materials, such as aluminium, steel, bricks or concrete, wood requires less processing energy which results to smaller amount of carbon dioxide emissions. It can also be seen in Table 3 that the embodied carbon dioxide of timber is very low when compared to concrete and steel. Therefore, it is recommended to use timber instead of other materials for housing (Buchanan and Levine, 1999). However, on the other hand, it is a problem when timber is used as formwork since it is required to be removed after construction process and the major problem of timber is it is non-reusable or only can be reused for small numbers of times. Therefore, unusable timber turns to construction waste. In order to solve this problem, traditional timber formwork is replaced with steel or plastic formworks because these materials can be recycled for more times after use. However, the carbon dioxide emission for turning raw material into steel or plastic is already very high which overweighs the advantages gained from their re-usefulness. Therefore, it is suggested to use a more environmentally friendly timber – plywood, which has lower embodied carbon dioxide (ISE, 1999), to replace traditional timber formwork instead of using steel or plastic formworks. Four types of alternative building materials are suggested in this study: slag cement replacing ordinary cement, recycled steel replacing steel, cullet glass replacing ordinary glass and plywood formwork replacing the timber formwork. The percentage reduction of carbon dioxide emissions by using these four types of alternative building materials are summarized in the following Table 4.

RESULTS & DISCUSSION

The following Table 5 summarizes the total CO_2 emissions before and after using the suggested alternative materials. The percentage of CO_2 emissions are referring to Table 4.

According to Table 5. there is about 1.7 million kg CO_2 reduction after the use of alternative materials. The percentage reduction of CO_2 emissions by using alternative building materials is more than one-third of the total CO_2 emissions (34.8%).The percentage distributions among the proposed environmentally friendly materials are summarized in the following Fig. 4.

Table 4. Percentage reduction of CO_2 emission by using slag cement, recycled steel, cullet glass and plywood

Alternative building materials	Weight used in construction (%)	Percentage of CO_2 emission (%)	References
Slag cement	60	-34	(Hammond and Jones, 2006)
Recycled steel	40	-35	(Das and Kandpal, 1997)
Cullet glass	100	-65	(Larsen, A. W. et al., 2009)
Plywood	100	-11	(ISE, 1999)

Table 5. Summaries of CO_2 reduction of the target building on before and after use of alternative materials

Traditional materials	Total ECO_2 Emissions ($x10^6$) kg	Alternative materials	ECO_2 Reduction (%)	Total ECO_2 Emissions ($x10^6$) kg
Cement	1795	**Slag cement (60%)**	-34	1185
Reinforced Steel	2165	**Recycled steel (40%)**	-35	1407
Steel H-pile	779	**Recycled steel (40%)**	-35	506
Glass windows	50	**Cullet glass (100%)**	-65	17.5
Timber	83	**Plywood (100%)**	-11	74
Total CO_2 Emissions	**4896**	**Total CO_2 Emissions**		**3190**
		Total CO_2 Reduction		**1706**
		Percentage Reduction		**34.8%**

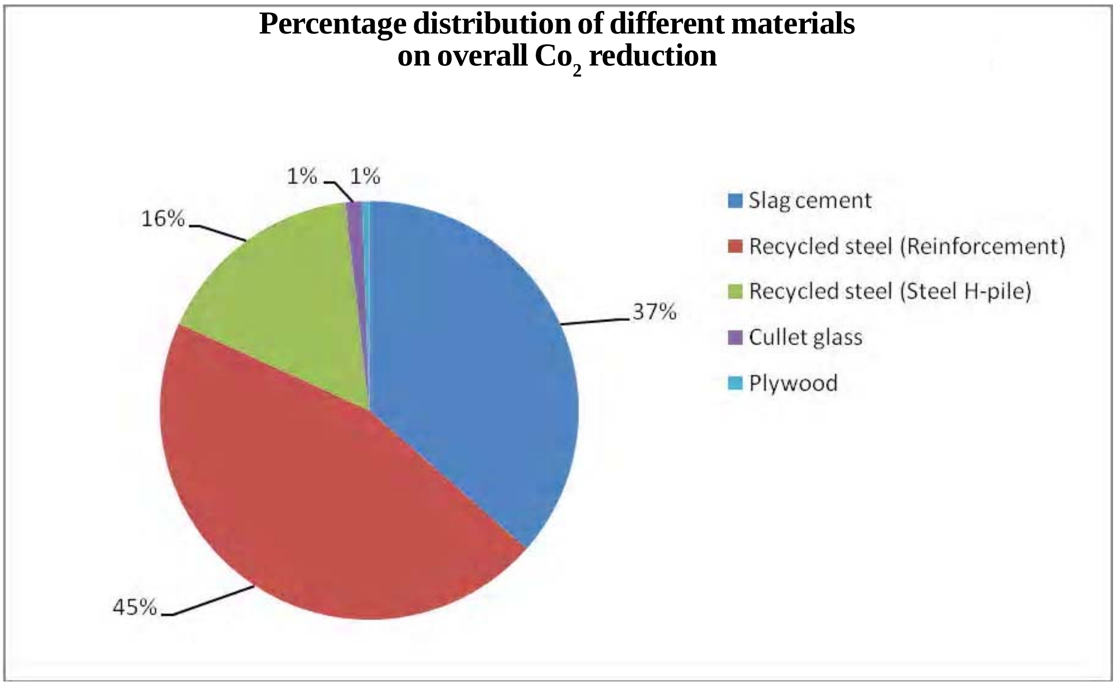

Fig. 4. Chart of percentage distribution of different materials on overall CO_2 reduction

According to Fig. 4. cullet glass and plywood contribute very small percentage of the overall CO_2 emission reduction and they are only about 1%. The largest proportion of percentage reduction falls to recycled steel used in reinforcement (45%) followed by use of slag cement (37%). The results show that in order to reduce CO_2 emission significantly, steel and cement is in high priority to be replaced or substituted by other environmentally friendly materials followed by glass or timber substitution.

CONCLUSION

This paper concludes that the idea of replacing or substituting the four major traditional building materials with the proposed environmentally friendly building materials can achieve a satisfactory result on reducing more than one-third (34.8%) of the total CO_2 emissions. In order to significantly reduce the emission of carbon dioxide, cement and steel are placed in high priority to be replaced by alternative building materials. Besides, the results are quite encouraging and given a general idea to the construction industry on the beneficial impact to the environment by using environmentally friendly materials. At least, the greenhouse gas, carbon dioxide can be greatly reduced by substitution. In summary, this study presents a simple but more realistic model on promoting the usage of alternative building materials in constructing high-rise buildings.

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